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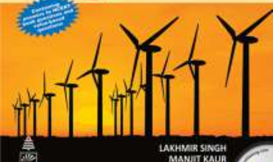
As per NCERT/CBSE Syllabus

Science for Tenth Class

Part - I

Physics

Containing answers to NCERT book exercises and value-based questions



LAKHMIR SINGH
MANJIT KAUR

This book has been revised according to the CCE pattern of school education based on NCERT syllabus prescribed by the Central Board of Secondary Education (CBSE) for Class X

Science for Tenth Class

(Part – 1)

PHYSICS

As per NCERT/CBSE Syllabus
(Based on CCE Pattern of School Education)

Containing answers to NCERT book questions and value-based questions

LAKHMIR SINGH

And

MANJIT KAUR

This Book Belongs to :

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Phone: 23672080-81-82, 9899107446, 9911310888; Fax: 91-11-23677446
www.schandpublishing.com; e-mail : helpdesk@schandpublishing.com

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Visakhapatnam	:	Ph: 2782609, visakhapatnam@schandpublishing.com (Marketing Office)

First Published in 1980
Revised Edition 2014, 2016
Reprints 1981, 82, 83, 84, 85, 86, 87, 88, 89, 90 (Twice), 91 (Twice), 92 (Twice), 93, 94, 95, 96, 97, 98, 99, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2015, 2016 (Thrice)

ISBN : 978-93-525-3028-1 **Code :** 1016H 282

ABOUT THE AUTHORS

LAKHMIR SINGH did his M.Sc. from Delhi University in 1969. Since then he has been teaching in Dyal Singh College of Delhi University, Delhi. He started writing books in 1980. Lakhmir Singh believes that book writing is just like classroom teaching. Though a book can never replace a teacher but it should make the student feel the presence of a teacher. Keeping this in view, he writes books in such a style that students never get bored reading his books. Lakhmir Singh has written more than 15 books so far on all the science subjects: Physics, Chemistry and Biology. He believes in writing quality books. He does not believe in quantity.

MANJIT KAUR did her B.Sc., B.Ed. from Delhi University in 1970. Since then she has been teaching in a reputed school of Directorate of Education, Delhi. Manjit Kaur is such a popular science teacher that all the students want to join those classes which she teaches in the school. She has a vast experience of teaching science to school children, and she knows the problems faced by the children in the study of science. Manjit Kaur has put all her teaching experience into the writing of science books. She has co-authored more than 15 books alongwith her husband, Lakhmir Singh.

It is the team-work of Lakhmir Singh and Manjit Kaur which has given some of the most popular books in the history of science education in India. Lakhmir Singh and Manjit Kaur both write exclusively for the most reputed, respected and largest publishing house of India : S.Chand and Company Pvt. Ltd.

AN OPEN LETTER

Dear Friend,

We would like to talk to you for a few minutes, just to give you an idea of some of the special features of this book. Before we go further, let us tell you that this book has been revised according to the NCERT syllabus prescribed by the Central Board of Secondary Education (CBSE) based on new "Continuous and Comprehensive Evaluation" (CCE) pattern of school education. Just like our earlier books, we have written this book in such a simple style that even the weak students will be able to understand physics very easily. Believe us, while writing this book, we have considered ourselves to be the students of Class X and tried to make things as simple as possible.

The most important feature of this revised edition of the book is that we have included a large variety of different types of questions as required by CCE for assessing the learning abilities of the students. This book contains :

(*i*) Very short answer type questions (including true-false type questions and fill in the blanks type questions),
(*ii*) Short answer type questions,
(*iii*) Long answer type questions (or Essay type questions),
(*iv*) Multiple choice questions (MCQs) based on theory,
(*v*) Questions based on high order thinking skills (HOTS),
(*vi*) Multiple choice questions (MCQs) based on practical skills in science,
(*vii*) NCERT book questions and exercises (with answers), and
(*viii*) Value based questions (with answers).

Please note that answers have also been given for the various types of questions, wherever required. All these features will make this book even more useful to the students as well as the teachers. "A picture can say a thousand words". Keeping this in mind, a large number of coloured pictures and sketches of various scientific processes, procedures, appliances, manufacturing plants and everyday situations involving principles of physics have been given in this revised edition of the book. This will help the students to understand the various concepts of physics clearly. It will also tell them how physics is applied in the real situations in homes, transport and industry.

Other Books by Lakhmir Singh and Manjit Kaur

1. Awareness Science for Sixth Class
2. Awareness Science for Seventh Class
3. Awareness Science for Eighth Class
4. Science for Ninth Class (Part 1) PHYSICS
5. Science for Ninth Class (Part 2) CHEMISTRY
6. Science for Tenth Class (Part 2) CHEMISTRY
7. Science for Tenth Class (Part 3) BIOLOGY
8. Rapid Revision in Science (A Question-Answer Book for Class X)
9. Science for Ninth Class (J & K Edition)
10. Science for Tenth Class (J & K Edition)
11. Science for Ninth Class (Hindi Edition) : PHYSICS and CHEMISTRY
12. Science for Tenth Class (Hindi Edition) : PHYSICS, CHEMISTRY and BIOLOGY
13. Saral Vigyan (A Question-Answer Science Book in Hindi for Class X)

We are sure you will agree with us that the facts and formulae of physics are just the same in all the books, the difference lies in the method of presenting these facts to the students. In this book, the various topics of physics have been explained in such a simple way that while reading this book, a student will feel as if a teacher is sitting by his side and explaining the various things to him. We are sure that after reading this book, the students will develop a special interest in physics and they would like to study physics in higher classes as well.

We think that the real judges of a book are the teachers concerned and the students for whom it is meant. So, we request our teacher friends as well as the students to point out our mistakes, if any, and send their comments and suggestions for the further improvement of this book.

Wishing you a great success,

Yours sincerely,

Lakhmir Singh

Manjit Kaur

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Alaknanda, New Delhi-110019
E-mail : singhlakhmir@hotmail.com

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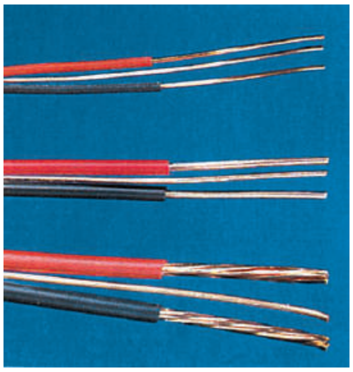

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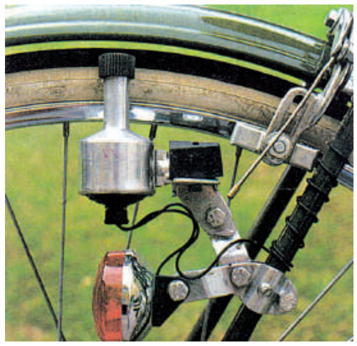

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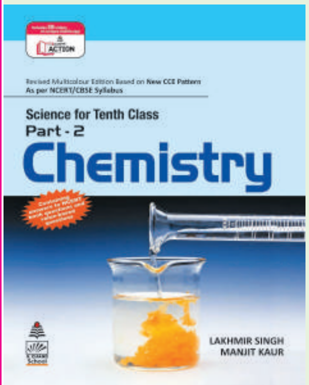

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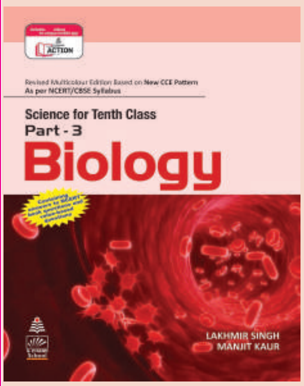

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LATEST CBSE SYLLABUS, CLASS 10 SCIENCE
(PHYSICS PART)

FIRST TERM
(April to September)

Electricity : Electric current ; Potential difference and electric current ; Ohm's law ; Resistance ; Resistivity ; Factors on which the resistance of a conductor depends ; Series combination of resistors, parallel combination of resistors, and its applications in daily life ; Heating effect of electric current and its applications in daily life ; Electric power ; Inter-relation between P, V, I and R

Magnetic effect of current : Magnetic field, field lines, field due to a current-carrying conductor, field due to a current-carrying coil or solenoid ; Force on current-carrying conductor, Fleming's left-hand rule ; Electromagnetic induction, Induced potential difference, Induced current, Fleming's right-hand rule ; Direct current ; Alternating current ; Frequency of AC ; Advantage of AC over DC ; Domestic electric circuits

Sources of energy : Different forms of energy ; Conventional and non-conventional sources of energy ; Fossil fuels, solar energy, biogas, wind, water and tidal energy ; Nuclear energy ; Renewable versus non-renewable sources of energy

SECOND TERM
(October to March)

Light : Reflection of light at curved surfaces ; Images formed by spherical mirrors, centre of curvature, principal axis, principal focus, focal length ; Mirror formula (Derivation not required) ; Magnification ; Refraction : Laws of refraction, refractive index ; Refraction of light by spherical lenses ; Image formed by spherical lenses ; Lens formula (Derivation not required) ; Magnification ; Power of a lens ; Functioning of lens in a human eye ; Defects of vision and their correction ; Applications of spherical mirrors and lenses ; Refraction of light through a prism ; Dispersion of light, scattering of light, applications in daily life

CHAPTER

1

Electricity

Electricity is an important source of energy in the modern times. Electricity is used in our homes, in industry and in transport. For example, electricity is used in our homes for lighting, operating fans and heating purposes (see Figure 1). In industry, electricity is used to run various types of machines, and in transport sector electricity is being used to pull electric trains. In this chapter, we will discuss electric potential, electric current, electric power and the heating effect of electric current. In order to understand electricity, we should first know something about the electric charges. These are discussed below.

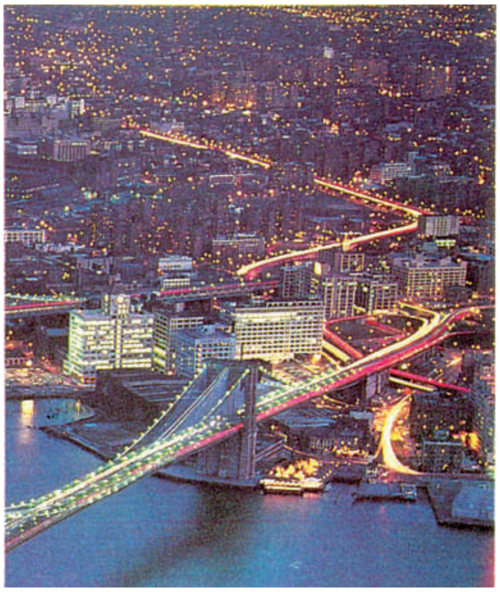


Figure 1. Can you imagine life without electricity ? What would this city look like at night if there was no electricity ?

If we bring a plastic comb near some very tiny pieces of paper, it will not have any effect on them. If, however, the comb is first rubbed with dry hair and then brought near the tiny pieces of paper, we find that the comb now attracts the pieces of paper towards itself. These observations are explained by saying that initially the comb is electrically neutral so it has no effect on the tiny pieces of paper. When the comb is rubbed with dry hair, then it gets electric charge. This electrically charged comb exerts an electric force on the tiny pieces of paper and attracts them. Similarly, a glass rod rubbed with silk cloth ; and an ebonite rod rubbed with woollen cloth also acquire the ability to attract small pieces of paper and are said to have electric charge.

Types of Electric Charges

It has been found by experiments that there are two types of electric charges : *positive* charges and *negative* charges. By convention, the charge acquired by a glass rod (rubbed with a silk cloth) is called positive charge and the charge acquired by an ebonite rod (rubbed with a woollen cloth) is called negative charge. An important property of electric charges is that :

(*i*) **Opposite charges (or Unlike charges) attract each other.** For example, a positive charge attracts a negative charge.

(*ii*) **Similar charges (or Like charges) repel each other.** For example, a positive charge repels a positive charge; and a negative charge repels a negative charge.

The SI unit of electric charge is coulomb which is denoted by the letter **C.** We can define this unit of charge as follows : One coulomb is that quantity of electric charge which exerts a force of 9×10^9 newtons on an equal charge placed at a distance of 1 metre from it. We now know that all the matter contains positively charged particles called *protons* and negatively charged particles called *electrons.* A proton possesses a positive charge of 1.6×10^{-19} C whereas **an electron possesses a negative charge of 1.6×10^{-19} C.** It is obvious that the unit of electric charge called 'coulomb' is much *bigger* than the charge of a proton or an electron. This point will become more clear from the following example.

Sample Problem. Calculate the number of electrons constituting one coulomb of charge.

(NCERT Book Question)

Solution. We know that the charge of an electron is 1.6×10^{-19} coulomb (or 1.6×10^{-19} C).

Now, If charge is 1.6×10^{-19} C, No. of electrons = 1

So, If charge is 1 C, then No. of electrons $= \frac{1}{1.6 \times 10^{-19}} \times 1$

$$= \frac{10^{19}}{1.6}$$

$$= \frac{10}{1.6} \times 10^{18}$$

$$= 6.25 \times 10^{18}$$

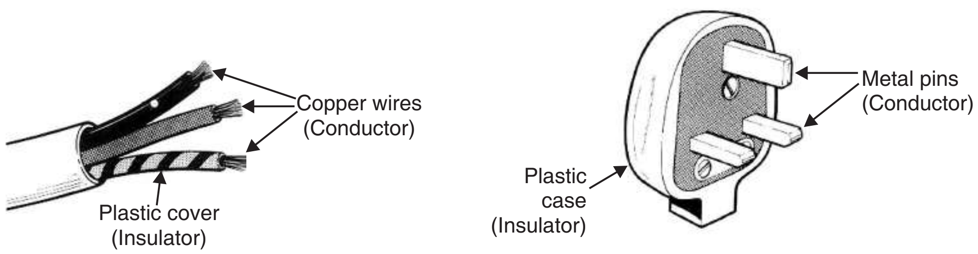
Thus, 6.25×10^{18} electrons taken together constitute 1 coulomb of charge.

The above example tells us that **the SI unit of electric charge 'coulomb' (C) is equivalent to the charge contained in 6.25×10^{18} electrons.** Thus, coulomb is a very big unit of electric charge.

Conductors and Insulators

In some substances, the electric charges can flow easily while in others they cannot. So, all the substances can be divided mainly into two electrical categories : conductors and insulators.

Those substances through which electric charges can flow, are called conductors. But the flow of electric charges is called electricity, so we can also say that : **Those substances through which electricity can flow are called conductors.** All the metals like silver, copper and aluminium, etc., are conductors (see Figure 2). The metal alloys such as nichrome, manganin and constantan (which are used for making heating elements of electrical appliances) are also conductors but their electrical conductivity is much less than that of pure metals. Carbon, in the form of graphite, is also a conductor. The human body is a fairly good conductor.



(*a*) An electric cable containing three insulated copper wires

(*b*) A three-pin plug

Figure 2. Conductors and insulators.

Those substances through which electric charges cannot flow, are called insulators. In other words : **Those substances through which electricity cannot flow are called insulators.** Glass, ebonite, rubber, most plastics, paper, dry wood, cotton, mica, bakelite, porcelain, and dry air, are all insulators because they do not allow electric charges (or electricity) to flow through them (see Figure 2). In the case of charged insulators like glass, ebonite, etc., the electric charges remain bound to them, and do not move away.

We have just seen that some of the substances are conductors whereas others are insulators. We will now explain the reason for this difference in their behaviour.

All the conductors (like metals) have some electrons which are loosely held by the nuclei of their atoms. These electrons are called "free electrons" and can move from one atom to another atom throughout the conductor. **The presence of "free electrons" in a substance makes it a conductor (of electricity).**

The electrons present in insulators are strongly held by the nuclei of their atoms. Since there are "no free electrons" in an insulator which can move from one atom to another, an insulator does not allow electric charges (or electricity) to flow through it.

Electricity can be classified into two parts :

1. Static electricity, and
2. Current electricity.

In static electricity, the electric charges remain at *rest* (or *stationary*), they do not move. The charge acquired by a glass rod rubbed with a silk cloth and the charge acquired by an ebonite rod rubbed with a woollen cloth are the examples of static electricity. The lightning which we see in the sky during the rainy season also involves static electricity. In current electricity, the electric charges are in *motion* (and produce an electric current). The electricity which we use in our homes is the current electricity (see Figure 3). In this chapter, we will discuss only current electricity in detail. So, when we talk of electricity in these discussions, it will actually mean current electricity.

Figure 3. The electricity which we use in our homes is current electricity.

Electric Potential

When a small positive test charge is placed in the electric field due to another charge, it experiences a force. So, work has to be done on the positive test charge to move it against this force of repulsion. **The electric potential (or potential) at a point in an electric field is defined as the work done in moving a unit positive charge from infinity to that point.** Potential is denoted by the symbol V and its unit is volt. A potential of 1 volt at a point means that 1 joule of work is done in moving 1 unit positive charge from infinity to that point. Since the unit of charge is coulomb, so we can also say that : A potential of 1 volt at a point means that 1 joule of work is done in moving 1 coulomb of positive charge from infinity to that point. A more common term used in electricity is, however, potential difference which we will discuss now.

Potential Difference

The *difference in electric potential* between two points is known as *potential difference.* **The potential difference between two points in an electric circuit is defined as the amount of work done in moving a unit charge from one point to the other point.** That is :

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Quantity of charge moved}}$$

If W joules of work has to be done to move Q coulombs of charge from one point to the other point, then the potential difference V between the two points is given by the formula :

$$\text{Potential difference,} \quad V = \frac{W}{Q}$$

where W = work done

and Q = quantity of charge moved

The SI unit of potential difference is volt which is denoted by the letter **V**. The potential difference is also sometimes written in symbols as p.d.

The potential difference between two points is said to be 1 volt if 1 joule of work is done in moving 1 coulomb of electric charge from one point to the other.

$$\text{Thus,} \quad 1\text{ volt} = \frac{1\text{ joule}}{1\text{ coulomb}}$$

$$\text{or} \quad 1\text{ V} = \frac{1\text{ J}}{1\text{ C}}$$

$$\text{or} \quad 1\text{ V} = 1\text{ J C}^{-1}$$

The potential difference is measured by means of an instrument called voltmeter (see Figure 4). The voltmeter is always connected in *parallel* across the two points where the potential difference is to be measured. For example, in Figure 5 we have a conductor *AB* such as a resistance wire (which is the part of a circuit), and we want to measure the potential difference across its ends. So, one end of the voltmeter *V* is connected to the point *A* and the other end to the point *B*. We can read the value of the potential difference in volts on the dial of the voltmeter. **A voltmeter has a high resistance** so that it takes a negligible current from the circuit. The term "volt" gives rise to the word "voltage". **Voltage is the other name for potential difference**. We will now solve some problems based on potential difference.

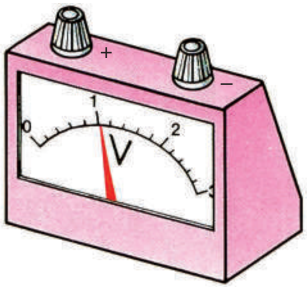


Figure 4. This is a voltmeter.

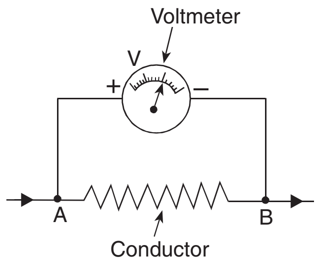


Figure 5. A voltmeter connected in parallel with conductor AB to measure the potential difference across its ends.

Sample Problem 1. How much work is done in moving a charge of 2 coulombs from a point at 118 volts to a point at 128 volts ?

Solution. We know that :

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge moved}}$$

$$\text{or} \quad V = \frac{W}{Q}$$

Here, Potential difference, V = 128 – 118

= 10 volts

Work done, W = ? (To be calculated)

And, Charge moved, Q = 2 coulombs

Putting these values in the above formula, we get :

$$10 = \frac{W}{2}$$

or $W = 10 \times 2$

Thus, Work done, $W = 20$ joules

Sample Problem 2. How much energy is given to each coulomb of charge passing through a 6 V battery ?

(NCERT Book Question)

Solution. The term 'each coulomb' means 'every 1 coulomb', so the charge here is 1 coulomb. The potential difference is 6 volts. We have to find out the energy. This energy will be equal to the work done. Now,

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge moved}}$$

or $$V = \frac{W}{Q}$$

$$6 = \frac{W}{1}$$

So, Work done, $W = 6 \times 1$ joules

$= 6$ J

Since the work done on each coulomb of charge is 6 joules, therefore, the energy given to each coulomb of charge is also 6 joules.

Before we go further and discuss electric current, **please answer the following questions :**

Very Short Answer Type Questions

1. By what other name is the unit joule/coulomb called ?

2. Which of the following statements correctly defines a volt ?

(*a*) a volt is a joule per ampere.

(*b*) a volt is a joule per coulomb.

3. (*a*) What do the letters p.d. stand for ?

(*b*) Which device is used to measure p.d. ?

4. What is meant by saying that the electric potential at a point is 1 volt ?

5. How much work is done when one coulomb charge moves against a potential difference of 1 volt ?

6. What is the SI unit of potential difference ?

7. How much work is done in moving a charge of 2 C across two points having a potential difference of 12 V ?

8. What is the unit of electric charge ?

9. Define one coulomb charge.

10. Fill in the following blanks with suitable words :

(*a*) Potential difference is measured in ....by using a ....placed in..............across a component.

(*b*) Copper is a good...............Plastic is an..................

Short Answer Type Questions

11. What is meant by conductors and insulators ? Give two examples of conductors and two of insulators.

12. Which of the following are conductors and which are insulators ?

Sulphur, Silver, Copper, Cotton, Aluminium, Air, Nichrome, Graphite, Paper, Porcelain, Mercury, Mica, Bakelite, Polythene, Manganin.

13. What do you understand by the term "electric potential" ? (or potential) at a point ? What is the unit of electric potential ?

14. (*a*) State the relation between potential difference, work done and charge moved.

(*b*) Calculate the work done in moving a charge of 4 coulombs from a point at 220 volts to another point at 230 volts.

15. (*a*) Name a device that helps to measure the potential difference across a conductor.

(*b*) How much energy is transferred by a 12 V power supply to each coulomb of charge which it moves around a circuit ?

Long Answer Type Question

16. (*a*) What do you understand by the term "potential difference" ?

(*b*) What is meant by saying that the potential difference between two points is 1 volt ?

(*c*) What is the potential difference between the terminals of a battery if 250 joules of work is required to transfer 20 coulombs of charge from one terminal of battery to the other ?

(*d*) What is a voltmeter ? How is a voltmeter connected in the circuit to measure the potential difference between two points. Explain with the help of a diagram.

(*e*) State whether a voltmeter has a high resistance or a low resistance. Give reason for your answer.

Multiple Choice Questions (MCQs)

17. The work done in moving a unit charge across two points in an electric circuit is a measure of :

(*a*) current (*b*) potential difference (*c*) resistance (*d*) power

18. The device used for measuring potential difference is known as :

(*a*) potentiometer (*b*) ammeter (*c*) galvanometer (*d*) voltmeter

19. Which of the following units could be used to measure electric charge ?

(*a*) ampere (*b*) joule (*c*) volt (*d*) coulomb

20. The unit for measuring potential difference is :

(*a*) watt (*b*) ohm (*c*) volt (*d*) kWh

21. One coulomb charge is equivalent to the charge contained in :

(*a*) 2.6×10^{19} electrons (*b*) 6.2×10^{19} electrons

(*c*) 2.65×10^{18} electrons (*d*) 6.25×10^{18} electrons

Questions Based on High Order Thinking Skills (HOTS)

22. Three 2 V cells are connected in series and used as a battery in a circuit.

(*a*) What is the p.d. at the terminals of the battery ?

(*b*) How many joules of electrical energy does 1 C gain on passing through (*i*) one cell (*ii*) all three cells ?

23. The atoms of copper contain electrons and the atoms of rubber also contain electrons. Then why does copper conduct electricity but rubber does not conduct electricity ?

ANSWERS

1. Volt **2.** (*b*) **5.** 1 J **7.** 24 J **10.** (*a*) volts ; voltmeter ; parallel (*b*) conductor ; insulator
14. (*b*) 40 J **15.** (*b*) 12 J **16.** (*c*) 12.5 V **17.** (*b*) **18.** (*d*) **19.** (*d*) **20.** (*c*) **21.** (*d*)
22. (*a*) 6 V (*b*) (*i*) 2 J (*ii*) 6 J

ELECTRIC CURRENT

When two charged bodies at different electric potentials are connected by a metal wire, then electric charges will flow from the body at higher potential to the one at lower potential (till they both acquire the same potential). This flow of charges in the metal wire constitutes an electric current. **It is the potential difference between the ends of the wire which makes the electric charges (or current) to flow in the wire.** We now know that the electric charges whose flow in a metal wire constitutes electric current are the negative charges called *electrons*. Keeping this in mind, we can now define electric current as follows.

The electric current is a flow of electric charges (called electrons) in a conductor such as a metal wire. *The magnitude of electric current in a conductor is the amount of electric charge passing through a given point of the conductor in one second.* If a charge of Q coulombs flows through a conductor in time t seconds, then the magnitude I of the electric current flowing through it is given by :

$$\text{Current,} \quad I = \frac{Q}{t}$$

The SI unit of electric current is ampere which is denoted by the letter **A.** We can use the above formula to obtain the definition of the unit of current called '*ampere*'. If we put charge Q = 1 coulomb and time t = 1 second in the above formula, then current I becomes 1 ampere. This gives us the following definition of ampere : **When 1 coulomb of charge flows through any cross-section of a conductor in 1 second, the electric current flowing through it is said to be 1 ampere.** That is,

$$1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

$$\text{or} \qquad 1 \text{ A} = \frac{1 \text{ C}}{1 \text{ s}}$$

Sometimes, however, a smaller unit of current called "milliampere" is also used, which is denoted by mA.

$$1 \text{ milliampere} = \frac{1}{1000} \text{ ampere}$$

$$\text{or} \qquad 1 \text{ mA} = \frac{1}{1000} \text{ A}$$

$$\text{or} \qquad 1 \text{ mA} = 10^{-3} \text{ A}$$

Thus, the small quantities of current are expressed in the unit of milliampere, mA (1 mA = 10^{-3} A). The very small quantities of current are expressed in a still smaller unit of current called microampere, μA (1 μA = 10^{-6} A).

Current is measured by an instrument called ammeter (see Figure 6). The ammeter is always connected in *series* with the circuit in which the current is to be measured. For example, if we want to find out the current flowing through a conductor BC (such as a resistance wire), then we should connect the ammeter A in series with the conductor BC as shown in Figure 7. Since the entire current passes through the ammeter, therefore, **an ammeter should have very low resistance** so that it may not change the value of the current flowing in the circuit. Let us solve one problem now.

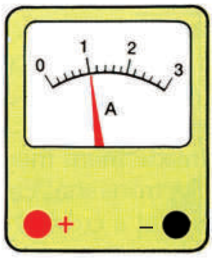


Figure 6. This is an ammeter.

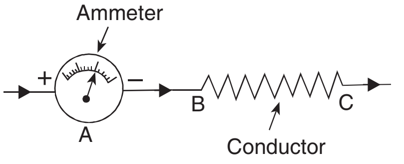


Figure 7. An ammeter connected in series with a conductor BC to measure the current passing through it.

Sample Problem. An electric bulb draws a current of 0.25 A for 20 minutes. Calculate the amount of electric charge that flows through the circuit.

Solution. Here, Current, I = 0.25 A

Charge, Q = ? (To be calculated)

And Time, t = 20 minutes

= 20 × 60 seconds

= 1200 s

We know that, $I = \frac{Q}{t}$

So, $0.25 = \frac{Q}{1200}$

$Q = 0.25 \times 1200$ C

$Q = 300$ C

Thus, the amount of electric charge that flows through the circuit is 300 coulombs.

How to Get a Continuous Flow of Electric Current

We have just studied that it is due to the potential difference between two points that an electric current flows between them. **The simplest way to maintain a potential difference between the two ends of a conductor so as to get a continuous flow of current is to connect the conductor between the terminals of a cell or a battery.** Due to the chemical reactions going on inside the cell or battery, a potential difference is maintained between its terminals. And this potential difference drives the current in a circuit in which the cell or battery is connected. For example, a single dry cell has a potential difference of 1.5 volts between its two terminals (+ terminal and – terminal). So, when a dry cell is connected to a torch bulb through copper connecting wires, then its potential difference causes the electric current to flow through the copper wires and the bulb, due to which the bulb lights up (see Figure 8). In order to maintain current in the external circuit, the cell has to expend the chemical energy which is stored in it. Please note that the torch bulb used in the circuit shown in Figure 8 is actually a kind of 'conductor'. We can also call it a resistor. It is clear from the above discussion that a common source of 'potential difference' or 'voltage' is a cell or a battery. It can make the current flow in a circuit.

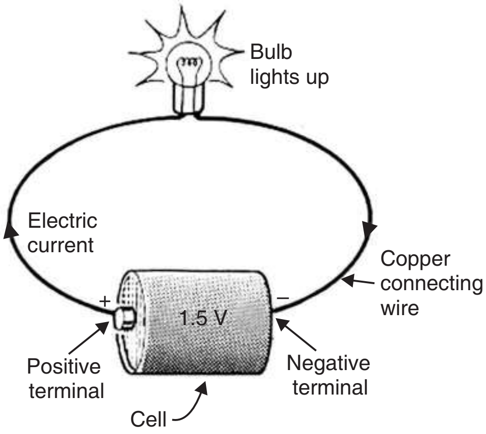


Figure 8. The potential difference between the two terminals of this cell causes electric current to flow through copper wires and the bulb.

Direction of Electric Current

When electricity was invented a long time back, it was known that there are two types of charges : positive charges and negative charges, but the electron had *not* been discovered at that time. So, electric current was considered to be a flow of positive charges and the direction of flow of the positive charges was taken to be the direction of electric current. Thus, **the conventional direction of electric current is from positive terminal of a cell (or battery) to the negative terminal, through the outer circuit.** So, in our circuit diagrams, we put the arrows on the connecting wires pointing from the positive terminal of the cell towards the negative terminal of the cell, to show the direction of conventional current (see Figure 8). *The actual flow of electrons (which constitute the current) is, however, from negative terminal to positive terminal of a cell, which is opposite to the direction of conventional current.*

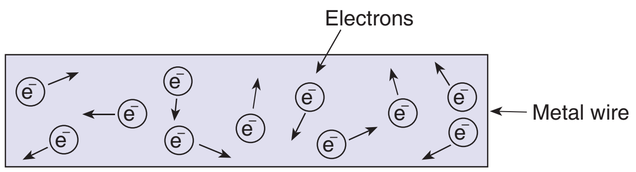


Figure 9. When no cell or battery is connected across a metal wire, the electrons in it flow at random in all directions (Please note that this is a highly magnified diagram of a metal wire).

How the Current Flows in a Wire

We know that **electric current is a flow of electrons in a metal wire (or conductor)** when a cell or battery is applied across its ends. A metal wire has plenty of free electrons in it.

(*i*) When the metal wire has not been connected to a source of electricity like a cell or a battery, then the electrons present in it move at random in all the directions between the atoms of the metal wire as shown in Figure 9.

(*ii*) When a source of electricity like a cell or a battery is connected between the ends of the metal wire, then an electric force acts on the electrons present in the wire. Since the electrons are negatively charged, they start moving from *negative* end to the *positive* end of the wire (see Figure 10). This flow of electrons constitutes the electric current in the wire.

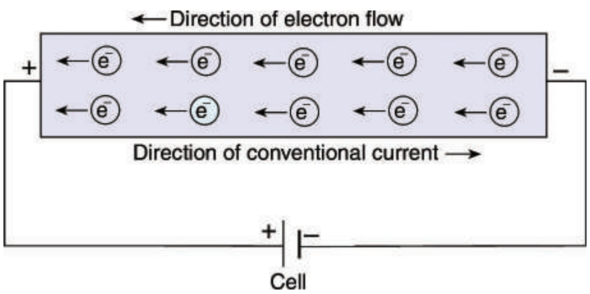
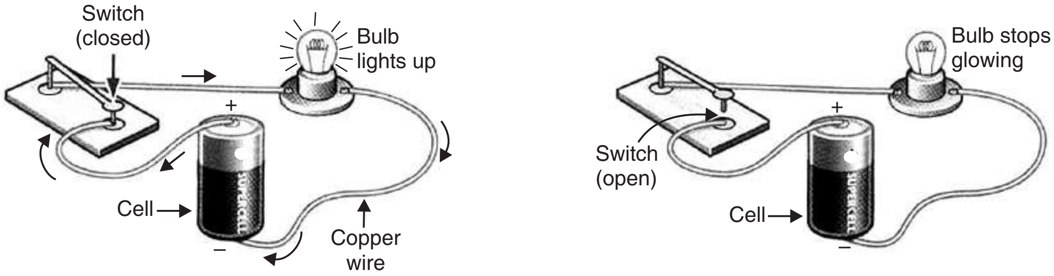


Figure 10. When a cell or battery is connected across a metal wire, the electrons in it flow towards positive terminal.

Electric Circuits

A cell (or battery) can make electrons move and electric current flow. But there must be a conducting path (like wires, bulb, etc.) between the two terminals of the cell through which electrons can move causing the electric current to flow. **A continuous conducting path consisting of wires and other resistances (like electric bulb, etc.) and a switch, between the two terminals of a cell or a battery along which an electric current flows, is called a circuit.** A simple electric circuit is shown in Figure 11(*a*).



(*a*) When the switch is closed, the circuit is complete and a current flows in it.

(*b*) When the switch is open, the circuit gets broken and no current flows in it.

Figure 11. The electric circuits showing actual components (like cell, bulb, switch, etc.).

In Figure 11(*a*) we have a cell having a positive terminal (+) and a negative terminal (–). The positive terminal of the cell is connected to one end of the bulb holder with a copper wire (called connecting wire) through a switch. The negative terminal of the cell is connected to the other end of bulb holder. In Figure 11(*a*) the switch is closed. So, the circuit in Figure 11(*a*) is complete and hence a current flows in this circuit. This current makes the bulb light up [see Figure 11(*a*)].

If we open the switch as shown in Figure 11(*b*), then a gap is created between the two ends of the connecting wire. Due to this, one terminal of the cell gets disconnected from the bulb and current stops flowing in the circuit. Thus, when the switch is open, the circuit breaks and no current flows through the bulb. The bulb stops glowing [see Figure 11(*b*)].

Symbols for Electrical Components (or Circuit Symbols)

In electric circuits, we have to show various electrical components such a cell, a battery, connecting wires, wire joints, fixed resistance, variable resistance, ammeter, voltmeter, galvanometer, an open switch, a closed switch, and an electric bulb (or lamp), etc. Now, to draw the electric circuits by making the *actual* sketches of the various electrical components is a difficult job and takes a lot of time. So, the scientists have devised some symbols for electrical components which are easy to draw. They are called electrical symbols or circuit symbols. The common electrical symbols for electrical components which are used in drawing circuit diagrams are given below :

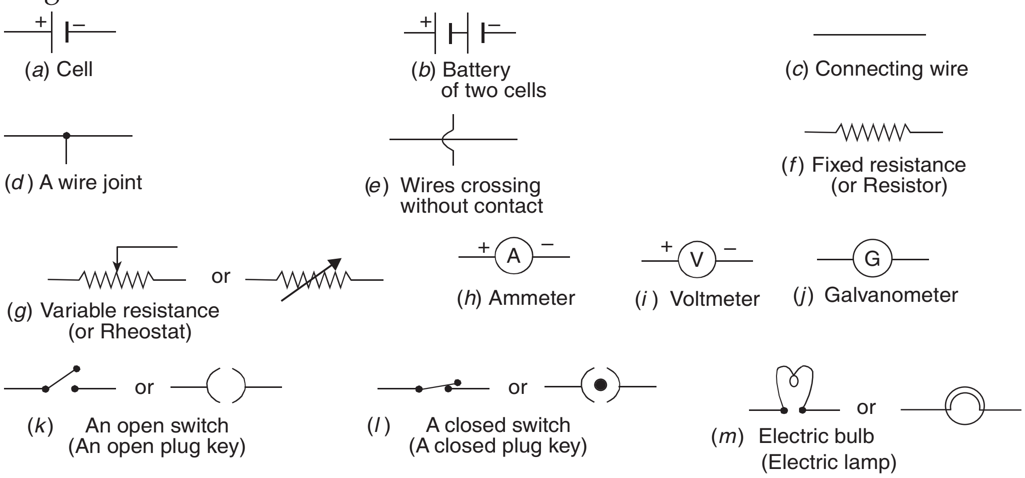


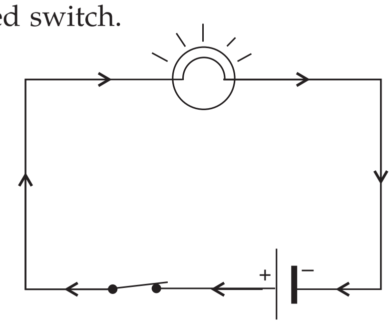
Figure 12. Electrical symbols (or circuit symbols).

The symbol for a single cell is shown in Figure 12(*a*). The symbol of a single cell consists of two parallel vertical lines, one thin and long and the other thick and short (having horizontal lines on the sides). The longer vertical line represents the positive terminal of the cell (so it is marked plus, +), whereas the shorter vertical line represents the negative terminal of the cell (so it is marked minus, –). **Battery is a combination of two (or more) cells connected in series.** In order to obtain a battery, the negative terminal of the first cell is joined with the positive terminal of the second cell, and so on. The symbol for a battery is shown in Figure 12(*b*). The battery shown in Figure 12(*b*) consists of two cells joined together in series. We can also draw the symbol for a battery having more than two cells in a similar way.

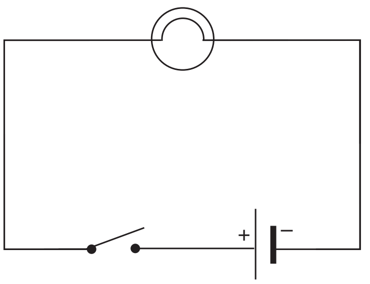
The resistance which can be changed as desired is called *variable* resistance. Variable resistance has two symbols shown in Figure 12(*g*). **Variable resistance is also known as rheostat.** Rheostat is a variable resistance which is usually operated by a sliding contact on a long coil (made of resistance wire). A rheostat is used to change the current in a circuit without changing the voltage source like the cell or battery. It can do so by changing the resistance of the circuit. The galvanometer is a current-detecting instrument (which we will come across in the next Chapter). The switch (or plug key) is a device for 'making' or 'breaking' an electric circuit. When the switch is open, then the circuit 'breaks' and no current flows in it [see Figure 12(*k*)]. But when the switch is closed, then the circuit is 'made' (or completed) and current flows in it [see Figure 12(*l*)].

Circuit Diagrams

Electrical circuits are represented by drawing circuit diagrams. **A diagram which indicates how different components in a circuit have been connected by using the electrical symbols for the components, is called a circuit diagram.** An electric circuit consisting of a cell, a bulb and a closed switch which was drawn in Figure 11(*a*) can be represented by drawing a circuit diagram shown in Figure 13(*a*). In the circuit diagram shown in Figure 13(*a*), a bulb has been connected to the two terminals of a cell by copper wires through a closed switch.



(*a*) This is the circuit diagram of the circuit shown in Figure 11(*a*).



(*b*) This is the circuit diagram of the circuit given in Figure 11(*b*).

Figure 13. Circuit diagrams drawn by using the electrical symbols of the various components.

The electric circuit consisting of a cell, a bulb and an open switch which was drawn in Figure 11(*b*) can be represented by drawing a circuit diagram shown in Figure 13(*b*). In the circuit diagram shown in Figure 13(*b*), a bulb has been connected to the two terminals of the cell by copper wires through an open switch.

The circuit shown in Figure 13(*a*) is complete (due to closed switch). Since there is no gap, therefore, current flows in this circuit and the bulb lights up. In this case, the electrons can move through the external circuit. These moving electrons form an electric current. The circuit given in Figure 13(*b*) is broken (due to a gap because of open switch), so no current flows in this circuit and bulb goes off. The electrons cannot flow in this circuit due to the gap produced by the open switch.

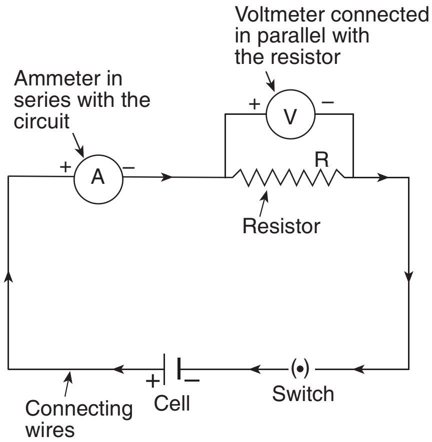


Figure 14. An electric circuit consisting of a cell, a resistor, an ammeter, a voltmeter and a switch (or plug key).

Another simple electric circuit has been shown in Figure 14. In this circuit, a resistor *R* has been connected to the two terminals of a cell through a switch. An ammeter *A* has been put in series with the resistor *R*. This is to measure current in the circuit. A voltmeter *V* has been connected across the ends of the resistor *R*, that is, voltmeter is connected in parallel with the resistor. This voltmeter is to measure potential difference (or voltage) across the ends of the resistor *R*. Before we go further and discuss Ohm's law, **please answer the following questions :**

Very Short Answer Type Questions

1. By what name is the physical quantity coulomb/second called ?

2. What is the flow of charge called ?

3. What actually travels through the wires when you switch on a light ?

4. Which particles constitute the electric current in a metallic conductor ?

5. (*a*) In which direction does conventional current flow around a circuit ?
(*b*) In which direction do electrons flow ?

6. Which of the following equation shows the correct relationship between electrical units ?
1 A = 1 C/s or 1 C = 1 A/s

7. What is the unit of electric current ?

8. (*a*) How many milliamperes are there in 1 ampere ?
(*b*) How many microamperes are there in 1 ampere ?

9. Which of the two is connected in series : ammeter or voltmeter ?

10. Compare how an ammeter and a voltmeter are connected in a circuit.

11. What do the following symbols mean in circuit diagrams ?

(*i*)  (*ii*) 

12. If 20 C of charge pass a point in a circuit in 1 s, what current is flowing ?

13. A current of 4 A flows around a circuit for 10 s. How much charge flows past a point in the circuit in this time ?

14. What is the current in a circuit if the charge passing each point is 20 C in 40 s ?

15. Fill in the following blanks with suitable words :
(*a*) A current is a flow of.................For this to happen there must be a ....circuit.
(*b*) Current is measured in..............using an..............placed in............in a circuit.

Short Answer Type Questions

16. (*a*) Name a device which helps to maintain potential difference across a conductor (say, a bulb).
(*b*) If a potential difference of 10 V causes a current of 2 A to flow for 1 minute, how much energy is transferred ?

17. (*a*) What is an electric current ? What makes an electric current flow in a wire ?
(*b*) Define the unit of electric current (or Define ampere).

18. What is an ammeter ? How is it connected in a circuit ? Draw a diagram to illustrate your answer.

19. (*a*) Write down the formula which relates electric charge, time and electric current.
(*b*) A radio set draws a current of 0.36 A for 15 minutes. Calculate the amount of electric charge that flows through the circuit.

20. Why should the resistance of :
(*a*) an ammeter be very small ?
(*b*) a voltmeter be very large ?

21. Draw circuit symbols for (*a*) fixed resistance (*b*) variable resistance (*c*) a cell (*d*) a battery of three cells (*e*) an open switch (*f*) a closed switch.

22. What is a circuit diagram ? Draw the labelled diagram of an electric circuit comprising of a cell, a resistor, an ammeter, a voltmeter and a closed switch (or closed plug key). Which of the two has a large resistance : an ammeter or a voltmeter ?

23. If the charge on an electron is 1.6×10^{-19} coulombs, how many electrons should pass through a conductor in 1 second to constitute 1 ampere current ?

24. The p.d. across a lamp is 12 V. How many joules of electrical energy are changed into heat and light when :
(*a*) a charge of 1 C passes through it ?

(*b*) a charge of 5 C passes through it ?
(*c*) a current of 2 A flows through it for 10 s ?

25. In 10 s, a charge of 25 C leaves a battery, and 200 J of energy are delivered to an outside circuit as a result.
(*a*) What is the p.d. across the battery ?
(*b*) What current flows from the battery ?

Long Answer Type Question

26. (*a*) Define electric current. What is the SI unit of electric current.
(*b*) One coulomb of charge flows through any cross-section of a conductor in 1 second. What is the current flowing through the conductor ?
(*c*) Which instrument is used to measure electric current ? How should it be connected in a circuit ?
(*d*) What is the conventional direction of the flow of electric current ? How does it differ from the direction of flow of electrons ?
(*e*) A flash of lightning carries 10 C of charge which flows for 0.01 s. What is the current ? If the voltage is 10 MV, what is the energy ?

Multiple Choice Questions (MCQs)

27. The other name of potential difference is :
(*a*) ampereage (*b*) wattage (*c*) voltage (*d*) potential energy

28. Which statement/statements is/are correct ?
1. An ammeter is connected in series in a circuit and a voltmeter is connected in parallel.
2. An ammeter has a high resistance.
3. A voltmeter has a low resistance.

(*a*) 1, 2, 3 (*b*) 1, 2 (*c*) 2, 3 (*d*) 1

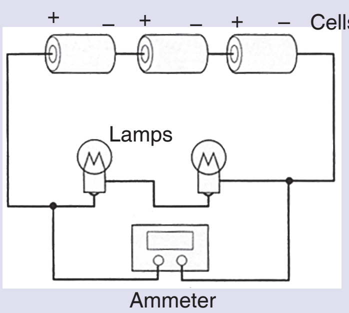
29. Which unit could be used to measure current ?
(*a*) Watt (*b*) Coulomb (*c*) Volt (*d*) Ampere

30. If the current through a floodlamp is 5 A, what charge passes in 10 seconds ?
(*a*) 0.5 C (*b*) 2 C (*c*) 5 C (*d*) 50 C

31. If the amount of electric charge passing through a conductor in 10 minutes is 300 C, the current flowing is :
(*a*) 30 A (*b*) 0.3 A (*c*) 0.5 A (*d*) 5 A

Questions Based on High Order Thinking Skills (HOTS)

32. A student made an electric circuit shown here to measure the current through two lamps.
(*a*) Are the lamps in series or parallel ?
(*b*) The student has made a mistake in this circuit.
What is the mistake ?
(*c*) Draw a circuit diagram to show the correct way to connect the circuit. Use the proper circuit symbols in your diagram.



33. Draw a circuit diagram to show how 3 bulbs can be lit from a battery so that 2 bulbs are controlled by the same switch while the third bulb has its own switch.

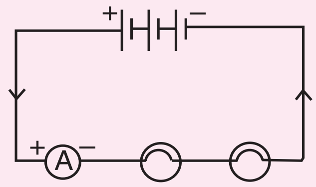
34. An electric heater is connected to the 230 V mains supply. A current of 8 A flows through the heater.
(*a*) How much charge flows around the circuit each second ?
(*b*) How much energy is transferred to the heater each second ?

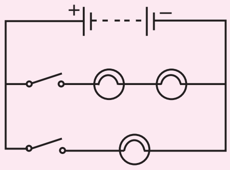
35. How many electrons are flowing per second past a point in a circuit in which there is a current of 5 amp ?

ANSWERS

1. Ampere **2.** Electric current **3.** Electrons **4.** Electrons **6.** 1 A = 1 C/s **9.** Ammeter **11.** (*i*) Variable resistance (*ii*) Closed plug key **12.** 20 A **13.** 40 C **14.** 0.5 A **15.** (*a*) electrons ; closed (*b*) amperes ; ammeter ; series **16.** (*a*) Cell or Battery (*b*) 1200 J **19.** (*b*) 324 C **22.** See Figure 14 on page 10;

Voltmeter **23.** 6.25×10^{18} electrons **24.** (*a*) 12 J (*b*) 60 J (*c*) 240 J **25.** (*a*) 8 V (*b*) 2.5 A **26.** (*b*) 1 ampere (*e*) 1000 A ; 100 MJ (or 100,000,000 J) *Note.* M = Mega which means 1 million or 1000,000 **27.** (*c*) **28.** (*d*) **29.** (*d*) **30.** (*d*) **31.** (*c*) **32.** (*a*) In series (*b*) Ammeter is connected in parallel with the lamps. It should be connected in series.

(*c*) 

33. 

34. (*a*) 8 C (*b*) 1840 J **35.** 31.25×10^{18}

OHM'S LAW

Ohm's law gives a relationship between *current* and *potential difference*. According to Ohm's law : **At constant temperature, the current flowing through a conductor is directly proportional to the potential difference across its ends.** If I is the current flowing through a conductor and V is the potential difference (or voltage) across its ends, then according to Ohm's law :

$$I \propto V \qquad \text{(At constant temp.)}$$

This can also be written as : $V \propto I$

or $V = R \times I$

where R is a constant called "resistance" of the conductor. The value of this constant depends on the nature, length, area of cross-section and temperature of the conductor. The above equation can also be written as :

$$\frac{V}{I} = R \qquad \text{...(1)}$$

where V = Potential difference

I = Current

and R = Resistance (which is a constant)

The above equation is a mathematical expression of Ohm's law. Equation (1) can be written in words as follows :

$$\frac{\text{Potential difference}}{\text{Current}} = \text{constant} \quad \text{(called resistance)}$$

We find that **the ratio of potential difference applied between the ends of a conductor and the current flowing through it is a constant quantity called resistance.**

We have just seen that : $\frac{V}{I} = R$

or $V = I \times R$

or $\frac{V}{R} = I$

So, Current, $I = \frac{V}{R}$

It is obvious from this relation that :

(*i*) **the current is directly proportional to potential difference,** and

(*ii*) **the current is inversely proportional to resistance.**

Since the current is directly proportional to the potential difference applied across the ends of a conductor, it means that **if the potential difference across the ends of a conductor is doubled, the current flowing through it also gets doubled,** and **if the potential difference is halved, the current also gets halved.** On the other hand, the current is inversely proportional to resistance. So, **if the resistance is doubled, the current gets halved,** and **if the resistance is halved, the current gets doubled.** Thus, the strength of an electric current in a given conductor depends on two factors :

(*i*) potential difference across the ends of the conductor, and

(*ii*) resistance of the conductor.

We will now discuss the electrical resistance of a conductor in detail.

Resistance of a Conductor

The electric current is a flow of electrons through a conductor. When the electrons move from one part of the conductor to the other part, they collide with other electrons and with the atoms and ions present in the body of the conductor. Due to these collisions, there is some obstruction or opposition to the flow of electron current through the conductor. **The property of a conductor due to which it opposes the flow of current through it is called resistance.** The resistance of a conductor is numerically equal to the ratio of potential difference across its ends to the current flowing through it. That is :

$$\text{Resistance} = \frac{\text{Potential difference}}{\text{Current}}$$

$$\text{or} \qquad R = \frac{V}{I}$$

The resistance of a conductor depends on length, thickness, nature of material and temperature, of the conductor. A long wire (or conductor) has more resistance and a short wire has less resistance. Again, a thick wire has less resistance whereas a thin wire has more resistance. Rise in temperature of a wire (or conductor) increases its resistance.

The SI unit of resistance is ohm which is denoted by the symbol omega, Ω. The unit of resistance ohm, can be defined by using Ohm's law as described below.

According to Ohm's law :

$$\frac{\text{Potential difference}}{\text{Current}} = \text{Resistance} \quad \text{(A constant)}$$

$$\text{That is,} \qquad \frac{V}{I} = R$$

$$\text{So,} \qquad \text{Resistance, } R = \frac{V}{I}$$

Now, if the potential difference V is 1 volt and the current I is 1 ampere, then resistance R in the above equation becomes 1 ohm.

$$\text{That is,} \qquad 1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

This gives us the following definition for ohm : **1 ohm is the resistance of a conductor such that when a potential difference of 1 volt is applied to its ends, a current of 1 ampere flows through it.** We can find out the resistance of a conductor by using Ohm's law equation $\frac{V}{I} = R.$ This will become more clear from the following examples.

Sample Problem 1. Potential difference between two points of a wire carrying 2 ampere current is 0.1 volt. Calculate the resistance between these points.

Solution. From Ohm's law we have :

$$\frac{\text{Potential difference}}{\text{Current}} = \text{Resistance}$$

$$\text{or} \qquad \frac{V}{I} = R$$

Here, Potential difference, $V = 0.1$ volt
Current, $I = 2$ amperes
And, Resistance, $R = ?$ (To be calculated)

Putting these values in the above formula, we get :

$$\frac{0.1}{2} = R$$

$$0.05 = R$$

or Resistance, $R = 0.05$ ohm (or $0.05\ \Omega$)

Sample Problem 2. A simple electric circuit has a 24 V battery and a resistor of 60 ohms. What will be the current in the circuit ? The resistance of the connecting wires is negligible.

Solution. In this case :

Potential difference, $V = 24$ volts
Resistance, $R = 60$ ohms
And, Current, $I = ?$ (To be calculated)

Now, putting these values in the Ohm's law equation :

$$\frac{V}{I} = R$$

we get : $$\frac{24}{I} = 60$$

So, $$60\,I = 24$$

And, $$I = \frac{24}{60} \text{ ampere}$$

$$I = 0.4 \text{ ampere} \quad (\text{or } 0.4\text{ A})$$

Thus, the current flowing in the circuit is 0.4 ampere.

Sample Problem 3. An electric iron draws a current of 3.4 A from the 220 V supply line. What current will this electric iron draw when connected to 110 V supply line ?

Solution. First of all we will calculate the resistance of electric iron. Now, in the first case, the electric iron draws a current of 3.4 A from 220 V supply line. So,

Potential difference, $V = 220$ V
Current, $I = 3.4$ A
And, Resistance, $R = ?$ (To be calculated)

Now, $$\frac{V}{I} = R$$

So, $$\frac{220}{3.4} = R$$

Resistance, $R = 64.7\ \Omega$

Thus, the resistance of electric iron is 64.7 ohms. This resistance will now be used to find out the current drawn when the electric iron is connected to 110 V supply line. So,

$$\frac{V}{I} = R$$

$$\frac{110}{I} = 64.7$$

$$\text{Current, } I = \frac{110}{64.7}$$

$$= 1.7\text{ A}$$

Thus, the electric iron will draw a current of 1.7 amperes from 110 volt supply line.

Graph Between V and I

If a graph is drawn between the potential difference readings (V) and the corresponding current values (I), the graph is found to be a straight line passing through the origin (see Figure 15). A straight line graph can be obtained only if the two quantities are directly proportional to one another. Since the 'current-potential difference' graph is a straight line, we conclude that **current is directly proportional to the potential difference.** It is clear from the graph OA that as the potential difference V increases, the current I also increases, but the ratio $\frac{V}{I}$ remains constant. This constant is called resistance of the conductor. We will now solve one problem based on the graph between V and I.

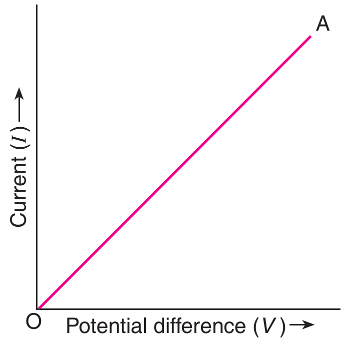


Figure 15. $V - I$ graph for a metal conductor.

Sample Problem. The values of current I flowing through a coil for the corresponding values of the potential difference V across the coil are shown below :

I (amperes)	:	0.05	0.10	0.20	0.30	0.4
V (volts)	:	0.85	1.70	3.5	5.0	6.8

Plot a graph between V and I and calculate the resistance of the coil.

Solution. We take a graph paper and mark the potential difference (V) values of 1, 2, 3, 4, 5, 6 and 7 on the x-axis. The current (I) values of 0.1, 0.2, 0.3 and 0.4 are marked on the y-axis (see Figure 16).

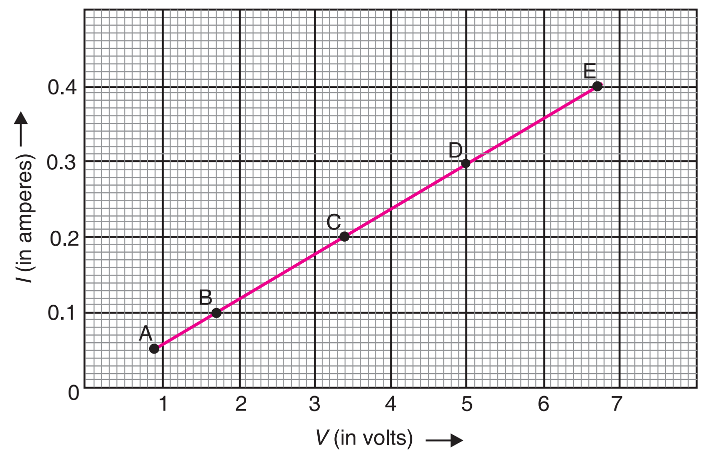


Figure 16.

(*i*) On plotting the first reading of 0.85 V on x-axis and 0.05 A on the y-axis, we get the point A on the graph paper (see Figure 16)

(*ii*) On plotting the second reading of 1.70 V on the x-axis and 0.10 A on the y-axis, we get a second point B on the graph paper.

(*iii*) On plotting the third reading of 3.5 V on the x-axis and 0.20 A on the y-axis, we get a third point C on the graph paper.

(*iv*) On plotting the fourth reading of 5.0 V on x-axis and 0.30 A on the y-axis, we get a fourth point D on the graph paper.

(*v*) And on plotting the fifth reading of 6.8 V on x-axis and 0.4 A on the y-axis, we get a fifth point E on the graph paper.

Let us now join all the five points A, B, C, D and E. In this way we get a straight-line graph between V and I. This straight-line graph shows that current (I) is directly proportional to the potential difference (V). And this conclusion proves Ohm's law.

Let us calculate the resistance now. If we look at the above graph, we find that at point E, potential difference (V) is 6.8 volts whereas the current (I) is 0.4 amperes. Now, we know that :

Resistance, $$R = \frac{V}{I}$$

So, $$R = \frac{6.8}{0.4}$$

$$R = 17 \text{ ohms}$$

Thus, the resistance is of 17 ohms.

Experiment to Verify Ohm's Law

If we can show that for a given conductor, say a piece of resistance wire (such as a nichrome wire), the ratio $\frac{\textit{potential difference}}{\textit{current}}$ is constant, then Ohm's law will get verified. Alternatively, we can draw a graph between the potential difference (V) and current (I), and if this graph is a straight line, even then Ohm's law gets verified. Let us see how this is done in the laboratory.

Suppose we have a piece of resistance wire R (which is the conductor here) (Figure 17), and we want to verify Ohm's law for it, that is, we want to show that the conductor R obeys Ohm's law. For this purpose we take a battery (B), a switch (S), a rheostat (Rh), an ammeter (A), a voltmeter (V) and some connecting wires. Using all these and the conductor R we make a circuit as shown in Figure 17.

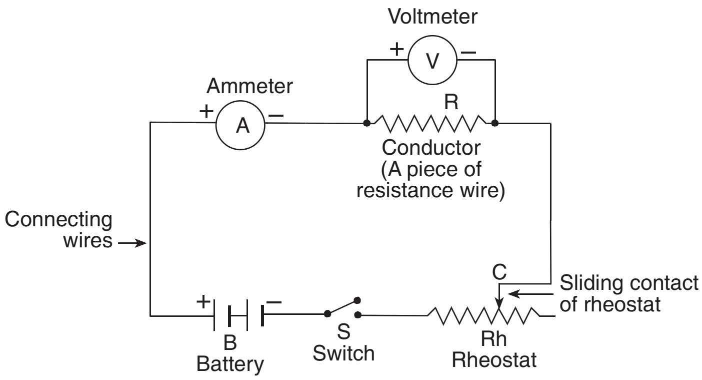


Figure17. Circuit to verify Ohm's law in the laboratory.

To start the experiment, the circuit is completed by pressing the switch S. On pressing the switch, a current starts flowing in the whole circuit including the conductor R. This current is shown by the ammeter. The rheostat Rh is initially so adjusted that a *small* current passes through the circuit. The ammeter reading is now noted. This reading gives us the current I flowing through the conductor R. The voltmeter reading is also noted which will give the potential difference V across the ends of the conductor. This gives us the first set of V and I readings. The current in the circuit is now *increased* step by step, by changing the position of the sliding contact C of the rheostat. The current values and the corresponding potential difference values are noted in all the cases. The ratio $\frac{\textit{potential difference}}{\textit{current}}$ or $\frac{V}{I}$ is calculated for all the readings. It is found that the ratio $\frac{V}{I}$ has constant value for all the observations. Since the ratio of potential difference and current, $\frac{V}{I}$ is constant, Ohm's law gets verified because this shows that the current is directly proportional to potential difference. The constant ratio $\frac{V}{I}$ gives us the resistance R of the conductor. So, this Ohm's law experiment can also be used to determine the resistance of a conductor. If a graph is drawn between potential difference readings and corresponding current readings, we will get a straight line graph showing that current is directly proportional to potential difference. This also verifies Ohm's law.

Good Conductors, Resistors and Insulators

On the basis of their electrical resistance, all the substances can be divided into three groups : Good conductors, Resistors and Insulators. **Those substances which have very low electrical resistance are called good conductors.** A good conductor allows the electricity to flow through it easily. Silver metal is the *best*

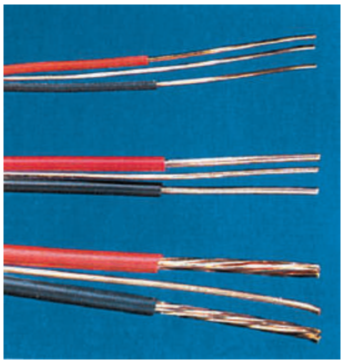


Figure 18. The electric wires are made of copper (good conductor). Their covering is made of plastic (insulator).

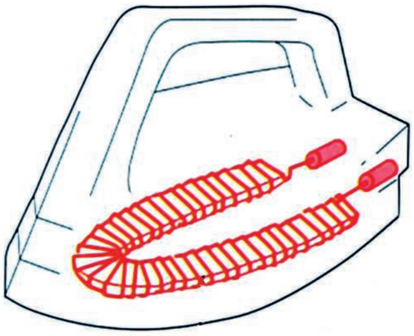


Figure 19. The heating element of electric iron is made of nichrome wire which is a resistor.

Figure 20. Rubber is an insulator. The electricians wear rubber gloves to protect themselves from electric shocks.

conductor of electricity. Copper and aluminium metals are also *good* conductors. Electric wires are made of copper or aluminium because they have very low electrical resistance (see Figure 18). **Those substances which have comparatively high electrical resistance, are called resistors.** The alloys like nichrome, manganin and constantan (or eureka), all have quite high resistances, so they are called resistors. Resistors are used to make those electrical devices where high resistance is required (see Figure 19). A resistor *reduces* the current in a circuit. **Those substances which have infinitely high electrical resistance are called insulators.** An insulator does not allow electricity to flow through it. Rubber is an excellent insulator. Electricians wear rubber handgloves while working with electricity because rubber is an insulator and protects them from electric shocks (see Figure 20). Wood is also a good insulator. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Name the law which relates the current in a conductor to the potential difference across its ends.

2. Name the unit of electrical resistance and give its symbol.

3. Name the physical quantity whose unit is "ohm".

4. What is the general name of the substances having infinitely high electrical resistance ?

5. Keeping the resistance constant, the potential difference applied across the ends of a component is halved. By how much does the current change ?

6. State the factors on which the strength of electric current flowing in a given conductor depends.

7. Which has less electrical resistance : a thin wire or a thick wire (of the same length and same material) ?

8. Keeping the potential difference constant, the resistance of a circuit is halved. By how much does the current change ?

9. A potential difference of 20 volts is applied across the ends of a resistance of 5 ohms. What current will flow in the resistance ?

10. A resistance of 20 ohms has a current of 2 amperes flowing in it. What potential difference is there between its ends ?

11. A current of 5 amperes flows through a wire whose ends are at a potential difference of 3 volts. Calculate the resistance of the wire.

12. Fill in the following blank with a suitable word :
Ohm's law states a relation between potential difference and ....

Short Answer Type Questions

13. Distinguish between good conductors, resistors and insulators. Name two good conductors, two resistors and two insulators.

14. Classify the following into good conductors, resistors and insulators :
Rubber, Mercury, Nichrome, Polythene, Aluminium, Wood, Manganin, Bakelite, Iron, Paper, Thermocol, Metal coin

15. What is Ohm's law ? Explain how it is used to define the unit of resistance.

16. (*a*) What is meant by the "resistance of a conductor" ? Write the relation between resistance, potential difference and current.

(*b*) When a 12 V battery is connected across an unknown resistor, there is a current of 2.5 mA in the circuit. Calculate the value of the resistance of the resistor.

17. (*a*) Define the unit of resistance (or Define the unit "ohm").

(*b*) What happens to the resistance as the conductor is made thinner ?

(*c*) Keeping the potential difference constant, the resistance of a circuit is doubled. By how much does the current change ?

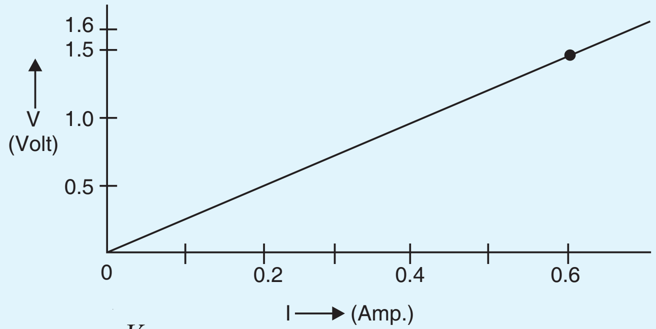
18. (*a*) Why do electricians wear rubber hand gloves while working with electricity ?

(*b*) What p.d. is needed to send a current of 6 A through an electrical appliance having a resistance of 40 Ω ?

19. An electric circuit consisting of a 0.5 m long nichrome wire XY, an ammeter, a voltmeter, four cells of 1.5 V each and a plug key was set up.

(*i*) Draw a diagram of this electric circuit to study the relation between the potential difference maintained between the points 'X' and 'Y' and the electric current flowing through XY.

(*ii*) Following graph was plotted between *V* and *I* values :



What would be the values of $\frac{V}{I}$ ratios when the potential difference is 0.8 V, 1.2 V and 1.6 V respectively ? What conclusion do you draw from these values ?

(*iii*) What is the resistance of the wire ?

Long Answer Type Question

20. (*a*) What is the ratio of potential difference and current known as ?

(*b*) The values of potential difference *V* applied across a resistor and the correponding values of current *I* flowing in the resistor are given below :

Potential difference, *V* (in volts)	:	2.5	5.0	10.0	15.0	20.0	25.0
Current, *I* (in amperes)	:	0.1	0.2	0.4	0.6	0.8	1.0

Plot a graph between *V* and *I*, and calculate the resistance of the resistor.

(*c*) Name the law which is illustrated by the above *V–I* graph.

(*d*) Write down the formula which states the relation between potential difference, current and resistance.

(*e*) The potential difference between the terminals of an electric iron is 240 V and the current is 5.0 A. What is the resistance of the electric iron ?

Multiple Choice Questions (MCQs)

21. The p.d. across a 3 Ω resistor is 6 V. The current flowing in the resistor will be :

(*a*) $\frac{1}{2}$ A (*b*) 1 A (*c*) 2 A (*d*) 6 A

22. A car headlight bulb working on a 12 V car battery draws a current of 0.5 A. The resistance of the light bulb is :

(*a*) 0.5 Ω (*b*) 6 Ω (*c*) 12 Ω (*d*) 24 Ω

23. An electrical appliance has a resistance of 25 Ω. When this electrical appliance is connected to a 230 V supply line, the current passing through it will be :

(*a*) 0.92 A (*b*) 2.9 A (*c*) 9.2 A (*d*) 92 A

24. When a 4 Ω resistor is connected across the terminals of a 12 V battery, the number of coulombs passing through the resistor per second is :

(*a*) 0.3 (*b*) 3 (*c*) 4 (*d*) 12

25. Ohm's law gives a relationship between :
(*a*) current and resistance
(*b*) resistance and potential difference
(*c*) potential difference and electric charge
(*d*) current and potential difference

26. The unit of electrical resistance is :
(*a*) ampere (*b*) volt (*c*) coulomb (*d*) ohm

27. The substance having infinitely high electrical resistance is called :
(*a*) conductor (*b*) resistor (*c*) superconductor (*d*) insulator

28. Keeping the potential difference constant, the resistance of a circuit is doubled. The current will become :
(*a*) double (*b*) half (*c*) one-fourth (*d*) four times

29. Keeping the p.d. constant, the resistance of a circuit is halved. The current will become :
(*a*) one-fourth (*b*) four times (*c*) half (*d*) double

Questions Based on High Order Thinking Skills (HOTS)

30. An electric room heater draws a current of 2.4 A from the 120 V supply line. What current will this room heater draw when connected to 240 V supply line ?

31. Name the electrical property of a material whose symbol is "omega".

32. The graph between *V* and *I* for a conductor is a straight line passing through the origin.
(*a*) Which law is illustrated by such a graph ?
(*b*) What should remain constant in a statement of this law ?

33. A p.d. of 10 V is needed to make a current of 0.02 A flow through a wire. What p.d. is needed to make a current of 250 mA flow through the same wire ?

34. A current of 200 mA flows through a 4 kΩ resistor. What is the p.d. across the resistor ?

ANSWERS

1. Ohm's law **3.** Electrical resistance **4.** Insulators **5.** Current becomes half **7.** Thick wire **8.** Current becomes double **9.** 4 A **10.** 40 V **11.** 0.6 Ω **12.** current **16.** (*b*) 4800 Ω **17.** (*c*) Current becomes half **18.** (*b*) 240 V **19.** (*ii*) 2.5, 2.5, 2.5 ; The ratio of potential difference applied to the wire and current passing through it is a constant (*iii*) 2.5 Ω **20.** (*a*) Resistance (*b*) 25 Ω (*c*) Ohm's law (*e*) 48 Ω **21.** (*c*) **22.** (*d*) **23.** (*c*) **24.** (*b*) **25.** (*d*) **26.** (*d*) **27.** (*d*) **28.** (*b*) **29.** (*d*) **30.** 4.8 A **31.** Resistance **32.** (*a*) Ohm's law (*b*) Temperature **33.** 125 V **34.** 800 V

FACTORS AFFECTING THE RESISTANCE OF A CONDUCTOR

The electrical resistance of a conductor (or a wire) depends on the following factors :

(*i*) length of the conductor,
(*ii*) area of cross-section of the conductor (or thickness of the conductor),
(*iii*) nature of the material of the conductor, and
(*iv*) temperature of the conductor.

We will now describe how the resistance depends on these factors.

1. Effect of Length of the Conductor

It has been found by experiments that on increasing the length of a wire, its resistance increases; and on decreasing the length of the wire, its resistance decreases. Actually, **the resistance of a conductor is directly proportional to its length.** That is,

Resistance, $R \propto l$ (where l is the length of conductor)

Since the resistance of a wire is directly proportional to its length, therefore, **when the length of a wire is doubled, its resistance also gets doubled;** and **if the length of a wire is halved, then its resistance also gets halved.** When we double the length of a wire, then this can be considered to be equivalent to two resistances joined in series, and their resultant resistance is the sum of the two resistances (which is double the original value). From this discussion we conclude that **a long wire (or long conductor) has more resistance,** and **a short wire has less resistance.**

2. Effect of Area of Cross-Section of the Conductor

It has been found by experiments that **the resistance of a conductor is inversely proportional to its area of cross-section.** That is,

Resistance, $R \propto \frac{1}{A}$ (where A is area of cross-section of conductor)

Since the resistance of a wire (or conductor) is inversely proportional to its area of cross-section, therefore, **when the area of cross-section of a wire is doubled, its resistance gets halved;** and **if the area of cross-section of wire is halved, then its resistance will get doubled.** We know that a thick wire has a greater area of cross-section whereas a thin wire has a smaller area of cross-section. This means that **a thick wire has less resistance,** and **a thin wire has more resistance.** A thick wire (having large area of cross-section) can be considered equivalent to a large number of thin wires connected in parallel. And we know that if we have two resistance wires connected in parallel, their resultant resistance is halved. So, doubling the area of cross-section of a wire will, therefore, halve the resistance. From the above discussion it is clear that to make resistance wires (or resistors) :

(*i*) short length of a thick wire is used for getting low resistance, and
(*ii*) long length of a thin wire is used for getting high resistance.

The thickness of a wire is usually represented by its diameter. It can be shown by calculations that **the resistance of a wire is inversely proportional to the square of its diameter.** Thus, when the diameter of a wire is doubled (made 2 times), its resistance becomes one-fourth $\left(\frac{1}{4}\right)$, and if the diameter of the wire is halved $\left(\text{made } \frac{1}{2}\right)$, then its resistance becomes four times (4 times). Similarly, if the diameter of a wire is tripled (made 3 times), then its resistance will become $\frac{1}{(3)^2}$ or $\frac{1}{9}$th of its original value.

3. Effect of the Nature of Material of the Conductor

The electrical resistance of a conductor (say, a wire) depends on the nature of the material of which it is made. Some materials have low resistance whereas others have high resistance. For example, if we take two similar wires, having equal lengths and diameters, of copper metal and nichrome alloy, we will find that the resistance of nichrome wire is about 60 times more than that of the copper wire. This shows that the resistance of a conductor depends on the nature of the material of the conductor.

4. Effect of Temperature

It has been found that **the resistance of all pure metals increases on raising the temperature; and decreases on lowering the temperature.** But the resistance of alloys like manganin, constantan and nichrome is almost unaffected by temperature.

RESISTIVITY

It has been found by experiments that :

(*i*) The resistance of a given conductor is directly proportional to its length. That is :

$$R \propto l \quad \text{... (1)}$$

(*ii*) The resistance of a given conductor is inversely proportional to its area of cross-section. That is :

$$R \propto \frac{1}{A} \quad \text{... (2)}$$

By combining the relations (1) and (2), we get :

$$R \propto \frac{l}{A}$$

or

$$R = \frac{\rho \times l}{A} \quad \text{... (3)}$$

where ρ (rho) is a constant known as *resistivity* of the material of the conductor. Resistivity is also known as specific resistance.

From equation (3), it is clear that for a given conductor having a specified length l and area of cross-section A, the resistance R is directly proportional to its resistivity ρ. So, if we change the material of a conductor to one whose resistivity is two times, then the resistance will also become two times. And if we change the material of a conductor to one whose resistivity is three times, then the resistance will also become three times.

If we rearrange equation (3), we can write it as :

$$\text{Resistivity, } \rho = \frac{R \times A}{l} \qquad \text{..... (4)}$$

where R = resistance of the conductor

A = area of cross-section of the conductor

and l = length of the conductor

This formula for calculating the resistivity of the material of a conductor should be memorised because it will be used to solve numerical problems. By using this formula, we will now obtain the definition of resistivity. Let us take a conductor having a unit area of cross-section of 1 m^2 and a unit length of 1 m. So, putting A = 1 and l = 1 in equation (4), we get :

$$\text{Resistivity, } \rho = R$$

Thus, **the resistivity of a substance is numerically equal to the resistance of a rod of that substance which is 1 metre long and 1 square metre in cross-section.** Since the length is 1 metre and the area of cross-section is 1 square metre, so it becomes a 1 metre cube. So, we can also say that *the resistivity of a substance is equal to the resistance between the opposite faces of a 1 metre cube of the substance.* We will now find out the unit of resistivity.

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We have just seen that :

$$\text{Resistivity, } \rho = \frac{R \times A}{l}$$

Now, to get the unit of resistivity ρ we should put the units of resistance R, area of cross-section A and length l in the above equation. We know that :

The unit of resistance R is ohm

The unit of area of cross-section A is $(\text{metre})^2$

And, The unit of length l is metre

So, putting these units in the above equation, we get :

$$\text{Unit of resistivity, } \rho = \frac{\text{ohm} \times (\text{metre})^2}{\text{metre}}$$

$$= \text{ohm–metre} \quad (\text{or } \Omega \text{ m})$$

Thus, **the SI unit of resistivity is ohm-metre** which is written in symbols as **Ω m.**

Please note that **the resistivity of a substance does not depend on its length or thickness. It depends on the nature of the substance and temperature.** The resistivity of a substance is its characteristic property. So, we can use the resistivity values to compare the resistances of two or more substances. Another point to be noted is that just as when we talk of resistance in the context of electricity, it actually means electrical resistance, in the same way, when we talk of *resistivity*, it actually means *electrical resistivity*. The resistivities of some of the common substances (or materials) are given on the next page.

Resistivities of Some Common Substances (at 20°C)

Category	*Substance (Material)*	*Resistivity*
Conductors :	***Metals***	
	1. Silver	$1.60 \times 10^{-8}\ \Omega$ m
	2. Copper	$1.69 \times 10^{-8}\ \Omega$ m
	3. Aluminium	$2.63 \times 10^{-8}\ \Omega$ m
	4. Tungsten	$5.20 \times 10^{-8}\ \Omega$ m
	5. Nickel	$6.84 \times 10^{-8}\ \Omega$ m
	6. Iron	$10.0 \times 10^{-8}\ \Omega$ m
	7. Chromium	$12.9 \times 10^{-8}\ \Omega$ m
	8. Mercury	$94.0 \times 10^{-8}\ \Omega$ m
	9. Manganese	$184.0 \times 10^{-8}\ \Omega$ m
	Alloys	
	1. Manganin (Cu–Mn–Ni)	$44 \times 10^{-8}\ \Omega$ m
	2. Constantan (Cu–Ni)	$49 \times 10^{-8}\ \Omega$ m
	3. Nichrome (Ni–Cr–Mn–Fe)	$110 \times 10^{-8}\ \Omega$ m
Semiconductors :	1. Germanium	$0.6\ \Omega$ m
	2. Silicon	$2300\ \Omega$ m
Insulators :	1. Glass	10^{10} to $10^{14}\ \Omega$ m
	2. Paper (Dry)	$10^{12}\ \Omega$ m
	3. Diamond	10^{12} to $10^{13}\ \Omega$ m
	4. Hard rubber	10^{13} to $10^{16}\ \Omega$ m
	5. Ebonite	10^{15} to $10^{17}\ \Omega$ m

From the above table we find that the resistivity of copper is 1.69×10^{-8} ohm-metre. Now, **by saying that the resistivity of copper is 1.69×10^{-8} ohm-metre, we mean that if we take a rod of copper metal 1 metre long and 1 square metre in area of cross-section, then its resistance will be 1.69×10^{-8} ohms.** Please note that a good conductor of electricity should have a low resistivity and a poor conductor of electricity will have a high resistivity. From the above table we find that of all the metals, silver has the lowest resistivity (of $1.60 \times 10^{-8}\ \Omega$ m), which means that silver offers the least resistance to the flow of current through it. Thus, **silver metal is the best conductor of electricity.** It is obvious that we should make electric wires of silver metal. But silver is a very costly metal. **We use copper and aluminium wires for the transmission of electricity because copper and aluminium have very low resistivities** (due to which they are very good conductors of electricity). From this discussion we conclude that *silver, copper* and *aluminium* are very good conductors of electricity.

The resistivities of alloys are much more higher than those of the pure metals (from which they are made). For example, the resistivity of manganin (which is an alloy of copper, manganese and nickel) is about 25 times more than that of copper; and the resistivity of constantan (which is an alloy of copper and nickel) is about 30 times more than that of copper metal. It is due to their high resistivities that manganin and constantan alloys are used to make resistance wires (or resistors) used in electronic appliances to reduce the current in an electrical circuit. Another alloy having a high resistivity is nichrome. This is an alloy of nickel, chromium, manganese and iron having a resistivity of about 60 times more than that of copper.

The heating elements (or heating coils) of electrical heating appliances such as electric iron and toaster, etc., are made of an alloy rather than a pure metal because (*i*) the resistivity of an alloy is much higher than that of pure metal, and (*ii*) an alloy does not undergo oxidation (or burn) easily even at high temperature, when it is red hot. For example, **nichrome alloy is used for making the heating elements of electrical appliances** such as electric iron, toaster, electric kettle, room heaters, water heaters (geysers), and hair dryers, etc., because :

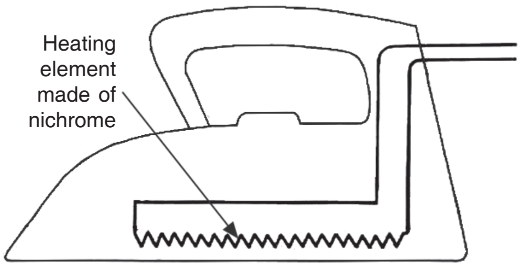


Figure 21. An electric iron.

(*i*) **nichrome has very high resistivity** (due to which the heating element made of nichrome has a high resistance and produces a lot of heat on passing current).

(*ii*) **nichrome does not undergo oxidation (or burn) easily even at high temperature.** Due to this nichrome wire can be kept red-hot without burning or breaking in air.

The resistivity of conductors (like metals) is very low. The resistivity of most of the metals increases with temperature. On the other hand, the resistivity of insulators like ebonite, glass and diamond is very high and does not change with temperature. **The resistivity of semi-conductors like silicon and germanium is in-between those of conductors and insulators,** and decreases on increasing the temperature. Semi-conductors are proving to be of great practical importance because of their marked change in conducting properties with temperature, impurity, concentration, etc. Semi-conductors are used for making solar cells and transistors. We will now solve some problems based on resistivity.

Sample Problem 1. A copper wire of length 2 m and area of cross-section 1.7×10^{-6} m^2 has a resistance of 2×10^{-2} ohms. Calculate the resistivity of copper.

Solution. The formula for resistivity is :

$$\text{Resistivity, } \rho = \frac{R \times A}{l}$$

Here, Resistance, $R = 2 \times 10^{-2}\ \Omega$

Area of cross-section, $A = 1.7 \times 10^{-6}$ m^2

And, Length, $l = 2$ m

So, putting these values in the above formula, we get :

$$\rho = \frac{2 \times 10^{-2} \times 1.7 \times 10^{-6}}{2}$$

$$= 1.7 \times 10^{-8}\ \Omega\ \text{m}$$

Thus, the resistivity of copper is 1.7×10^{-8} ohm-metre.

Sample Problem 2. A copper wire has a diameter of 0.5 mm and resistivity of $1.6 \times 10^{-8}\ \Omega$ m.

(*a*) What will be the length of this wire to make its resistance 10 Ω ?

(*b*) How much does the resistance change if the diameter is doubled ? **(NCERT Book Question)**

Solution. (*a*) First of all we will calculate the area of cross-section of the copper wire. Here the diameter of copper wire is 0.5 mm, so its radius (r) will be $\frac{0.5}{2}$ mm or 0.25 mm. This radius of 0.25 mm will be equal to $\frac{0.25}{1000}$ m or 0.25×10^{-3} m. Thus, the radius r of this copper wire is 0.25×10^{-3} m. We will now find out the area of cross-section of the copper wire by using this value of the radius. So,

Area of cross-section of wire, $A = \pi r^2$

$$= \frac{22}{7} \times (0.25 \times 10^{-3})^2$$

$$= 0.1964 \times 10^{-6}\ m^2$$

Resistivity, $\rho = 1.6 \times 10^{-8}\ \Omega\ m$

Resistance, $R = 10\ \Omega$

And, Length, $l = ?$ (To be calculated)

Now, putting these values in the formula :

$$\rho = \frac{R \times A}{l}$$

We get : $$1.6 \times 10^{-8} = \frac{10 \times 0.1964 \times 10^{-6}}{l}$$

So, $$l = \frac{10 \times 0.1964 \times 10^{-6}}{1.6 \times 10^{-8}}$$

$$l = \frac{1964}{16}$$

$$l = 122.7\ m$$

Thus, the length of copper wire required to make 10 Ω resistance will be 122.7 metres.

(*b*) The resistance of a wire is *inversely* proportional to the square of its diameter. So, when the diameter of the wire is doubled (that is, made 2 times), then its resistance will become $\left(\frac{1}{2}\right)^2$ or $\frac{1}{4}$ (one-fourth).

Sample Problem 3. A 6 Ω resistance wire is doubled up by folding. Calculate the new resistance of the wire.

Solution. Suppose the length of 6 Ω resistance wire is l, its area of cross-section is A and its resistivity is ρ. Then :

$$R = \frac{\rho \times l}{A}$$

or $$6 = \frac{\rho \times l}{A} \qquad \text{... (1)}$$

Now, when this wire is doubled up by folding, then its length will become half, that is, the length will become $\frac{l}{2}$. But on doubling the wire by folding, its area of cross-section will become double, that is, the area of cross-section will become $2A$. Suppose the new resistance of the doubled up wire (or folded wire) is R. So,

$$R = \frac{\rho \times l}{2 \times 2A}$$

or $$R = \frac{\rho \times l}{4A} \qquad \text{... (2)}$$

Now, dividing equation (2) by equation (1), we get :

$$\frac{R}{6} = \frac{\rho \times l \times A}{4A \times \rho \times l}$$

or $$\frac{R}{6} = \frac{1}{4}$$

$$4R = 6$$

$$R = \frac{6}{4}$$

$$R = 1.5\ \Omega$$

Thus, the new resistance of the doubled up wire is 1.5 Ω.

Before we go further and study the combination of resistances (or resistors) in series and parallel, **please answer the following questions :**

Very Short Answer Type Questions

1. What happens to the resistance as the conductor is made thicker ?
2. If the length of a wire is doubled by taking more of wire, what happens to its resistance ?
3. On what factors does the resistance of a conductor depend ?
4. Name the material which is the best conductor of electricity.
5. Which among iron and mercury is a better conductor of electricity ?
6. Why are copper and aluminium wires usually used for electricity transmission ?
7. Name the material which is used for making the heating element of an electric iron.
8. What is nichrome ? State its one use.
9. Give two reasons why nichrome alloy is used for making the heating elements of electrical appliances.
10. Why are the coils of electric irons and electric toasters made of an alloy rather than a pure metal ?
11. Which has more resistance :
(*a*) a long piece of nichrome wire or a short one ?
(*b*) a thick piece of nichrome wire or a thin piece ?
12. (*a*) How does the resistance of a pure metal change if its temperature decreases ?
(*b*) How does the presence of impurities in a metal affect its resistance ?
13. Fill in the following blanks with suitable words :
Resistance is measured in............ The resistance of a wire increases as the length.........; as the temperature............. ; and as the cross-sectional area.............

Short Answer Type Questions

14. (*a*) What do you understand by the "resistivity" of a substance ?
(*b*) A wire is 1.0 m long, 0.2 mm in diameter and has a resistance of 10 Ω. Calculate the resistivity of its material ?
15. (*a*) Write down an expression for the resistance of a metallic wire in terms of the resistivity.
(*b*) What will be the resistance of a metal wire of length 2 metres and area of cross-section 1.55×10^{-6} m^2, if the resistivity of the metal be 2.8×10^{-8} Ω m ?
16. (*a*) Give two examples of substances which are good conductors of electricity. Why do you think they are good conductors of electricity ?
(*b*) Calculate the resistance of a copper wire 1.0 km long and 0.50 mm diameter if the resistivity of copper is 1.7×10^{-8} Ωm.
17. Will current flow more easily through a thick wire or a thin wire of the same material when connected to the same source ? Give reason for your answer.
18. How does the resistance of a conductor depend on :
(*a*) length of the conductor ?
(*b*) area of cross-section of the conductor ?
(*c*) temperature of the conductor ?
19. (*a*) Give one example to show how the resistance depends on the nature of material of the conductor.
(*b*) Calculate the resistance of an aluminium cable of length 10 km and diameter 2.0 mm if the resistivity of aluminium is 2.7×10^{-8} Ωm.
20. What would be the effect on the resistance of a metal wire of :
(*a*) increasing its length ?
(*b*) increasing its diameter ?
(*c*) increasing its temperature ?
21. How does the resistance of a wire vary with its :
(*a*) area of cross-section ?
(*b*) diameter ?

22. How does the resistance of a wire change when :

(*i*) its length is tripled ?

(*ii*) its diameter is tripled ?

(*iii*) its material is changed to one whose resistivity is three times ?

23. Calculate the area of cross-section of a wire if its length is 1.0 m, its resistance is 23 Ω and the resistivity of the material of the wire is 1.84×10^{-6} Ω m.

Long Answer Type Question

24. (*a*) Define resistivity. Write an expression for the resistivity of a substance. Give the meaning of each symbol which occurs in it.

(*b*) State the SI unit of resistivity.

(*c*) Distinguish between resistance and resistivity.

(*d*) Name two factors on which the resistivity of a substance depends and two factors on which it does not depend.

(*e*) The resistance of a metal wire of length 1 m is 26 Ω at 20°C. If the diameter of the wire is 0.3 mm, what will be the resistivity of the metal at that temperature ?

Multiple Choice Questions (MCQs)

25. The resistance of a wire of length 300 m and cross-section area 1.0 mm^2 made of material of resistivity 1.0×10^{-7} Ωm is :

(*a*) 2 Ω (*b*) 3 Ω (*c*) 20 Ω (*d*) 30 Ω

26. When the diameter of a wire is doubled, its resistance becomes :

(*a*) double (*b*) four times (*c*) one-half (*d*) one-fourth

27. If the resistance of a certain copper wire is 1 Ω, then the resistance of a similar nichrome wire will be about :

(*a*) 25 Ω (*b*) 30 Ω (*c*) 60 Ω (*d*) 45 Ω

28. If the diameter of a resistance wire is halved, then its resistance becomes :

(*a*) four times (*b*) half (*c*) one-fourth (*d*) two times

29. The resistivity of a certain material is 0.6 Ω m. The material is most likely to be :

(*a*) an insulator (*b*) a superconductor (*c*) a conductor (*d*) a semiconductor

30. When the area of cross-section of a conductor is doubled, its resistance becomes :

(*a*) double (*b*) half (*c*) four times (*d*) one-fourth

31. The resistivity of copper metal depends on only one of the following factors. This factor is :

(*a*) length (*b*) thickness (*c*) temperature (*d*) area of cross-section

32. If the area of cross-section of a resistance wire is halved, then its resistance becomes :

(*a*) one-half (*b*) 2 times (*c*) one-fourth (*d*) 4 times

Questions Based on High Order Thinking Skills (HOTS)

33. A piece of wire of resistance 20 Ω is drawn out so that its length is increased to twice its original length. Calculate the resistance of the wire in the new situation.

34. The electrical resistivities of three materials P, Q and R are given below :

P	2.3×10^{3} Ω m
Q	2.63×10^{-8} Ω m
R	1.0×10^{15} Ω m

Which material will you use for making (*a*) electric wires (*b*) handle for soldering iron, and (*c*) solar cells ? Give reasons for your choices.

35. The electrical resistivities of four materials A, B, C and D are given below :

A	110×10^{-8} Ω m
B	1.0×10^{10} Ω m
C	10.0×10^{-8} Ω m
D	2.3×10^{3} Ω m

Which material is : (*a*) good conductor (*b*) resistor (*c*) insulator, and (*d*) semiconductor ?

36. The electrical resistivities of five substances A, B, C, D and E are given below :

A	5.20×10^{-8} Ω m

B	$110 \times 10^{-8}\ \Omega$ m
C	$2.60 \times 10^{-8}\ \Omega$ m
D	$10.0 \times 10^{-8}\ \Omega$ m
E	$1.70 \times 10^{-8}\ \Omega$ m

(*a*) Which substance is the best conductor of electricity ? Why ?
(*b*) Which one is a better conductor : A or C ? Why ?
(*c*) Which substance would you advise to be used for making heating elements of electric irons ? Why ?
(*d*) Which two substances should be used for making electric wires ? Why ?

ANSWERS

1. Resistance decreases **2.** Resistance gets doubled **5.** Iron **7.** Nichrome **11.** (*a*) Long piece of nichrome wire (*b*) Thin piece of nichrome wire **12.** (*a*) Resistance decreases (*b*) Resistance increases **13.** Ohms ; increases ; increases ; decreases **14.** (*b*) $31.4 \times 10^{-8}\ \Omega$m **15.** (*b*) 0.036 Ω **16.** (*b*) 86.5 Ω **17.** Thick wire ; Lesser electrical resistance **19.** (*b*) 86 Ω **22.** (*i*) Resistance becomes 3 times (*ii*) Resistance becomes $\frac{1}{9}$th. (*iii*) Resistance becomes 3 times **23.** 8.0×10^{-8} m^2 **24.** (*e*) $1.84 \times 10^{-8}\ \Omega$m, **25.** (*d*) **26.** (*d*) **27.** (*c*) **28.** (*a*) **29.** (*d*) **30.** (*b*) **31.** (*c*) **32.** (*b*) **33.** 80 Ω (*Hint*. In the new situation, length becomes $2l$ and area of cross-section becomes $\frac{A}{2}$) **34.** (*a*) Q ; Very low resistivity (*b*) R ; Very high resistivity (*c*) P; Semiconductor **35.** (*a*) C (*b*) A (*c*) B (*d*) D **36.** (*a*) E ; Least electrical resistivity (*b*) C ; Lesser electrical resistivity (*c*) B ; High electrical resistivity (*d*) C and E ; Low electrical resistivities

COMBINATION OF RESISTANCES (OR RESISTORS)

Apart from potential difference, current in a circuit depends on resistance of the circuit. So, in the electrical circuits of radio, television and other similar things, it is usually necessary to combine two or more resistances to get the required current in the circuit. We can combine the resistances lengthwise (called series) or we can put the resistances parallel to one another. Thus, **the resistances can be combined in two ways : (*i*) in series, and (*ii*) in parallel.** If we want to *increase* the total resistance, then the individual resistances are connected in *series*, and if we want to *decrease* the resistance, then the individual resistances are connected in *parallel*. We will study these two cases in detail, one by one.

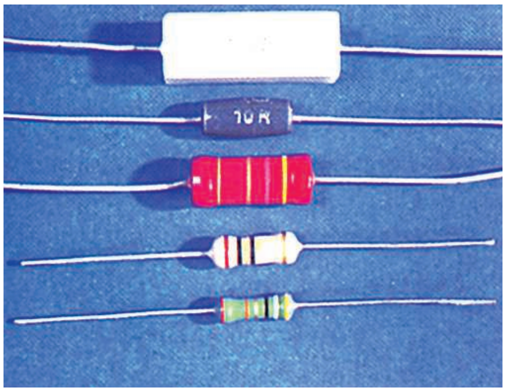


Figure 22. This picture shows some of the resistances (or resistors) . These can be connected in series or parallel combinations.

When two (or more) resistances are connected end to end consecutively, they are said to be connected in series. Figure 23 shows two resistances R_1 and R_2 which are connected in series. On

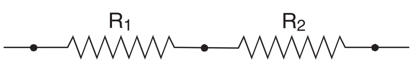


Figure 23. Two resistances (R_1 and R_2) connected in series.

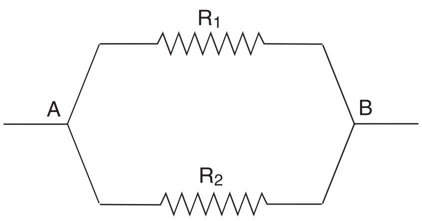


Figure 24. Two resistances (R_1 and R_2) connected in parallel.

the other hand, **when two (or more) resistances are connected between the same two points, they are said to be connected in parallel** (because they become parallel to one another). In Figure 24, the two resistances R_1 and R_2 are connected in parallel arrangement between the same two points *A* and *B*. In the above examples, we have shown only two resistances (or resistors) connected in series and parallel combinations. We can, however, connect any number of resistors in these two arrangements.

RESISTANCES (OR RESISTORS) IN SERIES

The combined resistance (or resultant resistance) of a number of resistances or resistors connected in series is calculated by using the law of combination of resistances in series. According to the law of combination of resistances in series : **The combined resistance of any number of resistances connected in series is equal to the sum of the individual resistances.** For example, if a number of resistances R_1, R_2, R_3 ...... etc., are connected in series, then their combined resistance R is given by : $R = R_1 + R_2 + R_3 + ...$

Suppose that a resistance R_1 of 2 ohms and another resistance R_2 of 4 ohms are connected in series and we want to find out their combined resistance R.

We know that : $R = R_1 + R_2$

So, $R = 2 + 4$

And, Combined resistance, $R = 6$ ohms

Thus, if we join two resistances of 2 ohms and 4 ohms in series, then their combined resistance (or resultant resistance) will be 6 ohms which is equal to the sum of the individual resistances. Before we derive the formula for the resultant resistance of a number of resistances connected in series, we should keep in mind that :

(*i*) When a number of resistances connected in series are joined to the terminals of a battery, then each resistance has a different potential difference across its ends (which depends on the value of resistance). But the total potential difference across the ends of all the resistances in series is equal to the voltage of the battery. Thus, when a number of resistances are connected in series, then the sum of the potential differences across all the resistances is equal to the voltage of the battery applied.

(*ii*) When a number of resistances are connected in series, then the same current flows through each resistance (which is equal to the current flowing in the whole circuit).

1. Resultant Resistance of Two Resistances Connected in Series

We will now derive a formula for calculating the combined resistance (equivalent resistance or resultant resistance) of two resistances connected in series.

Figure 25 shows two resistances R_1 and R_2 connected in series. A battery of V volts has been applied to the ends of this series combination. Now, suppose the potential difference across the resistance R_1 is V_1 and the potential difference across the resistance R_2 is V_2. We have applied a battery of voltage V, so the total potential difference across the two resistances should be equal to the voltage of the battery.

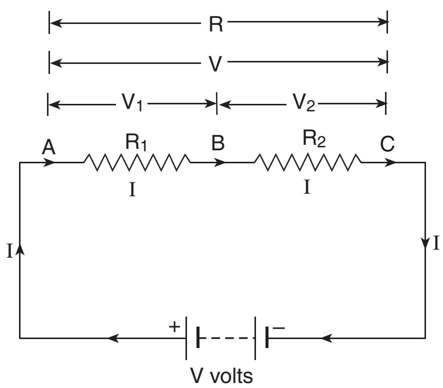


Figure 25.

That is : $V = V_1 + V_2$ ... (1)

We have just seen that the total potential difference due to battery is V. Now, suppose the total resistance of the combination be R, and the current flowing through the whole circuit be I. So, applying Ohm's law to the whole circuit, we get :

$$\frac{V}{I} = R$$

or $V = I \times R$ ... (2)

Since the same current I flows through both the resistances R_1 and R_2 connected in series, so by applying Ohm's law to both the resistances separately, we will get :

$V_1 = I \times R_1$ ... (3)

and $V_2 = I \times R_2$ ... (4)

Now, putting the values of V, V_1 and V_2 from equations (2), (3) and (4) in equation (1), we get :

$$I \times R = I \times R_1 + I \times R_2$$

or $$I \times R = I \times (R_1 + R_2)$$

Cancelling I from both sides, we get :

Resultant resistance (combined resistance or equivalent resistance),

$$R = R_1 + R_2$$

2. Resultant Resistance of Three Resistances Connected in Series

Figure 26 shows three resistances R_1, R_2 and R_3 connected in series. A battery of V volts has been applied to the ends of this series combination of resistances. Now, suppose the potential difference across the resistance R_1 is V_1, the potential difference across the resistance R_2 is V_2 and that across resistance R_3 is V_3. We have applied a battery of voltage V, so the total potential difference across the three resistances should be equal to the voltage of the battery applied. That is,

$$V = V_1 + V_2 + V_3 \qquad \text{... (1)}$$

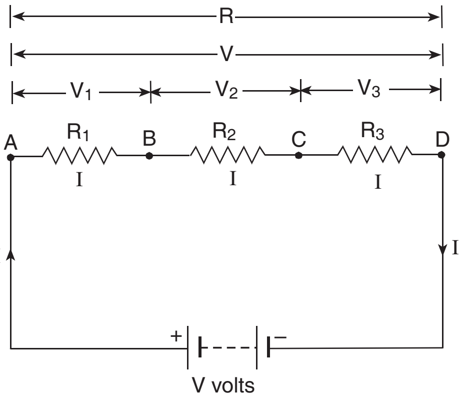


Figure 26.

We have just seen that the total potential difference due to battery is V. Now, let the total resistance (or resultant resistance) of the combination be R. The current flowing through the whole circuit is I. So, applying Ohm's law to the whole circuit, we get :

$$\frac{V}{I} = R$$

or $$V = I \times R \qquad \text{... (2)}$$

Since the same current I flows through all the resistances R_1, R_2 and R_3 in series, so by applying Ohm's law to each resistance separately, we will get :

$$V_1 = I \times R_1 \qquad \text{... (3)}$$

$$V_2 = I \times R_2 \qquad \text{... (4)}$$

and $$V_3 = I \times R_3 \qquad \text{... (5)}$$

Putting these values of V, V_1, V_2 and V_3 in equation (1), we get :

$$I \times R = I \times R_1 + I \times R_2 + I \times R_3$$

or $$I \times R = I \times (R_1 + R_2 + R_3)$$

Cancelling I from both sides, we get :

$$R = R_1 + R_2 + R_3$$

Thus, if three resistors R_1, R_2, and R_3 are connected in series then their total resistance R is given by the formula :

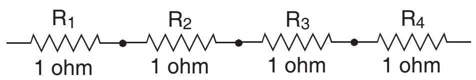
$$R = R_1 + R_2 + R_3$$

Similarly, if there are four resistors R_1, R_2, R_3 and R_4 connected in series, then their resultant resistance R is given by the formula : $R = R_1 + R_2 + R_3 + R_4$ and so on.

We will now solve some problems based on the combination of resistances in series.

Sample Problem 1. If four resistances, each of value 1 ohm, are connected in series, what will be the resultant resistance ?

Solution. Here we have four resistances, each of 1 ohm, connected in series. These are shown in the Figure below.



Now, if we have four resistances R_1, R_2, R_3 and R_4 connected in series, then their resultant resistance R is given by : $R = R_1 + R_2 + R_3 + R_4$

Here $R_1 = 1\ \Omega$, $R_2 = 1\ \Omega$, $R_3 = 1\ \Omega$, $R_4 = 1\ \Omega$

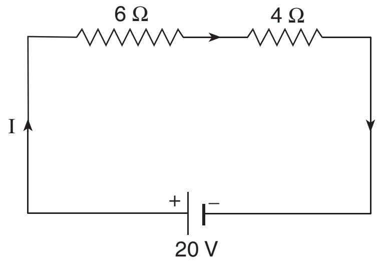
So, Resultant resistance, $R = 1 + 1 + 1 + 1$

or $R = 4\ \Omega$

Thus, the resultant resistance is equal to 4 ohms.

We will now solve some problems by applying Ohm's law to the circuits having resistances in series.

Sample Problem 2. A resistance of 6 ohms is connected in series with another resistance of 4 ohms. A potential difference of 20 volts is applied across the combination. Calculate the current through the circuit and potential difference across the 6 ohm resistance.



Solution. The first step in solving such problems based on current electricity is to draw a proper circuit diagram. For example, in this problem we have two resistances of 6 ohms and 4 ohms which are connected in series. So, first of all we have to draw these two resistances on paper as shown in Figure alongside. Now, a potential difference of 20 volts has been applied across this combination of resistances. So, we draw a cell or a battery of 20 volts and complete the circuit as shown in Figure alongside. Suppose the current flowing in the circuit is I amperes.

We will now find out the value of current I flowing through the circuit. To do this we should know the total resistance R of the circuit. Here we have two resistances of 6 Ω and 4 Ω connected in series. So,

Total resistance, $R = R_1 + R_2$

$R = 6 + 4$

$R = 10$ ohms

Now, Total resistance, $R = 10$ ohms

Potential difference, $V = 20$ volts

and, Current in the circuit, $I = ?$ (To be calculated)

So, applying Ohm's law to the whole circuit, we get :

$$\frac{V}{I} = R$$

So that, $$\frac{20}{I} = 10$$

And, $$10\,I = 20$$

$$I = \frac{20}{10}$$

So, Current, $I = 2$ amperes (or 2 A)

Thus, the current flowing through the circuit is 2 amperes.

The second part of this problem is to find out the potential difference across the ends of the 6 ohm resistance. To do this we will have to apply Ohm's law to this resistance only. We know that the current flowing through the 6 ohm resistance will also be 2 amperes. Now,

Potential difference (across 6 Ω resistance), $V = ?$ (To be calculated)

Current (through 6 Ω resistance), $I = 2$ amperes

And, Resistance, $R = 6$ ohms

So, applying Ohm's law to the 6 Ω resistance only, we get :

$$\frac{V}{I} = R$$

or $$\frac{V}{2} = 6$$

So, Potential difference, $V = 12$ volts

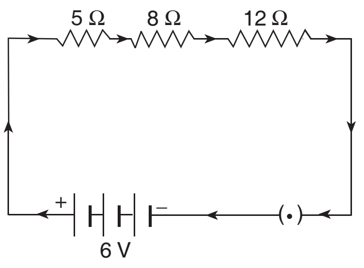
Thus, the potential difference across the 6 ohm resistance is 12 volts.

Here is an exercise for you. Find out the potential difference across the 4 ohm resistance yourself. The answer will be 8 volts. Remember that the same current of 2 amperes flows through the 4 ohm resistance.

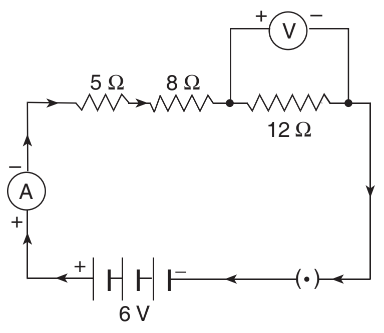
Sample Problem 3. (*a*) Draw the diagram of a circuit consisting of a battery of three cells of 2 V each, a 5 Ω resistor, an 8 Ω resistor and a 12 Ω resistor, and a plug key, all connected in series.

(*b*) Redraw the above circuit putting an ammeter to measure the current through the resistors and a voltmeter to measure the potential difference across the 12 Ω resistor. What would be the readings in the ammeter and the voltmeter ? **(NCERT Book Question)**

Solution. (*a*) In this problem, we have a battery of 3 cells of 2 V each, so the total potential difference (or voltage) of the battery will be $3 \times 2 = 6$ V. The circuit consisting of a battery of three cells of 2 V each (having a voltage of 6 V), resistors of 5 Ω, 8 Ω, 12 Ω and a plug key, all connected in series is given in Figure alongside.



(*b*) The above circuit can be redrawn by including an ammeter in the main circuit and a voltmeter across the 12 Ω resistor, as shown in Figure alongside. Please note that the ammeter has been put in series with the circuit but the voltmeter has been put in parallel with the 12 Ω resistor. We will now calculate the current reading in the ammeter and potential difference reading in the voltmeter.



(*i*) Calculation of current flowing in the circuit. The three resistors of 5 Ω, 8 Ω and 12 Ω are connected in series. So,

Total resistance, $R = 5 + 8 + 12$

$= 25\ \Omega$

Potential difference, $V = 6$ V

And, Current, $I = ?$ (To be calculated)

Now, $$\frac{V}{I} = R$$

So, $$\frac{6}{I} = 25$$

$$25\,I = 6$$

$$I = \frac{6}{25}$$

$$I = 0.24 \text{ A}$$

Now, since the current in the circuit is 0.24 amperes, therefore, the ammeter will show a reading of 0.24 A.

(*ii*) Calculation of potential difference across 12 Ω resistor. We have just calculated that a current of 0.24 A flows in the circuit. The same current of 0.24 A also flows through the 12 Ω resistor which is connected in series. Now, for the 12 Ω resistor :

Current, $I = 0.24$ A (Calculated above)

Resistance, $R = 12\ \Omega$ (Given)

And, Potential difference, $V = ?$ (To be calculated)

We know that, $$\frac{V}{I} = R$$

So, $\frac{V}{0.24} = 12$

And $V = 0.24 \times 12$

$V = 2.88$ V

Thus, the potential difference across the 12 Ω resistor is 2.88 volts. So, the voltmeter will show a reading of 2.88 V.

RESISTANCES (OR RESISTORS) IN PARALLEL

The combined resistance (or resultant resistance) of a number of resistances or resistors connected in parallel can be calculated by using the law of combination of resistances in parallel. According to the law of combination of resistances in parallel : **The reciprocal of the combined resistance of a number of resistances connected in parallel is equal to the sum of the reciprocals of all the individual resistances.** For example, if a number of resistances, R_1, R_2, R_3 ...... etc., are connected in parallel, then their combined resistance R is given by the formula :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$$

Suppose that a resistance R_1 of 6 ohms and another resistance R_2 of 12 ohms are connected in parallel and we want to find out their combined resistance R.

We know that : $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

$$= \frac{1}{6} + \frac{1}{12}$$

$$= \frac{2+1}{12}$$

$$= \frac{3}{12}$$

Now, $\frac{1}{R} = \frac{1}{4}$

So, Combined resistance, $R = 4$ ohms

This means that if we join two resistances of 6 ohms and 12 ohms in parallel then their combined resistance is only 4 ohms which is less than either of the two individual resistances (of 6 ohms and 12 ohms). Thus, **when a number of resistances are connected in parallel then their combined resistance is less than the smallest individual resistance.** This is due to the fact that when we have two or more resistances joined parallel to one another, then the same current gets additional paths to flow and the overall resistance decreases. Before we derive a formula for the resultant resistance of a number of resistances connected in parallel, we should keep in mind that :

(*i*) When a number of resistances are connected in parallel, then the potential difference across each resistance is the same which is equal to the voltage of the battery applied.

(*ii*) When a number of resistances connected in parallel are joined to the two terminals of a battery, then different amounts of current flow through each resistance (which depends on the value of resistance). But the current flowing through all the individual parallel resistances, taken together, is equal to the current flowing in the circuit as a whole. Thus, when a number of resistances are connected in parallel, then the sum of the currents flowing through all the resistances is equal to the total current flowing in the circuit.

1. Combined Resistance of Two Resistances Connected in Parallel

We will now derive a formula for calculating the combined resistance (resultant resistance or equivalent resistance) of two resistors connected in parallel. In Figure 27, two resistances R_1 and R_2 are connected parallel to one another between the same two points A and B. A battery of V volts has been applied across the ends of this combination. In this case the potential difference across the ends of both the resistances will be the same. And it will be equal to the voltage of the battery used. The current flowing through the two resistances in parallel is, however, not the same.

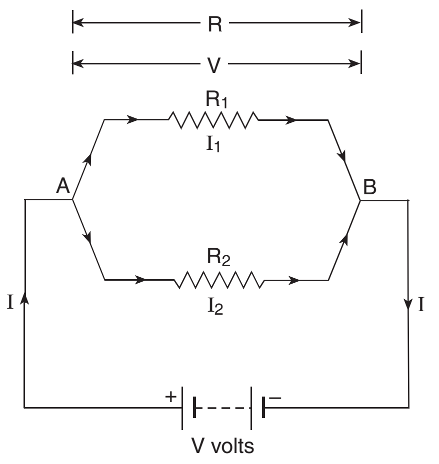


Figure 27.

Suppose the total current flowing in the circuit is I, then the current passing through resistance R_1 will be I_1 and the current passing through the resistance R_2 will be I_2 (see Figure 27). It is obvious that :

$$\text{Total current, } I = I_1 + I_2 \qquad \text{... (1)}$$

Suppose the resultant resistance of this parallel combination is R. Then by applying Ohm's law to the whole circuit, we get :

$$I = \frac{V}{R} \qquad \text{... (2)}$$

Since the potential difference V across both the resistances R_1 and R_2 in parallel is the same, so by applying Ohm's law to each resistance separately, we get :

$$I_1 = \frac{V}{R_1} \qquad \text{... (3)}$$

and $$I_2 = \frac{V}{R_2} \qquad \text{... (4)}$$

Now, putting the values of I, I_1 and I_2 from equations (2), (3) and (4) in equation (1), we get :

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

or $$V\left[\frac{1}{R}\right] = V\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

Cancelling V from both sides, we get :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

Thus, if two resistances R_1 and R_2 are connected in parallel, then their resultant resistance R is given by the formula :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

2. Combined Resistance of Three Resistances Connected in Parallel

In Figure 28, three resistances R_1, R_2 and R_3 are connected parallel to one another between the same two points A and B. A battery of V volts has been applied across the ends of this combination. In this case the potential difference across the ends of all the three resistances will be the same. And it will be equal to the voltage of the battery used. The current flowing through the three resistances connected in parallel is, however, not the same. Suppose the total current flowing through the circuit is I, then the current passing through resistance R_1 will be I_1, the current passing through resistance R_2 will be I_2, and that through R_3 will be I_3 (see Figure 28). It is obvious that :

Total current, $I = I_1 + I_2 + I_3$ ... (1)

Suppose the resultant resistance of this combination is R. Then, by applying Ohm's law to the whole circuit, we get :

$$I = \frac{V}{R} \quad \text{... (2)}$$

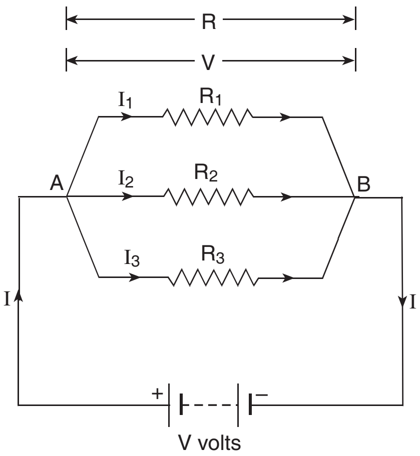


Figure 28.

Since the potential difference V across all the three resistances R_1, R_2 and R_3 in parallel is the same, so by applying Ohm's law to each resistance separately, we get :

$$I_1 = \frac{V}{R_1} \quad \text{... (3)}$$

$$I_2 = \frac{V}{R_2} \quad \text{... (4)}$$

and $$I_3 = \frac{V}{R_3} \quad \text{... (5)}$$

Putting these values of I, I_1, I_2 and I_3 in equation (1), we get :

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

or $$V \frac{1}{R} = V \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Cancelling V from both sides, we get :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Thus, if three resistances R_1, R_2 and R_3 are connected in parallel, then their resultant resistance R is given by the formula :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Similarly, when four resistances R_1, R_2, R_3 and R_4 are connected in parallel, then their resultant resistance R is given by the formula :

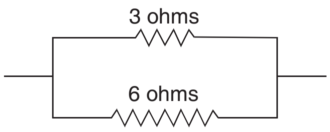
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \quad \text{and so on}$$

Let us solve some problems now.

Sample Problem 1. Calculate the equivalent resistance when two resistances of 3 ohms and 6 ohms are connected in parallel.

Solution. Here we have two resistances of 3 ohms and 6 ohms which are connected in parallel. This arrangement is shown in Figure given below. Now, we want to find out their equivalent resistance or resultant resistance. We know that when two resistances R_1 and R_2 are connected in parallel, then their equivalent resistance R is given by :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$



Here, $R_1 = 3$ ohms

and, $R_2 = 6$ ohms

So, $$\frac{1}{R} = \frac{1}{3} + \frac{1}{6}$$

or $$\frac{1}{R} = \frac{2+1}{6}$$

or $$\frac{1}{R} = \frac{3}{6}$$

or $$\frac{1}{R} = \frac{1}{2}$$

and $$R = 2\ \Omega$$

Thus, the equivalent resistance is 2 ohms.

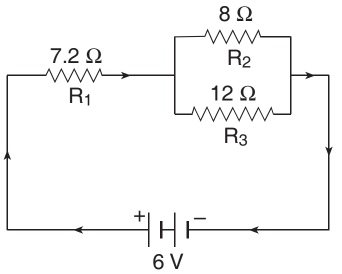
So far we have studied the combination of resistances in series and parallel separately. Many times, however, the practical electrical circuits involve the combination of resistances in series as well as in parallel in the same circuit. **We will now solve a problem in which the resistances are connected in series as well as in parallel in the same circuit.**

Sample Problem 2. In the circuit diagram given alongside, find :

(*i*) total resistance of the circuit,

(*ii*) total current flowing in the circuit, and

(*iii*) the potential difference across R_1



Solution. In this problem the resistances are connected in series as well as in parallel combination. For example, the two resistances R_2 and R_3 are in parallel combination to each other but, taken together, they are in series combination with the resistance R_1.

(*i*) **Calculation of Total Resistance.** We will now find out the total resistance of the circuit. For doing this, let us first calculate the resultant resistance R of R_2 and R_3 which are connected in parallel.

Now, $$\frac{1}{R} = \frac{1}{R_2} + \frac{1}{R_3}$$

Here, $$R_2 = 8\ \Omega$$

and, $$R_3 = 12\ \Omega$$

So, $$\frac{1}{R} = \frac{1}{8} + \frac{1}{12}$$

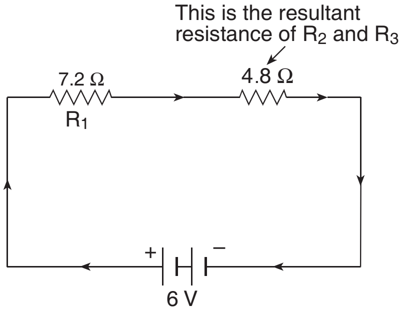
or $$\frac{1}{R} = \frac{3+2}{24}$$

$$\frac{1}{R} = \frac{5}{24}$$

$$R = \frac{24}{5}$$

and $$R = 4.8 \text{ ohms}$$

Thus, the two resistances of 8 ohms and 12 ohms connected in parallel are equal to a single resistance of 4.8 ohms. It is obvious that in the above given diagram, we can replace the two resistances R_2 and R_3 by a single resistance of 4.8 ohms. We can now draw another circuit diagram for this problem by showing a single resistance of 4.8 ohms in place of two parallel resistances. Such a circuit diagram is given alongside.



It is clear from this diagram that now we have two resistances of 7.2 ohms and 4.8 ohms which are connected in series. So,

$$\text{Total resistance} = 7.2 + 4.8$$
$$= 12 \text{ ohms}$$

Thus, the total resistance of the circuit is 12 ohms.

(*ii*) **Calculation of Total Current.** The battery shown in the given circuit is of 6 volts. So,

Total potential difference, $V = 6$ volts

Total current, $I = ?$ (To be calculated)

and Total resistance, $R = 12$ ohms (Calculated above)

So, applying Ohm's law to the whole circuit, we get :

$$\frac{V}{I} = R$$

or $$\frac{6}{I} = 12$$

or $$12\,I = 6$$

or $$I = \frac{6}{12}$$

$$I = \frac{1}{2}$$

So, Total current, $I = 0.5$ ampere (or 0.5 A)

Thus, the total current flowing in the circuit is 0.5 ampere. It should be noted that the same current flows through all the parts of a series circuit. So, the current flowing through the resistance R_1 is also 0.5 ampere.

(*iii*) **Calculation of Potential Difference Across R_1.** We have now to find out the potential difference across the resistance R_1 of 7.2 ohms.

Now,Potential difference across $R_1 = ?$ (To be calculated)

Current through $R_1 = 0.5$ ampere

And, Resistance of $R_1 = 7.2$ ohms

Applying Ohm's law to the resistance R_1 only, we get :

$$\frac{V}{I} = R$$

or $$\frac{V}{0.5} = 7.2$$

or $$V = 7.2 \times 0.5$$

or $$V = 3.6 \text{ volts}$$

Thus, the potential difference across the ends of the resistance R_1 is 3.6 volts.

Before we go further and discuss the advantages and disadvantages of series and parallel circuits, **please answer the following questions and problems yourself :**

Very Short Answer Type Questions

1. Give the law of combination of resistances in series.
2. If five resistances, each of value 0.2 ohm, are connected in series, what will be the resultant resistance ?
3. State the law of combination of resistances in parallel.
4. If 3 resistances of 3 ohm each are connected in parallel, what will be their total resistance ?
5. How should the two resistances of 2 ohms each be connected so as to produce an equivalent resistance of 1 ohm ?
6. Two resistances X and Y are connected turn by turn : (*i*) in parallel, and (*ii*) in series. In which case the resultant resistance will be less than either of the individual resistances ?
7. What possible values of resultant resistance one can get by combining two resistances, one of value 2 ohm and the other 6 ohm ?

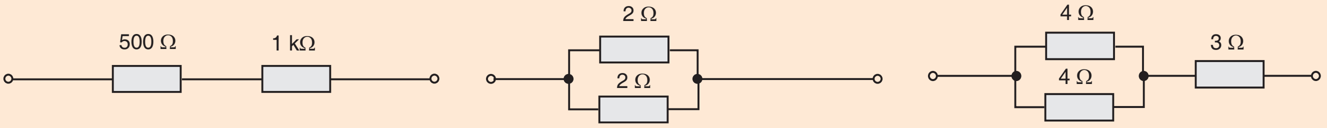
8. Show how you would connect two 4 ohm resistors to produce a combined resistance of (*a*) 2 ohms (*b*) 8 ohms.

9. Which of the following resistor arrangement, A or B, has the lower combined resistance ?

(A) (B)

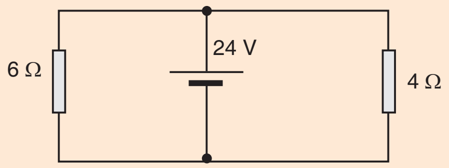
10. A wire that has resistance *R* is cut into two equal pieces. The two parts are joined in parallel. What is the resistance of the combination ?

11. Calculate the combined resistance in each case :



(*a*) (*b*) (*c*)

12. Find the current in each resistor in the circuit shown below :



Short Answer Type Questions

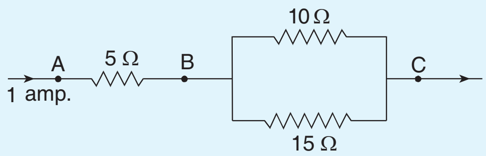
13. Explain with diagrams what is meant by the "series combination" and "parallel combination" of resistances. In which case the resultant resistance is : (*i*) less, and (*ii*) more, than either of the individual resistances ?

14. A battery of 9 V is connected in series with resistors of 0.2 Ω, 0.3 Ω, 0.4 Ω, 0.5 Ω and 12 Ω. How much current would flow through the 12 Ω resistor ?

15. An electric bulb of resistance 20 Ω and a resistance wire of 4 Ω are connected in series with a 6 V battery. Draw the circuit diagram and calculate :

(*a*) total resistance of the circuit.
(*b*) current through the circuit.
(*c*) potential difference across the electric bulb.
(*d*) potential difference across the resistance wire.

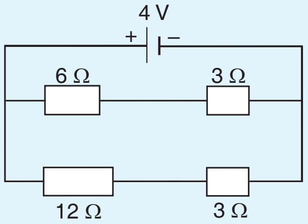
16. Three resistors are connected as shown in the diagram.



Through the resistor 5 ohm, a current of 1 ampere is flowing.

(*i*) What is the current through the other two resistors ?
(*ii*) What is the p.d. across *AB* and across *AC* ?
(*iii*) What is the total resistance ?

17. For the circuit shown in the diagram below :



What is the value of :

(*i*) current through 6 Ω resistor ?

(*ii*) potential difference across 12 Ω resistor ?

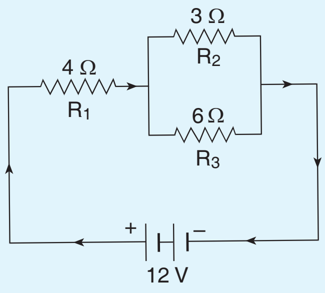
18. Two resistors, with resistances 5 Ω and 10 Ω respectively are to be connected to a battery of emf 6 V so as to obtain :

(*i*) minimum current flowing (*ii*) maximum current flowing

(*a*) How will you connect the resistances in each case ?

(*b*) Calculate the strength of the total current in the circuit in the two cases.

19. The circuit diagram given below shows the combination of three resistors R_1, R_2 and R_3 :

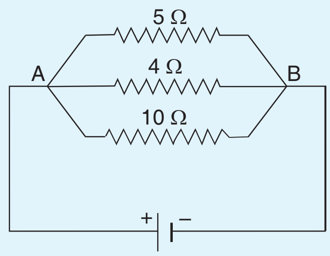


Find : (*i*) total resistance of the circuit.

(*ii*) total current flowing in the circuit.

(*iii*) the potential difference across R_1.

20. In the circuit diagram given below, the current flowing across 5 ohm resistor is 1 amp. Find the current flowing through the other two resistors.



21. A resistor has a resistance of 176 ohms. How many of these resistors should be connected in parallel so that their combination draws a current of 5 amperes from a 220 volt supply line ?

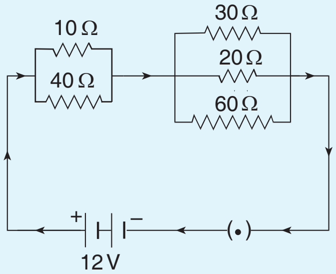
22. An electric heater which is connected to a 220 V supply line has two resistance coils *A* and *B* of 24 Ω resistance each. These coils can be used separately (one at a time), in series or in parallel. Calculate the current drawn when :

(*a*) only one coil *A* is used.

(*b*) coils *A* and *B* are used in series.

(*c*) coils *A* and *B* are used in parallel.

23. In the circuit diagram given below five resistances of 10 Ω, 40 Ω, 30 Ω, 20 Ω and 60 Ω are connected as shown to a 12 V battery.

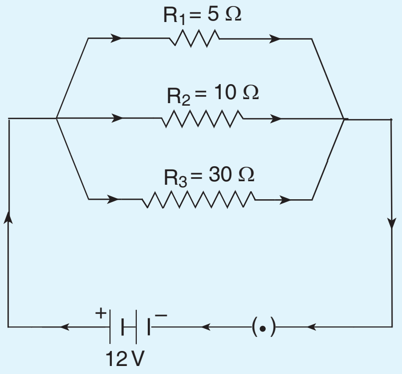


Calculate :

(*a*) total resistance in the circuit.

(*b*) total current flowing in the circuit.

24. In the circuit diagram given below, three resistors R_1, R_2, and R_3 of 5 Ω, 10 Ω and 30 Ω, respectively are connected as shown.



Calculate :

(*a*) current through each resistor.

(*b*) total current in the circuit.

(*c*) total resistance in the circuit.

25. A p.d. of 4 V is applied to two resistors of 6 Ω and 2 Ω connected in series. Calculate :

(*a*) the combined resistance

(*b*) the current flowing

(*c*) the p.d. across the 6 Ω resistor

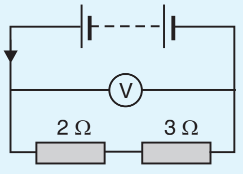
26. A p.d. of 6 V is applied to two resistors of 3 Ω and 6 Ω connected in parallel. Calculate :

(*a*) the combined resistance

(*b*) the current flowing in the main circuit

(*c*) the current flowing in the 3 Ω resistor.

27. In the circuit shown below, the voltmeter reads 10 V.



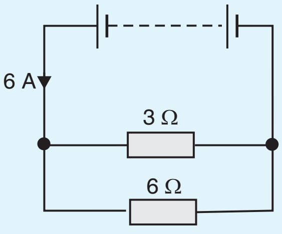
(*a*) What is the combined resistance ?

(*b*) What current flows ?

(*c*) What is the p.d. across 2 Ω resistor ?

(*d*) What is the p.d. across 3 Ω resistor ?

28. In the circuit given below :



(*a*) What is the combined resistance ?

(*b*) What is the p.d. across the combined resistance ?

(*c*) What is the p.d. across the 3 Ω resistor ?

(*d*) What is the current in the 3 Ω resistor ?

(*e*) What is the current in the 6 Ω resistor ?

29. A 5 V battery is connected to two 20 Ω resistors which are joined together in series.

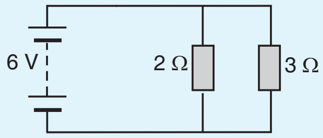
(*a*) Draw a circuit diagram to represent this. Add an arrow to indicate the direction of conventional current flow in the circuit.

(*b*) What is the effective resistance of the two resistors ?

(*c*) Calculate the current that flows from the battery.

(*d*) What is the p.d. across each resistor ?

30. The figure given below shows an electric circuit in which current flows from a 6 V battery through two resistors.



(*a*) Are the resistors connected in series with each other or in parallel ?

(*b*) For each resistor, state the p.d. across it.

(*c*) The current flowing from the battery is shared between the two resistors. Which resistor will have bigger share of the current ?

(*d*) Calculate the effective resistance of the two resistors.

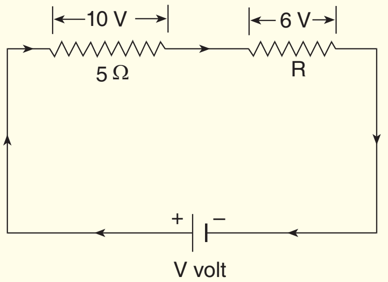
(*e*) Calculate the current that flows from the battery.

31. A 4 Ω coil and a 2 Ω coil are connected in parallel. What is their combined resistance ? A total current of 3 A passes through the coils. What current passes through the 2 Ω coil ?

Long Answer Type Questions

32. (*a*) With the help of a circuit diagram, deduce the equivalent resistance of two resistances connected in series.

(*b*) Two resistances are connected in series as shown in the diagram :



(*i*) What is the current through the 5 ohm resistance ?

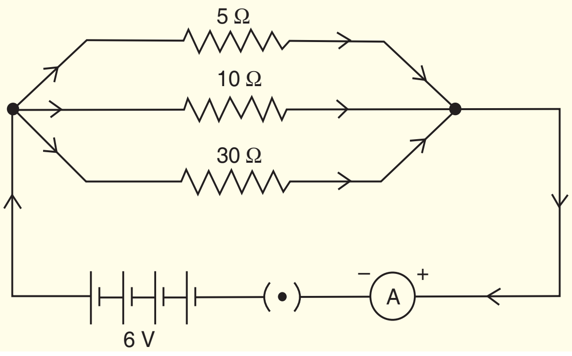
(*ii*) What is the current through *R* ?

(*iii*) What is the value of *R* ?

(*iv*) What is the value of *V* ?

33. (*a*) With the help of a diagram, derive the formula for the resultant resistance of three resistors connected in series.

(*b*) For the circuit shown in the diagram given below :

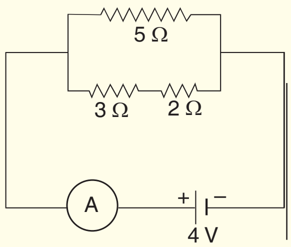


Calculate :

(*i*) the value of current through each resistor.
(*ii*) the total current in the circuit.
(*iii*) the total effective resistance of the circuit.

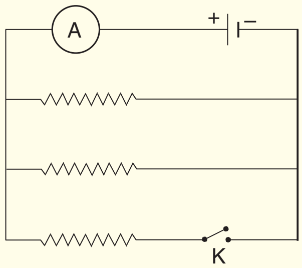
34. (*a*) With the help of a circuit diagram, obtain the relation for the equivalent resistance of two resistances connected in parallel.

(*b*) In the circuit diagram shown below, find :
(*i*) Total resistance.
(*ii*) Current shown by the ammeter *A*



35. (*a*) Explain with the help of a labelled circuit diagram, how you will find the resistance of a combination of three resistors of resistances R_1, R_2 and R_3 joined in parallel.

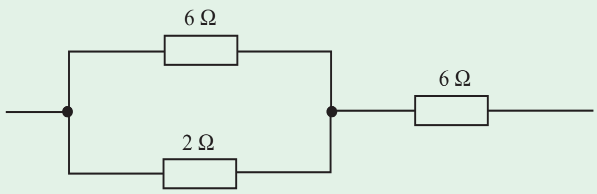
(*b*) In the diagram shown below, the cell and the ammeter both have negligible resistance. The resistors are identical.



With the switch *K* open, the ammeter reads 0.6 A. What will be the ammeter reading when the switch is closed ?

Multiple Choice Questions (MCQs)

36. The figure given below shows three resistors :



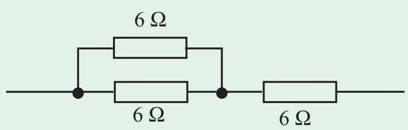
Their combined resistance is :

(*a*) $1\frac{5}{7}$ Ω (*b*) 14 Ω (*c*) $6\frac{2}{3}$ Ω (*d*) $7\frac{1}{2}$ Ω

37. If two resistors of 25 Ω and 15 Ω are joined together in series and then placed in parallel with a 40 Ω resistor, the effective resistance of the combination is :

(*a*) 0.1 Ω (*b*) 10 Ω (*c*) 20 Ω (*d*) 40 Ω

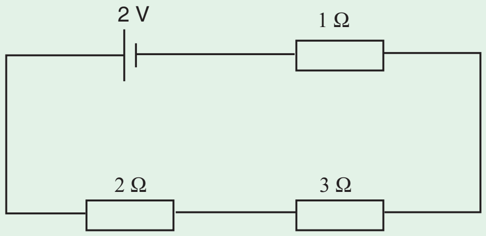
38. The diagram below shows part of a circuit :



If this arrangement of three resistors was to be replaced by a single resistor, its resistance should be :

(*a*) 9 Ω (*b*) 4 Ω (*c*) 6 Ω (*d*) 18 Ω

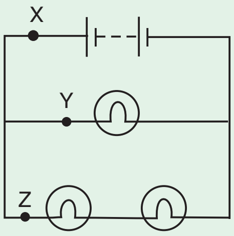
39. In the circuit shown below :



The potential difference across the 3 Ω resistor is :

(*a*) $\frac{1}{9}$ V (*b*) $\frac{1}{2}$ V (*c*) 1 V (*d*) 2 V

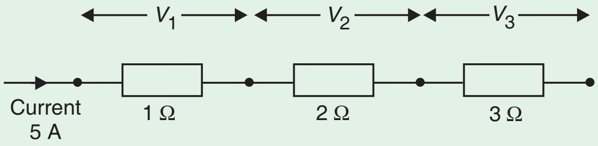
40. A battery and three lamps are connected as shown :



Which of the following statements about the currents at X, Y and Z is correct ?

(*a*) The current at Z is greater than that at Y.
(*b*) The current at Y is greater than that at Z.
(*c*) The current at X equals the current at Y.
(*d*) The current at X equals the current at Z.

41. V_1, V_2 and V_3 are the p.ds. across the 1 Ω , 2 Ω and 3 Ω resistors in the following diagram, and the current is 5 A.



Which one of the columns (*a*) to (*d*) shows the correct values of V_1 , V_2 and V_3 measured in volts ?

	V_1	V_2	V_3
(*a*)	1.0	2.0	3.0
(*b*)	5.0	10.0	15.0
(*c*)	5.0	2.5	1.6
(*d*)	4.0	3.0	2.0

42. A wire of resistance R_1 is cut into five equal pieces. These five pieces of wire are then connected in parallel. If the resultant resistance of this combination be R_2, then the ratio $\frac{R_1}{R_2}$ is :

(*a*) $\frac{1}{25}$ (*b*) $\frac{1}{5}$ (*c*) 5 (*d*) 25

Questions Based on High Order Thinking Skills (HOTS)

43. Show with the help of diagrams, how you would connect three resistors each of resistance 6 Ω, so that the combination has resistance of (*i*) 9 Ω (*ii*) 4 Ω.

44. Two resistances when connected in parallel give resultant value of 2 ohm; when connected in series the value becomes 9 ohm. Calculate the value of each resistance.

45. A resistor of 8 ohms is connected in parallel with another resistor *X*. The resultant resistance of the combination is 4.8 ohms. What is the value of the resistor *X* ?

46. You are given three resistances of 1, 2 and 3 ohms. Show by diagrams, how with the help of these resistances you can get :

(*i*) 6 Ω (*ii*) $\frac{6}{11}$ Ω (*iii*) 1.5 Ω

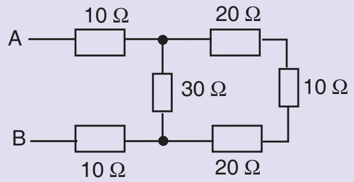
47. How will you connect three resistors of 2 Ω, 3 Ω and 5 Ω respectively so as to obtain a resultant resistance of 2.5 Ω ? Draw the diagram to show the arrangement.

48. How will you connect three resistors of resistances 2 Ω, 3 Ω and 6 Ω to obtain a total resistance of : (*a*) 4 Ω, and (*b*) 1 Ω ?

49. What is (*a*) highest, and (*b*) lowest, resistance which can be obtained by combining four resistors having the following resistances ?

4 Ω, 8 Ω, 12 Ω, 24 Ω

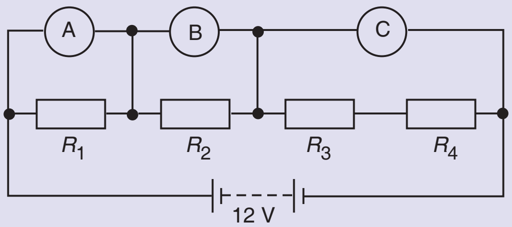
50. What is the resistance between A and B in the figure given below ?



51. You are given one hundred 1 Ω resistors. What is the smallest and largest resistance you can make in a circuit using these ?

52. You are supplied with a number of 100 Ω resistors. How could you combine some of these resistors to make a 250 Ω resistor ?

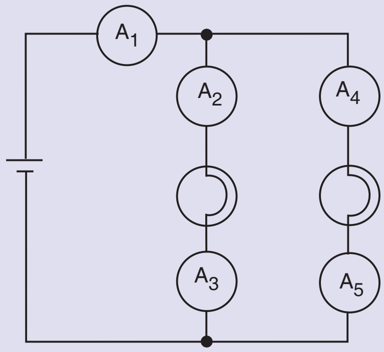
53. The resistors R_1, R_2, R_3 and R_4 in the figure given below are all equal in value.



What would you expect the voltmeters A, B and C to read assuming that the connecting wires in the circuit have negligible resistance ?

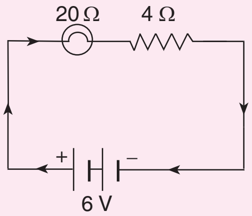
54. Four resistances of 16 ohms each are connected in parallel. Four such combinations are connected in series. What is the total resistance ?

55. If the lamps are both the same in the figure given below and if A_1 reads 0.50 A, what do A_2, A_3, A_4 and A_5 read ?



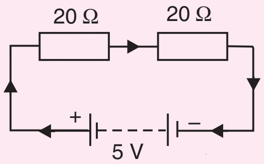
ANSWERS

2. 1 ohm **4.** 1 ohm **5.** In parallel **6.** In parallel **7.** 8 Ω ; 1.5 Ω **8.** (*a*) In parallel (*b*) In series **9.** B **10.** $\frac{R}{4}$ **11.** (*a*) 1500 Ω (*b*) 1 Ω (*c*) 5 Ω **12.** Current in 6 Ω resistor = 4 A ; Current in 4 Ω resistor = 6 A. **13.** (*i*) Parallel combination (*ii*) Series combination **14.** 0.67 A

15. 

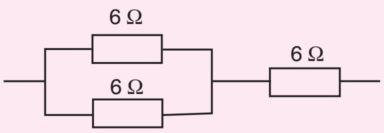
(*a*) 24 Ω (*b*) 0.25 A (*c*) 5 V (*d*) 1 V **16.** (*i*) 0.6 A ; 0.4 A (*ii*) 5 V ; 11 V (*iii*) 11 Ω

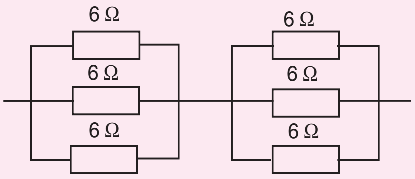
17. (*i*) 0.44 A (*ii*) 3.2 V **18.** (*a*) For minimum current flowing : In series ; For maximum current flowing : In parallel (*b*) 0.4 A ; 1.8 A **19.** (*i*) 6 Ω (*ii*) 2 A (*iii*) 8 V **20.** 1.25 A ; 0.5 A **21.** 4 resistors **22.** (*a*) 9.2 A (*b*) 4.6 A (*c*) 18.3 A **23.** (*a*) 18 Ω (*b*) 0.67 A **24.** (*a*) 2.4 A ; 1.2 A ; 0.4 A (*b*) 4 A (*c*) 3 Ω **25.** (*a*) 8 Ω (*b*) 0.5 A (*c*) 3 V **26.** (*a*) 2 Ω (*b*) 3 A (*c*) 2 A **27.** (*a*) 5 Ω (*b*) 2 A (*c*) 4 V (*d*) 6 V **28.** (*a*) 2 Ω (*b*) 12 V (*c*) 12 V (*d*) 4 A (*e*) 2 A

29. (*a*) 

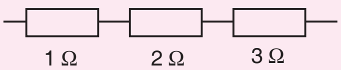
(*b*) 40 Ω (*c*) 0.125 A (*d*) 2.5 V **30.** (*a*) Parallel (*b*) 6 V (*c*) 2 Ω resistor (*d*) 1.2 Ω (*e*) 5 A **31.** $\frac{4}{3}$ Ω ; 2 A **32.** (*b*) (*i*) 2 A (*ii*) 2 A (*iii*) 3 Ω (*iv*) 16 V **33.** (*b*) (*i*) Current through 5 Ω resistor = 1.2 A ; Current through 10 Ω resistor = 0.6 A ; Current through 30 Ω resistor = 0.2 A (*ii*) 2 A (*iii*) 3 Ω **34.** (*b*) (*i*) 2.5 Ω (*ii*) 1.6 A **35.** (*b*) 0.9 A **36.** (*d*) **37.** (*c*) **38.** (*a*) **39.** (*c*) **40.** (*b*)

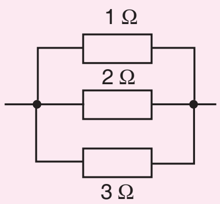
41. (*b*) **42.** (*d*) *Hint.* Resistance of one piece of wire will be $\frac{R_1}{5}$. And $\frac{1}{R_2} = \frac{5}{R_1} + \frac{5}{R_1} + \frac{5}{R_1} + \frac{5}{R_1} + \frac{5}{R_1} = \frac{25}{R_1}$

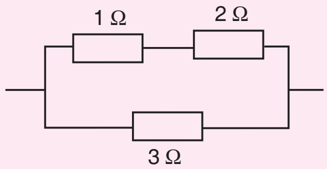
43. (*i*) 

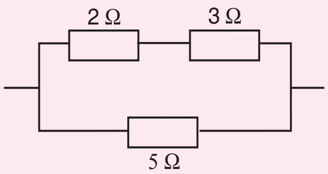
(*ii*) 

44. 3 Ω and 6 Ω

45. 12 Ω **46.** (*i*) 

(*ii*) 

(*iii*) 

47. 

48. (*a*) Connect 2 Ω resistor in series with a parallel combination of 3 Ω and 6 Ω resistors (*b*) Connect 2 Ω , 3 Ω and 6 Ω resistors in parallel **49.** (*a*) 48 Ω (*b*) 2 Ω **50.** 38.75 Ω **51.** 0.01 Ω ; 100 Ω **52.** Combine two 100 Ω resistors in series with a parallel combination of two 100 Ω resistors **53.** A = 3 V ; B = 3 V; C = 6 V **54.** 16 Ω **55.** All read 0.25 A.

DOMESTIC ELECTRIC CIRCUITS : SERIES OR PARALLEL

When designing an electric circuit, we should consider whether a series circuit or a parallel circuit is better for the intended use. For example, if we want to connect (or join) a large number of electric bulbs (say, hundreds or thousands of electric bulbs) for decorating buildings and trees as during festivals such as *Diwali* or marriage functions, then the series circuit is *better* because all the bulbs connected in series can be controlled with just one switch (see Figure 29). A series circuit is also safer because the current in it is smaller. But there is a problem in this series lighting circuit. This is because if one bulb gets fused (or blows off), then the circuit breaks and all the bulbs are turned off. An electrician has to spend a lot of time in locating the fused bulb from among hundreds of bulbs, so as to replace it and restore the lighting.

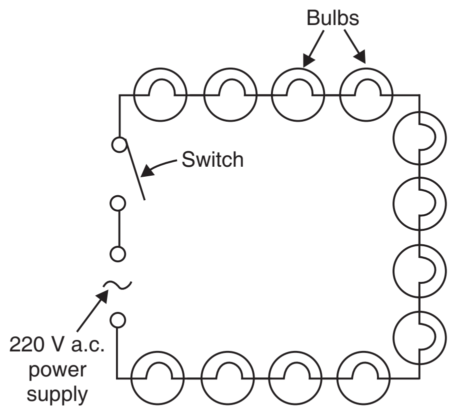


Figure 29. The electric bulbs for decoration are usually connected in series circuit with the 220 volt a.c. (alternating current) power supply line (The circuit symbol for alternating current or a.c. supply is —o ~ o—). Please note that all the bulbs have just one switch.

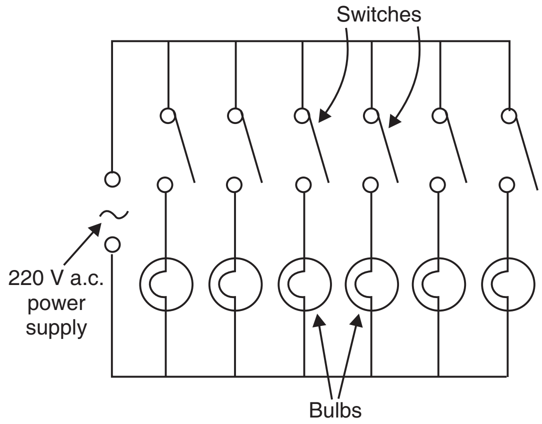


Figure 30. The electric bulbs in a house are connected in parallel circuit with the 220 volt a.c. power supply line. Please note that all the bulbs have separate switches (Just like bulbs, all other appliances like fan, TV, fridge, electric iron, etc., are also connected in parallel in a similar way).

The parallel electric circuit is *better* for connecting bulbs (and other electrical appliances) in a house because then we can have separate switches for each bulb (or electrical appliance) and hence operate it separately (see Figure 30). In addition to having ease of operation, parallel domestic circuits (or household circuits) have many other advantages over the series circuits. We will first give the disadvantages of the series electric circuits for domestic purposes and then the advantages of the parallel electric circuits.

Disadvantages of Series Circuits for Domestic Wiring

The arrangement of lights and various other electrical appliances in series circuit is not used in domestic wiring because of the following disadvantages :

1. In series circuit, if one electrical appliance stops working due to some defect, then all other appliances also stop working (because the whole circuit is broken). For example, if a number of bulbs are connected in series and just one bulb gets fused (or blows off), then all other bulbs will also stop glowing.

2. In series circuit, all the electrical appliances have only one switch due to which they cannot be turned on or off separately. For example, all the bulbs connected in series have only one switch due to which all the bulbs can be switched on or switched off together and not separately.

Figure 31. Christmas tree bulbs are usually wired in series.

3. In series circuit, the appliances do not get the same voltage (220 V) as that of the power supply line because the voltage is shared by all the appliances. The appliances get less voltage and hence do not work properly. For example, all the bulbs connected in series do not get the same voltage of 220 volts of the power supply line. They get less voltage and hence glow less brightly.

4. In the series connection of electrical appliances, the overall resistance of the circuit increases too much due to which the current from the power supply is low. Moreover, the same current flows throughout a series circuit due to which all the appliances of different power ratings cannot draw sufficient current for their proper working.

Advantages of Parallel Circuits in Domestic Wiring

The arrangement of lights and various other electrical appliances in parallel circuits is used in domestic wiring because of the following advantages :

1. In parallel circuits, if one electrical appliance stops working due to some defect, then all other appliances keep working normally. For example, if a number of bulbs are connected in parallel circuits and one bulb gets fused (or blows out), then all the remaining bulbs will keep glowing.

2. In parallel circuits, each electrical appliance has its own switch due to which it can be turned on or turned off independently, without affecting other appliances. For example, all the bulbs joined in parallel circuits in a house have separate switches due to which we can switch on or switch off any bulb as required, without affecting other bulbs in the house.

3. In parallel circuits, each electrical appliance gets the same voltage (220 V) as that of the power supply line. Due to this, all the appliances will work properly. For example, all the bulbs connected in parallel circuits get the same voltage of 220 volts of the power supply line and hence glow very brightly.

4. In the parallel connection of electrical appliances, the overall resistance of the household circuit is reduced due to which the current from the power supply is high. Every appliance can, therefore, draw the required amount of current. For example, in parallel circuits, even the high power rating appliances like electric irons, water heaters and air-conditioners, etc., can draw the high current needed for their proper functioning.

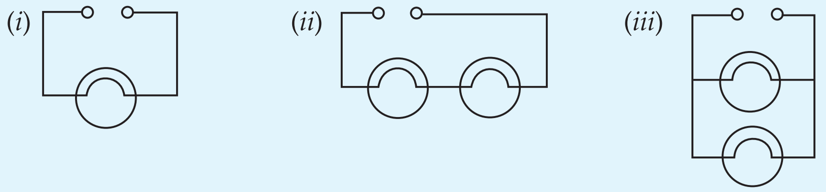
We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Are the lights in your house wired in series ?
2. What happens to the other bulbs in a series circuit if one bulb blows off ?
3. What happens to the other bulbs in a parallel circuit if one bulb blows off ?
4. Which type of circuit, series or parallel, is preferred while connecting a large number of bulbs :
   (*a*) for decorating a hotel building from outside ?
   (*b*) for lighting inside the rooms of the hotel ?
5. Draw a circuit diagram to show how two 4 V electric lamps can be lit brightly from two 2 V cells.

Short Answer Type Questions

6. Why is a series arrangement not used for connecting domestic electrical appliances in a circuit ?
7. Give three reasons why different electrical appliances in a domestic circuit are connected in parallel.
8. Ten bulbs are connected in a series circuit to a power supply line. Ten identical bulbs are connected in a parallel circuit to an identical power supply line.
   (*a*) Which circuit would have the highest voltage across each bulb ?
   (*b*) In which circuit would the bulbs be brighter ?
   (*c*) In which circuit, if one bulb blows out, all others will stop glowing ?
   (*d*) Which circuit would have less current in it ?
9. Consider the circuits given below :



   (*a*) In which circuit are the lamps dimmest ?
   (*b*) In which circuit or circuits are the lamps of equal brightness to the lamps in circuit (*i*) ?
   (*c*) Which circuit gives out the maximum light ?

10. If you were going to connect two light bulbs to one battery, would you use a series or a parallel arrangement ? Why ? Which arrangement takes more current from the battery ?

Long Answer Type Question

11. (*a*) Which is the better way to connect lights and other electrical appliances in domestic wiring : series circuits or parallel circuits ? Why ?

(*b*) Christmas tree lamps are usually wired in series. What happens if one lamp breaks ?

(*c*) An electrician has wired a house in such a way that if a lamp gets fused in one room of the house, all the lamps in other rooms of the house stop working. What is the defect in the wiring ?

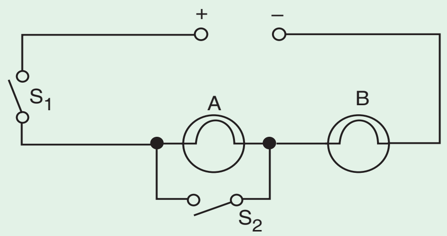
(*d*) Draw a circuit diagram showing two electric lamps connected in parallel together with a cell and a switch that works both lamps. Mark an Ⓐ on your diagram to show where an ammeter should be placed to measure the current.

Multiple Choice Questions (MCQs)

12. The lamps in a household circuit are connected in parallel because :

(*a*) this way they require less current
(*b*) if one lamp fails the others remain lit
(*c*) this way they require less power
(*d*) if one lamp fails the others also fail

13. Using the circuit given below, state which of the following statement is correct ?



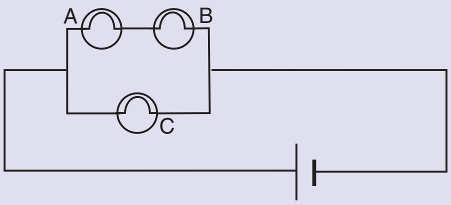
(*a*) When S_1 and S_2 are closed, lamps A and B are lit.
(*b*) With S_1 open and S_2 closed, A is lit and B is not lit.
(*c*) With S_2 open and S_1 closed A and B are lit.
(*d*) With S_1 closed and S_2 open, lamp A remains lit even if lamp B gets fused.

Questions Based on High Order Thinking Skills (HOTS)

14. (*a*) Draw a circuit diagram showing two lamps, one cell and a switch connected in series.

(*b*) How can you change the brightness of the lamps ?

15. Consider the circuit given below where A, B and C are three identical light bulbs of constant resistance.



(*a*) List the bulbs in order of increasing brightness.
(*b*) If C burns out, what will be the brightness of A now compared with before ?
(*c*) If B burns out instead, what will be the brightness of A and C compared with before ?

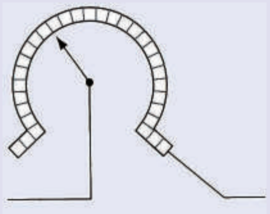
16. How do you think the brightness of two lamps arranged in parallel compares with the brightness of two lamps arranged in series (both arrangements having one cell) ?

17. If current flows through two lamps arranged :

(*a*) in series,
(*b*) in parallel,

and the filament of one lamps breaks, what happens to the other lamp ? Explain your answer.

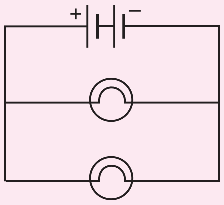
18. The figure below shows a variable resistor in a dimmer switch.



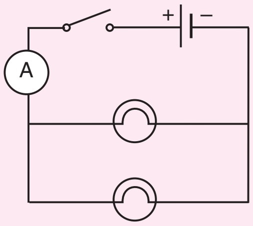
How would you turn the switch to make the lights : (*a*) brighter, and (*b*) dimmer ? Explain your answer.

ANSWERS

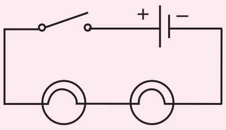
1. No **2.** All other bulbs stop glowing **3.** All other bulbs keep glowing **4.** (*a*) Series circuit (*b*) Parallel circuit **5.**



8. (*a*) Parallel circuit (*b*) Parallel circuit (*c*) Series circuit (*d*) Series circuit
9. (*a*) Circuit (*ii*) (*b*) Circuit (*iii*) (*c*) Circuit (*iii*) **10.** Parallel arrangement ; Series arrangement
11. (*a*) Parallel circuit (*b*) All other lamps stop glowing (*c*) All the lamps have been connected in series (*d*)



12. (*b*) **13.** (*c*) **14.** (*a*)



(*b*) Connect the lamps in parallel

15. (*a*) A and B are the same ; C is brighter (*b*) The same (*c*) A goes out ; C remains the same **16.** The brightness of two lamps arranged in parallel is much more than those arranged in series
17. (*a*) In series : The other lamp stops glowing (*b*) In parallel : The other lamp keeps glowing
18. (*a*) Turn the switch to right side (*b*) Turn the switch to left side.

ELECTRIC POWER

When an electric current flows through a conductor, electrical energy is used up and we say that the current is doing work. We know that the rate of doing work is called power, so **electric power is the electrical work done per unit time.** That is,

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

or

$$P = \frac{W}{t}$$

Unit of Power

We have calculated the power by dividing work done by time taken. Now, the unit of work is “joule” and that of time is “second”. So, the unit of power is “joules per second”. This unit of power is called watt. Thus, **the SI unit of electric power is watt** which is denoted by the letter W. **The power of 1 watt is a rate of working of 1 joule per second.** That is,

$$1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$$

Actually, watt is a small unit, therefore, a bigger unit of electric power called kilowatt is used for commercial purposes. It is obvious that :

$$1 \text{ kilowatt} = 1000 \text{ watts}$$

or $$1 \text{ kW} = 1000 \text{ W}$$

It should be noted that the symbol for watt is W and that for kilowatt is kW. When work is done, an equal amount of energy is consumed. So, we can also say that **electric power is the rate at which electrical energy is consumed.** In other words, *electric power is the electrical energy consumed per second.* We can now write down another definition of watt based on electrical energy. **When an electrical appliance consumes electrical energy at the rate of 1 joule per second, its power is said to be 1 watt.** We have just given two definitions of electric power, one by using the term 'work' and another by using the term 'energy'. We can combine these two definitions and say that : **The rate at which electrical work is done or the rate at which electrical energy is consumed, is called electric power.**

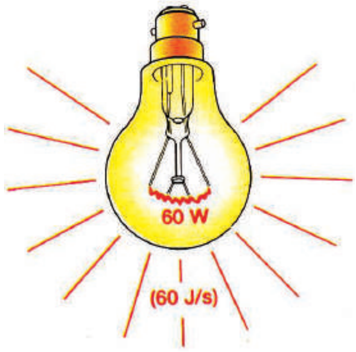


Figure 32. This electric bulb consumes electric energy at the rate of 60 joules per second, so its power is 60 watts.

Formula for Calculating Electric Power

We know that :

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

or $$P = \frac{W}{t} \qquad \text{... (1)}$$

We have already studied that the work done W by current I when it flows for time t under a potential difference V is given by :

$$W = V \times I \times t \text{ joules}$$

Putting this value of W in equation (1), we get :

$$P = \frac{V \times I \times t}{t} \text{ joules per second}$$

or $$P = V \times I \text{ joules per second}$$

or Power, $$\boldsymbol{P = V \times I} \text{ watts}$$

where V = Potential difference (or Voltage) in volts

and I = Current in amperes

Thus, the power in watts is found by multiplying the potential difference in volts by the current in amperes. We can write down the above formula for electric power in words as follows :

Electric power = Potential difference × Current

Since the potential difference is also known by the name of voltage, we can also say that :

Electric power = Voltage × Current

It is clear from the above discussion that in electric circuits, **the power expended in heating a resistor or turning a motor depends upon the potential difference between the terminals of the device and the electric current passing through it.**

We can also use the formula $P = V \times I$ for defining the unit of power called 'watt' in another way as described below.

Power, $$P = V \times I \text{ watts}$$

Now, if an electrical device is operated at a potential difference of 1 volt and the device carries a current of 1 ampere, then power becomes 1 watt. That is :

$$1 \text{ watt} = 1 \text{ volt} \times 1 \text{ ampere}$$

or $$1 \text{ W} = 1 \text{ V} \times 1 \text{ A}$$

or $$1 \text{ W} = 1 \text{ V A}$$

This gives us another definition of the unit of power called 'watt'. We can now say that : One watt is the power consumed by an electrical device which when operated at a potential difference (or voltage) of 1 volt carries a current of 1 ampere.

Some Other Formulae for Calculating Electric Power

We have just obtained a formula for calculating electric power, which is :

$$P = V \times I$$

This formula can be used when both, the potential difference (or voltage) V and the current I are known to us. Sometimes, however, they do not give us V and I. We are given either voltage V and resistance R or current I and resistance R. In that case we have to take the help of Ohm's law. This will become clear from the following discussion.

(*i*) Power P in terms of I and R. We have just seen that :

$$P = V \times I \qquad \text{... (1)}$$

Now, from Ohm's law we have, $\frac{V}{I} = R$

or $\quad V = I \times R \qquad$ ... (2)

Putting this value of V in equation (1), we get :

$$P = I \times R \times I$$

or Power, $\boldsymbol{P = I^2 \times R}$

where I = Current

and R = Resistance

This formula is to be used for calculating electric power when only current I and resistance R are known to us.

(*ii*) Power P in terms of V and R. We know that :

$$P = V \times I \qquad \text{... (1)}$$

Also, from Ohm's law we have, $\frac{V}{I} = R$

or $\quad V = I \times R$

or $\quad I = \frac{V}{R} \qquad$ ... (2)

Putting this value of I in equation (1), we get :

$$P = V \times \frac{V}{R}$$

or Power, $\boldsymbol{P = \frac{V^2}{R}} \qquad$ ... (3)

where V = Potential difference (or Voltage)

and R = Resistance

This formula is to be used for calculating power when voltage V and resistance R are known to us.

It is clear from equation (3) that **power is inversely proportional to the resistance.** Thus, the resistance of high power devices is smaller than the low power ones. For example, the resistance of 100 watt (220 volt) bulb is smaller than that of a 60 watt (220 volt) bulb (see Figure 33). We have now three formulae for calculating electric power. These are :

First formula for power : $\boldsymbol{P = V \times I}$

Second formula for power : $\boldsymbol{P = I^2 \times R}$

Figure 33. The bulb on left side has higher resistance, so its power is less. It glows less brightly. The bulb on right side has less resistance, so its power is more. It glows much more brightly.

Third formula for power : $P = \frac{V^2}{R}$

These three formulae should be memorized because they will be used to solve numerical problems. Before we solve the problems based on electric power, it is very important to know the meaning of 'power-voltage' rating of electrical appliances.

Power-Voltage Rating of Electrical Appliances

Every electrical appliance like an electric bulb, radio or fan has a label or engraved plate on it which tells us the voltage (to be applied) and the electrical power consumed by it. For example, if we look at a particular bulb in our home, it may have the figures 100 W – 220 V written on it. Now, 100 W means that this bulb has a power consumption of 100 watts and 220 V means that it is to be used on a voltage of 220 volts. The power rating of an electrical appliance tells us the rate at which electrical energy is consumed by the appliance. For example, **a power rating of 100 watts on the bulb means that it will consume electrical energy at the rate of 100 joules per second.** If we know the power P and voltage V of an electrical appliance, then we can very easily find out the current I drawn by it. This can be done by using the formula : $P = V \times I$. The usual power-voltage ratings of some of the common household electrical appliances and the current drawn by them are given below.

Power-Voltage Ratings of Some Electrical Appliances and the Current Drawn by Them

Electrical appliance	*Usual power*	*Usual voltage*	*Current drawn*
1. Tube light	40 W	220 V	0.18 A
2. Electric bulb (or Lamp)	60 W	220 V	0.27 A
3. Radio set	80 W	220 V	0.36 A
4. Electric fan	100 W	220 V	0.45 A
5. T.V. set	120 W	220 V	0.54 A
6. Refrigerator	150 W	220 V	0.68 A
7. Electric iron	750 W	220 V	3.4 A
8. Electric heater	1000 W	220 V	4.5 A
9. Immersion heater	1500 W	220 V	6.8 A
10. Washing machine	3000 W	220 V	13.6 A

(*a*) An electric bulb may have power of 15 W, 40 W, 60 W, 100 W or more

(*b*) The usual power of a TV set is about 120 W

(*c*) An electric iron has a power of 750 W or more

(*d*) An electric heater may have power of 1000 W or 2000 W, etc.

(*e*) The usual power of a washing machine is 3000 W (or 3 kW)

Figure 34. Different electrical appliances have different power ratings.

Let us solve some problems now.

Sample Problem 1. What will be the current drawn by an electric bulb of 40 W when it is connected to a source of 220 V ?

Solution. In this case we have been given power P and voltage V, so the formula to be used for calculating the current will be :

$$P = V \times I$$

Here, Power, P = 40 watts

Voltage, V = 220 volts

And, Current, I = ? (To be calculated)

Now, putting these values in the above formula, we get :

$$40 = 220 \times I$$

$$I = \frac{40}{220}$$

$$= \frac{2}{11}$$

Thus, Current, I = 0.18 ampere

Sample Problem 2. An electric bulb is rated 220 V and 100 W. When it is operated on 110 V, the power consumed will be :

(*a*) 100 W (*b*) 75 W (*c*) 50 W (*d*) 25 W **(NCERT Book Question)**

Solution. ***In the first case :***

Power, P = 100 W

Potential difference, V = 220 V

And, Resistance, R =? (To be calculated)

Now, $$P = \frac{V^2}{R}$$

So, $$100 = \frac{(220)^2}{R}$$

And $$R = \frac{220 \times 220}{100} = 484\ \Omega$$

This resistance of 484 Ω of the bulb will remain unchanged.

In the second case :

Power, P = ? (To be calculated)

Potential difference, V = 110 V

And, Resistance, R = 484 Ω (Calculated above)

Now, $$P = \frac{V^2}{R}$$

$$P = \frac{(110)^2}{484} = \frac{110 \times 110}{484} = 25\text{ W}$$

Thus, the correct answer is : (*d*) 25 W.

Sample Problem 3. Which of the following does not represent electrical power in a circuit ?

(*a*) I^2R (*b*) IR^2 (*c*) VI (*d*) $\frac{V^2}{R}$ **(NCERT Book Question)**

Answer. (*b*) IR^2

An Important Formula for Calculating Electrical Energy

We will now derive a formula for calculating electrical energy in terms of power and time. We have already studied that :

$$\text{Electric power} = \frac{\text{Work done by electric current}}{\text{Time taken}}$$

Now, according to the law of conservation of energy,

Work done by electric current = Electric energy consumed

So, we can now write down the above relation as :

$$\text{Power} = \frac{\text{Electrical energy}}{\text{Time}}$$

or **Electrical energy = Power × Time**

or $E = P \times t$

It is obvious that **the electrical energy consumed by an electrical appliance is given by the product of its power rating and the time for which it is used.** From this we conclude that *the electrical energy consumed by an electrical appliance depends on two factors : (i) power rating of the appliance, and (ii) time for which the appliance is used.* We should memorize the above formula for calculating electrical energy because it will be used in solving numerical problems.

In the formula : *Electrical energy = Power × Time,* if we take the power in 'watts'and time in 'hours' then the unit of electrical energy becomes 'Watt-hour' (Wh). **One watt-hour is the amount of electrical energy consumed when an electrical appliance of 1 watt power is used for 1 hour.** We will now describe the commercial unit (or trade unit) of electrical energy called kilowatt-hour.

COMMERCIAL UNIT OF ELECTRICAL ENERGY : KILOWATT-HOUR

The SI unit of electrical energy is joule and we know that *"1 joule is the amount of electrical energy consumed when an appliance of 1 watt power is used for 1 second".* Actually, joule represents a very small quantity of energy and, therefore, it is inconvenient to use where a large quantity of energy is involved. So, for commercial purposes we use a bigger unit of electrical energy which is called "kilowatt-hour". **One kilowatt-hour is the amount of electrical energy consumed when an electrical appliance having a power rating of 1 kilowatt is used for 1 hour.** Since a kilowatt means 1000 watts, so we can also say that *one kilowatt-hour is the amount of electrical energy consumed when an electrical appliance of 1000 watts is used for 1 hour.* In other words, one kilowatt-hour is the energy dissipated by a current at the rate of 1000 watts for 1 hour. From this discussion we conclude that **the commercial unit of electrical energy is kilowatt-hour** which is written in short form as kWh.

Relation between kilowatt-hour and joule

1 kilowatt-hour is the amount of energy consumed at the rate of 1 kilowatt for 1 hour. That is,

1 kilowatt-hour = 1 kilowatt for 1 hour

or 1 kilowatt-hour = 1000 watts for 1 hour ... (1)

But : $1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$

So, equation (1) can be rewritten as :

$$1 \text{ kilowatt-hour} = 1000 \frac{\text{joules}}{\text{seconds}} \text{ for 1 hour}$$

And, 1 hour = 60 × 60 seconds

So, $$1 \text{ kilowatt-hour} = 1000 \frac{\text{joules}}{\text{seconds}} \times 60 \times 60 \text{ seconds}$$

or **1 kilowatt-hour = 36,00,000 joules (or 3.6×10^6 J)**

From this discussion we conclude that **1 kilowatt-hour is equal to 3.6×10^6 joules of electrical energy.** It should be noted that watt or kilowatt is the unit of electrical power but kilowatt-hour is the unit of electrical energy. Let us solve some problems now.

Sample Problem 1. A radio set of 60 watts runs for 50 hours. How much electrical energy is consumed ?

Solution. We know that :

Electrical energy = Power × Time

or $E = P \times t$ ... (1)

We want to calculate the electrical energy in kilowatt-hours, so first we should convert the power of 60 watts into kilowatts by dividing it by 1000. That is :

$$\text{Power, } P = 60 \text{ watts}$$
$$= \frac{60}{1000} \text{ kilowatt}$$
$$= 0.06 \text{ kilowatt}$$

And, $\quad$ Time, $t = 50$ hours

Now, putting $P = 0.06$ kW and, $t = 50$ hours in equation (1), we get :

$$\text{Electrical energy, } E = 0.06 \times 50$$
$$= 3 \text{ kilowatt-hours} \quad (\text{or } 3 \text{ kWh})$$

Thus, electrical energy consumed is 3 kilowatt-hours.

Note. In the above problem we have calculated the electrical energy consumed in the commercial unit of energy 'kilowatt-hour' (kWh). We can also convert this electrical energy into SI unit of energy called joule by using the relation between kilowatt-hour and joule. Now,

$$1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

So, $\quad 3 \text{ kWh} = 3.6 \times 10^6 \times 3 \text{ J}$

$$= 10.8 \times 10^6 \text{ J} \quad (\text{or } 10.8 \times 10^6 \text{ joules})$$

Sample Problem 2. A current of 4 A flows through a 12 V car headlight bulb for 10 minutes. How much energy transfer occurs during this time ?

Solution. $\quad$ Energy = Power × Time

or $E = P \times t$ ... (1)

First of all we should calculate power P by using the current of 4 A and voltage of 12 V.

Now, $\quad P = V \times I$

So, $\quad P = 12 \times 4$

or, $\quad$ Power, $P = 48$ watts

$$= \frac{48}{1000} \text{ kilowatts}$$

Thus, $\quad$ Power, $P = 0.048$ kW

And, $\quad$ Time, $t = 10$ minutes

$$= \frac{10}{60} \text{ hours}$$
$$= \frac{1}{6} \text{ hours}$$

Now, putting $P = 0.048$ kW and, $t = \frac{1}{6}$ hours in equation (1), we get :

$$E = 0.048 \times \frac{1}{6}$$
$$= 0.008 \text{ kWh}$$

Thus, the energy transferred is 0.008 kilowatt-hour.

Sample Problem 3. Calculate the energy transferred by a 5 A current flowing through a resistor of 2 ohms for 30 minutes.

Solution. We will first calculate the power by using the given values of current and resistance. This can be done by using the formula :

$$P = I^2 \times R$$

Here, Current, $I = 5$ amperes

And, Resistance, $R = 2$ ohms

So, Power, $P = (5)^2 \times 2$

$= 25 \times 2$

$= 50$ watts

$= \frac{50}{1000}$ kilowatts

Thus, Power, $P = 0.05$ kW ... (1)

And, Time, $t = 30$ minutes

$= \frac{30}{60}$ hours

$= \frac{1}{2}$ hours

$= 0.5$ hours ... (2)

Now, Energy, $E = P \times t$

$= 0.05 \times 0.5$

Energy, $E = 0.025$ kWh

In the above given sample problems, we have calculated the electrical energy in the commercial unit of "kilowatt-hour". Please calculate the energy in "joules" yourself.

How to Calculate the Cost of Electrical Energy Consumed

Kilowatt-hour is the "unit" of electrical energy for which we pay to the Electricity Supply Department of our City. One unit of electricity costs anything from rupees 3 to rupees 5 (or even more). The rates vary from place to place and keep on changing from time to time. Now, **by saying that 1 unit of electricity costs say, 3 rupees, we mean that 1 kilowatt-hour of electrical energy costs 3 rupees.** The electricity meter in our homes measures the electrical energy consumed by us in kilowatt-hours (see Figure 35). Now, we use different electrical appliances in our homes. We use electric bulbs, tube-lights, fans, electric iron, radio, T.V., and refrigerator, etc. All these household electrical appliances consume electrical energy at different rates. Our electricity bill depends on the total electrical energy consumed by our appliances over a given period of time, say a month. We will now describe **how the cost of electricity consumed is calculated**. Since the electricity is sold in units of kilowatt-hour, so first we should convert the power consumed in watts into kilowatts by dividing the total watts by 1000. The kilowatts are then converted into kilowatt-hours by multiplying the kilowatts by the number of hours for which the appliance has been used. This gives us the total electrical energy consumed in kilowatt-hours. In other words, this gives us the total number of "units" of electricity consumed. Knowing the cost of 1 unit of electricity, we can find out the total cost. This will become more clear from the following examples.

Figure 35. This is a domestic electricity meter. The reading in this meter shows the number of kilowatt-hours (or units) that have been used. The reading from this electricity meter is used to prepare our monthly electricity bill.

Sample Problem 1. A refrigerator having a power rating of 350 W operates for 10 hours a day. Calculate the cost of electrical energy to operate it for a month of 30 days. The rate of electrical energy is Rs. 3.40 per kWh.

Solution. Electrical energy, $E = P \times t$

Here, Power, $P = 350$ W

$= \frac{350}{1000}$ kW

$= 0.35$ kW

And, Time, $t = 10 \times 30$ hours

$= 300$ h

Now, putting these values of P and t in the formula,

$E = P \times t$

We get : $E = 0.35 \times 300$ kWh

$= 105$ kWh

Thus, the electrical energy consumed by the refrigerator in a month of 30 days is 105 kilowatt-hours.

Now, Cost of 1 kWh of electricity = Rs. 3.40

So, Cost of 105 kWh of electricity = Rs. 3.40 × 105

= Rs. 357

Sample Problem 2. A bulb is rated at 200 V-100 W. What is its resistance ? Five such bulbs burn for 4 hours. What is the electrical energy consumed ? Calculate the cost if the rate is ₹ 4.60 per unit.

Solution. (*a*) **Calculation of Resistance.** Here we know the voltage and power of the bulb. So, the resistance can be calculated by using the formula :

$$P = \frac{V^2}{R}$$

Here, Power, $P = 100$ watts

Voltage, $V = 200$ volts

And, Resistance, $R = ?$ (To be calculated)

Now, putting these values in the above formula, we get :

$$100 = \frac{(200)^2}{R}$$

$$100\,R = 40000$$

And, $R = \frac{40000}{100}$

$= 400$ ohms

(*b*) **Calculation of Electrical Energy Consumed.** The electrical energy consumed in kilowatt-hours can be calculated by using the formula :

$E = P \times t$

Here, Power, $P = 100$ watts

$= \frac{100}{1000}$ kilowatt

$= 0.1$ kilowatt ... (1)

And, Time, $t = 4$ hours ... (2)

So, Energy consumed by 1 bulb $= 0.1 \times 4$

$= 0.4$ kilowatt-hours

And,Energy consumed by 5 bulbs $= 0.4 \times 5$

$= 2$ kilowatt-hours (or 2 kWh)

Thus, the total electrical energy consumed is "2 kilowatt-hours" or "2 units".

(*c*) **Calculation of Cost of Electrical Energy.** We have been given that :

Cost of 1 unit of electricity = ₹ 4.60

So, Cost of 2 units of electricity = ₹ 4.60 × 2

= ₹ 9.20

Sample Problem 3. An electric heater draws a current of 10 A from a 220 V supply. What is the cost of using the heater for 5 hours everyday for 30 days if the cost of 1 unit (1 kWh) is ₹ 5.20 ?

Solution. In this problem, first of all we have to calculate the power of the heater by using the given values of current and voltage. This can be done by using the formula :

$$
\begin{aligned}
&& P &= V \times I \\
\text{Here,} && \text{Voltage (or p.d.), } V &= 220 \text{ V} \\
\text{And,} && \text{Current, } I &= 10 \text{ A} \\
\text{So,} && \text{Power, } P &= 220 \times 10 \text{ W} \\
&& &= 2200 \text{ W} \\
&& &= \frac{2200}{1000} \text{ kW} \\
&& &= 2.2 \text{ kW} \qquad \ldots (1) \\
\text{Now,} && \text{Electric energy consumed, } E &= P \times t \\
\text{Here,} && \text{Power, } P &= 2.2 \text{ kW} \\
\text{And,} && \text{Time, } t &= 5 \text{ h} \\
\text{So,} && \text{Electric energy consumed in 1 day} &= 2.2 \times 5 \\
&& &= 11 \text{ kWh} \\
\text{And,} && \text{Electric energy consumed in 30 days} &= 11 \times 30 \\
&& &= 330 \text{ kWh} \quad \text{(or 330 units)} \qquad \ldots (2) \\
\text{Now,} && \text{Cost of 1 unit of electricity} &= ₹\ 5.20 \\
\text{So,} && \text{Cost of 330 units of electricity} &= ₹\ 5.20 \times 330 \\
&& &= ₹\ 1716
\end{aligned}
$$

Before we go further and discuss the heating effect of electric current, **please answer the following questions :**

Very Short Answer Type Questions

1. State two factors on which the electrical energy consumed by an electrical appliance depends.
2. Which one has a higher electrical resistance : a 100 watt bulb or a 60 watt bulb ?
3. Name the commercial unit of electric energy.
4. An electric bulb is rated at 220 V, 100 W. What is its resistance ?
5. What is the SI unit of (*i*) electric energy, and (*ii*) electric power ?
6. Name the quantity whose unit is (*i*) kilowatt, and (*ii*) kilowatt-hour.
7. Which quantity has the unit of watt ?
8. What is the meaning of the symbol kWh ? Which quantity does it represent ?
9. If the potential difference between the end of a wire of fixed resistance is doubled, by how much does the electric power increase ?
10. An electric lamp is labelled 12 V, 36 W. This indicates that it should be used with a 12 V supply. What other information does the label provide ?
11. What current will be taken by a 920 W appliance if the supply voltage is 230 V ?

Short Answer Type Questions

12. Define watt. Write down an equation linking watts, volts and amperes.
13. Define watt-hour. How many joules are equal to 1 watt-hour ?
14. How much energy is consumed when a current of 5 amperes flows through the filament (or element) of a heater having resistance of 100 ohms for two hours ? Express it in joules.
15. An electric bulb is connected to a 220 V power supply line. If the bulb draws a current of 0.5 A, calculate the power of the bulb.
16. In which of the following cases more electrical energy is consumed per hour ?
    (*i*) A current of 1 ampere passed through a resistance of 300 ohms.
    (*ii*) A current of 2 amperes passed through a resistance of 100 ohms.
17. An electric kettle rated at 220 V, 2.2 kW, works for 3 hours. Find the energy consumed and the current drawn.

18. In a house two 60 W electric bulbs are lighted for 4 hours, and three 100 W bulbs for 5 hours everyday. Calculate the electric energy consumed in 30 days.

19. A bulb is rated as 250 V; 0.4 A. Find its : (*i*) power, and (*ii*) resistance.

20. For a heater rated at 4 kW and 220 V, calculate :
(*a*) the current,
(*b*) the resistance of the heater,
(*c*) the energy consumed in 2 hours, and
(*d*) the cost if 1 kWh is priced at ₹ 4.60.

21. An electric motor takes 5 amperes current from a 220 volt supply line. Calculate the power of the motor and electrical energy consumed by it in 2 hours.

22. Which uses more energy : a 250 W TV set in 1 hour or a 1200 W toaster in 10 minutes ?

23. Calculate the power used in the 2 Ω resistor in each of the following circuits :
(*i*) a 6 V battery in series with 1 Ω and 2 Ω resistors.
(*ii*) a 4 V battery in parallel with 12 Ω and 2 Ω resistors.

24. Two lamps, one rated 40 W at 220 V and the other 60 W at 220 V, are connected in parallel to the electric supply at 220 V.
(*a*) Draw a circuit diagram to show the connections.
(*b*) Calculate the current drawn from the electric supply.
(*c*) Calculate the total energy consumed by the two lamps together when they operate for one hour.

25. An electric kettle connected to the 230 V mains supply draws a current of 10 A. Calculate :
(*a*) the power of the kettle.
(*b*) the energy transferred in 1 minute.

26. A 2 kW heater, a 200 W TV and three 100 W lamps are all switched on from 6 p.m. to 10 p.m. What is the total cost at Rs. 5.50 per kWh ?

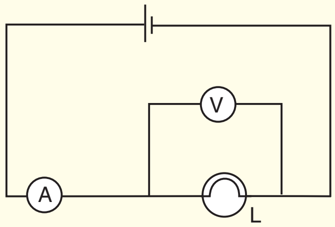
27. What is the maximum power in kilowatts of the appliance that can be connected safely to a 13 A ; 230 V mains socket ?

28. An electric fan runs from the 230 V mains. The current flowing through it is 0.4 A. At what rate is electrical energy transferred by the fan ?

Long Answer Type Question

29. (*a*) What is meant by "electric power" ? Write the formula for electric power in terms of potential difference and current.

(*b*) The diagram below shows a circuit containing a lamp L, a voltmeter and an ammeter. The voltmeter reading is 3 V and the ammeter reading is 0.5 A.



(*i*) What is the resistance of the lamp ?
(*ii*) What is the power of the lamp ?

(*c*) Define kilowatt-hour. How many joules are there in one kilowatt-hour ?

(*d*) Calculate the cost of operating a heater of 500 W for 20 hours at the rate of ₹ 3.90 per unit.

Multiple Choice Questions (MCQs)

30. When an electric lamp is connected to 12 V battery, it draws a current of 0.5 A. The power of the lamp is :
(*a*) 0.5 W (*b*) 6 W (*c*) 12 W (*d*) 24 W

31. The unit for expressing electric power is :
(*a*) volt (*b*) joule (*c*) coulomb (*d*) watt

32. Which of the following is likely to be the correct wattage for an electric iron used in our homes ?
(*a*) 60 W (*b*) 250 W (*c*) 850 W (*d*) 2000 W

33. An electric heater is rated at 2 kW. Electrical energy costs ₹ 4 per kWh. What is the cost of using the heater for 3 hours ?

(*a*) ₹ 12 (*b*) ₹ 24 (*c*) ₹ 36 (*d*) ₹ 48

34. The SI unit of energy is :
(*a*) joule (*b*) coulomb (*c*) watt (*d*) ohm-metre

35. The commercial unit of energy is :
(*a*) watt (*b*) watt-hour (*c*) kilowatt-hour (*d*) kilo-joule

36. How much energy does a 100 W electric bulb transfer in 1 minute ?
(*a*) 100 J (*b*) 600 J (*c*) 3600 J (*d*) 6000 J

37. An electric kettle for use on a 230 V supply is rated at 3000 W. For safe working, the cable connected to it should be able to carry at least :
(*a*) 2 A (*b*) 5 A (*c*) 10 A (*d*) 15 A

38. How many joules of electrical energy are transferred per second by a 6 V ; 0.5 A lamp ?
(*a*) 30 J/s (*b*) 12 J/s (*c*) 0.83 J/s (*d*) 3 J/s

39. At a given time, a house is supplied with 100 A at 220 V. How many 75 W, 220 V light bulbs could be switched on in the house at the same time (if they are all connected in parallel) ?
(*a*) 93 (*b*) 193 (*c*) 293 (*d*) 393

40. If the potential difference between the ends of a fixed resistor is halved, the electric power will become :
(*a*) double (*b*) half (*c*) four times (*d*) one-fourth

Questions Based on High Order Thinking Skills (HOTS)

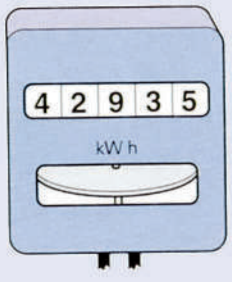
41. State whether an electric heater will consume more electrical energy or less electrical energy per second when the length of its heating element is reduced. Give reasons for your answer.

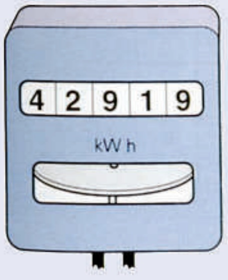
42. The table below shows the current in three different electrical appliances when connected to the 240 V mains supply :

Appliance	*Current*
Kettle	8.5 A
Lamp	0.4 A
Toaster	4.8 A

(*a*) Which appliance has the greatest electrical resistance ? How does the data show this ?
(*b*) The lamp is connected to the mains supply by using a thin, twin-cored cable consisting of live and neutral wires. State two reasons why this cable should not be used for connecting the kettle to the mains supply.
(*c*) Calculate the power rating of the kettle when it is operated from the 240 V mains supply.
(*d*) A man takes the kettle abroad where the mains supply is 120 V. What is the current in the kettle when it is operated from the 120 V supply ?

43. A boy noted the readings on his home's electricity meter on Sunday at 8 AM and again on Monday at 8 AM (see Figures below).





(*a*) What was the meter reading on Sunday ?
(*b*) What was the meter reading on Monday ?
(*c*) How many units of electricity have been used ?
(*d*) In how much time these units have been used ?
(*e*) If the rate is Rs. 5 per unit, what is the cost of electricity used during this time ?

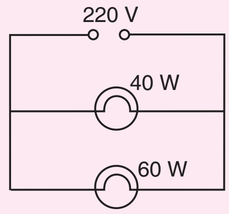
44. An electric bulb is rated as 10 W, 220 V. How many of these bulbs can be connected in parallel across the two wires of 220 V supply line if the maximum current which can be drawn is 5 A ?

45. Two exactly similar electric lamps are arranged (*i*) in parallel, and (*ii*) in series. If the parallel and series combination of lamps are connected to 220 V supply line one by one, what will be the ratio of electric power consumed by them ?

ANSWERS

2. 60 watt bulb **4.** 484 Ω **9.** Four times **10.** The electric lamp consumes energy at the rate of 36 J/s **11.** 4 A **14.** 18.0×10^6 J **15.** 110 W **16.** 2 A ; 100 Ω **17.** 6.6 kWh ; 10 A **18.** 59.4 kWh **19.** (*i*) 100 W (*ii*) 625 Ω **20.** (*a*) 18.18 A (*b*) 12.1 Ω (*c*) 8 kWh (*d*) ₹ 36.80 **21.** 1.1 kW ; 2.2 kWh **22.** TV set uses 0.25 kWh energy whereas toaster uses 0.20 kWh energy. So, TV uses more energy.

23. (*i*) 8 W (*ii*) 8 W **24.** (*a*)



(*b*) 0.45 A (*c*) 356.4 kJ **25.** (*a*) 2300 W or 2.3 kW (*b*) 1,38,000 J or 138 kJ **26.** Rs. 55.00 **27.** 2.99 kW **28.** 92 J/s **29.** (*b*) (*i*) 6 Ω (*ii*) 1.5 W (*d*) ₹ 39.00 **30.** (*b*) **31.** (*d*) **32.** (*c*) **33.** (*b*) **34.** (*a*) **35.** (*c*) **36.** (*d*) **37.** (*d*) **38.** (*d*) **39.** (*c*) **40.** (*d*)
41. More electrical energy ; Power is inversely proportional to resistance **42.** (*a*) Lamp ; Least current flowing in it (*b*) Large current drawn by kettle ; Earth connection needed (*c*) 2040 W (*d*) 4.25 A
43. (*a*) 42919 (*b*) 42935 (*c*) 16 units (*d*) 24 hours (*e*) Rs. 80 **44.** 110 bulbs **45.** 4 : 1

Effects Produced by Electric Current

An electric current can produce three important effects. These are : (1) Heating effect, (2) Magnetic effect, and (3) Chemical effect. We will now discuss the heating effect of current. The magnetic effect of current will be discussed in the next Chapter whereas the chemical effect of current will be described in higher classes.

HEATING EFFECT OF CURRENT

When an electric current is passed through a high resistance wire, like nichrome wire, the resistance wire becomes very hot and produces heat. This is called the heating effect of current. The heating effect of current is obtained by the transformation of electrical energy into heat energy. Just as mechanical energy used to overcome friction is converted into heat, in the same way, electrical energy is converted into heat energy when an electric current flows through a resistance wire. Thus, *the role of 'resistance' in electrical circuits is similar to the role of 'friction' in mechanics.* We will now derive a formula for calculating the heat produced when an electric current flows through a resistance wire.

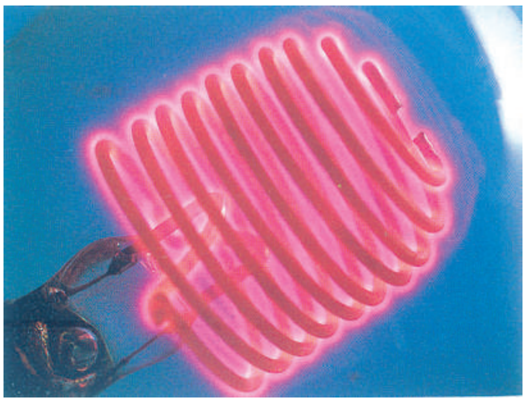


Figure 36. An electric current produces heating effect. This filament has become red-hot due to the heating effect of current.

Since a conductor, say a resistance wire, offers resistance to the flow of current, so work must be done by the current continuously to keep itself flowing. We will calculate the work done by a current I when it flows through a resistance R for time t. Now, when an electric charge Q moves against a potential difference V, the amount of work done is given by :

$$W = Q \times V \qquad \text{... (1)}$$

From the definition of current we know that :

$$\text{Current,} \quad I = \frac{Q}{t}$$

$$\text{So,} \quad Q = I \times t \qquad \text{... (2)}$$

And from Ohm's law, we have :

$$\frac{V}{I} = R$$

or $$\text{Potential difference, } V = I \times R \qquad \text{... (3)}$$

Now, putting $Q = I \times t$ and $V = I \times R$ in equation (1), we get :

$$W = I \times t \times I \times R$$

So, Work done, $W = I^2 \times R \times t$

Assuming that all the electrical work done or all the electrical energy consumed is converted into heat energy, we can write 'Heat produced' in place of 'Work done' in the above equation. Thus,

Heat produced, $\boldsymbol{H = I^2 \times R \times t}$ joules

This formula gives us the heat produced in joules when a current of I amperes flows in a wire of resistance R ohms for time t seconds. This is known as **Joule's law of heating.** According to Joule's law of heating given by the formula $H = I^2 \times R \times t$, it is clear that **the heat produced in a wire is directly proportional to :**

(*i*) square of current (I^2)

(*ii*) resistance of wire (R)

(*iii*) time (t), for which current is passed

(*a*) Since the heat produced is directly proportional to the square of current :

$$H \propto I^2$$

so, if we *double* the current, then the heat produced will become *four times*. And if we *halve* the current, then heat generated will become *one-fourth.*

(*b*) Since the heat produced in a wire is directly proportional to the resistance :

$$H \propto R$$

so, if we *double* the resistance, then heat produced will also get *doubled*. And if we *halve* the resistance, then the heat produced will also be *halved*. This means that **a given current will produce more heat in a high resistance wire than in a low resistance wire**.

We know that when two similar resistance wires are connected in series, then their combined resistance gets doubled but when they are connected in parallel then their combined resistance gets halved. So, **a given current will produce more heat per unit time if the two resistances are connected in series than when they are connected in parallel.**

(*c*) Since the heat produced in a wire is directly proportional to the time for which current flows :

$$H \propto t$$

so, if the current is passed through a wire for *double* the time, then the heat produced is *doubled*. And if the time is *halved*, the heat produced is also *halved*.

We will now solve some problems based on the heating effect of current. Please note that the formula : $H = I^2 \times R \times t$ for calculating the heat produced can be used only if the current I, resistance R and time t are known to us. In some cases, however, they give us the power P and time t only. In that case the heat energy is to be calculated by using the formula : $E = P \times t$.

It should be noted that **all the appliances which run on electricity do not convert all the electric energy into heat energy.** Only the electrical heating appliances convert most of the electric energy into heat energy. For example, when electric current is passed through an electric appliance such as a fan, then most of the electric energy is used up in running the fan (or turning the fan), only a very small amount of electric energy is converted into heat energy by a fan. Due to this, an electric fan becomes slightly warm when run continuously for a long time. On the other hand, when electric current is passed through an electrical heating appliance such as an electric heater, electric kettle, hair dryer, immersion rod or a geyser, then most of the electrical energy is converted into heat. All the electrical heating appliances have a 'heating element' or 'heating coil' made of high resistance wire (like nichrome wire) which helps in converting most of the electric energy into heat energy. We will now solve some problems based on the heating effect of current.

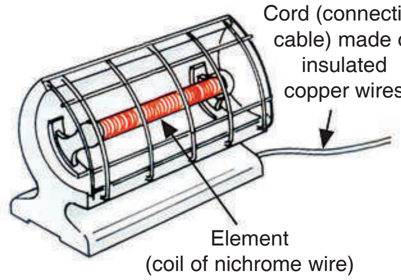


Figure 37. An electric room heater converts almost all the electrical energy into heat.

Sample Problem 1. A potential difference of 250 volts is applied across a resistance of 500 ohms in an electric iron. Calculate (*i*) current, and (*ii*) heat energy produced in joules in 10 seconds.

Solution. (*i*) **Calculation of Current.** The current can be calculated by using Ohm's law equation :

$$\frac{V}{I} = R$$

Here, Potential difference, $V = 250$ volts

Current, $I = ?$ (To be calculated)

Resistance, $R = 500$ ohms

Putting these values in the above formula, we get :

$$\frac{250}{I} = 500$$

So, $$I = \frac{250}{500}$$

$$= \frac{1}{2}$$

$$= 0.5 \text{ ampere}$$

Thus, the current flowing in the electric iron is 0.5 A.

(*ii*) **Calculation of Heat Energy.** The heat energy in joules can be calculated by using the formula :

$$H = I^2 \times R \times t$$

Here, Current, $I = 0.5$ A

Resistance, $R = 500\ \Omega$

And, Time, $t = 10$ s

Putting these values in the above formula, we get :

$$H = (0.5)^2 \times 500 \times 10$$

$$= 1250 \text{ joules}$$

Sample Problem 2. Calculate the heat produced when 96,000 coulombs of charge is transferred in 1 hour through a potential difference of 50 volts. **(NCERT Book Question)**

Solution. First of all we will calculate the current by using the values of charge and time. We know that :

$$\text{Current, } I = \frac{Q}{t}$$

$$I = \frac{96{,}000}{60 \times 60} \quad \text{(Because 1 h = 60 × 60 s)}$$

$$I = 26.67 \text{ A}$$

We will now calculate the resistance by using Ohm's law :

$$R = \frac{V}{I}$$

$$R = \frac{50}{26.67}$$

$$R = 1.87\ \Omega$$

$$\text{Heat produced, } H = I^2 \times R \times t$$

$$= (26.67)^2 \times 1.87 \times 60 \times 60$$

$$= 4788400 \text{ J}$$

$$= 4788.4 \text{ kJ}$$

Thus, the heat produced is 4788.4 kilojoules.

Sample Problem 3. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in series and then in parallel in a circuit across the same potential difference. The ratio of heat produced in series and parallel combinations would be :

(*a*) 1 : 2 (*b*) 2 : 1 (*c*) 1 : 4 (*d*) 4 : 1 **(NCERT Book Question)**

Solution. Suppose the resistance of each one of the two wires is x.

(*i*) When the two resistance wires, each having a resistance x, are connected in series, then :

Combined resistance, $R_1 = 2x$

And, if the potential difference in the circuit is V, then applying Ohm's law :

$$\text{Current, } I_1 = \frac{V}{2x}$$

Suppose the heat produced with the series combination of wires is H_1. Then :

$$H_1 = I_1^2 \times R_1 \times t$$

or $$H_1 = \left(\frac{V}{2x}\right)^2 \times 2x \times t = \frac{V^2}{4x^2} \times 2x \times t$$

or $$H_1 = \frac{V^2 \times t}{2x} \quad \text{... (1)}$$

(*ii*) When the two resistance wires, each of resistance x, are connected in parallel, then :

Combined resistance, $R_2 = \frac{x}{2}$

And if the potential difference in the circuit is V, then applying Ohm 's law :

$$\text{Current, } I_2 = \frac{V \times 2}{x}$$

Suppose the heat produced with the parallel combination of wires is H_2. Then :

$$H_2 = I_2^2 \times R_2 \times t$$

or $$H_2 = \left(\frac{V \times 2}{x}\right)^2 \times \frac{x}{2} \times t = \frac{V^2 \times 4 \times x \times t}{x^2 \times 2}$$

or $$H_2 = \frac{V^2 \times 2 \times t}{x} \quad \text{... (2)}$$

Dividing equation (1) by equation (2), we get :

$$\frac{H_1}{H_2} = \frac{V^2 \times t \times x}{2x \times V^2 \times 2 \times t}$$

$$\frac{H_1}{H_2} = \frac{1}{4} \quad \text{or} \quad H_1 : H_2 = 1 : 4$$

Thus, the correct option is : (*c*) 1 : 4

Applications of the Heating Effect of Current

The important applications of the heating effect of electric current are given below :

1. The heating effect of current is utilised in the working of electrical heating appliances such as electric iron, electric kettle, electric toaster, electric oven, room heaters, water heaters (geysers), etc. All these heating appliances contain coils of high resistance wire made of nichrome alloy. When these appliances are connected to power supply by insulated copper wires then a large amount of heat is produced in the heating coils (because they have high resistance), but a negligible heat is produced in the connecting wires of copper (because copper has very, very low resistance). For example, the heating element (or coil) of an electric heater made of nichrome glows because it becomes red-hot due to the large amount of heat produced on passing current (because of its high resistance), but the cord or connecting cable of the electric heater made of copper does not glow because negligible heat is produced in it by passing current (because of its extremely low resistance). The temperature of the heating element (or heating coil) of an electrical heating device when it becomes red-hot and glows is about 900°C.

Figure 38. This is an electric iron.

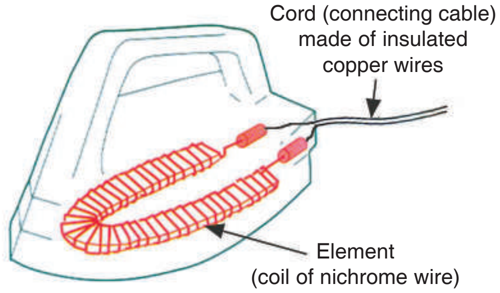


Figure 39. An electric iron works on the heating effect of current. When current is passed, its heating element made of nichrome wire becomes red-hot and produces heat.

2. The heating effect of electric current is utilised in electric bulbs (electric lamps) for producing light. When electric current passes through a very thin, high resistance tungsten filament of an electric bulb, the filament becomes white-hot and emits light. Please note that the same current flowing through the tungsten filament of an electric bulb produces enormous heat but almost negligible heat is produced in the connecting wires of copper. This is because of the fact that the fine tungsten filament has very high resistance whereas copper connecting wires have very low resistance.

Tungsten metal is used for making the filaments of electric bulbs because it has a very high melting point (of 3380°C). Due to its very high melting point, the tungsten filament can be kept white-hot without melting away. The other properties of tungsten which make it suitable for making filaments of electric bulbs are its *high flexibility* and *low rate of evaporation at high temperature.* Please note that when the tungsten filament of an electric bulb becomes white-hot and glows to emit light, then its temperature is about 2500°C !

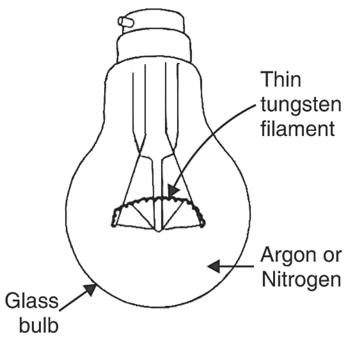


Figure 40. An electric bulb works on the heating effect of electric current. When current is passed, its filament becomes white-hot and produces heat and light.

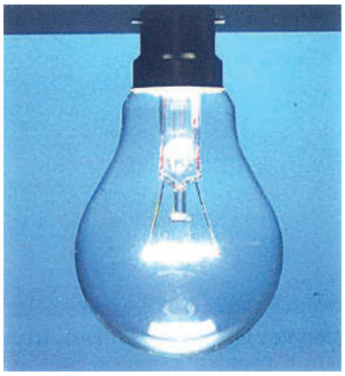


Figure 41. The glowing filament of this electric bulb is producing light and heat.

If air is present in an electric bulb, then the extremely hot tungsten filament would burn up quickly in the oxygen of air. So, **the electric bulb is filled with a chemically unreactive gas like argon or nitrogen (or a mixture of both).** The gases like argon and nitrogen do not react with the hot tungsten filament and hence prolong the life of the filament of the electric bulb. It should be noted that most of the electric power consumed by the filament of an electric bulb appears as heat (due to which the bulb becomes hot), only a small amount of electric power is converted into light. So, filament-type electric bulbs are not power efficient. On the other hand, tube-lights are much more power efficient, because they have no filaments.

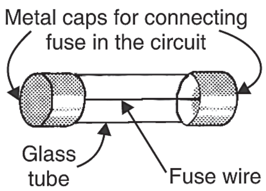


Figure 42. An electric fuse works on the heating effect of current. This diagram shows a fuse which is used to protect individual electrical appliances.

3. The heating effect of electric current is utilised in electric fuse for protecting household wiring and electrical appliances. A fuse is a short length of a thin tin-plated copper wire having low melting point. The thin fuse wire has a *higher* resistance than the rest of the electric wiring in a house. So, when the current in a household electric circuit rises too much due to some reason, then the fuse wire gets heated too much, melts and breaks the circuit (due to which the current stops flowing). This prevents the fire in house (due to over-heating of wiring) and also prevents damage to various electrical appliances in the house due to excessive current flowing through them. Thus, an electric fuse is a very important application of the heating effect of current. We will discuss the electric fuse in more detail in the topic on domestic electric circuits in the next Chapter. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. How does the heat H produced by a current passing through a fixed resistance wire depend on the magnitude of current I ?

2. If the current passing through a conductor is doubled, what will be the change in heat produced ?

3. Name two effects produced by electric current.

4. Which effect of current is utilised in an electric light bulb ?

5. Which effect of current is utilised in the working of an electric fuse ?

6. Name two devices which work on the heating effect of electric current.

7. Name two gases which are filled in filament type electric light bulbs.

8. Explain why, filament type electric bulbs are not power efficient.

9. Why does the connecting cord of an electric heater not glow hot while the heating element does ?

Short Answer Type Questions

10. (*a*) Write down the formula for the heat produced when a current I is passed through a resistor R for time t.

(*b*) An electric iron of resistance 20 ohms draws a current of 5 amperes. Calculate the heat produced in 30 seconds.

11. State three factors on which the heat produced by an electric current depends. How does it depend on these factors ?

12. (*a*) State and explain Joule's law of heating.

(*b*) A resistance of 40 ohms and one of 60 ohms are arranged in series across 220 volt supply. Find the heat in joules produced by this combination of resistances in half a minute.

13. Why is an electric light bulb not filled with air ? Explain why argon or nitrogen is filled in an electric bulb.

14. Explain why, tungsten is used for making the filaments of electric bulbs.

15. Explain why, the current that makes the heater element very hot, only slightly warms the connecting wires leading to the heater.

16. When a current of 4.0 A passes through a certain resistor for 10 minutes, 2.88×10^4 J of heat are produced. Calculate :

(*a*) the power of the resistor.

(*b*) the voltage across the resistor.

17. A heating coil has a resistance of 200 Ω. At what rate will heat be produced in it when a current of 2.5 A flows through it ?

18. An electric heater of resistance 8 Ω takes a current of 15 A from the mains supply line. Calculate the rate at which heat is developed in the heater.

19. A resistance of 25 Ω is connected to a 12 V battery. Calculate the heat energy in joules generated per minute.

20. 100 joules of heat is produced per second in a 4 ohm resistor. What is the potential difference across the resistor ?

Long Answer Type Question

21. (*a*) Derive the expression for the heat produced due to a current 'I' flowing for a time interval 't' through a resistor 'R' having a potential difference 'V' across its ends. With which name is this relation known ?

(*b*) How much heat will an instrument of 12 W produce in one minute if it is connected to a battery of 12 V ?

(*c*) The current passing through a room heater has been halved. What will happen to the heat produced by it ?

(*d*) What is meant by the heating effect of current ? Give two applications of the heating effect of current.

(*e*) Name the material which is used for making the filaments of an electric bulb.

Multiple Choice Questions (MCQs)

22. The heat produced by passing an electric current through a fixed resistor is proportional to the square of :

(*a*) magnitude of resistance of the resistor
(*b*) temperature of the resistor
(*c*) magnitude of current
(*d*) time for which current is passed

23. The current passing through an electric kettle has been doubled. The heat produced will become :
(*a*) half (*b*) double (*c*) four times (*d*) one-fourth

24. An electric fuse works on the :
(*a*) chemical effect of current (*b*) magnetic effect of current
(*c*) lighting effect of current (*d*) heating effect of current

25. The elements of electrical heating devices are usually made of :
(*a*) tungsten (*b*) bronze (*c*) nichrome (*d*) argon

26. The heat produced in a wire of resistance 'x' when a current 'y' flows through it in time 'z' is given by :
(*a*) $x^2 \times y \times z$ (*b*) $x \times z \times y^2$ (c) $y \times z^2 \times x$ (*d*) $y \times z \times x$

27. Which of the following characteristic is not suitable for a fuse wire ?
(*a*) thin and short (*b*) thick and short
(*c*) low melting point (*d*) higher resistance than rest of wiring

28. In a filament type light bulb, most of the electric power consumed appears as :
(*a*) visible light (*b*) infra-red-rays (*c*) ultraviolet rays (*d*) fluorescent light

29. Which of the following is the most likely temperature of the filament of an electric light bulb when it is working on the normal 220 V supply line ?
(*a*) 500°C (*b*) 1500°C (*c*) 2500°C (*d*) 4500°C

30. If the current flowing through a fixed resistor is halved, the heat produced in it will become :
(*a*) double (*b*) one-half (*c*) one-fourth (*d*) four times

Questions Based on High Order Thinking Skills (HOTS)

31. The electrical resistivities of four materials P, Q, R and S are given below :

P	$6.84 \times 10^{-8}\ \Omega m$
Q	$1.70 \times 10^{-8}\ \Omega m$
R	$1.0 \times 10^{15}\ \Omega m$
S	$11.0 \times 10^{-7}\ \Omega m$

Which material will you use for making : (*a*) heating element of electric iron (*b*) connecting wires of electric iron (*c*) covering of connecting wires ? Give reason for your choice in each case.

32. (*a*) How does the wire in the filament of a light bulb behave differently to the other wires in the circuit when the current flows ?
(*b*) What property of the filament wire accounts for this difference ?

33. Two exactly similar heating resistances are connected (*i*) in series, and (*ii*) in parallel, in two different circuits, one by one. If the same current is passed through both the combinations, is more heat obtained per minute when they are connected in series or when they are connected in parallel ? Give reason for your answer.

34. An electric iron is connected to the mains power supply of 220 V. When the electric iron is adjusted at 'minimum heating' it consumes a power of 360 W but at 'maximum heating' it takes a power of 840 W. Calculate the current and resistance in each case.

35. Which electric heating devices in your home do you think have resistors which control the flow of electricity ?

ANSWERS

2. Heat produced becomes four times **10.** (*b*) 15000 J **12.** (*b*) 14520 J **16.** (*a*) 48 W (*b*) 12 V **17.** 1250 J/s **18.** 1800 J **19.** 345.6 J **20.** 20 V **21.** (*b*) 720 J (*c*) Heat produced becomes one-fourth **22.** (*c*) **23.** (*c*) **24.** (*d*) **25.** (*c*) **26.** (*b*) **27.** (*b*) **28.** (*b*) **29.** (*c*) **30.** (*c*) **31.** (*a*) S ; Because it has high resistivity of $11.0 \times 10^{-7}\ \Omega m$ (It is actually nichrome) (*b*) Q ; Because it has very low resistivity of $1.70 \times 10^{-8}\ \Omega$ m (It is actually copper) (*c*) R ; Because it has very, very high resistivity of $1.0 \times 10^{15}\ \Omega$ m (It is actually rubber) **32.** (*a*) The filament wire becomes white hot whereas other wires in the circuit do not get heated much (*b*) High resistance of filament wire **33.** In series **34.** 1.64 A ; 134.15 Ω ; 3.82 A , 57.60 Ω **35.** Electric iron ; Electric oven ; Water heater (Geyser) ; Room heater (Convector)

CHAPTER

2

Magnetic Effect of Electric Current

In the previous Chapter we have studied that an electric current can produce *heating effect*. We will now study that an electric current can also produce a *magnetic effect*. **The term 'magnetic effect of electric current' means that 'an electric current flowing in a wire produces a magnetic field around it'.** In other words, **electric current can produce magnetism.** This will become more clear from the following activity. Take about one metre long insulated copper wire and wind it round and round closely on a large iron nail (see Figure 1). Then connect the ends of the wire to a battery. We will find that the large iron nail can now attract tiny iron nails towards it (as shown in Figure 1). This has happened because an electric current flowing in the wire has produced a magnetic field which has turned the large iron nail into a magnet. Please note that the current-carrying straight electric wires (like an electric iron connecting cable) do not attract the nearby iron objects towards them because the strength of magnetic field produced by them is quite *weak*. We will now describe a magnet, poles of a magnet, magnetic field and magnetic field lines briefly. This is necessary to understand the magnetic effect of current.

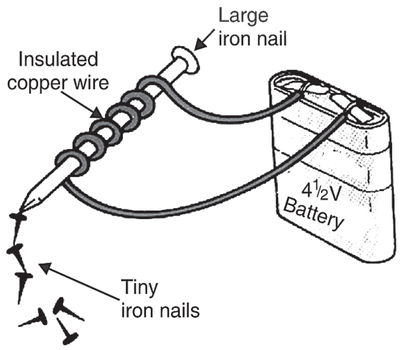


Figure 1. An electric current flowing in the coiled copper wire has turned the large iron nail into a magnet. This is an example of magnetic effect of current.

A magnet is an object which attracts pieces of iron, steel, nickel and cobalt. Magnets come in various shapes and sizes depending on their intended use. One of the most common magnets is the *bar* magnet. **A bar magnet is a long, rectangular bar of uniform cross-section which attracts pieces of iron, steel, nickel and cobalt.** We usually use bar magnets for

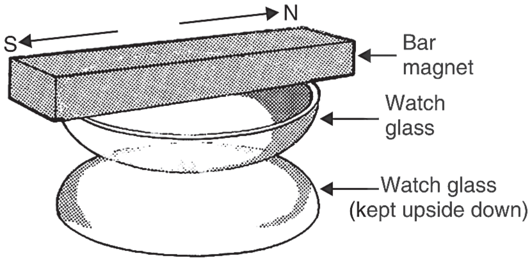


Figure 2. This diagram shows how to support a bar magnet on two watch glasses so that it can rotate freely.

performing practicals in a science laboratory. A magnet has two poles near its ends : north pole and south pole. The end of a freely suspended magnet (or a freely pivoted magnet) which points towards the north direction is called the **north pole of the magnet** (see Figure 2). And the end of a freely suspended magnet (or freely pivoted magnet) which points towards the south direction is called the **south pole of the magnet.** It has been found by experiments that **like magnetic poles repel each other** whereas **unlike magnetic poles attract each other.** This means that the north pole of a magnet repels the north pole of another magnet and the south pole of a magnet repels the south pole of another magnet; but the north pole of a magnet attracts the south pole of another magnet. These days magnets are used for a variety of purposes. Magnets are used in radio, television, and stereo speakers, in refrigerator doors, on audio and video cassette tapes, on hard discs and floppies for computers, and in children's toys. Magnets are also used in making electric generators and electric motors. The Magnetic Resonance Imaging (MRI) technique which is used to scan inner human body parts in hospitals also uses magnets for its working.

Figure 3. A magnetic strip in the refrigerator door is used to keep it closed properly.

Magnetic Field

Just as an electric charge creates an electric field, in the same way, a magnet creates a magnetic field around it. **The space surrounding a magnet in which magnetic force is exerted, is called a magnetic field.** A compass needle placed near a magnet gets deflected due to the magnetic force exerted by the magnet, and the iron filings also cling to the magnet due to magnetic force. The magnetic field pattern due to a bar magnet is shown in Figure 8. The magnetic field has both, *magnitude* as well as *direction.* **The direction of magnetic field at a point is the direction of the resultant force acting on a hypothetical north pole placed at that point.** The north end of the needle of a compass indicates the direction of magnetic field at a point where it is placed.

Magnetic Field Lines

A magnetic field is described by drawing the magnetic field lines. When a small north magnetic pole is placed in the magnetic field created by a magnet, it will experience a force. And if the north pole is free, it will move under the influence of magnetic field. The path traced by a north magnetic pole free to move under the influence of a magnetic field is called a magnetic field line. In other words, **the magnetic field lines are the lines drawn in a magnetic field along which a north magnetic pole would move.** The *magnetic field lines* are also known as *magnetic lines of force.* The direction of a magnetic field line at any point gives the direction of the magnetic force on a north pole placed at that point. Since the direction of magnetic field line is the direction of force on a north pole, so **the magnetic field lines always begin from the N-pole of a magnet and end on the S-pole of the magnet** (see Figure 8). Inside the magnet, however, the direction of magnetic field lines is from the S-pole of the magnet to the N-pole of the magnet. Thus, the magnetic field lines are closed curves. The magnetic field lines due to a bar magnet are shown in Figure 8. When a small compass is moved along a magnetic field line, the compass needle always sets itself along the line tangential to it. So, a line drawn from the south pole of the compass needle to its north pole indicates the direction of the magnetic field at that point. We will now describe how the magnetic field lines (or magnetic field) produced by a bar magnet can be plotted on paper.

1. To Plot the Magnetic Field Pattern Due to a Bar Magnet by Using Iron Filings

Place a card (thick, stiff paper) over a strong bar magnet (as shown in Figure 4). Sprinkle a thin layer of iron filings over the card with the help of a sprinkler, and then tap the card gently. The iron filings arrange themselves in a regular pattern as shown in Figure 5. This arrangement of iron filings gives us a rough picture of the pattern of magnetic field produced by a bar magnet. This happens as follows : The bar magnet exerts a magnetic field all around it. The iron filings experience the force of magnetic field of the

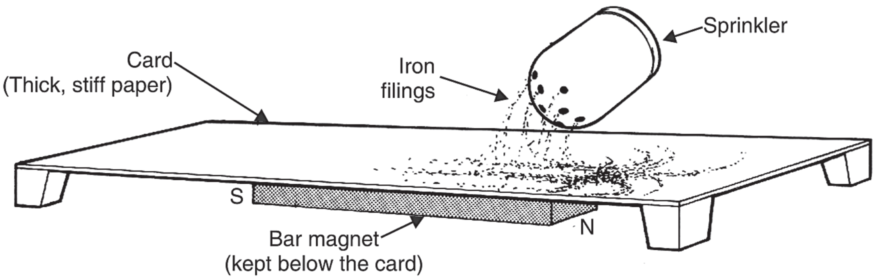


Figure 4. Experiment to trace the magnetic field pattern of a bar magnet by using iron filings.

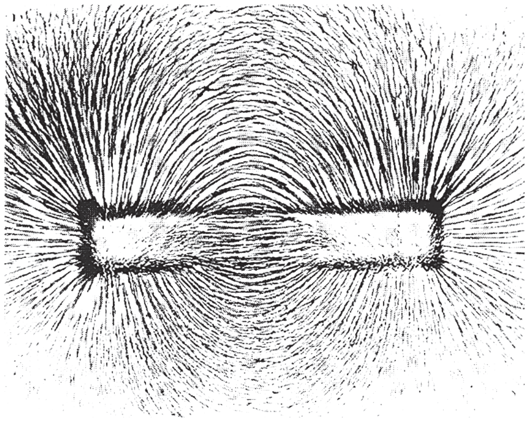


Figure 5. This picture shows the magnetic field pattern of a bar magnet as traced by iron filings. The black lines in the above picture consist of iron filings lying along the magnetic field lines of the bar magnet.

bar magnet. The force of magnetic field of the bar magnet makes the iron filings to arrange themselves in a particular pattern. Actually, under the influence of the magnetic field of the bar magnet, the iron filings behave like tiny magnets and align themselves along the directions of magnetic field lines. Thus, **iron filings show the shape of magnetic field produced by a bar magnet by aligning themselves with the magnetic field lines.**

There is also another method of obtaining the magnetic field pattern around a bar magnet. This is done by using a compass. A compass is a device used to show magnetic field direction at a point. A compass is also known as a plotting compass. **A compass (or plotting compass) consists of a tiny pivoted magnet usually in the form of a pointer which can turn freely in the horizontal plane.** It is enclosed in a *non-magnetic* metal case having a glass top (see Figure 6). The tiny magnet of the compass is also called 'magnetic needle' (or just 'needle'). The ends of the compass needle point approximately towards the *north* and *south* directions. Actually, the tip of compass needle points towards the north direction whereas its tail points in the south direction. When the compass is placed in a magnetic field (say, in the magnetic field due to a bar magnet), then a force acts on it and it is deflected from its usual north-south position (the axis of needle lines up in the direction of magnetic field). Thus, a compass needle gets deflected when brought near a bar magnet because the bar magnet exerts a magnetic force on the compass needle, which is itself a tiny pivoted magnet (free to move in the horizontal plane). We can trace the magnetic field lines around a bar magnet by using a plotting compass as decribed below.

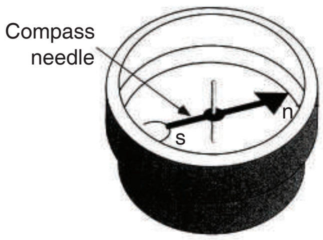


Figure 6. A compass (or plotting compass). Its north pole has been marked n and south pole s.

2. To Plot the Magnetic Field Pattern Due to a Bar Magnet by Using a Compass

The bar magnet *M* whose magnetic field pattern is to be traced is placed on a sheet of paper and its boundary is marked with a pencil (see Figure 7). A plotting compass is now brought near the N-pole of the bar magnet (see position *X* in Figure 7). In this position, the N-pole of magnet repels the n-pole of compass needle due to which the tip of the compass needle moves away from the N-pole of the magnet. On the other hand, the N-pole of magnet attracts the s-pole of compass needle due to which the tail of compass needle comes near the N-pole of the magnet (see position *X* in Figure 7). We mark the positions of the tip and the tail of compass needle by pencil dots *B* and *A*. That is, we mark the positions of the two poles of the compass needle by pencil dots *B* and *A* (tip representing north pole and tail representing south pole).

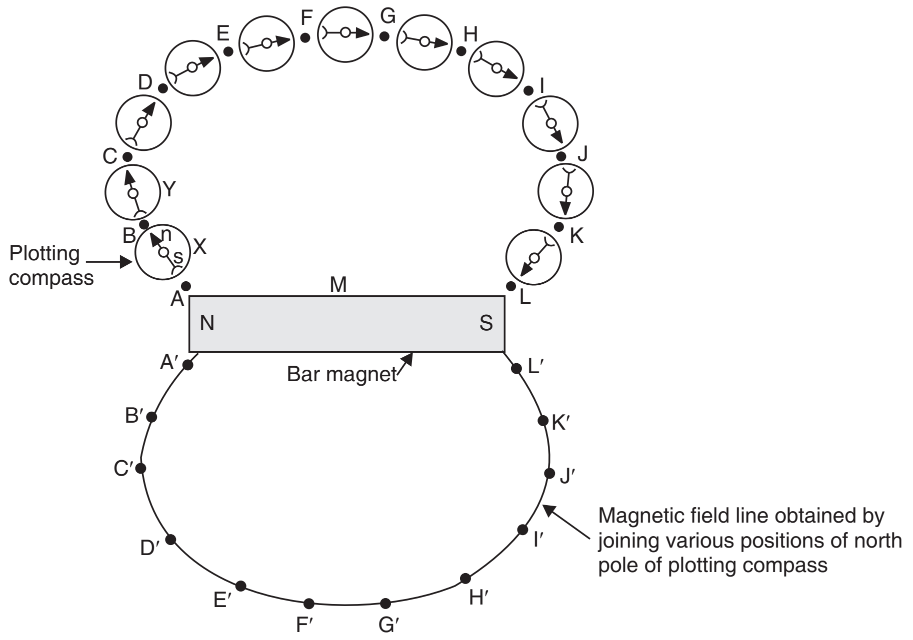


Figure 7. To draw the magnetic field pattern (or magnetic field lines) due to a bar magnet by using a plotting compass.

We now move the compass to position *Y* so that the tail of compass needle (or south pole) points at dot *B* (previously occupied by n-pole of compass needle). We mark a dot *C* at the tip of the compass needle to show the position of its north pole. In this manner we go on step by step till we reach the south pole of the magnet. By doing this we get the various dots *A, B, C, D, E, F, G, H, I, J, K* and *L*, all denoting the path in which the north pole of the compass needle moves. By joining the various dots, we get a smooth curve representing a magnetic field line, which begins on the north pole of the bar magnet and ends on its south pole (see Figure 7). We can draw a large number of lines of force in the same way by starting from different points near the magnet. Every line is labelled with an arrow to indicate its direction. In this way we will get the complete pattern of the magnetic field around a bar magnet.

The magnetic field pattern around a bar magnet is shown in Figure 8. This has been traced by using a plotting compass. **The magnetic field lines leave the north pole of a magnet and enter its south pole** (as shown in Figure 8). In other words, each magnetic field line is directed from the north pole of a magnet to its south pole. Each field line indicates, at every point on it, the direction of magnetic force that would act on a north pole if it were placed at that point. **The strength of magnetic field is indicated by the degree of closeness of the field lines. Where the field lines are closest together, the magnetic field is the strongest.** For example, the field lines are closest together at the two poles of the bar magnet, so the magnetic field is the strongest at the poles. Please note that no two magnetic field lines are found to cross each other. If two field lines crossed each other, it would mean that at the point of intersection, the compass needle would point in two directions at the same time, which is not possible. It should be noted that we have drawn the magnetic lines

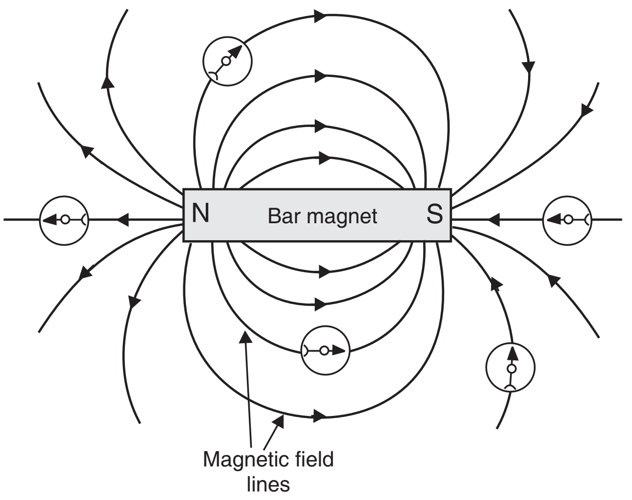


Figure 8. The magnetic field pattern (or magnetic field lines) produced by a bar magnet (These have been traced by using a plotting compass).

of force only in one plane around the magnet. Actually, **the magnetic field and hence the magnetic lines of force exist in all the planes all round the magnet.**

Properties (or Characteristics) of the Magnetic Field Lines

1. **The magnetic field lines originate from the north pole of a magnet and end at its south pole.**

2. **The magnetic field lines come closer to one another near the poles of a magnet but they are widely separated at other places.** A north magnetic pole experiences a stronger force when it approaches one of the poles of the magnet. This means that the magnetic field is stronger near the poles. From this we conclude that where magnetic field lines are closer together, it indicates a stronger magnetic field. On the other hand, when magnetic field lines are widely separated, then it indicates a weak magnetic field.

3. **The magnetic field lines do not intersect (or cross) one another.** This is due to the fact that the resultant force on a north pole at any point can be only in one direction. But if the two magnetic field lines intersect one another, then the resultant force on a north pole placed at the point of intersection will be along two directions, which is not possible.

Magnetic Field of Earth

A freely suspended magnet always points in the north-south direction even in the absence of any other magnet. This suggests that **the earth itself behaves as a magnet** which causes a freely suspended magnet (or magnetic needle) to point always in a particular direction : north and south. **The shape of the earth's magnetic field resembles that of an imaginary bar magnet** of length one-fifth of earth's diameter buried at its centre (see Figure 9).

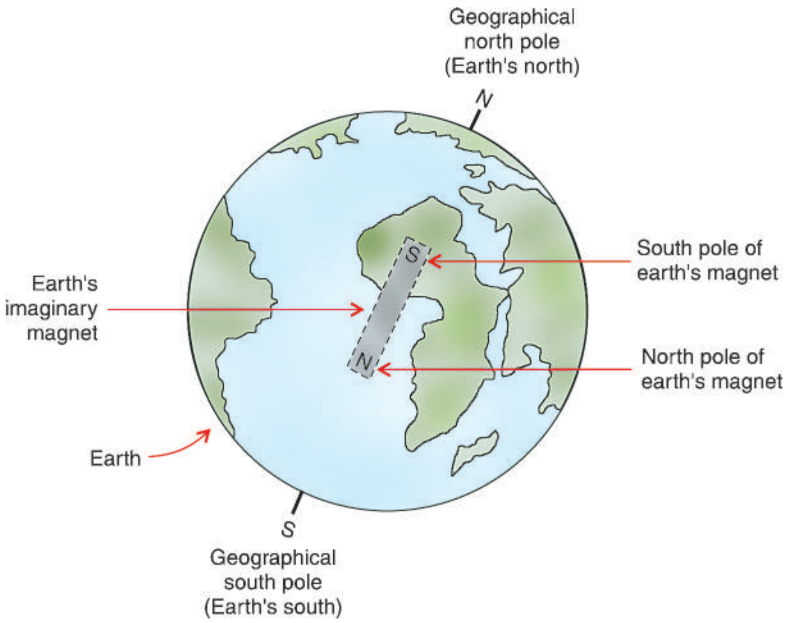


Figure 9. The earth's magnetism is due to an imaginary bar magnet buried at its centre. The S pole of earth's magnet is towards its north; and the N pole of earth's magnet is towards its south.

The south pole of earth's magnet is in the geographical north because it attracts the north pole of the suspended magnet. Similarly, the north pole of earth's magnet is in the geographical south because it attracts the south pole of the suspended magnet. Thus, there is a magnetic S-pole near the geographical north, and a magnetic N-pole near the geographical south. The positions of the earth's magnetic poles are not well defined on the globe, they are spread over an area. The axis of earth's magnet and the geographical axis do not coincide with each other. **The axis of earth's magnetic field is inclined at an angle of about 15° with the geographical axis.** Due to this a freely suspended magnet (or magnetic needle) makes an angle of about 15° with the geographical axis and points only approximately in the north-south directions at a place. In other words, a freely suspended magnet does not show exact geographical north and south because the magnetic axis and geographical axis of the earth do not coincide. It is now believed that **the earth's magnetism is due to the magnetic effect of current (which is flowing in the liquid core at the centre of the earth). Thus, earth is a huge electromagnet.** Before we go further and discuss the magnetic effect of current in detail, **please answer the following questions :**

Very Short Answer Type Questions

1. State any two properties of magnetic field lines.
2. What are the two ways in which you can trace the magnetic field pattern of a bar magnet ?
3. You are given the magnetic field pattern of a magnet. How will you find out from it where the magnetic field is the strongest ?
4. State whether the following statement is true or false :
   The axis of earth's imaginary magnet and the geographical axis coincide with each other.
5. Why does a compass needle get deflected when brought near a bar magnet ?
6. Where do the manufacturers use a magnetic strip in the refrigerator ? Why is this magnetic strip used ?
7. Fill in the following blanks with suitable words :
   (*a*) Magnetic field lines leave the..........pole of a bar magnet and enter at its........pole.
   (*b*) The earth's magnetic field is rather like that of a .... magnet with its........pole in the northern hemisphere.

Short Answer Type Questions

8. Draw a diagram to show the magnetic field lines around a bar magnet.
9. What is a magnetic field ? How can the direction of magnetic field lines at a place be determined ?
10. Explain why, two magnetic field lines do not intersect each other.
11. When an electric current is passed through any wire, a magnetic field is produced around it. Then why an electric iron connecting cable does not attract nearby iron objects when electric current is switched on through it ?

Long Answer Type Question

12. (*a*) Define magnetic field lines. Describe an activity to draw a magnetic field line outside a bar magnet from one pole to another pole.
    (*b*) Explain why, a freely suspended magnet always points in the north-south direction.

Multiple Choice Questions (MCQs)

13. A strong bar magnet is placed vertically above a horizontal wooden board. The magnetic lines of force will be :
    (*a*) only in horizontal plane around the magnet
    (*b*) only in vertical plane around the magnet
    (*c*) in horizontal as well as in vertical planes around the magnet
    (*d*) in all the planes around the magnet
14. The magnetic field lines produced by a bar magnet :
    (*a*) originate from the south pole and end at its north pole
    (*b*) originate from the north pole and end at its east pole
    (*c*) originate from the north pole and end at its south pole
    (*d*) originate from the south pole and end at its west pole
15. Which of the following is not attracted by a magnet ?
    (*a*) steel (*b*) cobalt (*c*) brass (*d*) nickel
16. The magnetic field lines :
    (*a*) intersect at right angles to one another
    (*b*) intersect at an angle of 45° to each other
    (*c*) do not cross one another
    (*d*) cross at an angle of 60° to one another
17. The north pole of earth's magnet is in the :
    (*a*) geographical south (*b*) geographical east
    (*c*) geographical west (*d*) geographical north
18. The axis of earth's magnetic field is inclined with the geographical axis at an angle of about :
    (*a*) 5° (*b*) 15° (*c*) 25° (*d*) 35°

19. The shape of the earth's magnetic field resembles that of an imaginary :
(*a*) U-shaped magnet (*b*) Straight conductor carrying current
(*c*) Current-carrying circular coil (*d*) Bar magnet

20. A magnet attracts :
(*a*) plastics (*b*) any metal (*c*) aluminium (*d*) iron and steel

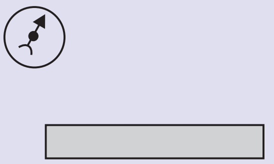
21. A plotting compass is placed near the south pole of a bar magnet. The pointer of plotting compass will :
(*a*) point away from the south pole (*b*) point parallel to the south pole
(*c*) point towards the south pole (*d*) point at right angles to the south pole

22. The metallic pointer of a plotting compass gets deflected only when it is placed near a bar magnet because the pointer has :
(*a*) electromagnetism (*b*) permanent magnetism
(*c*) induced magnetism (*d*) ferromagnetism

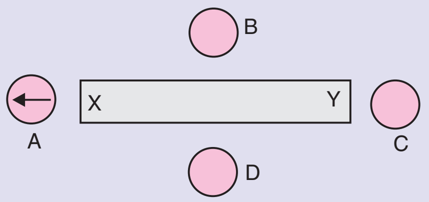
23. Which of the following statements is incorrect regarding magnetic field lines ?
(*a*) The direction of magnetic field at a point is taken to be the direction in which the north pole of a magnetic compass needle points.
(*b*) Magnetic field lines are closed curves
(*c*) If magnetic field lines are parallel and equidistant, they represent zero field strength
(*d*) Relative strength of magnetic field is shown by the degree of closeness of the field lines

Questions Based on High Order Thinking Skills (HOTS)

24. Copy the figure given below which shows a plotting compass and a magnet. Label the N pole of the magnet and draw the field line on which the compass lies.

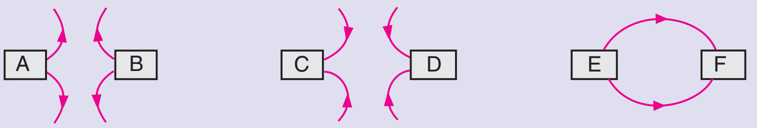


25. (*a*) The diagram shows a bar magnet surrounded by four plotting compasses. Copy the diagram and mark in it the direction of the compass needle for each of the cases B, C and D.

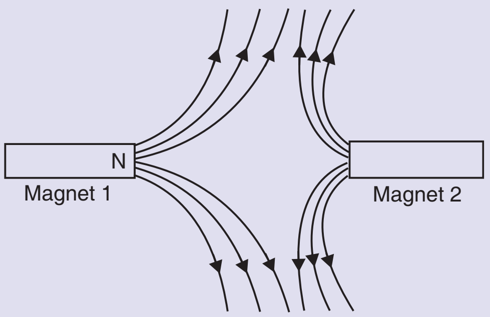


(*b*) Which is the north pole, X or Y ?

26. The three diagrams in the following figure show the lines of force (field lines) between the poles of two magnets. Identify the poles A, B, C, D, E and F.



27. The figure given below shows the magnetic field between two magnets :

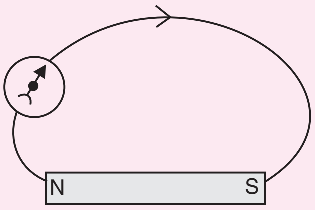


(*i*) Copy the diagram and label the other poles of the magnets.
(*ii*) Which is the weaker magnet ?

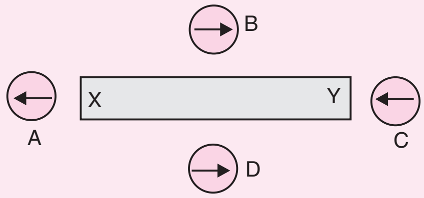
ANSWERS

4. False **7.** (*a*) north ; south (*b*) bar ; south **13.** (*d*) **14.** (*c*) **15.** (*c*) **16.** (*c*) **17.** (*a*) **18.** (*b*)
19. (*d*) **20.** (*d*) **21.** (*c*) **22.** (*b*) **23.** (*c*)

24.



25(*a*)



(*b*) X

26. A = N ; B = N ; C = S, D = S ; E = N, F = S **27.** (*i*) S—N ; N—S (*ii*) Magnet 2

MAGNETIC EFFECT OF CURRENT (OR ELECTROMAGNETISM)

The magnetic effect of current was discovered by Oersted in 1820. Oersted found that a wire carrying a current was able to deflect a compass needle. Now, the compass needle is a tiny magnet which can be deflected only by a magnetic field. Since a current carrying wire was able to deflect a compass needle, it was concluded that **a current flowing in a wire always gives rise to a magnetic field around it.** The importance of magnetic effect of current lies in the fact that it gives rise to *mechanical forces*. The electric motor, electric generator, telephone and radio, all utilize the magnetic effect of current. The magnetic effect of current is also called electromagnetism which means electricity produces magnetism.

Experiment to Demonstrate the Magnetic Effect of Current

We will now describe Oersted's experiment to show that a current carrying wire produces a magnetic field around it. We take a thick insulated copper wire and fix it in such a way that the portion *AB* of the wire is in the north-south direction as shown in Figure 10(*a*). A plotting compass *M* is placed under the wire *AB*. The two ends of the wire are connected to a battery through a switch. When no current is flowing in the wire *AB*, the compass needle is parallel to the wire *AB* and points in the usual north-south direction [Figure 10(*a*)].

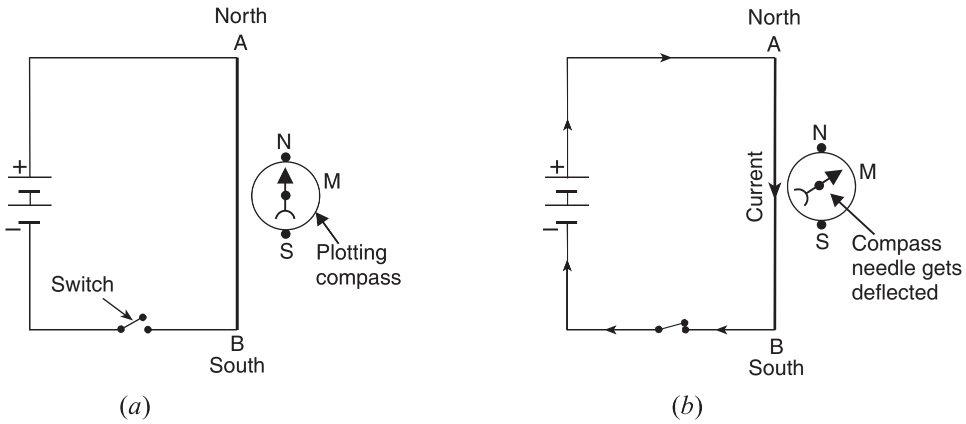


Figure 10. Experiment to show that an electric current produces a magnetic effect.

Let us pass the electric current through wire *AB* by pressing the switch. On passing the current we find that compass needle is deflected from its north-south position as shown in Figure 10(*b*). And when the current is switched off, the compass needle returns to its original position. We know that a freely pivoted compass needle always sets itself in the north-south direction. It deflects from its usual north-south direction only when it is acted upon by another magnetic field. So, **the deflection of compass needle by the current-carrying wire in the above experiment shows that an electric current produces a magnetic field around it.** It is this magnetic field which deflects the compass needle placed near the current-carrying wire.

If we reverse the direction of electric current flowing in the wire *AB* by reversing the battery connections, we will find that the compass needle is deflected in the *opposite* direction. This shows that when we reverse the direction of electric current flowing in the wire, then the direction of magnetic field produced by it is also reversed.

A concealed current-carrying conductor can be located due to the magnetic effect of current by using a plotting compass. For example, if a plotting compass is moved on a wall, its needle will show deflection at the place where current-carrying wire is concealed.

Magnetic Field Patterns Produced by Current-Carrying Conductors Having Different Shapes

The pattern of magnetic field (or shape of magnetic field lines) produced by a current-carrying conductor depends on its shape. Different magnetic field patterns are produced by current-carrying conductors having different shapes. We will now study the magnetic field patterns produced by :

(*i*) a straight conductor (or straight wire) carrying current,
(*ii*) a circular loop (or circular wire) carrying current, and
(*iii*) a solenoid (long coil of wire) carrying current.

We will discuss all these cases, one by one. Let us start with the straight current-carrying conductor.

1. Magnetic Field Pattern due to Straight Current-Carrying Conductor (Straight Current-Carrying Wire)

The magnetic field lines around a straight conductor (straight wire) carrying current are concentric circles whose centres lie on the wire (Figure 11). In Figure 11, we have a straight vertical wire (or conductor) *AB* which passes through a horizontal cardboard sheet *C*. The ends of the wire *AB* are connected to a battery through a switch. When current is passed through wire *AB*, it produces a magnetic field around it. This magnetic field has magnetic field lines around the wire *AB* which can be shown by sprinkling iron filings on the cardboard *C*. The iron filings get magnetised. And on tapping the cardboard sheet, the iron filings arrange themselves in circles around the wire showing that **the magnetic field lines are circular in nature.** A small plotting compass *M* placed on the cardboard indicates the direction of the magnetic field. When current in the wire flows in the *upward* direction (as shown in Figure 11), then the lines of magnetic field are in the *anticlockwise* direction. If the direction of current in the wire is reversed, the direction of magnetic field lines also gets reversed.

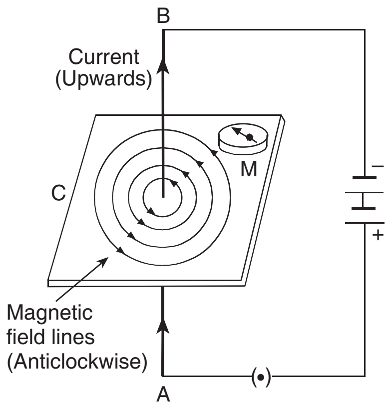


Figure 11. Magnetic field pattern due to a straight current-carrying wire.

It has been shown by experiments that **the magnitude of magnetic field produced by a straight current-carrying wire at a given point is : (*i*) directly proportional to the current passing in the wire, and (*ii*) inversely proportional to the distance of that point from the wire.** So, greater the current in the wire, stronger will be the magnetic field produced. And greater the distance of a point from the current-carrying wire, weaker will be the magnetic field produced at that point. In fact, as we move away from a current-carrying straight wire, the concentric circles around it representing magnetic field lines, become larger and larger indicating the decreasing strength of the magnetic field.

Direction of Magnetic Field Produced by Straight Current-Carrying Conductor (Straight Current-Carrying Wire)

If the direction of current is known, then the direction of magnetic field produced by a straight wire carrying current can be obtained by using Maxwell's right-hand thumb rule. According to Maxwell's right-hand thumb rule : **Imagine that you are grasping (or holding) the current-carrying wire in your right**

hand so that your thumb points in the direction of current, then the direction in which your fingers encircle the wire will give the direction of magnetic field lines around the wire. Figure 12 shows a straight current-carrying wire *AB* in which the current is flowing vertically upwards from *A* to *B*. To find out the direction of magnetic field lines produced by this current, we imagine the wire *AB* to be held in our right hand as shown in Figure 12 so that our thumb points in the direction of current towards *B*. Now, the direction in which our fingers are folded gives the direction of magnetic field lines. In this case our fingers are folded in the anticlockwise direction, so the direction of magnetic field (or magnetic field lines) is also in the anticlockwise direction (as shown by the circle drawn at the top of the wire).

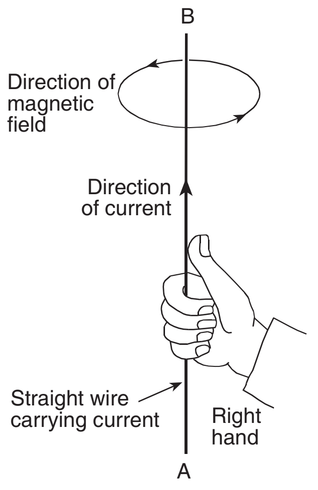


Figure 12. Right-hand thumb rule to find the direction of magnetic field.

Maxwell's right-hand thumb rule is also known as Maxwell's corkscrew rule (Corkscrew is a device for pulling corks from bottles, and consists of a spiral metal rod and a handle). According to Maxwell's corkscrew rule : *Imagine driving a corkscrew in the direction of current, then the direction in which we turn its handle is the direction of magnetic field (or magnetic field lines).* The corkscrew rule is illustrated in Figure 13. In Figure 13, the direction of current is vertically downwards. Now, if we imagine driving the corkscrew downwards in the direction of current, then the handle of corkscrew is to be turned in the clockwise direction. So, the direction of magnetic field (or magnetic field lines) will also be in the clockwise direction. This example is *opposite* to the one we considered in right-hand thumb rule given above. Thus, when electric current flows vertically *upwards* the direction of magnetic field produced is *anticlockwise.* On the other hand, when electric current flows vertically *downwards* then the direction of magnetic field is *clockwise.*

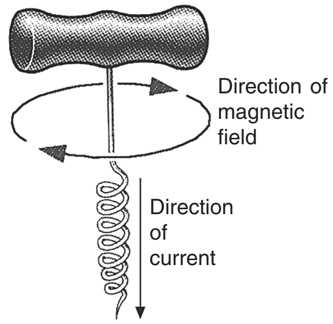


Figure 13. Maxwell's corkscrew rule to find the direction of magnetic field.

2. Magnetic Field Pattern due to a Circular Loop (or Circular Wire) Carrying Current

We know that when current is passed through a straight wire, a magnetic field is produced around it. It has been found that the magnetic effect of current increases if instead of using a straight wire, the wire is converted into a circular loop (as shown in Figure 14). In Figure 14, a circular loop (or circular wire) is fixed to a thin cardboard sheet *T*. When a current is passed through the circular loop of wire, a magnetic field is produced around it. The pattern of magnetic field due to a current-carrying circular loop (or circular wire) is shown in Figure 14. The magnetic field lines are *circular* near the current-carrying loop. As we move away, the concentric circles representing magnetic field lines become bigger and bigger. At the centre of the circular loop, the magnetic field lines are *straight* (see point *M* in Figure 14). By applying right-hand thumb rule, it can be seen that each segment of circular loop carrying current produces magnetic field lines in the same direction within the loop. At the centre of the circular loop, all the magnetic field lines are in the same direction and aid each other, due to which the strength of magnetic field increases.

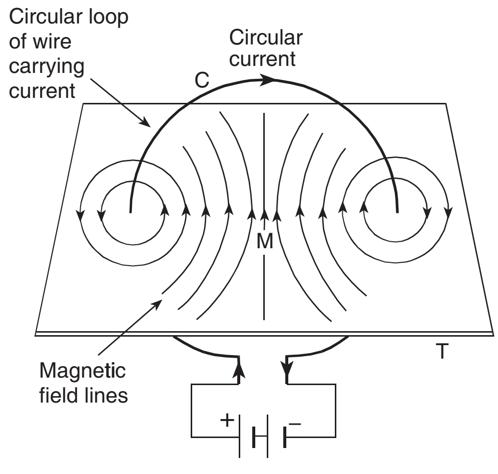


Figure 14. Magnetic field lines due to circular loop (or circular wire) carrying current.

The magnitude of magnetic field produced by a current-carrying circular loop (or circular wire) at its centre is :

(*i*) directly proportional to the current passing through the circular loop (or circular wire), and (*ii*) inversely proportional to the radius of circular loop (or circular wire).

In this discussion we have considered the magnetic field produced by a circular loop (or circular wire) which consists of only 'one turn' of the wire. The strength of magnetic field can be increased by taking a circular coil consisting of a number of turns of insulated copper wire closely wound together. Thus, if there is a circular coil having n turns, the magnetic field produced by this current-carrying circular coil will be n times as large as that produced by a circular loop of a single turn of wire. This is because the current in each circular turn of coil flows in the same direction and magnetic field produced by each turn of circular coil then just adds up. We can now say that : The strength of magnetic field produced by a circular coil carrying current is directly proportional to both, number of turns (n) and current (I); but inversely proportional to its radius (r). Thus, the strength of magnetic field produced by a current-carrying circular coil can be increased : (*i*) by increasing the number of turns of wire in the coil, (*ii*) by increasing the current flowing through the coil, and (*iii*) by decreasing the radius of the coil.

Clock Face Rule

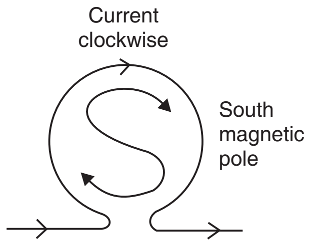
A current-carrying circular wire (or loop) behaves like a thin disc magnet whose one face is a north pole and the other face is a south pole. The polarity (north or south) of the two faces of a current-carrying circular coil (or loop) can be determined by using the clock face rule given below.

According to Clock face rule, look at one face of a circular wire (or coil) through which a current is passing :

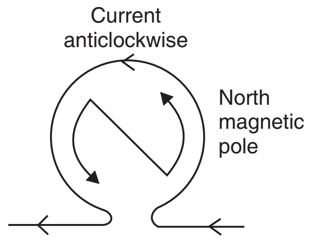
(*i*) if the current around the face of circular wire (or coil) flows in the *Clockwise direction*, then that face of the circular wire (or coil) will be *South pole* (S-pole).

(*ii*) if the current around the face of circular wire (or coil) flows in the *Anticlockwise direction*, then that face of circular wire (or coil) will be a *North pole* (N-pole)

For example, in Figure 15(*a*), the current in a face of the circular wire is flowing in the Clockwise direction, so this face of current-carrying circular wire will behave as a South magnetic pole (or S-pole). On the other hand, in Figure 15(*b*) the current in the face of the circular wire is flowing in the Anticlockwise direction, so this face of current-carrying circular wire will behave as a North magnetic pole (or N-pole).



(*a*) The direction of current in this face of circular wire is Clockwise, so this face of circular wire carrying current will act as a South magnetic pole (S-pole)



(*b*) The direction of current in this face of circular wire is Anticlockwise, so this face of circular wire carrying current will act as a North magnetic pole (or N-pole)

Figure 15.

Please note that **if the direction of current in the front face of a circular wire is clockwise, then the direction of current in the back face of this circular wire will be anticlockwise (and vice versa)**. This means that the front face of this current-carrying circular wire will be a south pole but its back face will be a north pole. For example, the direction of current in the front face of current-carrying circular wire shown in Figure 14 is clockwise, so the front face of this current-carrying circular wire will be a south magnetic pole (S-pole). If, however, we view the current-carrying circular wire given in Figure 14 from back side, we will find that the direction of current flowing in the back face of this circular wire is anticlockwise. Due to this, the back face of this current-carrying circular wire will be a North magnetic pole (N-pole). The Clock face rule is also used in determining the polarities of the two faces (or two ends) of a current-carrying solenoid as well as an electromagnet.

3. Magnetic Field due to a Solenoid

The solenoid is a long coil containing a large number of close turns of insulated copper wire. Figure 16 shows a solenoid *SN* whose two ends are connected to a battery *B* through a switch *X*. When an electric current is passed through the solenoid, it produces a magnetic field around it. The magnetic field produced by a current carrying solenoid is shown in Figure 16. **The magnetic field produced by a current-carrying solenoid is similar to the magnetic field produced by a bar magnet.** Please note that the lines of magnetic field pass through the solenoid and return to the other end as shown in Figure 16. The magnetic field lines inside the solenoid are in the form of *parallel straight lines.* This indicates that the strength of magnetic field is the *same* at all the points inside the solenoid. If the strength of magnetic field is just the same in a region, it is said to be *uniform* magnetic field. Thus, the magnetic field is *uniform* inside a current-carrying solenoid. The uniform magnetic field inside the current-carrying solenoid has been represented by drawing parallel straight field lines (see Figure 16). Even the earth's magnetic field at a given place is *uniform* which consists of parallel straight field lines (which run roughly from south geographical pole to north geographical pole).

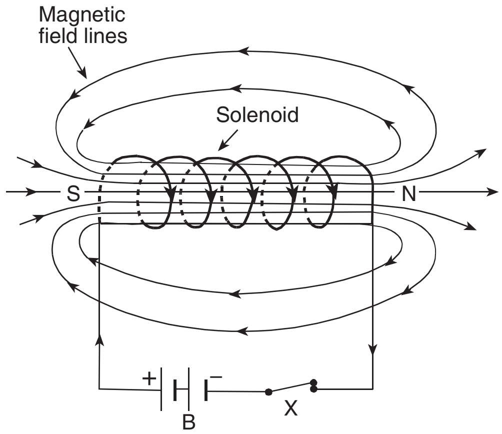


Figure 16. Magnetic field due to a current carrying solenoid is similar to that of a bar magnet.

One end of the current-carrying solenoid acts like a north-pole (N-pole) and the other end a south pole (S-pole). So, if a current-carrying solenoid is suspended freely, it will come to rest pointing in the north and south directions (just like a freely suspended bar magnet). We can determine the north and south poles of a current-carrying solenoid by using a bar magnet. This can be done as follows : We bring the north pole of a bar magnet near both the ends of a current-carrying solenoid. The end of solenoid which will be repelled by the north pole of bar magnet will be its north pole, and the end of solenoid which will be attracted by the north pole of bar magnet will be its south pole.

The current in each turn of a current-carrying solenoid flows in the same direction due to which the magnetic field produced by each turn of the solenoid adds up, giving a strong magnetic field inside the solenoid. The strong magnetic field produced inside a current-carrying solenoid can be used to magnetise a piece of magnetic material like soft iron, when placed inside the solenoid. The magnet thus formed is called an electromagnet. So, a solenoid is used for making electromagnets.

The strength of magnetic field produced by a current carrying solenoid depends on :

(*i*) **The number of turns in the solenoid.** Larger the number of turns in the solenoid, greater will be the magnetism produced.

(*ii*) **The strength of current in the solenoid.** Larger the current passed through solenoid, stronger will be the magnetic field produced.

(*iii*) **The nature of "core material" used in making solenoid.** The use of soft iron rod as core in a solenoid produces the strongest magnetism.

Electromagnet

An electric current can be used for making temporary magnets known as electromagnets. **An electromagnet works on the magnetic effect of current.** Let us discuss it in detail. We have just studied that when current is passed through a long coil called solenoid, a magnetic field is produced. It has been found that if a soft iron rod called core is placed inside a solenoid, then the strength of magnetic field becomes very large because the iron core gets magnetised by induction. This combination of a solenoid and a soft iron core is called an electromagnet. Thus, **An electromagnet is a magnet consisting of a long coil of insulated copper wire wrapped around a soft iron core that is magnetised only when electric current is passed through the coil.** A simple electromagnet is shown in Figure 17. To make an electromagnet all that we have to do is to take a rod *NS* of soft iron and wind a coil *C* of insulated copper wire round it. When the two ends of the copper coil are connected to a battery, an electromagnet is formed (see Figure 17).

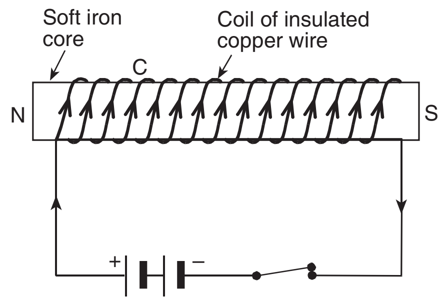


Figure 17. Electromagnet.

It should be noted that the solenoid containing soft iron core in it acts as a magnet only as long as the current is flowing in the solenoid. If we switch off the current in the solenoid, it no more behaves as a magnet. All the magnetism of the soft iron core disappears as soon as the current in the coil is switched off. A very important point to be noted is that it is the iron piece inside the coil which becomes a strong electromagnet on passing the current. **The core of an electromagnet must be of soft iron because soft iron loses all of its magnetism when current in the coil is switched off.** On the other hand, if steel is used for making the core of an electromagnet, the steel does not lose all its magnetism when the current is stopped and it becomes a permanent magnet. This is why **steel is not used for making electromagnets.** Electromagnets can be made in different shapes and sizes depending on the purpose for which they are to be used.

Factors Affecting the Strength of an Electromagnet. The strength of an electromagnet depends on :

(*i*) **The number of turns in the coil.** If we increase the number of turns in the coil, the strength of electromagnet increases.

(*ii*) **The current flowing in the coil.** If the current in the coil is increased, the strength of electromagnet increases.

(*iii*) **The length of air gap between its poles.** If we reduce the length of air gap between the poles of an electromagnet, then its strength increases. For example, the air gap between the poles of a straight, bar type electromagnet is quite large, so a bar type electromagnet is not very strong. On the other hand, the air gap between the poles of a U-shaped electromagnet is small, so it is a very strong electromagnet (see Figure 18).

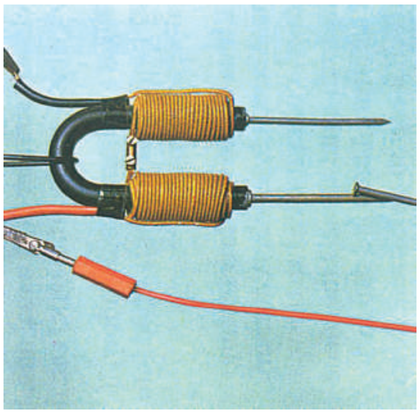


Figure 18. This is a U-shaped electromagnet with iron nails sticking to its two poles.

It should be noted that in many respects an electromagnet is better than a permanent magnet because it can produce very strong magnetic fields and its strength can be controlled by varying the number of turns in its coil or by changing the current flowing through the coil.

We can determine the polarity of electromagnet shown in Figure 17 by using the clock face rule. If we view the electromagnet from its left end, we will see that the direction of current flowing in the coil is anticlockwise. So, the left end of this electromagnet will be North pole (N-pole). And if we view the electromagnet given in Figure 17 from its right end, we will see that the direction of current in its coil is clockwise. So, the right side end of this electromagnet is a South pole (S-pole). Some uses of electromagnets are shown in Figures 19 and 20.

Figure 19. In hospitals, doctors use an electromagnet to remove particles of iron or steel from a patient's eye.

Figure 20. This is a Maglev train (Magnetic leviation train) which does not need wheels. It floats above its track by strong magnetic forces produced by computer-controlled electromagnets.

Differences Between a Bar Magnet (or Permanent Magnet) and an Electromagnet

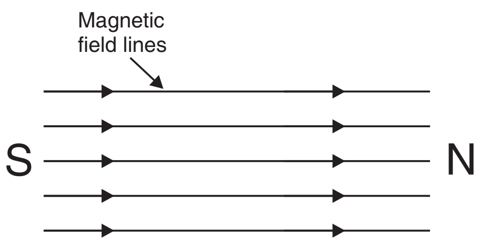
Bar magnet (or Permanent magnet)	*Electromagnet*
1. The bar magnet is a permanent magnet.	1. An electromagnet is a temporary magnet. Its magnetism is only for the duration of current passing through it. So, the magnetism of an electromagnet can be switched on or switched off as desired.
2. A permanent magnet produces a comparatively weak force of attraction.	2. An electromagnet can produce very strong magnetic force.
3. The strength of a permanent magnet cannot be changed.	3. The strength of an electromagnet can be changed by changing the number of turns in its coil or by changing the current passing through it.
4. The (north-south) polarity of a permanent magnet is fixed and cannot be changed.	4. The polarity of an electromagnet can be changed by changing the direction of current in its coil.

Permanent magnets are usually made of alloys such as : Carbon steel, Chromium steel, Cobalt steel, Tungsten steel, and Alnico (Alnico is an alloy of aluminium, nickel, cobalt and iron). Permanent magnets of these alloys are much more strong than those made of ordinary steel. Such strong permanent magnets are used in microphones, loudspeakers, electric clocks, ammeters, voltmeters, speedometers, and many other devices. Let us solve one problem now.

Sample Problem. The magnetic field in a given region is uniform. Draw a diagram to represent it.

(NCERT Book Question)

Answer. A uniform magnetic field in a region is represented by drawing equidistant, parallel straight lines, all pointing in the same direction. For example, the uniform magnetic field which exists inside a current-carrying solenoid can be represented by parallel straight lines pointing from its S-pole to N-pole (as shown in Figure alongside).



The uniform magnetic field inside a current-carrying solenoid.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Which effect of current can be utilised in detecting a current-carrying wire concealed in a wall ?
2. What conclusion do you get from the observation that a current-carrying wire deflects a compass needle placed near it ?

3. Name the scientist who discovered the magnetic effect of current.

4. State qualitatively the effect of inserting an iron core into a current-carrying solenoid.

5. Name the rule for finding the direction of magnetic field produced by a straight current-carrying conductor.

6. State the form of magnetic field lines around a straight current-carrying conductor.

7. What is the other name of Maxwell's right-hand thumb rule ?

8. State whether the following statement is true or false :
The magnetic field inside a long circular coil carrying current will be parallel straight lines.

9. What is the shape of a current-carrying conductor whose magnetic field pattern resembles that of a bar magnet ?

10. State three ways in which the strength of an electromagnet can be increased.

11. Fill in the following blanks with suitable words :

(*a*) The lines of.............round a straight current-carrying conductor are in the shape of............

(*b*) For a current-carrying solenoid, the magnetic field is like that of a..............

(*c*) The magnetic effect of a coil can be increased by increasing the number of............., increasing the ...., or inserting an.............core.

(*d*) If a coil is viewed from one end and the current flows in an anticlockwise direction, then this end is a.........pole.

(*e*) If a coil is viewed from one end, and the current flows in a clockwise direction, then this end is a ..... pole.

Short Answer Type Questions

12. Describe how you will locate a current-carrying wire concealed in a wall.

13. Describe some experiment to show that the magnetic field is associated with an electric current.

14. (*a*) Draw a sketch to show the magnetic lines of force due to a current-carrying straight conductor.

(*b*) Name and state the rule to determine the direction of magnetic field around a straight current-carrying conductor.

15. State and explain Maxwell's right-hand thumb rule.

16. What is Maxwell's corkscrew rule ? For what purpose is it used ?

17. (*a*) Draw the magnetic lines of force due to a circular wire carrying current.

(*b*) What are the various ways in which the strength of magnetic field produced by a current-carrying circular coil can be increased ?

18. State and explain the Clock face rule for determining the polarities of a circular wire carrying current.

19. Name any two factors on which the strength of magnetic field produced by a current-carrying solenoid depends. How does it depend on these factors ?

20. (*a*) Draw a circuit diagram to show how a soft iron piece can be transformed into an electromagnet.

(*b*) Describe how an electromagnet could be used to separate copper from iron in a scrap yard.

21. (*a*) How does an electromagnet differ from a permanent magnet ?

(*b*) Name two devices in which electromagnets are used and two devices where permanent magnets are used.

Long Answer Type Questions

22. (*a*) What is a solenoid ? Draw a sketch to show the magnetic field pattern produced by a current-carrying solenoid.

(*b*) Name the type of magnet with which the magnetic field pattern of a current-carrying solenoid resembles.

(*c*) What is the shape of field lines inside a current-carrying solenoid ? What does the pattern of field lines inside a current-carrying solenoid indicate ?

(*d*) List three ways in which the magnetic field strength of a current-carrying solenoid can be increased ?

(*e*) What type of core should be put inside a current-carrying solenoid to make an electromagnet ?

23. (*a*) What is an electromagnet ? Describe the construction and working of an electromagnet with the help of a labelled diagram.

(*b*) Explain why, an electromagnet is called a temporary magnet.

(*c*) Explain why, the core of an electromagnet should be of soft iron and not of steel.

(*d*) State the factors on which the strength of an electromagnet depends. How does it depend on these factors ?

(*e*) Write some of the important uses of electromagnets.

Multiple Choice Questions (MCQs)

24. The strength of the magnetic field between the poles of an electromagnet would be unchanged if :

(*a*) current in the electromagnet winding were doubled

(*b*) direction of current in electromagnet winding were reversed

(*c*) distance between the poles of electromagnet were doubled

(*d*) material of the core of electromagnet were changed

25. The diagram given below represents magnetic field caused by a current-carrying conductor which is :

(*a*) a long straight wire (*b*) a circular coil

(*c*) a solenoid (*d*) a short straight wire

26. The magnetic field inside a long straight solenoid carrying current :

(*a*) is zero

(*b*) decreases as we move towards its end.

(*c*) increases as we move towards its end.

(*d*) is the same at all points.

27. Which of the following correctly describes the magnetic field near a long straight wire ?

(*a*) The field consists of straight lines perpendicular to the wire.

(*b*) The field consists of straight lines parallel to the wire.

(*c*) The field consists of radial lines originating from the wire.

(*d*) The field consists of concentric circles centred on the wire.

28. The north-south polarities of an electromagnet can be found easily by using :

(*a*) Fleming's right-hand rule (*b*) Fleming's left-hand rule

(*c*) Clock face rule (*d*) Left-hand thumb rule

29. The direction of current in the coil at one end of an electromagnet is clockwise. This end of the electromagnet will be :

(*a*) north pole (*b*) east pole (*c*) south pole (*d*) west pole

30. If the direction of electric current in a solenoid when viewed from a particular end is anticlockwise, then this end of solenoid will be :

(*a*) west pole (*b*) south pole (*c*) north pole (*d*) east pole

31. The most suitable material for making the core of an electromagnet is :

(*a*) soft iron (*b*) brass (*c*) aluminium (*d*) steel

32. The magnetic effect of current was discovered by :

(*a*) Maxwell (*b*) Fleming (*c*) Oersted (*d*) Faraday

33. A soft iron bar is inserted inside a current-carrying solenoid. The magnetic field inside the solenoid :

(*a*) will decrease (*b*) will increase

(*c*) will become zero (*d*) will remain the same

34. The magnetic field lines in the middle of the current-carrying solenoid are :

(*a*) circles (*b*) spirals

(*c*) parallel to the axis of the tube (*d*) perpendicular to the axis of the tube

35. The front face of a circular wire carrying current behaves like a north pole. The direction of current in this face of the circular wire is :

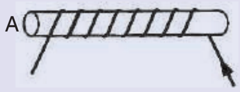
(*a*) clockwise (*b*) downwards (*c*) anticlockwise (*d*) upwards

36. The back face of a circular loop of wire is found to be south magnetic pole. The direction of current in this face of the circular loop of wire will be :
(*a*) towards south (*b*) clockwise (*c*) anticlockwise (*d*) towards north

Questions Based on High Order Thinking Skills (HOTS)

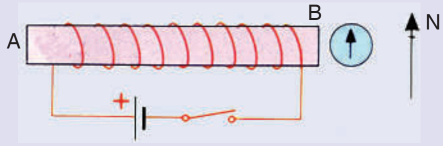
37. In the straight wire *A*, current is flowing in the vertically downward direction whereas in wire *B* the current is flowing in the vertically upward direction. What is the direction of magnetic field :
(*a*) in wire *A* ?
(*b*) in wire *B* ?
Name the rule which you have used to get the answer.

38. The figure shows a solenoid wound on a core of soft iron. Will the end A be a N pole or S pole when the current flows in the direction shown ?



39. A current-carrying straight wire is held in exactly vertical position. If the current passes through this wire in the vertically upward direction, what is the direction of magnetic field produced by it ? Name the rule used to find out the direction of magnetic field.

40. For the coil in the diagram below, when the switch is pressed :
(*a*) what is the polarity of end A ?
(*b*) which way will the compass point then ?



41. A current flows downwards in a wire that passes vertically through a table top. Will the magnetic field lines around it go clockwise or anticlockwise when viewed from above the table ?

42. The directions of current flowing in the coil of an electromagnet at its two ends X and Y are as shown below :

(*a*) What is the polarity of end X ?
(*b*) What is the polarity of end Y ?
(*c*) Name and state the rule which you have used to determine the polarities.

43. The magnetic field associated with a current-carrying straight conductor is in anticlockwise direction. If the conductor was held along the east-west direction, what will be the direction of current through it ? Name and state the rule applied to determine the direction of current ?

44. A current-carrying conductor is held in exactly vertical direction. In order to produce a clockwise magnetic field around the conductor, the current should be passed in the conductor :
(*a*) from top towards bottom (*b*) from left towards right
(*c*) from bottom towards top (*d*) from right towards left

45. A thick wire is hanging from a wooden table. An anticlockwise magnetic field is to be produced around the wire by passing current through this wire by using a battery. Which terminal of the battery should be connected to the :
(*a*) top end of wire ?
(*b*) bottom end of wire ?
Give reason for your choice.

ANSWERS

1. Magnetic effect **4.** Magnetic field becomes very strong **8.** True **9.** Solenoid
11. (*a*) magnetic field ; concentric circles (*b*) bar magnet (*c*) turns ; current ; iron (*d*) north (*e*) south
21. (*b*) Electromagnets : Electric bell, Electric motors ; Permanent magnets : Refrigerator doors ; Toys

22. (*b*) Bar magnet **24.** (*b*) **25.** (*b*) **26.** (*d*) **27.** (*d*) **28.** (*c*) **29.** (*c*) **30.** (*c*) **31.** (*a*) **32.** (*c*) **33.** (*b*) **34.** (*c*) **35.** (*c*) **36.** (*b*) **37.** (*a*) Clockwise (*b*) Anticlockwise **38.** S-pole **39.** Anti-clockwise ; Right-hand thumb rule **40.** (*a*) S-pole (*b*) Away from the end B (Because end B is a N-pole) **41.** Clockwise **42.** (*a*) S-pole (*b*) N-pole (*c*) Clock-face rule **43.** East to West **44.** (*a*) **45.** (*a*) Negative terminal (*b*) Positive terminal ; The current should be passed into wire upwards

MAGNETISM IN HUMAN BEINGS

Extremely weak electric currents are produced in the human body by the movement of charged particles called ions. These are called ionic currents. Now, we have studied that whenever there is an electric current, a magnetic field is produced. So, when the weak ionic currents flow along the nerve cells, they produce magnetic field in our body. For example, when we try to touch something with our hand, our nerves carry electric impulse to the appropriate muscles. And this electric impulse creates a temporary magnetism in the body. The magnetism produced in the human body is very, very weak as compared to the earth's magnetism. **The two main organs of the human body where the magnetic field produced is quite significant are the heart and the brain.**

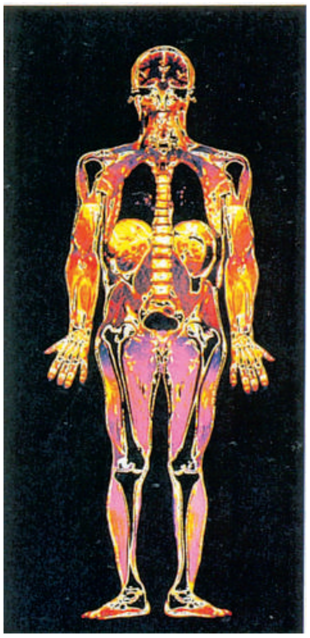


Figure 21. This picture showing the insides of the body was produced by using Magnetic Resonance Imaging (MRI).

The magnetism produced inside the human body (by the flow of ionic currents) forms the basis of a technique called Magnetic Resonance Imaging (MRI) which is used to obtain images (or pictures) of the internal parts of our body (see Figure 21). It is obvious that magnetism has an important use in medical diagnosis because, through MRI scans, it enables the doctors to see inside the body. For example, MRI can detect cancerous tissue inside the body of a person. Please note that the magnetism in human body is actually electromagnetism (which is produced by the flow of ionic currents inside the human body). Before we go further, and describe the force acting on a current-carrying conductor placed in a magnetic field, **please answer the following questions :**

Very Short Answer Type Questions

1. What produces magnetism in the human body ?
2. Name one medical technique which is based on magnetism produced in human body. For what purpose is this technique used ?
3. Name two human body organs where magnetism produced is significant.
4. What is the full form of MRI ?
5. Name the technique by which doctors can produce pictures showing insides of the human body.
6. Name one technique which can detect cancerous tissue inside the body of a person.

FORCE ON CURRENT-CARRYING CONDUCTOR PLACED IN A MAGNETIC FIELD

Figure 22. In this photograph we can see a piece of aluminium foil that has been fixed between the poles of a strong magnet. When a current is passed through the foil, it is pushed upwards, away from the magnet. It happens due to repulsion between the two magnetic fields : one from the magnet and one from current.

We have already described Oersted's experiment which shows that a current-carrying wire exerts a force on a compass needle and deflects it from its usual north-south position. Since a compass needle is actually a small freely pivoted magnet, we can also say that a current-carrying wire exerts a mechanical force on a magnet, and if the magnet is free to move, this force can produce a motion in the magnet. The reverse of this is also true, that is, **a magnet exerts a mechanical force on a current-carrying wire, and if the wire is free to move, this force can produce a motion in the wire** (see Figure 22). In fact, this result can be obtained by applying

Newton's third law of motion according to which if a current-carrying wire exerts a force on a magnet, then the magnet will exert an *equal* and *opposite* force on the current carrying wire. In 1821, Faraday discovered that : **When a current-carrying conductor is placed in a magnetic field, a mechanical force is exerted on the conductor which can make the conductor move.** This is known as the motor principle and forms the basis of a large number of electrical devices like electric motor and moving coil galvanometer. We will now describe an experiment to demonstrate the force exerted by a magnet on a current-carrying wire and to show how the direction of force is related to the direction of current and the direction of magnetic field.

Experiment to Demonstrate the Force Acting on a Current-Carrying Conductor Placed in a Magnetic Field : The Kicking Wire Experiment

A thick copper wire *AB* is suspended vertically from a support *T* by means of a flexible joint *J* (Figure 23). The lower end *B* of this wire is free to move between the poles of a U-shaped magnet *M*. The lower end *B* of the wire just touches the surface of mercury kept in a shallow vessel *V* so that it can move when a force acts on it. The positive terminal of a battery is connected to end *A* of the wire. The circuit is completed by dipping another wire from the negative terminal of the battery into the mercury pool as shown in Figure 23. We know that mercury is a liquid which is a good conductor of electricity, so the circuit is completed through mercury contained in the vessel *V*.

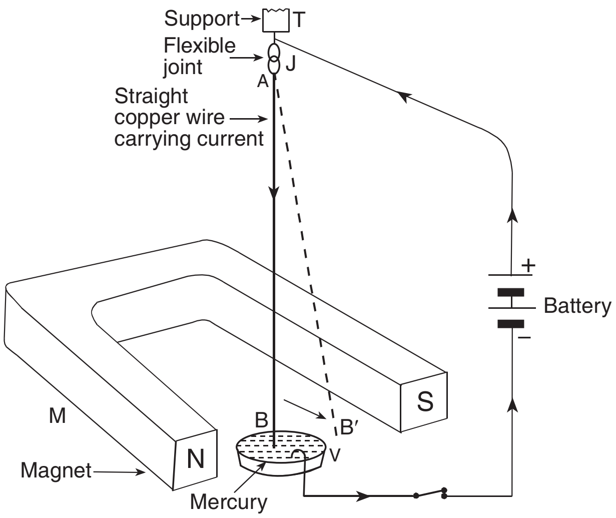


Figure 23. Experiment to demonstrate the force acting on a current-carrying wire (or conductor) *AB*, when placed in a magnetic field.

On pressing the switch, a current flows in the wire *AB* in the vertically downward direction. The wire *AB* is kicked in the forward direction (towards south) and its lower end *B* reaches the position *B′*, so that the wire comes to the new position *AB′* as shown by dotted line in Figure 23. When the lower end *B* of the hanging wire comes forward to *B′*, its contact with the mercury surface is broken due to which the circuit breaks and current stops flowing in the wire *AB*. Since no current flows in the wire, no force acts on the wire in this position and it falls back to its original position. As soon as the wire falls back, its lower end again touches the mercury surface, current starts flowing in the wire and it is kicked again. This action is repeated as long as the current is passed in wire *AB*. It should be noted that the current-carrying wire is kicked forward because a force is exerted on it by the magnetic field of the U-shaped magnet. From this experiment we conclude that **when a current-carrying conductor is placed in a magnetic field, a mechanical force is exerted on the conductor which makes it move.**

In Figure 23, the current is flowing in the vertically downward direction and the direction of magnetic field is from left to right directed towards east, thus, the current carrying conductor is at right angles to the magnetic field. Now, we have just seen that the motion of the conductor is in the forward direction (towards south) which is at right angles to both, the direction of current and the direction of magnetic field. Since the direction of motion of the wire represents the direction of force acting on it, we can say that : **The direction of force acting on a current-carrying wire placed in a magnetic field is (*i*) perpendicular to the direction of current, and (*ii*) perpendicular to the direction of magnetic field.** In other words, we can say that the current, the magnetic field and the force, are at right angles to one another. It should be noted that **the maximum force is exerted on a current-carrying conductor only when it is *perpendicular* to the direction of magnetic field. No force acts on a current-carrying conductor when it is *parallel* to the magnetic field.**

If we reverse the direction of current in the wire *AB* so that it flows in the vertically upward direction from *B* to *A*, then the wire swings in the backward direction (towards north). This means that the direction of force on the current-carrying wire has been reversed. From this we conclude that **the direction of force on a current-carrying conductor placed in a magnetic field can be reversed by reversing the direction of current flowing in the conductor.** Keeping the direction of current unchanged, if we reverse the direction of magnetic field applied in Figure 23 by turning the magnet *M* so that its poles are reversed, even then the wire swings backwards showing that the direction of force acting on it has been reversed. Thus, **the direction of force on a current-carrying conductor placed in a magnetic field can also be reversed by reversing the direction of magnetic field.**

If the direction of *current* in a conductor and the direction of *magnetic* field (in which it is placed), are known, then the direction of *force* acting on the current-carrying conductor can be found out by using Fleming's left-hand rule. This is described below.

Fleming's Left-Hand Rule for the Direction of Force

When a current carrying wire is placed in a magnetic field, a force is exerted on the wire. Fleming gave a simple rule to determine the direction of force acting on a current carrying wire placed in a magnetic field. This rule is known as Fleming's left-hand rule and it can be stated as follows. According to Fleming's left-hand rule : **Hold the forefinger, the centre finger and the thumb of your left hand at right angles to one another [as shown in Figure 24(*a*)]. Adjust your hand in such a way that the forefinger points in the direction of magnetic field and the centre finger points in the direction of current, then the direction in which thumb points, gives the direction of force acting on the conductor.** Since the conductor (say, a wire) moves along the direction in which the force acts on it, we can also say that the direction in which

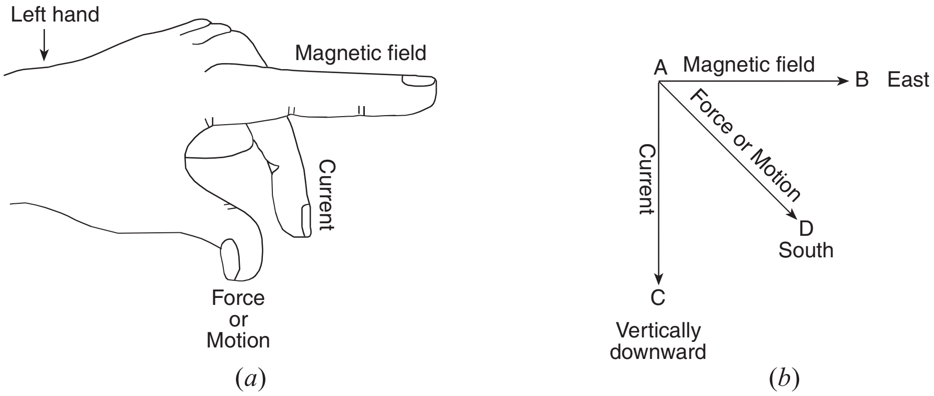


Figure 24. Diagrams to illustrate Fleming's left-hand rule.

the thumb points gives the direction of motion of the conductor. Thus, we can write Fleming's left-hand rule in another way as follows : *Hold the forefinger, the centre finger and the thumb of your left hand at right angles to one another. Adjust your hand in such a way that the forefinger points in the direction of magnetic field and the centre finger points in the direction of current in the conductor, then the direction in which the thumb points gives the direction of motion of the conductor.* To memorize Fleming's left-hand rule we should remember that the forefinger represents the (magnetic) field (both, forefinger and field, start with the same letter *f*), the centre finger represents current (both, centre and current start with letter *c*), and the thumb represents force or motion (both, thumb and motion contain the letter *m*). We will make the Fleming's left hand rule more clear by taking an example.

Suppose we have a vertical current-carrying wire or conductor placed in a magnetic field. Let the direction of magnetic field be from west to east as shown by arrow *AB* in Figure 24(*b*). Again suppose that the direction of current in the wire is vertically downwards as shown by arrow *AC*. Now, we want to find out the direction of force which will be exerted on this current-carrying wire. We will find out this direction by using Fleming's left-hand rule as follows : We stretch our left hand as shown in Figure 24(*a*) so that the forefinger, the centre finger and the thumb are perpendicular to one another. Since the direction of magnetic field is from west to east, so we point our forefinger from west to east direction to represent the magnetic field [Figure 24(*a*)]. Now, the current is flowing vertically downwards, so we point our centre finger vertically downwards to represent the direction of current. Now, let us look at the direction of our thumb. The thumb points in the forward direction towards south. This gives us the direction of force acting on the wire (or direction of motion of wire). So, the force acting on the current carrying wire will be in the south direction as shown by the arrow *AD* in Figure 24(*b*), and the wire will move in the south direction.

The devices which use current-carrying conductors and magnetic fields include electric motor, electric generator, microphone, loudspeakers, and current detecting and measuring instruments (such as ammeter and galvanometer, etc.)

Before we solve problems involving direction of current, direction of magnetic field and the direction of force by using Fleming's left-hand rule, we should keep the following points in mind :

(*i*) By convention, the direction of flow of positive charges is taken to be the direction of flow of current. So, the direction in which the positively charged particles such as protons or alpha particles, etc., move will be the direction of electric current.

(*ii*) The direction of electric current is, however, taken to be *opposite* to the direction of flow of negative charges (such as electrons). So, if we are given the direction of flow of electrons, then the direction of electric current will be taken as opposite to the direction of flow of electrons.

(*iii*) The direction of deflection of a current-carrying conductor (or a stream of positively charged particles or a stream of negatively charged particles like electrons) tells us the direction of force acting on it.

Let us solve some problems now.

Sample Problem 1. A stream of positively charged particles (alpha particles) moving towards west is deflected towards north by a magnetic field. The direction of magnetic field is :

(*a*) towards south (*b*) towards east

(*c*) downward (*d*) upward **(NCERT Book Question)**

Solution. Here the positively charged alpha particles are moving towards *west,* so the direction of current is towards *west.* The deflection is towards *north*, so the force is towards *north*. So, we are given that :

(*i*) direction of current is towards west, and

(*ii*) direction of force is towards north.

Let us now hold the forefinger, centre finger and thumb of our left-hand at right angles to one another. Adjust the hand in such a way that our centre finger points towards west (in the direction of current) and thumb points towards north (in the direction of force). Now, if we look at our forefinger, it will be pointing upward. Since the direction of forefinger gives the direction of magnetic field, therefore, the magnetic field is in the upward direction. So, the correct answer is : (*d*) upward.

Sample Problem 2. Think you are sitting in a chamber with your back to one wall. An electron beam moving horizontally from back wall towards the front wall is deflected by a strong magnetic field to your right side. What is the direction of magnetic field ? **(NCERT Book Question)**

Solution. Here the electron beam is moving from our back wall to the front wall, so the direction of current will be in the opposite direction, from front wall towards back wall or towards us. The direction of deflection (or force) is towards our right side. We now know two things :

(*i*) direction of current is from front towards us, and

(*ii*) direction of force is towards our right side.

Let us now hold the forefinger, centre finger and thumb of our left hand at right angles to one another. We now adjust the hand in such a way that our centre finger points towards us (in the direction of current) and thumb points towards right side (in the direction of force). Now, if we look at our forefinger, it will be pointing vertically downwards. Since the direction of forefinger gives the direction of magnetic field, therefore, the magnetic field is in the vertically *downward* direction.

THE ELECTRIC MOTOR

A motor is a device which converts electrical energy into mechanical energy. Every motor has a shaft or spindle which rotates continuously when current is passed into it. The rotation of its shaft is used to

(*a*) This is an electric motor

(*b*) Washing machine uses an electric motor for its working

(*c*) Mixer and grinder has an electric motor in it

(*d*) Each wheel of this electric car is turned by an electric motor

Figure 25. Electric motor and some of its uses.

drive the various types of machines in homes and industry. Electric motor is used in electric fans, washing machines, refrigerators, mixer and grinder, electric cars and many, many other appliances (see Figure 25). A common electric motor works on direct current. So, it is also called D.C. motor, which means a "Direct Current motor". The electric motor which we are going to discuss now is actually a D.C. motor.

Principle of a Motor

An electric motor utilises the magnetic effect of current. **A motor works on the principle that when a rectangular coil is placed in a magnetic field and current is passed through it, a force acts on the coil which rotates it continuously.** When the coil rotates, the shaft attached to it also rotates. In this way the electrical energy supplied to the motor is converted into the mechanical energy of rotation.

Construction of a Motor

An electric motor consists of a rectangular coil *ABCD* of insulated copper wire, which is mounted between the curved poles of a horseshoe-type permanent magnet *M* in such a way that it can rotate freely between the poles N and S on a shaft (The shaft is a long cylindrical rotating rod at the centre of the coil which has not been shown in Figure 26 to keep the diagram simple). The sides *AB* and *CD* of the coil are kept perpendicular to the direction of magnetic field between the poles of the magnet. This is done so that the maximum magnetic force is exerted on the current-carrying sides *AB* and *CD* of the coil. **A device which reverses the direction of current through a circuit is called a commutator (or split ring)**. The two ends of the coil are soldered (or welded) permanently to the two half rings *X* and *Y* of a commutator. A commutator is a copper ring split into two parts *X* and *Y*, these two parts are insulated from one another and mounted on the shaft of the motor. End *A* of the coil is welded to part *X* of the commutator and end *D* of the coil is welded to part *Y* of the commutator. The commutator rings are mounted on the shaft of the coil and they also rotate when the coil rotates. As we will see later on, **the function of commutator rings is to reverse the direction of current flowing through the coil every time the coil just passes the vertical position during a revolution.** In other words, commutator rings reverse the direction of current flowing through the coil after every half rotation of the coil.

We cannot join the battery wires directly to the two commutator half rings to pass current into the coil because if we do so, then the connecting wires will get twisted when the coil rotates. So, to pass in electric current to the coil, we use two carbon strips *P* and *Q* known as brushes. The carbon brushes *P* and *Q* are fixed to the base of the motor and they press lightly against the two half rings of the commutator. The battery to supply current to the coil is connected to the two carbon brushes *P* and *Q* through a switch.

The function of carbon brushes is to make contact with the rotating rings of the commutator and through them to supply current to the coil. It should be noted that any one brush touches only one ring at a time, so that when the coil rotates, the two brushes will touch both the rings one by one.

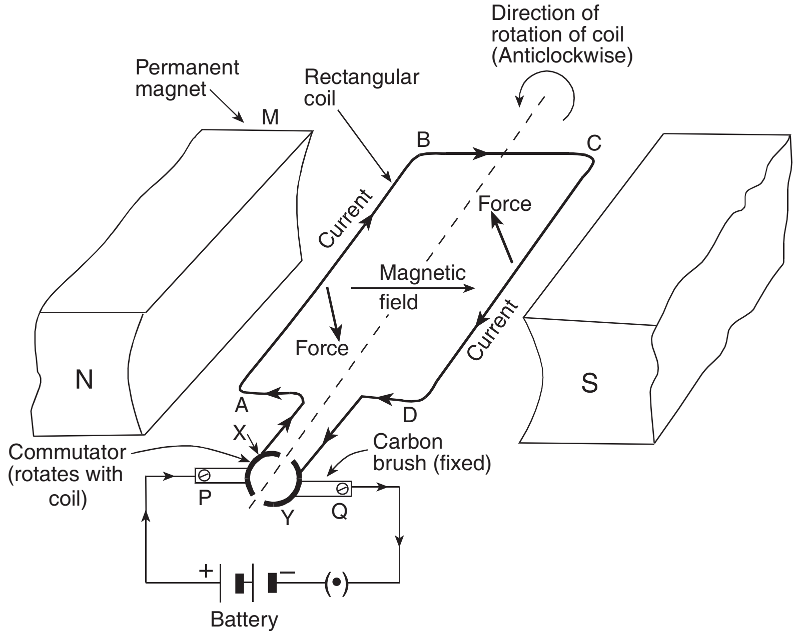


Figure 26. An electric motor.

Working of a Motor

When an electric current is passed into the rectangular coil, this current produces a magnetic field around the coil. The magnetic field of the horseshoe-type magnet then interacts with the magnetic field of the current-carrying coil and causes the coil to rotate (or spin) continuously. The working of a motor will become more clear from the following discussion.

Suppose that initially the coil *ABCD* is in the horizontal position as shown in Figure 26. On pressing the switch, current from battery enters the coil through carbon brush *P* and commutator half ring *X*. The current flows in the direction *ABCD* and leaves via ring *Y* and brush *Q*.

(*i*) In the side *AB* of the rectangular coil *ABCD*, the direction of current is from *A* to *B* (see Figure 26). And in the side *CD* of the coil, the direction of current is from *C* to *D* (which is opposite to the direction of current in side *AB*). The direction of magnetic field is from N pole of the magnet to its S pole. By applying Fleming's left-hand rule to sides *AB* and *CD* of the coil we find that the force on side *AB* of the coil is in the downward direction whereas the force on side *CD* of the coil is in the upward direction. Due to this the side *AB* of the coil is pushed down and side *CD* of the coil is pushed up. This makes the coil *ABCD* rotate in the anticlockwise direction (see Figure 26).

(*ii*) While rotating, when the coil reaches vertical position, then the brushes *P* and *Q* will touch the gap between the two commutator rings and current to the coil is cut off. Though the current to the coil is cut off when it is in the exact vertical position, the coil does not stop rotating because it has already gained momentum due to which it goes beyond the vertical position.

(*iii*) After half rotation, when the coil goes beyond vertical position, the side *CD* of the coil comes on the left side whereas side *AB* of the coil comes to the right side, and the two commutator half rings automatically change contact from one brush to the other. So, after half rotation of the coil, the commutator half ring *Y* makes contact with brush *P* whereas the commutator half ring *X* makes contact with brush *Q* (see Figure 26). This reverses the direction of current in the coil. The reversal of direction of current reverses the direction of forces acting on the sides *AB* and *CD* of the coil. The side *CD* of the coil is now on the left side with a downward force on it whereas the side *AB* is now on the right side with an upward force on it. Due to this the side *CD* of the coil is pushed down and the side *AB* of coil is pushed up. This makes the coil rotate anticlockwise by another half rotation.

(*iv*) The reversing of current in the coil is repeated after every half rotation due to which the coil (and its shaft) continue to rotate as long as current from the battery is passed through it. The rotating shaft of electric motor can drive a large number of machines which are connected to it.

It should be noted that the current flowing in the other two sides, *AD* and *BC* of the rectangular coil is parallel to the direction of magnetic field, so no force acts on the sides *AD* and *BC* of the coil.

We have just described the construction and working of a simple electric motor. **In commercial motors :**

(*a*) the coil is wound on a soft iron core. The soft iron core becomes magnetised and increases the strength of magnetic field. This makes the motor more powerful. The assembly of soft iron core and coil is called an armature.

(*b*) the coil contains a large number of turns of the insulated copper wire.

(*c*) a powerful electromagnet is used in place of permanent magnet.

All these features together help in increasing the power of commercial electric motors.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. What happens when a current-carrying conductor is placed in a magnetic field ?

2. When is the force experienced by a current-carrying conductor placed in a magnetic field largest ?

3. In a statement of Fleming's left-hand rule, what do the following represent ?

(*a*) direction of centre finger.

(*b*) direction of forefinger.

(*c*) direction of thumb.

4. Name one device which works on the magnetic effect of current.

5. Name the device which converts electrical energy into mechanical energy.

6. A motor converts one form of energy into another. Name the two forms.

7. State whether the following statement is true or false :

An electric motor converts mechanical energy into electrical energy.

8. For Fleming's left-hand rule, write down the three things that are 90° to each other, and next to each one write down the finger or thumb that represents it.

9. Name the device which is used to reverse the direction of current in the coil of a motor.

10. What is the other name of the split ring used in an electric motor ?

11. What is the function of a commutator in an electric motor ?

12. Of what substance are the brushes of an electric motor made ?

13. Of what substance is the core of the coil of an electric motor made ?

14. In an electric motor, which of the following remains fixed and which rotates with the coil ?

Commutator ; Brush

15. What is the role of the split ring in an electric motor ?

16. Fill in the following blanks with suitable words :

(*a*) Fleming's Rule for the motor effect uses the............... hand.

(*b*) A motor contains a kind of switch called a .... which reverses the current every half............ .

Short Answer Type Questions

17. (*a*) A current-carrying conductor is placed perpendicularly in a magnetic field. Name the rule which can be used to find the direction of force acting on the conductor.

(*b*) State two ways to increase the force on a current-carrying conductor in a magnetic field.

(*c*) Name one device whose working depends on the force exerted on a current-carrying coil placed in a magnetic field.

18. State Fleming's left-hand rule. Explain it with the help of labelled diagrams.

19. What is the principle of an electric motor ? Name some of the devices in which electric motors are used.

20. (*a*) In a d.c. motor, why must the current to the coil be reversed twice during each rotation ?
(*b*) What device reverses the current ?

21. (*a*) State what would happen to the direction of rotation of a motor if :
(*i*) the current were reversed
(*ii*) the magnetic field were reversed
(*iii*) both current and magnetic field were reversed simultaneously.
(*b*) In what ways can a motor be made more powerful ?

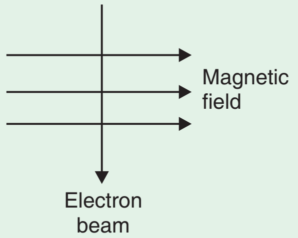
Long Answer Type Question

22. (*a*) What is an electric motor ? With the help of a labelled diagram, describe the working of a simple electric motor.
(*b*) What are the special features of commercial electric motors ?

Multiple Choice Questions (MCQs)

23. In an electric motor, the direction of current in the coil changes once in each :
(*a*) two rotations (*b*) one rotation (*c*) half rotation (*d*) one-fourth rotation

24. An electron beam enters a magnetic field at right angles to it as shown in the Figure.

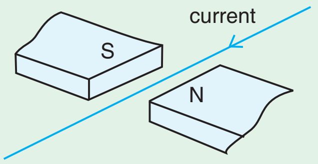


The direction of force acting on the electron beam will be :
(*a*) to the left (*b*) to the right (*c*) into the page (*d*) out of the page

25. The force experienced by a current-carrying conductor placed in a magnetic field is the largest when the angle between the conductor and the magnetic field is :
(*a*) 45° (*b*) 60° (*c*) 90° (*d*) 180°

26. The force exerted on a current-carrying wire placed in a magnetic field is zero when the angle between the wire and the direction of magnetic field is :
(*a*) 45° (*b*) 60° (*c*) 90° (*d*) 180°

27. A current flows in a wire running between the S and N poles of a magnet lying horizontally as shown in Figure below :

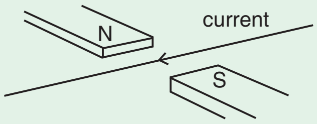


The force on the wire due to the magnet is directed :
(*a*) from N to S (*b*) from S to N (*c*) vertically downwards (*d*) vertically upwards

28. An electric motor is a device which transforms :
(*a*) mechanical energy to electrical energy
(*b*) heat energy to electrical energy
(*c*) electrical energy to heat energy only
(*d*) electrical energy to mechanical energy

29. A magnetic field exerts no force on :
(*a*) an electric charge moving perpendicular to its direction (*b*) an unmagnetised iron bar
(*c*) a stationary electric charge (*d*) a magnet

30. A horizontal wire carries a current as shown in Figure below between magnetic poles N and S :



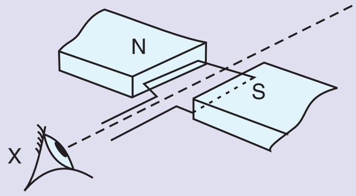
Is the direction of the force on the wire due to the magnet :

(*a*) in the direction of the current (*b*) vertically downwards

(*c*) opposite to the current direction (*d*) vertically upwards

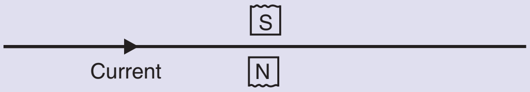
Questions Based on High Order Thinking Skills (HOTS)

31. In the simple electric motor of figure given below, the coil rotates anticlockwise as seen by the eye from the position X when current flows in the coil.



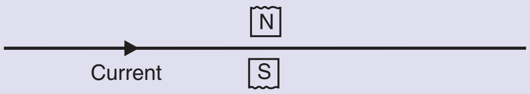
Is the current flowing clockwise or anticlockwise around the coil when viewed from above ?

32. Which way does the wire in the diagram below tend to move ?



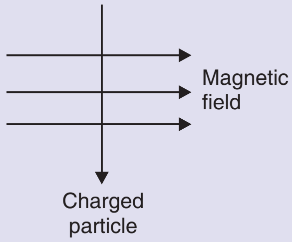
33. If the current in a wire is flowing in the vertically downward direction and a magnetic field is applied from west to east, what is the direction of force on the wire ?

34. Which way does the wire in the diagram below tend to move ?



35. What is the force on a current-carrying wire that is parallel to a magnetic field ? Give reason for your answer.

36. A charged particle enters at right angles into a uniform magnetic field as shown :



What should be the nature of charge on the particle if it begins to move in a direction pointing vertically out of the page due to its interaction with the magnetic field ?

ANSWERS

2. When the current-carrying conductor is at right angles to the magnetic field **6.** Electrical energy to Mechanical energy **7.** False **14.** Remains fixed : Brush ; Rotates with the coil : Commutator **16.** (*a*) left (*b*) commutator; rotation; **17.** (c) Electric motor **21.** (*a*) (*i*) Direction of rotation would be reversed (*ii*) Direction of rotation would be reversed (*iii*) Direction of rotation would remain unchanged **23.** (*c*) **24.** (*c*) **25.** (*c*) **26.** (*d*) **27.** (*c*) **28.** (*d*) **29.** (*c*) **30.** (*d*) **31.** Clockwise **32.** Upward (out of the page) **33.** South **34.** Downward (into the page) **35.** Nil **36.** Positive charge

ELECTROMAGNETIC INDUCTION : ELECTRICITY FROM MAGNETISM

We have already studied that an electric current can produce magnetism. The reverse of this is also true. That is, magnetism (or magnets) can produce electric current. **The production of electricity from magnetism is called electromagnetic induction.** For example, when a straight wire is moved up and down rapidly between the two poles of a horseshoe magnet, then an electric current is produced in the wire. This is an example of electromagnetic induction. Again, if a bar magnet is moved in and out of a coil of wire, even then an electric current is produced in the coil. This is also an example of electromagnetic induction.

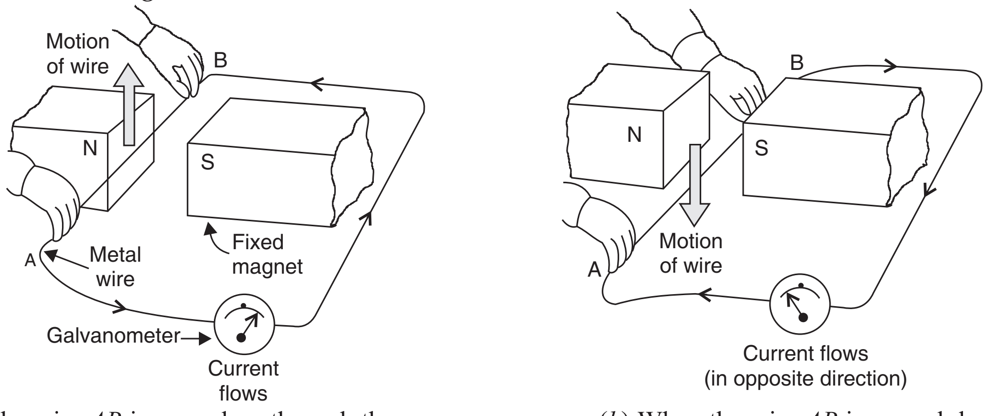
The current produced by moving a straight wire in a magnetic field (or by moving a magnet in a coil) is called *induced current.* The phenomenon of electromagnetic induction was discovered by a British scientist Michael Faraday and an American scientist Joseph Henry independently in 1831. **The process of electromagnetic induction has led to the construction of generators for producing electricity at power stations.** Before we describe experiments to demonstrate the phenomenon of electromagnetic induction, we should know something about the galvanometer which we will be using now.

Figure 27. Singers rely on induced currents in a microphone.

A galvanometer is an instrument which can detect the presence of electric current in a circuit. It is connected in series with the circuit. When no current is flowing through a galvanometer, its pointer is at the zero mark (in the centre of semi-circular scale). When an electric current passes through the galvanometer, then its pointer deflects (or moves) either to the left side of zero mark or to the right side of the zero mark, depending on the direction of current. We will describe the experiments now.

1. To Demonstrate Electromagnetic Induction by Using a Straight Wire and a Horseshoe–Type Magnet

In Figure 28(*a*), we have a straight wire *AB* held between the poles N and S of a horseshoe magnet (which is a U-shaped magnet). The two ends of wire are connected to a current-detecting instrument called galvanometer. When the wire *AB* is held standstill between the poles of the horseshoe magnet, then there is no deflection in the galvanometer pointer. This shows that no current is produced in the wire when it is held stationary in the magnetic field.



(*a*) As the wire *AB* is moved up through the magnetic field, a current is produced in it

(*b*) When the wire *AB* is moved down in the magnetic field, even then current is produced in it (but in the opposite direction)

Figure 28. Experiment to demonstrate electromagnetic induction. A current is induced in the wire when it is moved up or down between the poles of the magnet.

1. Let us move the wire *AB upwards* rapidly between the poles of the horseshoe magnet [see Figure 28(*a*)]. When the wire is moved up, there is a deflection in the galvanometer pointer showing that a current is produced in the wire *AB* momentarily which causes the deflection in galvanometer [see Figure 28(*a*)]. The deflection lasts only while the wire is in motion. Thus, *as the wire is moved up through the magnetic field, an electric current is produced in it.*

2. We now move the wire *AB downwards* rapidly between the poles of the horseshoe magnet [see Figure 28(*b*)]. When the wire is moved down, the galvanometer pointer again shows a deflection, but in the opposite direction (to the left side) [see Figure 28(*b*)]. This means that *when the wire is moved down in the magnetic field, even then an electric current is produced in it.* But when the direction of movement of wire is reversed (from up to down), then the direction of current produced in the wire is also reversed.

If we move the wire *AB* up and down continuously between the poles of the horse-shoe magnet, then a continuous electric current will be produced in the wire. But the direction of this electric current will change rapidly as the direction of movement of the wire changes. This is because when the wire moves up, then the current in it will flow in one direction but when the wire moves down, then the current in it will flow in opposite direction. We will see the pointer of galvanometer move to and fro rapidly as the current in the wire changes direction of flow continuously. The electric current produced in the wire (which changes direction continuously) is called alternating current or a.c.

The above experiment shows that when the direction of motion of wire in the magnetic field is reversed, then the direction of induced current is also reversed. Please note that the direction of induced current in the wire can also be reversed by reversing the positions of the poles of the magnet which means that **the direction of induced current can also be reversed by reversing the direction of magnetic field.** We will now discuss why the movement of a wire in the magnetic field produces an electric current in the wire.

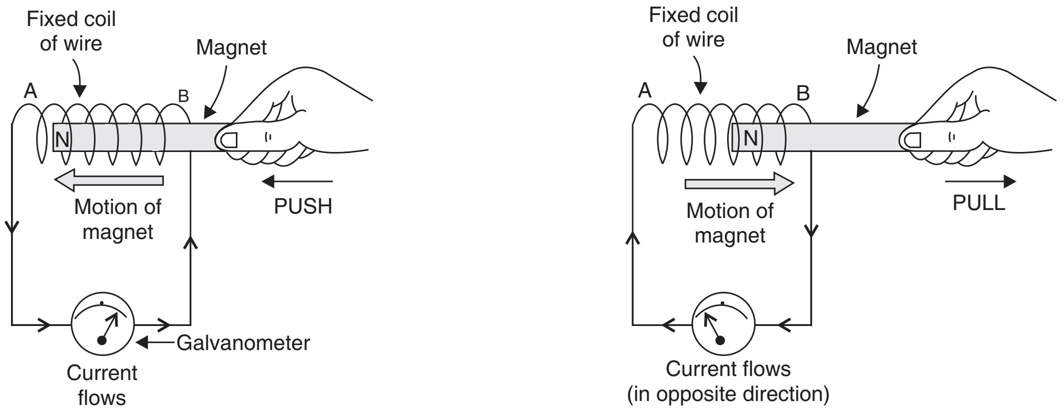
When a wire is moved in a magnetic field between the poles of a magnet, then the free electrons present in the wire experience a force. This force makes the electrons move along the wire. And the movement of these electrons produces current in the wire. We are spending energy (from our body) in moving the wire up and down in the magnetic field. So, it is the energy spent by us in moving the wire in the magnetic field which is getting converted into electrical energy in the wire and producing an electric current in the wire. Thus, **the movement of a wire in a magnetic field can produce electric current.** So, we can generate electricity by moving a wire continuously in the magnetic field between the poles of a magnet. This principle is used in producing electricity through generators. **A generator uses the movement (or rotation) of a rectangular coil of wire between the poles of a horseshoe magnet to produce an electric current (or electricity).** Thus, the phenomenon of electromagnetic induction is used in the production of electricity by a generator.

In the above experiment we have seen that **when a wire is moved between the poles of a fixed magnet, then an electric current is produced in the wire.** The reverse of this is also true. That is, **if a wire (in the form of a coil) is kept fixed but a magnet is moved inside it, even then a current is produced in the coil of wire**. This point will become more clear from the following experiment.

2. To Demonstrate Electromagnetic Induction by Using a Coil and a Bar Magnet

In Figure 29(*a*), we have a fixed coil of wire *AB*. The two ends of the coil are connected to a current-detecting instrument called galvanometer. Now, when a bar magnet is held standstill inside the hollow coil of wire, then there is no deflection in the galvanometer pointer showing that no electric current is produced in the coil of wire when the magnet is held stationary in it.

When a bar magnet is moved quickly into a fixed coil of wire *AB*, then a current is produced in the coil. This current causes a deflection in the galvanometer pointer [see Figure 29(*a*)]. Similarly, when the magnet is moved out quickly from inside the coil, even then a current is produced in the coil [see Figure 29(*b*)]. This current also causes a deflection in the galvanometer pointer but in the opposite direction (showing that when the direction of movement of magnet changes, then the direction of current produced in the coil also changes). So, the current produced in this case is also alternating current or a.c.



(*a*) As a magnet is pushed into the fixed coil, a current is produced in the coil

(*b*) When the magnet is pulled out from the fixed coil, even then a current is produced in the coil (but in the opposite direction)

Figure 29. Another way of demonstrating electromagnetic induction. A current is induced in the coil when the magnet is moved in or out.

The production of electric current by moving a magnet inside a fixed coil of wire is also a case of electromagnetic induction. The concept of a fixed coil and a rotating magnet is used to produce electricity on large scale in big generators of power houses. Please note that **the condition necessary for the production of electric current by electromagnetic induction is that there must be a relative motion between the coil of wire and a magnet.** Out of the coil of wire and a magnet, one can remain fixed but the other has to rotate (or move).

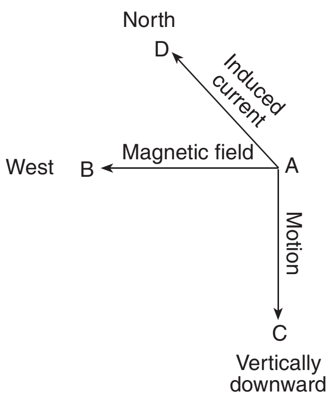
After performing a large number of experiments, Faraday and Henry made the following observations about electromagnetic induction :

1. A current is induced in a coil when it is moved (or rotated) relative to a fixed magnet.
2. A current is also induced in a fixed coil when a magnet is moved (or rotated) relative to the fixed coil.
3. No current is induced in a coil when the coil and magnet both are stationary relative to one another.
4. When the direction of motion of coil (or magnet) is reversed, the direction of current induced in the coil also gets reversed.
5. The magnitude of current induced in the coil can be increased :
   (*a*) by winding the coil on a soft iron core,
   (*b*) by increasing the number of turns in the coil,
   (*c*) by increasing the strength of magnet, and
   (*d*) by increasing the speed of rotation of coil (or magnet).

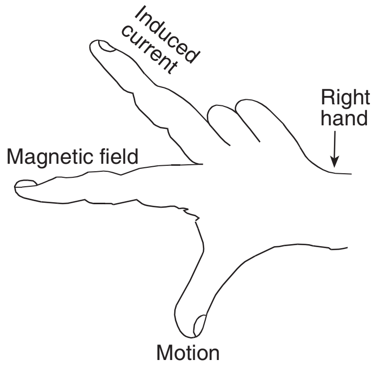
Fleming's Right-Hand Rule for the Direction of Induced Current

The direction of induced current produced in a straight conductor (or wire) moving in a magnetic field is given by Fleming's right-hand rule. According to Fleming's right-hand rule : **Hold the thumb, the forefinger and the centre finger of your right-hand at right angles to one another [as shown in Figure 30(*b*)]. Adjust your hand in such a way that forefinger points in the direction of magnetic field, and thumb points in the direction of motion of conductor, then the direction in which centre finger points, gives the direction of induced current in the conductor.**

Suppose the direction of magnetic field is directed from east to west as shown by arrow *AB* in Figure 30(*a*), and the direction of motion of conductor is vertically downwards, as shown by the arrow *AC* in Figure 30(*a*). Then to find out the direction of induced current in the conductor, we hold the thumb, the forefinger and centre finger of our right-hand mutually at right angles to one another. We adjust the right hand in such a way that the forefinger points from east to west (to represent the magnetic field), and the thumb points vertically downwards (to represent the direction of motion), then we will find that our centre finger points towards north [Figure 30(*b*)] and this gives the direction of induced current. Thus, the induced current in this case will be towards north as represented by arrow *AD* in Figure 30(*a*). Please note that Fleming's right-hand rule is also called dynamo rule.



(*a*)

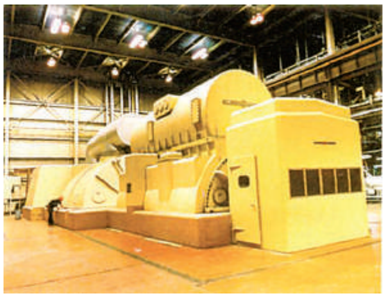


(*b*)

Figure 30. Diagrams to illustrate Fleming's right-hand rule for finding the direction of induced current in a conductor.

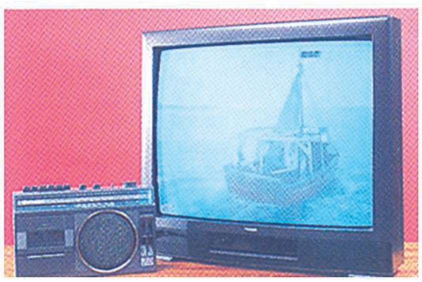
Direct Current and Alternating Current

Before we discuss the construction and working of an electric generator, it is necessary to know the meaning of direct current and alternating current. This is discussed below. **If the current flows in one direction only, it is called a direct current.** Direct current is written in short form as D.C. (or d.c.) The current which we get from a cell or a battery is direct current because it always flows in the same direction. The positive (+) and negative (–) polarity of a direct current is fixed. Some of the sources of direct current (or d.c.) are dry cell, dry cell battery, car battery and d.c. generator. **If the current reverses direction after equal intervals of time, it is called alternating current.** Alternating current is written in short form as A.C. (or a.c.). Most of the power stations in India generate alternating current. The alternating current produced in India reverses its direction every $\frac{1}{100}$ second. Thus, the positive (+) and negative (–) polarity of an alternating current is not fixed. Some of the sources which produce alternating current (or a.c.) are power house generators, car alternators and bicycle dynamos. An important advantage of alternating current (over direct current) is that **alternating current can be transmitted over long distances without much loss of**



(*a*) This is a very large power house generator. It produces alternating current (a.c.)

(*b*) Lamps and kettles can work with a.c. or d.c.



(*c*) Radios and televisions work only with d.c. (They have a device in them which converts a.c. supplied to them into d.c.).

Figure 31.

electrical energy. Both a.c. and d.c. can be used for lighting and heating purposes. But radios and televisions, etc., need a d.c. supply. The radios and televisions have a special device inside them which changes the a.c. supplied to them into d.c.

ELECTRIC GENERATOR

The electric generator is a machine for producing electric current or electricity. **The electric generator converts mechanical energy into electrical energy.** A small generator is called a dynamo. For example, the small generator used on bicycles for lighting purposes is called a bicycle dynamo.

Principle of Electric Generator

The electric generator is an application of electromagnetic induction. **The electric generator works on the principle that when a straight conductor is moved in a magnetic field, then current is induced in the conductor.** In an electric generator, a rectangular coil (having straight sides) is made to rotate rapidly in the magnetic field between the poles of a horseshoe-type magnet. When the coil rotates, it cuts the magnetic field lines due to which a current is produced in the coil.

Electric generators are of two types :

1. Alternating Current generator (A.C. generator), and
2. Direct Current generator (or D.C. generator).

Please note that A.C. generator is also written as a.c. generator and D.C. generator is also written as d.c. generator. We will now discuss both the types of electric generators, one by one. Let us start with the A.C. generator.

A.C. GENERATOR

"A.C. generator" means "Alternating Current generator". That is, an A.C. generator produces alternating current, which reverses its direction continuously. A.C. generator is also known as an alternator. We will now describe the construction and working of an A.C. generator.

Construction of an A.C. Generator

A simple A.C. generator consists of a rectangular coil *ABCD* which can be rotated rapidly between the poles N and S of a strong horseshoe-type permanent magnet *M* (see Figure 32). The coil is made of a large number of turns of insulated copper wire. The two ends *A* and *D* of the rectangular coil are connected to two circular pieces of copper metal called slip rings R_1 and R_2. As the slip rings R_1 and R_2 rotate with the coil, the two fixed pieces of carbon called carbon brushes, B_1 and B_2, keep contact with them. So, the current produced in the rotating coil can be tapped out through slip rings into the carbon brushes. The outer ends of carbon brushes are connected to a galvanometer to show the flow of current in the external circuit (which is produced by the generator).

Working of an A.C. generator

Suppose that the generator coil *ABCD* is initially in the horizontal position (as shown in Figure 32). Again suppose that the coil *ABCD* is being rotated in the anticlockwise direction between the poles N and S of a horseshoe-type magnet by rotating its shaft.

(*i*) As the coil rotates in the anticlockwise direction, the side *AB* of the coil moves down cutting the magnetic field lines near the N-pole of the magnet, and side *CD* moves up, cutting the magnetic field lines near the S-pole of the magnet (see Figure 32). Due to this, induced current is produced in the sides *AB* and *CD* of the coil. On applying Fleming's right-hand rule to the sides *AB* and *CD* of the coil, we find that the currents are in the directions *B* to *A* and *D* to *C*. Thus, the induced currents in the two sides of the coil are in the same direction, and we get an effective induced current in the direction *BADC* (see Figure 32). Thus, in the first half revolution (or rotation) of coil, the current in the external circuit flows from brush B_1 to B_2.

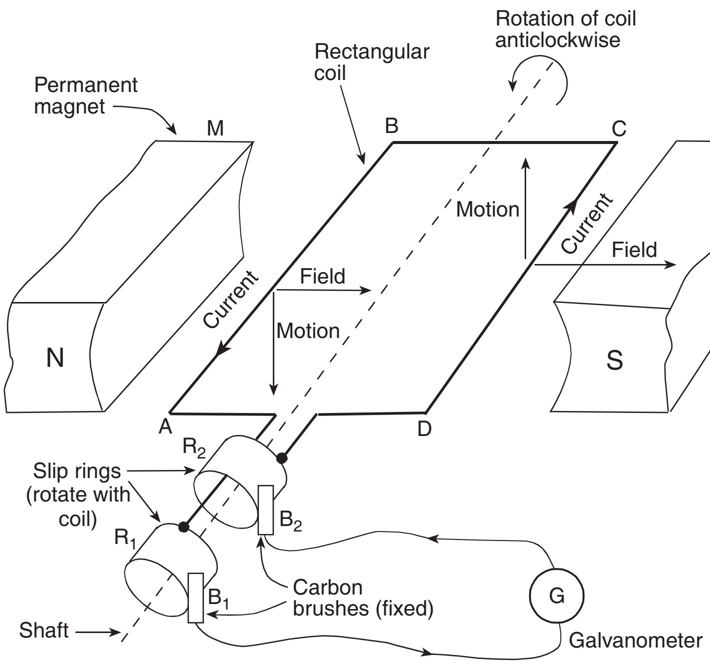


Figure 32. A.C. generator.

(*ii*) After half revolution, the sides *AB* and *CD* of the coil will interchange their positions. The side *AB* will come on the right hand side and side *CD* will come on the left side. So, after half a revolution, side *AB* starts moving up and side *CD* starts moving down. As a result of this, the direction of induced current in each side of the coil is reversed after half a revolution giving rise to the net induced current in the direction *CDAB* (of the reversed coil). The current in the external circuit now flows from brush B_2 to B_1.

Since the direction of induced current in the coil is reversed after half revolution so the polarity (positive and negative) of the two ends of the coil also changes after half revolution. The end of coil which was positive in the first half of revolution becomes negative in the second half. And the end which was negative in the first half revolution becomes positive in the second half of revolution. Thus, in 1 revolution of the coil, the current reverses its direction 2 times. In this way alternating current is produced in this generator.

The alternating current (A.C.) produced in India has a frequency of 50 Hz. That is, the coil is rotated at the rate of 50 revolutions per second. Since in 1 revolution of coil, the current reverses its direction 2 times, so in 50 revolutions of coil, the current reverses its direction $2 \times 50 = 100$ times. Thus, the A.C. supply in India reverses its direction 100 times in 1 second. Another way of saying this is that the alternating current produced in India reverses its direction every $\frac{1}{100}$ second. That is, each terminal of the coil is positive (+) for $\frac{1}{100}$ of a second and negative (–) for the next $\frac{1}{100}$ of a second. This process is repeated again and again with the result that there is actually no positive and negative in an A.C. generator.

A.C. generators are used in power stations to generate electricity which is supplied to our homes. These days most of the cars are fitted with small A.C. generators commonly known as alternators. The bicycle dynamos are very small A.C. generators.

We have just described a simple A.C. generator. In practical generators, the voltage (and the current) produced can be increased :

(*a*) by using a powerful electromagnet to make the magnetic field stronger in place of a permanent magnet.

(*b*) by winding the coil round a soft iron core to increase the strength of magnetic field.

(*c*) by using a coil with more turns.

(*d*) by rotating the coil faster.

(*e*) by using a coil with a larger area.

In power stations, huge A.C. generators (or alternators) are used to generate current for the A.C. mains which is supplied to homes, transport and industry. **The power house A.C. generators have a fixed set of coils arranged around a rotating electromagnet** (see Figure 33). Thus, in large power house generators, the *coils are stationary* and the *electromagnet rotates.* The big coils of a power house generator are kept stationary because they are very heavy and hence difficult to rotate. The electromagnet can, however, be rotated more easily. The shaft of electromagnet of a generator is connected to a turbine. When the turbine is turned by fast flowing water (or pressure of steam), then the electromagnet turns inside the coils and generator produces electricity.

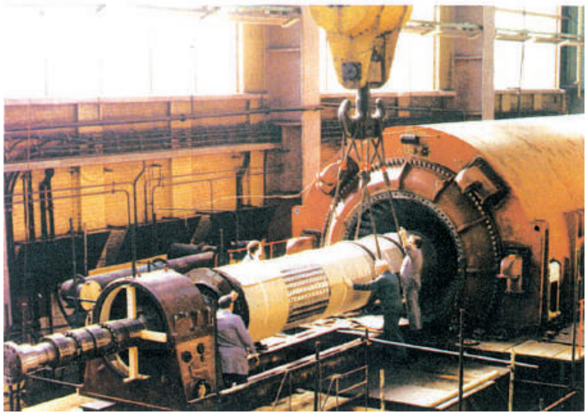


Figure 33. This power house generator produces electricity by rotating an electromagnet inside fixed coils of wire.

Figure 34. The bicycle dynamo in this picture also uses a rotating magnet inside a fixed coil of wire.

At Hydroelectric Power House, the generator is driven by the power of fast flowing water released from a dam across a river. In Thermal Power House, the generator is driven by the power of high pressure steam. The heat energy for making steam from water comes from burning coal, natural gas or oil. At Nuclear Power House, the heat energy for making steam comes from nuclear reactions taking place inside the nuclear reactor. The high pressure steam turns a turbine. The turbine turns the generator. And the generator converts mechanical energy (or kinetic energy) into electrical energy (or electricity). This electricity is then supplied to our homes.

D.C. GENERATOR

We have just studied an A.C. generator which produces alternating current. In order to obtain direct current (which flows in one direction only), a D.C. generator is used. Actually, **if we replace the slip rings of an A.C. generator by a commutator, then it will become a D.C. generator.** Thus, in a D.C. generator, a split ring type commutator is used (like the one used in an electric motor). When the two half rings of commutator are connected to the two ends of the generator coil, then one carbon brush is at all times in contact with the coil arm moving down in the magnetic field while the other carbon brush always remains in contact with the coil arm moving up in the magnetic field. Due to this, the current in outer circuit always flows in one direction. So, it is direct current. A diagram of D.C. generator is given in Figure 35.

We can see from Figure 35 that *the only difference between a D.C. generator and an A.C. generator is in the way the two ends of the generator coil are linked to the outer circuit.* In a D.C. generator we connect the two ends of the coil to a *commutator* consisting of two half rings of copper. On the other hand, in an A.C. generator, we connect the two ends of the coil to two full rings of copper called *slip rings*. There is no commutator in an A.C. generator

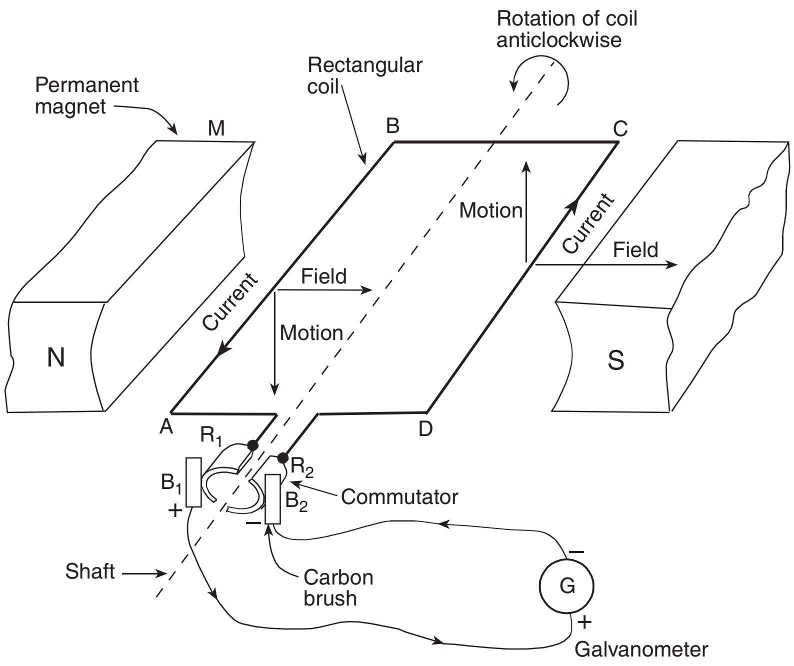


Figure 35. D.C. generator.

Electromagnetic Induction Using Two Coils

So far we have learnt that electromagnetic induction can be brought about by moving a straight wire between the poles of a U-shaped magnet or by moving a bar magnet in a circular coil of wire. We will now study that electromagnetic induction can also be produced by using two coils. This is because **if current is changed in one coil, then current is induced in the other coil kept near it.** No relative motion of the coils is needed in this case. This will become more clear from the following discussion.

Two circular coils *A* and *B* are placed side by side, close to each other (see Figure 36). Coil *A* is connected to a battery and a switch *S* whereas coil *B* is connected to a galvanometer *G*.

(*i*) Let us pass current in coil *A* by pressing the switch. As soon as we pass current in coil *A*, the pointer of galvanometer attached to coil *B* shows a deflection, but quickly returns to zero position. This means that on switching on the current in coil *A*, an electric current is induced in coil *B* momentarily. If the current is now kept 'on' in coil *A*, nothing happens in the galvanometer of coil *B*.

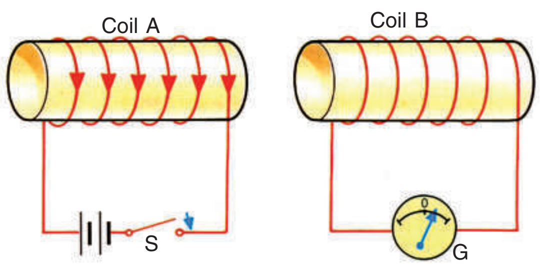


Figure 36. When the current in coil *A* is changed then a current is induced in coil *B*.

(*ii*) Let us now switch off the current in coil *A*. As soon as we switch off the current in coil *A*, the pointer of galvanometer attached to coil *B* again shows a momentary deflection, but on the opposite side. This means that on switching off current in coil *A*, an electric current is induced in coil *B* but in a direction opposite to that when the current was switched on.

(*iii*) If we keep on switching the current 'on and off' in coil *A* rapidly, then the galvanometer pointer will keep moving on both the sides of zero mark continuously, showing that a continuous current is induced in coil *B*. Since the current induced in coil *B* changes direction continuously, so it is an alternating current (or a.c.).

From this discussion we conclude that whenever the current in coil *A* is changing (starting or stopping) then an electric current is induced in the nearby coil *B*. Coil *A* which causes induction is called *primary* coil whereas coil *B* in which current is induced is known as *secondary* coil. A current is induced here even though the coils are *not moving* relative to each other. **We will now explain why a change in current in coil *A* induces current in coil *B*.**

(*i*) When we switch on current in coil *A*, it becomes an electromagnet and produces a magnetic field around coil *B*. The effect is just the same as pushing a magnet into coil *B*. So, an induced current flows in coil *B* for a moment. When the current in coil *A* becomes steady, its magnetic field also becomes steady and the current in coil *B* stops.

(*ii*) When we switch off the current in coil *A*, its magnetic field in coil *B* stops quickly. This effect is just the same as pulling a magnet quickly out of coil *B*. So, an induced current flows in coil *B* in the opposite direction.

Thus, the current is induced in coil *B* by the changing magnetic field in it when the current in coil *A* is 'switched on' or 'switched off'.

If the coil *A* is connected to alternating current (which keeps on changing), then a constant current will be induced in coil *B* whose magnitude will depend on the relative number of turns of wire in coil *A* and coil *B*. This fact is used in making transformers for stepping up (increasing) or stepping down (decreasing) the voltage of alternating current. These transformers are used at power stations and in a variety of electronic appliances such as radio sets and T.V. sets, etc. Let us solve some problems now.

Sample Problem 1. A coil of insulated copper wire is connected to a galvanometer. What will happen if a bar magnet is :

(*i*) pushed into the coil ?

(*ii*) held stationary inside the coil ?

(*iii*) withdrawn from inside the coil ? **(NCERT Book Question)**

Solution. (*i*) As a bar magnet is pushed into the coil, a momentary deflection is observed in the galvanometer indicating the production of a momentary current in the coil.

(*ii*) When the bar magnet is held stationary inside the coil, there is no deflection in galvanometer indicating that no current is produced in the coil.

(*iii*) When the bar magnet is withdrawn (or pulled out) from the coil, the deflection of galvanometer is in opposite direction showing the production of an opposite current.

Sample Problem 2. Explain why, the direction of induced current in the coil of an A.C. generator changes after every half revolution of the coil.

Solution. After every half revolution, each side of the generator coil starts moving in the opposite direction in the magnetic field. The side of the coil which was initially moving downwards in the magnetic field, after half revolution, it starts moving in opposite direction – upwards. Similarly, the side of coil which was initially moving upwards, after half revolution, it starts moving downwards. *Due to the change in the direction of motion of the two sides of the coil in the magnetic field after every half revolution, the direction of current produced in them also changes after every half revolution.*

Before we go further and describe the household electric circuits or domestic wiring, **please answer the following questions :**

Very Short Answer Type Questions

1. Name the device which converts mechanical energy into electric energy.

2. Out of an A.C. generator and a D.C. generator :

(*a*) which one uses a commutator (split rings) ?

(*b*) which one uses slip rings ?

3. Name the phenomenon which is made use of in an electric generator.

4. Name the rule which gives the direction of induced current.

5. What condition is necessary for the production of current by electromagnetic induction ?

6. What type of generator is used at Power Stations ?

7. What change should be made in an a.c. generator so that it may become a d.c. generator ?

8. State whether the following statements are true or false :

(*a*) A generator works on the principle of electromagnetic induction.

(*b*) A motor works on the principle of electromagnetic induction.

9. What is the function of brushes in an electric generator ?

10. When a wire is moved up and down in a magnetic field, a current is induced in the wire. What is this phenomenon known as ?

11. When current is 'switched on' and 'switched off' in a coil, a current is induced in another coil kept near it. What is this phenomenon known as ?

12. What is the major difference between the simple alternator and most practical alternators ?

13. Why are Thermal Power Stations usually located near a river ?

14. List three sources of magnetic fields.

15. Complete the following sentence :

A generator with commutator produces...........current.

Short Answer Type Questions

16. Two circular coils A and B are placed close to each other. If the current in coil A is changed, will some current be induced in the coil B ? Give reason for your answer.

17. (*a*) Explain the principle of an electric generator.

(*b*) State two ways in which the current induced in the coil of a generator could be increased.

18. (*a*) What is the difference between alternating current and direct current ?

(*b*) What type of current is given by (*i*) a dry cell, and (*ii*) a Power House generator ?

19. State and explain Fleming's right hand rule.

20. Name and state the rule to find the direction of :

(*a*) current induced in a coil due to its rotation in a magnetic field.

(*b*) force experienced by a current-carrying straight conductor placed in a magnetic field which is perpendicular to it.

21. (*a*) In what respect does the construction of an A.C. generator differ from that of a D.C. generator ?

(*b*) What normally drives the alternators in a Thermal Power Station ? What fuels can be used to heat water in the boiler ?

Long Answer Type Questions

22. Draw the labelled diagram of an A.C. generator. With the help of this diagram, explain the construction and working of an A.C. generator.

23. (*a*) What do you understand by the term "electromagnetic induction"? Explain with the help of a diagram.

(*b*) Name one device which works on the phenomenon of electromagnetic induction.

(*c*) Describe different ways to induce current in a coil of wire.

24. (*a*) What do you understand by the terms 'direct current' and 'alternating current' ?

(*b*) Name some sources of direct current and some of alternating current.

(*c*) State an important advantage of alternating current over direct current.

(*d*) What is the frequency of A.C. supply in India ?

Multiple Choice Questions (MCQs)

25. A rectangular coil of copper wire is rotated in a magnetic field. The direction of induced current changes once in each :

(*a*) two revolutions (*b*) one revolution

(*c*) half revolution (*d*) one-fourth revolution

26. The phenomenon of electromagnetic induction is :

(*a*) the process of charging a body.

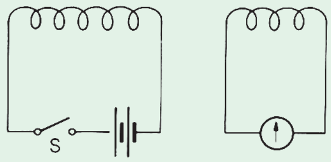
(*b*) the process of generating magnetic field due to a current passing through a coil.

(*c*) producing induced current in a coil due to relative motion between a magnet and the coil.
(*d*) the process of rotating a coil of an electric motor.

27. The device used for producing electric current is called a :
(*a*) generator (*b*) galvanometer (*c*) ammeter (*d*) motor

28. The essential difference between an AC generator and a DC generator is that :
(*a*) AC generator has an electromagnet while a DC generator has permanent magnet.
(*b*) DC generator will generate a higher voltage.
(*c*) AC generator will generate a higher voltage.
(*d*) AC generator has slip rings while the DC generator has a commutator.

29. When the switch S is closed in the figure given below, the pointer of the galvanometer moves to the right.



If S is kept closed, will the pointer :
(*a*) return to zero ?
(*b*) stay over on the right ?
(*c*) move to the left and stay there
(*d*) move to and fro until S is opened

30. Each one of the following changes will increase emf (or voltage) in a simple generator except :
(*a*) increasing the number of turns in the armature coil
(*b*) winding the coil on a soft iron armature
(*c*) increasing the size of the gap in which the armature turns
(*d*) increasing the speed of rotation

31. The north pole of a long bar magnet was pushed slowly into a short solenoid connected to a galvanometer. The magnet was held stationary for a few seconds with the north pole in the middle of the solenoid and then withdrawn rapidly. The maximum deflection of the galvanometer was observed when the magnet was :
(*a*) moving towards the solenoid (*b*) moving into solenoid
(*c*) at rest inside the solenoid (*d*) moving out of the solenoid

32. An electric generator converts :
(*a*) electrical energy into mechanical energy
(*b*) mechanical energy into heat energy
(*c*) electrical energy into chemical energy
(*d*) mechanical energy into electrical energy.

33. A d.c. generator is based on the principle of :
(*a*) electrochemical induction (*b*) electromagnetic induction
(*c*) magnetic effect of current (*d*) heating effect of current

34. An induced current is produced when a magnet is moved into a coil. The magnitude of induced current does not depend on :
(*a*) the speed with which the magnet is moved
(*b*) the number of turns of the coil
(*c*) the resistivity of the wire of the coil
(*d*) the strength of the magnet

35. The frequency of direct current (d.c.) is :
(*a*) 0 Hz (*b*) 50 Hz (*c*) 60 Hz (*d*) 100 Hz

36. The frequency of alternating current (a.c.) supply in India is :
(*a*) 0 Hz (*b*) 50 Hz (*c*) 60 Hz (*d*) 100 Hz

Questions Based on High Order Thinking Skills (HOTS)

37. A coil is connected to a galvanometer. When the N-pole of a magnet is pushed into the coil, the galvanometer deflected to the right. What deflection, if any, is observed when :

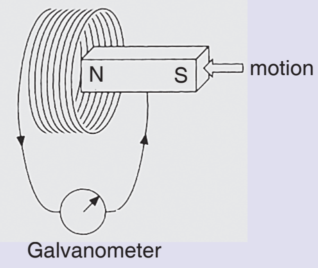
(*a*) the N-pole is removed ?

(*b*) the S-pole is inserted ?

(*c*) the magnet is at rest in the coil ?

State three ways of increasing the deflection on the galvanometer.

38. When the magnet shown in the diagram below is moving towards the coil, the galvanometer gives a reading to the right.



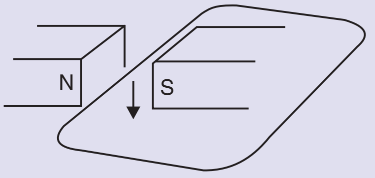
(*i*) What is the name of the effect being produced by the moving magnet ?

(*ii*) State what happens to the reading shown on the galvanometer when the magnet is moving away from the coil.

(*iii*) The original experiment is repeated. This time the magnet is moved towards the coil at a great speed. State two changes you would notice in the reading on the galvanometer.

39. If you hold a coil of wire next to a magnet, no current will flow in the coil. What else is needed to induce a current ?

40. The wire in Figure below is being moved downwards through the magnetic field so as to produce induced current.



What would be the effect of :

(*a*) moving the wire at a higher speed ?

(*b*) moving the wire upwards rather than downwards ?

(*c*) using a stronger magnet ?

(*d*) holding the wire still in the magnetic field ?

(*e*) moving the wire parallel to the magnetic field lines ?

41. Two coils A and B of insulated wire are kept close to each other. Coil A is connected to a galvanometer while coil B is connected to a battery through a key. What would happen if :

(*i*) a current is passed through coil B by plugging the key ?

(*ii*) the current is stopped by removing the plug from the key ?

Explain your answer mentioning the name of the phenomenon involved.

42. A portable radio has a built-in transformer so that it can work from the mains instead of batteries. Is this a step-up or step down transformer ?

ANSWERS

1. Electric generator **2.** (*a*) D.C. generator (*b*) A.C. generator **3.** Electromagnetic induction **4.** Fleming's right-hand rule **6.** A.C. generator (or Alternator) **8.** (*a*) True (*b*) False **10.** Electromagnetic induction **11.** Electromagnetic induction **12.** Simple alternator : Magnet fixed and coil rotates ; Practical alternator : Coil fixed and magnet rotates **13.** To obtain water for making steam for turning turbines and for cooling spent steam to condense it back into hot water for making fresh steam

14. Permanent magnets ; Electromagnets ; Conductors carrying current (such as straight wire, circular coil and solenoid carrying current) **15.** direct **20.** (*a*) Fleming's right-hand rule (*b*) Fleming's left-hand rule **21.** (*b*) High pressure steam ; Coal ; Natural gas ; Oil **23.** (*b*) Electric generator **25.** (*c*) **26.** (*c*) **27.** (*a*) **28.** (*d*) **29.** (*a*) **30.** (*c*) **31.** (*d*) **32.** (*d*) **33.** (*b*) **34.** (*c*) **35.** (*a*) **36.** (*b*) **37.** (*a*) The galvanometer is deflected to the left (*b*) The galvanometer is deflected to the left (*c*) No deflection in galvanometer ; Increase the number of turns in the coil ; Use a stronger magnet ; Increase the speed with which magnet is pushed into the coil (or removed) **38.** (*i*) Electromagnetic induction (*ii*) Deflected to left (*iii*) Large deflection to right occurs more quickly **39.** Motion of the magnet into the coil (and out of the coil) **40.** (*a*) Current increased (*b*) Current reversed (*c*) Current increased (*d*) Current zero (*e*) Current zero **41.** (*i*) Galvanometer pointer moves to one side showing that a current is induced in the coil (*b*) Galvanometer pointer moves to the other side showing that the direction of induced current has been reversed ; Electromagnetic induction **42.** Step-down transformer (which reduces the voltage)

DOMESTIC ELECTRIC CIRCUITS (OR DOMESTIC WIRING)

Electricity is generated at the power station. It is brought to our homes by two thick copper wires or aluminium wires fixed over tall electric poles (or by underground cables). From the electric pole situated in our street, two insulated wires L and N come to our house (see Figure 37). One of these wires is called *live wire* (read as *laa-ive* wire) and it is at a high potential of 220 volts whereas the other wire is called *neutral wire* and it is at the ground potential of zero volt. Thus, the potential difference between the live wire and the neutral wire in India is 220 – 0 = 220 volts. In Figure 37, L is the live wire and N is the neutral wire. The live wire has red insulation covering whereas neutral wire has black insulation covering. There is no harm if we touch the neutral wire but we will get an electric shock if, by chance, we touch the live wire.

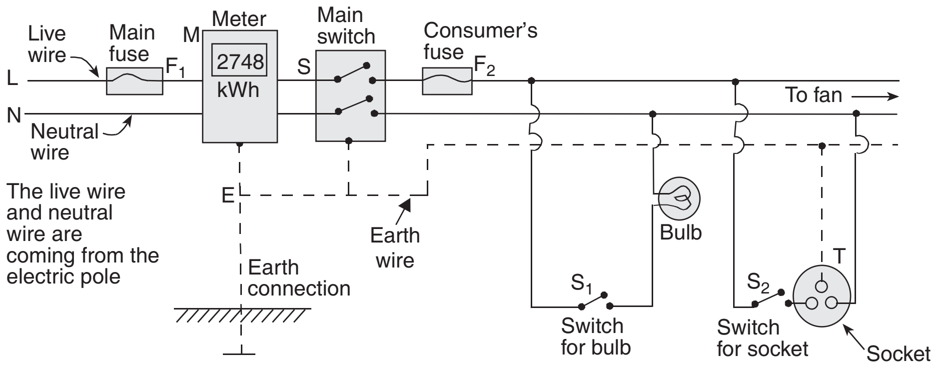


Figure 37. Diagram to show domestic electric wiring from electric pole to a room
(In this diagram we have shown the wiring for an electric bulb and a three-pin socket only).

The two insulated wires L and N, coming from the electric pole, enter a box fitted just inside our house. In this box, a main fuse F_1 is put in the live wire. This fuse has a high rating of about 50 amperes. The two line wires then enter the electricity meter M which records the electrical energy consumed by us in the units of kilowatt-hours. The main fuse and the meter are both installed by the Electric Supply Department of our City.

The two wires coming out of the meter are connected to a main switch S. This main switch is to switch off the electricity supply when required so as to repair any faults in the internal wiring. After the main switch, there is another fuse F_2 in the live wire. This is called consumer's fuse. It is very important to note here that **usually there are two separate circuits in a house, the lighting circuit with a 5 A fuse and the power circuit with a 15 A fuse.** The lighting circuit is for running low power-rating devices such as electric bulbs, tube-lights, fans, radio, and TV, etc., which draw *small* current. On the other hand, power circuit is for running high power-rating devices such as electric iron, room heater, geyser, electric stove, refrigerator, etc., which draw *heavy* current. But to make things simple, we will describe only a lighting circuit with a 5 ampere fuse. **Each distribution circuit is provided with a separate fuse so that if a fault like short-circuiting occurs in one circuit, its corresponding fuse blows off but the other circuit remains unaffected.** Another point to remember is that the **various distribution circuits are connected in parallel** so that if a fault occurs in one circuit, its fuse will melt leaving the other circuit in operation. For example, the lighting circuit and power circuit in our home are in *parallel* so that if a short-circuit occurs in, say the power circuit, then the power-fuse will blow off but our lights will not go off because our lighting circuit will keep working.

Before we describe the wiring of our rooms, it is very important to note here that alongwith the live wire and the neutral wire, a third wire called earth wire also goes into our rooms. In Figure 37, the earth wire E has been shown by dotted line. One end of the earth wire E is connected to a copper plate and buried deep under the earth near the house (as shown in Figure 37) or at the nearest electric sub-station. The earth connection is first made to the electric meter and then to the main switch. This earth wire then goes into our room alongwith the live wire and the neutral wire. Please note that the earth wire up to the main switch of our house is usually an uncovered, thick copper wire having no plastic insulation over it. But the earth wire which goes from the main switch into our rooms is a copper wire having green insulation covering over it. Thus, **in order to distinguish between the live wire, neutral wire and earth wire, the wire having red plastic covering is made live wire, the wire having black plastic covering is made neutral wire, and the wire having green plastic covering is made earth wire.**

Now, three wires, live wire, neutral wire and the earth wire enter our room where we have to use an electric bulb, a fan and a three-pin socket for radio, and TV etc. We will now describe the internal wiring of a room. In a room, **all the electrical appliances like bulbs, fans and sockets, etc., are connected in parallel across the live wire and the neutral wire.** The main **advantage** of the parallel connection is that if one of the appliances is switched off, or gets fused, there is no effect on the other appliances and they keep on operating. Another **advantage** of the parallel circuits is that the same voltage of the mains line is available for all the electrical appliances. If, however, we connect the various electric bulbs in series, then if one bulb is switched off or gets fused then all other bulbs will also stop working because their electricity supply will be cut off. On the other hand, if the bulbs are connected in parallel, then switching on or off in a room has no effect on other bulbs in the same building. Moreover, if the various electric bulbs are connected in series, they will not get the same voltage (220 V) of the mains line. The bulbs connected in series will get lower voltage (than 220 V) and hence glow less brightly. All the bulbs connected in parallel will, however, get the same voltage (220 V) and hence glow brightly.

First of all we will describe the wiring for an electric bulb. One end of the bulb-holder is connected to the live wire through a switch S_1 and the other end of the bulb-holder is connected to the neutral wire (see Figure 37). When we press the switch S_1, the circuit for bulb gets completed and it lights up. We will now describe the wiring for a three-pin socket. One of the lower terminals of the socket T is connected to the live wire through a switch S_2 and the second lower terminal is connected to the neutral wire. The upper terminal of the socket is connected to the earth wire (see Figure 37). Let us now describe the wiring for a fan. The live wire is connected to one terminal of the fan through a switch and a regulator. The neutral wire is connected to the other terminal of the fan. We have not shown the wiring for a fan in Figure 37. Please do it yourself.

It is obvious from the circuit given in Figure 37 that **all the electrical appliances are provided with separate switches.** It should be noted that **all the switches are put in the live wire,** so that when we switch off an electrical appliance (like an electric iron), then its connection with the live wire is cut off and there will be no danger of an electric shock if we touch the metal case of the electrical appliance. If , however, we put switches in the neutral wire, then the live wire will be in connection with the electrical appliance even when the switch is in the off position, and there is a danger of an electric shock.

Earthing of Electrical Appliances

Sometime or the other we have received an electric shock from an electric iron or a room cooler. We will now discuss why we get the electric shock and how it can be prevented. In order to work an electrical appliance like an electric iron, electric kettle or a room cooler, we need two wires of the supply line, the live wire and the neutral wire. Sometimes, due to wear and tear or due to excessive heating, the plastic covering (or insulation) of the connecting wires gets removed or gets burnt and the live wire (which is at a high potential of 220 volts) becomes naked. This naked live wire may touch the metal case (or metal body) of the electrical appliance due to which the case becomes *live* and comes to the high voltage of 220 volts. If we happen to touch any part of this live appliance, a very high current flows through our body into the earth. Due to this high current flowing through our body, we get an electric shock (see Figure 38). It has been found that we do not get an electric shock if we are standing on a *wooden* plank. This is due to the fact that wood acts as an insulator and the circuit of current with earth does not get completed through our body.

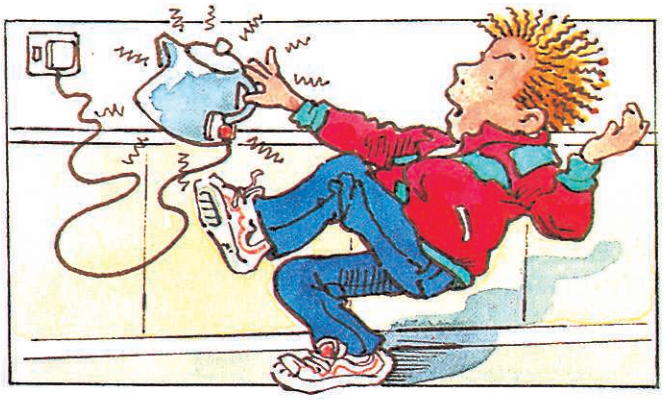


Figure 38. This electric kettle does not have a proper earth connection to its metal case. So, when touched, it gives an electric shock.

To avoid the risk of electric shocks, the metal body of an electrical appliance is "earthed". Earthing means to connect the metal case of electrical appliance to the earth (at zero potential) by means of a metal wire called "earth wire". In household circuits, we have three wires, the live wire, the neutral wire and the earth wire. One end of the earth wire is buried in the earth. We connect the earth wire to the metal case of the electrical appliance by using a three-pin plug. The metal casing of the appliance will now always remain at the zero potential of the earth. We say that the appliance has been earthed or grounded. Let us make it more clear with the help of a diagram. Figure 39 shows the earthing of an electric iron or press.

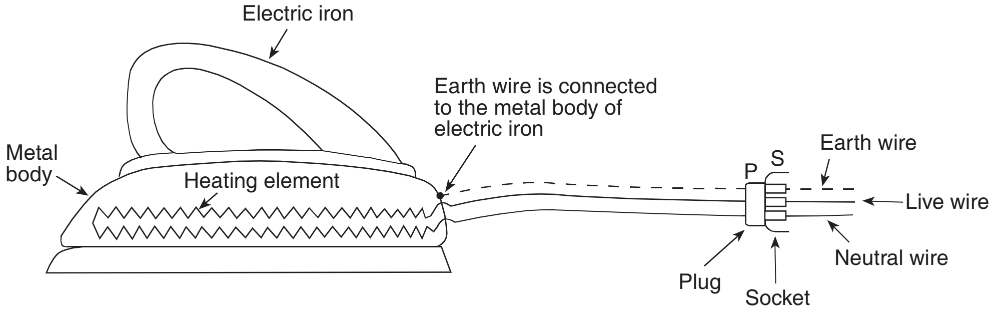


Figure 39. Diagram to show the connection of "earth wire" in an electric iron.

In Figure 39, the live wire and the neutral wire are connected to the two ends of the heating element whereas the earth wire is connected to the metal body of the electric iron. These three wires are connected to a three-pin plug *P*. The plug *P* is connected to a three-pin socket *S*. Let us see how the earth connection actually works.

If, by chance, the live wire touches the metal case of the electric iron (or any other appliance), which has been earthed, then the current passes directly to the earth through the earth wire. It does not need our body to pass the current and, therefore, we do not get an electric shock. Actually, a very heavy current flows through the earth wire and the fuse of household wiring blows out or melts. And it cuts off the power supply. In this way, earthing also saves the electrical appliance from damage due to excessive current. From the above discussion we conclude that **we earth the metallic body of an electrical appliance to save ourselves from electric shocks.** Thus, the earthing of electrical appliances is used as a safety measure. It should be noted that we give earth connections to only those electrical appliances which have metallic body, which draw heavy current, and which we are liable to touch. For example, electric iron, electric heater, room cooler and refrigerator, are all provided with earth connections. We, however, do not do earthing of an electric bulb or a tube-light because we hardly touch them when they are on. The metal casings of the switches are, however, earthed.

It should be noted that the connecting cable of an electrical appliance like an electric iron, electric kettle, water heater, room cooler or refrigerator contains three insulated copper wires of three different colours : red, black and green. **The red coloured wire is the live wire, the black wire is the neutral wire, whereas green wire is the earth wire** (see Figure 40).

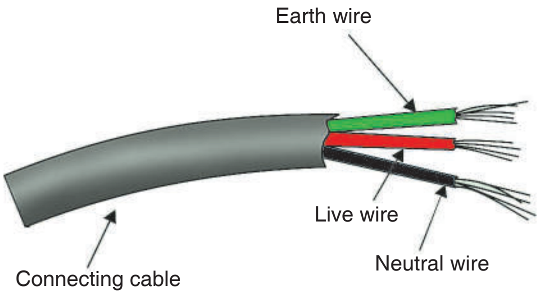


Figure 40. A three core connecting cable has three insulated copper wires in it. The red coloured wire is the live wire, the black wire is the neutral wire, whereas the green wire is the earth wire.

Electric Fuse

The electric wires used in domestic wiring are made of copper metal because copper is a good conductor of electricity having very low resistance. Now, the copper wires chosen for household wiring are of such thickness so as to allow a certain maximum current to pass through them. If the current passing through wires exceeds this maximum value, the copper wires get over-heated and may even cause a fire. **An extremely large current can flow in domestic wiring under two circumstances : short circuiting and overloading.**

(*i*) **Short Circuiting.** If the plastic insulation of the live wire and neutral wire gets torn, then the two wires touch each other (see Figure 41). This **touching of the live wire and neutral wire directly is known as short circuit.** When the two wires touch each other, the resistance of the circuit so formed is very, very small. Since the resistance is very small, the current flowing through the wires becomes very large and heats the wires to a dangerously high temperature, and a fire may be started.

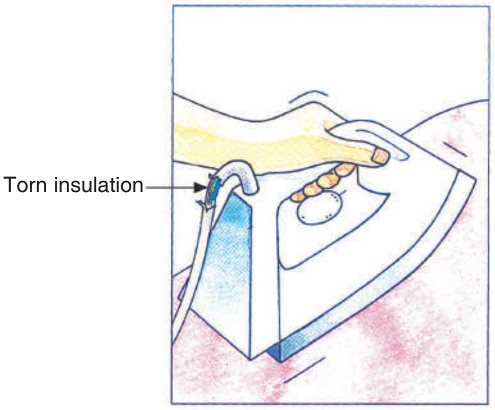


Figure 41. The insulation of connecting cable of this electric iron is getting torn. An electric short circuit is waiting to happen.

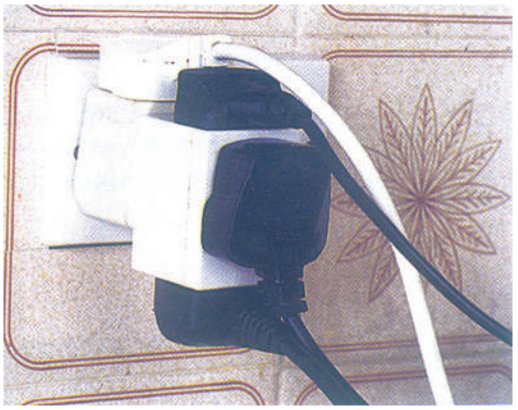


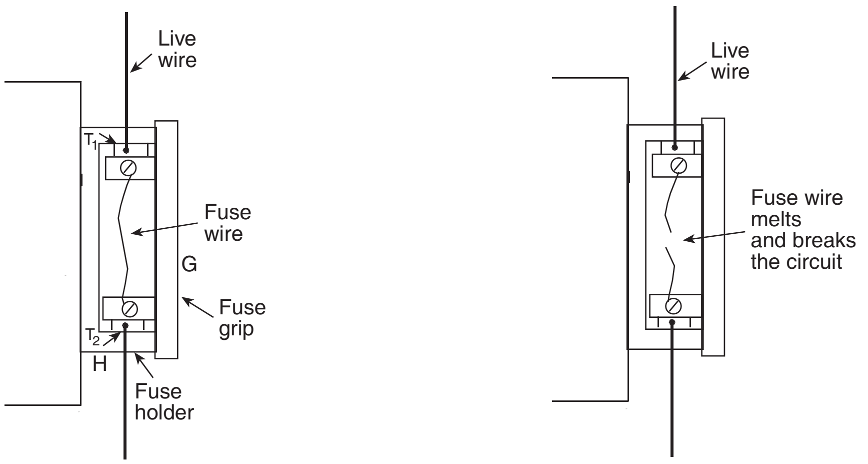
Figure 42. Too many appliances connected to a single socket. A case of overloading.

(*ii*) **Overloading.** The current flowing in domestic wiring at a particular time depends on the power ratings of the appliances being used. If too many electrical appliances of high power rating (like electric iron, water heater, air conditioner, etc.,) are switched on at the same time, they draw an extremely large current from the circuit. This is known as overloading the circuit. Overloading can also occur if too many appliances are connected to a single socket (see Figure 42). Now, due to an extremely large current flowing through them, the copper wires of household wiring get heated to a very high temperature and a fire may be started.

It is obvious that we should have some device which may disconnect the electricity supply when a short circuit or overloading occurs so that the electric fires are prevented in our homes. To avoid this danger of electric fires we use an electric fuse in the wiring. So, **when a building is wired, the wiring is protected by fuses**. We will now describe what a fuse is and how it works.

A fuse is a safety device having a short length of a thin, tin-plated copper wire having low melting point, which melts and breaks the circuit if the current exceeds a safe value. The thickness and length of the fuse wire depends on the maximum current allowed through the circuit. **An electric fuse works on the heating effect of current.** The fuse for protecting our domestic wiring is fitted just above our main switch on the switch board. **A fuse wire is connected in series in the electric circuits.**

The main fuse in domestic wiring consists of a porcelain fuse holder *H* having two brass terminals T_1 and T_2 in it [see Figure 43(*a*)]. This is connected in the live wire. The other part of the fuse is a removable fuse grip *G* which is also made of porcelain. The fuse grip has a fuse wire fixed in it. When fuse grip is inserted in the fuse holder as shown in Figure 43(*a*), then the circuit of our domestic wiring is completed. So, under normal circumstances when the current is within limit, the fuse wire is intact and electric current is available in our wiring.



(*a*) Under normal circumstances the fuse wire is intact and hence current flows in the circuit

(*b*) When excessive current flows in the circuit, the fuse wire gets heated too much, melts and breaks the circuit

Figure 43. Electric fuse.

When a short circuit takes place, or when overloading takes place, the current becomes large and heats the fuse wire too much. Since the melting point of fuse wire is much lower than copper wires, the fuse wire melts and breaks the circuit as shown in Figure 43(*b*). When the fuse wire breaks, electricity supply is automatically switched off before any damage can be done to the rest of the wiring (or the electrical appliances being used).

We will now give some important points about the fuse wire to be used in electrical circuits. First of all we should know why we use a *thin wire* as a fuse wire and not a *thick wire*. We use a thin wire in a fuse because it has a much greater resistance than the rest of connecting wires. Due to its high resistance, the heating effect of current will be much more in the fuse wire than anywhere else in the circuit. This will melt the fuse wire whereas other wiring will remain safe. We should not use a thick wire as a fuse wire because it will have a low resistance and hence it will not get heated to its melting point easily. The fuse wire is usually made from tin-plated copper wire having low melting point so that it may melt easily. **A pure copper wire cannot be used as a fuse wire** because it has a high melting point due to which it will not melt easily when a short circuit takes place.

The fuse wire must have proper thickness which depends on the maximum current which the household wiring can safely carry. The thickness of the fuse wire should be such that it is able to withstand only a little more current than drawn by the household circuit. Fuse wires are rated as 1 A, 2 A, 3 A, 5 A, 10 A, 13 A, 15 A, and so on. It is clear that a "10 ampere" fuse wire will be thicker than a "5 ampere" fuse wire. The fuse in the lighting and fans circuit of a small house is of 5 amperes rating which means that the fuse wire will melt if the current exceeds 5 amperes value. The fuse used in the power circuit of a small house for running electric iron, immersion heater, geyser and toaster, etc., having power of 1000 watts or more is of 15 A capacity. A blown fuse should be replaced only after the cause of excessive current flow has been found and removed. These days more and more houses are using 'Miniature Circuit Breakers' (MCBs) to protect the household wiring from the excessive flow of electric current through it (see Figure 44). If the current becomes too large, the miniature circuit breaker puts off a switch cutting off the electric supply. The MCB can be re-set when the fault has been corrected. Miniature circuit beaker (MCB) contains an electromagnet which, when the current exceeds the rated value of circuit breaker, becomes strong enough to separate a pair of contacts (by putting off a switch) and breaks the circuit. So, unlike fuses, MCBs do not work on heating effect of current. MCBs work on the magnetic effect of current.

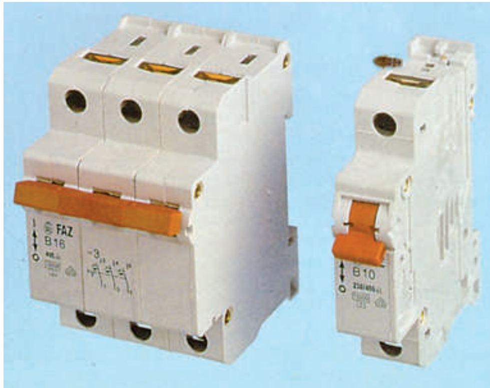


Figure 44. Miniature Circuit Breakers (MCBs) are now used in domestic wiring instead of fuses.

So far we have discussed the fuses which are put on the main switch-board in our houses to protect the whole wiring of the house. **Fuses are also used to protect the individual domestic electrical appliances from damage which may be caused due to excessive current flow through them** (see Figure 45). Costly electrical appliances like T.V. sets and refrigerators have their own fuses which protect them against damage by too much current. The fuse used for each electrical appliance should be slightly larger than the normal current drawn by it. For example, a T.V. set which normally takes less than 1 ampere of current should be fused at 2 amperes, and not, for example, at 10 amperes.

Figure 45. These are the cartridge fuses. They are used to protect the individual electrical appliances.

The fuse used in an electrical appliance is shown in Figure 46(*a*). It consists of a glass tube *T* having a thin fuse wire sealed inside it. The glass tube has two metal caps at its two ends. The two ends of the fuse wire are connected

(*a*) Diagram of the fuse used in electrical appliances

(*b*) Symbol of an electric fuse used in circuit diagrams

Figure 46.

to these metal caps. The metal caps are for connecting the fuse in the circuit in a suitably made bracket. In a circuit diagram, the electric fuse is represented by the symbol shown in Figure 46(*b*). We will now solve some problems based on electric fuse.

Sample Problem 1. An electric oven of 2 kW power rating is operated in a domestic electric circuit (220 V) that has a current rating of 5 A. What result do you expect ? Explain. **(NCERT Book Question)**

Solution. We will first calculate the current drawn by this electric oven.

Now, Power, $P = 2$ kW

$= 2 \times 1000$ W

$= 2000$ W

Potential difference or Voltage, $V = 220$ V

And, Current drawn, $I = ?$ (To be calculated)

Now, Power, $P = V \times I$

So, $2000 = 220 \times I$

And Current drawn, $I = \frac{2000}{220}$

$= 9$ A

Now, the current drawn by this electric oven is 9 amperes which is very high but the fuse in this circuit is only of 5 ampere capacity. So, when a very high current of 9 A flows through the 5 A fuse, the fuse wire will get heated too much, melt and break the circuit, cutting off the power supply. Thus, when a 2 kW power rating electric oven is operated in a circuit having 5 A fuse, the fuse will blow off cutting off the power supply in this circuit.

Sample Problem 2. A circuit has a fuse of 5 A. What is the maximum number of 100 W (220 V) bulbs that can be safely used in the circuit ?

Solution. Suppose x bulbs can be used safely.

Now, Power of 1 bulb = 100 W

So, Power of x bulbs, $P = 100 \times x$ watts

Potential difference, $V = 220$ volts

Current, $I = 5$ amperes

Now, Power, $P = V \times I$

So, $100 \times x = 220 \times 5$

$$x = \frac{220 \times 5}{100}$$

$$x = 11$$

Thus, a maximum number of 11 bulbs can be used.

Sample Problem 3. What precautions should be taken to avoid overloading of domestic electric circuits ? **(NCERT Book Question)**

Answer. (*i*) Too many high power rating electrical appliances (such as electric iron, geyser, air conditioner, etc.) should not be switched on at the same time.

(*ii*) Too many electrical appliances should not be operated on a single socket.

Sample Problem 4. Name two safety measures commonly used in domestic electric circuits and appliances. **(NCERT Book Question)**

Answer. (*i*) Provision of electric fuse.

(*ii*) Earthing of metal bodies of electrical appliances.

Hazards of Electricity (or Dangers of Electricity)

Though electricity is one of the most important and convenient form of energy but its improper use is associated with the following hazards or dangers :

1. If a person happens to touch a live electric wire, he gets a severe electric shock. In some cases, electric shock can even kill a person.
2. Short-circuiting due to damaged wiring or overloading of the circuit can cause electrical fire in a building.
3. The defects in the household wiring like loose connections and defective switches, sockets and plugs can cause sparking and lead to fires.

Figure 47. This man suffered a severe electric shock. A current passing through his hands caused heating which led to burns.

Precautions in the Use of Electricity

To avoid the hazards like electric shocks or electric fires, we should observe the following precautions in the use of electricity :

1. If a person accidently touches a live electric wire or if an electric fire starts in the house, the main switch should be turned off at once so as to cut off the electricity supply. This will prevent the fire from spreading.

2. The person who happens to touch the live electric wire should be provided an insulated support of wood, plastic or rubber. We should never try to pull away the person who is in contact with the live wire, otherwise we will also get a shock.

3. All the electrical appliances like electric iron, cooler, and refrigerator, etc., should be given earth connections to save ourselves from the risk of electric shocks. Even if the earth connection is there, we should avoid touching the metal body of an electric appliance when it is on.

4. All the switches should be put in the live wire of the A.C. circuit, so that when the switch is turned off, the appliance gets disconnected from the live wire and there is no risk of electric shock.

5. We should never operate switches of electrical appliances with wet hands. The plugs should also not be inserted into sockets with wet hands (see Figure 48). This is because water conducts electricity to some extent, so touching the switches and sockets with wet hands can lead to electric shocks.

Figure 48. Never touch switches or sockets with wet hands.

6. The fuse should always be connected in the live wire of the circuit. The fuse wire should be of proper rating and material. We should never use a copper wire (connecting wire) as fuse wire because a copper wire has a very high current rating due to which a copper wire fuse cannot protect the wiring against short circuiting or overloading.

7. The household wiring should be done by using good quality wires having proper thickness and insulation. All the wire connections with switches, sockets and plugs should be tight, and all the wire joints should be covered with insulated adhesive tape. Defective switches, sockets and plugs should be replaced immediately.

8. We should avoid working on a live circuit for repairs, etc. If, however, it is necessary to handle a live circuit, then rubber gloves and rubber shoes must be put on, and we should stand on a dry wooden board. The electricians should wear rubber hand gloves and rubber shoes while working. The tools used for electrical repairs like testers, screw drivers, pincers, etc., should have properly insulated handles made of wood or bakelite plastic.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. What name is given to the device which automatically cuts off the electricity supply during short-circuiting in household wiring ?

2. What is the usual capacity of an electric fuse used (*i*) in the lighting circuit, and (*ii*) in the power circuit, of a small house ?

3. Give the symbol of an electric fuse used in circuit diagrams.

4. State whether the following statements are true or false :

(*a*) A wire with a green insulation is usually the live wire.

(*b*) A miniature circuit breaker (MCB) works on the heating effect of current.

5. Alongwith live wire and neutral wire, a third wire is also used in domestic electric wiring. What name is given to this third wire ?

6. List the colours of the three wires in the cable connected to the plug of an electric iron.

7. What is the electric potential of the neutral wire in a mains supply cable ?

8. If fuses of 250 mA, 500 mA, 1 A, 5 A and 10 A were available, which one would be the most suitable for protecting an amplifier rated at 240 V, 180 W ?

9. When does an electric short circuit occur ?

10. In which wire in an A.C. housing circuit is the switch introduced to operate the lights ?

11. In household circuits, is a fuse wire connected in series or in parallel ?

12. Usually three insulated wires of different colours are used in an electrical appliance. Name the three colours.

13. What is the usual colour of the insulation of : (*a*) live wire, (*b*) neutral wire, and (*c*) earth wire ?

14. What is the main purpose of earthing an electrical appliance ?

15. Give two reasons why different electrical appliances in a domestic circuit are connected in parallel.

16. How should the electric lamps in a building be connected so that the switching on or off in a room has no effect on other lamps in the same building ?

17. Fill in the following blanks with suitable words :

(*a*) A fuse should always be placed in the ....wire of a mains circuit.

(*b*) The earth wire should be connected to the.............of an appliance.

Short Answer Type Questions

18. (*a*) Of what substance is the fuse wire made ? Why ?

(*b*) Explain why, a copper wire cannot be used as a fuse wire.

19. What type of electric fuse is used in electrical appliances like car stereos ? Explain with the help of a labelled diagram.

20. Distinguish between the terms 'overloading' and 'short-circuiting ' as used in domestic circuits.

21. (*a*) When does a fuse cut off current ? How does it do it ?

(*b*) What is the maximum number of 60 W bulbs that can be run from the mains supply of 220 volts if you do not want to overload a 5 A fuse ?

22. Explain the importance of using in a household electric circuit (*i*) fuse, and (*ii*) earthing wire.

23. (*a*) An electric iron is rated at 230 V, 750 W. Calculate (*i*) the maximum current, and (*ii*) the number of units of electricity it would use in 30 minutes.

(*b*) Which of the following fuse ratings would be suitable for this electric iron ?

1 A, 3 A, 5 A, 13 A

24. What is the function of an earth wire ? Why is it necessary to earth the metallic bodies of electrical appliances ?

25. (*a*) What current is taken by a 3 kW electric geyser working on 240 V mains ?

(*b*) What size fuse should be used in the geyser circuit ?

26. (*a*) Why are fuses fitted in the fuse box of a domestic electricity supply ?

(*b*) What device could be used in place of the fuses ?

Long Answer Type Question

27. (*a*) Draw a labelled diagram to show the domestic electric wiring from an electric pole to a room. Give the wiring for a bulb and a three-pin socket only.

(*b*) State two hazards associated with the use of electricity.

(*c*) State the important precautions which should be observed in the use of electricity.

(*d*) What will you do if you see a person coming in contact with a live wire ?

(*e*) Explain why, electric switches should not be operated with wet hands.

Multiple Choice Questions (MCQs)

28. At the time of short circuit, the current in the circuit :

(*a*) reduces substantially (*b*) does not change

(*c*) increases heavily (*d*) varies continuously

29. A 1.25 kW heater works on a 220 V mains supply. What current rating would a suitable fuse have ?

(*a*) 2 A (*b*) 5 A (*c*) 10 A (*d*) 13 A

30. The maximum number of 40 W tube-lights connected in parallel which can safely be run from a 240 V supply with a 5 A fuse is :

(*a*) 5 (*b*) 15 (*c*) 20 (*d*) 30

31. In normal use, a current of 3.5 A flows through a hair dryer. Choose a suitable fuse from the following :

(*a*) 3 A (*b*) 5 A (*c*) 10 A (*d*) 30 A

32. Which one of the following statements is not true ?

(*a*) In a house circuit, lamps are used in parallel.

(*b*) Switches, fuses and circuit breakers should be placed in the neutral wire

(*c*) An electric iron has its earth wire connected to the metal case to prevent the user receiving a shock

(*d*) When connecting a three-core cable to a 13 A three-pin plug, the red wire goes to the live pin.

33. A car headlamp of 48 W works on the car battery of 12 V. The correct fuse for the circuit of this car headlamp will be :

(*a*) 5 A (*b*) 10 A (*c*) 3 A (*d*) 13 A

34. A 3-pin mains plug is fitted to the cable for a 1 kW electric kettle to be used on a 250 V a.c. supply. Which of the following statement is not correct ?

(*a*) The fuse should be fitted in the live wire

(*b*) A 13 A fuse is the most appropriate value to use

(*c*) The neutral wire is coloured black

(*d*) The green wire should be connected to the earth pin.

35. A TV set consumes an electric power of 230 watts and runs on 230 volts mains supply. The correct fuse for this TV set is :

(*a*) 5 A (*b*) 3 A (*c*) 1 A (*d*) 2 A

36. Circuit Breaker Device which can be used in place of fuse in domestic electric wiring is called :

(*a*) CBD (*b*) DCB (*c*) MCD (*d*) MCB

37. An MCB which cuts off the electricity supply in case of short-circuiting or overloading works on the :

(*a*) chemical effect of current

(*b*) heating effect of current

(*c*) magnetic effect of current

(*d*) electroplating effect of current

Questions Based on High Order Thinking Skills (HOTS)

38. An air-conditioner of 3.2 kW power rating is connected to a domestic electric circuit having a current rating of 10 A. The voltage of power supply is 220 V. What will happen when this air-conditioner is switched on ? Explain your answer.

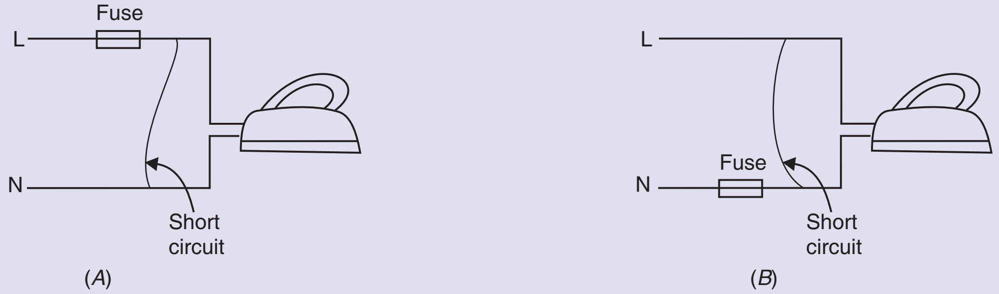
39. Three appliances are connected in parallel to the same source which provides a voltage of 220 V. A fuse connected to the source will blow if the current from the source exceeds 10 A. If the three appliances are rated at 60 W, 500 W and 1200 W at 220 V, will the fuse blow ?

40. A vacuum cleaner draws a current of 2 A from the mains supply.

(*a*) What is the appropriate value of the fuse to be fitted in its circuit ?

(*b*) What will happen if a 13 A fuse is fitted in its circuit ?

41. Which of the following circuits will still be dangerous even if the fuse blows off and electric iron stops working during a short circuit ?



42. An electric kettle rated as 1200 W at 220 V and a toaster rated at 1000 W at 220 V are both connected in parallel to a source of 220 V. If the fuse connected to the source blows when the current exceeds 9.0 A, can both appliances be used at the same time ? Illustrate your answer with calculations.

43. What is the main difference in the wiring of an electric bulb and a socket for using an electric iron in a domestic electric circuit ? What is the reason for this difference ?

44. (*a*) Explain why, it is more dangerous to touch the live wire of a mains supply rather than the neutral wire.

(*b*) Why is it safe for birds to sit on naked power lines fixed atop tall electric poles ?

45. A domestic lighting circuit has a fuse of 5 A. If the mains supply is at 230 V, calculate the maximum number of 36 W tube-lights that can be safely used in this circuit.

ANSWERS

1. Electric fuse **2.** (*i*) 5 A (*ii*) 15 A **4.** (*a*) False (*b*) False **5.** Earth wire **7.** 0 volt **8.** 1 A **10.** Live wire **11.** In series **16.** In parallel **17.** (*a*) live (*b*) body **19.** Cartridge fuse **21.** (*b*) 18 bulbs **23.** (*a*) (*i*) 3.26 A (*ii*) 0.375 kWh (*b*) 5 A **25.** (*a*) 12.5 A (*b*) 13 A fuse **26.** (*b*) MCB **28.** (*c*) **29.** (*c*) **30.** (*d*) **31.** (*b*) **32.** (*b*) **33.** (*a*) **34.** (*b*) **35.** (*d*) **36.** (*d*) **37.** (*c*) **38.** Fuse will blow cutting off the power supply **39.** No **40.** (*a*) 3 A (*b*) A 13 A fuse could allow very high current to flow through the vacuum cleaner during short-circuiting or overloading which can damage the vacuum cleaner **41.** Circuit A is not dangerous after fuse blows because fuse is in live wire ; Circuit B is dangerous even if fuse blows because the fuse is in neutral wire **42.** No **43.** No earth connection for electric bulb ; Earth connection given to socket for electric iron **44.** (*a*) Live wire at high potential of 220 V; Neutral wire at ground potential of 0 V (*b*) Bird's body is not connected to the earth, so no current flows through bird's body into the earth **45.** 31 tube-lights

CHAPTER

3

Sources of Energy

We use heat energy obtained by burning fuels like wood, coal, kerosene or LPG for cooking our food. The energy of fuels like petrol and diesel is used to run cars, buses, trucks and trains. Diesel is also used to provide energy to run pump-sets for irrigation in agriculture. Coal, fuel oil and natural gas are used to provide energy in factories and run thermal power plants. Electrical energy (or electricity) is used for lighting bulbs and tubes, and to run radio, television, household appliances, electric trains and factory machines. In fact, all our everyday activities use energy in one form or the other. And if there is no energy, all our activities will come to a stop. For example, if there is no energy, we won't be able to cook food. If there is no energy, we won't be able to run cars, buses, trucks, trains and aeroplanes. And if there is no energy, we won't be able to run machines in factories, power plants or pump-sets in agriculture. So, energy is essential for our survival in this world. We will now discuss the various sources which can provide us energy.

Figure 1. Coal is one of the most important sources of energy. Burning of coal produces heat energy. This heat energy can be used as such for cooking or heating purposes, or converted into electricity.

A source of energy is one which can provide adequate amount of energy in a convenient form over a long period of time. All the sources of energy can be divided into two main categories : Non-renewable sources of energy and Renewable sources of energy. These are described below.

1. Non-Renewable Sources of Energy

Those sources of energy which have accumulated in nature over a very, very long time and cannot be quickly replaced when exhausted are called non-renewable sources of energy. For example, coal is a non-renewable source of energy because coal has accumulated in the earth over a very, very long time, and if all the coal gets exhausted, it cannot be produced quickly in nature (see Figure 2). The non-renewable sources of energy are : Fossil fuels (Coal, Petroleum and Natural gas), and Nuclear fuels (such as Uranium). **Non-renewable sources of energy are dug out from the earth.**

The non-renewable sources of energy are also called **conventional sources of energy**. The non-renewable sources of energy like fossil fuels (coal, petroleum and natural gas) are present in a limited amount in the earth. Once exhausted, they will not be available to us again. The nuclear fuels (like uranium) have been put in the category of non-renewable sources of energy because the nuclear materials which can be conveniently extracted from the earth are limited and hence they will get exhausted one day. Please note that since the non-renewable sources of energy can get exhausted one day, they are also known as **exhaustible sources of energy**. Another point to be noted is that though nuclear fuels are non-renewable source of energy dug out from the earth, they are *not* conventional source of energy.

Figure 2. Coal is a non-renewable source of energy.

2. Renewable Sources of Energy

Those sources of energy which are being produced continuously in nature and are inexhaustible, are called renewable sources of energy. For example, wood is a renewable source of energy because if trees are cut from the forests for obtaining wood, then more trees will grow in the forest in due course of time. So, the loss of wood by cutting trees is made good by nature (see Figure 3). The renewable sources of energy are : Hydroenergy (Energy from flowing water); Wind energy; Solar energy; Energy from sea (Tidal energy, Sea-wave energy and Ocean thermal energy) ; Geothermal energy ; Biomass energy (Energy from bio-fuels such as Wood, Biogas and Alcohol); and Hydrogen.

The renewable sources of energy are also called **non-conventional sources of energy.** These sources of energy can be used again and again, endlessly. They will never get exhausted. Since renewable sources of energy will never get exhausted, so they are also known as **inexhaustible sources of energy**. A yet another name for renewable sources of energy is the **alternative sources of energy**.

According to the above classification, wood (obtained by the cutting of trees) is a renewable source of energy. Now, a newly planted sapling usually takes more than 15 years to grow and mature into a tree. So, replenishment of cut down trees takes a very long time. Another disadvantage is that the cutting down of trees on a large scale (for obtaining wood) causes depletion of the forests leading to an imbalance in nature. Due to these reasons, using wood as a source of energy is not a wise decision (even though it is a renewable source of energy).

Figure 3. Wood is a renewable source of energy.

What is a Good Source of Energy

Whenever *work* has to be done, *energy* is needed. This energy is supplied by a 'source of energy'. Different sources of energy are used depending on the 'type of work' to be done. Some sources of energy may be good whereas others may not be so good. We can find out whether a given source of energy is good or not by making use of the following 'characteristics' or 'qualities' of a good source of energy. A good source of energy is one :

(*i*) which would do a large amount of work per unit mass (or per unit volume),
(*ii*) which is cheap and easily available,
(*iii*) which is easy to store and transport,

(*iv*) which is safe to handle and use, and

(*v*) which does not cause environmental pollution.

The most common sources of energy available to us are the fuels. These are discussed below.

FUELS

The materials which are burnt to produce heat energy are known as fuels. Examples of fuels are : **Wood, Coal, Cooking gas (LPG), Kerosene, Diesel and Petrol** (see Figure 4). In our day to day life, the most important sources of energy are fuels. Fuels are, in fact, the concentrated store-house of energy. This energy is released in the form of heat when the fuels are burnt. Since a variety of fuels are available to us, we should have some means of deciding which fuel is the best for our purpose. Before we describe some of the characteristics (or properties) of fuels which will help us choose the best possible fuel for a particular use, we should know the meaning of two terms 'calorific value of a fuel' and 'ignition temperature' of a fuel. These are discussed below.

Figure 4. Coal burns to produce heat, so it is a fuel.

All the fuels produce heat energy on burning. Different fuels produce different amounts of heat on burning. Some fuels produce more heat whereas others produce less heat. The usefulness of a fuel is measured in terms of its calorific value. Higher the calorific value, better the fuel will be. **The amount of heat produced by burning a unit mass of the fuel completely is known as its calorific value.** The unit of mass usually taken for measuring the calorific value of a fuel is "gram". So, we can also say that "**The amount of heat produced by burning 1 gram of a fuel completely is called its calorific value**". For example, when one gram of a carbon fuel (like charcoal) is burned completely, it produces about 33000 joules of heat, so the calorific value of charcoal is 33000 joules per gram or 33000 J/g. Since joule is a very small unit of heat energy, so the calorific value is usually expressed as kilojoules per gram (kJ/g). Thus, the calorific value of charcoal becomes 33 kilojoules per gram which is written in short form as 33 kJ/g. Thus, **the common unit of measuring calorific value is kilojoules per gram** (kJ/g). Please note that the *'calorific value' of a fuel represents the 'heat value'* of the fuel. The calorific values of some common fuels are given below.

Calorific Values (or Heat Values) of Some Common Fuels

Fuel		*Calorific value*	*Fuel*		*Calorific value*
1. Dung cakes (*Uple*)	:	6 to 8 kJ/g	8. Petrol	:	50 kJ/g
2. Wood	:	17 kJ/g	9. Biogas	:	35 to 40 kJ/g
3. Coal	:	25 to 30 kJ/g	10. Natural gas	:	33 to 50 kJ/g
4. Charcoal	:	33 kJ/g	11. Cooking gas (LPG)	:	50 kJ/g
5. Alcohol (Ethanol)	:	30 kJ/g	12. Methane	:	55 kJ/g
6. Diesel (and Fuel oil)	:	45 kJ/g	13. Hydrogen gas	:	150 kJ/g
7. Kerosene oil	:	48 kJ/g			

From the above table we find that the calorific value of kerosene oil is 48 kJ/g. Now, **by saying that the calorific value of kerosene oil is 48 kilojoules per gram, we mean that if 1 gram of kerosene oil is burnt completely, then it will produce 48 kilojoules of heat energy.** Actually, the term "calorific value" comes from the fact that the earlier unit of measurement of heat was calorie. These days, although we mostly use joule as the unit of heat but the term calorific value continues to be used as such. If we look up the table of calorific values, we will find that **hydrogen gas has the highest calorific value of 150 kilojoules per gram.** Thus, because of its high calorific value, hydrogen is an extremely good fuel. Most of the common fuels are the compounds of hydrogen and carbon called 'hydrocarbons'. Since hydrogen has the highest calorific value, therefore, a fuel containing higher percentage of hydrogen will have a higher calorific value than another fuel which has a lower percentage of hydrogen in it. For example, LPG has a higher percentage of hydrogen than coal, so LPG has a higher calorific value than coal. We will now describe the ignition temperature of a fuel.

We know that **a fuel has to be burnt to obtain heat energy.** Now, before a fuel can catch fire and burn, it must be heated to a certain minimum temperature. **The minimum temperature to which a fuel must be heated so that it may catch fire and start burning, is known as its ignition temperature.** When we apply a burning matchstick (or a lighter spark) to the burner of a gas stove, we actually supply a little heat to cooking gas coming out of gas burner so that it gets heated to its ignition temperature and start burning. No fuel can burn unless it is heated to its ignition temperature.

Choice of a Good Fuel

The fuel which we choose for our domestic or industrial use should have a high calorific value. This means that the fuel chosen should be such that it gives us more heat per unit mass. The fuel should burn without giving any smoke or harmful gases. In other words, the combustion products produced by the burning of fuel should not be poisonous, and they should not pollute the environment. Carbon dioxide and water vapour are the harmless products produced by the burning of fuels. But some fuels produce poisonous gases like carbon monoxide (CO) and sulphur dioxide (SO_2), etc., which pollute the air around us. The fuel should have a proper ignition temperature which should be well above the normal room temperature.

Figure 5. Natural gas has high calorific value (high heat value) and it burns without producing any smoke or harmful gases, so natural gas is a good fuel.

The fuel which we choose should be cheap and easily available. Another point which we have to keep in mind is that the fuel should be easy to handle, safe to transport and convenient to store. The fuel should have low percentage of non-combustible materials. This means that the residue left behind after the burning of a fuel should be as low as possible. For example, coal is a fuel which leaves behind a lot of ash after burning. The removal and disposal of ash poses a big problem in factories and power plants where large quantities of coal are burnt everyday. The fuel should burn smoothly and at a steady rate. This is because if a fuel burns too fast, then most of the heat produced by it will be wasted. And if the fuel burns too slowly, then the heat produced may not serve our purpose. The fuels should have a low rate of evaporation at room temperature. We will now write down the characteristics of an ideal fuel (or good fuel) point-wise.

Characteristics of an Ideal Fuel (or Good Fuel)

While choosing the most appropriate fuel for our domestic use or for use in industry, we should keep in mind the following characteristics of an ideal fuel or good fuel.

1. **It should have a high calorific value.** In other words, an ideal fuel (or good fuel) is that which gives us more heat per unit mass.
2. **It should burn without giving out any smoke or harmful gases.** That is, an ideal fuel (or good fuel) is that which does not pollute air on burning by giving out smoke or poisonous gases.
3. **It should have a proper ignition temperature,** so that it can be burned easily. The ignition temperature of an ideal fuel (or good fuel) should neither be too low nor too high. Because if the ignition temperature of the fuel is very low, then the fuel will catch fire too easily and hence it will be very unsafe to use it. On the other hand, if the ignition temperature is too high, then it will be very difficult to light the fuel.
4. **It should be cheap and easily available.** That is, an ideal fuel (or good fuel) is that which is not expensive and which is available in plenty everywhere.

5. **It should be easy to handle, safe to transport, and convenient to store.** That is, an ideal fuel (or good fuel) is that which does not create any safety risks during handling, during its transportation from one place to another or during its storage.
6. **It should not leave much ash behind after burning.** That is, an ideal fuel (or good fuel) should have low percentage of non-volatile materials which do not burn, so that it may burn completely without leaving much ash.
7. **It should burn smoothly.** That is, an ideal fuel (or good fuel) should have a moderate rate of combustion, and burn at a steady rate. In other words, the fuel should not burn either too fast or too slow.

From the above discussion we conclude that the various factors which should be kept in mind while choosing a proper fuel for homes and factories are : high calorific value; absence of smoke and harmful gases (or polluting gases) on burning ; proper ignition temperature ; low cost and easy availability ; ease of handling, transportation and storage ; low non-volatile content ; and a moderate rate of combustion. We will now take some examples to decide which of the two given fuels is a better fuel or a more ideal fuel.

Suppose we have two fuels *A* and *B*. The calorific value of fuel *A* is 55 kJ/g and its ignition temperature is 20°C whereas the calorific value of fuel *B* is 50 kJ/g and its ignition temperature is 80°C. Now, we find that fuel *A* has a higher calorific value of 55 kJ/g than that of fuel *B*. So, at first sight it would appear that fuel *A* is a better fuel than fuel *B*. But it is not so. This is because fuel *A* has a very low ignition temperature of 20°C due to which it can catch fire easily and hence it is unsafe to use. On the other hand, though the calorific value of fuel *B* is little less (than that of fuel *A*), but it has the right ignition temperature of 80°C which is neither very low nor very high. So, here fuel *B* will be a better fuel on the basis of its appropriate ignition temperature.

Again suppose that, on burning, fuel *A* produces gases like CO_2, H_2O, CO, SO_2, SO_3, etc., whereas fuel *B* produces only CO_2 and H_2O. Out of these gases carbon monoxide (CO), sulphur dioxide (SO_2) and sulphur trioxide (SO_3) are poisonous gases or harmful gases. Now, since fuel *A* produces poisonous gases like CO, SO_2 and SO_3, on burning, therefore, fuel *A* is not a good fuel. On the other hand, burning of fuel *B* produces only harmless products like carbon dioxide (CO_2) and water vapour (H_2O), so fuel *B* is a better fuel. Similarly, if a fuel burns with an explosion, it will not be a good fuel and if it leaves behind a lot of ash on burning, even then it cannot be a good fuel. Let us solve one problem now.

Sample Problem. The calorific value and ignition temperature of fuel A are 55 kJ/g and 20°C respectively. These values for another fuel B are 50 kJ/g and 80°C respectively. Which of the two will be more ideal fuel if, on burning, the fuel A produces CO_2, SO_2 and SO_3 as by-products while the fuel B produces CO_2 and H_2O ? Give two reasons in support of your answer.

Solution. Fuel B will be a more ideal fuel because of the following reasons :

(*i*) Fuel B has a moderate ignition temperature of 80°C which is neither very high nor very low. On the other hand, the ignition temperature of fuel A is very low (20°C) and hence it is unsafe to use.

(*ii*) Fuel B does not produce any harmful gases on burning. On the other hand, fuel A produces poisonous gases like SO_2 and SO_3 on burning.

Before we go further and describe the conventional sources of energy, **please answer the following questions** :

Very Short Answer Type Questions

1. Name a non-renewable source of energy other than fossil fuels.
2. Define calorific value of a fuel.
3. "The calorific value of cooking gas (LPG) is 50 kJ/g". What does it mean ?
4. Which of the following produces more heat (per unit mass) on burning ?
Coal or LPG

5. Define ignition temperature of a fuel.
6. "The ignition temperature of a fuel is 80°C". What does this mean ?
7. Fill in the following blank with a suitable word :
   The amount of heat produced by burning a unit mass of a fuel completely is known as its ....value.

Short Answer Type Questions

8. What is a source of energy ? What are the two main categories of the sources of energy ?
9. State any four characteristics of a good source of energy.
10. What is meant by a non-renewable source of energy ? Give two examples of non-renewable sources of energy.
11. What is meant by a renewable source of energy ? Give two examples of renewable sources of energy.
12. What is the difference between a renewable and a non-renewable source of energy ? Explain with examples.
13. Why are fossil fuels classified as non-renewable sources of energy ?
14. Name two sources of energy that you think are renewable. Give reason for your choice.
15. Name two sources of energy which you consider to be non-renewable. Give reason for your choice.
16. (*a*) Classify the following into renewable and non-renewable sources of energy :
    Coal, Wind, Tides, Petroleum, Wood, Natural gas
    (*b*) What is the basis of above classification ?
17. Coal is said to be formed from the wood of trees. Why then is coal considered to be a non-renewable source of energy whereas wood is a renewable source of energy ?

Long Answer Type Question

18. (*a*) What is a fuel ? Give five examples of fuels.
    (*b*) What are the characteristics of an ideal fuel (or good fuel) ?
    (*c*) The calorific value and ignition temperature of fuel A are 55 kJ/g and 80°C, respectively. These values for fuel B are 80 kJ/g and 10°C, respectively. On burning, the fuel A produces CO_2 and H_2O while the fuel B produces CO_2, CO and SO_2 . Give three points of relative advantages and disadvantages of these two fuels.

Multiple Choice Questions (MCQs)

19. An example of a renewable source of energy is :
    (*a*) petrol (*b*) natural gas (*c*) biogas (*d*) kerosene
20. A non-renewable source of energy is :
    (*a*) wood (*b*) alcohol (*c*) hydrogen gas (*d*) natural gas
21. Which of the following is not a renewable source of energy ?
    (*a*) wind (*b*) flowing water (*c*) fossil fuels (*d*) fuel wood
22. A good fuel is one which possesses :
    (*a*) high calorific value and low ignition temperature
    (*b*) high calorific value and high ignition temperature
    (*c*) high calorific value and moderate ignition temperature
    (*d*) low calorific value and moderate ignition tempeature
23. The fuel having a calorific value of 55 kJ/g is likely to be :
    (*a*) biogas (*b*) methane gas (*c*) hydrogen gas (*d*) natural gas
24. A newly planted sapling usually grows and matures into a tree in more than :
    (*a*) 50 years (*b*) 25 years (*c*) 45 years (*d*) 15 years
25. Which of the following fuels has the highest calorific value ?
    (*a*) natural gas (*b*) methane gas (*c*) hydrogen gas (*d*) biogas
26. The fuel having the lowest calorific value is :
    (*a*) coal (*b*) wood (*c*) charcoal (*d*) kerosene

27. There are four fuels which all contain only carbon and hydrogen. The fuel having highest calorific value will be one which has :
(*a*) more of carbon but less of hydrgogn (*b*) less of carbon but more of hydrogen
(*c*) equal proportions of carbon and hydrogen (*d*) less of carbon as well as less of hydrogen

28. One of the following is not a characteristic of a good fuel. This is :
(*a*) high calorific value (*b*) no emission of smoke (*c*) smooth burning (*d*) high ignition temperature

29. Which of the following is not a fossil fuel ?
(*a*) coal (*b*) petroleum gas (*c*) biogas (*d*) natural gas

Questions Based on High Order Thinking Skills (HOTS)

30. The calorific values of three fuels A, B and C are 33 kJ/g, 48 kJ/g and 150 kJ/g, respectively. A is solid, B is liquid and C is a gas at room temperature. On combustion, both A and B produce carbon dioxide while C explodes forming steam. B and C leave no residue after combustion while A leaves behind some solid residue. Which one of the three fuels is the most ideal ? Give two reasons to support your answer.

31. Calorific value and ignition temperature of fuel X are 75 kJ/g and 20°C respectively. These values for fuel Y are 50 kJ/g and 75°C respectively. On burning, the fuel Y produces only CO_2 while fuel X produces CO_2 and CO. Which of the two is a better fuel ? Give two reasons to support your answer.

32. The calorific values of five fuels A, B, C, D and E are given below :

A	48 kJ/g
B	17 kJ/g
C	150 kJ/g
D	50 kJ/g
E	30 kJ/g

Which of the fuels could be : (*i*) cooking gas (*ii*) alcohol (*iii*) wood (*iv*) hydrogen (*v*) kerosene ?

33. Arrange the following fuels in the order of decreasing calorific values (keeping the fuel with highest calorific value first) :
Biogas, Kerosene, Wood, Petrol, Hydrogen gas, Methane

34. Arrange the following fuels in the order of increasing calorific values (keeping the fuel with lowest calorific value first) :
LPG, Coal, Alcohol, Dung cakes, Diesel

35. Most of the fuels contain carbon as one of the constituents. Name a fuel which has very high calorific value but does not contain carbon.

ANSWERS

1. Nuclear fuels (like uranium) **4.** LPG **7.** calorific **18.** (*c*) Fuel *A* (*i*) Lower calorific value of 55 kJ/g (Disadvantage) (*ii*) Moderate ignition temperature of 80°C (Advantage) (*iii*) No harmful gases produced (Advantage); Fuel *B* (*i*) High calorific value of 80 kJ/g (Advantage) (*ii*) Very low ignition temperature of 10°C (Disadvantage) (*iii*) Harmful gases like CO and SO_2 produced (Disadvantage) **19.** (*c*) **20.** (*d*) **21.** (*c*) **22.** (*c*) **23.** (*b*) **24.** (*d*) **25.** (*c*) **26.** (*b*) **27.** (*b*) **28.** (*d*) **29.** (*c*) **30.** Fuel *B* is the most ideal fuel; (*i*) Leaves no residue on burning (*ii*) High calorific value of 48 kJ/g (*iii*) Does not burn explosively **31.** Fuel Y is a better fuel ; (*i*) Moderate ignition temperature of 75°C (*ii*) Produces no harmful gas (like CO) on burning. **32.** (*i*) D (*ii*) E (*iii*) B (*iv*) C (*v*) A **33.** Hydrogen gas > Methane > Petrol > Kerosene > Biogas > Wood 34. Dung cakes < Coal < Alcohol < Diesel < LPG **35.** Hydrogen gas

CONVENTIONAL SOURCES OF ENERGY

The traditional sources of energy which are familiar to most people are called conventional sources of energy. The main conventional sources of energy are wood and fossil fuels (like coal, petroleum and natural gas). The fuels derived from wood, coal and petroleum such as charcoal, coke, coal gas, petrol, diesel, kerosene, fuel oil and liquefied petroleum gas (LPG) are also known as conventional sources of energy (or conventional fuels). Even dung cakes (*uple*) is a conventional source of energy in our country.

In ancient times, the energy of flowing water and blowing wind were used through water-mills and wind-mills respectively, for very limited purposes like running flour mills (to grind grain to obtain flour) and water-lifting pumps. The energy of flowing water or wind is no longer used for these purposes. The energy of flowing water and that of wind is now used to generate electricity. So, the energy of flowing water and of wind is now considered to be a non-conventional source of energy (or alternative source of energy). We will now discuss the most commonly used conventional sources of energy called fossil fuels which include coal, petroleum and natural gas. They are also called conventional fuels.

FOSSIL FUELS

A natural fuel formed deep under the earth from the pre-historic remains of living organisms (like plants and animals) is called a fossil fuel. Coal, petroleum and natural gas are fossil fuels. Fossil fuels are dug out from the earth. Besides being used directly in homes, transport vehicles and industry, **fossil fuels are the major source of energy for generating electricity in power plants.** We will first understand how fossil fuels were formed.

How Fossil Fuels Were Formed

The plants and animals which died millions of years ago, were gradually buried deep in the earth and got covered with sediments like mud and sand, away from the reach of oxygen of air. In the absence of oxygen, the chemical effects of pressure, heat and bacteria, converted the buried remains of plants and animals into fossil fuels like coal, petroleum and natural gas. It should be noted that the buried remains of large plants were converted into coal whereas those of small plants and animals were converted into petroleum and natural gas.

Figure 6. A piece of coal showing a fossilled leaf.

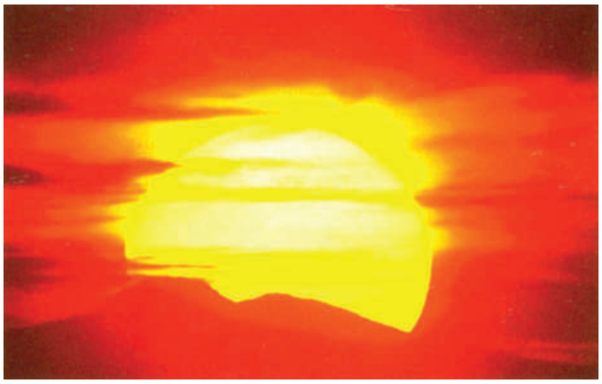


Figure 7. Sun is the ultimate source of fossil fuels.

Sun is the Ultimate Source of Fossil Fuels

We have just seen that fossil fuels have been produced from the remains of plants and animals that were buried in the earth long ago. Actually, **it was the sunlight of long ago that made plants grow, which were then converted into fossil fuels.** This can be explained as follows : The green plants need sunlight energy to grow. They get this energy from sunlight, and store it in the form of carbon compounds. So, every leaf and every bit of wood in the plant was made with the energy of sunlight. The animals also eat plants, so the animal material is also a store-house of sun's energy. These plants and animals which were originally made by using sun's energy have been converted into fossil fuels like coal, petroleum and natural gas. Thus, **fossil fuels are energy-rich compounds of carbon which were originally made by the plants with the help of sun's energy (solar energy).** Without sunlight, there could have been no coal, petroleum, natural gas, wood or any other fuel in this world. Today when we burn coal, petroleum or natural gas, we are actually making use of the sunlight energy that was stored by the plants millions of years ago. We will now discuss the three fossil fuels, coal, petroleum and natural gas, one by one. Let us start with coal.

COAL

Coal is a complex mixture of compounds of carbon, hydrogen and oxygen, and some free carbon. Small amounts of nitrogen and sulphur compounds are also present in coal (see Figure 8). It is found in deep coal mines under the surface of earth. Coal is important because it can be used as a source of energy as such, or it can be converted into other forms of energy like coal gas, electricity and oil (synthetic petrol). The exploitation of coal as a source of energy made the industrial revolution possible.

Figure 8. Coal.

When coal is burnt, the carbon present in coal reacts with the oxygen of air to form carbon dioxide. **A lot of heat is produced during the burning of coal which makes it a good fuel.** The burning of coal, however, produces a lot of smoke which pollutes the air. When coal is subjected to destructive distillation (by heating strongly in the absence of air), then all the volatile material is removed from coal and coke is formed. Coke is 98% carbon. **Coke is a better fuel than coal because it produces more heat (than an equal mass of coal), and it does not produce smoke while burning.** Thus, burning of coke does not cause air pollution. Coke is, however, more valuable when used as a reducing agent in the extraction of metals from their ores.

Uses of Coal

1. Coal is used as a fuel for heating purposes in homes and in industry.
2. Coal is used as a fuel in thermal power plants for generating electricity.
3. Coal is used to make coke. And this coke is then used as a reducing agent in the extraction of metals.
4. Coal is used in the manufacture of fuel gases like coal gas.
5. Coal is used in the manufacture of petrol and synthetic natural gas.

PETROLEUM

Petroleum is a dark coloured, viscous, and foul smelling crude oil (see Figure 9). The name petroleum means rock oil (petra = rock; oleum = oil). It is called petroleum because it is found under the crust of earth trapped in rocks. **The crude oil petroleum is a complex mixture of several solid, liquid and gaseous hydrocarbons mixed with water, salt and earth particles.** It also contains small amounts of other carbon compounds containing oxygen, nitrogen and sulphur. Thus, the crude petroleum oil is not a single chemical compound, it is a mixture of compounds. Petroleum is lighter than water and insoluble in it.

Figure 9. This is petroleum (which is also called crude oil). It is used to obtain fuels like petrol, diesel and kerosene, etc.

Petroleum occurs deep down under the earth between two layers of impervious rocks (non-porous rocks). Natural gas occurs above the petroleum oil trapped under the rocks. Petroleum is obtained by drilling holes (called oil wells) into the earth's crust where the presence of oil has been predicted by survey. When a well is drilled through the rocks, natural gas comes out first with a great pressure and for a time, the crude oil comes out by itself due to gas pressure. After the pressure has subsided, the crude oil is pumped out of the oil well. It should be noted that many wells yield only natural gas but no oil. So, hundreds of wells may have to be drilled into the rocks and tested before getting an oil well from which oil can be produced profitably.

Petroleum is the crude oil which is a complex mixture of alkane hydrocarbons with water, salt and earth particles. Petroleum cannot be used as a fuel as such. So, before petroleum can be used as a fuel for specific purposes, it has to be purified or refined by the process of fractional distillation. **The fractional distillation of petroleum gives us the following fractions which can be used as fuels : Petroleum gas, Petrol (or Gasoline), Diesel, Kerosene and Fuel oil.** The fuel oil obtained from petroleum is sometimes just called 'oil'. The fraction of petroleum called lubricating oil is not used as a fuel.

Petroleum gas is used as a fuel for domestic heating purposes in the form of liquefied petroleum gas (LPG). Petrol is used as a fuel in motor cars, scooters, motor-cycles, and other light vehicles. Diesel is used as a fuel for heavy vehicles like buses, trucks, tractors, and railway engines. Diesel is also used as a fuel to run water-pumps for irrigation purposes, and in diesel generators to produce electricity on a small scale. Kerosene oil is used as a household fuel. For example, kerosene is used in wick stoves or pressure stoves to cook food. Kerosene is also used as an illuminant (for lighting purposes) in hurricane lamps. A special grade of kerosene oil is used as 'aviation fuel' in jet aeroplanes. Fuel oil is used in industries to heat boilers and in furnaces. Fuel oil is also used in thermal power plants for generating electricity. **Fuel oil is a better fuel than coal because fuel oil burns completely and does not leave any residue.** On the other hand, when coal is burned, it leaves behind a lot of ash which has to be removed regularly from the coal furnace.

Petroleum Gas

The main constituent of petroleum gas is butane though it also contains smaller amounts of propane and ethane. Thus, we can say that petroleum gas is a mixture of three hydrocarbons : butane, propane and ethane. Butane, propane and ethane, all burn readily, producing a lot of heat. This makes petroleum gas a very good fuel. Petroleum gas is obtained as a by-product in oil refineries from the fractional distillation of petroleum. It is also produced by the cracking of petrol.

Figure 10. These gas cylinders contain LPG.

Butane, propane and ethane are gases under ordinary pressure (atmospheric pressure) but they can be easily liquefied under pressure. The petroleum gas which has been liquefied under pressure is called Liquefied Petroleum Gas (LPG) (see Figure 10). Thus, **liquefied petroleum gas (or LPG) consists mainly of butane (alongwith smaller amounts of propane and ethane) which has been liquefied by applying pressure.** In other words, **the domestic gas cylinders like Indane contain mainly butane,** with smaller amounts of propane and ethane, under pressure. Petroleum gas is supplied in liquid form so that even a small cylinder may contain a good weight of the gas. A domestic gas cylinder contains about 14 kilograms of LPG (see Figure 10). A strong smelling substance called ethyl mercaptan (C_2H_5SH) is added to LPG cylinders to help in the detection of gas leakage. Ethyl mercaptan has a foul smell resembling that of hydrogen sulphide gas which can be easily detected. The gas used for domestic cooking is called 'Liquefied Petroleum Gas' (LPG) because it is obtained from petroleum and it is liquefied by compression before filling into the cylinders.

Our domestic gas cylinders contain a mixture of liquefied butane, propane and ethane hydrocarbons under pressure. When we turn on the knob of the gas cylinder, the pressure is released and the highly volatile LPG gets converted into gas. This gas goes into the burner of our cooking stove. When a burning matchstick is applied to the burner, the gas burns with a blue flame producing a lot of heat. This heat is used for cooking food.

Advantages of LPG

1. LPG has a high calorific value. So, it is a good fuel. The calorific value of LPG is about 50 kJ/g. That is, when 1 gram of LPG burns in a gas stove, it produces 50 kilojoules of heat energy.

2. LPG burns with a smokeless flame and so does not cause air pollution (see Figure 11).
3. LPG does not produce any poisonous gases on burning.
4. LPG is easy to handle and convenient to store.
5. LPG is a very neat and clean domestic fuel.

Figure 11. LPG burns in a kitchen stove with a smokeless blue flame and hence does not cause any air pollution.

Dangers of LPG

Though LPG is an extremely good domestic fuel but it can be dangerous too. LPG is a highly inflammable gas, that is, it catches fire easily. Any leakage of LPG from the gas cylinder, stove or the rubber pipe (connecting the cylinder and stove) will form an explosive mixture with air in the kitchen. And on lighting the matchstick, an explosion will take place, the whole kitchen will be set on fire and the person working in the kitchen may get burnt. In fact, many such accidents occur quite often and should be avoided by observing a few precautions.

Precautions for Using LPG

1. Before lighting a matchstick we should make sure that there is no foul smell of the leaking gas in the kitchen, near the gas cylinder or gas stove. If we smell gas leakage on entering the kitchen, then the door and windows should be opened at once to allow the gas to escape. This is because, though LPG is not a poisonous gas, but when inhaled in large quantities, it is quite harmful and can even cause death. The gas cylinder, rubber tubing and gas stove should then be checked to find out the source of gas leakage. The gas should be used only when the leakage has been set right by the gas mechanic. We should never light a matchstick or a candle during the leakage of LPG in the kitchen.
2. We should not use any hot flames like a kerosene lamp, kerosene stove or electric heater near the gas cylinder.
3. We should never use a leaking gas cylinder. The Gas Agency should be informed and the leaking gas cylinder replaced at the earliest.
4. We should handle the gas cylinder with care so that its valve does not get damaged.
5. The rubber pipe connecting the gas cylinder to gas stove should be checked periodically for any wear and tear.
6. In order to light the gas stove, we should first open the valve of the cylinder and then turn on the knob of gas stove.
7. In order to put off the gas stove, we should first close the valve of the cylinder and after that the knob of the gas stove should be turned off.
8. When the gas is not being used, the valve of the gas cylinder and the knobs of the gas stove must be kept closed.

NATURAL GAS

Natural gas is another important fossil fuel. Natural gas burns easily and produces a lot of heat. **Natural gas consists mainly of methane (CH_4), with small quantities of ethane and propane.** In fact, natural gas contains upto **95% methane,** the remaining being ethane and propane. **Natural gas occurs deep under the crust of the earth either alone or alongwith oil above the petroleum deposits.** Thus, some wells dug into the earth produce only natural gas, whereas others produce natural gas as well as petroleum oil. **Natural gas is formed under the earth by the decomposition of vegetable matter lying under water. This decomposition is carried out by anaerobic bacteria** in the absence of oxygen. Natural gas is used as a fuel for a number of purposes.

1. Natural gas is used as a domestic and industrial fuel. Natural gas burns readily to produce a lot of heat. So, in many areas natural gas is used as the main fuel for domestic and industrial heating purposes.

2. Natural gas is used as a fuel in thermal power plants for generating electricity.

3. Compressed Natural Gas (CNG) is being used increasingly as a fuel in transport vehicles (like cars, buses and trucks) (see Figure 12). It is a good alternative to petrol and diesel because it does not cause any air pollution.

Figure 12. CNG being filled in a car at a Filling Station.

Advantages of Natural Gas

1. Natural gas being a complete fuel in itself can be used directly for heating purposes in homes and industries. There is no need to add anything else to it.
2. Natural gas is a good fuel because it has a high calorific value of up to 50 kJ/g. Moreover, natural gas burns with a smokeless flame and causes no air pollution. It also does not produce any poisonous gases on burning. Natural gas is, therefore, an environment friendly fuel as compared to other fossil fuels.
3. A great advantage of natural gas is that it can be supplied directly from the gas wells to the homes and factories for burning through a net-work of underground pipelines, and this eliminates the need for additional storage and transport.

Thermal Power Plant

An installation where electricity (or electrical power) is generated is called a power plant. A power plant is also called a power house or power station. **A power plant in which the heat required to make steam to drive turbines (to make electricity) is obtained by burning fuels (coal, oil or gas) is called thermal power plant.** We will now decribe how fossil fuels are used to produce electricity.

Coal (fuel oil or natural gas) is burned in a furnace *F* to produce heat (see Figure 13). This heat boils the water in a boiler *B* to form steam. The steam formed from the boiling water builds up a pressure. The hot steam at high pressure is introduced into a turbine chamber *C* having a steam turbine *T*. The steam passes over the blades of the turbine as a high pressure jet making the turbine rotate (see Figure 13). The shaft *S*

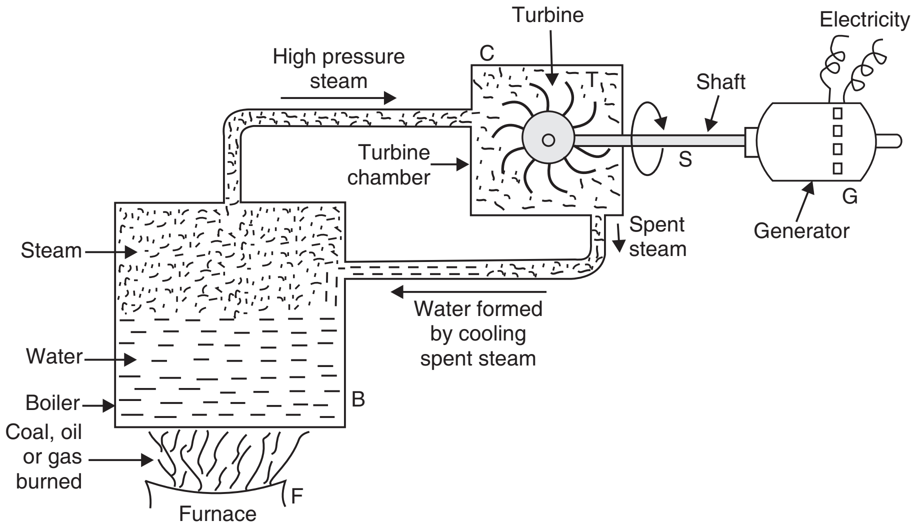


Figure 13. The principle of working of a thermal power plant.

of turbine is connected to a generator *G*. When the turbine rotates, its shaft also rotates and drives the generator. The generator produces electricity. The spent steam coming out of turbine chamber is cooled.

On cooling, steam condenses to form water. This water is again sent to the boiler to form fresh steam. This process is repeated again and again.

Since it is easier to transmit electricity over long distances than to carry coal (oil or gas) over the same distance, therefore, many thermal power plants are established near coal fields (or oil fields). **We produce a major part of our electricity by burning fossil fuels.** Due to this, large amounts of fossil fuels (coal, oil and gas) are being burnt everyday at thermal power plants to generate electricity. Because our supplies of coal, oil and gas are running out at a rapid rate, and because of the pollution caused by burning fossil fuels, other ways of generating electricity must be found. Please note that electricity is not a fuel. It is a form of energy. At thermal power plants, it is the chemical energy of fossil fuels (coal, oil and gas) which is transformed into electrical energy.

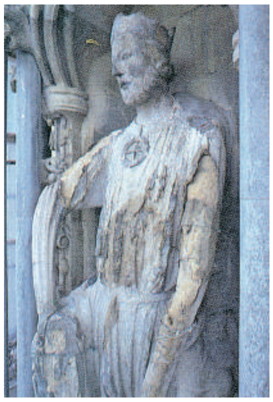
Pollution Caused by Fossil Fuels

The main disadvantage of using fossil fuels is that the burning (or combustion) of fossils fuels causes a lot of pollution in the environment. This is explained below.

1. The burning of fossil fuels produces acidic gases such as sulphur dioxide and nitrogen oxides. These acidic gases cause acid rain. The acid rain damages trees and plants (crops, etc.), reduces fertility of soil by making it acidic, and poses a danger to aquatic life (like fish) by making the water of lakes and rivers acidic. Acid rain damages buildings by corroding them slowly. The monuments made of marble stone and statues are also damaged by acid rain. The burning of fossil fuels also puts a poisonous gas, carbon monoxide, into air.

(*a*) The leaves of these forest trees have been damaged by acid rain

(*b*) These fish have been killed by the high acidity of lake water caused by acid rain



(*c*) This statue has been damaged by acid rain

Figure 14. Some of the harmful effects of acid rain produced by the burning of fossil fuels.

2. The burning of fossil fuels produces large amount of carbon dioxide which goes into air. Though carbon dioxide gas is not harmful immediately, it damages the environment in the long run. The presence of increasing amounts of carbon dioxide gas in the atmosphere is causing increased greenhouse effect leading to excessive heating of the earth. This is harmful for all the life on earth.

3. The burning of fossil fuels (especially coal) produces smoke which pollutes the air.

4. The burning of coal leaves behind a lot of ash. It also puts tiny particles of ash (called fly-ash) into the air causing air pollution.

Controlling Pollution Caused by Fossil Fuels

The pollution caused by burning fossil fuels can be controlled (or reduced) to some extent by increasing the efficiency of the combustion process, and by using various techniques to reduce the escape of harmful gases and ash into the surrounding air. This will become clear from the following discussion.

1. The pollution of air caused by burning petroleum fuels (like petrol and diesel) in vehicles can be controlled by fitting the vehicles with catalytic converters (see Figure 15). The catalytic converter is a device which changes the harmful gases coming from the engine of a car into harmless gases before releasing them into air. For example, the catalytic converter brings about the complete combustion of the poisonous gas carbon monoxide to form carbon dioxide which is not poisonous at all. It also changes harmful nitrogen oxides into harmless nitrogen gas. The catalytic converter is fitted in the exhaust system of a vehicle (like a car).

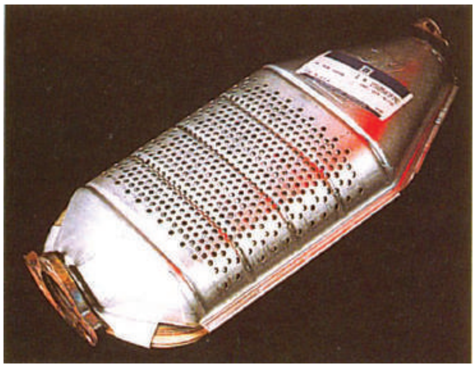


Figure 15. A catalytic converter.

2. The pollution of air caused by burning coal in thermal power plants and factories can be controlled by washing down the smoke and acidic gases by water in a scrubber. Scrubbers are tanks where the smoke and waste gases produced by thermal power plants and factories, etc., are sprayed by jets of water before they reach the chimney. Water washes away soot (carbon) present in smoke and dissolves most of the harmful acidic gases like sulphur dioxide and nitrogen oxides.

3. The pollution of air caused by burning coal in thermal power plants and factories can also be controlled by installing electrostatic precipitators in their chimneys. When an electrostatic precipitator is installed in the chimney, then the unburnt carbon particles and fly-ash particles present in smoke keep on depositing on the inner walls of the chimney and do not go into air. The 'deposit' of carbon and fly-ash particles can be removed by sweeping the chimney from time to time.

Effect of Industrialisation

All the factories and companies which are engaged in the process of manufacturing goods from raw materials, taken together, are called an industry. The process of developing industries in a country on a large scale is called industrialisation. Industrialisation has led to a better quality of life of the people all over the world. But the setting up of industries and running them needs energy. So, **the increasing industrialisation has caused the demand for energy to grow at a tremendous rate.** At present, the growing demand for energy is largely met through the use of fossil fuels : coal, petroleum and natural gas.

The fossil fuels have been used at such a fast pace in the past that only limited reserves of these fuels are now left in the earth. Even today, we are mainly dependent on the fossil fuels for our energy needs. If we continue to consume fossil fuels at such a rapid rate, they will soon get exhausted. And since fossil fuels, which we are using today, were formed very, very slowly over the past millions of years, so once exhausted they will not be available to us in the near future. This will create an energy crisis. In order to avoid running out of fossil fuels and face an energy crisis, we should explore alternative sources of energy which do not depend on the fuels dug out from the earth. This will help us conserve fossil fuels for a much longer time to come. Thus, **we are looking at the alternative sources of energy because of the following reasons :** (*i*) The fossil fuel reserves in the earth are limited which may get exhausted soon if continued to be used at the current rate, (*ii*) The use of alternative sources of energy will reduce pressure on fossil fuels making them last for a much longer time, and (*iii*) By using alternative sources of energy, the pollution being caused by the burning of fossil fuels can be avoided. Before we go further and study the alternative sources of energy, **please answer the following questions :**

Very Short Answer Type Questions

1. Name the product of petroleum that is used to drive heavy vehicles.
2. Give one example of a good domestic fuel.
3. Name any one hydrocarbon fraction obtained during the fractional distillation of petroleum which is used as a domestic fuel.
4. What are the various fuels which are used to generate electricity in a thermal power plant ?
5. Name any four fractions obtained from petroleum which are used as fuels.

6. What is the composition of liquefied petroleum gas (LPG) ?
7. Which gaseous fuel is being used increasingly in transport vehicles like cars and buses these days ?
8. Write the full form of : (*i*) LPG, and (*ii*) CNG.
9. What is the main constituent of :
   (*i*) petroleum gas ?
   (*ii*) natural gas ?
10. Name the component which is found in natural gas as well as in biogas.
11. State two important uses of natural gas.
12. State one important use of CNG these days.
13. Complete the following sentence :
    Domestic gas cylinders like Indane contain mainly...........

Short Answer Type Questions

14. Explain why, natural gas is considered to be a good fuel.
15. What is meant by conventional sources of energy ? Write the names of two conventional sources of energy.
16. Explain the principle of working of a thermal power plant. Draw a labelled diagram to illustrate your answer.
17. What are the disadvantages of burning fossil fuels ?
18. Write a short note on the pollution caused by burning fossil fuels.
19. What are the various steps which can be taken to control (or reduce) pollution caused by burning fossil fuels ?
20. If you could use any source of energy for heating your food, which one would you use and why ?
21. Why is LPG considered a good fuel ?
22. Why is LPG considered a better fuel than coal ?
23. Why is the leakage of LPG detected easily although it is odourless ? State the steps to be taken in case its leakage is detected in the kitchen.

Long Answer Type Question

24. (*a*) What are fossil fuels ? Give three examples of fossil fuels.
    (*b*) Describe how fossil fuels were formed.
    (*c*) Explain how, sun is considered to be the ultimate source of fossil fuels.
    (*d*) Which fossil fuels were formed by the buried remains of small plants and animals ?
    (*e*) Which fossil fuel was formed by the buried remains of large land plants ?

Multiple Choice Questions (MCQs)

25. The main constituent of petroleum gas is :
    (*a*) methane (*b*) ethane (*c*) butane (*d*) propane
26. The natural gas consists mainly of :
    (*a*) methane (*b*) ethane (*c*) propane (*d*) butane
27. Which of the following is not produced by the burning of fossil fuels ?
    (*a*) nitrogen oxides (*b*) sulphur oxides (*c*) sodium oxides (*d*) carbon oxides
28. The product of petroleum used to drive heavy vehicles like trucks is :
    (*a*) petrol (*b*) kerosene (*c*) diesel (*d*) petroleum gas
29. The aviation fuel which is used in the engines of jet aeroplanes is :
    (*a*) diesel (*b*) kerosene (*c*) petrol (*d*) CNG
30. The ultimate source of energy stored in fossil fuels is :
    (*a*) moon (*b*) earth (*c*) sun (*d*) sea
31. Which of the following is not a fossil source of energy ?
    (*a*) kerosene oil (*b*) cow-dung cakes (*c*) CNG (*d*) coal
32. The fuel which is not used at thermal power plants is :
    (*a*) coal (*b*) uranium (*c*) natural gas (*d*) fuel oil

33. LPG consists mainly of :
(*a*) butane (*b*) ethane (*c*) butanone (*d*) methane

34. Coke is more valuable when used :
(*a*) as a fuel for industrial boilers (*b*) as an oxidising agent
(*c*) as a reducing agent (*d*) as a fuel in domestic ovens

35. Coal cannot be converted into one of the following forms of energy. This is :
(*a*) coal gas (*b*) electricity (*c*) oil (*d*) charcoal

36. One of the following does not contribute to acid rain. That is :
(*a*) nitrogen monoxide (*b*) sulphur dioxide
(*c*) carbon monoxide (*d*) carbon dioxide

Questions Based on High Order Thinking Skills (HOTS)

37. Fossil fuels are energy rich compounds of an element X which were originally made by the plants with the help of sun's energy.
(*a*) Name the element X.
(*b*) Name another element which is usually found in combination with X in fossil fuels.

38. The energy in petrol originally came from the sun. Explain how it got into petrol.

39. A substance X is added to LPG cylinders while filling so as to make the detection of leakage of LPG from the cylinders easy.
(*a*) Name the substance X.
(*b*) How does substance X make the detection of leakage of LPG easy ?

40. The pollution of air caused by burning petroleum fuels (like petrol and diesel) in vehicles can be controlled by fitting a device X in the exhaust system of vehicles.
(*a*) Name the device X.
(*b*) How does this device help in controlling air pollution ?

ANSWERS

1. Diesel **2.** Liquefied petroleum gas (LPG) **3.** Kerosene **7.** Compressed natural gas (CNG) **10.** Methane **13.** butane **20.** LPG ; High calorific value ; Burns with smokeless flame **24.** (*d*) Petroleum and Natural gas (*e*) Coal **25.** (*c*) **26.** (*a*) **27.** (*c*) **28.** (*c*) **29.** (*b*) **30.** (*c*) **31.** (*b*) **32.** (*b*) **33.** (*a*) **34.** (*c*) **35.** (*d*) **36.** (*c*) **37.** (*a*) Carbon (*b*) Hydrogen **39.** (*a*) Ethyl mercaptan (*b*) Ethyl mercaptan has a foul smell which can be detected easily **40.** (*a*) Catalyltic converter (*b*) Changes poisonous carbon monoxide into non-poisonous carbon dioxide ; Converts harmful nitrogen oxides into harmless nitrogen gas.

ALTERNATIVE SOURCES OF ENERGY
(Non-Conventional Sources of Energy)

Those sources of energy which are not based on the burning of fossil fuels or the splitting of atoms of nuclear fuels, are called alternative sources of energy (or non-conventional sources of energy). We know that both fossil fuels as well as nuclear fuels are dug from the earth, so we can also say that : Those sources of energy which do not use fuels dug from the earth are called alternative sources of energy. The examples of alternative sources of energy are : Hydroelectric energy, Wind energy, Solar energy, Biomass energy, Energy from the sea (Tidal energy, Sea-wave energy, Ocean thermal energy), and Geothermal energy. The scientists have started showing renewed interest in exploring and using the alternative sources of energy due to two reasons : (*i*) because the fossil fuels and nuclear fuels in the earth are limited which may not last for long, and (*ii*) because of the undesirable effects of pollution both from the burning of fossil fuels and from the radioactive nuclear wastes of nuclear power plants. We will now describe all the alternative sources of energy, one by one. Let us start with hydroelectric energy.

HYDROELECTRIC ENERGY

Flowing water possesses kinetic energy. The energy of flowing water has been traditionally used for rotating the water-wheels and drive water-mills to grind wheat to make flour. **The traditional use of energy of flowing water has been modified by improvements in technology and used to generate electricity.** This is done by establishing hydro-power plants. At hydro-power plants, the energy of falling water (or flowing water) is tapped by using a 'water turbine' and then made to drive generators. We will now describe a hydro-power plant in detail.

Hydro-Power Plant (or Hydroelectric Power Plant)

A power plant that produces electricity by using flowing water to rotate a turbine (which drives the generator), is called hydro-power plant (or hydroelectric power plant). The electricity produced by using the energy of falling water (or flowing water) is called hydroelectricity. A hydro-power plant produces electricity as follows.

Rain falling on the high ground in hilly areas flows down as rivers. In order to produce electricity, a high-rise dam *D* is built to stop the flowing river water (see Figure 16). Due to this, a large lake or reservoir *R* builds up behind the dam. As more and more water collects in the reservoir, the level of water behind the dam rises to a large height. In this way, the kinetic energy of the flowing river water is converted into the potential energy of water stored behind the dam. Thus, the water stored behind a tall dam has a lot of potential energy (due to its great height).

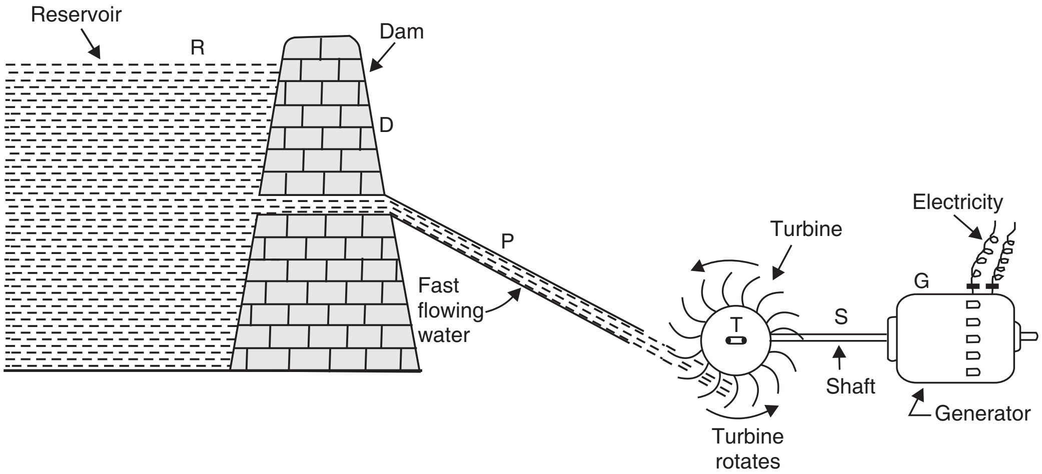


Figure 16. The principle of working of a hydro-power plant.

The sluice gates (sliding gates) at half the height of dam are opened to allow some of the stored water to escape. This water is taken through pipe *P* to the turbine *T* installed at the bottom of the dam (see Figure 16). Since the water falls down through a large height from the dam, it flows very fast (its potential energy is changed into kinetic energy). A high pressure jet of fast flowing water pushes on the blades of turbine with a great force and makes the turbine rotate rapidly. The turbine is connected to generator through its shaft *S*. When the turbine rotates, its shaft also rotates and drives the generator. The generator produces electricity.

When the hydroelectric generator works and produces electricity, water flows out of the dam continuously and the level of water in the reservoir falls slowly. The reservoir is filled up again by the rain water brought in by the rivers. Please note that since water in the dam reservoir needed for generating electricity is refilled each time it rains, therefore, hydroelectric power is a renewable source of energy. It will never get exhausted. Another point to be noted is that water to the turbine is taken from a point midway up the dam (see Figure 16), so that the generators continue to work even if the water level in the reservoir falls below normal.

A hydro-power plant converts the potential energy of water stored in the reservoir of a tall dam into electric energy. The dams for generating hydroelectricity can be built only in a limited number of places, usually in the hilly areas or at the foothill (where the water can fall from a considerable height). At present, of the total electric power generated in our country, almost one-fourth is contributed by hydroelectricity.

Figure 17. A hydroelectric power station. We can see the dam and reservoir clearly.

Figure 18. The turbines inside a hydroelectric power station which rotate by the force of fast flowing water.

Advantages of Generating Hydroelectricity

The advantages of using the energy of flowing water for the generation of electricity are the following :

(*i*) The generation of electricity from flowing water does not produce any environmental pollution.

(*ii*) Flowing water is a renewable source of electric energy which will never get exhausted.

(*iii*) The construction of dams on rivers helps in controlling floods, and in irrigation.

Disadvantages of Generating Hydroelectricity

The production of hydroelectric power by constructing high-rise dams on rivers has certain problems associated with it. Some of these are given below.

1. Large areas of agricultural land, a vast variety of flora and fauna (plants and animals) as well as human settlements (or villages) get submerged in the water of reservoir formed by the dam. Due to this many plants and trees are destroyed, animals get killed and many people are rendered homeless. This creates the problem of satisfactory rehabilitation of the people displaced from the dam site.

2. Large eco-systems are destroyed when land is submerged under the water of reservoir of a dam. The construction of dam on a river also disturbs the ecological balance in the downstream area of the river. For example, due to the construction of dam there are no annual floods in the river. And because of this the soil of downstream region does not get nutrient-rich "silt". This decreases the fertility of soil in the downstream area and finally the crop yields also decrease.

3. Due to the construction of dam on the river, the fish in the downstream area do not get sufficient nutrient materials due to which the production of fish decreases rapidly (because the fish nutrients remain trapped in the reservoir formed by the dam).

4. The vegetation which is submerged under water at the dam site rots under anaerobic conditions and produces a large amount of methane which is a greenhouse gas (and hence harmful for the environment).

The opposition to the construction of Tehri Dam on the river Ganga and Sardar Sarovar Project on the river Narmada are due to such problems. So, before taking a decision to generate hydroelectricity by constructing high-rise dams on rivers, it is necessary to consider its long-term effects on the environment and social life carefully.

The energy of flowing water is called hydroenergy. The energy of flowing water (or hydroenergy) is in fact an indirect source of solar energy. This is because it is the solar energy which recirculates water in nature in the form of water-cycle. It is this water which then flows in the rivers and makes water-energy available to us.

WIND ENERGY

Moving air is called wind. Wind has energy. The energy possessed by wind is due to its high speed (or motion). So, **the wind possesses kinetic energy.** It is this kinetic energy of wind which is utilised for doing work. Solar energy (or sun's energy) is responsible for the blowing of wind. Wind blows due to the uneven heating of earth by the sun in different regions. So, wind energy comes from the sun in an indirect way.

The energy of wind is harnessed by using a windmill. A windmill consists of big sized, table fan like blades which are fixed over the top of a tall pole in such a way that they are free to rotate. When the fast moving wind strikes on the blades of windmill, it makes them rotate continuously. The rotatory motion of the windmill is then used to do mechanical work through a shaft connected to the rotating blades.

In the past, wind energy was used through windmills to pump water (or lift water) from a well and to grind wheat into flour. This happened as follows : When the blades of windmill rotate by the force of wind, a shaft connected to them also rotates. This rotating shaft was made to run a water pump to lift water from a well by a suitable mechanism. It could also turn the mill-stones of a flour mill. **The traditional use of wind energy has now been modified by the improvement in technology to generate electricity through wind-powered generators.** This is explained below.

Wind Generator

The windmill used for generating electricity is called a wind turbine, and the complete set-up of generating electricity by using wind energy is called 'wind generator'. We will now describe a wind powered electric generator in somewhat detail.

A wind generator which is used to generate electricity by using wind energy is shown in Figure 19. When the fast moving wind strikes the blades of wind turbine, then the wind turbine starts rotating continuously. The shaft of wind turbine is connected to a small generator. When the wind turbine rotates, its shaft also rotates and drives the generator. The generator produces electricity.

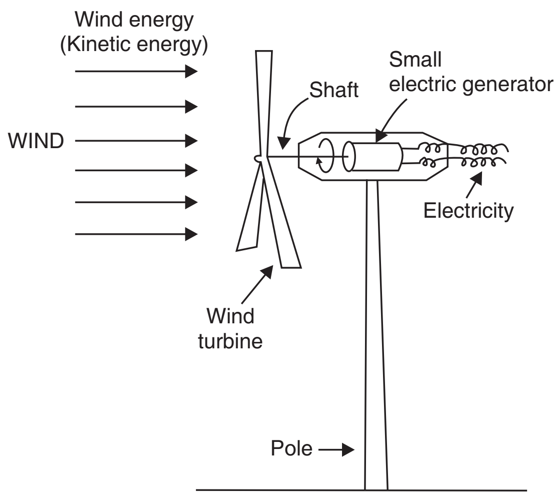


Figure 19. A wind-powered electric generator.

The electricity generated by a single wind turbine is quite small (because a single wind turbine can run only a small generator). So, in order to generate a large amount of electricity, a large number of wind turbines are erected over a big area of land. Such a set-up of having a large number of wind turbines working at a place to generate electrical energy on a large scale is called a wind energy farm (see Figure 20). The small electricity generated by each wind generator is combined together to obtain electricity on a large scale.

An important **advantage of using wind energy** for generating electricity is that its use does not cause any pollution. Another advantage is that wind energy is a renewable source of energy which will never get exhausted. As long as the sun keeps shining, the wind will keep blowing and provide us energy. The increased use of wind energy for generating electricity will help us conserve fossil fuels (like coal, petroleum and natural gas) so that they may last longer. Moreover, wind energy is available free of cost !

Some of the **limitations of harnessing wind energy** for generating electricity are as follows :

(*i*) Wind energy farms cannot be established everywhere. The wind energy farms can be established only at those places where wind blows for most part of the year.

(*ii*) The wind required for generating electricity should be strong and steady to maintain the desired level of generation. The minimum wind speed necessary for satisfactory working of a wind generator is about 15 km/h. This is not always so.

(*iii*) The wind energy farms require a large area of land.

(*iv*) The setting up of wind energy farms is very expensive.

The wind-power potential of our country is estimated to be about 45,000 MW. This means that if India's wind energy is fully harnessed, then 45,000 megawatt of electrical power can be generated. At present we are generating more than 1025 MW of electricity from wind energy. This is going to increase soon when some more wind energy farms start working. The largest wind energy farm established near Kanyakumari in Tamil Nadu can generate 380 MW electricity. India is ranked *fifth* in the world for harnessing wind energy for the production of electricity. The *first* position is occupied by Germany. Denmark is, however, called the country of 'winds' because more than 25% of the electricity needs of Denmark are met by utilising wind energy.

Figure 20. A large number of wind turbines at a wind energy farm.

SOLAR ENERGY

The sun is the source of all energy. The sun provides us heat and light energy free of cost ! **The energy obtained from the sun is called solar energy** (see Figure 21). The nuclear fusion reactions taking place inside the sun keep on liberating enormous amounts of heat and light energy. This heat and light energy is radiated by the sun in all directions in the form of solar energy. The sun has been radiating an enormous amount of energy at the present rate for nearly 5 billion years (5×10^9 years) and will continue radiating energy at that rate for about 5 billion years more. Since the sun is very, very far away, only a small fraction of the solar energy radiated by the sun reaches the outer layer of the earth's atmosphere. A little less than half (about 47 per cent) of solar energy which falls on the periphery (top surface) of the atmosphere actually reaches the surface of earth (the rest of solar energy is reflected back into space by the atmosphere and also absorbed by the atmosphere as it comes down through it towards the surface of earth).

The solar energy which reaches the earth is absorbed by land and water-bodies (like rivers, lakes and oceans), and plants. The solar energy trapped by land and water-bodies causes many phenomena in nature like winds, storms, rain, snowfall, and sea-waves, etc. And the plants utilise solar energy to prepare food by the process of photosynthesis.

India is fortunate to receive solar energy for greater part of the year. It has been estimated that India receives solar energy equivalent to more than 5000 trillion kWh (5000×10^{18} kWh) during a year. Under clear cloudless sky conditions, the daily average of solar energy varies from 4 to 7 kWh/m^2 in our country.

Figure 21. The energy obtained from the sun is called solar energy.

Solar Constant

The energy that the near earth space receives from the sun is about 1.4 kilojoules per second per square metre, and this quantity is called the **solar constant.** We can define the solar constant as follows : **The amount of solar energy received per second by one square metre area of the near earth space (exposed perpendicularly to the rays of the sun) at an average distance between the sun and the earth, is called solar constant.** Thus, the solar constant tells us the amount of energy which falls in 1 second on a 1 square metre area of the near earth space at an average distance between the sun and the earth. The value of solar constant is 1.4 kJ/s/m^2 or 1.4 kW/m^2 (because : 1 kJ/s = 1 kW).

Solar Energy Devices

The sun is one of the major sources of renewable energy. Solar energy consists of heat and light. Scientists have made a number of devices which help in utilising the solar energy directly in our everyday life. The devices which work by using solar energy (or sun's energy) are : Solar cooker, Solar water heater, and Solar cell.

A device which gets heated by using sun's heat energy is called a solar heating device. A solar cooker and solar water heater are solar heating devices. Though a large amount of sun's heat energy falls on the earth but it is very much diffused (spread over a large area) and not concentrated. So, in order to use sun's heat energy for heating purposes, we have to collect and concentrate it.

All the solar heating devices are designed in such a way that they help in collecting as much sun's heat rays as possible. This is done by using a black painted surface, a glass sheet cover, and in some cases also a plane mirror reflector. A black painted surface is used because black surface absorbs more heat rays of the sun than a white surface. A glass sheet is used as a cover in solar heating devices because a glass sheet traps more and more of sun's heat rays by producing greenhouse effect. A plane mirror reflector is used (in solar cooker) to increase the area over which solar energy is collected so that more heat rays of the sun may enter the solar cooker box. Keeping these points in mind we will now describe the construction and working of a solar cooker in detail.

Solar Cooker

The solar cooker is a device which is used to cook food by utilising the heat energy radiated by the sun. A solar cooker consists of an insulated metal box or wooden box which is painted all black from inside (see Figure 22). There is a thick glass sheet cover over the box and a plane mirror reflector is also attached to the box as shown in Figure 22. The food to be cooked is put in metal containers which are painted black from outside. These metal containers are then placed inside the solar cooker box and covered with the glass sheet. We will now describe how the solar cooker works.

In order to cook food, the solar cooker is kept in sunshine, outside the house. The reflector of solar cooker is adjusted in such a way that it faces the sun. When the sun's rays fall on the reflector, the reflector sends them to the top of solar cooker box in the form of a strong beam of sunlight. The sun's heat rays pass through the glass sheet cover and get absorbed by the black inside surface of the cooker box. Once the sun's heat rays enter the cooker box, then the glass sheet cover does not allow them to go back. In this way, more and more heat rays of the sun get trapped in the box due to which the temperature in the solar cooker box rises to about 100°C to 140°C in two to three hours. This heat cooks the food materials kept in the black containers. For example, **the food materials like rice, pulses *(dal)* and vegetables can be cooked in a box-type solar cooker**.

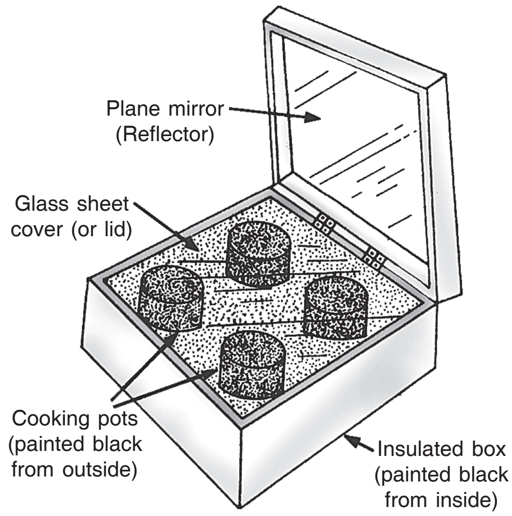


Figure 22. A box-type solar cooker.

The box-type solar cooker can be used to cook only those food materials which require slow heating. The box-type solar cooker cannot be used to cook those foods where strong heating is required. For example, the box-type solar cooker cannot be used for baking (*chapattis*, etc.) and for frying because they require stronger heating. In order to achieve higher temperatures required for baking and frying, spherical reflector-type solar cooker (having a concave reflector) is used. When a concave mirror reflector is attached to a solar cooker, it converges a large amount of sun's heat rays at its focus due to which a high temperature is produced in the focus area (which is suitable for baking and frying). Thus, a concave mirror reflector is best suited for use in a solar cooker. We will now give the advantages and limitations of a solar cooker.

The important **advantages of a solar cooker** for cooking food are the following :

(*i*) The use of solar cooker for cooking food saves precious fuels like coal, kerosene and LPG.

(*ii*) The use of solar cooker does not produce smoke due to which it does not pollute air.

(*iii*) When food is cooked in solar cooker, its nutrients do not get destroyed. This is because in a solar cooker, food is cooked at a comparatively lower temperature.

(*iv*) In a solar cooker, up to four food items can be cooked at the same time.

Some of the important **limitations (or disadvantages) of a solar cooker** are given below :

(*i*) The solar cooker cannot be used to cook food during night time (because sunshine is not available at that time).

(*ii*) If the day-sky is covered with clouds, even then solar cooker cannot be used to cook food.

(*iii*) The direction of reflector of solar cooker has to be changed from time to time to keep it facing the sun.

(*iv*) The box-type solar cooker cannot be used for baking (making *chapattis*, etc.) or for frying.

Figure 23. Solar water heater fitted on the roof of a house.

If a coil of copper tube painted black from outside is placed in a box similar to that of solar cooker, it will work as a solar water heater. This is because when water is passed through the copper coil, it will absorb sun's heat rays and become hot. Solar water heaters are used to supply hot water in big buildings like hotels and hospitals. A solar water heater cannot be used to get hot water during the night or on a cloudy day. Let us solve one problem now.

Sample Problem. A student constructed a model of box-type solar cooker. He used a transparent plastic sheet to cover the open face of the box. He found that this cooker does not function well. What modification should he make to enhance its efficiency ? Give reason.

Solution. Instead of using a plastic sheet, the student should use a transparent glass sheet to cover the open face of the box. This is because a glass sheet can trap the heat rays of the sun very effectively by producing greenhouse effect. A transparent plastic sheet cannot do that.

Solar Cells

Solar cells use the energy in sunlight to produce electricity. Thus, **solar cell is a device which converts solar energy (or sun's energy) directly into electricity.** Since solar energy is also called sunlight energy, so we can also say that *a solar cell converts sunlight energy into electrical energy*. We will now discuss the solar cell in somewhat detail.

A solar cell is usually made from silicon. A simple solar cell consists of sandwich of a 'silicon-boron layer' and a 'silicon-arsenic layer' (see Figure 24). The amount of boron and arsenic present in the two silicon layers is, however, very small. A small piece of wire is soldered into the top of upper layer of cell and another piece of wire is soldered at the bottom of the lower layer (to tap the current).

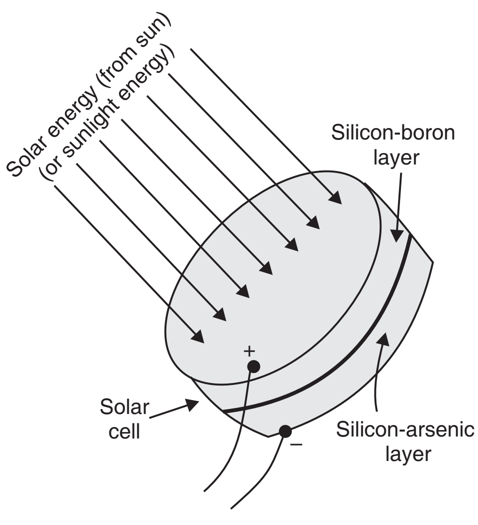


Figure 24. A solar cell.

The solar cell is covered with a glass cover or a transparent plastic cover for protection. When sunlight falls on the surface of solar cell, it makes the loosely held electrons in the silicon atoms move due to which a current begins to flow in the wires connected to the top and bottom of the solar cell. The strength of current produced depends on the brightness of the light and the efficiency of solar cell. A potential difference (or voltage) of about 0.5 V is generated between the top and bottom surface of a solar cell. At present, the best designed solar cells can generate 240 W/m^2 in bright sunlight, with a maximum efficiency of about 25%.

A single solar cell can produce only a small amount of electricity. In those cases where more electrical power is needed, a large number of solar cells are joined together in series. This group of solar cells is called a 'solar cell panel'. Thus, **a solar cell panel consists of a large number of solar cells joined together in a definite pattern** (see Figure 25). A solar cell panel can provide much more electric power than a single solar cell. The various solar cells in a solar cell panel are joined together by using connecting wires made of silver metal. This is because silver is the best conductor of electricity. The use of silver for connecting solar cells makes it more expensive but it increases the efficiency of solar cell panel. At many places, the solar cell panels are mounted on specially designed inclined roofs so that more solar energy (or sunlight) is incident on them.

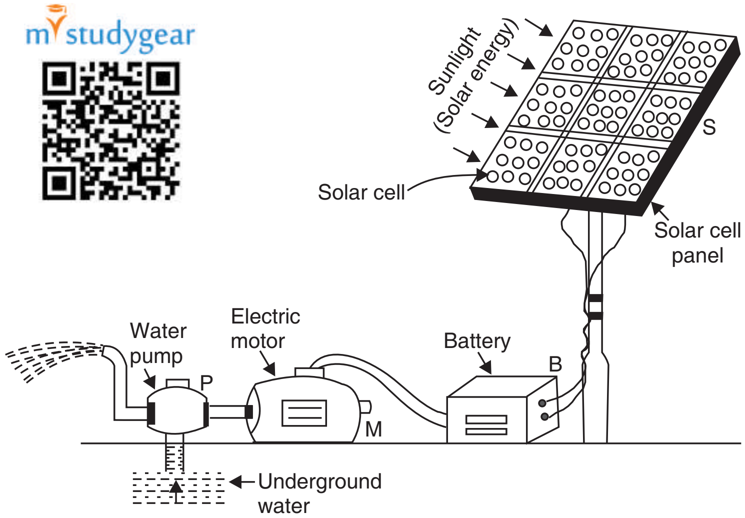


Figure 25. A solar cell panel is being used for running a water pump in a remote and inaccessible village where power transmission lines do not exist.

Solar cell panels can provide electricity at all those places where the usual electricity is not available. For example, solar cell panels are used to provide electricity in remote and inaccessible rural areas. This electricity is used there for lighting purposes, to run radio and TV sets and to operate water pumps for irrigation of fields. In Figure 25, a solar cell panel is being used for running a water pump for irrigation in a distant village. The solar cell panel *S* has hundreds of solar cells joined together. The electricity produced by this solar cell panel is stored in battery *B* (by charging it). This battery runs an electric motor *M*. And finally, this motor drives a pump *P* which pumps out the underground water.

The solar cells cannot work at night (when sunlight is not available). So, the electricity produced by a solar cell panel during the day time can be stored by charging a battery (like a car battery) and then used at night to power lights.

The main **advantages of solar cells** are that they have no moving parts, they require almost no maintenance, and work quite satisfactorily without the use of any light focussing device. Another advantage of solar cells is that they can be set up in remote, inaccessible and very sparsely inhabited areas where the laying of usual power transmission lines is difficult and expensive.

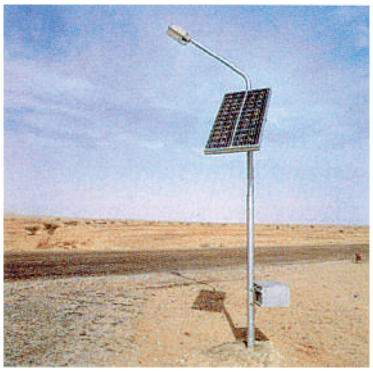
The main **disadvantage of solar cells** is that they are very expensive. This is due to the following reasons : (*i*) the special grade silicon needed for making solar cells is expensive, (*ii*) silver wire used to interconnect solar cells for making solar cell panels is expensive, and (*iii*) the entire process of making solar cells is still very expensive. So, the extensive use of solar cells for generating electric power is limited due to their high cost. Another disadvantage of solar cells is their low efficiency. They can convert only about 25 per cent of the light energy falling on them into electricity.

Uses of Solar Cells

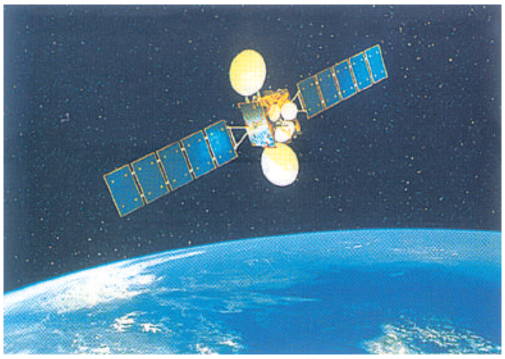
1. Solar cells are used for providing electricity in artificial satellites and space probes.
2. Solar cells are used for providing electricity to remote, inaccessible and isolated places where normal electricity transmission lines do not exist.

3. Solar cells are used for the transmission of radio and television programmes in remote areas.
4. Solar cells are used for providing electricity to 'light houses' situated in the sea and to off-shore oil drilling rig platforms.
5. Solar cells are used for operating traffic signals, watches, calculators and toys.

(*a*) This is a solar cell panel. It has a large number of solar cells joined in series



(*b*) A streel light working on solar cell panel



(*c*) Solar cell panels are used to power artificial satellites

Figure 26. Solar cells and some of their uses.

Before we end this discussion on solar energy, we would like to compare the **fossil fuels** and the **sun** as sources of energy.

(*i*) The sun is a *renewable* source of energy but fossil fuels are a *non-renewable* source of energy.
(*ii*) The sun's energy *does not* cause any pollution but burning of fossil fuels *causes* a lot of pollution.
(*iii*) The sun's energy is available in a *diffused form* (scattered form) but fossil fuels provide energy in *concentrated* form.
(*iv*) A *special device* (like solar cooker or solar cell) is always needed to utilise sun's energy but this is *not* so in the case of fossil fuels.
(*v*) The sun's energy is available only during the *day* time when the sun shines but energy of fossil fuels can be used *all* the time.

Before we go further and discuss biomass as a source of energy, **please answer the following questions** :

Very Short Answer Type Questions

1. A hydro-power plant converts one form of energy into another. Name the two forms of energy.
2. What type of energy is possessed by flowing water ?
3. Flowing water can rotate a turbine. Which type of energy is used up by the turbine ?
4. Name the original source of wind energy.
5. What should be the minimum wind speed for the satisfactory working of a wind-powered electric generator ?
6. Write one use of wind energy (*a*) in the past (*b*) at present.
7. Why is the copper tube of a solar water heater painted black from outside ?
8. What type of reactions occurring inside the sun produce solar energy ?
9. Name some of the solar energy devices.
10. What type of reflector is used in a box-type solar cooker ?
11. What is the range of temperature which can be achieved in a box-type solar cooker in two to three hours ?
12. Name the device which converts sunlight into electricity.
13. How much solar energy will be received by 1 m^2 area in one hour if the solar constant be 1.4 kW/m^2 ?
14. Fill in the following blanks with suitable words :
    A solar cell converts............energy into...............energy.

Short Answer Type Questions

15. (*a*) What is the difference between a thermal power plant and a hydro power plant ?
    (*b*) Which of the two causes serious air pollution and how ?

16. Compare the sun and the fossil fuels as the sources of energy.

17. What kind of mirror, concave, convex or plane, would be best suited for use in a solar cooker ? Why ?

18. (*a*) Name that part of a box-type solar cooker which allows the sun's heat rays to enter the box but does not allow inside heat to go out.

(*b*) Explain why, a plane mirror reflector is used in a box-type solar cooker.

19. What are the advantages and disadvantages of using a solar cooker ?

20. (*a*) What is a solar cell ? Draw the labelled diagram of a solar cell.

(*b*) Name the semi-conductor material which is usually used for making solar cells.

(*c*) Write the uses of solar cells.

21. State the advantages and disadvantages of using solar cells.

22. What is a solar cell panel ? For what purpose is it used ? State its two main advantages.

23. (*a*) What is solar constant ? What is the value of solar constant ?

(*b*) If the energy received by 5 m^2 area in 10 minutes is 4200 kJ, calculate the value of solar constant.

24. How has the traditional use of energy of flowing water been modified for our convenience ?

25. How has the traditional use of wind energy been modified for our convenience ?

Long Answer Type Questions

26. (*a*) What is hydroelectricity ? Explain the basic principle of generation of hydroelectricity with the help of a labelled diagram.

(*b*) State two advantages of producing hydroelectricity.

(*c*) State two disadvantages of producing hydroelectricity.

27. (*a*) With the help of a labelled diagram, explain the construction and working of a solar cooker.

(*b*) Why is the solar cooker box painted black from inside ?

(*c*) Why is the solar cooker box covered with a glass sheet ?

28. (*a*) What is wind ? What type of energy is possessed by wind ?

(*b*) Explain how, wind energy can be used to generate electricity. Illustrate your answer with the help of a labelled diagram.

(*c*) State two advantages of using wind energy for generating electricity.

(*d*) Mention two limitations of wind energy for generating electricity.

Multiple Choice Questions (MCQs)

29. A solar water heater cannot be used to get hot water on :

(*a*) a sunny day (*b*) a cloudy day (*c*) a hot day (*d*) a windy day

30. At a hydro power plant :

(*a*) kinetic energy possessed by stored water is converted into electrical energy

(*b*) electricity is extracted from water

(*c*) water is converted into steam to turn turbines and produce electricity.

(*d*) potential energy possessed by stored water is converted into electricity.

31. The part of box-type solar cooker which is responsible for producing greenhouse effect is :

(*a*) plane mirror reflector (*b*) black coating inside the box

(*c*) glass sheet cover (*d*) utensils placed in the cooker box

32. Solar cells are made of :

(*a*) conductors (*b*) insulators (*c*) semi-conductors (*d*) super-conductors

33. The value of solar constant is :

(*a*) 1.4 kWh (*b*) 1.4 kW/m (*c*) 1.4 kW/m^2 (*d*) 1.4 kW/m^3

34. The radiations present in sunlight which make a solar cooker work are :

(*a*) visible light rays (*b*) ultraviolet rays (*c*) cosmic rays (*d*) infrared rays

35. In order to make an efficient solar cooker, the cover of cooker box should be made of :

(*a*) transparent plastic sheet (*b*) shining aluminium sheet

(*c*) butter paper sheet (*d*) transparent glass sheet

36. The minimum speed of wind necessary for the satisfactory working of a wind generator to produce electricity is about :
(*a*) 15 km/h (*b*) 25 km/h (*c*) 35 km/h (*d*) 45 km/h

37. If the solar constant is 1.4 kW/m^2, then the solar energy received by 1 m^2 area in one hour is :
(*a*) 5040 J (*b*) 504.0 kJ (*c*) 5040 kJ (*d*) 5.04 kJ

38. A solar cooker may not cook food if :
(*a*) the solar cooker is not placed in the shade (*b*) the glass sheet cover of solar cooker is not closed
(*c*) a convex mirror reflector is not used (*d*) the food containers of insulating material are not used

Questions Based on High Order Thinking Skills (HOTS)

39. A large coal-fired power station produces 2000 MW of electrical energy. A wind turbine with 33 m blades can produce 300 kW.
(*a*) How many turbines would be needed to replace the power station ?
(*b*) Why, in actual practice, this number of turbines could not replace the coal-fired power station ?

40. In a solar water heater, why is the storage tank placed at a higher level than the solar panel containing coils ?

41. In many applications, solar cells are connected to rechargeable batteries. Why is this so ?

42. (*a*) Solar cells are used to provide the electric current to charge the batteries of a car driven by an electric motor. Describe the energy changes which take place.
(*b*) What differences would you expect in the charging of car batteries (*i*) in bright sunlight (*ii*) on a cloudy day (*iii*) at night ?

ANSWERS

1. Potential energy (of stored water) into Electrical energy **2.** Kinetic energy **3.** Kinetic energy **4.** Sun **8.** Nuclear fusion reactions **12.** Solar cell **13.** 5040 kJ **14.** sunlight ; electrical **15.** (*b*) Thermal power plant ; Emits harmful gases and fly-ash into the air **18.** (*a*) Glass sheet cover **23.** (*b*) 1.4 kJ/s/m^2 **29.** (*b*) **30.** (*d*) **31.** (*c*) **32.** (*c*) **33.** (*c*) **34.**(*d*) **35.** (*d*) **36.** (*a*) **37.** (*c*) **38.** (*b*) **39.** (*a*) 6667 turbines (*b*) Efficiency of steam turbines used in coal-fired power station remains the same but the efficiency of wind turbines changes due to the changes in wind speed **40.** Hot water, being lighter, rises to the top **41.** The electricity made by solar cells during the day time is stored in rechargeable batteries so that it can be used later on, for example, at night **42.** (*a*) Solar cells convert Sunlight energy into Electrical energy ; During charging the batteries, Electrical energy is converted into Chemical energy ; During the use of batteries, Chemical energy is converted into Electrical energy ; Electric motor converts Electric energy into Kinetic energy (which drives the car) (*b*) (*i*) Batteries are charged quickly (*ii*) Batteries are charged very slowly (*iii*) Batteries are not charged at all.

BIOMASS ENERGY

The dead parts of plants and trees, and the waste material of animals are called biomass. Biomass is the organic matter which is used as a fuel to produce energy. **Biomass includes wood, agricultural wastes (crop residues) and cow-dung**. Biomass contains chemical energy in the form of carbon compounds. Dried biomass (like wood) is the oldest source of heat energy which is still widely used as a fuel for domestic purposes. Actually, biomass is another form in which solar energy manifests itself. This is because all the plants and trees which provide biomass (like wood) used sun's energy to grow. Even the animal wastes (like cow-dung) are given by cattle who grew by consuming plant food made with the help of sunlight energy. Since the fuels like wood, agricultural wastes and cow-dung are all plant and animal products, so they are called biomass (or biofuels). Please note that **biomass is a renewable source of energy** because it is obtained from plants (or animals) which can be produced again and again.

The Case of Wood and Charcoal

Wood is biomass. When wood is burnt, heat is produced. So, wood has been used as a fuel for a long time (Wood that is burnt as a fuel is called firewood). Wood is a renewable source of energy. Wood is obtained by cutting down the trees. Now, if we can ensure that enough trees are planted in place of cut down trees, then a continuous supply of firewood can be obtained. The traditional use of wood as a fuel has many **disadvantages**. For example : (*i*) the burning of wood produces a lot of smoke which pollutes the air, and (*ii*) the calorific value (or heat value) of wood is low, being only 17 kJ/g. This means that wood produces less heat per unit mass, on burning.

Figure 27. Wood is still used as a domestic fuel to cook food in many parts of our country.

Figure 28. Charcoal is a better fuel than wood. It has a higher calorific value and burns without producing smoke.

Due to improvement in the technology for using the conventional sources of energy, **wood can be converted into a much better fuel called charcoal**. Charcoal can be prepared from wood as follows : When wood is burnt in a limited supply of air, then water and other volatile materials present in it get removed and a black substance 'charcoal' is left behind. Thus, wood minus volatile material is charcoal. **Charcoal is mainly carbon (C).** Charcoal is mainly used as a fuel for domestic purposes. **Charcoal is a better fuel than wood** because of the following reasons :

(*i*) **Charcoal has a higher calorific value than wood.** That is, charcoal produces more heat on burning than an equal mass of wood. For example, the calorific value (heat producing value) of charcoal is higher, being about 33 kilojoules per gram, whereas that of wood is low, being only 17 kilojoules per gram.

(*ii*) **Charcoal does not produce smoke while burning** whereas wood produces a lot of smoke on burning and pollutes the air.

(*iii*) Charcoal is a compact fuel which is easy to handle and convenient to use.

The Case of Cow-Dung and Biogas

Cow-dung is biomass. It is also known as 'cattle dung' or 'animal dung' or just 'dung'. Cow-dung is the 'excreta' of cattle such as cows and buffaloes, etc. Cow-dung is usually semi-solid. In our villages, dried cow-dung cakes have been traditionally used as a fuel for cooking food. When cow-dung cakes are burnt, they produce heat. This heat is used for cooking food, etc. It is, however, not good to burn cow-dung directly as a fuel because of the following **disadvantages** :

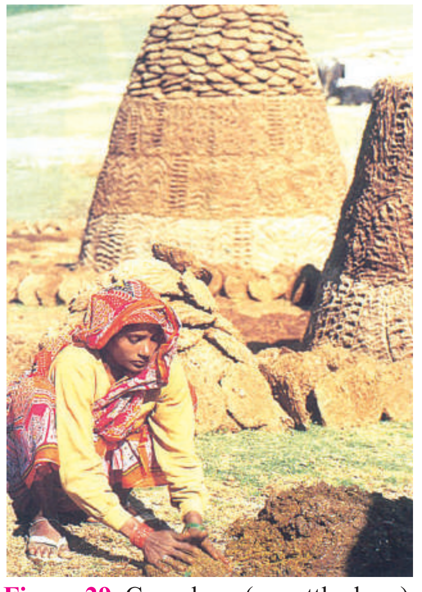


Figure 29. Cow-dung (or cattle dung) has been traditionaly used as a fuel in the form of dried dung cakes. Burning of dried dung cakes releases biomass energy as heat.

(*i*) Cow-dung contains important elements like nitrogen and phosphorus (called nutrients), which are required by the soil to support crops. So, burning of dung in the form of dung cakes destroys the useful nutrients which can otherwise be used as a manure in agriculture.

(*ii*) Dung cakes produce a lot of smoke on burning which causes air pollution.

(*iii*) Dung cakes do not burn completely, they produce a lot of ash as residue.

(*iv*) Dung cakes have low calorific value (low heat producing value).

Since there are many disadvantages in using cow-dung as a fuel directly, it is better to prepare biogas (or *gobar* gas) from cow-dung. And this gas can then be used as a smokeless fuel. After extracting the biogas, the spent cow-dung can be used as a manure because it still contains all the 'nutrient elements' which were present in it initially. Only the organic matter of cow dung is decomposed and converted into biogas. The other elements like nitrogen and phosphorus, etc., remain intact. In this way, the nutrients like nitrogen and phosphorus can be returned to the soil in the form of manure. When used in this way, cow-dung gives us a double advantage : (*i*) *it gives us a clean fuel called biogas*, and (*ii*) *the spent dung can be used as a manure*.

Before we discuss biogas in detail, it will be good to know the meaning of the term "anaerobic degradation". **The decomposition which takes place in the absence of oxygen is called anaerobic degradation.** Anaerobic degradation is carried out by the micro-organisms called **anaerobic bacteria** (which do not require oxygen to decompose complex organic compounds like those present in cow-dung). Let us discuss the biogas now.

Biogas is not a single gas. It is a mixture of gases. **Biogas is a mixture of methane, carbon dioxide, hydrogen and hydrogen sulphide. The major constituent of biogas is methane**, which is an extremely good fuel. In fact, biogas contains up to 75 per cent of methane gas which makes it an excellent fuel. **Biogas is produced by the anaerobic degradation of animal wastes like cow-dung (or plant wastes) in the presence of water.** This degradation is carried out by anaerobic micro-organisms called anaerobic bacteria in the *presence* of water but in the *absence* of oxygen. Cow-dung and plant wastes contain a lot of complex carbon compounds like carbohydrates, proteins and fats. The anaerobic bacteria degrade (decompose) these carbon compounds to form methane gas, which is the main constituent of biogas. Some other gases like carbon dioxide, hydrogen and hydrogen sulphide are also formed. Cow-dung is known as '*gobar*' in Hindi. Since biogas is prepared mainly from cow-dung, so biogas is popularly known as '*gobar* gas' in our villages. We will now describe a biogas plant which is also known as *gobar*-gas plant.

Biogas Plant

A biogas plant consists of a well-shaped, underground tank *T* called digester, which is made of bricks, and has a dome-shaped roof *D*, also made of cement and bricks (Figure 30). The digester is a kind of sealed tank in which there is no air (or oxygen). The dome of the digester tank acts as a gas-holder or storage tank for the biogas. There is a gas outlet *S* at the top of the dome having a valve *V*. On the left side of the digester tank is a sloping inlet chamber *I* and on the right side is a rectangular outlet chamber *O*, both

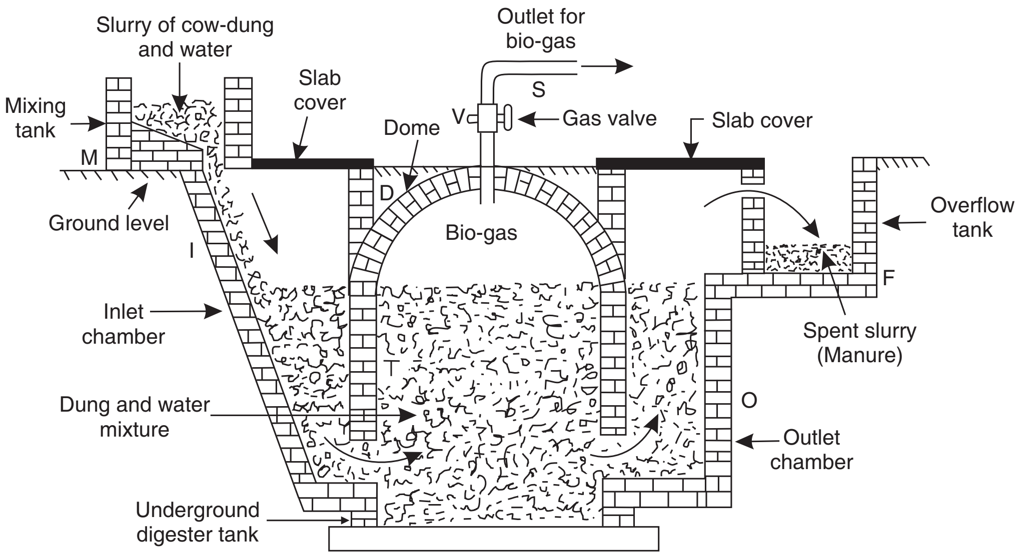


Figure 30. A biogas plant.

made of bricks. The inlet chamber is for introducing fresh dung slurry into the main digester tank whereas the outlet chamber is for taking out the spent dung slurry after the extraction of biogas. The inlet chamber is connected to a mixing tank *M* while the outlet chamber is connected to the overflow tank *F*.

We will now describe the working of a biogas plant. Cow-dung and water are mixed in equal proportions in the mixing tank *M* to prepare the slurry. This slurry of dung and water is fed into the digester tank *T* through the inlet chamber *I*. The digester tank is filled with dung slurry upto the cylindrical level (as shown in Figure 30), the dome being left free for the collection of biogas. It takes about 50 to 60 days for the new gas-plant to become operative (start functioning). During this period, the cow-dung undergoes degradation by anaerobic bacteria in the presence of water (but absence of oxygen) with the gradual evolution of biogas. This biogas starts collecting in the dome. As more and more biogas collects in the dome, it exerts pressure on the slurry in the digester tank, and forces the spent slurry to go into overflow tank *F* (Figure 30), through the outlet chamber *O*. From the overflow tank, the spent slurry is removed gradually. The spent dung-slurry, left after the extraction of biogas, is rich in nitrogen and phosphorus compounds and hence forms a good manure.

Once the gas-plant becomes operative, more fresh dung slurry is added to the digester tank regularly and this leads to the continuous biogas production. The biogas which has collected in the dome of the digester tank is taken out through the outlet *S* and supplied to village homes through a network of pipes to be used as a cooking gas.

Please note that though mostly we use cow-dung in biogas plants, but **human excreta (human faeces) can also be added alongwith cow-dung in biogas plants.** Agricultural wastes, vegetable wastes, poultry droppings, and paper scrap can also be used for producing biogas. In some of the cities of our country we have sewage gas plants (Sewage is the dirty drain water containing human excreta). **Biogas can also be obtained by the action of anaerobic bacteria on domestic sewage in the absence of air.** The biogas obtained from the degradation of domestic sewage is also called **sewage gas.** So, at many places in our country, domestic sewage is digested in large sewage gas plants to produce biogas as well as manure. The large scale utilisation of biowastes and sewage materials for producing biogas can provide us a safe and efficient method of waste disposal besides supplying energy and manure. The important uses of biogas are given below :

Figure 31. Cow-dung being fed into a biogas plant in a village of India.

1. **Biogas is used as a fuel for cooking food.** When biogas is burned in a gas stove, it produces a lot of heat. This heat is used for cooking food and for other domestic heating purposes. **Biogas is a good domestic fuel** because of the following reasons :
   (*a*) Biogas burns without smoke and hence does not cause air pollution.
   (*b*) Biogas has a high calorific value. That is, biogas produces a large amount of heat per unit mass.
   (*c*) Biogas burns completely without leaving behind any residue (unlike wood, charcoal or coal). So, it is a clean fuel.
   (*d*) There is no storage problem for biogas as it is supplied by pipes directly from the gas plant.
   (*e*) Biogas is cheaper than most common fuels.
2. **Biogas is also used for lighting.**
3. **Biogas is used as a fuel to run engines.** At many places, the engines of water pumping sets used for irrigation are run on biogas, instead of diesel.
4. **Biogas is used for generating electricity.**

Biogas is a renewable source of energy. Since India has a large population of cattle and other farm animals (called livestock) to provide animal dung, therefore, biogas can become a steady source of energy in our rural areas. Before we end this discussion on biomass as a source of energy, we would like to compare the **biomass** and **hydroelectricity** as sources of energy.

(*i*) Biomass is a renewable source of energy and hydroelectricity is also a renewable source of energy.

(*ii*) The use of biomass by burning causes air pollution but the use of hydroelectricity does not cause any pollution.

(*iii*) Biomass gives heat energy which can be used for cooking and heating only. On the other hand, hydroelectricity can run all types of electrical appliances.

(*iv*) Biomass energy can be obtained without using any special device but hydroelectricity can be produced only by establishing hydro-power plants.

ENERGY FROM THE SEA

The energy from the sea can be obtained mainly in three forms :

(*i*) Tidal energy,

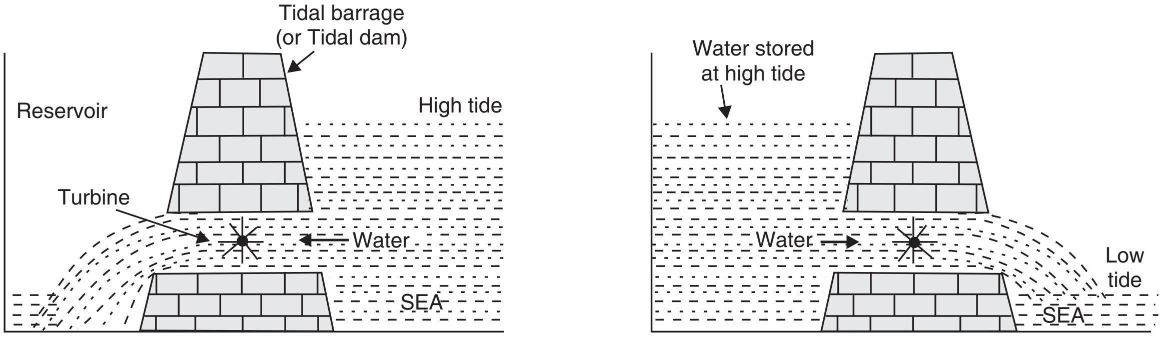
(*ii*) Wave energy, and

(*iii*) Ocean thermal energy.

We will now describe these three means of obtaining energy from the sea in somewhat detail.

1. Tidal Energy

The rise of sea water due to gravitational pull of the moon is called "high tide" whereas the fall of sea water is called "low tide." The tidal waves in the sea build up and recede (rise and fall) twice a day. The enormous movement of water between the high tides and low tides provides a very large source of energy in the coastal areas of the world. The tidal energy can be harnessed by constructing a tidal barrage or tidal dam across a narrow opening to the sea (see Figure 32).



(*a*) At high tide, water flows from sea into reservoir and turns the turbine

(*b*) At low tide, stored water flows out from reservoir into sea and turns the turbine

Figure 32. Tidal energy.

During high tide, when the level of water in the sea is high, sea-water flows into the reservoir of the barrage and turns the turbines [see Figure 32(*a*)]. The turbines then turn the generators to produce electricity. And during the low tide, when the level of sea-water is low, the sea-water stored in the barrage reservoir is allowed to flow out into the sea. This flowing water also turns the turbines and generates electricity [see Figure 32(*b*)]. Thus, as sea-water flows in and out of the tidal barrage during high and low tides, it turns the turbines to generate electricity. The tidal energy is not likely to be a potential source of energy in future because of the following reasons :

Figure 33. A tidal power station. It generates electricity from the tides in the sea.

(*i*) There are very few sites around the world which are suitable for building tidal barrages (or tidal dams).

(*ii*) The rise and fall of sea-water during high and low tides is not enough to generate electricity on a large scale.

2. Wave Energy

Wave energy here means 'sea-waves energy'. Energy from the sea is also available in the form of sea waves. Due to the blowing of wind on the surface of sea, very fast sea-waves (or water waves) move on its surface. Due to their high speed, sea-waves have a lot of kinetic energy in them. The energy of moving sea-waves can be used to generate electricity. A wide variety of devices have been developed to trap sea wave energy to turn turbines and drive generators for the production of electricity.

(*i*) One idea is to set-up floating generators in the sea. These would move up and down with the sea-waves. This movement would drive the generators to produce electricity.

(*ii*) Another idea is to let the sea-waves move up and down inside large tubes. As the waves move up, the air in the tubes is compressed. This compressed air can then be used to turn a turbine of a generator to produce electricity.

These ideas are only experimental in nature. Models have been made based on these ideas but it will be many years before full-size wave-energy generators can be built to harness the sea-waves energy on a large scale. The harnessing of sea-waves energy would be a viable proposition only at those places where sea-waves are very strong.

3. Ocean Thermal Energy

A very large area of sea is called an ocean. The water at the surface of an ocean gets heated by the heat of the sun and attains a higher temperature than the colder water at deeper levels in the ocean. So, there is always a temperature difference between the water "at the surface of ocean" and "at deeper levels." **The energy available due to the difference in the temperature of water at the surface of the ocean and at deeper levels is called ocean thermal energy (OTE).** The ocean thermal energy can be converted into a "usable form" of energy like electricity. This can be done as follows :

The devices used to harness ocean thermal energy are called Ocean Thermal Energy Conversion power plants (or OTEC power plants). A temperature difference of 20°C (or more) between the surface water of ocean and deeper water is needed for operating OTEC power plants. In one type of OTEC power plant, the warm surface water of ocean is used to boil a liquid like ammonia or a chlorofluorocarbon (CFC). The high pressure vapours of the liquid (formed by boiling) are then used to turn the turbine of a generator and produce electricity. The colder water from the deeper ocean is pumped up to cool the used up vapours and convert them again into a liquid. This process is repeated again and again.

A great advantage of the ocean thermal energy is that it can be used continuously 24 hours a day throughout the year. Another advantage is that ocean thermal energy is a renewable source of energy and its use does not cause any pollution. Please note that **wave energy and ocean thermal energy are the two forms in which solar energy manifests itself in oceans.** Another point to be noted is that though the energy potential from the sea (tidal energy, wave energy and ocean thermal energy) is very large but its large scale exploitation is difficult at the moment.

GEOTHERMAL ENERGY

'Geo' means 'earth' and 'thermal' means 'heat'. Thus, **geothermal energy is the heat energy from hot rocks present inside the earth.** This heat can be used as a source of energy to produce electricity. Please note that **geothermal energy is one of the few sources of energy that do not come directly or indirectly from solar energy (or sun's energy).**

At some places in the world, the rocks at some depth below the surface of the earth are very, very hot. This heat comes from the fission of radioactive materials which are naturally present in these rocks. The places where very hot rocks occur at some depth below the surface of earth are called 'hot spots', and are sources of geothermal energy. The geothermal energy is harnessed as follows :

The extremely hot rocks present below the surface of earth heat the underground water and turn it into steam (see Figure 34). As more and more steam is formed between the rocks, it gets compressed to high pressures. A hole is drilled into the earth up to the hot rocks and a pipe is put into it. The steam present around the hot rocks comes up through the pipe at high pressure. This high pressure steam turns the turbine of a generator to produce electricity.

Figure 34. Geothermal energy can be used to produce electricity.

Sometimes two holes are drilled into the earth in the region of hot rocks and two pipes are put into them. Cold water is pumped in through one of the pipes. This cold water is turned into steam by the hot rocks. The steam thus formed comes out through the other pipe and used to generate electricity.

Some of the **advantages** of using geothermal energy are as follows : It is economical to use geothermal energy. This is because the cost of electricity produced by using geothermal energy is almost half of that produced from conventional energy sources. Another advantage is that the use of geothermal energy does not cause any pollution. So, it is a clean and environment friendly source of energy. Some of the **disadvantages** of geothermal energy are as follows : Geothermal energy is not available everywhere. It is available only in those areas where there are hot rocks near the earth's surface. Another disadvantage is that deep drilling in the earth to obtain geothermal energy is technically very difficult and expensive.

In our country there are a very limited number of places where geothermal energy can be harnessed on a commercial scale. Two places where geothermal energy can be exploited on commercial scale are located in Madhya Pradesh and Himachal Pradesh. In USA and Newzealand, a number of geothermal energy power plants are working successfully. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. What substance is obtained as a residue when wood is burned in a limited supply of air ?

2. Name one source of energy which is not derived from solar energy directly or indirectly.

3. What name is given to the heat energy obtained from hot rocks inside the earth ?

4. Name the agent which decomposes animal dung into biogas.

5. Which component of biogas is used as a fuel ?

6. Name the constitutents of biogas.

7. Which of the following is needed for the formation of biogas from cow-dung and which not ?

Water, Oxygen

8. Name the clean fuel which can be obtained from cow-dung.

9. Apart from cattle dung, what other substances can be added to a biogas plant ?

10. Name any three forms of energy which could be harnessed from the sea.

11. Write two forms in which solar energy manifests itself in sea.

12. Write the full form of OTE.

13. What is the function of anaerobic micro-organisms such as anaerobic bacteria in a biogas plant ?

14. State whether the following statement is true or false :

Tidal energy is one of the forms in which solar energy manifests itself in oceans.

15. Fill in the following blanks with suitable words :

(*a*) Biomass is another form in which .... energy manifests itself.

(*b*) Tidal waves build up and recede.............. a day.

Short Answer Type Questions

16. (*a*) What is biomass ? Give three examples of biomass.

(*b*) Name the biomass which is still widely used as a source of heat energy in many households of our country.

17. What are the two ways in which cow-dung can be used as a fuel ? Which of them is better and why ?

18. How is charcoal prepared ? Explain why, charcoal is a better fuel than wood.

19. Compare and contrast biomass and hydroelectricity as sources of energy.

20. Why is biogas considered an ideal fuel for domestic use ?

21. (*a*) Explain how tidal energy can be used to generate electricity.
(*b*) Why is tidal energy not likely to be a potential source of energy ?

22. State two ways in which the energy of sea-waves can be harnessed.

23. What is meant by ocean thermal energy ? Explain how ocean thermal energy can be used to generate electricity.

24. What are the limitations of energy that can be harnessed from the sea ?

25. Suggest a safe and efficient method for the disposal of biowastes and sewage materials. How is this method advantageous to us ?

26. Which of the following sources of energy are not derived from the sun ?
Biomass, Wind, Ocean thermal energy, Geothermal energy, Nuclear fuels, Hydroelectricity, Wave energy, Coal, Petroleum, Tidal energy

Long Answer Type Questions

27. (*a*) What is biogas ? Name the major component of biogas.
(*b*) What are the raw materials used for making biogas ?
(*c*) Describe the construction and working of a biogas plant with the help of a labelled diagram.
(*d*) Write any two uses of biogas.
(*e*) Write any two advantages of using biogas.

28. (*a*) What is geothermal energy ?
(*b*) What is the source of heat contained in geothermal energy ?
(*c*) Explain how, geothermal energy is used to generate electricity.
(*d*) State two advantages of geothermal energy.
(*e*) State two disadvantages of geothermal energy.

Multiple Choice Questions (MCQs)

29. Which of the following is not an example of a biomass energy source ?
(*a*) wood (*b*) biogas (*c*) atomic energy (*d*) cow-dung

30. Most of the sources of energy that we use represent stored solar energy. Which of the following is not ultimately derived from the sun's energy ?
(*a*) wind energy (*b*) geothermal energy (*c*) fossil fuels (*d*) biomass

31. The constituent of biogas which makes it an excellent fuel is :
(*a*) butane (*b*) methane (*c*) propane (*d*) ethane

32. The major component of biogas is :
(*a*) hydrogen (*b*) butane (*c*) hydrogen sulphide (*d*) methane

33. Which of the following is more environment friendly ?
(*a*) burning of diesel (*b*) burning of coal (*c*) burning of charcoal (*d*) burning of wood

34. Which one of the following is not renewable energy technology ?
(*a*) solar cells (*b*) windmills (*c*) nuclear power (*d*) tidal power

35. The rise of sea-water during high tide is caused by the gravitational pull of the :
(*a*) Sun (*b*) Earth (*c*) Moon (*d*) Mars

36. One of the following is not required in the formation of biogas in a biogas plant. This is :
(*a*) cow-dung (*b*) water (*c*) oxygen (*d*) anaerobic bacteria

37. The fuel which is not obtained from biomass is :
(*a*) firewood (*b*) cow-dung cakes (*c*) coke (*d*) charcoal

38. The non-renewable source of energy among the following is :
(*a*) hydroelectricity (*b*) sewage gas (*c*) natural gas (*d*) *gobar* gas

39. Geothermal energy is produced by the :
(*a*) fission of radioactive materials

(*b*) burning of coal inside the coal mines
(*c*) combustion of natural gas deep inside the earth
(*d*) fusion of radioactive substances

40. The harnessing of which of the following leads to the destruction of large eco-systems ?
(*a*) thermal power (*b*) tidal power (*c*) hydro power (*d*) geothermal power

41. Which of the following is not a consequence of establishing hydroelectric power plants ?
(*a*) displacement of people (*b*) production of methane
(*c*) occurrence of floods (*d*) ecological disturbance

Questions Based on High Order Thinking Skills (HOTS)

42. A certain form of energy is available due to the difference in the temperature of water at the surface of the ocean and its deeper levels.
(*a*) Name the form of energy.
(*b*) Is this energy ultimately derived from the sun or not ?
(*c*) Explain how this form of energy can be converted into electricity.
(*d*) What is the minimum temperature difference in water at the surface of ocean and its deeper level which is required to operate power plants based on this energy ?

43. The gravitational pull of the moon causes the sea-water to rise periodically.
(*a*) What name is given to the condition of the sea when its water is raised ?
(*b*) What name is given to the condition of the sea when its raised water recedes ?
(*c*) What name is given to the energy which can be harnessed from this natural phenomenon ?
(*d*) Draw labelled diagram to show how this energy can be harnessed to generate electricity.

44. When the material A mined from the earth is heated strongly in an insufficeint supply of air, it produces a solid fuel B which consists mainly of carbon. When another material C obtained from trees is heated in an insufficient supply of air, it produces another solid fuel D which also consists mainly of carbon. Name A, B, C and D.

45. A certain form of energy which is not sourced directly or indirectly from the sun and does not cause any pollution is very easily converted into electricity. This form of energy is, however, not available everywhere. Moreover, it is technically very difficult and expensive to obtain it. Name the form of energy.

ANSWERS

1. Charcoal **2.** Geothermal energy **3.** Geothermal energy **4.** Anaerobic bacteria **5.** Methane **7.** Needed : Water ; Not needed : Oxygen **8.** Biogas **11.** Sea-waves energy ; Ocean thermal energy **14.** False **15.** (*a*) solar (*b*) twice **16.** (*b*) Wood **29.** (*c*) **30.** (*b*) **31.** (*b*) **32.** (*d*) **33.** (*c*) **34.** (*c*) **35.** (*c*) **36.** (*c*) **37.** (*c*) **38.** (*c*) **39.** (*a*) **40.** (*c*) **41.** (*c*) **42.** (*a*) Ocean thermal energy (*b*) No (*d*) 20°C **43.** (*a*) High tide (*b*) Low tide (*c*) Tidal energy **44.** A is coal ; B is coke; C is wood; D is charcoal **45.** Geothermal energy

NUCLEAR ENERGY

A physical reaction which involves changes in the nucleus of an atom is called a nuclear reaction. **The energy released during a nuclear reaction is called nuclear energy** (because it comes from the nucleus of an atom). Nuclear energy can be obtained by two types of nuclear reactions :

(*i*) Nuclear fission, and
(*ii*) Nuclear fusion.

The source of nuclear energy is the mass of nucleus. A small amount of mass of nucleus is destroyed during a nuclear reaction which gets converted into a tremendous amount of energy. **The nuclear energy is released mainly in the form of heat** (and some light). The *nuclear* energy is also known as *atomic* energy because it can be considered to be coming from the atoms. We will now describe the nuclear reactions of fission and fusion in detail, one by one. Let us start with nuclear fission.

1. NUCLEAR FISSION

The word '*fission*' means to '*split up*' into two or more parts. **The process in which the heavy nucleus of a radioactive atom (such as uranium, plutonium or thorium) splits up into smaller nuclei when bombarded with low energy neutrons, is called nuclear fission.** A tremendous amount of energy is produced in the nuclear fission process. The sum of masses of the smaller nuclei formed in a fission reaction is a little less than that of the mass of the original heavy nucleus. So, *there is a small loss of mass in the nuclear fission process which appears as a tremendous amount of energy.* Please note that nuclear fission is carried out by bombarding the heavy nuclei with low energy neutrons which are also called slow moving neutrons. We will now give an example of a nuclear fission reaction. We will use the easily fissionable isotope of uranium called uranium-235 in this example.

When uranium-235 atoms are bombarded with slow moving neutrons, the heavy uranium nucleus breaks up to produce two medium-weight atoms, barium-139 and krypton-94, with the emission of 3 neutrons. A tremendous amount of energy is produced during the fission of uranium. This fission reaction can be represented in the form of a nuclear equation as :

$$\underset{\text{Heavy atom}}{{}^{235}_{92}\text{U}} + \underset{\text{Neutron}}{{}^{1}_{0}\text{n}} \xrightarrow{\text{Fission}} \underbrace{{}^{139}_{56}\text{Ba} + {}^{94}_{36}\text{Kr}}_{\text{Medium weight atoms}} + \underset{\text{Neutrons}}{3\,{}^{1}_{0}\text{n}} + \textbf{Tremendous amount of energy}$$

In the fissioning of uranium, some mass of uranium disappears (is lost), and a tremendous amount of energy is produced. An idea of the tremendous amount of energy produced during nuclear fission reaction can be had from the fact that the fission of 1 atom of uranium-235 produces 10 million times more energy than the energy produced by the burning of 1 atom of carbon from coal. **The energy produced during nuclear fission reactions is used for generating electricity at nuclear power plants.** Please note that the energy produced in a fission reaction is due to the conversion of *mass* into *energy*.

If we look at the above nuclear fission reaction equation, we find that the neutrons are used up as well as produced. For example, in the nuclear fission of uranium-235 described above, 1 neutron is consumed and 3 neutrons are produced in the fission of each nucleus. The neutrons produced in a fission process cause further fission of the heavy nuclei leading to a self-sustaining chain reaction. When all the neutrons produced during fission of uranium-235 are allowed to cause further fission, then so much energy is produced in a very short time that it cannot be controlled and leads to an explosion called atom bomb. We can, however, control a nuclear fission reaction by using control rods made of boron. **Boron has a property that it can absorb neutrons.** So, when a nuclear fission reaction is carried out in the presence of boron rods, the excess neutrons produced during successive fissions of uranium-235 atoms are absorbed by boron rods and hence not available to cause further fission. Due to this a controlled fission reaction of uranium-235 takes place liberating heat energy at a slow, steady and manageable rate which can be used for generating electricity at a nuclear power plant.

Figure 35. These hands hold a piece of uranium that is used as a fuel in nuclear power plants to generate electricity.

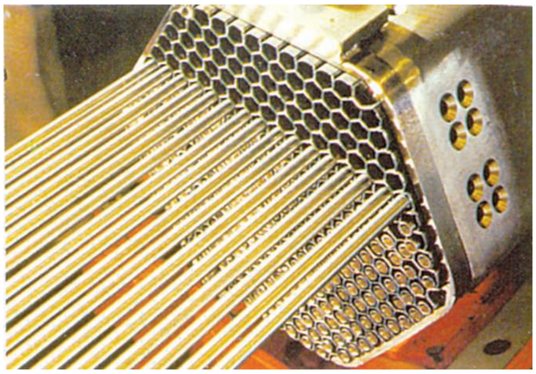


Figure 36. Uranium is used as a fuel in the reactor of a nuclear power plant in the form of uranium rods.

Nuclear Power Plant

A power plant in which the heat required to make steam and turn turbines (to drive generators for making electricity) is obtained by *nuclear reactions*, is called a nuclear power plant. The nuclear power plants use the nuclear fission reaction to generate electricity. Most of **the nuclear power plants use uranium-235 as fuel to produce heat**. But uranium-235 fuel is not burnt like coal, oil or gas to obtain energy. Its energy is released by the nuclear fission process. A nuclear power plant is shown in Figure 37.

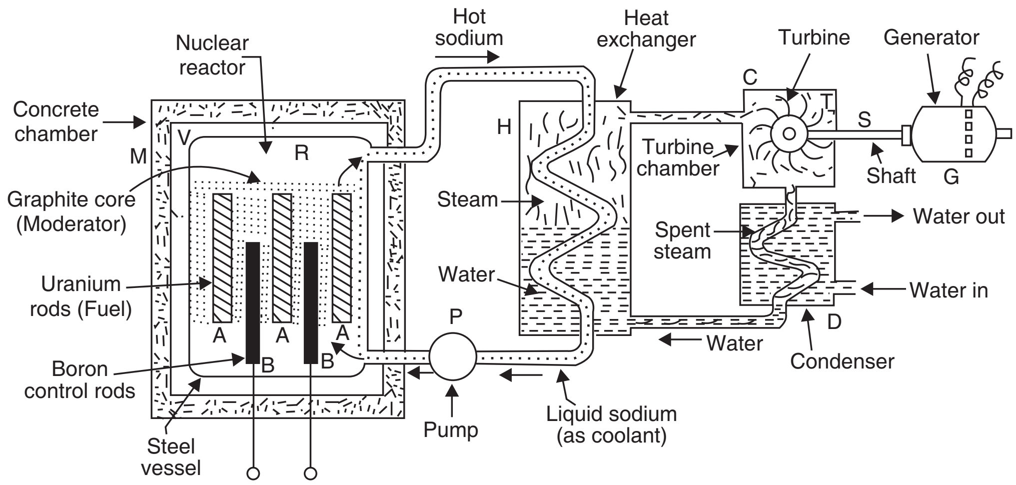


Figure 37. A nuclear power plant (or atomic power plant).

In a nuclear power plant, the fission of nuclear fuel uranium-235 is carried out in a steel pressure vessel *V* of reactor *R* (Reactor is a kind of nuclear furnace) (see Figure 37). The enriched uranium-235 rods marked *A* (called fuel elements) are inserted in a core made of graphite blocks inside the reactor. Graphite is called a *moderator*. It slows down the speed of neutrons to make them fit for causing fission. In-between the uranium rods are inserted boron rods *B*. Boron rods are called *control rods* because they absorb excess neutrons and prevent the fission reaction from going out of control. Boron rods can be raised or lowered in the reactor from outside (The part of boron rods which is inside the reactor absorbs neutrons). The reactor is enclosed in a concrete chamber *M* having thick walls to absorb the nuclear radiations (so as to protect the outside world from the dangerous nuclear radiations). Liquid sodium (or carbon dioxide gas) is used as a 'coolant' to transfer the heat produced in the reactor by fission to heat exchanger (or boiler) for converting water into steam. The rest of the arrangement at a nuclear power plant is shown in Figure 37. We will now describe the working of a nuclear power plant.

The controlled fission of uranium-235 in the nuclear reactor produces a lot of heat energy. Liquid sodium (or carbon dioxide gas) is pumped continuously through the pipes embedded in reactor by using a pump *P* (see Figure 37). Sodium absorbs the heat produced in the reactor. This extremely hot sodium is then passed into the coil of the heat exchanger *H* containing water. Water absorbs heat from hot sodium and boils to form steam. The hot steam at high pressure is introduced into a turbine chamber *C* having a turbine *T*. The pressure of steam makes the turbine rotate. The shaft *S* of turbine is connected to a generator *G*. When the turbine rotates, its shaft also rotates and drives the generator. The generator produces electricity.

The spent steam coming out from the turbine chamber is passed through a condenser *D*. The condenser cools the spent steam to form water. This water is again sent to the heat exchanger for forming fresh steam. A nuclear power plant can work day and night for two to three years with the same uranium fuel. Please note that the waste materials (called nuclear wastes) which are produced by the fission of uranium-235 during the generation of electricity at a nuclear power plant are *radioactive* and hence extremely *harmful* to all living beings, plants as well as animals, including human beings.

Nuclear Power Plants in India

There are a total of six nuclear power plants in India at present. These nuclear power plants are located at : (*i*) **Tarapur** in Maharashtra, (*ii*) **Rana Pratap Sagar** near Kota in Rajasthan, (*iii*) **Kalpakkam** in Tamil Nadu, (*iv*) **Narora** in Uttar Pradesh, (*v*) **Kaprapur** in Gujarat, and (*vi*) **Kaiga** in Karnataka.

At present only about 3% of the total electrical power produced in India is obtained from nuclear power plants (or nuclear reactors). Please note that in some of the industrialised countries like France, Germany and Japan, etc., more than 30% of their total electrical power comes from nuclear power plants.

Figure 38. This picture shows the devastation caused by a nuclear bomb explosion in Hiroshima, Japan, in 1945.

Nuclear Bomb (or Atom Bomb)

The highly destructive nuclear bomb (or atom bomb) is based on the nuclear fission reactions of uranium–235 or plutonium–239. In the nuclear bomb, the fission reaction of uranium–235 (or plutonium–239) is deliberately allowed to go out of control so as to produce an enormous amount of energy in a very short time. This energy causes destruction all around. The atom bombs based on the fission of uranium-235 and plutonium–239 were dropped on the Japanese cities of Hiroshima and Nagasaki, respectively in 1945 during the second world war. Both these atom bombs caused a great loss of human life and property. About 1.54 lakh people were killed in these two atom bomb attacks (see Figure 38).

Einstein's Mass-Energy Relation

Einstein said that **mass and energy are equivalent**, and are related by the equation :

$$E = mc^2$$

where E is the amount of energy produced if mass m is destroyed, and c is the speed of light (in vacuum).

Since the speed of light is very, very large, so an extremely large amount of energy is produced even if a small mass gets destroyed. The destruction of mass happens in nuclear reactions (like nuclear fission and fusion) with the liberation of tremendous amount of energy. Please note that in the mass-energy equation, if we put the mass in *kilograms* (kg), and the speed of light in *metres per second* (m/s), then the energy will come in *joules* (J). For example, if a mass of 1 kg of any matter could be destroyed in a nuclear reaction, then the amount of energy produced would be given by Einstein's equation as :

$$E = mc^2$$
$$E = 1 \times (3 \times 10^8)^2$$
$$E = 9 \times 10^{16}\ \text{J}$$

Thus, 1 kg mass produces a huge amount of energy of 9×10^{16} joules.

Energy Units for Expressing Nuclear Energy

We know that the common unit of energy is joule (J). But the energy released in nuclear reactions is expressed in the units of 'electron Volt' (eV) or 'Million electron Volt' (MeV). **1 electron volt is the amount of energy acquired by an electron (having a charge of 1.602×10^{-19} coulombs) when accelerated through a potential difference of 1 volt**.

$$1 \text{ electron volt} = 1.602 \times 10^{-19} \text{ joules}$$

or $$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

The electron volt is a small unit, so the energy released in nuclear reactions is usually expressed in terms of a bigger unit called million electron volts. We can obtain the value of million electron volt (MeV) by multiplying the above value of electron volt (eV) by 1 million (which is 10^6). Thus,

1 million electron volts = $1.602 \times 10^{-19} \times 10^6$ joules

or 1 million electron volts = 1.602×10^{-13} joules

or **1 MeV = 1.602×10^{-13} J**

The Value of Atomic Mass Unit in Terms of Energy

We can calculate the value of atomic mass unit (u) in terms of energy in joules by using the Einstein's mass-energy equation : $E = mc^2$. Now, the *absolute mass* of atomic mass unit is 1.66×10^{-27} kg and the exact value of speed of light is 2.998×10^8 m/s. So, by putting these values in the Einstein's equation, we will find that :

1 atomic mass unit = 1.492×10^{-10} joules

or **1 u = 1.492×10^{-10} J**

Thus, 1 atomic mass unit (u) is equivalent to 1.492×10^{-10} joules of energy. We can convert this energy from joules to million electron volts (MeV) by using the relation : 1.602×10^{-13} J = 1 MeV. This will give us the following value of atomic mass unit :

1 atomic mass unit = 931 million electron volts

or **1 u = 931 MeV**

Thus, 1 atomic mass unit (u) is equivalent to 931 MeV of energy.

2. NUCLEAR FUSION

The word '*fusion*' means '*to join*' or '*to combine*'. **The process in which two nuclei of light elements (like that of hydrogen) combine to form a heavy nucleus (like that of helium), is called nuclear fusion**. A tremendous amount of energy is produced during the fusion process. We know that the nuclei of atoms are positively charged. So, when two nuclei are brought together, they repel each other due to their similar charges. Due to this a lot of initial heat energy and high pressure are required to force the lighter nuclei to fuse together to form a bigger nucleus. So, **the conditions needed for carrying out nuclear fusion process are 'millions of degrees of temperature' and 'millions of pascals of pressure'**. In other words, nuclear fusion is carried out by heating the lighter atoms to extremely high temperatures under extremely high pressure. There is some loss of mass during the fusion process which appears as a tremendous amount of energy. Here is an example of nuclear fusion reaction.

When deuterium atoms (heavy hydrogen atoms of mass number 2) are heated to an extremely high temperature under extremely high pressure, then two deuterium nuclei combine together to form a heavy nucleus of helium, and a neutron is emitted. A tremendous amount of energy is liberated in this fusion reaction. This fusion reaction can be written as :

$$\underset{\substack{\text{Two deuterium atoms}\\\text{(Light atoms)}}}{{}^2_1H + {}^2_1H} \xrightarrow{\text{Fusion}} \underset{\substack{\text{One helium atom}\\\text{(Heavy atom)}}}{{}^3_2He} + \underset{\text{Neutron}}{{}^1_0n} + \textbf{Tremendous amount of energy}$$

A fusion process is just the opposite of fission process. The energy produced in nuclear fusion reaction is, however, *much more* than that produced in a nuclear fission reaction. **The energy produced during nuclear fusion has not been controlled so far**. So, nuclear fusion energy could not be used for generating electricity so far. Please note that the nuclear reactions which occur at extremely high temperatures are called *thermonuclear* reactions. Before we describe a hydrogen bomb, please note that the hydrogen isotope of mass number 3 is called tritium.

Hydrogen Bomb

Figure 39. This huge fireball is caused by the release of nuclear energy during a test hydrogen bomb explosion.

Thermonuclear reactions (fusion reactions which occur at very high temperatures) are used for producing a weapon of mass destruction called hydrogen bomb. **The hydrogen bomb consists of heavy isotopes of hydrogen called deuterium (^{2}H)and tritium (^{3}H) alongwith an element lithium-6 (^{6}Li). The detonation (or explosion) of hydrogen bomb is done by using an atom bomb (based on the fission of uranium-235 or plutonium-239).** When the atom bomb is exploded, then its fission reaction produces a lot of heat. This heat raises the temperature of deuterium and tritium to 10^{7}°C in a few microseconds. At this temperature, fusion reactions of deuterium and tritium take place producing a tremendous amount of energy. This explodes the hydrogen bomb releasing an enormous amount of energy in a very short time (see Figure 39). This energy causes destruction of life and property.

The function of lithium-6 used in hydrogen bomb is to produce more tritium needed for fusion. This is because when lithium is hit by neutrous (produced during fusion reactions), it forms tritium and helium. From the above discussion we conclude that **a hydrogen bomb is based on the thermonuclear fusion reactions of heavy hydrogen atoms (like deuterium and tritium) to produce helium atoms.** The hydrogen bomb (based on nuclear fusion) is exploded by using an atom bomb (based on nuclear fission). A hydrogen bomb is actually an uncontrolled nuclear fusion process. Thus, the source of energy of a hydrogen bomb is the same as that of the sun's energy, the only difference being that sun's energy supports life on earth, whereas the energy of hydrogen bomb destroys life on earth ! (because it is much more near to us than the sun). Please note that a hydrogen bomb is much more powerful than an atom bomb.

The Source of Sun's Energy

The sun is a huge mass of hydrogen gas and the temperature in it is extremely high. The sun may be considered a big thermonuclear furnace where hydrogen atoms are continuously being fused into helium atoms. Mass is being lost during these fusion reactions and energy is being produced. Thus, **the sun which gives us heat and light, derives its energy from the fusion of hydrogen nuclei into helium nuclei, which is going on inside it, all the time.**

The main nuclear fusion reaction taking place in the sun which releases a tremendous amount of energy is the fusion of 4 hydrogen atom nuclei to form a bigger nucleus of helium atom. That is :

$$\underset{\text{Hydrogen nuclei}}{4\,{}^{1}_{1}H} \xrightarrow[\text{(Inside the sun)}]{\text{Nuclear fusion}} \underset{\text{Helium nucleus}}{{}^{4}_{2}He} + \underset{\text{Positrons}}{2\,{}^{0}_{+1}e} + \textbf{Tremendous amount of energy}$$

The total energy produced by the fusion of hydrogen into helium is tremendous. All this energy is released in the form of heat and light. It is this energy which makes the sun shine and give us heat and light. Thus, **nuclear fusion reactions of hydrogen are the source of sun's energy**. Please note that just like the sun, other **stars also obtain their energy from the nuclear fusion reactions of hydrogen**.

An **advantage** of nuclear fusion reactions over nuclear fission for producing electricity is that the amount of energy released in a fusion reaction is much more than that liberated in a fission reaction. Moreover, the products of a fusion reaction are not radioactive. So, they are harmless and can be disposed of easily without causing any contamination in the environment. The biggest **disadvantage** of a nuclear fusion reaction is that it has not been possible to have a controlled fusion reaction so far, and to safely use the enormous heat produced during this reaction for the production of electricity.

Advantages of Nuclear Energy

The advantages of nuclear energy are that :

(*i*) it produces a large amount of useful energy from a very small amount of a nuclear fuel (like uranium-235).

(*ii*) once the nuclear fuel (like uranium-235) is loaded into the reactor, the nuclear power plant can go on producing electricity for two to three years at a stretch. There is no need for putting in nuclear fuel again and again.

(*iii*) it does not produce gases like carbon dioxide which contribute to greenhouse effect or sulphur dioxide which causes acid rain.

Disadvantages of Nuclear Energy

The disadvantages of nuclear energy are that :

(*i*) the waste products of nuclear fission reactions (produced at nuclear power plants) are radioactive which keep on emitting harmful nuclear radiations for thousands of years. So, it is very difficult to store or dispose of nuclear wastes safely. Improper nuclear waste storage or disposal can pollute the environment.

(*ii*) there is the risk of accidents in nuclear reactors (especially the old nuclear reactors). Such accidents lead to the leakage of radioactive materials which can cause serious damage to the plants, animals (including human beings) and the environment.

(*iii*) the high cost of installation of nuclear power plants and the limited availability of uranium fuel make the large scale use of nuclear energy prohibitive.

Let us solve one problem now.

Sample Problem. The mass numbers of four different elements A, B, C and D are 2, 35, 135 and 239 respectively. Which of them would provide the most suitable fuel for (*i*) nuclear fission, and (*ii*) nuclear fusion ?

Solution. (*i*) In the process of nuclear fission, a very big atom (having a very big mass number) is used as a fuel. Here, out of the four elements A, B, C and D, the atom of element D is the biggest, having a mass number of 239. So, element D would provide the most suitable fuel for nuclear fission.

(*ii*) In the process of nuclear fusion, a very small atom (having a very small mass number) is used as a fuel. Here, out of the four elements A, B, C and D, the atom of element A is the smallest, having a mass number of 2. So, element A would provide the most suitable fuel for nuclear fusion.

Before we go further and discuss the consequences of using energy sources on the environment, **please answer the following questions** :

Very Short Answer Type Questions

1. What type of nuclear reaction is responsible for the liberation of energy :
(*a*) in a nuclear reactor ?
(*b*) in the sun ?

2. Which product of the nuclear fission of uranium-235 is utilised to cause further fission of its nuclei ?

3. Which particles bring about the fission of uranium-235 ?

4. State whether the fission of uranium-235 is caused by low energy neutrons or high energy neutrons.

5. Name the type of nuclear reaction which is involved in the working of :
(*a*) a hydrogen bomb.
(*b*) an atom bomb.

6. Name the moderator used in a nuclear reactor.

7. Of what material are the control rods of a nuclear reactor made ?

8. What do you think is the purpose of the thick, concrete chamber surrounding the reactor of a nuclear power plant ?

9. Where, in a nuclear power station, is uranium used up ?
10. State one use of nuclear fission reactions.
11. Name the unit which is commonly used for expressing the energy released in nuclear reactions.
12. How many MeV are equivalent to 1 atomic mass unit (u) ?
13. Fill in the following blanks with suitable words :
    (*a*) Splitting of a heavy nucleus into two lighter nuclei is called............
    (*b*) Uranium-235 atoms will split when hit by........... This is called...................
    (*c*) Nuclear...............is used in nuclear power stations for the production of electricity.
    (*d*) In a nuclear power station, nuclear fission takes place in the ....

Short Answer Type Questions

14. What is nuclear fission ? Explain with an example. Write the equation of the nuclear reaction involved.
15. (*a*) What is nuclear fusion ? Explain with an example. Write the equation of the reaction involved.
    (*b*) Why are very high temperatures required for fusion to occur ?
16. What is the nuclear fuel in the sun ? Describe the process by which energy is released in the sun. Write the equation of the nuclear reaction involved.
17. (*a*) Write Einstein's mass-energy equation. Give the meaning of each symbol which occurs in it.
    (*b*) If 25 atomic mass units (u) of a radioactive material are destroyed in a nuclear reaction, how much energy is released in MeV ?
18. (*a*) What is the source of energy of ths sun and other stars ?
    (*b*) Describe the working of a hydrogen bomb.
    (*c*) What is common between the sun and a hydrogen bomb ?
19. (*a*) What will happen if slow moving neutrons are made to strike the atoms of a heavy element $^{235}_{92}U$? What is the name of this process ?
    (*b*) Write a nuclear equation to represent the process which takes place.
    (*c*) Name one installation where such a process is utilised.
20. (*a*) What are the advantages of nuclear energy ?
    (*b*) State the disadvantages of nuclear energy.
21. The following questions are about the nuclear reactor of a power plant.
    (*a*) Which isotope of uranium produces the energy in the fuel rods ?
    (*b*) Will the fuel rods last for ever ?
    (*c*) Is the energy produced by nuclear fission or nuclear fusion ?
    (*d*) What is the purpose of using the graphite moderator ?
    (*e*) What is the function of boron rods in the nuclear reactor ?
    (*f*) Why is liquid sodium (or carbon dioxide gas) pumped through the reactor ?
22. In the reactor of a nuclear power plant, name the material which is used :
    (*a*) as a moderator (*b*) to absorb radiations (*c*) in the fuel rods
    (*d*) in the control rods (*e*) to carry away heat
23. In the nuclear reactor of a power plant :
    (*a*) how do control rods control the rate of fission ?
    (*b*) how is heat removed from the reactor core, and what use is made of this heat ?
24. How does inserting the control rods in the graphite core affect the fission in the reactor ? Explain your answer.
25. What are the advantages and disadvantages of using nuclear fuel for generating electricity ?

Long Answer Type Questions

26. (*a*) What is a nuclear reactor ? What is the fuel used in a nuclear reactor ?
    (*b*) With the help of a labelled diagram, describe the working of a nuclear power plant.
    (*c*) How is the working nuclear reactor of a power plant shut down in an emergency ?
    (*d*) Name five places in India where nuclear power plants are located.

27. (*a*) Differentiate between nuclear fission and nuclear fusion.
(*b*) Which of the two, nuclear fission and nuclear fusion, is made use of :
(*i*) for the production of electricity ?
(*ii*) for making a hydrogen bomb ?
(*c*) Which produces more energy : nuclear fusion or nuclear fission ?
(*d*) Calculate the energy released in joules when 5 g of a material is completely converted into energy during a nuclear reaction.
(*e*) How much is this energy in MeV ? (Speed of light = 3×10^8 m/s)

Multiple Choice Questions (MCQs)

28. Which of the following is used as a moderator in the reactor of a nuclear power station ?
(*a*) liquid sodium (*b*) boron (*c*) graphite (*d*) carbon dioxide

29. The control rods used in the reactor of a nuclear power plant are made of :
(*a*) steel (*b*) graphite (*c*) uranium (*d*) boron

30. The 'coolants' which can be used in the reactor of a nuclear power station are :
(*a*) liquid mercury and nitrogen dioxide (*b*) liquid sodium and carbon dioxide
(*c*) liquid ammonia and carbon monoxide (*d*) liquid boron and uranium oxide.

31. In a nuclear power plant, coolant is a substance :
(*a*) which cools the hot, spent steam to condense it back to water
(*b*) which transfers heat from reactor to water in heat exchanger
(*c*) which is boiled to make steam to turn the turbine
(*d*) which cools the generator coils to prevent their overheating.

32. Which of the following is ultimately not derived from the sun's energy (or solar energy) ?
(*a*) wind energy (*b*) nuclear energy
(*c*) biomass energy (*d*) ocean thermal energy

33. One atomic mass unit (u) is equivalent to an energy of :
(*a*) 931 eV (*b*) 9.31 MeV (*c*) 1 MeV (*d*) 931 MeV

34. The energy in the reactor of a nuclear power station is produced by the process of :
(*a*) nuclear diffusion (*b*) nuclear fission
(*c*) nuclear fusion (*d*) nuclear fermentation

35. One eV (electron volt) of nuclear energy is equivalent to :
(*a*) 1.6×10^{-14} J (*b*) 1.6×10^{-12} J (*c*) 1.6×10^{-19} J (*d*) 1.6×10^{-13} J

36. Which of the following can be produced during the nuclear fission as well as nuclear fusion reactions ?
(*a*) protons (*b*) deutrons (*c*) electrons (*d*) neutrons

37. Nuclear fission reactions are not a source of energy for one of the following. This is :
(*a*) atom bomb (*b*) power plants (*c*) sun (*d*) pacemaker

38. The energy produced by converting 1 gram mass of a nuclear fuel into energy completely is :
(*a*) 9×10^{16} J (*b*) 9×10^{14} J (*c*) 9×10^{15} J (*d*) 9×10^{13} J

39. The source of energy of the sun is :
(*a*) conversion of hydrogen gas into helium
(*b*) conversion of carbon fuel into carbon dioxide
(*c*) burning of hydrogen gas present in the sun
(*d*) disintegration of uranium into barium and krypton

40. An uncontrolled nuclear chain reaction forms the basis of :
(*a*) nuclear power plant (*b*) hydrogen bomb (*c*) thermal power station (*d*) atom bomb

41. One MeV of nuclear energy is equivalent to :
(*a*) 1.6×10^{-13} J (*b*) 1.6×10^{-19} J (*c*) 1.6×10^{-16} J (*d*) 1.6×10^{-15} J

42. One type of energy which has not been controlled so far is :
(*a*) ocean thermal energy (*b*) nuclear fusion energy
(*c*) geothermal energy (*d*) nuclear fission energy

43. The disposal of wastes produced in a nuclear power plant poses a big problem because it is :
(*a*) too heavy (*b*) highly inflammable
(*c*) extremely foul smelling (*d*) highly radioactive

44. The heat energy released during nuclear fission and fusion is due to the :
(*a*) conversion of stored chemicals into energy (*b*) conversion of momentum into energy
(*c*) conversion of mass into energy (*d*) conversion of magnetism into energy

45. Which of the following can undergo nuclear fusion reaction ?
(*a*) uranium (*b*) deuterium (*c*) barium (*d*) krypton

Questions Based on High Order Thinking Skills (HOTS)

46. A nuclear reaction is represented by the following equation :

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \longrightarrow ^{139}_{56}\text{Ba} + ^{94}_{36}\text{Kr} + xc + E$$

(*a*) Name the process represented by this equation and describe what takes place in this reaction.
(*b*) Identify the particle *c* and the number *x* of such particles produced in the reaction.
(*c*) What does *E* represent ?
(*d*) Name one installation where the above nuclear reaction is utilised.
(*e*) What type of bomb is based on similar type of reactions ?

47. A nuclear reaction is represented by the equation :

$$^{2}_{1}\text{H} + ^{2}_{1}\text{H} \longrightarrow ^{3}_{2}\text{He} + xc + E$$

(*a*) Name the process represented by this equation and describe what happens during this reaction.
(*b*) Identify the particle *c* and the number *x* of such particles produced in the reaction.
(*c*) What does *E* represent ?
(*d*) State two conditions under which such a reaction takes place.
(*e*) What type of nuclear bomb is based on similar reactions ?

48. The mass numbers of four elements A, B, C and D are 2, 20, 135 and 235, respectively. Which one of them will be most suitable to make : (*i*) an atom bomb, and (*ii*) a hydrogen bomb ?

49. A nuclear power plant is working normally. What would you do if the reactor core suddenly got too hot ?

50. A nuclear reactor has half the length of all its control rods inserted in graphite. What must be done so that the reactor produces more heat ? Explain your answer.

51. Explain why, in a nuclear reactor, the chain reaction stops if the control rods are fully inserted into the graphite.

ANSWERS

1. (*a*) Nuclear fission (*b*) Nuclear fusion **2.** Neutrons **5.** (*a*) Nuclear fusion (*b*) Nuclear fission **9.** Reactor **13.** (*a*) nuclear fission (*b*) neutrons ; nuclear fission (*c*) fission (*d*) reactor **17.** (*b*) 23275 MeV **18.** (*c*) In the sun as well as in the hydrogen bomb, energy is produced by nuclear fusion reactions **19.** (*c*) Nuclear Power Station **26.** (*c*) The control rods of boron are fully inserted in the reactor. They absorb all the neutrons, shutting down the reactor **27.** (*b*) (*i*) Nuclear fission (*ii*) Nuclear fusion (*c*) Nuclear fusion (*d*) 4.5×10^{14} J (*e*) 2.8×10^{27} MeV **28.** (*c*) **29.** (*d*) **30.** (*b*) **31.** (*b*) **32.** (*b*) **33.** (*d*) **34.** (*b*) **35.** (*c*) **36.** (*d*) **37.** (*c*) **38.** (*d*) **39.** (*a*) **40.** (*d*) **41.** (*a*) **42.** (*b*) **43.** (*d*) **44.** (*c*) **45.** (*b*) **46.** (*a*) Nuclear fission ; A large nucleus splits into two smaller nuclei with the release of energy, brought about by the absorption of a neutron (*b*) Particle *c* is neutron ; $x = 3$ (*c*) Energy liberated (*d*) Nuclear Power Station (*e*) Atom bomb **47.** Nuclear fusion ; Two smaller nuclei combine to form a bigger nucleus with the release of energy, brought about under the conditions of high temperature and pressure (*b*) Particle *c* is neutron ; $x = 1$ (*c*) Energy liberated (*d*) Millions of degrees of temperature and Millions of pascals of pressure (*e*) Hydrogen bomb **48.** (*i*) D (Mass number 235) (*ii*) A (Mass number 2) **49.** Insert the control rods of boron a little more into the reactor to reduce the rate of nuclear fission process **50.** Withdraw the control rods a little more from inside the reactor. This will increase the rate of nuclear fission process and hence produce more heat **51.** The control rods absorb all the neutrons, stopping the nuclear chain reaction.

ENVIRONMENTAL CONSEQUENCES

In this Chapter we have studied various sources of energy. The use of each and every source of energy disturbs the environment in one way or the other. For example, the use of fossil fuels causes air pollution and the production of hydroelectricity causes ecological imbalance. In some cases, the actual operation of the device used for harnessing energy may be pollution-free but the making of the device itself must have caused some environmental damage. For example, the use of a wind generator, solar cooker and solar cells for obtaining energy is pollution-free but the processes involved in making the materials for these energy devices must have damaged the environment in some way. From this we conclude that, **in reality, no source of energy can be said to be pollution-free.** So, when we talk of a 'clean fuel', it actually means that it is a cleaner fuel than some other fuel. For example, when we say that CNG is a clean fuel, it means that CNG is a cleaner fuel than, say petrol or diesel. Similarly, we can say that hydrogen is a cleaner fuel than CNG. This will become more clear from the following example.

Figure 40. Hydrogen is used as a fuel in rockets. Hydrogen powered cars are also being developed now.

Sample Problem. Hydrogen has been used as a rocket fuel. Would you consider it a cleaner fuel than CNG ? Why or why not ?

(**NCERT Book Question**)

Answer. Hydrogen is a cleaner fuel than CNG. This is because the burning of hydrogen produces only water, which is totally harmless. On the other hand, burning of CNG produces carbon dioxide gas and water. This carbon dioxide can produce greenhouse effect in the atmosphere and lead to the excessive heating of the environment in the long run.

Some of the **environmental consequences of the increasing demand for energy** are the following :

1. The combustion of fossil fuels is producing acid rain and damaging plants (crops), soil and aquatic life.
2. The burning of fossil fuels is increasing the amount of greenhouse gas carbon dioxide in the atmosphere.
3. The cutting down of trees from the forest (deforestation) for obtaining fire-wood is causing soil erosion and destroying wild life.
4. The construction of hydro-power plants is disturbing ecological balance.
5. Nuclear power plants are increasing radioactivity in the environment.

The various factors which we should keep in mind while choosing a source of energy are : (*i*) the ease of extracting energy from that source, (*ii*) the cost of extracting energy from the source, (*iii*) the efficiency of technology available to extract energy from that source, and (*iv*) the damage to environment which will be caused by using that source.

How Long Will Energy Resources of Earth Last

Most of the energy that we use today comes mainly from the three non-renewable energy resources of the earth : coal, petroleum and natural gas (which are called fossil fuels). We have been using these energy resources of the earth at a very rapid rate in the past. So, the amount of coal, petroleum and natural gas left in the earth is limited. It has been estimated that **the world's known coal reserves are expected to last for another 200 years compared to around 40 years for the known petroleum oil reserves and around 60 years for the known reserves of natural gas**. So, it is high time that we start using alternative sources of energy to conserve the depleting reserves of coal, petroleum and natural gas so that they may last longer. We should also reduce energy consumption wherever possible. Some of **the steps which can be taken to**

reduce energy consumption are as follows :

1. Switch off lights, fans, TV and other such electrical appliances when not needed, to save electricity.
2. Use energy efficient electrical appliances to save electricity. This can be done by using compact fluorescent lamps (CFL) and tube-lights in place of conventional filament-type electric bulbs (see Figure 41).
3. Good quality stoves should be used to burn fuels like kerosene and LPG so as to obtain maximum heat.
4. Pressure cookers should be used for cooking food to save fuel.
5. Solar cookers should be used to cook food whenever possible and solar water heaters should be used to get hot water.
6. The use of biogas as fuel should be encouraged in rural areas.
7. Bicycles should be used for short distances to save precious fuel like petrol (which is used in cars, scooters and motorcycles).

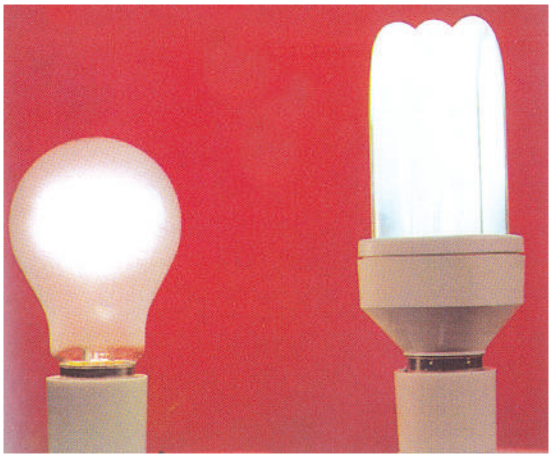


Figure 41. The bulb shown on the left side is the traditional, filament-type bulb. This is not energy efficient because it wastes a lot of electric energy as heat. The bulb shown on the right side is called Compact Fluorescent Lamp (CFL) which is energy efficient because it consumes much less electric energy. This is because it wastes much less electric energy as heat.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Which of the two is a cleaner fuel : hydrogen or CNG ? Why ?
2. Which of the two is more energy efficient : filament type electric bulb or CFL ? Why ?
3. How long are the energy resources of the earth like coal, petroleum and natural gas expected to last ?
4. Name two devices which can be utilised for the cooking of food so as to save fuel .

Short Answer Type Questions

5. What are the various factors which we should keep in mind while choosing a source of energy ?
6. Can any source of energy be pollution free ? Explain your answer with an example.
7. What are the environmental consequences of the increasing demand for energy ?
8. What steps would you suggest to reduce energy consumption ?

Multiple Choice Questions (MCQs)

9. The major cause of environmental pollution is the use of :
(*a*) hydrogen as fuel (*b*) biomass energy (*c*) ocean energy (*d*) fossil fuels

10. The world's known coal reserves are expected to last for about :
(*a*) 200 years (*b*) 400 years (*c*) 500 years (*d*) 100 years

11. The fossil fuel whose known reserves in the earth are expected to last for the minimum period is :
(*a*) coal (*b*) uranium (*c*) petroleum (*d*) natural gas

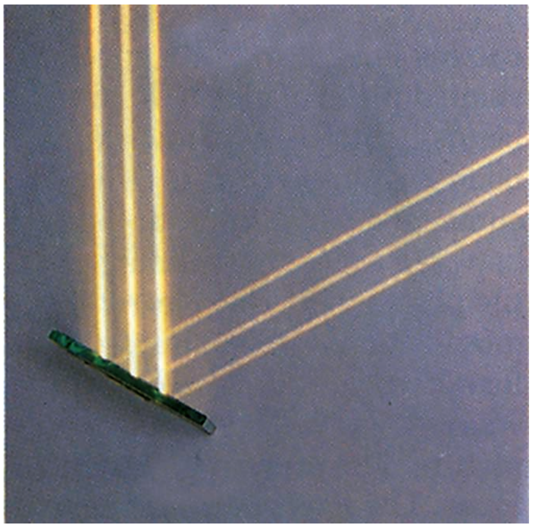
12. An energy efficient device for producing light is :
(*a*) DLF (*b*) CFL (*c*) FCL (*d*) LPG

ANSWERS

1. Hydrogen **2.** CFL **4.** Solar cooker ; Pressure cooker **9.** (*d*) **10.** (*a*) **11.** (*c*) **12.** (*b*)

CHAPTER

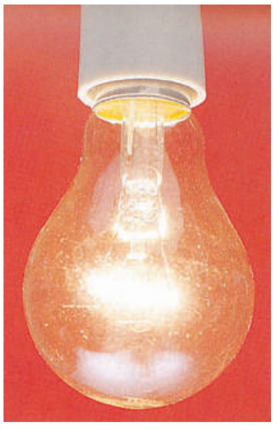
4



Reflection of Light

Light is a form of energy. Light is needed to see things around us. We are able to see the beautiful world around us because of light. We can read a book, see pictures in a magazine, and watch television and movies due to the existence of light. And it is light which makes us see our image in a looking mirror. **We detect light with our eyes**. Though we see the various objects (or things) around us with our eyes but eyes alone cannot see any object. We also need a source of light to make objects visible. For example, we cannot see any object in a dark room or in the darkness of night because there is no light in a dark room or in the night to make objects visible. But as soon as an electric bulb (a tube-light or a torch, etc.) is switched on and light falls on the objects, we are able to see them clearly. *It is only when light coming from an object enters our eyes that we are able to see that object*. This light may have been *emitted* by the object itself or it may have been *reflected* by the object.

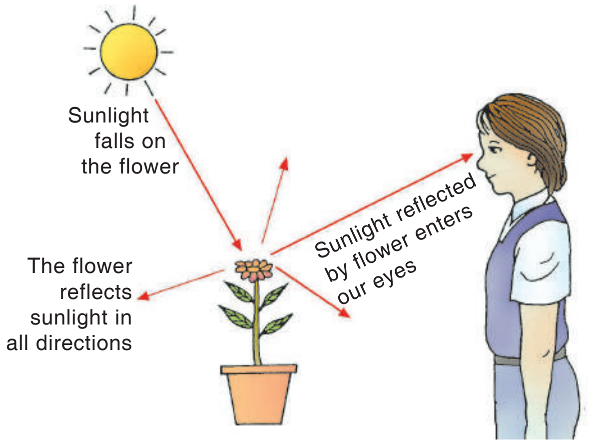
Light enables us to see objects from which it comes or from which it is reflected. For example, the sun gives out light. We can see the sun because the light coming from the sun enters our eyes. **The objects like the sun, other stars, electric bulb, tube-light, torch, candle and fire, etc., which emit their own light are called luminous objects** (see Figure 1). We can see the luminous objects due to the light emitted by them. Though luminous objects are very small in number but they help us to see a large variety of non-luminous objects around us. The objects like a flower, a chair or a table do not have light of their own but even then we are able to see them. This can be explained as follows : Though the objects like a flower, a chair or a table, etc., do not emit light themselves, we can see them by the light which they reflect (or scatter) by taking it from a luminous object like the sun or an electric bulb, etc. (see Figure 2). So, when the sunlight or bulb light falls on a flower or chair (or any other object), some of this light is reflected towards us. And



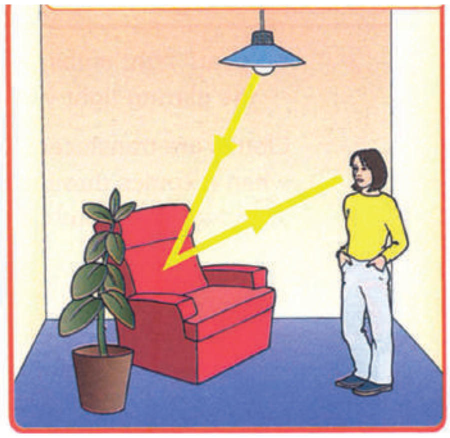
(*a*) An electric bulb gives its own light. It is a luminous object.

(*b*) A flower does not give its own light. It is a non-luminous object.

Figure 1. Luminous and non-luminous objects.



(*a*) We can see the flower during day time because it reflects sunlight falling on it into our eyes.



(*b*) We can see the chair at night because it reflects bulb light falling on it into our eyes.

Figure 2. We see most of the objects around us by the light reflected from them.

when this reflected light enters our eyes, then we are able to see the flower or chair (because to our eyes, this light appears to be coming from the flower or chair) (see Figure 2). **Those objects which do not emit light themselves but only reflect (or scatter) the light which falls on them, are called non-luminous objects** (see Figure 2). A flower, chair, table, book, trees, other plants, human beings, fan, bed, mirror, diamond, walls, floor, and road, etc., are all non-luminous objects. In fact, *most of the objects around us are non-luminous objects.* **We can see the non-luminous objects because they reflect light (received from a luminous object) into our eyes**. Even the moon is a non-luminous object (because it does not have its own light). We can see the moon because it reflects the sunlight falling on its surface towards us (on the earth).

From the above discussion we conclude that light is a form of energy which causes in us the sensation of sight. **Light travels in straight lines**. The fact that a small source of light casts a sharp shadow of an opaque object tells us that light travels in a straight line path. This is because if light could bend easily and go behind the opaque object, then no shadow could be formed. We will now discuss the nature of light.

Nature of Light

There are two theories about the nature of light : wave theory of light and particle theory of light. **According to wave theory : Light consists of electromagnetic waves which do not require a material medium (like solid, liquid or gas) for their propagation.** The wavelength of visible light waves is very small (being only about 4×10^{-7} m to 8×10^{-7} m). The speed of light waves is very high (being about 3×10^{8} metres per second in vacuum). **According to particle theory : Light is composed of particles which travel in a straight line at very high speed.** The elementary particle that defines light is the '*photon*'.

Some of the phenomena of light can be explained only if light is considered to be made up of waves whereas others can be explained only if light is thought to be made up of particles. For example, the phenomena of *diffraction* (bending of light around the corners of tiny objects), *interference* and *polarization* of light can only be explained if light is considered to be of wave nature. The particle theory of light cannot explain these phenomena. On the other hand, the phenomena of *reflection* and *refraction* of light, and *casting of shadows* of objects by light, can be explained only if light is thought to be made of particles. Wave theory of light cannot explain these phenomena. Thus, there is evidence for the wave nature of light as well as for particle nature of light.

Physics experiments over the past hundred years or so have demonstrated that **light has a dual nature (double nature) : light exhibits the properties of both waves and particles (depending on the situation it is in).** The modern theory of light called 'Quantum Theory of Light' combines both the wave and particle models of light.

REFLECTION OF LIGHT

When light falls on the surface of an object, some of it is sent back. **The process of sending back the light rays which fall on the surface of an object, is called reflection of light.** The reflection of light is shown in Figure 3. When a beam of light *AO* falls on a mirror at point *O*, it is sent back by the mirror in another direction *OB* (see Figure 3). And we say that the mirror has reflected the beam of light falling on it. We can compare the reflection of light to the bouncing back of a tennis ball on hitting a wall. For example, if we throw a tennis ball at a wall, the ball bounces back. This means that the wall sends it back. Similarly, when light falls on the surface of an object, the object sends the light back. And we say that the object reflects the light. Most of the objects reflect light which falls on them. Some objects reflect more light whereas other objects reflect less light. **The objects having polished, shining surfaces reflect more light than objects having unpolished, dull surfaces.**

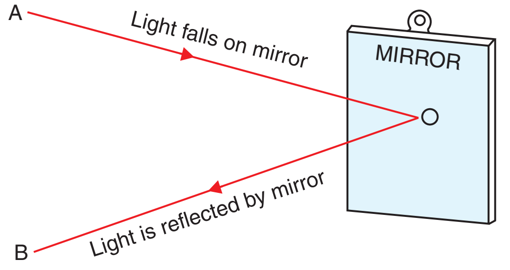
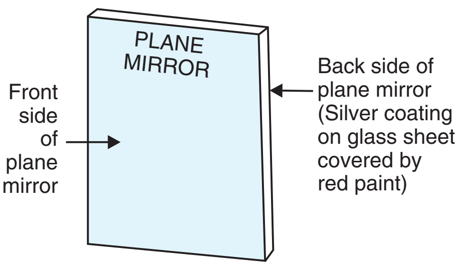


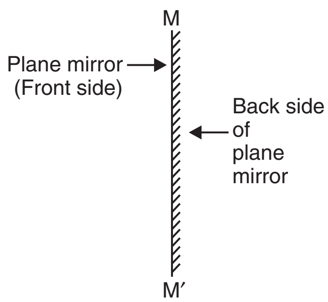
Figure 3. A mirror reflects the light falling on it.

We know that an object (say, a chair) kept in a room can be seen from all the parts of the room. This is due to the fact that usually, because of its rough surface, an object reflects light (or scatters light) in all the directions. Since the reflected light reaches all the parts of the room, the object can be seen from all the parts of the room. If, however, the surface of an object is smooth (like that of a mirror), then the light falling on it is reflected in only one direction (as shown in Figure 3).

Silver metal is one of the best reflectors of light. For example, a polished block of silver metal reflects almost all the light falling on it and does not transmit any light through it. But the surface of silver metal is easily scratched and soon becomes rough. So, **ordinary mirrors are made by depositing a thin layer of silver metal on the back side of a plane glass sheet. The silver layer is then protected by a coat of red paint. The reflection of light in a plane mirror (or any other mirror) takes place at the silver surface in it.** Thus, a plane mirror is a thin, flat and smooth sheet of glass having a shining coating of silver metal on one side. The silver coating is protected by a red paint. These days mirrors are being made increasingly by depositing a thin coating of aluminium metal at the back of a glass sheet (instead of silver coating). This is because aluminium is much cheaper than silver and it reflects light very well. A plane mirror is shown in Figure 4(*a*). The mirror on our dressing table in which we see our face is a plane mirror.



(*a*) A plane mirror.



(*b*) This is how a plane mirror is represented in diagrams.

Figure 4.

In our everyday life, we use plane mirrors of different shapes and sizes depending on where they are being used. But in a science laboratory, a small rectangular strip of plane mirror is usually used for performing experiments on the reflection of light. **In our diagrams, a plane mirror is represented by a straight line having a number of short, oblique lines on one side** [see Figure 4(*b*)]. The plane side of straight line is the front side of the mirror (where the reflection of light takes place). And the side having short, oblique lines represents the back side of the plane mirror. In Figure 4(*b*), the straight line *MM*′ (read as : *MM-dash*) represents a plane mirror.

We will also be using rays of light in constructing the ray-diagrams. **A ray of light is the straight line along which light travels.** The arrow head put on the straight line tells us the direction in which the light is travelling. **A 'bundle of light rays' is called a 'beam of light'.** We will now study the reflection of light from the plane surfaces like that of a plane mirror. This is necessary to understand the reflection of light from spherical mirrors.

REFLECTION OF LIGHT FROM PLANE SURFACES : PLANE MIRROR

When a ray of light falls on a plane mirror (or any other plane surface), it is reflected according to some laws, called the laws of reflection of light. In order to understand the laws of reflection of light, we should first know the meaning of the terms : incident ray, point of incidence, reflected ray, normal (at the point of incidence), angle of incidence, and angle of reflection. So, we will discuss these terms first.

In Figure 5, we have a plane mirror *MM′*. **The ray of light which falls on the mirror surface is called the incident ray**. In Figure 5, *AO* is the incident ray of light. The incident ray gives the direction in which light falls on the mirror. **The point at which the incident ray falls on the mirror is called the point of incidence**. In Figure 5, point *O* on the surface of the mirror is the point of incidence (because the incident ray *AO* touches the mirror surface at this point). We know that when a ray of light falls on a mirror, the mirror sends it back in another direction and we say that the mirror has reflected the ray of light. **The ray of light which is sent back by the mirror is called the reflected ray.** In Figure 5, *OB* is the reflected ray of light. The reflected ray of light shows the direction in which the light goes after reflection from the mirror.

Another term that we will be using is the 'normal'. **The 'normal' is a line at right angle to the mirror surface at the point of incidence.** In other words, *'normal' is a line which is perpendicular to the mirror at the point of incidence*. In Figure 5, the mirror is *MM′* and the point of incidence is *O*. So, the line *ON* is the normal to the mirror surface at point *O*. The normal has been represented by a dotted line to distinguish it from the incident ray and the reflected ray. Please note that 'normal' is just a 'perpendicular line' to the mirror, and it should not be called the 'normal ray' like the incident ray or reflected ray. The normal is a line at right angles to the mirror surface. In other words, normal makes an angle of 90° with the surface of the plane mirror. We will now discuss the angle of incidence and the angle of reflection.

The angle of incidence is the angle made by the incident ray with the normal at the point of incidence. In other words, the angle between the incident ray and normal is called the angle of incidence. In Figure 5, the incident ray is *AO* and the normal is *ON*, so the angle *AON* is the angle of incidence. The angle of incidence is denoted by the letter i.

The angle of reflection is the angle made by the reflected ray with the normal at the point of incidence. In other words, the angle between the reflected ray and normal is called the angle of reflection. In Figure 5, the reflected ray is *OB* and the normal is *ON*, so the angle *NOB* is the angle of reflection. The angle of reflection is denoted by the letter r. Keeping these points in mind, we will now describe the laws of reflection of light.

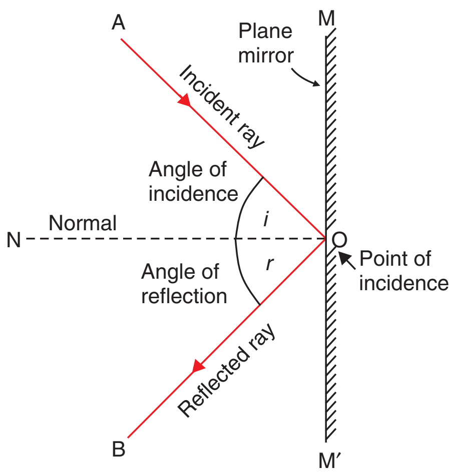


Figure 5. Reflection of light from a plane mirror.

Laws of Reflection of Light

The reflection of light from a plane surface (like that of a plane mirror) or from a spherical surface (like that of a concave mirror or convex mirror) takes place according to two laws, which are known as the laws of reflection of light. The laws of reflection of light are given below :

1. First Law of Reflection. According to the first law of reflection of light : **The incident ray, the reflected ray, and the normal (at the point of incidence), all lie in the same plane.** For example, in Figure 5, the incident ray *AO*, the reflected ray *OB* and the normal *ON*, all lie in the same plane, the plane of paper. They are neither coming up out of the paper; nor going down into the paper.

2. Second Law of Reflection. According to the second law of reflection of light : **The angle of reflection is always equal to the angle of incidence.** We can also state the second law of reflection of light as follows by writing the angle of incidence first : *The angle of incidence is equal to the angle of reflection*. If the angle of incidence is i and the angle of reflection is r, then according to the second law of reflection :

$$\angle i = \angle r$$

For example, if we measure the angle of reflection NOB in Figure 5, we will find that it is exactly equal to the angle of incidence AON.

The second law of reflection of light means that if the angle of incidence is 35°, then the angle of reflection will also be 35° (see Figure 6). And if the angle of incidence is changed to 45°, then the angle of reflection will also change and become 45° (see Figure 7). *In every case, the angle of reflection remains equal to the angle of incidence*.

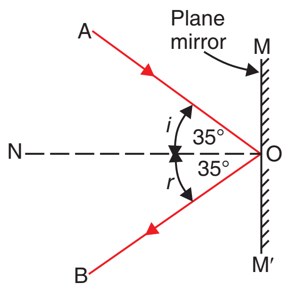


Figure 6. If the angle of incidence is 35°, then the angle of reflection is also 35°.

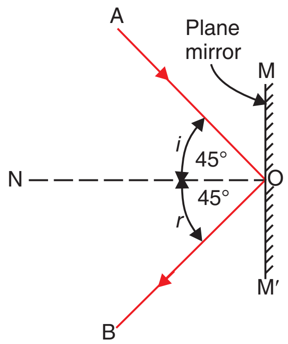


Figure 7. When the angle of incidence is changed to 45°, the angle of reflection also becomes 45°.

We will now describe **what happens when a ray of light falls normally (or perpendicularly) on the surface of a mirror.** If a ray of light is incident normally on a mirror, it means that it is travelling along the normal to the mirror. So, the angle of incidence (i) for such a ray of light is zero (0). And since the angle of incidence is zero, therefore, according to the second law of reflection, its angle of reflection (r) will also be zero (0). This means that **a ray of light which is incident normally (or perpendicularly) on a mirror, is reflected back along the same path (because the angle of incidence as well as the angle of reflection for such a ray of light are zero).** For example, in Figure 8, a ray of light falls on the plane mirror along the normal NO, therefore, it will be reflected along the same path ON. So, in this case, the incident ray will be NO and the reflected ray will be ON. In other words, the same line represents incident ray, normal and reflected ray. We should, however, put two arrow heads on the same 'normal' line pointing in opposite directions – one arrow to represent incident ray and the other arrow to represent reflected ray (as shown in Figure 8).

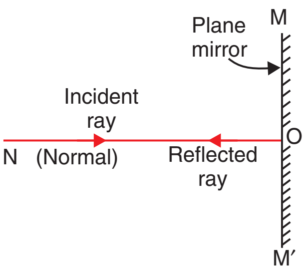


Figure 8. A ray of light incident normally (at 90°) to the mirror surface is reflected back along the same path.

Please note that **the laws of reflection of light apply to all kinds of mirrors, plane mirrors as well as spherical mirrors (like concave mirrors and convex mirrors).** By using the laws of reflection of light, we can find out the nature and position of the images (of objects) formed by the various types of mirrors.

Regular Reflection and Diffuse Reflection of Light

In regular reflection, a parallel beam of incident light is reflected as a parallel beam in one direction. In this case, parallel incident rays remain parallel even after reflection and go only in one direction (see Figure 9). **Regular reflection of light occurs from smooth surfaces like that of a plane mirror (or highly polished metal surfaces).** For example, when a parallel beam of light falls on the smooth surface of a plane mirror, it is reflected as a parallel beam in only one direction as shown in Figure 9. Thus, **a plane mirror produces regular reflection of light.** Images are formed by regular reflection of light. For example, a smooth surface (like that of a plane mirror) produces a clear image of an object due to regular reflection of light. A highly polished metal surface and a still water surface also produce regular reflection of light and form images. This is why we can see our face in a polished metal object as well as in the still water surface of a pond or lake. A polished wooden table is very smooth and hence produces regular reflection of light.

The regular reflection of light from a smooth surface can be explained as follows : All the particles of a smooth surface (like a plane mirror) are facing in *one direction*. Due to this the angle of incidence for all the parallel rays of light falling on a smooth surface is the same and hence the angle of reflection for all the rays of light is also the same. *Since the angle of incidence and the angle of reflection are the same (or equal), a beam of parallel rays of light falling on a smooth surface is reflected as a beam of parallel light rays in one direction only* (see Figure 9).

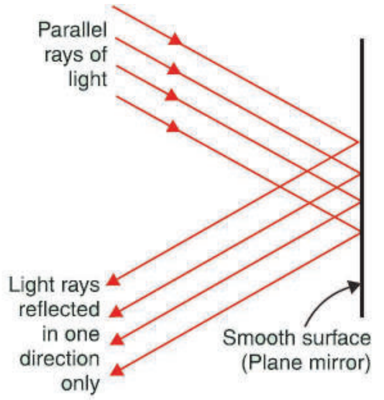


Figure 9. Regular reflection : Incident light is reflected in only one direction.

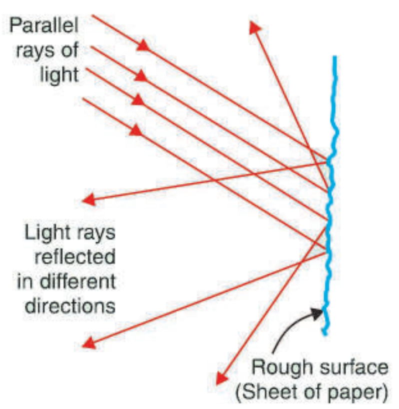


Figure 10. Diffuse reflection : Incident light is reflected in different directions.

In diffuse reflection, a parallel beam of incident light is reflected in different directions. In this case, the parallel incident rays do not remain parallel after reflection, they are scattered in different directions (see Figure 10). The diffuse reflection is also known as *irregular reflection* or scattering. **The diffuse reflection of light takes place from rough surfaces like that of paper, cardboard, chalk, table, chair, walls and unpolished metal objects.** For example, when a parallel beam of light rays falls on the rough surface of a sheet of paper, the light is scattered by making reflected rays in different directions (see Figure 10). Thus, **a sheet of paper produces diffuse reflection of light.** No image is formed in diffuse reflection of light. For example, a rough surface (like that of paper) does not produce an image of the object due to diffuse reflection of light. Actually, the light rays falling on the rough surface of paper are scattered in all directions and hence no image is formed.

The diffuse reflection of light from a rough surface can be explained as follows : The particles of a rough surface (like that of paper) are all facing in *different directions*. Due to this, the angles of incidence for all the parallel rays of light falling on a rough surface are different and hence the angles of reflection for all the rays of light are also different. *Since the angles of incidence and the angles of reflection are different, the parallel rays of light falling on a rough surface go in different directions* (see Figure 10). **Please note that the diffuse reflection of light is not due to the failure of the laws of reflection.** Diffuse reflection is caused by the roughness (or irregularities) in the reflecting surface of an object (like paper or cardboard, etc.). The laws of reflection are valid at each point even on the rough surface of an object.

The surfaces of most of the objects are rough (or uneven) to some extent. So, **most of the objects around us cause diffuse reflection of light and scatter the light falling on them in all directions.** In fact, we can see these objects only because they scatter light rays falling on them in all directions. For example, a book lying on a table can be seen from all parts of the room due to diffuse reflection of light from its surface. The surface of book, being rough, scatters the incident light in all parts of a room. Hence the book can be seen from all parts of the room. A cinema screen has a rough surface and causes diffuse reflection of light falling on it. The cinema screen receives light from a film projector and scatters it in all directions in the cinema hall so that people sitting anywhere in the hall can see the picture focused on the screen.

Objects and Images

In the study of light, the term 'object' has a special meaning. **Anything which gives out light rays (either its own or reflected by it) is called an object.** A bulb, a candle, a pin-head, an arrow, our face, or a tree, are all examples of objects from the point of view of study of light. The objects can be of two types : very small objects (called point objects) or large objects (called extended objects). In drawing the ray-diagrams for the formation of images, we will be using both type of objects according to our convenience. In ray-diagrams, the point objects (like point sources of light or a pin-head) are represented by a 'dot', and the extended objects are represented by drawing 'an arrow pointing upwards'.

In physics, **image is an optical appearance produced when light rays coming from an object are reflected from a mirror (or refracted through a lens).** This will become clear from the following example. When we look into a mirror, we see our face. What we see in the mirror is actually a 'reflection' of our face and it is called 'image' of our face. Thus, **when we look into a mirror, we see the image of our face in it.** In this case, 'our face' is the 'object' and what we see in the mirror is the 'image'. The image of our face appears to be situated behind the mirror. **While watching a movie in the cinema hall, we see the images of actors and actresses on the cinema screen.** Please note that *an image is formed when the light rays coming from an object meet (or appear to meet) at a point, after reflection from a mirror* (*or refraction through a lens*). The images are of two types : real images and virtual images. These are discussed below.

Real Images and Virtual Images

The image which *can* be obtained on a screen is called a real image. In a cinema hall, we see the images of actors and actresses on the screen. So, **the images formed on a cinema screen is an example of real images** (see Figure 11). A real image is formed when light rays coming from an object actually meet at a point after reflection from a mirror (or refraction through a lens). A real image can be formed on a screen because light rays actually pass through a real image. Real images can be formed by a concave mirror. A convex lens can also form real images. We will study the formation of real images with the help of ray-diagrams after a while.

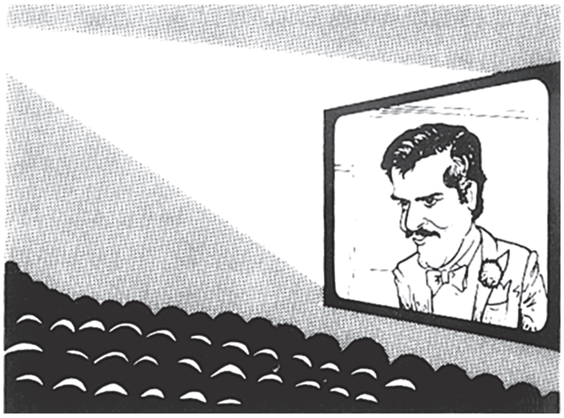


Figure 11. The image of actors and actresses formed on a cinema screen is a *real* image.

Figure 12. When we look into a mirror, we see our image in it. The image formed in a plane mirror is a *virtual* image.

The image which *cannot* be obtained on a screen is called a virtual image. A virtual image can be seen only by looking into a mirror (or a lens). The image of our face formed by a plane mirror cannot be obtained on a screen, it can be seen only by looking into the mirror. So, **the image of our face in a plane mirror is an example of virtual image** (see Figure 12). Virtual images are also called unreal images. **A**

virtual image is just an illusion. A virtual image is formed when light rays coming from an object only appear to meet at a point when produced backwards (but do not actually meet) after reflection from a mirror (or refraction through a lens). A virtual image cannot be formed on a screen because light rays do not actually pass through a virtual image. A plane mirror always forms virtual images. Similarly, a convex mirror also forms only virtual images. A concave mirror can form a virtual image only when the object is kept within its focus. As we will study in the topic on lenses, a concave lens always forms virtual images but a convex lens forms a virtual image only when the object is within its focus. We will study the formation of virtual images with the help of ray-diagrams after a while.

We will now describe the formation of image in a plane mirror. Before we do that please remember that an object gives out a large number of light rays in all the directions but we will use only two light rays coming from the object to show the formation of image. This is done just to keep the ray-diagram simple. Another point to be noted is that the real rays of light are represented by full lines (solid lines) whereas virtual rays of light are represented by dotted lines (broken lines). The real rays of light can exist only in front of a mirror. The virtual rays of light are those which we show behind a mirror. The virtual light rays do not exist at all (because light cannot reach behind the mirror by passing through it). They just appear to be coming from behind the mirror. We will now describe how the image of an object is formed in a plane mirror by using the laws of reflection of light.

Formation of Image in a Plane Mirror

Consider a small object *O* (say, a point source of light) placed in front of a plane mirror *MM*′ (see Figure 13). The mirror will form an image *I* of the object *O*. Now, we want to know how this image has been formed. This happens as follows : The object *O* gives out light rays in all directions but we need only two rays of light to locate the image. Now, a ray of light *OA* coming from the object *O* is incident on the plane mirror at point *A* and it gets reflected in the direction *AX* according to the laws of reflection of light making the angle of reflection r_1 equal to the angle of incidence i_1 (see Figure 13). Another ray of light *OB* coming from the object *O* strikes the mirror at point *B* and gets reflected in the direction *BY*, again making the angle of reflection r_2 equal to the angle of incidence i_2.

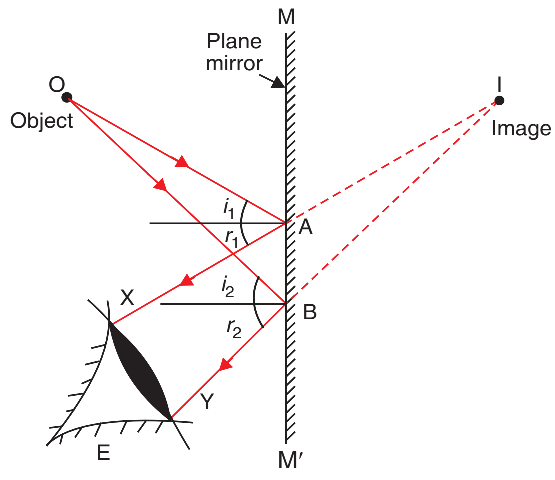


Figure 13. Formation of image in a plane mirror.

The two reflected rays *AX* and *BY* are diverging (moving away from one another), so they cannot meet on the left side. Let us produce the reflected rays *AX* and *BY* backwards (as shown by dotted lines in Figure 13). They meet at point *I* behind the mirror. Now, when the reflected rays *AX* and *BY* enter the eye of a person at position *E*, the eye sees the rays of light in the straight line direction in which the reflected rays enter it. So, the person looking into the mirror from position *E* sees the reflected rays as if they are coming from the point *I* behind the mirror (because *I* is the point of intersection of the reflected rays when produced backwards to the right side). Thus, point *I* is the image of the object *O* formed by the plane mirror. For example, if our face is at position *O* in front of the plane mirror, then we will see the image of our face in the mirror at point *I*.

Please note that **the image formed by a plane mirror can be seen only by looking into the mirror.** So, if a screen is placed at position *I*, no image would be formed on it because the light rays do not actually pass through the point *I*, they only appear to do so. **An image of this type, which cannot be received on a screen, is known as a virtual image.** Another point to be noted is that the light rays shown by dotted lines behind the mirror are only imaginary light rays. There can be no real light rays behind a mirror because it has a silvered reflecting surface at its back (covered with a paint) which does not allow light rays to pass through it and go behind the mirror. So, there is no light coming to the person directly from the image point *I*. It is only the light reflected from the mirror which appears to be coming from the image point *I*.

Image of an Extended Object (or Finite Object)

We have just studied that a plane mirror forms a point image of a point object. But most of the actual objects are much bigger than a mere 'point' and they are called 'extended objects' or 'finite objects'. An extended object (or bigger object) can be considered to be made up of a very, very large number of point objects. So, the image of an extended object is a collection of the image points corresponding to the various points of the object. We will now describe how a plane mirror forms the image of an extended object. In our ray-diagrams, we will use an 'arrow pointing upwards' to represent an extended object (or finite object).

In Figure 14, an extended object *AB* (an arrow pointing upwards) is placed in front of a plane mirror *MM′*. In order to locate the image of arrow *AB* in the plane mirror, we will first find out the positions of images of its top point *A* and bottom point *B*. This can be done as follows :

(*i*) From point *A*, we draw an incident ray *AC* perpendicular to the mirror (see Figure 14). This will be reflected back along the same path. So, *CA* is the first reflected ray. We now draw another incident ray *AD* which strikes the mirror at point *D*. The ray *AD* is reflected along *DE*, making an angle of reflection (r_1) equal to the angle of incidence (i_1). Thus, *DE* is the second reflected ray here. We produce the two reflected rays *CA* and *DE* backwards by dotted lines. They meet at point *A′* (*A*–dash). So, *A′* is the virtual image of the top point *A* of the object.

(*ii*) From point *B*, we draw an incident ray *BF* perpendicular to the mirror. This will be reflected back along the same path, giving the reflected ray *FB*. Another incident ray *BG* is reflected along *GH* making the angle of reflection (r_2) equal to the angle of incidence (i_2). We produce the two reflected rays *FB* and *GH* backwards by dotted lines. They meet at point *B′* (*B*–dash). So, *B′* is the virtual image of the bottom point *B* of the object.

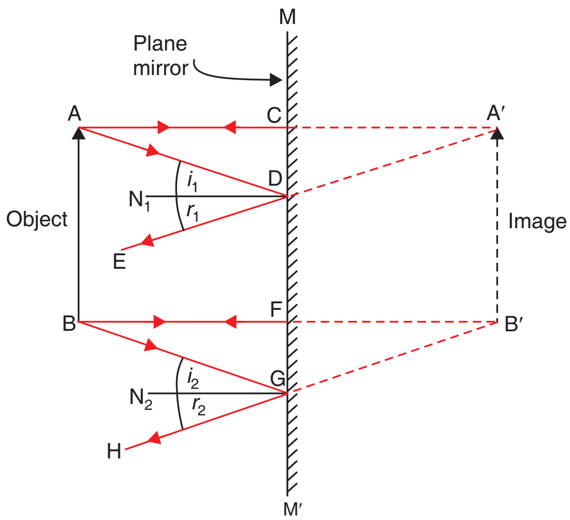


Figure 14. The formation of image of an extended object (here an arrow *AB*) in a plane mirror.

In this way we have located the images of the top point *A* and bottom point *B* of the object. Now, each point of the object (or arrow) between *A* and *B* will give a point image which will lie between the points *A′* and *B′*. So, to get the complete image of object *AB*, we join the points *A′* and *B′* by a dotted line. Thus, *A′B′* (A–dash *B*–dash) is the complete image of the object *AB* which has been formed by the plane mirror (see Figure 14).

The image is virtual, erect (same side up as the object, because both the object and image have arrow-head at the top), and of the same size as the object. Please note that in Figure 14, the image *A′B′* has been drawn by dotted line just to show that it is a virtual image. Thus, **the nature of image formed by a plane mirror is virtual and erect.** And **the size of image formed by a plane mirror is equal to that of the object.** The image is at the same distance behind the plane mirror as the object (arrow) is in front of the mirror.

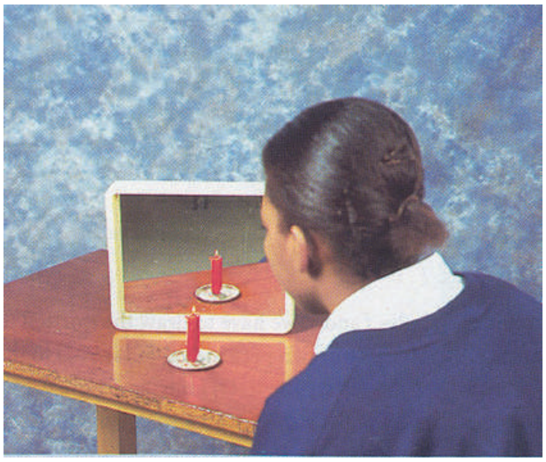


Figure 15. The image of candle in the plane mirror is the same distance behind the mirror as the candle is in front of the mirror.

The Position of Image Formed in a Plane Mirror

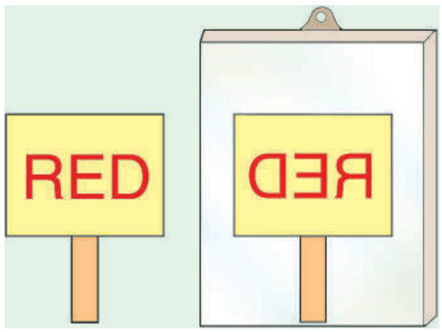
The image formed in a plane mirror is at the same distance behind the mirror as the object is in front of the mirror (see Figure 15). In other words, the image and object are at equal distances from a plane mirror but they are on the opposite sides of the plane mirror. For example, if an object is placed at a distance of 5 cm in front of a plane mirror, then its image will also be formed at a distance of 5 cm behind the mirror. And the total distance between the object and its image will be 5 + 5 = 10 cm. That is, the object will be at a distance of 10 cm from its image.

Lateral Inversion

If we stand in front of a big plane mirror, we see the image of our body in it. Though our image appears to be just as we are, but there is a difference. This is because if we lift our right hand, then our image lifts its left hand. And if we lift our left hand, then the image appears to lift its right hand (see Figure 16). This means that **the right side of our body becomes left side in the image; whereas the left side of our body becomes right side in the image**. It appears as if our image has been 'reversed sideways' with respect to our body. This effect of reversing the sides of an object and its image is called *lateral inversion.* And we say that the image formed in a plane mirror is laterally inverted. In other words, the image formed in a plane mirror is 'sideways reversed' with respect to the object. We can now define lateral inversion as follows :

Figure 16. Our left hand appears to be right hand in the mirror image.

When an object is placed in front of a plane mirror, then the right side of object appears to become the left side of image; and the left side of object appears to become the right side of image. This change of sides of an 'object' and its 'mirror image' is called lateral inversion. The phenomenon of lateral inversion will become clear from the following example. Suppose we have a placard having the word RED written on it [see Figure 17(*a*)]. When we hold this placard in front of a plane mirror, the image of word RED appears to be like ᗡƎЯ [see Figure 17(*b*)]. Please note that the object (placard) has the letter R on its left side but the image has this letter in reversed form Я on its right side. Similarly, the image of letter E appears to be reversed like Ǝ. And the letter D on the right side of the object (placard) is on the left side of the image in the reversed form as ᗡ. Thus, all the letters written on the placard are reversed from left to right. We say that the image is laterally inverted. This is an example of lateral inversion. **The phenomenon of lateral inversion is due to the reflection of light.**



(*a*) Object (*b*) Laterally inverted image (as seen in plane mirror)

Figure 17. Diagram to show lateral inversion.

From the above discussion we conclude that **the image formed in a plane mirror is laterally inverted (or sideways reversed) with respect to the object.** It is due to lateral inversion that the image of our right hand appears to be our left hand. So, when we sit in front of a plane mirror and write with our right hand, it appears in the mirror that we are writing with the left hand. And it is also due to lateral inversion that the parting in our hair on the right appears to be on the left when seen in a mirror. The word AMBULANCE on the hospital vans is written in the form of its mirror image as ƎƆИA⅃UᙠMA (see Figure 18). This is because when we are driving our car and see the hospital van coming from behind in our rear-view mirror, then we will get the laterally inverted image of ƎƆИA⅃UᙠMA and read it as AMBULANCE. Since an ambulance carries seriously ill patients, we can make way for it to pass through and reach the hospital quickly. We are now in a position to give all the **characteristics of an image formed by a plane mirror.**

Figure 18. An ambulance. Please note the word AMBULANCE written in the form of its mirror image.

1. The image formed in a plane mirror is virtual. It cannot be received on a screen.

2. The image formed in a plane mirror is erect. It is the same side up as the object.
3. The image in a plane mirror is of the same size as the object.
4. The image formed by a plane mirror is at the same distance behind the mirror as the object is in front of the mirror.
5. The image formed in a plane mirror is laterally inverted (or sideways reversed).

Uses of Plane Mirrors

(*i*) Plane mirrors are used to see ourselves. The mirrors on our dressing table and in bathrooms are plane mirrors.
(*ii*) Plane mirrors are fixed on the inside walls of certain shops (like jewellery shops) to make them look bigger.
(*iii*) Plane mirrors are fitted at blind turns of some busy roads so that drivers can see the vehicles coming from the other side and prevent accidents.
(*iv*) Plane mirrors are used in making periscopes.

We will now solve some problems based on plane mirrors.

Sample Problem 1. An incident ray makes an angle of 35° with the surface of a plane mirror. What is the angle of reflection ?

Solution. In order to find out the angle of reflection, we should first know the angle of incidence. In this case, the incident ray makes an angle of 35° with the surface of the mirror (see Figure 19), so the angle of incidence is not 35°. The angle of incidence is the angle between incident ray and normal. So, in this case, the angle of incidence will be 90° – 35°= 55°. Since the angle of incidence is 55 degrees, therefore, the angle of reflection is also 55 degrees. This is shown clearly in Figure 19.

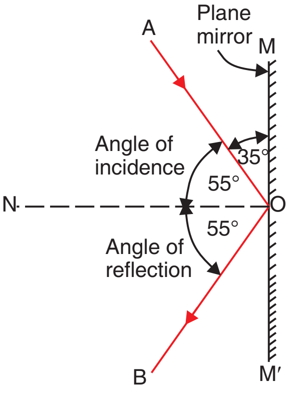


Figure 19.

Sample Problem 2. David is observing his image in a plane mirror. The distance between the mirror and his image is 4 m. If he moves 1 m towards the mirror, then the distance between David and his image will be :

(*a*) 3 m (*b*) 5 m (*c*) 6 m (*d*) 8 m

Solution. (*i*) In this problem, David is the object. Initially, the distance between the mirror and David's image is 4 m. Since the distance of object from plane mirror is equal to distance of image from plane mirror, therefore, the distance of David (which is object), from the plane mirror is also 4 m (see Figure 20).

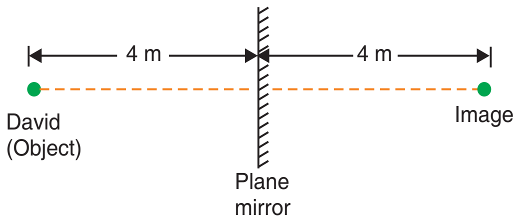


Figure 20.

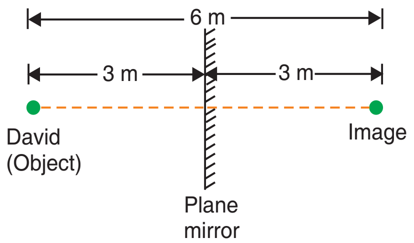


Figure 21.

(*ii*) David moves 1 m towards the mirror. This means that the distance of David from mirror will be 4 – 1 = 3 m. Since the image is formed at the same distance behind the mirror as the object is in front of it, therefore, the distance of image from mirror in this case will also be 3 m (see Figure 21)

Now, Distance of David from mirror = 3 m (in front)
And, Distance of image from mirror = 3 m (at the back)
So, Distance between David and his image = 3 m + 3 m
= 6 m

Thus, the correct option is : (*c*) 6 m.

Sample Problem 3. The rear view mirror of a car is a plane mirror. A driver is reversing his car at a speed of 2 m/s. The driver sees in his rear view mirror, the image of a truck parked behind his car. The speed at which the image of the truck appears to approach the driver will be :

(*a*) 1 m/s (*b*) 2 m/s (*c*) 4 m/s (*d*) 8 m/s

Solution. In a plane mirror, the object and its image always remain at the same distance from the mirror. So, when the car reverses at a speed of 2 m/s, then the image will also appear to move towards the mirror at the same speed of 2 m/s. So, the speed at which the image of truck appears to approach the car driver will be 2 m/s + 2 m/s = 4 m/s. Thus, the correct option will be : (*c*) 4 m/s.

Before we go further and discuss spherical mirrors, **please answer the following questions :**

Very Short Answer Type Questions

1. What happens when a ray of light falls normally (or perpendicularly) on the surface of a plane mirror ?

2. A ray of light is incident on a plane mirror at an angle of 30°. What is the angle of reflection ?

3. A ray of light strikes a plane mirror at an angle of 40° to the mirror surface. What will be the angle of reflection ?

4. A ray of light is incident normally on a plane mirror. What will be the :

(*a*) angle of incidence ?

(*b*) angle of reflection ?

5. What type of image is formed :

(*a*) in a plane mirror ?

(*b*) on a cinema screen ?

6. What kind of mirror is required for obtaining a virtual image of the same size as the object ?

7. What is the name of the phenomenon in which the right side of an object appears to be the left side of the image in a plane mirror ?

8. Name the phenomenon responsible for the following effect :

When we sit in front of a plane mirror and write with our right hand, it appears in the mirror that we are writing with the left hand.

9. If an object is placed at a distance of 10 cm in from of a plane mirror, how far would it be from its image ?

10. Which property of light makes a pencil cast a shadow when it is held in front of a light source ?

11. The image seen in a plane mirror cannot be formed on a screen. What name is given to this type of image ?

12. Fill in the following blank with a suitable word :

When light is reflected, the angles of incidence and reflection are.......... .

13. State whether the following statement is true or false :

A student says that we can see an object because light from our eyes is reflected back by the object.

14. Where is the image when you look at something in a mirror ?

15. A ray of light strikes a plane mirror such that its angle of incidence is 30°. What angle does the reflected ray make with the mirror surface ?

Short Answer Type Questions

16. What is the difference between a real image and a virtual image ? Give one example of each type of image.

17. The letter F is placed in front of a plane mirror :

(*a*) How would its image look like when seen in a plane mirror ?

(*b*) What is the name of the phenomenon involved ?

18. What is lateral inversion ? Explain by giving a suitable example.

19. Write the word AMBULANCE as it would appear when reflected in a plane mirror. Why is it sometimes written in this way (as its mirror image) on the front of an ambulance ?

20. What are the important differences between looking at a photograph of your face and looking at yourself in a plane mirror ?

21. (*a*) A wall reflects light and a mirror also reflects light. What difference is there in the way they reflect light ?

(*b*) Which type of reflection of light leads to the formation of images ?

22. What is the difference between regular reflection of light and diffuse reflection of light ? What type of reflection of light takes place from :

(*a*) a cinema screen (*b*) a plane mirror (*c*) a cardboard (*d*) still water surface of a lake

23. What can you see in a completely dark room ? If you switch on an electric bulb in this dark room as a light source, explain how you could now see :

(*a*) the electric bulb.

(*b*) a piece of white paper.

24. (*a*) A boy with a mouth 5 cm wide stands 2 m away from a plane mirror. Where is his image and how wide is the image of his mouth ?

(*b*) The boy walks towards the mirror at a speed of 1 m/s. At what speed does his image approach him ?

25. (*a*) An extended object in the form of an arrow pointing upward has been placed in front of a plane mirror. Draw a labelled ray-diagram to show the formation of its image.

(*b*) State the uses of plane mirrors.

Long Answer Type Questions

26. What is meant by 'reflection of light' ? Define the following terms used in the study of reflection of light by drawing a labelled ray-diagram :

(*a*) Incident ray (*b*) Point of incidence (*c*) Normal

(*d*) Reflected ray (*e*) Angle of incidence (*f*) Angle of reflection

27. State and explain the laws of reflection of light at a plane surface (like a plane mirror), with the help of a labelled ray-diagram. Mark the angles of 'incidence' and 'reflection' clearly on the diagram. If the angle of reflection is 47.5°, what will be the angle of incidence ?

28. With the help of a labelled ray-diagram, describe how a plane mirror forms an image of a point source of light placed in front of it. State the characteristics of the image formed in a plane mirror.

29. (*a*) Explain why, though both a plane mirror and a sheet of paper reflect light but we can see the image of our face in a plane mirror but not in a sheet of paper.

(*b*) The image in a plane mirror is virtual and laterally inverted. What does this statement mean ?

(*c*) Write all the capital letters of the alphabet which look the same in a plane mirror.

Multiple Choice Questions (MCQs)

30. The angle of reflection is equal to the angle of incidence :

(*a*) always (*b*) sometimes (*c*) under special conditions (*d*) never

31. The angle between an incident ray and the plane mirror is 30°. The total angle between the incident ray and reflected ray will be :

(*a*) 30° (*b*) 60° (*c*) 90° (*d*) 120°

32. A ray of light is incident on a plane mirror making an angle of 90° with the mirror surface. The angle of reflection for this ray of light will be :

(*a*) 45° (*b*) 90° (*c*) 0° (*d*) 60°

33. The image of an object formed by a plane mirror is :

(*a*) virtual (*b*) real (*c*) diminished (*d*) upside-down

34. The image formed by a plane mirror is :

(*a*) virtual, behind the mirror and enlarged.

(*b*) virtual, behind the mirror and of the same size as the object.

(*c*) real, at the surface of the mirror and enlarged.

(*d*) real, behind the mirror and of the same size as the object.

35. The figure given alongside shows the image of a clock as seen in a plane mirror. The correct time is :

(*a*) 2.25 (*b*) 2.35 (*c*) 6.45 (*d*) 9.25

Questions Based on High Order Thinking Skills (HOTS)

36. A man stands 10 m in front of a large plane mirror. How far must he walk before he is 5 m away from his image ?

37. An object is placed 20 cm in front of a plane mirror. The mirror is moved 2 cm towards the object. The distance between the positions of the original and final images seen in the mirror is :

(*a*) 2 cm (*b*) 4 cm (*c*) 10 cm (*d*) 22 cm

38. A man sits in an optician's chair, looking into a plane mirror which is 2 m away from him and views the image of a chart which faces the mirror and is 50 cm behind his head. How far away from his eyes does the chart appear to be ?

39. A ray of light strikes a plane mirror *PQ* at an angle of incidence of 30°, is reflected from the plane mirror and then strikes a second plane mirror *QR* placed at right angles to the first mirror. The angle of reflection at the second mirror is :

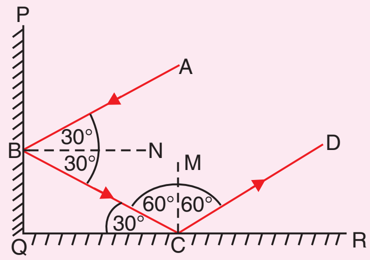
(*a*) 30° (*b*) 45° (*c*) 60° (*d*) 90°

Draw a ray-diagram to illustrate your answer.

40. Explain how to read the following message which was found on some blotting paper :

ANSWERS

2. 30° **3.** 50° **4.** (*a*) 0° (*b*) 0° **6.** Plane mirror **7.** Lateral inversion **8.** Lateral inversion **9.** 20 cm **10.** Light travels in straight lines **11.** Virtual image **12.** equal **13.** False **14.** Behind the mirror **15.** 60° **17.** (*a*) ꟻ (*b*) Lateral inversion **24.** (*a*) 2 m behind the plane mirror ; 5 cm wide (*b*) 2 m/s **27.** 47.5° **29.** (*c*) A, H, I, M, O, T, U, V, W, X, Y **30.** (*a*) **31.** (*d*) **32.** (*c*) **33.** (*a*) **34.** (*b*) **35.** (*d*) **36.** 7.5 m **37.** (*b*) **38.** 4.5 m **39.** (*c*) 60°



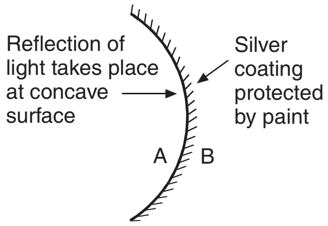
40. The impression on blotting paper is the mirror image of the written message ; Hold the written message in front of a mirror to read it.

REFLECTION OF LIGHT FROM CURVED SURFACES : SPHERICAL MIRRORS

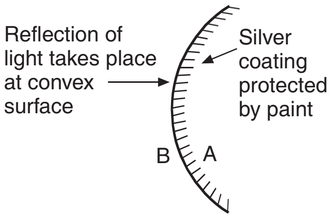
So far we have discussed the reflection of light from plane surfaces like that of a plane mirror. **When a parallel beam of light rays falls on a plane mirror, it is reflected as a parallel beam.** So, a plane mirror changes only the direction of incident light rays, it does not 'converge' or 'diverge' the parallel rays of light (To bring the parallel rays of light '*closer together*' is called '*to converge*' the light rays whereas '*to spread out*' the parallel rays of light is called '*to diverge*' the light rays). **We will now describe the spherical mirrors which can converge or diverge the parallel rays of light which fall on them**. Please note that the spherical mirrors have a curve-like surface, so they are also known as curved mirrors. We will first define the spherical mirrors and then study the reflection of light from these spherical mirrors.

A spherical mirror is that mirror whose reflecting surface is the part of a hollow sphere of glass. The spherical mirrors are of two types : Concave mirrors, and Convex mirrors.

(*i*) A concave mirror is that spherical mirror in which the reflection of light takes place at the concave surface (or bent-in surface). A concave mirror is shown in Figure 22(*a*), in which the concave reflecting surface has been marked *A*. The other surface *B* in Figure 22(*a*), having short, oblique lines is the non-reflecting surface. The inner shining surface of a steel spoon is an example of concave mirror (see Figure 23). In our ray-diagrams, we use only the side-view of a concave mirror as shown in Figure 22(*a*). If, however, we look at a concave mirror from the front, it appears to be like a piece of thin round glass whose front surface is shining and bent inward whereas back surface is covered with a paint and bulging outward.



(*a*) A concave mirror



(*b*) A convex mirror

Figure 22.

(*ii*) A convex mirror is that spherical mirror in which the reflection of light takes place at the convex surface (or bulging-out surface). A convex mirror is shown in Figure 22(*b*), in which the convex reflecting surface has been marked *B*. The other surface *A* in Figure 22(*b*), having short, oblique lines is the non-reflecting surface. The back-side of a shining steel spoon is an example of convex mirror (see Figure 23). In our ray diagrams, we use only the side-view of a convex mirror as shown in Figure 22(*b*). If, however, we look at a convex mirror from the front, it appears like a piece of thin, round glass whose front shining surface is bulging outward but the back surface covered with paint is bent inward. **A spherical mirror (concave mirror or convex mirror) works on the reflection of light**. We will now understand the meaning of some new terms such as centre of curvature, radius of curvature, pole, and principal axis, which are used in the study of spherical mirrors.

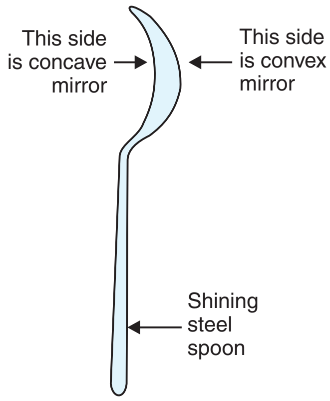
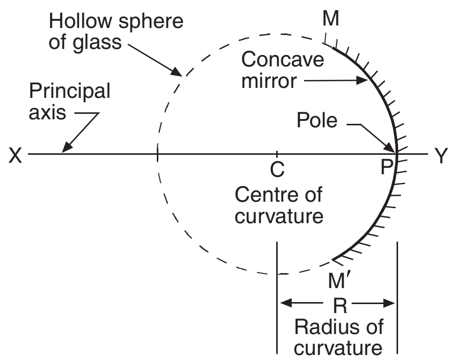


Figure 23. The front side of a shining steel spoon is a concave mirror whereas its back side is a convex mirror.

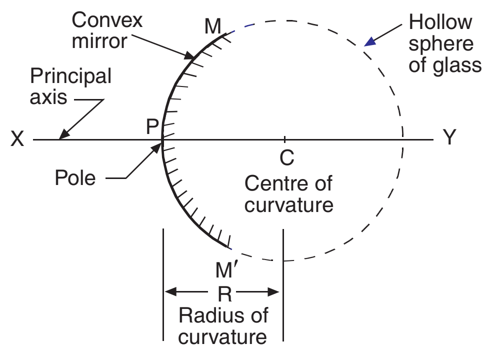
Centre of Curvature, Radius of Curvature, Pole and Principal Axis of a Spherical Mirror

The centre of curvature of a spherical mirror is the centre of the hollow sphere of glass of which the mirror is a part. The centre of curvature of a mirror is represented by the letter *C*. In Figure 24(*a*), *C* is the centre of curvature of the concave mirror and in Figure 24(*b*), *C* is the centre of curvature of the convex mirror. The centre of curvature is not a part of the mirror. It lies outside the reflecting surface of the mirror. It should be noted that **the centre of curvature of a concave mirror is in front of it but the centre of curvature of a convex mirror is behind it.**

The radius of curvature of a spherical mirror is the radius of the hollow sphere of glass of which the mirror is a part. In Figure 24(*a*), the distance *CP* is the radius of curvature of the concave mirror and in Figure 24(*b*), the distance *CP* is the radius of curvature of the convex mirror. The radius of curvature of a mirror is represented by the letter *R*.



(*a*)



(*b*)

Figure 24. Diagrams to show how a concave mirror and a convex mirror can be considered to be the part of a hollow sphere of glass.

The centre of a spherical mirror is called its pole. In other words, the middle point of a spherical mirror is called its pole. In Figure 24(*a*), *P* is the pole of the concave mirror and in Figure 24(*b*), *P* is the pole of the convex mirror. The pole of a spherical mirror lies on the surface of the mirror.

The straight line passing through the centre of curvature and pole of a spherical mirror is called its principal axis. In Figure 24(*a*), *C* is the centre of curvature of the concave mirror and *P* is the pole of the concave mirror, so the line *XY*, passing through *C* and *P* is the principal axis of the concave mirror. Similarly, in Figure 24(*b*), *XY* is the principal axis of the convex mirror. The principal axis is normal (or perpendicular) to the mirror at its pole.

That portion of a mirror from which the reflection of light actually takes place is called the aperture of the mirror. The aperture of a spherical mirror is represented by the diameter of its reflecting surface. In Figure 24, the distance *MM′* is the aperture of the mirror. In fact, *the aperture of a mirror represents the size of the mirror.*

Principal Focus and Focal Length of a Concave Mirror

The principal focus of a concave mirror is a point on its principal axis to which all the light rays which are parallel and close to the axis, converge after reflection from the concave mirror. Look at Figure 25 in which a parallel beam of light rays is falling on a concave mirror *MM′*. In Figure 25, point *F* is the principal focus of the concave mirror because all the parallel rays of light converge at this point after getting reflected from the concave mirror. Since all the reflected light rays actually pass through the focus (*F*) of a concave mirror, therefore, **a concave mirror has a real focus. The focus of a concave mirror is in front of the mirror**. Since a concave mirror converges a parallel beam of light rays, it is also called a converging mirror. **The focal length of a concave mirror is the distance between its pole and principal focus.** In Figure 25, *P* is the pole of the concave mirror and *F* is the principal focus, so the distance *PF* is the focal length of this concave mirror. The focal length of a mirror is denoted by the letter *f*.

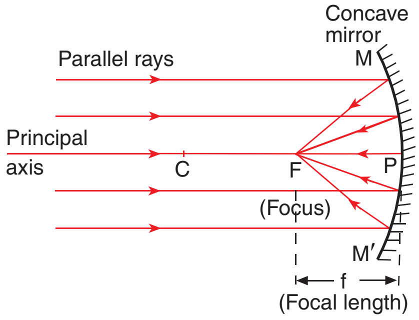


Figure 25. A concave mirror converges (brings closer) a beam of parallel rays of light.

We will now describe how an image of the sun can be formed by a concave mirror. The sun is at a far off distance from us, so the sunlight rays reaching us are parallel rays. **An image of the sun can be produced by a concave mirror at its focus** (see Figure 26). This can be done by performing a simple experiment as follows. We take a concave mirror and point it towards the sun. Hold a piece of paper in front of the concave mirror in such a way that the sunlight reflected by concave mirror falls on the paper (see Figure 26). A small patch of bright reflected light will appear on the paper. Adjust the distance of paper from the concave mirror in such a way that the sharpest point of bright light is obtained. This sharp point of light on paper is the image of sun formed by the concave mirror (see Figure 26). This image of the sun is formed at the focus of concave mirror (where the paper is held by us). If we keep this piece of paper in this position for a few minutes, the paper would start burning at the point of sun's image and a hole will be formed in it. This is because the concave mirror converges (or concentrates) a lot of sun's rays to a small point on paper. The heat energy of these concentrated sun rays burns the paper. Please note that the image of the sun formed by the concave mirror is real because it can be received on screen (such as a sheet of paper).

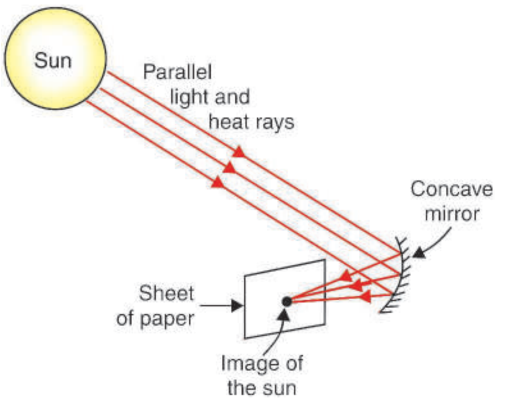


Figure 26. A concave mirror forms a real image of the sun.

Since the sun's image is formed at the focus of the concave mirror, therefore, the distance of sun's image (or paper) from the concave mirror gives us an approximate value of the focal length of the concave mirror.

Principal Focus and Focal Length of a Convex Mirror

The principal focus of a convex mirror is a point on its principal axis from which a beam of light rays, initially parallel to the axis, appears to diverge after being reflected from the convex mirror. In Figure 27, a parallel beam of light rays is incident on a convex mirror *MM′*. Each ray of light is reflected by the convex mirror, and the reflected rays diverge (spread out) from the mirror surface. Let us produce all the reflected rays backwards (as shown by dotted lines) so that they appear to meet at a point *F* behind the convex mirror. Now, to a person looking into the mirror from the left side, all the reflected rays appear to be coming (or diverging) from the same point *F* behind the convex mirror. This point *F* is the principal focus of the convex mirror. It should be noted that the reflected rays do not actually pass through the focus (*F*) of a convex mirror, therefore, **a convex mirror has virtual focus**. Another point to be noted is that **the focus of a convex mirror is situated behind the mirror**. The focal length of a convex mirror is the distance from the pole *P* to its principal focus *F*. Thus, in Figure 27, the distance *PF* is the focal length of the convex mirror.

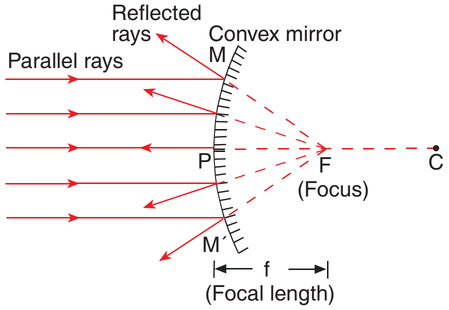


Figure 27. A convex mirror diverges (spreads out) a beam of parallel rays of light.

A plane mirror neither converges parallel rays of light nor diverges them. The focal length of a plane mirror can be considered to be 'infinite' or 'infinity' (which means very, very great or limitless).

Relation between Radius of Curvature and Focal Length of a Spherical Mirror

For a spherical mirror having small aperture, the principal focus (*F*) lies exactly mid-way between the pole (*P*) and centre of curvature (*C*) (see Figures 26 and 27). So, **the focal length of a spherical mirror (a concave mirror or a convex mirror) is equal to half of its radius of curvature.** If f is the focal length of a spherical mirror and R is its radius of curvature, then :

$$f = \frac{R}{2}$$

Let us solve one problem now.

Sample Problem. If the radius of curvature of a spherical mirror is 20 cm, what is its focal length ?

(NCERT Book Question)

Solution. We know that : $f = \dfrac{R}{2}$

Here, Focal length, f = ? (To be calculated)

And, Radius of curvature, R = 20 cm

So, $f = \dfrac{20}{2}$ cm

= 10 cm

Thus, the focal length of this spherical mirror is 10 cm.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Name the spherical mirror which has :
   (*a*) virtual principal focus.
   (*b*) real principal focus.
2. Out of convex mirror and concave mirror, whose focus is situated behind the mirror ?
3. Find the focal length of a concave mirror whose radius of curvature is 32 cm.
4. If the focal length of a convex mirror is 25 cm, what is its radius of curvature ?

5. Fill in the following blanks with suitable words :
   (*a*) Parallel rays of light are reflected by a concave mirror to a point called the ....
   (*b*) The focal length of a concave mirror is the distance from the ....to the mirror.
   (*c*) A concave mirror............rays of light whereas a convex mirror..........rays of light.
   (*d*) For a convex mirror, parallel rays of light appear to diverge from a point called the.......... .

Short Answer Type Questions

6. What is a spherical mirror ? Distinguish between a concave mirror and a convex mirror.
7. Name the two types of spherical mirrors. What type of mirror is represented by the :
   (*a*) back side of a shining steel spoon ?
   (*b*) front side of a shining steel spoon ?
8. What is the relation between the focal length and radius of curvature of a spherical mirror (concave mirror or convex mirror) ? Calculate the focal length of a spherical mirror whose radius of curvature is 25 cm.
9. Explain with a suitable diagram, how a concave mirror converges a parallel beam of light rays. Mark clearly the pole, focus and centre of curvature of concave mirror in this diagram.
10. Describe with a suitable diagram, how a convex mirror diverges a parallel beam of light rays. Mark clearly the pole, focus and centre of curvature of convex mirror in this diagram.

Long Answer type Questions

11. Define (*a*) centre of curvature (*b*) radius of curvature (*c*) pole (*d*) principal axis, and (*e*) aperture, of a spherical mirror with the help of a labelled diagram.
12. (*a*) Define (*i*) principal focus of a concave mirror, and (*ii*) focal length of a concave mirror.
    (*b*) Draw diagram to represent the action of a concave mirror on a beam of parallel light rays. Mark on this diagram principal axis, focus F, centre of curvature C, pole P and focal length *f*, of the concave mirror.
13. (*a*) What is meant by (*i*) principal focus of a convex mirror, and (*ii*) focal length of a convex mirror ?
    (*b*) Draw diagram to show the action of convex mirror on a beam of parallel light rays. Mark on this diagram principal axis, focus F, centre of curvature C, pole P and focal length *f*, of the convex mirror.

Multiple Choice Questions (MCQs)

14. In a convex spherical mirror, reflection of light takes place at :
    (*a*) a flat surface (*b*) a bent-in surface (*c*) a bulging-out surface (*d*) an uneven surface
15. A diverging mirror is :
    (*a*) a plane mirror (*b*) a convex mirror (*c*) a concave mirror (*d*) a shaving mirror
16. If R is the radius of curvature of a spherical mirror and f is its focal length, then :
    (*a*) $R = f$ (*b*) $R = 2f$ (*c*) $R = \frac{f}{2}$ (*d*) $R = 3f$
17. The focal length of a spherical mirror of radius of curvature 30 cm is :
    (*a*) 10 cm (*b*) 15 cm (*c*) 20 cm (*d*) 30 cm
18. If the focal length of a spherical mirror is 12.5 less cm, its radius of curvature will be :
    (*a*) 25 cm (*b*) 15 cm (*c*) 20 cm (*d*) 35 cm

Questions Based on High Order Thinking Skills (HOTS)

19. A communications satellite in orbit sends a parallel beam of signals down to earth. If these signals obey the same laws of reflection as light and are to be focussed onto a small receiving aerial, what should be the best shape of the metal 'dish' used to collect them ?
20. When a spherical mirror is held towards the sun and its sharp image is formed on a piece of carbon paper for some time, a hole is burnt in the carbon paper.
    (*a*) What is the nature of spherical mirror ?
    (*b*) Why is a hole burnt in the carbon paper ?
    (*c*) At which point of the spherical mirror the carbon paper is placed ?
    (*d*) What name is given to the distance between spherical mirror and carbon paper ?
    (*e*) What is the advantage of using a carbon paper rather than a white paper ?

ANSWERS

1. (*a*) Convex mirror (*b*) Concave mirror **2.** Convex mirror **3.** 16 cm **4.** 50 cm **5.** (*a*) principal focus (*b*) principal focus (*c*) converges ; diverges (*d*) principal focus **8.** 12.5 cm **14.** (*c*) **15.** (*b*) **16.** (*b*) **17.** (*b*) **18.** (*a*) **19.** Concave metal dish : It will collect the parallel beam of satellite signals at its focus where receiving aerial is fixed. **20.** (*a*) Concave mirror (*b*) A lot of sun's heat rays are concentrated at the point of sun's image which burn the hole in carbon paper (*c*) At the focus (*d*) Focal length (*e*) A black carbon paper absorbs more heat rays and hence burns a hole more easily (than a white paper).

RULES FOR OBTAINING IMAGES FORMED BY CONCAVE MIRRORS

When an object is placed in front of a concave mirror, an image is formed. **The image is formed at that point where at least two reflected rays intersect (or appear to intersect).** Now, to find out the position of an image formed by a concave mirror, we will use only those two rays of light (starting from the object), whose paths, after reflection from the mirror, are known to us and easy to draw. The following rays of light are usually used to locate the images formed by concave mirrors. We can call them rules for obtaining images in concave mirrors.

Rule 1. **A ray of light which is parallel to the principal axis of a concave mirror, passes through its focus after reflection from the mirror.** This is shown in Figure 28. Here, we have a concave mirror *M* and its principal axis is *XP*. The centre of curvature is *C* and its focus is *F*. Now, a ray of light *AB* is parallel to the principal axis of the mirror. It strikes the mirror at point *B* and gets reflected. After reflection its path changes and it passes through the focus *F* and goes in the direction *BY* (see Figure 28).

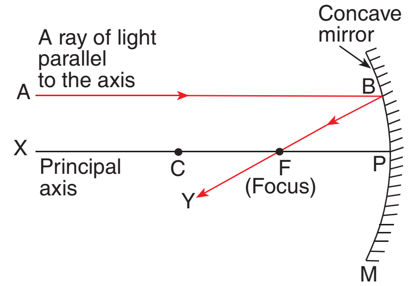


Figure 28.

Rule 2. **A ray of light passing through the centre of curvature of a concave mirror is reflected back along the same path** (because it strikes the mirror normally or perpendicularly). This is shown in Figure 29. A ray of light *AD* is passing through the centre of curvature *C* of the concave mirror. It falls normally (or perpendicularly) on the mirror at point *D* and gets reflected back along the same path *DA*. It should be noted that we have put two arrow-heads on the line *AD* which point in the opposite directions. *The arrow pointing from left to right indicates the direction of incident ray and the arrow pointing from right to left indicates the direction of reflected ray* (see Figure 29). The ray of light passing through the centre of curvature of a concave mirror is reflected back along the same path because it strikes the concave mirror at right angles (90°) to its surface due to which the angle of incidence and angle of reflection both are 0°.

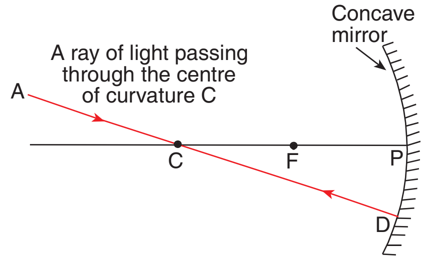


Figure 29.

Rule 3. **A ray of light passing through the focus of a concave mirror becomes parallel to the principal axis after reflection.** This rule is just the reverse case of the first rule and it is shown in Figure 30. Here, the incident ray *AE* is passing through the focus *F* of the concave mirror. It strikes the mirror surface at point *E* and gets reflected. After reflection, it becomes parallel to the axis and goes in the direction *EG*.

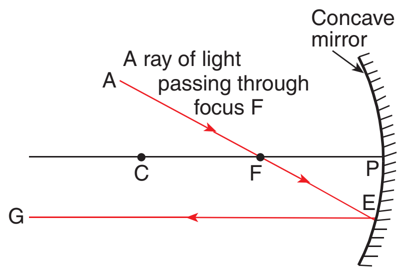


Figure 30.

Rule 4. **A ray of light which is incident at the pole of a concave mirror is reflected back making the same angle with the principal axis.** This is shown in Figure 31. Here a ray of light *AP* is incident at the pole *P* of the concave mirror making an angle of incidence *i* with the principal axis. It gets reflected along the direction *PH* such that the angle of reflection (*r*) is equal to the angle of incidence (*i*).

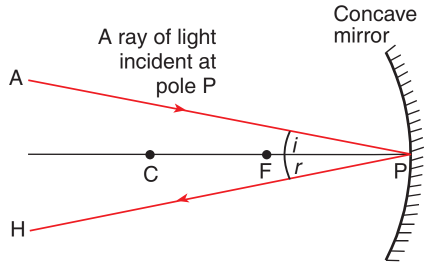


Figure 31.

Please note that if a ray of light is incident on a concave mirror along its principal axis, then it is reflected back along the same path (because it will be normal to the mirror surface). The angle of incidence as well as the angle of reflection for such a ray of light will be zero.

FORMATION OF DIFFERENT TYPES OF IMAGES BY A CONCAVE MIRROR

The type of image formed by a concave mirror depends on the position of object in front of the mirror. We can place the object at different positions (or different distances) from a concave mirror to get different types of images. For example, we can place the object :

(*i*) between the pole (*P*) and focus (*F*) (see Figure 32),
(*ii*) at the focus (*F*),
(*iii*) between focus (*F*) and centre of curvature (*C*),
(*iv*) at the centre of curvature (*C*),
(*v*) beyond the centre of curvature (*C*), and
(*vi*) at far-off distance called infinity (This distance cannot be shown in the Figure).

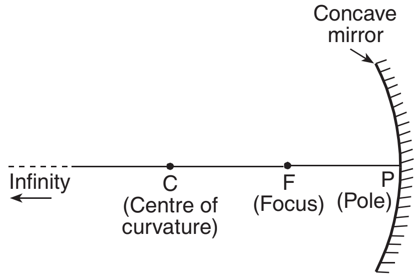


Figure 32.

Please note that in all our ray-diagrams the object, an arrow *AB* pointing upwards, will be placed on the principal axis. So, a ray of light coming from the bottom *B* of the object always travels along the principal axis and gets reflected back along the same path. We, however, do not put arrows on the principal axis to show this ray of light.

We will now draw the ray-diagrams to show the images formed by a concave mirror for the different positions of an object. We will consider all the six positions of the object, one by one.

Case 1. Image formed by a concave mirror when the object is placed between pole and focus of the mirror (Object between P and F)

In Figure 33, we have an object *AB* placed between the pole (*P*) and focus (*F*) of a concave mirror, that is, the object is within the focus of the concave mirror. To find out the position and nature of the image, starting from *A*, we draw a ray *AD* parallel to the axis (see Figure 33). This ray gets reflected at *D* and then passes through the focus *F*. A second ray of light *AE* passing through the centre of curvature *C* strikes the mirror normally (or perpendicularly) at point *E* and gets reflected back along the same path.

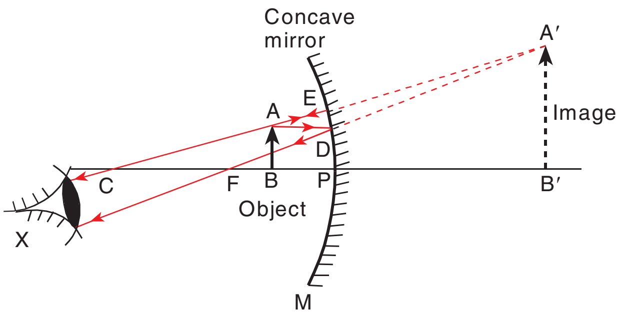


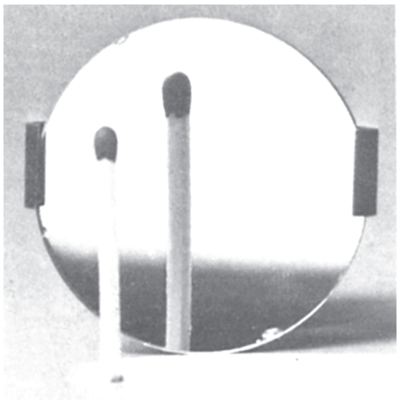
Figure 33. Formation of image by a concave mirror when the object is placed between its pole (P) and focus (F).

Now, the two reflected rays *DF* and *EC* are diverging rays and, therefore, do not intersect each other on the left side. The reflected rays *DF* and *EC* are produced backwards (as shown by dotted lines). On producing backwards, they appear to intersect at point *A′* behind the concave mirror. Thus, *A′* is the virtual image of point *A* of the object. To get the complete image of the object we draw *A′B′* perpendicular to the axis from point *A′*. Thus *A′B′* is the image of the object *AB* formed by the concave mirror. Now, an eye at position *X*, sees the reflected rays as if they have come from points *A′B′* behind the mirror. Since there is no actual intersection of the reflected rays, so the image *A′B′* is a virtual image. This image can be seen only by looking into the concave mirror, it cannot be obtained on a screen. We can see from Figure 33 that the image is same side up as object (both of them have arrow-head at the top), so it is an erect image. And if we compare the size of the object *AB* and its image *A′B′*, the image appears to be bigger in size than the object. Thus, it is an enlarged image or magnified image. From the above discussion we conclude that : **When an object is placed between the pole (*P*) and focus (*F*) of a concave mirror, the image formed is :**

(*i*) behind the mirror,
(*ii*) virtual and erect, and
(*iii*) larger than the object (or magnified).

It is clear from the above discussion that to obtain a magnified and erect image with a concave mirror, the object should be placed between the pole and focus of the concave mirror, that is, the object should be placed within the focus (or focal length) of the concave mirror. For example, if the focal length of a concave mirror is 10 cm, then its focus (*F*) will be at a distance of 10 cm from the pole of the mirror. So, to obtain a magnified and erect image with this concave mirror, we will have to place the object at a distance of less than 10 cm so that it remains between the pole and focus. Thus, if we place the object at a distance of, say 8 cm, from this concave mirror, the object will be within the focus and a magnified, virtual and erect image will be formed behind the concave mirror (which can be seen by looking into the concave mirror).

If we hold a matchstick (as object) within the focus of a concave mirror, then a magnified, virtual and erect image of the matchstick is seen on looking into the concave mirror [as shown in Figure 34(*a*)]. This



(*a*) A concave mirror can be used to magnify objects. Here it is magnifying a matchstick kept close to it

(*b*) A concave mirror being used as a make-up mirror. It is magnifying a part of the face here.

(*c*) Dentist's mirror is a small concave mirror fitted in a frame with a long handle. It gives a magnified image of tooth.

Figure 34.

also explains the use of a concave mirror as a shaving mirror. When the face is placed close to a concave mirror (so that the face is within its focus) the concave mirror produces a magnified (large) and erect image of the face. Since a large image of the face is seen in the concave mirror, it becomes easier to make a smooth shave. Thus, **while using a concave mirror as a shaving mirror, the face should be close to the concave mirror.** For the same reason, concave mirrors are also used as make-up mirrors by women for putting on make-up (such as painting eye-lashes) [see Figure 34(*b*)]. In order to use a concave mirror as a make-up mirror, the face is held close to the concave mirror so that it lies within the focus of concave mirror. Dentists use concave mirrors to see the large image of the teeth for examining the teeth of a person (see Figure 34(*c*)]. For this purpose, the dentist holds a small concave mirror in such a way that the tooth lies within its focus. A magnified image of the tooth is then seen by the dentist in the concave mirror. Since the tooth looks much bigger, it becomes easy to examine the defect in the tooth.

Case 2. When the object is placed at the focus of a concave mirror (Object at F)

In Figure 35, the object *AB* has been placed at the focus (*F*) of the concave mirror. Now, the parallel ray of light *AD* (coming from the top of the object) gets reflected at *D* and passes through the focus *F*, giving us the reflected ray *DX*. A second ray of light *AE* passing through the centre of curvature *C*, is reflected back along the same path giving us another reflected ray *EY*. We find that the reflected rays *DX* and *EY* are parallel to one another. These parallel rays will intersect (or meet) at a far off distance to

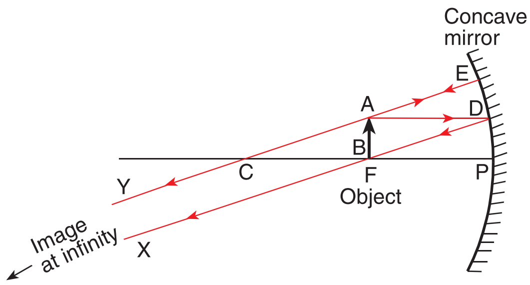


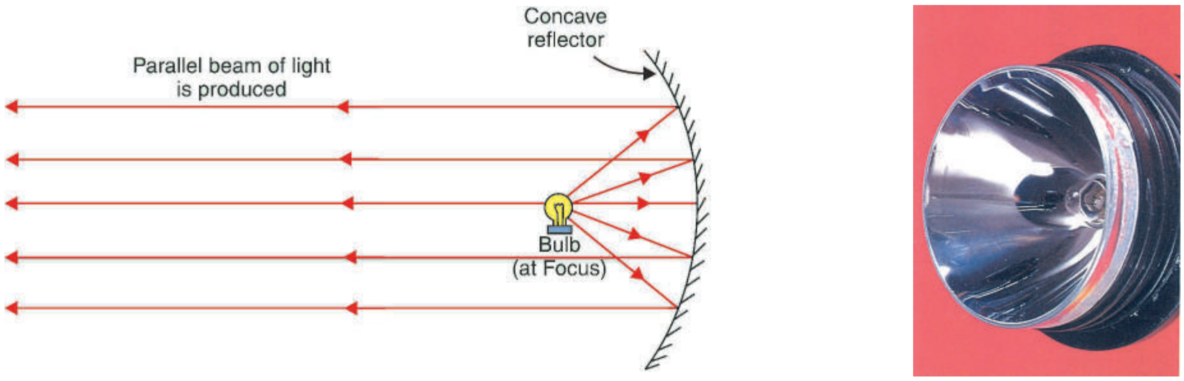
Figure 35. Formation of image by a concave mirror when the object is placed at its focus (F).

form an image 'at infinity'. And since the image is formed at infinity, it is not possible to show it in our diagram. From this discussion we conclude that : **When an object is placed at the focus of a concave mirror, the image formed is :**

(*i*) **at infinity,**
(*ii*) **real and inverted,** and
(*iii*) **highly magnified (or highly enlarged).**

Suppose we have a concave mirror of focal length 10 cm, then its focus (*F*) will be at a distance of 10 cm from it. So, by saying that an object is placed at the focus of this concave mirror, we will mean that the object is placed at a distance of 10 cm from the concave mirror. In this case, the concave mirror converts the diverging rays of light coming from the object into a parallel beam of light rays (which form image at infinity).

When a lighted bulb is placed at the focus of a concave mirror reflector, the diverging light rays of the bulb are collected by the concave reflector and then reflected to produce a strong, parallel-sided beam of light [see Figure 36(*a*)]. This explains the use of concave reflectors in torches, car head-lights, and



(*a*) When a lighted bulb is placed at the focus of a concave reflector, a parallel beam of light is produced.

(*b*) This picture shows the concave reflector of a torch.

Figure 36.

search lights to produce a strong beam of light (which travels a considerable distance in the darkness of night).

Case 3. When the object is placed between focus and centre of curvature (Object between F and C)

In Figure 37, the object *AB* has been placed between the focus *F* and centre of curvature *C* of a concave mirror. Now, a ray of light *AD* parallel to the principal axis gets reflected at point *D* and then passes through the focus *F*. A second ray of light *AE* passing through the centre of curvature *C* falls normally on the mirror surface at *E* and returns along the same path. Thus, we have two reflected rays *DF* and *EC* which are converging in the downward direction. If we extend these rays further in the downward direction, they actually intersect at point *A′*. Thus *A′* is the real image of point *A* of the object. To get the complete image we draw *A′B′* perpendicular to the axis from point *A′*. Thus, *A′B′* is the real image of the object *AB* and it can be received on a screen. For example, if we take a lighted candle as the object then the image of its wick will be formed on a white screen placed at the image position. If we look at the image *A′B′*, we find that it is wrong side up having arrow-head at its bottom. So, we say that the image is inverted. The size of image is larger than the object, so the image is magnified, and

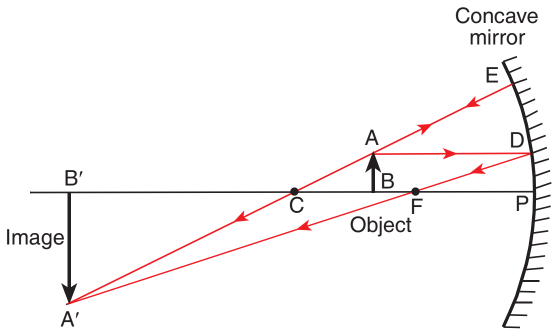


Figure 37. Formation of image by a concave mirror when the object is placed between focus (F) and centre of curvature (C).

it has been formed beyond the centre of curvature of the mirror. From the above discussion we conclude that : **When an object is placed between the focus (*F*) and centre of curvature (*C*) of a concave mirror, the image formed is :**

(*i*) **beyond the centre of curvature,**
(*ii*) **real and inverted,** and
(*iii*) **larger than the object (or magnified).**

Please remember that **a real image is always inverted,** and **a virtual image is always erect.** Suppose we have a concave mirror of focal length 10 cm. Then its focus (*F*) will be at a distance of 10 cm and centre of curvature (*C*) will be at a distance of 2 × 10 = 20 cm from it. Now, by saying that the object is placed between the focus and centre of curvature of this concave mirror, we mean that the object is at any distance between 10 cm and 20 cm from the concave mirror. For example, it may be at a distance of say, 15 cm from the concave mirror. And by saying that the image is formed beyond centre of curvature, we mean that it is at a distance greater than 20 cm from this concave mirror.

Case 4. When the object is placed at the centre of curvature of a concave mirror (Object at C)

In Figure 38, the object *AB* has been placed at the centre of curvature *C* of the concave mirror. A ray of light *AD* which is parallel to the principal axis passes through the focus *F* after reflection. Now, the second ray of light that we usually use is the one passing through the centre of curvature *C*. But in this case the object itself is placed at the centre of curvature, so we cannot use this ray of light to locate the image. Here we will use rule No. 3 of image formation which says that "A ray of light passing through the focus of a concave mirror becomes parallel to the principal axis after reflection". So, we now take the ray *AE* passing through the focus *F*. It strikes the mirror at point *E* and gets reflected in the direction *EA′* parallel to the principal axis.

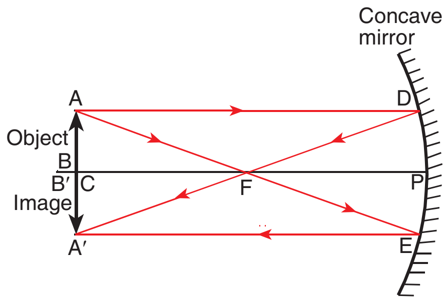


Figure 38. Formation of image by a concave mirror when the object is placed at the centre of curvature (C).

The reflected rays *DA′* and *EA′* meet at point *A′*, so *A′* is the real image of point *A* of the object. To get the complete image, we draw *A′B′* perpendicular to the principal axis. Thus, *A′B′* is the real image of the object *AB* (Note that *B* and *B′* is just the same point). The image is of the same size as the object, it is real, inverted and formed at the centre of curvature, where the object itself is placed. From this discussion we conclude that : **When an object is placed at the centre of curvature (*C*) of a concave mirror, the image formed is :**

(*i*) **at the centre of curvature (*C*),**
(*ii*) **real and inverted,** and
(*iii*) **same size as the object.**

Suppose we have a concave mirror of focal length 10 cm, then its focus (*F*) will be at a distance of 10 cm and its centre of curvature (*C*) will be at a distance of 2 × 10 = 20 cm. So, by saying that the object is at the centre of curvature, we mean that the object is at a distance of 20 cm from this concave mirror. And by saying that the image is formed at the centre of curvature, we mean that the image is also formed at a distance of 20 cm from the concave mirror.

Case 5. When the object is beyond the centre of curvature of the concave mirror (Object beyond C)

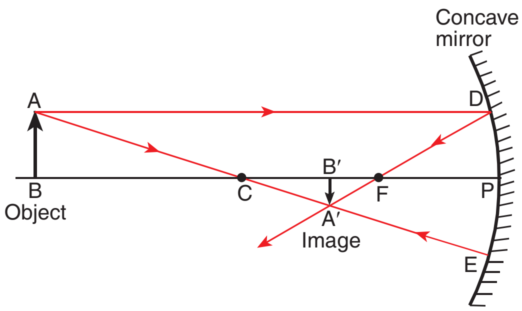


Figure 39. Formation of image by a concave mirror when the object is placed beyond the centre of curvature C.

In Figure 39, the object *AB* has been placed beyond the centre of curvature *C* of the concave mirror. A ray of light *AD* which is parallel to the principal axis, passes through the focus *F* after reflection. A second ray of light *AE* passing through the centre of curvature falls normally on the mirror surface at *E* and returns along the same path. The two reflected rays intersect at A'. Thus, A' is the real image of point A of the object. To get the complete image, we draw $A'B'$ perpendicular to the axis. Thus, $A'B'$ is the complete image of the object AB. It is clear from Figure 39 that the image $A'B'$ is formed between the focus (F) and centre of curvature (C). The image is real and inverted. It is smaller in size than the object AB, so we call it a diminished image. From the above discussion we conclude that : **When an object is placed beyond the centre of curvature (*C*) of a concave mirror, the image formed is :**

(*i*) **between the focus and centre of curvature,**
(*ii*) **real and inverted,** and
(*iii*) **smaller than the object (or diminished).**

Suppose we have a concave mirror of focal length 10 cm, then its focus (F) will be at a distance of 10 cm and its centre of curvature (C) will be at a distance of $2 \times 10 = 20$ cm from it. Now, by saying that an object is placed beyond the centre of curvature of this concave mirror, we mean that the object is placed at a distance greater than 20 cm (say, 25 cm) from the concave mirror. And by saying that the image is formed between focus and centre of curvature, we mean that the image is formed at a distance between 10 cm and 20 cm.

Figure 40. The formation of a real, inverted and diminished image of face in the front side (concave surface) of a shining steel spoon.

We know that the front side of a shining steel spoon is a kind of concave mirror. So, if we keep our face at a fairly good distance from the front side of a shining steel spoon (so that it is beyond its centre of curvature), we will see a real, inverted and smaller image (diminished image) of our face in the spoon (as shown in Figure 40).

Case 6. When the Object is at Infinity

When the object is at a very large distance, we say that the object is at infinity. In Figure 41 we have a concave mirror M. Suppose an object (an arrow pointing upwards) has been placed at infinity in front of the concave mirror (Since the object is very far off, it cannot be shown in the diagram). Because the object AB is very far off, the two rays AD and AP coming from its top point A are parallel to one-another but at an angle to the principal axis as shown in Figure 41. These parallel rays get reflected at points D and P and then intersect at point A' in the focal plane of the mirror. Thus, A' is the real image of the top point A of the object. To get the full image of the object, we draw $A'B'$ perpendicular to the principal axis from A'. Thus, $A'B'$ is the image of the object AB placed at infinity. We find that image $A'B'$ is formed at the focus (F) of the concave mirror.

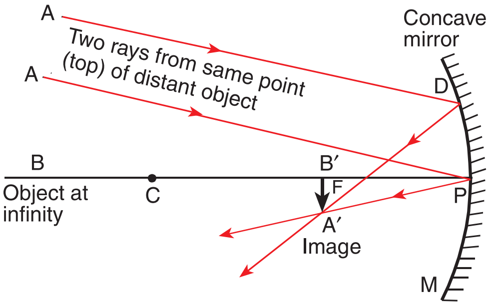


Figure 41. Formation of image by a concave mirror when the object is at a considerable distance (or infinity).

It is real, inverted and much smaller than the object or highly diminished. From the above discussion we conclude that : **When an object is at infinity from a concave mirror, the image formed is :**

(*i*) **at the focus (*F*),**
(*ii*) **real and inverted,** and
(*iii*) **much smaller than the object (or highly diminished).**

It should be noted that this case is just opposite of case No. 2 which we have already discussed. There we studied that **"when the object is at focus of concave mirror, the image is formed at infinity"** and here we have seen that **"when the object is at infinity, the image is formed at the focus of concave mirror".** This means that a concave mirror can concentrate all the parallel rays of light to its focus.

Suppose we have a concave mirror of focal length 10 cm, then its focus (F) will be at a distance of 10 cm from it. Now, by saying that the object is at infinity, we mean that the object is at a distance which is many, many times its focal length : it may be 1000 cm, 10,000 cm or even more. And by saying that the image is formed at the focus of this concave mirror, we mean that the image is formed at a distance of 10 cm from the pole of this concave mirror.

Please note that when the object kept at infinity in front of a concave mirror is assumed to be a big arrow pointing upwards, then its image is formed at focus according to the ray-diagram shown in Figure 41. If, however, the object kept at infinity in front of a concave mirror is round in shape (like the sun), then its image is formed at the focus according to the ray-diagram shown in Figure 25 on page 177.

The fact that when a parallel beam of light rays falls on a concave mirror, the concave mirror concentrates all the light at its focus, explains the use of concave mirror as a doctor's head-mirror. **A concave mirror is used as a "head-mirror" by the doctors to concentrate light coming from a lamp on to the body part of a patient (like ear, nose, throat, etc.) to be examined.** This is done as follows : A concave mirror is fixed to the front part of a doctor's head with the help of a strap [as shown in Figure 42(*a*)]. When the beam of light coming from a lamp falls on the doctor's concave head-mirror, the mirror focusses this light on to the body part of the patient. The body part gets illuminated brightly with this light due to which the doctor can look into the body part (like ear, nose, throat, etc.) very clearly.

(*a*) The doctor's head-mirror is a concave mirror

(*b*) The metal 'dish' of dish antenna of television is concave.

Figure 42.

The concave 'metal dishes' are used in dish antennas (or dish aerials) of televisions to receive TV signals from the very distant communications satellites which are high up in the sky [see Figure 42(*b*)]. The dish is a concave reflector. The dish collects a large amount of parallel beams of TV signals coming from the far off satellite and converges them to its focus. The antenna (or signal detector) is fixed in front of the concave dish at its focus. Since the antenna is fixed at the focus of dish, it receives the strongest possible TV signals from the satellite which make our television work. The TV signals coming from satellite can be made even more stronger by using a bigger dish in the dish antenna. Please note that though the TV signals coming from the satellite are not light rays, they obey the laws of reflection of light.

How to find out the Focal Length of a Concave Mirror Quickly but Approximately

The fact that "when the object is at a considerable distance (or at infinity) from a concave mirror, then its image is formed at the focus" can be used to find out the focal length of a concave mirror quickly but approximately. We focus a distant object (several metres away) like a window or tree on a screen by using a concave mirror whose focal length is to be determined (see Figure 43). The sharp image of window or tree will be formed at the focus of the concave mirror. That is, the distance of image (or screen) from the

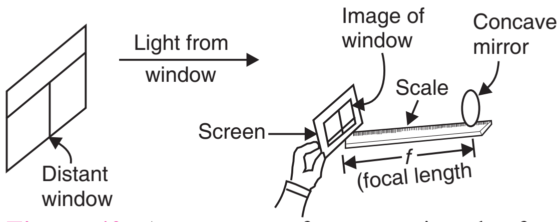


Figure 43. Arrangement for measuring the focal length of a concave mirror quickly but approximately.

concave mirror will be equal to the focal length of concave mirror. This distance can be measured with a scale. It will give us the approximate focal length of the concave mirror. And before we conclude this discussion, here is a summary of the images formed by a concave mirror.

Summary of the Images Formed by a Concave Mirror

Position of object	*Position of image*	*Size of image*	*Nature of image*
1. Within focus (between pole *P* and focus *F*)	Behind the mirror	Enlarged	Virtual and erect
2. At focus (*F*)	At infinity	Highly enlarged	Real and inverted
3. Between *F* and *C*	Beyond *C*	Enlarged	Real and inverted
4. At *C*	At *C*	Equal to object	Real and inverted
5. Beyond *C*	Between *F* and *C*	Diminished	Real and inverted
6. At infinity	At focus (*F*)	Highly diminished	Real and inverted

Uses of Concave Mirrors

(*i*) Concave mirrors are used as shaving mirrors to see a large image of the face. This is because when the face is held within the focus of a concave mirror, then an enlarged image of the face is seen in the concave mirror. This helps in making a smooth shave. For the same reason, **concave mirrors are used as make-up mirrors.**

(*ii*) Concave mirrors are used by dentists to see the large images of the teeth of patients. This is because when a tooth is within the focus of a concave mirror, then an enlarged image of the tooth is seen in the concave mirror. Due to this, it becomes easier to locate the defect in the tooth. The concave mirrors used by dentists are very small in size. They are fitted in a frame with a long handle.

(*iii*) Concave mirrors are used as reflectors in torches, vehicle head-lights and search lights to get powerful beams of light. This is because when a lighted bulb is placed at the focus of a concave reflector, then the concave reflector produces a powerful beam of parallel light rays. This helps us see things up to a considerable distance in the darkness of night. **Concave reflectors are also used in room heaters.** The concave reflectors of room heaters direct heat rays into the whole room.

(*iv*) Concave mirrors are used as doctor's head-mirrors to focus light coming from a lamp on to the body parts of a patient (such as eye, ear, nose, throat, etc.) to be examined by the doctor.

(*v*) Concave dishes are used in TV dish antennas to receive TV signals from the distant communications satellites. The concave dish collects a lot of TV signals and focusses them on to an antenna (or aerial) fixed at its focus, so as to produce strong signals to run the television.

(*vi*) Large concave mirrors are used in the field of solar energy to focus sun's rays for heating solar furnaces. This can be explained as follows : The solar furnace is placed at the focus of a large concave reflector. The concave reflector focuses the sun's heat rays on the furnace due to which the solar furnace gets very hot. Even steel can be melted in this solar furnace.

Let us solve some problems now.

Sample Problem 1. We wish to obtain an erect image of an object using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror ? What is the nature of the image ? Is the image larger or smaller than the object ? Draw a ray-diagram to show the image formation in this case. **(NCERT Book Question)**

Solution. In order to obtain an erect image of an object with a concave mirror, the object should be at a distance less than its focal length. Here the focal length of concave mirror is 15 cm. So to obtain an erect image of the object by using this concave mirror, the object should be placed at any distance which is less than 15 cm from the mirror. The nature of image will be virtual. The image will be larger than the object (For ray-diagram, see Figure 33 on page 181).

Sample Problem 2. The image formed by a concave mirror is seen to be virtual, erect and larger than the object. The position of the object must then be :

(*i*) between the focus and centre of curvature.
(*ii*) at the centre of curvature.
(*iii*) beyond the centre of curvature.
(*iv*) between the pole of the mirror and its focus.

Choose the correct alternative. **(NCERT Book Question)**

Solution. The correct alternative is (*iv*) : between the pole of the mirror and its focus.

Sample Problem 3. A concave mirror has a focal length of 10 cm. Where should an object be placed in front of this concave mirror so as to obtain an image which is real, inverted and same size as the object ?

Solution. When the image formed by a concave mirror is real, inverted and of the same size as the object, then the object must be placed at its centre of curvature (C). Now, the centre of curvature of a concave mirror is at a distance of 'twice the focal length' or '$2f$'. Here,

Focal length, $f = 10$ cm

So, $2f = 2 \times 10$ cm

$= 20$ cm

Thus, the object should be placed at a distance of 20 cm in front of this concave mirror.

Sample Problem 4. An object is placed at the following distances from a concave mirror of focal length 10 cm :

(*a*) 8 cm (*b*) 15 cm (*c*) 20 cm (*d*) 25 cm

Which position of the object will produce :

(*i*) a diminished real image ?
(*ii*) a magnified real image ?
(*iii*) a magnified virtual image ?
(*iv*) an image of the same size as the object ?

Solution. In this case the focal length of concave mirror is 10 cm. This means that the focus (F) of this concave mirror is at a distance of 10 cm from the mirror and its centre of curvature (C) is at a distance of $2 \times 10 = 20$ cm from the mirror.

(*i*) A diminished real image is formed by a concave mirror when the object is beyond C. Here C is at 20 cm. So, the diminished real image will be formed when the object is at a distance greater than 20 cm, which in this problem is 25 cm. So, the position of object for a diminished real image is **25 cm**.

(*ii*) A magnified real image is formed by a concave mirror when the object is between F and C. Here F is at 10 cm and C is at 20 cm. So, the magnified real image will be formed when the object is at a distance between 10 cm and 20 cm, which in this problem is 15 cm. So, the position of object for a magnified real image is **15 cm.**

(*iii*) A magnified virtual image is formed by a concave mirror when the object is within focus (F) at a distance less than focal length or less than 10 cm, which in this problem is 8 cm. So, the position of object for a magnified virtual image is **8 cm.**

(*iv*) An image of the same size as object is formed by a concave mirror when the object is at centre of curvature (C). Here C is at 20 cm. So, the image of same size as the object will be formed when the object is at 20 cm from the concave mirror. Thus, the position of object for an image of same size as the object is **20 cm.**

Please note that we have given so many details in answering the above question just to make you understand clearly. There is, however, no need to give so many details in the examination. In the examination, the answer to the above question can just be written as :

(*i*) 25 cm (*ii*) 15 cm (*iii*) 8 cm (*iv*) 20 cm

Before we go further and discuss the sign convention for spherical mirrors, **please answer the following questions :**

Very Short Answer Type Questions

1. For what position of an object, a concave mirror forms a real image equal in size to the object ?

2. Where should an object be placed in front of the concave mirror so as to obtain its virtual, erect and magnified image ?

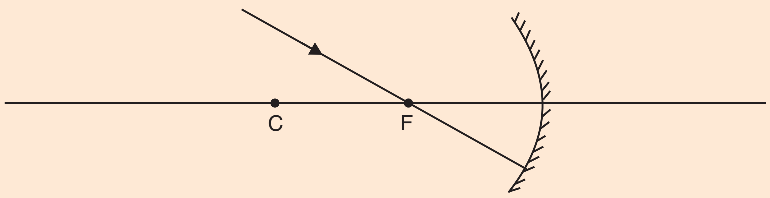
3. For which positions of the object does a concave mirror produce an inverted, magnified and real image ?

4. If an object is placed at the focus of a concave mirror, where is the image formed ?

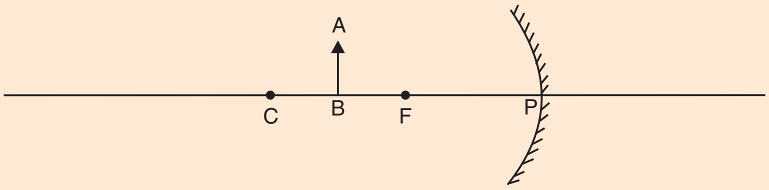
5. If an object is at infinity (very large distance) in front of a concave mirror, where is the image formed ?

6. For what position of an object, a real and diminished image is formed by a concave mirror ?

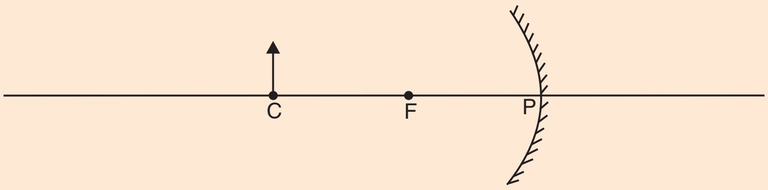
7. Copy this figure in your answer book and show the direction of the light ray after reflection :



8. Draw the following diagram in your answer book and show the formation of image of the object AB with the help of suitable rays :



9. Draw the following diagram in your answer book and show the formation of image with the help of suitable rays :



10. Which type of mirror could be used as a dentist's mirror ?

Short Answer Type Questions

11. Which kind of mirror is used in the headlights of a car ? Why is it used for this purpose ?

12. Explain why, a ray of light passing through the centre of curvature of a concave mirror gets reflected back along the same path.

13. What is the minimum number of rays required for locating the image formed by a concave mirror for an object ? Draw a ray diagram to show the formation of a virtual image by a concave mirror.

14. With the help of a ray diagram, determine the position, nature and size of the image formed of an object placed at the centre of curvature of a concave mirror.

15. Describe with the help of a diagram, the nature, size and position of the image formed when an object is placed beyond the centre of curvature of a concave mirror.

16. If an object is placed at a distance of 8 cm from a concave mirror of focal length 10 cm, discuss the nature of the image formed by drawing the ray diagram.

17. Draw a ray diagram showing how a concave mirror can be used to produce a real, inverted and diminished image of an object.

18. Which mirror is used as a torch reflector ? Draw a labelled diagram to show how a torch reflector can be used to produce a parallel beam of light. Where is the bulb placed in relation to the torch reflector ?

19. State where an object must be placed so that the image formed by a concave mirror is :

(*a*) erect and virtual.

(*b*) at infinity.

(*c*) the same size as the object.

20. With the help of a labelled ray diagram, describe how a converging mirror can be used to give an enlarged upright image of an object.

21. Make labelled ray diagrams to illustrate the formation of :

(*a*) a real image by a converging mirror.

(*b*) a virtual image by a converging mirror.

Mark clearly the pole, focus, centre of curvature and position of object in each case.

22. Briefly describe how you would find the focal length of a concave mirror quickly but approximately.

23. Which type of mirror is used in a solar furnace ? Support your answer with reason.

24. Name the type of mirror used by dentists. How does it help ?

25. Explain why, concave mirrors are used as shaving mirrors.

26. Give two uses of concave mirrors. Explain why you would choose concave mirrors for these uses.

Long Answer Type Questions

27. (*a*) Draw ray-diagrams to show the formation of images when the object is placed in front of a concave mirror (converging mirror) :

(*i*) between its pole and focus

(*ii*) between its centre of curvature and focus

Describe the nature, size and position of the image formed in each case.

(*b*) State one use of concave mirror based on the formation of image as in case (*i*) above.

28. (*a*) Give two circumstances in which a concave mirror can form a magnified image of an object placed in front of it. Illustrate your answer by drawing labelled ray diagrams for both.

(*b*) Which one of these circumstances enables a concave mirror to be used as a shaving mirror ?

Multiple Choice Questions (MCQs)

29. The real image formed by a concave mirror is larger than the object when the object is :

(*a*) at a distance equal to radius of curvature (*b*) at a distance less than the focal length

(*c*) between focus and centre of curvature (*d*) at a distance greater than radius of curvature

30. The real image formed by a concave mirror is smaller than the object if the object is :

(*a*) between centre of curvature and focus (*b*) at a distance greater than radius of curvature

(*c*) at a distance equal to radius of curvature (*d*) at a distance equal to focal length

31. The image formed by a concave mirror is virtual, erect and magnified. The position of object is :

(*a*) at focus (*b*) between focus and centre of curvature

(*c*) at pole (*d*) between pole and focus

32. The image formed by a concave mirror is real, inverted and of the same size as the object. The position of the object must then be :

(*a*) at the focus (*b*) between the centre of curvature and focus

(*c*) at the centre of curvature (*d*) beyond the centre of curvature

33. The image formed by a concave mirror is real, inverted and highly diminished (much smaller than the object). The object must be :

(*a*) between pole and focus (*b*) at focus

(*c*) at the centre of curvature (*d*) at infinity

34. The angle of incidence for a ray of light passing through the centre of curvature of a concave mirror is :

(*a*) 45° (*b*) 90° (*c*) 0° (*d*) 180°

35. In the concave reflector of a torch, the bulb is placed :
(*a*) between the pole and focus of reflector (*b*) at the focus of reflector
(*c*) between focus and centre of curvature of reflector (*d*) at the centre of curvature of reflector

36. The focal length of a small concave mirror is 2.5 cm. In order to use this concave mirror as a dentist's mirror, the distance of tooth from the mirror should be :
(*a*) 2.5 cm (*b*) 1.5 cm (*c*) 4.5 cm (*d*) 3.5 cm

Questions Based on High Order Thinking Skills (HOTS)

37. An object is 100 mm in front of a concave mirror which produces an upright image (erect image). The radius of curvature of the mirror is :
(*a*) less than 100 mm (*b*) between 100 mm and 200 mm
(*c*) exactly 200 mm (*d*) more than 200 mm

38. A virtual, erect and magnified image of an object is to be produced with a concave mirror of focal length 12 cm. Which of the following object distance should be chosen for this purpose ?
(*i*) 10 cm (*ii*) 15 cm (*iii*) 20 cm
Give reasons for your choice.

39. A concave mirror has a focal length of 25 cm. At which of the following distance should a person hold his face from this concave mirror so that it may act as a shaving mirror ?
(*a*) 45 cm (*b*) 20 cm (*c*) 25 cm (*d*) 30 cm
Give reason for your choice.

40. An object is placed at the following distances from a concave mirror of focal length 15 cm, turn by turn :
(*a*) 35 cm (*b*) 30 cm (*c*) 20 cm (*d*) 10 cm
Which position of the object will produce :
(*i*) a magnified real image ?
(*ii*) a magnified virtual image ?
(*iii*) a diminished real image ?
(*iv*) an image of same size as the object ?

ANSWERS

1. At the centre of curvature **2.** Between pole and focus **3.** Between focus and centre of curvature **4.** At infinity **5.** At focus **6.** Beyond centre of curvature **12.** It falls normally (perpendicularly) on the mirror surface; The angle of incidence is 0° and the angle of reflection is also 0° **13.** Two rays **16.** Virtual, erect and magnified **29.** (*c*) **30.** (*b*) **31.** (*d*) **32.** (*c*) **33.** (*d*) **34.** (*c*) **35.** (*b*) **36.** (*b*) **37.** (*d*) **38.** 10 cm ; Because it is less than focal length **39.** 20 cm **40.** (*i*) 20 cm (*ii*) 10 cm (*iii*) 35 cm (*iv*) 30 cm.

SIGN CONVENTION FOR SPHERICAL MIRRORS

These days New Cartesian Sign Convention is used for measuring the various distances in the ray-diagrams of spherical mirrors (concave mirrors and convex mirrors). According to the New Cartesian Sign Convention :

(*i*) All the distances are measured from *pole* of the mirror as origin.
(*ii*) Distances measured in the *same* direction as that of incident light are taken as *positive*.
(*iii*) Distances measured *against* the direction of incident light are taken as *negative.*
(*iv*) Distances measured *upward* and perpendicular to the principal axis are taken as *positive*.
(*v*) Distances measured *downward* and perpendicular to the principal axis are taken as *negative.*

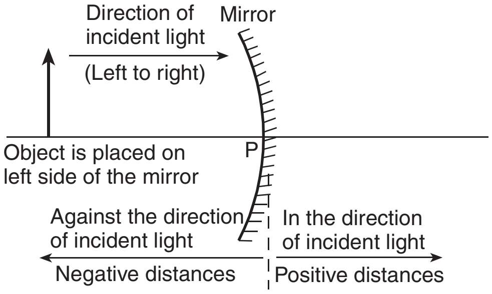


Figure 44. Sign convention for mirrors.

The New Cartesian Sign Convention for mirrors is shown in Figure 44. **The object is always placed on the left side of the mirror** (as shown in Figure 44) so that the direction of incident light is from *left* to *right*. Since the incident light always goes from left to right, **all the distances measured from the pole (*P*) of mirror to the right side will be considered positive** (because they will be in the same direction as the incident light). On the other hand, **all the distances measured from pole (*P*) of mirror to the left side will be negative** (because they are measured against the direction of incident light).

Some Important Conclusions

According to the sign convention, the distances towards the left of the mirror are negative. Since an object is always placed to the left side of a mirror, therefore, **the object distance *(u)* is always negative.**

The images formed by a concave mirror can be either behind the mirror (virtual) or in front of the mirror (real). So, the image distance (v) for a concave mirror can be either positive or negative depending on the position of the image. **If an image is formed behind a concave mirror (to the right side), the image distance *(v)* is positive** but **if the image is formed in front of the mirror (on the left side), then the image distance will be negative.**

In a convex mirror, the image is always formed on the right hand side (behind the mirror), so **the image distance *(v)* for a convex mirror will be always positive.**

The focus of concave mirror is in front of the mirror on the left side, so **the focal length of a concave mirror is considered negative** (and written with a minus sign, say, –10 cm). On the other hand, the focus of a convex mirror is behind the mirror on the right side, so **the focal length of a convex mirror is positive** (and written with a plus sign, say +20 cm or just 20 cm).

We will now discuss the signs for the heights of objects and images. An object is always placed above the principal axis in the upward direction, so **the height of an object is always considered positive.** On the other hand, an image can be formed above the principal axis or below the principal axis. **If an image is formed above the principal axis, its height is taken as positive** and **if an image is formed below the principal axis, then its height is taken as negative.** Now, we know that all the virtual images are erect and are formed above the principal axis, so **the height of all the virtual and erect images is considered positive.** On the other hand, all the real images are inverted and they are formed below the principal axis, so **the height of all the real and inverted images is taken as negative.** We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. According to the "New Cartesian Sign Convention" for mirrors, what sign has been given to the focal length of :
   (*i*) a concave mirror ?
   (*ii*) a convex mirror ?
2. Which type of mirror has :
   (*a*) positive focal length ?
   (*b*) negative focal length ?
3. What is the nature of a mirror having a focal length of, +10 cm ?
4. What kind of mirror can have a focal length of, – 20 cm ?
5. Complete the following sentence :
   All the distances are measured from the .... of a spherical mirror.
6. What sign (+ve or –ve) has been given to the following on the basis of Cartesian Sign Convention ?
   (*a*) Height of a real image.
   (*b*) Height of a virtual image.

Short Answer Type Questions

7. Describe the New Cartesian Sign Convention used in optics. Draw a labelled diagram to illustrate this sign convention.

8. Giving reasons, state the 'signs' (positive or negative) which can be given to the following :
(*a*) object distance (u) for a concave mirror or convex mirror
(*b*) image distances (v) for a concave mirror
(*c*) image distances (v) for a convex mirror

Multiple Choice Questions (MCQs)

9. According to New Cartesian Sign Convention :
(*a*) focal length of concave mirror is positive and that of convex mirror is negative
(*b*) focal length of both concave and convex mirrors is positive
(*c*) focal length of both concave and convex mirrors is negative
(*d*) focal length of concave mirror is negative and that of convex mirror is positive

10. One of the following does not apply to a concave mirror. This is :
(*a*) focal length is negative
(*b*) image distance can be positive or negative
(*c*) image distance is always positive
(*d*) height of image can be positive or negative

ANSWERS

3. Convex mirror **4.** Concave mirror **5.** pole **9.** (*d*) **10.** (*c*)

MIRROR FORMULA

The distance of an object from the pole of a mirror is known as object distance. Object distance is denoted by the letter u. The distance of image from the pole of a mirror is known as image distance. Image distance is denoted by the letter v. The distance of focus from the pole of a mirror is known as focal length. Focal length is denoted by the letter f. There is a relationship between the object distance, image distance and focal length of a spherical mirror (concave mirror or convex mirror). This relationship is given by the mirror formula.

A formula which gives the relationship between image distance (v), object distance (u) and focal length (f) of a spherical mirror is known as the mirror formula. The mirror formula can be written as :

$$\frac{1}{\text{Image distance}} + \frac{1}{\text{Object distance}} = \frac{1}{\text{Focal length}}$$

or
$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

where v = distance of image from mirror
u = distance of object from mirror
and f = focal length of the mirror

The mirror formula has three values in it. If any two values are known, the third value can be calculated. The known values should be put in this formula with their proper signs but no sign should be given to the unknown value to be calculated. Its proper sign will come by itself by calculations. The proper signs of the known values of u, v or f can be found by using New Cartesian Sign Convention for spherical mirrors. Another point to be noted is that the mirror formula can be applied to both type of spherical mirrors : concave mirrors as well as convex mirrors. By using this mirror formula, we can find out the position and nature of the images formed by concave mirrors and convex mirrors. Before we do that, we will discuss the 'magnification' produced by spherical mirrors.

Linear Magnification Produced by Mirrors

The size of image formed by a spherical mirror depends on the position of the object from the mirror. The image formed by a spherical mirror can be bigger than the object, equal to the object or smaller than the object. The size of the image relative to the object is given by the linear magnification. This is discussed on the next page.

The ratio of the height of image to the height of object is known as linear magnification. That is,

$$\text{Magnification} = \frac{\text{height of image}}{\text{height of object}}$$

or $$m = \frac{h_2}{h_1}$$

where m = magnification

h_2 = height of image

and h_1 = height of object

In our ray-diagrams, the object is always placed above the principal axis, so **the height (h_1) of the object will always be positive**. We also know that a virtual image is always formed above the principal axis, therefore, **the height (h_2) of a virtual image will be positive**. But a real image is formed below the principal axis, so **the height (h_2) of a real image will be negative** because it is measured in the downward direction. From this discussion we conclude that though the height of object h_1 is always positive, the height h_2 of the image can be either positive or negative.

Now, for a virtual image h_2 is positive and h_1 is also positive, so the magnification $\left(\frac{h_2}{h_1}\right)$ of a virtual (and erect) image is always positive. In other words, **if the magnification has a plus sign, then the image is virtual and erect.** For a real image, h_2 is negative and h_1 is positive, so the magnification $\left(\frac{h_2}{h_1}\right)$ for a real (and inverted) image is always negative. In other words, **if the magnification has a minus sign, then the image is real and inverted.**

Since a concave mirror can produce virtual images as well as real images, the magnification produced by a concave mirror can be either positive or negative. A convex mirror, however, forms only virtual images, so the magnification produced by a convex mirror is always positive. Another point to be noted is that if the magnification m has a value greater than 1 then the image is bigger than the object, that is, the image is magnified or enlarged. And if the magnification m is exactly 1, then the image is of the same size as the object. But if the magnification is less than 1 then the image is smaller than the object (or diminished).

A concave mirror can form images which are smaller than the object, equal to the object or bigger than the object, therefore, the linear magnification (or just magnification) (m) produced by a concave mirror can be less than 1, equal to 1 or more than 1. On the other hand, a convex mirror forms images which are always smaller than the object, so the linear magnification (m) produced by a convex mirror is always less than 1. A plane mirror forms images which are always of the same size as the object, therefore, the magnification (m) produced by a plane mirror is always 1.

If we know the height (or size) of the object and that of the image, then we can calculate the magnification by using the formula given above. Many times, however, we do not know their heights, so we will now write another formula for calculating the magnification produced by a spherical mirror in terms of "object distance" and "image distance".

The linear magnification produced by a mirror is equal to the ratio of the image distance to the object distance, with a minus sign. That is,

$$\text{Magnification} = -\frac{\text{Image distance}}{\text{Object distance}}$$

or $$m = -\frac{v}{u}$$

where m = magnification

v = image distance

and u = object distance

Thus, if we know the image distance v and the object distance u, then the magnification m can be calculated.

So, now we have two formulae for calculating the magnification :

$$m = \frac{h_2}{h_1} \quad \text{and} \quad m = -\frac{v}{u}$$

We will use these two formulae to solve numerical problems. We can also combine these two formulae to get another formula :

$$\frac{h_2}{h_1} = -\frac{v}{u}$$

This will also be used in solving problems.

Numerical Problems Based on Concave Mirrors

We will now solve some numerical problems based on concave mirrors by using the mirror formula and the magnification formulae. Here are some examples.

Sample Problem 1. Find the size, nature and position of image formed when an object of size 1 cm is placed at a distance of 15 cm from a concave mirror of focal length 10 cm.

Solution. Here we have been given the object distance and focal length, so first of all we will find out the image distance which will give us the position of image.

(*i*) Position of image

Here, Object distance, u = – 15 cm (To the left of mirror)
Image distance, v = ? (To be calculated)
And, Focal length, f = – 10 cm (It is concave mirror)

Now, putting these values in the mirror formula :

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

we get : $$\frac{1}{v} + \frac{1}{-15} = \frac{1}{-10}$$

or $$\frac{1}{v} - \frac{1}{15} = -\frac{1}{10}$$

or $$\frac{1}{v} = -\frac{1}{10} + \frac{1}{15}$$

$$\frac{1}{v} = \frac{-3+2}{30}$$

$$\frac{1}{v} = -\frac{1}{30}$$

So, Image distance, v = – 30 cm

Thus, the position of image is 30 cm to the left side of mirror or 30 cm in front of mirror (Minus sign shows the left side of mirror).

(*ii*) Nature of image. Since the image is formed in front of the concave mirror, its nature will be "Real and Inverted".

(*iii*) Size of image. To find the size of image, we will have to calculate the magnification first. The magnification produced by a mirror is given by :

$$m = -\frac{v}{u}$$

Here, Image distance, v = – 30 cm
Object distance, u = – 15 cm

So, $m = -\frac{(-30)}{(-15)}$

$m = -\frac{30}{15}$

Magnification, $m = -2$

We also have another formula for magnification, which is :

$$m = \frac{h_2}{h_1}$$

Here, Magnification, $m = -2$ (Found above)

Height of image, $h_2 = ?$ (To be calculated)

Height of object, $h_1 = 1$ cm (Given)

Now, putting these values in the above magnification formula, we get :

$$-2 = \frac{h_2}{1}$$

So, Height of image, $h_2 = -2 \times 1$

$= -2$ cm

Thus, the size of image is 2 cm long. The minus sign here shows that the image is formed below the principal axis. That is, it is a real and inverted image.

Sample Problem 2. An object 2 cm high is placed at a distance of 16 cm from a concave mirror which produces a real image 3 cm high.

(*i*) What is the focal length of the mirror ?

(*ii*) Find the position of the image.

Solution. (*i*) **Calculation of position of image**

The height of object is 2 cm and that of real image is 3 cm. So, we will first calculate the magnification by using the formula :

$$m = \frac{h_2}{h_1}$$

Please note that an object is always placed above the axis, so the height of object is always taken as positive and written with a plus sign. A real image is formed below the axis. So, the height of a real image is taken as negative and written with a minus sign.

Here, Height of real image, $h_2 = -3$ cm

Height of object, $h_1 = +2$ cm

So, putting these values in the above magnification formula, we get :

Magnification, $m = \frac{-3}{+2}$

or $m = -1.5$

Now, we have another magnification formula for mirrors, which is :

$$m = -\frac{v}{u}$$

Here, Magnification, $m = -1.5$ (Found above)

Image distance, $v = ?$ (To be calculated)

and Object distance, $u = -16$ cm (To the left of mirror)

So, putting these values in the above formula, we get :

$$-1.5 = -\frac{v}{(-16)}$$

or $-1.5 = \frac{v}{16}$

So, $v = -1.5 \times 16$

or $v = -24$ cm

Thus, the position of image is 24 cm in front of the mirror, to the left side of mirror (The minus sign shows that the image is on the left side of the mirror).

(*ii*) Calculation of focal length

Here, Object distance, $u = -16$ cm
Image distance, $v = -24$ cm
Focal length, $f = ?$ (To be calculated)

Now, putting these values in the mirror formula :

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

we get :

$$\frac{1}{-24} + \frac{1}{-16} = \frac{1}{f}$$

or

$$-\frac{1}{24} - \frac{1}{16} = \frac{1}{f}$$

$$\frac{-2-3}{48} = \frac{1}{f}$$

$$-\frac{5}{48} = \frac{1}{f}$$

$$f = -\frac{48}{5}$$

So, Focal length, $f = -9.6$ cm

Sample Problem 3. A concave mirror produces three times magnified (enlarged) real image of an object placed at 10 cm in front of it. Where is the image located ? **(NCERT Book Question)**

Solution. In this problem we have been given magnification (m) and object distance (u). We are to find out the image distance (v). Now,

Magnification, $m = -3$ (Image is real)
Object distance, $u = -10$ cm (To the left of mirror)
And, Image distance, $v = ?$ (To be calculated)

Putting these values in the magnification formula for a mirror :

$$m = -\frac{v}{u}$$

we get :

$$-3 = -\frac{v}{-10}$$

$$-3 \times -10 = -v$$

$$v = -30 \text{ cm}$$

Thus, the image is located at a distance of 30 cm in front of the mirror (on its left side).

Sample Problem 4. The magnification produced by a plane mirror is +1. What does this mean ? **(NCERT Book Question)**

Answer. The plus sign (+) of the magnification shows that the image is virtual and erect. And the value 1 for magnification shows that the image is exactly of the same size as the object. So, the magnification of +1 produced by a plane mirror means that the image formed in a plane mirror is virtual and erect, and of the same size as the object.

Sample Problem 5. What is the nature of the image formed by a concave mirror if the magnification produced by the mirror is +3 ?

Answer. If the magnification has a plus sign (+), then the image is virtual and erect. In this case, the magnification has a plus sign (it is +3), therefore, the nature of this image is virtual and erect.

Sample Problem 6. What is the nature of the image formed by a concave mirror if the magnification produced by the mirror is, – 0.75 ?

Answer. If the magnification has a minus sign (–), then the image is real and inverted. In this case, the magnification has a minus sign (it is, – 0.75), so the nature of image is real and inverted.

Before we go further and discuss the images formed by convex mirrors, **please answer the following questions and problems yourself :**

Very Short Answer Type Questions

1. If the magnification of a body of size 1 m is 2, what is the size of the image ?

2. What is the position of the image when an object is placed at a distance of 20 cm from a concave mirror of focal length 20 cm ?

3. What is the nature of image formed by a concave mirror if the magnification produced by the mirror is (*a*) + 4, and (*b*) – 2 ?

4. State the relation between object distance, image distance and focal length of a spherical mirror (concave mirror or convex mirror).

5. Write the mirror formula. Give the meaning of each symbol which occurs in it.

6. What is the ratio of the height of an image to the height of an object known as ?

7. Define linear magnification produced by a mirror.

8. Write down a formula for the magnification produced by a concave mirror.

(*a*) in terms of height of object and height of image

(*b*) in terms of object distance and image distance

9. Describe the nature of image formed when the object is placed at a distance of 20 cm from a concave mirror of focal length 10 cm.

10. Fill in the following blanks with suitable words :

(*a*) If the magnification has a plus sign, then image is..............and............

(*b*) If the magnification has a minus sign, then the image is...........and............

Short Answer Type Questions

11. An object is placed at a distance of 10 cm from a concave mirror of focal length 20 cm.

(*a*) Draw a ray diagram for the formation of image.

(*b*) Calculate the image distance.

(*c*) State two characteristics of the image formed.

12. If an object of 10 cm height is placed at a distance of 36 cm from a concave mirror of focal length 12 cm, find the position, nature and height of the image.

13. At what distance from a concave mirror of focal length 10 cm should an object 2 cm long be placed in order to get an erect image 6 cm tall ?

14. When an object is placed at a distance of 15 cm from a concave mirror, its image is formed at 10 cm in front of the mirror. Calculate the focal length of the mirror.

15. An object 3 cm high is placed at a distance of 8 cm from a concave mirror which produces a virtual image 4.5 cm high :

(*i*) What is the focal length of the mirror ?

(*ii*) What is the position of image ?

(*iii*) Draw a ray-diagram to show the formation of image.

16. A converging mirror forms a real image of height 4 cm of an object of height 1 cm placed 20 cm away from the mirror :

(*i*) Calculate the image distance.

(*ii*) What is the focal length of the mirror ?

17. An object of size 7.0 cm is placed at 27 cm in front of a concave mirror of focal length 18 cm. At what distance from the mirror should a screen be placed so that a sharp focussed image can be obtained ? Find the size and nature of image.

[**Hint.** Find the value of image distance (v) first. The screen should be placed from the mirror at a distance equal to image distance].

18. An object 3 cm high is placed at a distance of 10 cm in front of a converging mirror of focal length 20 cm. Find the position, nature and size of the image formed.

19. A concave mirror has a focal length of 4 cm and an object 2 cm tall is placed 9 cm away from it. Find the nature, position and size of the image formed.

20. When an object is placed 20 cm from a concave mirror, a real image magnified three times is formed. Find :

(*a*) the focal length of the mirror.

(*b*) Where must the object be placed to give a virtual image three times the height of the object ?

21. A dentist's mirror has a radius of curvature of 3 cm. How far must it be placed from a small dental cavity to give a virtual image of the cavity that is magnified five times ?

22. A large concave mirror has a radius of curvature of 1.5 m. A person stands 10 m in front of the mirror. Where is the person's image ?

23. An object of 5.0 cm size is placed at a distance of 20.0 cm from a converging mirror of focal length 15.0 cm. At what distance from the mirror should a screen be placed to get the sharp image ? Also calculate the size of the image.

24. A concave mirror produces three times enlarged virtual image of an object placed at 10 cm in front of it. Calculate the radius of curvature of the mirror.

25. A bright object 50 mm high stands on the axis of a concave mirror of focal length 100 mm and at a distance of 300 mm from the concave mirror. How big will the image be ?

26. How far should an object be placed from the pole of a converging mirror of focal length 20 cm to form a real image of the size exactly $\frac{1}{4}$th the size of the object ?

27. When an object is placed at a distance of 50 cm from a concave spherical mirror, the magnification produced is, $-\frac{1}{2}$. Where should the object be placed to get a magnification of, $-\frac{1}{5}$?

28. An object is placed (*a*) 20 cm, (*b*) 4 cm, in front of a concave mirror of focal length 12 cm. Find the nature and position of the image formed in each case.

29. A concave mirror produces a real image 1 cm tall of an object 2.5 mm tall placed 5 cm from the mirror. Find the position of the image and the focal length of the mirror.

30. A man holds a spherical shaving mirror of radius of curvature 60 cm, and focal length 30 cm, at a distance of 15 cm, from his nose. Find the position of image, and calculate the magnification.

Long Answer Type Question

31. (*a*) An object is placed just outside the principal focus of concave mirror. Draw a ray diagram to show how the image is formed, and describe its size, position and nature.

(*b*) If the object is moved further away from the mirror, what changes are there in the position and size of the image ?

(*c*) An object is 24 cm away from a concave mirror and its image is 16 cm from the mirror. Find the focal length and radius of curvature of the mirror, and the magnification of the image.

Multiple Choice Questions (MCQs)

32. Linear magnification produced by a concave mirror may be :

(*a*) less than 1 or equal to 1 (*b*) more than 1 or equal to 1
(*c*) less than 1, more than 1 or equal to 1 (*d*) less than 1 or more than 1

33. Magnification produced by a convex mirror is always :

(*a*) more than 1 (*b*) less than 1 (*c*) equal to 1 (*d*) more or less than 1

34. Magnification produced by a plane mirror is :

(*a*) less than one (*b*) greater than one (*c*) zero (*d*) equal to one

35. In order to obtain a magnification of, –2 (minus 2) with a concave mirror, the object should be placed :

(*a*) between pole and focus (*b*) between focus and centre of curvature
(*c*) at the centre of curvature (*d*) beyond the centre of curvature

36. A concave mirror produces a magnification of + 4. The object is placed :

(*a*) at the focus (*b*) between focus and centre of curvature
(*c*) between focus and pole (*d*) beyond the centre of curvature

37. If a magnification of, –1 (minus one) is to be obtained by using a converging mirror, then the object has to be placed :

(*a*) between pole and focus (*b*) at the centre of curvature

(*c*) beyond the centre of curvature (*d*) at infinity

38. In order to obtain a magnification of, – 0.6 (minus 0.6) with a concave mirror, the object must be placed :

(*a*) at the focus (*b*) between pole and focus

(*c*) between focus and centre of curvature (*d*) beyond the centre of curvature

39. An object is placed at a large distance in front of a concave mirror of radius of curvature 40 cm. The image will be formed in front of the mirror at a distance of :

(*a*) 20 cm (*b*) 30 cm (*c*) 40 cm (*d*) 50 cm

40. In order to obtain a magnification of, –1.5 with a concave mirror of focal length 16 cm, the object will have to be placed at a distance :

(*a*) between 6 cm and 16 cm (*b*) between 32 cm and 16 cm

(*c*) between 48 cm and 32 cm (*d*) beyond 64 cm

41. Linear magnification (m) produced by a rear view mirror fitted in vehicles :

(*a*) is equal to one (*b*) is less than one

(*c*) is more than one (*d*) can be more or less than one depending on the position of object

Questions Based on High Order Thinking Skills (HOTS)

42. Between which two points of concave mirror should an object be placed to obtain a magnification of :

(*a*) – 3 (*b*) + 2.5 (*c*) – 0.4

43. At what distance from a concave mirror of focal length 10 cm should an object be placed so that :

(*a*) its real image is formed 20 cm from the mirror ?

(*b*) its virtual image is formed 20 cm from the mirror ?

44. If a concave mirror has a focal length of 10 cm, find the two positions where an object can be placed to give, in each case, an image twice the height of the object.

45. A mirror forms an image which is 30 cm from an object and twice its height.

(*a*) Where must the mirror be situated ?

(*b*) What is the radius of curvature ?

(*c*) Is the mirror convex or concave ?

ANSWERS

1. 2 m **2.** At infinity **3.** (*a*) Virtual and erect (*b*) Real and inverted **6.** Magnification **9.** Real and inverted **10.** (*a*) virtual ; erect (*b*) real ; inverted **11.** (*b*) 20 cm (*c*) Virtual and erect ; Magnified **12.** v = –18 cm ; The position of image is 18 cm in front of concave mirror (to its left side); Real and inverted ; 5 cm **13.** u = – 6.66 cm ; The object should be placed at a distance of 6.66 cm on the left side of concave mirror **14.** 6 cm **15.** (*i*) 24 cm (*ii*) 12 cm behind the concave mirror (on its right side) **16.** (*i*) 80 cm in front of the mirror (*ii*) 16 cm **17.** v = – 54 cm ; The screen should be placed at a distance of 54 cm in front of the concave mirror ; 14.0 cm; Real and inverted **18.** v = +20 cm ; The image is formed at a distance of 20 cm behind the converging mirror; Virtual and erect ; 6 cm **19.** Real and inverted ; v = – 7.2 cm : The image is formed at a distance of 7.2 cm in front of concave mirror ; 1.6 cm **20.** (*a*) 15 cm (*b*) 10 cm from the concave mirror ; **21.** 1.2 cm **22.** 0.81 m in front of the concave mirror **23.** 60 cm in front of the converging mirror ; 15.0 cm **24.** 30 cm **25.** 25 mm **26.** 100 cm **27.** 100 cm **28.** (*a*) v = –30 cm ; The image is formed at a distance of 30 cm in front of mirror (on its left side); Real and inverted (*b*) v = + 6 cm ; The image is formed at a distance of 6 cm behind the mirror (on its right side); Virtual and erect **29.** v = –20 cm ; The image is formed 20 cm in front of the mirror ; 4 cm **30.** v = + 30 cm ; The image is formed at a distance of 30 cm behind the mirror ; m = + 2 **31.** (*c*) 9.6 cm ; 19.2 cm ; 0.66 **32.** (*c*) **33.** (*b*) **34.** (*d*) **35.** (*b*) **36.** (*c*) **37.** (*b*) **38.** (*d*) **39.** (*a*) **40.** (*b*) **41.** (*b*) **42.** (*a*) Between focus and centre of curvature (*b*) Between pole and focus (*c*) Beyond the centre of curvature **43.** (*a*) 20 cm (*b*) $\frac{20}{3}$ cm **44.** 15 cm ; 5 cm **45.** (*a*) 10 cm from the object (*b*) 40 cm (*c*) Concave mirror

RULES FOR OBTAINING IMAGES FORMED BY CONVEX MIRRORS

In order to construct ray-diagrams to find out the position, nature and size of the images formed by a convex mirror, we should remember the paths of the following rays of light. We can call them the rules for obtaining images in convex mirrors.

Rule 1. **A ray of light which is parallel to the principal axis of a convex mirror, appears to be coming from its focus after reflection from the mirror.** This is shown in Figure 45. In Figure 45, the ray of light *AB* is parallel to the principal axis *XP* of a convex mirror. The ray of light *AB* gets reflected at point *B* on the mirror and goes in the direction *BD*. To a person on the left side, the reflected ray *BD* appears to be coming from the focus *F* of the convex mirror situated behind the mirror (as shown by dotted line).

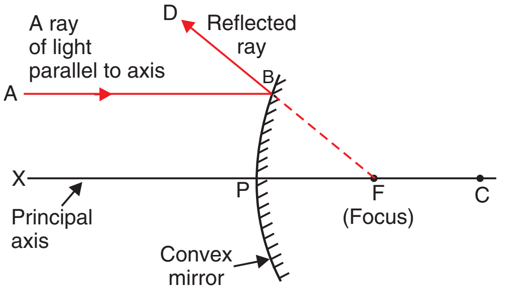


Figure 45.

Rule 2. **A ray of light going towards the centre of curvature of a convex mirror is reflected back along the same path.** This is shown in Figure 46. In Figure 46, the ray of light *AD* is going towards the centre of curvature *C* of a convex mirror. It strikes the mirror surface at point *D* and gets reflected back along the same path *DA.* To a person on the left side, the reflected ray *DA* appears to be coming from the centre of curvature *C* (as shown by dotted line behind the mirror). Please note that the ray *AD* gets reflected back along the same path because it falls normally (or perpendicularly) on the mirror surface at point *D.*

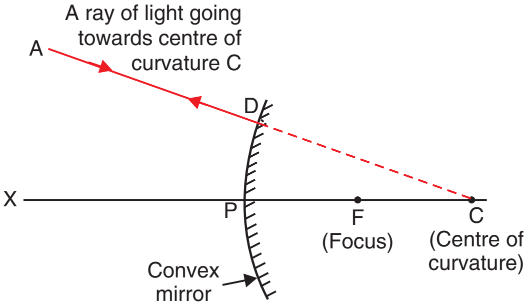


Figure 46.

Please note that if a ray of light is incident on a convex mirror along its principal axis, then it is reflected back along the same path (because it will be normal or perpendicular to the mirror surface). The angle of incidence as well as the angle of reflection for such a ray of light will be zero.

Rule 3. **A ray of light going towards the focus of a convex mirror becomes parallel to the principal axis after reflection.** This is just the reverse case of the first rule and it is shown in Figure 47. Here the incident ray of light *AE* is going towards the focus *F* of the convex mirror. It strikes the mirror surface at point *E* and gets reflected. After reflection, it becomes parallel to the principal axis and goes in the direction *EG* (see Figure 47).

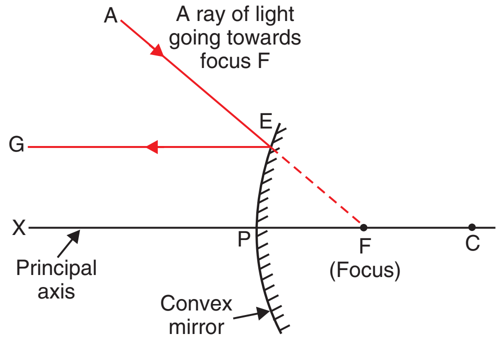


Figure 47.

Rule 4. **A ray of light which is incident at the pole of a convex mirror is reflected back making the same angle with the principal axis.** This is shown in Figure 48. Here a ray of light *AP* is incident on the pole *P* of the convex mirror making an angle of incidence *i* with the principal axis *XP*. It gets reflected along the direction *PH* making an equal angle of reflection *r* with the principal axis (see Figure 48).

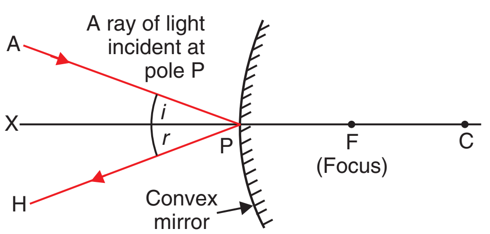


Figure 48.

It should be noted that a convex mirror has its focus and centre of curvature behind it. Since no real rays of light can go behind the convex mirror, all the rays shown behind the convex mirror are virtual (or unreal) and hence they have been represented by dotted lines. In fact, no actual rays can pass through the focus and centre of curvature of a convex mirror.

Please note that **whatever be the position of object in front of a convex mirror, the image formed by a convex mirror is always behind the mirror, it is virtual, erect and smaller than the object (or diminished).** When the distance of the object is changed from convex mirror, then only the position and size of the image changes. There are two main positions of an object in the case of a convex mirror from the point of view of position and size of image. The object can be :

(*i*) anywhere between pole (*P*) and infinity, and
(*ii*) at infinity.

We will discuss both these cases one by one. Let us first describe the formation of image by a convex mirror when the object is placed between pole (*P*) of the mirror and infinity.

FORMATION OF IMAGE BY A CONVEX MIRROR

In Figure 49, we have an object *AB* placed in front of a convex mirror *M* anywhere between pole *P* and infinity. A ray of light *AD*, parallel to the principal axis of the convex mirror, strikes the mirror at point *D*. Now, according to the first rule of image formation, this parallel ray of light should appear to be coming from focus *F* after reflection. So, we join the points *D* and *F* by a dotted line and produce the line *FD* towards the left in the direction *DX*. Now, *DX* gives us the reflected ray which appears to be coming from focus *F* of the convex mirror.

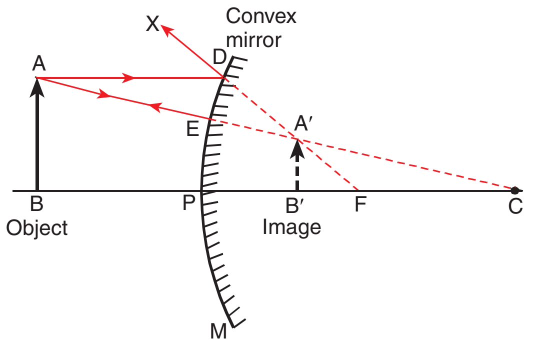


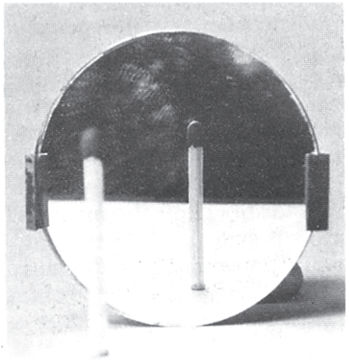
Figure 49. Formation of image by a convex mirror when the object is placed anywhere between the pole of mirror and infinity.

We have now to draw a second ray of light from the point *A* going towards the centre of curvature *C* of the convex mirror. For this we join the point *A* with point *C* by a line which cuts the mirror at point *E*. The line from *A* to *E* is a solid line and it represents a real ray of light but the line from *E* to *C* is a dotted line which represents a virtual ray of light. Now, *AE* represents a ray of light going towards the centre of curvature *C* of the convex mirror. According to the second rule of image formation, this ray is reflected along the same path *EA* but it appears to be coming from the centre of curvature *C.*

The two reflected rays *DX* and *EA* are diverging rays but they appear to intersect at point *A′* when produced backwards. Thus *A′* is the virtual image of point *A* of the object. To get the full image of the object, we draw the perpendicular *A′B′* to the axis from point *A′*. Thus *A′B′* is the virtual image of the object *AB*. It is clear from Figure 49 that the image is formed behind the convex mirror between the pole and the focus. It is virtual, erect and smaller than the object (or diminished). From the above discussion we conclude that : **When an object is placed anywhere between pole (*P*) and infinity in front of a convex mirror, the image formed is :**

(*i*) behind the mirror between pole (*P*) and focus (*F*),
(*ii*) virtual and erect, and
(*iii*) diminished (smaller than the object).

If we hold a matchstick (as object) in front of a convex mirror, a virtual, erect and diminished (smaller) image of the matchstick is seen on looking into the convex mirror [see Figure 50(*a*)]. We know that the back side of a shining steel spoon (which is bulging outwards) is a kind of convex mirror. So, if we keep our face in front of the back side of a shining steel spoon we will see a virtual and erect image of the face which is smaller in size as compared to the face [see Figure 50 (*b*)].



(*a*) The image of matchstick in the convex mirror is virtual, erect and diminished (smaller in size).

(*b*) The image of face in the backside (convex surface) of a shining steel spoon is virtual, erect and diminished.

Figure 50.

If we move the object more and more away from the pole of the convex mirror, the image becomes smaller and smaller in size and moves away from the mirror towards its focus but it remains virtual and erect for all the positions of the object. And *when the object is at infinity, the image is formed at the focus*. This is discussed below.

When the Object is at Infinity

When the object is at a far-off distance, we say that the object is at infinity. In Figure 51, we have a convex mirror *M*. Suppose an object (an arrow pointing upwards) has been placed at infinity in front of the convex mirror (Since the object is very far-off, it cannot be shown in the diagram). Because the object *AB* is very far-off, the two rays *AD* and *AP* coming from its top point *A* are parallel to one another but at an angle to the principal axis as shown in Figure 51. The ray *AD* gets reflected in the direction *DX* and the ray *AP* gets reflected in the direction *PY*. When the diverging reflected rays *DX* and *PY* are produced backwards (as shown by dotted lines in Figure 51), they intersect at point *A′* in the focal plane of the convex mirror. Thus, *A′* is the virtual image of the top point *A* of the object. To get the full image of the object, we draw *A′B′* perpendicular to the axis. So, *A′B′* is the image of the object *AB* placed at infinity. We find that the image is formed at the focus (*F*) of the convex mirror behind the mirror. It is virtual, erect and highly diminished (much smaller than the object). From the above discussion we conclude that : **When an object is at infinity from a convex mirror, the image formed is :**

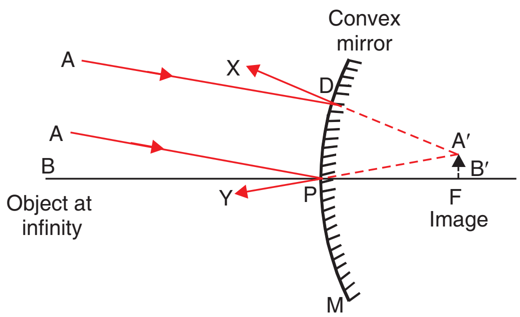


Figure 51. Formation of image by a convex mirror when the object is at infinity (large distance).

(*i*) behind the mirror at focus (*F*),

(*ii*) virtual and erect, and

(*iii*) highly diminished (much smaller than the object).

Since the image of a distant object formed by a convex mirror is highly diminished, we can see the full image of a tall building or tree even in a small convex mirror. Please note that when the object kept at infinity in front of a convex mirror is assumed to be a big arrow pointing upwards, then its image is formed at focus according to the ray-diagram shown in Figure 51. If, however, the object kept at infinity in front of a convex mirror is round in shape, then its image is formed at the focus according to the ray diagram shown in Figure 27 on page 178. And before we conclude this discussion, here is a summary of the images formed by a convex mirror.

Summary of the Images Formed by a Convex Mirror

Position of object	*Position of image*	*Size of image*	*Nature of image*
1. Anywhere between pole *P* and infinity	Behind the mirror between *P* and *F*	Diminished	Virtual and erect
2. At infinity	Behind the mirror at focus (*F*)	Highly diminished	Virtual and erect

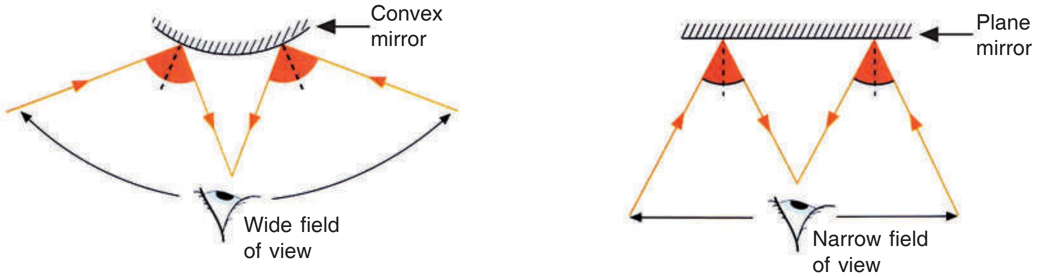
Uses of Convex Mirrors

(*i*) Convex mirrors are used as rear-view mirrors in vehicles (like cars, trucks and buses) to see the traffic at the rear side (or back side) (see Figure 52). A driver prefers to use a convex mirror as rear-view mirror because of two reasons :

(*a*) A convex mirror always produces an erect (right side up) image of the objects.

(*b*) The image formed in a convex mirror is highly diminished or much smaller than the object, due to which a convex mirror gives a wide field of view (of the traffic behind) [see Figure 53(*a*)]. A convex mirror enables a driver to view much larger area of the traffic behind him than would be possible with a plane mirror. A plane mirror gives a narrow field of view [see Figure 53(*b*)]. Due to this if a plane mirror is used as a rear-view mirror in vehicles, it will give the driver a much smaller view of the road and traffic behind. Rear-view mirrors are also known as driving mirrors or side-view mirrors or wing mirrors.

Figure 52. Convex mirror is used as a rear view mirror (or side view mirror) in vehicles.



(*a*) A convex mirror gives a wide field of view (or large field of view).

(*b*) A plane mirror gives a narrow field of view (or small field of view).

Figure 53.

Please note that **we cannot use a concave mirror as a rear-view mirror in motor vehicles.** This is because a concave mirror produces inverted images (upside down images) of distant objects. So, if we use a concave mirror as a rear view mirror in a car (bus or truck, etc.) we will see in the mirror that all the vehicles on the road (at the back side) are running upside down with their wheels up in the air. This will be really a very funny situation to watch.

(*ii*) Big convex mirrors are used as 'shop security mirrors' (see Figure 54). By installing a big convex mirror at a strategic point in the shop, the shop owner can keep an eye on the customers to look for thieves and shoplifters among them.

Figure 54. This picture shows a big convex mirror installed as a security mirror in a shop. A large number of goods displayed in the shop can be seen in this convex mirror.

How to Distinguish Between a Plane Mirror, a Concave Mirror and a Convex Mirror Without Touching Them

We can distinguish between these mirrors just by looking into them, that is, by bringing our face close to each mirror, turn by turn. All of them will produce an image of our face but of different types. **A plane mirror will produce an image of the same size** as our face and we will look our normal self. **A concave mirror will produce a magnified image** and our face will look much bigger (like that of a giant !). **A convex mirror will produce a diminished image** and our face will look much smaller (like that of a small child !). Let us answer one question now.

Sample Problem. No matter how far you stand from a mirror, your image appears erect. The mirror may be :

(*i*) plane (*ii*) concave (*iii*) convex (*iv*) either plane or convex

Choose the correct alternative. **(NCERT Book Question)**

Answer. The correct alternative is : (*iv*) either plane or convex.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. What type of image/images are formed by :
(*a*) a convex mirror ?
(*b*) a concave mirror ?

2. Which mirror has a wider field of view ?

3. If you want to see an enlarged image of your face, state whether you will use a concave mirror or a convex mirror ?

4. Which mirror always produces a virtual, erect and diminished image of an object ?

5. An object is placed at a long distance in front of a convex mirror of radius of curvature 30 cm. State the position of its image.

6. Name the spherical mirror which can produce a real and diminished image of an object.

7. Name the spherical mirror which can produce a virtual and diminished image of an object.

8. One wants to see a magnified image of an object in a mirror. What type of mirror should one use ?

9. Name the mirror which can give :
(*a*) an erect and enlarged image of an object.
(*b*) an erect and diminished image of an object.

10. State whether the following statement is true or false :
A diverging mirror is used as a rear-view mirror.

11. What type of mirror could be used :
(*a*) as a shaving mirror ?
(*b*) as a shop security mirror ?

12. Which type of mirror is usually used as a rear-view mirror in motor cars ?

13. What kind of mirrors are used in big shopping centres to watch the activities of the customers ?

14. A ray of light going towards the focus of a convex mirror becomes parallel to the principal axis after reflection from the mirror. Draw a labelled diagram to represent this situation.

15. Fill in the following blank with a suitable word :
A ray of light which is parallel to the principal axis of a convex mirror, appears to be coming from...........after reflection from the mirror.

Short Answer Type Questions

16. Why does a driver prefer to use a convex mirror as a rear-view mirror in a vehicle ?

17. Why can you not use a concave mirror as a rear-view mirror in vehicles ?

18. Where would the image be formed by a convex mirror if the object is placed :

(*a*) between infinity and pole of the mirror ?

(*b*) at infinity ?

Draw labelled ray-diagrams to show the formation of image in both the cases.

19. The shiny outer surface of a hollow sphere of aluminium of radius 50 cm is to be used as a mirror :

(*a*) What will be the focal length of this mirror ?

(*b*) Which type of spherical mirror will it provide ?

(c) State whether this spherical mirror will diverge or converge light rays.

20. What is the advantage of using a convex mirror as a rear-view mirror in vehicles as compared to a plane mirror ? Illustrate your answer with the help of labelled diagrams.

21. Give two uses of a convex mirror. Explain why you would choose convex mirror for these uses.

22. What would your image look like if you stood close to a large :

(*a*) convex mirror ?

(*b*) concave mirror ?

Give reasons for your answer.

23. Which of the following are concave mirrors and which convex mirrors ?

Shaving mirrors, Car headlight mirror, Searchlight mirror, Driving mirror, Dentist's inspection mirror, Torch mirror, Staircase mirror in a double-decker bus, Make-up mirror, Solar furnace mirror, Satellite TV dish, Shop security mirror.

24. How will you distinguish between a plane mirror, a concave mirror and a convex mirror without touching them ?

25. If a driver has one convex and one plane rear-view mirror, how would the images in each mirror appear different ?

Long Answer Type Questions

26. (*a*) Draw a labelled ray diagram to show the formation of image of an object by a convex mirror. Mark clearly the pole, focus and centre of curvature on the diagram.

(*b*) What happens to the image when the object is moved away from the mirror gradually ?

(*c*) State three characteristics of the image formed by a convex mirror.

27. (*a*) Draw a labelled ray diagram to show the formation of image in a convex mirror when the object is at infinity. Mark clearly the pole and focus of the mirror in the diagram.

(*b*) State three characteristics of the image formed in this case.

(*c*) Draw diagram to show how a convex mirror can be used to give a large field of view.

Multiple Choice Questions (MCQs)

28. The image formed by a spherical mirror is virtual. The mirror will be :

(*a*) concave (*b*) convex (*c*) either concave or convex (*d*) metallic

29. Whatever be the position of the object, the image formed by a mirror is virtual, erect and smaller than the object. The mirror then must be :

(*a*) plane (*b*) concave (*c*) convex (*d*) either concave or convex

30. The mirror used by a dentist to examine the teeth of a person is :

(*a*) convex (*b*) concave (*c*) plane (*d*) any one of the above

31. If the image formed is always virtual, the mirror can be :

(*a*) concave or convex (*b*) concave or plane

(*c*) convex or plane (*d*) only convex

32. A concave mirror cannot be used as :

(*a*) a magnifying mirror (*b*) a torch reflector

(*c*) a dentist's mirror (*d*) a rear view mirror

33. A boy is standing in front of and close to a special mirror. He finds the image of his head bigger than normal, the middle part of his body of the same size, and his legs smaller than normal. The special mirror is made up of three types of mirrors in the following order from top downwards :

(*a*) Convex, Plane, Concave (*b*) Plane, Convex, Concave
(*c*) Concave, Plane, Convex (*d*) Convex, Concave, Plane

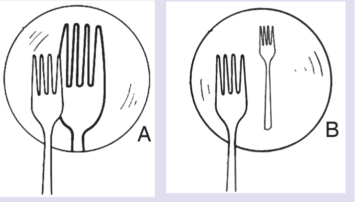
34. The mirror which can form a magnified image of an object is :
(*a*) convex mirror (*b*) plane mirror
(*c*) concave mirror (*d*) both convex and concave mirrors

35. A real image of an object is to be obtained. The mirror required for this purpose is :
(*a*) convex (*b*) concave (*c*) plane (*d*) either convex or concave

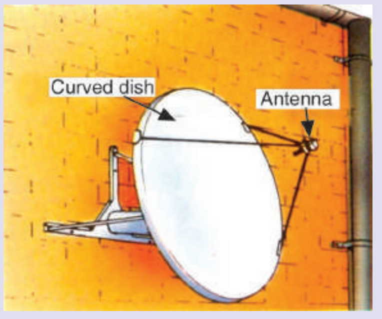
36. Consider two statements A and B given below :
A : real image is always inverted
B : virtual image is always erect
Out of these two statements :
(*a*) only A is true (*b*) only B is true (*c*) both A and B are true (*d*) none is true

Questions Based on High Order Thinking Skills (HOTS)

37. The diagrams show the appearance of a fork when placed in front of and close to two mirrors A and B, turn by turn.
(*a*) Which mirror is convex ?
(*b*) Which mirror is concave ?
Give reasons for your choice.



38. The diagram shows a dish antenna which is used to receive television signals from a satellite. The antenna (signal detector) is fixed in front of the curved dish.
(*a*) What is the purpose of the dish ?
(*b*) Should it be concave or convex ?
(*c*) Where should the antenna be positioned to receive the strongest possible signals ?
(*d*) Explain what change you would expect in the signals if a larger dish was used.



39. A man standing in front of a special mirror finds his image having a very small head, a fat body and legs of normal size. What is the shape of :
(*a*) top part of the mirror ?
(*b*) middle part of the mirror ?
(*c*) bottom part of the mirror ?
Give reasons for your choice.

40. Two big mirrors A and B are fitted side by side on a wall. A man is standing at such a distance from the wall that he can see the erect image of his face in both the mirrors. When the man starts walking towards the mirrors, he finds that the size of his face in mirror A goes on increasing but that in mirror B remains the same.
(*a*) mirror A is concave and mirror B is convex
(*b*) mirror A is plane and mirror B is concave
(*c*) mirror A is concave and mirror B is plane
(*d*) mirror A is convex and mirror B is concave

ANSWERS

1. (*a*) Virtual and erect (*b*) Virtual and erect ; Real and inverted **5.** At focus ; 15 cm behind convex mirror **9.** (*a*) Concave mirror (*b*) Convex mirror **10.** True **15.** focus **19.** (*a*) 25 cm (*b*) Convex mirror (*c*) Diverge light **28.** (*c*) **29.** (*c*) **30.** (*b*) **31.** (*c*) **32.** (*d*) **33.** (*c*) **34.** (*c*) **35.** (*b*) **36.** (*c*) **37.** (*a*) Mirror B is convex ; It forms a smaller image of fork (*b*) Mirror A is concave ; It forms a larger image of fork **38.** (*a*) To collect a large amount of TV signals from the satellite (*b*) Concave (*c*) At the focus of the dish (*d*) Stronger signals will be received **39.** (*a*) Convex (*b*) Concave (*c*) Plane **40.** (*c*)

NUMERICAL PROBLEMS BASED ON CONVEX MIRRORS

In order to solve the numerical problems based on convex mirrors, we should remember that the mirror formula for a convex mirror is the same as that for a concave mirror, which is :

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

where v = image distance
u = object distance
and f = focal length

Please note that since a convex mirror always forms an image behind the mirror (on the right side of the mirror), therefore, **the image distance (v) in the case of convex mirrors is always positive**. The object is always placed to the left of mirror, so the object distance (u) is always taken with a negative sign. The focus of a convex mirror is behind the mirror on its right side, therefore, **the focal length of a convex mirror is always taken as positive.**

The two magnification formulae for convex mirror are also just the same as that for a concave mirror. That is :

$$m=\frac{h_2}{h_1} \quad \text{and} \quad m=-\frac{v}{u}$$

where the symbols have their usual meaning. Let us now solve one numerical problem based on convex mirror.

Sample Problem. An object 5 cm high is placed at a distance of 10 cm from a convex mirror of radius of curvature 30 cm. Find the nature, position and size of the image.

Solution. Here, Object distance, u = – 10 cm (To left of mirror)
Image distance, v = ? (To be calculated)

And, Focal length, $f = \frac{\text{Radius of curvature}}{2}$

$= \frac{30}{2}$ cm

$= + 15$ cm (Convex mirror)

Putting these values in the mirror formula :

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

we get :
$$\frac{1}{v}+\frac{1}{-10}=\frac{1}{+15}$$

or
$$\frac{1}{v}-\frac{1}{10}=\frac{1}{15}$$

or
$$\frac{1}{v}=\frac{1}{15}+\frac{1}{10}$$

$$\frac{1}{v}=\frac{2+3}{30}$$

$$\frac{1}{v}=\frac{5}{30}$$

$$\frac{1}{v}=\frac{1}{6}$$

So, Image distance, v = + 6 cm

Thus, the position of image is 6 cm behind the convex mirror. Since the image is formed behind the convex mirror, its nature will be virtual and erect.

To find the size of image, we will calculate the magnification first.

Now, Magnification, $m = -\frac{v}{u}$

Here, Image distance, $v = +6$ cm
and Object distance, $u = -10$ cm

So,
$$m = -\frac{(+6)}{(-10)}$$
$$m = \frac{6}{10}$$
Magnification, $m = 0.6$

We also have another formula for magnification, which is :
$$m = \frac{h_2}{h_1}$$

Here, Magnification, $m = +0.6$
Height of image, $h_2 = ?$ (To be calculated)
and Height of object, $h_1 = +5$ cm

So,
$$+0.6 = \frac{h_2}{+5}$$
$$h_2 = 5 \times 0.6$$
Height of image, $h_2 = 3$ cm (or + 3 cm)

Thus, the size of image is 3 cm.

We are now in a position to **answer the following questions and problems :**

Short Answer Type Questions

1. An object is kept at a distance of 5 cm in front of a convex mirror of focal length 10 cm. Calculate the position and magnification of the image and state its nature.
2. An object is placed at a distance of 10 cm from a convex mirror of focal length 5 cm.
   (*i*) Draw a ray-diagram showing the formation of image.
   (*ii*) State two characteristics of the image formed.
   (*iii*) Calculate the distance of the image from mirror.
3. An object is placed at a distance of 6 cm from a convex mirror of focal length 12 cm. Find the position and nature of the image.
4. An object placed 20 cm in front of a mirror is found to have an image 15 cm (*a*) in front of it, (*b*) behind the mirror. Find the focal length of the mirror and the kind of mirror in each case.
5. An arrow 2.5 cm high is placed at a distance of 25 cm from a diverging mirror of focal length 20 cm. Find the nature, position and size of the image formed.
6. A convex mirror used as a rear-view mirror in a car has a radius of curvature of 3 m. If a bus is located at a distance of 5 m from this mirror, find the position of image. What is the nature of the image ?
7. A diverging mirror of radius of curvature 40 cm forms an image which is half the height of the object. Find the object and image positions.
8. The radius of curvature of a convex mirror used as a rear view mirror in a moving car is 2.0 m. A truck is coming from behind it at a distance of 3.5 m. Calculate (*a*) position, and (*b*) size, of the image relative to the size of the truck. What will be the nature of the image ?

Long Answer Type Question

9. (*a*) Draw a diagram to represent a convex mirror. On this diagram mark principal axis, principal focus F and the centre of curvature C if the focal length of convex mirror is 3 cm.
   (*b*) An object 1 cm tall is placed 30 cm in front of a convex mirror of focal length 20 cm. Find the size and position of the image formed by the convex mirror.

Questions Based on High Order Thinking Skills (HOTS)

10. A shop security mirror 5.0 m from certain items displayed in the shop produces one-tenth magnification.
    (*a*) What is the type of mirror ?
    (*b*) What is the radius of curvature of the mirror ?

11. An object is placed 15 cm from (*a*) a converging mirror, and (*b*) a diverging mirror, of radius of curvature 20 cm. Calculate the image position and magnification in each case.

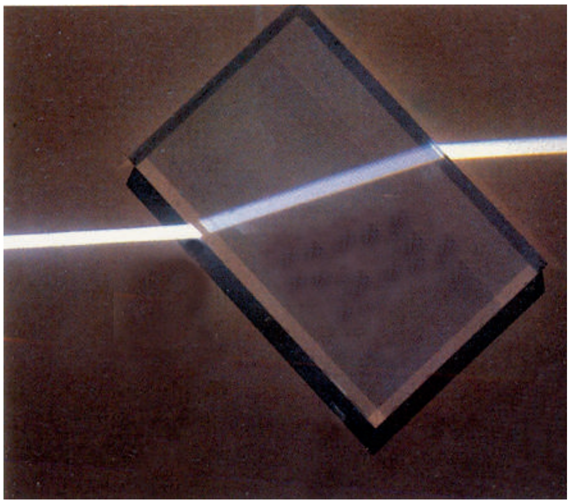
12. An object 20 cm from a spherical mirror gives rise to a virtual image 15 cm behind the mirror. Determine the magnification of the image and the type of mirror used.

ANSWERS

1. 3.3 cm behind the convex mirror ; 0.66 ; Virtual and erect **2.** (*ii*) Virtual and erect ; Diminished (Smaller than the object) (*iii*) 3.3 cm behind the convex mirror **3.** 4 cm behind the mirror ; Virtual and erect **4.** (*a*) Concave mirror of focal length $\frac{60}{7}$ cm (*b*) Convex mirror of focal length 60 cm **5.** v = 11.1 cm ; The image is formed 11.1 cm behind the convex mirror ; Virtual and erect ; 1.1 cm tall **6.** 1.15 m behind the mirror ; Virtual and erect **7.** 20 cm ; 10 cm behind the mirror **8.** (*a*) 0.77 m behind the mirror (*b*) $\frac{1}{4.5}$; Virtual and erect **9.** 0.4 cm ; 12 cm behind the mirror **10.** (*a*) Convex mirror (*b*) $\frac{10}{9}$ m
11. (*a*) v = –30 cm ; The image is formed 30 cm in front of converging mirror ; m = –2 (*b*) v = + 6 cm; The image is formed 6 cm behind the diverging mirror ; m = + 0.4 **12.** m = + 0.75 ; Convex mirror

CHAPTER

5



Refraction of Light

We know that light travels in a straight line path. This is true as long as light rays are travelling in the same medium (or same substance) having the same density throughout. If, however, the light rays are made to go from one medium to another, the light rays change their direction (or bend) at the boundary between the two media. For example, when a ray of light travelling in 'air' goes *obliquely* into another medium 'glass', it changes the direction (or bends) on entering the glass block (see Figure 1). The change in direction of ray of light (or bending of ray of light) occurs again when it goes out from 'glass' into 'air' (see Figure 1). **The change in direction of light when it passes from one medium to another obliquely, is called refraction of light**. In other words, **the bending of light when it goes from one medium to another obliquely is called refraction of light.** The refraction of light takes place when light rays enter from *air* into *glass;* or from *glass* into *air.* The refraction of light takes place when light enters from *air* into *water* ; or from *water* into *air*. And the refraction of light also takes place when light enters from *water* into *glass*; or from *glass* into *water*. The optical instruments like camera, microscope, and telescope work on the refraction of light through glass lenses. We will now understand the refraction of light more clearly with the help of a diagram.

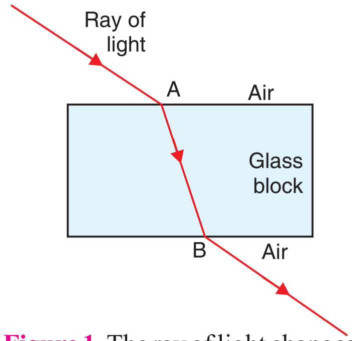


Figure 1. The ray of light changes direction (or refracts) at point *A* when it goes from air into glass. The ray of light changes direction (or refracts) again at point *B* when it goes from glass into air.

Consider a rectangular glass slab *PQRS* shown in Figure 2. Now, here we have two different media, one is air and the other is glass ('media' is the plural of 'medium'). Please note that glass is optically denser medium as compared to air (we will give the meaning of optically denser medium after a while). Now, a ray of light *AO* travelling in air is incident (or falls) obliquely on the glass slab at point *O* (see Figure 2). Since the glass slab is transparent, most of the incident light passes into the glass slab. Since glass is an optically denser medium than air, so when the ray of light *AO* passes from air into glass, its direction changes, it goes along the line *OB* inside the glass slab and we say that the light ray has been refracted (or bent). This is because *AO* and *OB* are not in the same straight line. Please note that **the refraction (or bending) of light takes place at the boundary between the two media.** For example, in Figure 2, the refraction of light (or bending of light) takes place at point *O* at the boundary of the two media : air and glass. We will now define the angle of incidence and the angle of refraction.

In Figure 2, for the light passing from air into glass, *AO* is the incident ray and *OB* is the refracted ray. Let us draw a normal *NON′* at the point of incidence *O*. Now, **the angle between incident ray and normal (at the point of incidence) is called the angle of incidence.** In Figure 2, the angle *AON* is the angle of incidence. The angle of incidence is denoted by the letter *i*. **The angle between the refracted ray and the normal (at the point of incidence) is called the angle of refraction.** In Figure 2, the angle *N′OB* is the angle of refraction. The angle of refraction is denoted by the letter *r*.

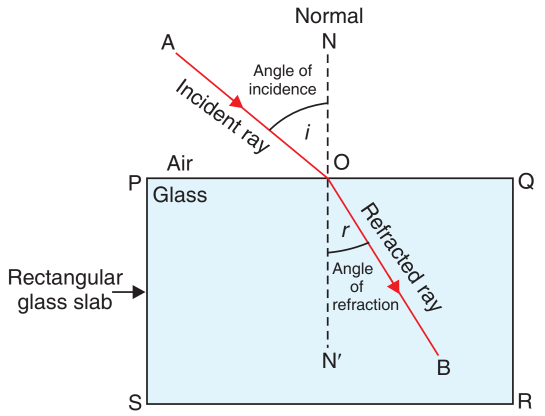


Figure 2. Diagram to show the refraction of light when it passes from air into glass. In this diagram, the light ray going along *AO* in air bends in the direction *OB* on entering the glass.

Please note that though in the reflection of light, the angle of reflection is always equal to the angle of incidence, but **in the refraction of light, the angle of refraction is usually not equal to the angle of incidence.** The angle of refraction is either *smaller* than the angle of incidence or *greater* than the angle of incidence. For example, in Figure 2, the angle of refraction (*r*) is not equal to the angle of incidence (*i*). In this case the angle of refraction (*r*) is smaller than the angle of incidence (*i*). We will give the reasons for this later on in this chapter. At the moment we will discuss why the refraction of light takes place on going from one medium to another.

Cause of Refraction

The speed of light is different in different media (or substances). For example, the speed of light in air is 3×10^8 m/s whereas that in glass is 2×10^8 m/s. It is clear from these values that the speed of light is more in air but less in glass. In other words, light travels faster in air but slower in glass. **The refraction of light is due to the change in the speed of light on going from one medium to another.** Thus, when light goes from one medium to another, its speed changes. And this change in speed of light causes the refraction of light. The refraction of light on going from air to glass takes place because the speed of light is different in air and glass : being more in air and lesser in glass. So, when light enters from air into glass, its speed changes (it gets reduced). And this change in speed of light in going from air to glass causes the refraction of light (or bending of light). Please note that **greater the difference in the speeds of light in the two media, greater will be the amount of refraction (or bending) of light.**

Why a Change in Speed of Light Causes Refraction of Light (or Bending of Light)

The refraction of light or change in direction of light on going from one medium to another can be explained by using the ***wave theory*** of light. A beam of light is made up of tiny waves. When a beam of light consisting of light waves and travelling in a certain medium falls obliquely (at an angle) on the boundary of another medium, then one part of the light waves enters into the other medium first and its speed changes first but the rest of waves enter the other medium a little later and hence its speed changes a little later. **The fact that the speed of light waves on one side of a beam of light changes a little before the change in speed of light waves on its other side, causes a change in the direction of light.** And this change in direction of light is called refraction of light or bending of light. This will become more clear from the following example in which a beam of light is entering from air into a glass slab obliquely and then emerging into air from its other side.

Light waves travel faster in air but slower in glass. Now, when a beam of light consisting of light waves and travelling in air falls on a glass slab obliquely then the part of light waves on the left side of the beam of light reaches the glass slab first (at point *A*) and slows down first on entering the glass slab (see Figure 3). The rest of light waves on the right side of the beam of light are still in air and have to travel more distance in air before reaching the glass slab (at point *B*) and hence slow down a little later on entering the glass slab (see Figure 3). **Since the speed of left side of the beam of light is reduced a little before its**

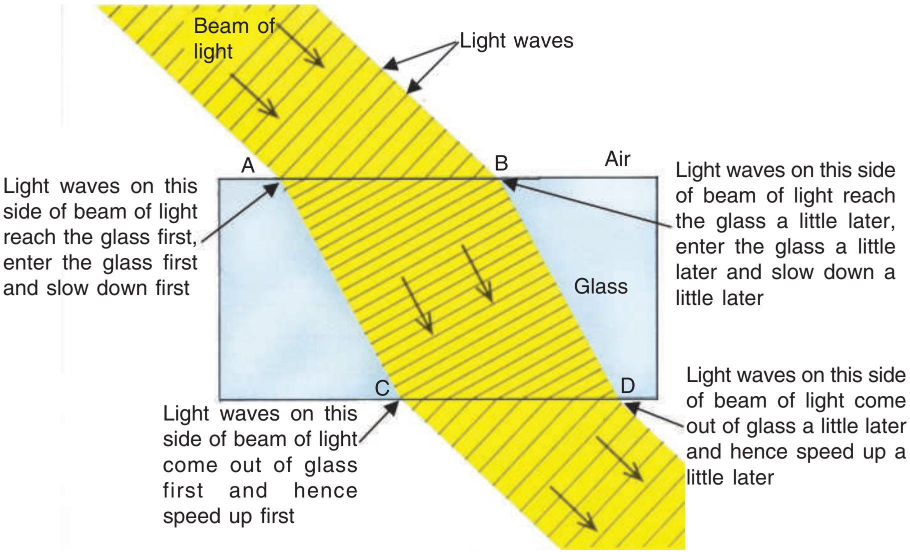


Figure 3. Diagram to explain the refraction of light on going from air into glass; and from glass into air.

right side, therefore, the direction of light changes (or bending of light occurs) on entering the glass slab (see Figure 3). Please note that a decrease in speed of light waves on going from air into glass causes bending of light towards left side (towards the normal) (see Figure 3).

When the beam of light travelling in glass slab comes out into air obliquely (at an angle), then the part of light waves on the left side of beam of light emerges out into air first (at point *C*) and speeds up first (see Figure 3). The part of light waves on the right side of beam of light emerges out into air (at point *D*) a little later and hence its speed increases a little later. **Since the speed of left side of the beam of light increases a little before its right side, therefore, the direction of light changes (or bending of light occurs) on coming out of glass slab into air** (see Figure 3). Please note that an increase in speed of light waves on coming out from glass into air causes bending of light towards the right side (away from the normal) (see Figure 3).

When light waves move from air into glass, their speed decreases and their wavelength also decreases (they become closer). On the other hand, when light waves come out from glass into air, their speed increases and their wavelength also increases (they become farther apart). Before we discuss the refraction of light in detail, we should know the meaning of the terms 'optically rarer medium' and 'optically denser medium'. This is described below.

Optically Rarer Medium and Optically Denser Medium

A transparent substance in which light travels is known as a medium. Air, glass, certain plastics, water, kerosene, alcohol, etc., are all examples of medium. Different media are said to have different optical densities. **A medium in which the speed of light is more is known as optically rarer medium** (or less dense medium). Air is an optically rarer medium as compared to glass and water. **A medium in which the speed of light is less, is known as optically denser medium.** Glass is an optically denser medium than air and water. Now, the speed of light in water is 2.25×10^8 m/s, which is less than that in air but more than that in glass. So, water is optically denser medium than air but it is optically rarer than glass. Please note that the refraction of light takes place whenever it goes from an optically rarer medium to an optically denser medium; or from a denser medium to a rarer medium. The optically rarer medium and optically denser medium can also be defined on the basis of their refractive index. We will learn this after a while. Keeping the above discussion in mind, we can now write down two rules which give the direction of bending of a ray of light when it goes from one medium to another.

It has been found that :

1. **When a ray of light goes from a rarer medium to a denser medium, it bends towards the normal** (at the point of incidence).

2. **When a ray of light goes from a denser medium to a rarer medium, it bends away from the normal** (at the point of incidence).

We will now understand these rules more clearly with the help of ray-diagrams.

Case 1 : Refraction of Light When it Goes From a Rarer Medium to a Denser Medium

Figure 4 shows a ray of light *AO* going from air (a rarer medium) into glass (which is a denser medium). In this case, the incident ray *AO* gets refracted at point *O* and bends towards the normal *ON′* and goes in the direction *OB* inside the glass slab. Thus, **when a ray of light goes from air into glass, it bends towards the normal** (at the point of incidence). In this case, the angle of refraction (*r*) is smaller than the angle of incidence (*i*).

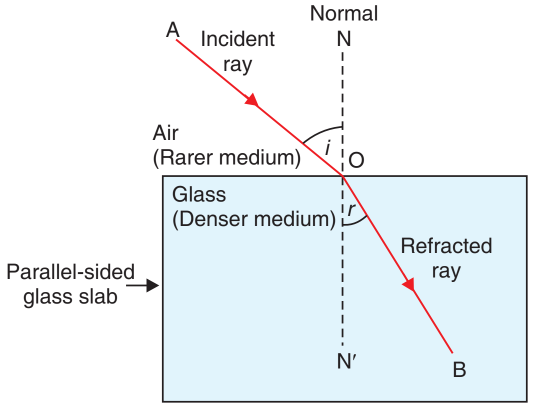


Figure 4.

Water is also an optically denser medium than air, so **when a ray of light goes from air into water, it bends towards the normal.** Thus, the refraction of light on going from air to water is similar to the refraction of light from air to glass (which has been shown in Figure 4). To show the path of a ray of light going from air into water, we can use Figure 4 but we will have to write 'water' in place of 'glass' and in place of glass slab we will have to show water by drawing some dotted lines. Please draw the diagram to show the refraction of a ray of light from air to water yourself.

Case 2 : Refraction of Light When it Goes From a Denser Medium to a Rarer Medium

Figure 5 shows a ray of light *AO* going from glass (a denser medium) into air (which is a rarer medium). In this case, the incident ray *AO* gets refracted at point *O* and bends away from the normal *ON′* in the direction *OB*. Thus, **when a ray of light goes from glass into air, it bends away from the normal** (at the point of incidence). In this case the angle of refraction (*r*) is greater than the angle of incidence (*i*).

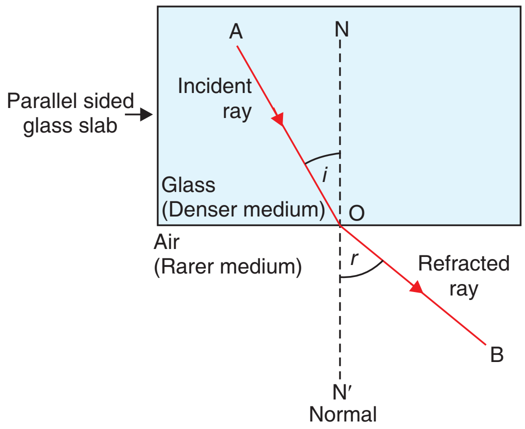


Figure 5.

Please note that water is also optically denser than air, so **when a beam of light travelling in water enters into air, it bends away from the normal.** We can show the refraction of light on going from water into air by using the ray-diagram given in Figure 5. All that we have to do is to write 'water' in place of 'glass' and show water by drawing some dotted lines. Please draw the diagram to show the refraction of a ray of light from water to air yourself. Please note that **a parallel-sided glass slab is also called rectangular glass block.**

When a ray of light goes from a rarer medium to a denser medium, its speed decreases or it slows down. On the other hand, when a ray of light goes from a denser medium to a rarer medium, then its speed increases or it speeds up. So, we can now say that a ray of light travelling from a rarer medium to a denser medium slows down and bends towards the normal but when a ray of light travels from a denser medium to a rarer medium, it speeds up and bends away from the normal.

The Case of Light Going From Air into Glass and Again into Air

We have just studied the refraction of light from air into glass (Figure 4), and from glass into air (Figure 5). We will now show these two types of refraction in the same diagram. In other words, we will now show the complete path of a ray of light when it passes from air into glass slab and again into air. This is shown in Figure 6.

A ray of light *AO* travelling in air is incident on a rectangular glass slab *PQRS* at point *O*. On entering the glass slab, it gets refracted along *OB* and bends towards the normal *ON′* (see Figure 6). A second change of direction takes place when the refracted ray of light *OB*, travelling in glass emerges (or comes out) into air at point *B*. Since the ray of light *OB* now goes from a denser medium 'glass' into the rarer medium 'air', it bends away from the normal BN_1' and goes in the direction *BC*. Please note that the incident ray *AO* and the emergent ray *BC* are parallel to each other (though the emergent ray has been displaced parallel to the incident ray). The incident ray *AO* and emergent ray *BC* are parallel to each other because the extent of bending of the ray of light at points *O* and *B* on the opposite, parallel faces (*PQ* and *SR*) of the rectangular glass slab is equal and opposite. The incident ray *AO* bends towards the normal at point *O* whereas the refracted ray *OB* bends away from the normal at point *B* by an equal amount. Thus, **the light emerges from a parallel-sided glass slab in a direction parallel with that in which it enters the glass slab.** Though the emergent ray *BC* is parallel to the incident ray *AO*, but the emergent ray has been sideways displaced (or laterally displaced) from the original path of the incident ray by a perpendicular distance *CD* (see Figure 6). In Figure 6, the original path of incident light is *AOD* but the emergent light goes along *BC,* the lateral displacement between them being *CD.* **The perpendicular distance between the original path of incident ray and the emergent ray coming out of the glass slab is called lateral displacement of the emergent ray of light**. Lateral displacement depends mainly on three factors : angle of incidence, thickness of glass slab, and refractive index of glass slab. Actually, lateral displacement is directly proportional to (*i*) angle of incidence (*ii*) thickness of glass slab, and (*iii*) refractive index of glass slab. Higher the values of these factors, greater will be the lateral displacement. Another point to be noted is that in this case the refraction (or bending) of light takes place twice : first at point *O* (when light enters from air into glass), and then at point *B* (when light goes out from glass into air).

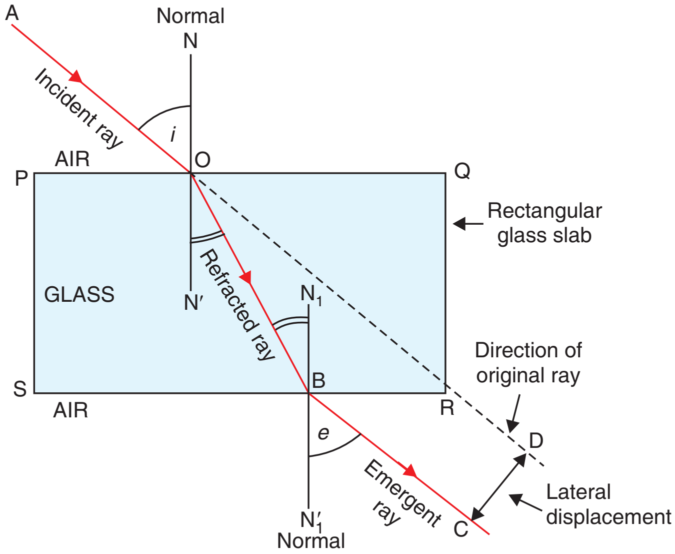


Figure 6.

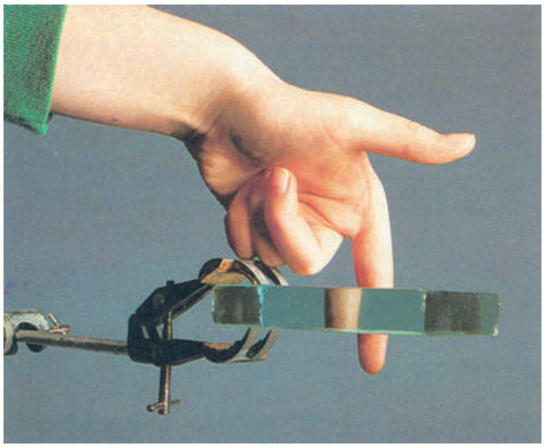


Figure 7. This picture shows the lateral displacement of a finger caused by the refraction of light through a glass slab.

The angle which the emergent ray makes with the normal is called the angle of emergence. In Figure 6, the angle $N_1'BC$ is the angle of emergence. Since the incident ray *AO* and the emergent ray *BC* are parallel to one another, so the angle of emergence (*e*) is equal to the angle of incidence (*i*). Please note that if a beam of light travelling in air passes into water and then emerges into air, we will get a ray-diagram similar to that shown in Figure 6. Draw it yourself by writing 'water' in place of 'glass'.

The Case of Light Falling Normally (or Perpendicularly) on a Glass Slab

In all our discussions so far we have assumed that the incident ray of light falls *obliquely* to the surface of glass slab and bending of ray of light takes place. **If the incident ray falls normally (or perpendicularly) to the surface of a glass slab, then there is no bending of the ray of light, and it goes straight.** For example, in Figure 8, a ray of light *AO* travelling in air falls on a glass slab normally (or perpendicularly) at

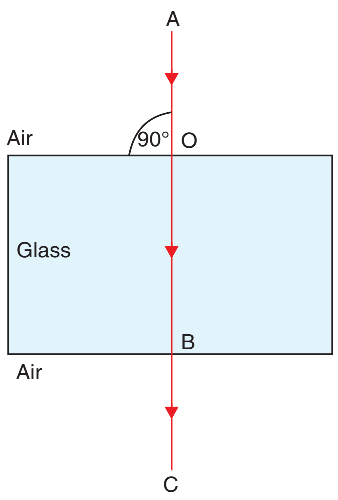


Figure 8.

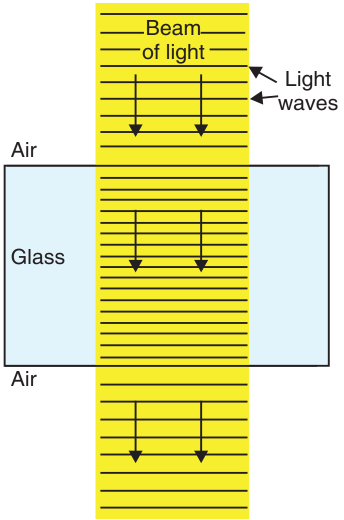


Figure 9.

point *O*, so it does not bend on entering the glass slab or on coming out of the glass slab. It goes straight in the direction *AOBC*. Since the incident ray goes along the normal to the surface, the angle of incidence in this case is zero (0) and the angle of refraction is also zero (0).

We can explain the case of *no refraction* (or *no bending*) of light on going perpendicularly from air to glass as follows : When a beam of light consisting of light waves and travelling in air falls perpendicularly (at right angles) to the surface of glass slab, then all the parts of light waves reach the glass slab at the same time, enter the glass slab at the same time and hence get slowed down at the same time (see Figure 9). Due to this no change in direction of light takes place. In other words, no refraction of light (no bending of light) takes place. Similarly, all the parts of the light waves of the beam of light travelling in glass slab come out of the glass slab into air at the same time and hence speed up at the same time. Due to this, no bending of light occurs when the light waves go out from glass slab into air (see Figure 9).

Please note that if a ray of light falls normally (or perpendicularly) to the surface of water, even then there is no bending of light ray, and it goes straight through water.

EFFECTS OF REFRACTION OF LIGHT

The refraction of light produces many effects which can be easily observed in our day to day life. We will now describe some of the important effects of the refraction of light. It is due to the refraction of light that :

(*i*) a stick (or pencil) held obliquely and partly immersed in water appears to be bent at the water surface.
(*ii*) an object placed under water appears to be raised.
(*iii*) a pool of water appears to be less deep than it actually is.
(*iv*) when a thick glass slab is placed over some printed matter, the letters appear raised when viewed from the top.
(*v*) a lemon kept in water in a glass tumbler appears to be bigger than its actual size, when viewed from the sides.
(*vi*) the stars appear to twinkle on a clear night.

All these effects are produced by the refraction of light (or change in direction of light) when it passes from one medium to another. Let us discuss some of these effects of refraction in detail.

1. A Stick Partly Immersed in Water Appears to be Bent at the Water Surface

When a straight stick is partly immersed in water and held obliquely to the surface, it appears to be bent at the point where it enters water (see Figure 10). This apparent bending of the stick is due to the refraction of light when it passes from water into air. Let us understand it more clearly with the help of a ray-diagram.

Figure 10 shows a straight stick *AO* whose lower portion *BO* is immersed in water. Though the stick is actually straight but on immersing in water, it appears to be bent at point *B*, in the direction *BI* (see Figure 10). This can be explained as follows : A ray of light *OC* coming from the lower end *O* of the stick passes from water into air at point *C* and gets refracted away from normal in the direction *CX* (because it passes from a denser medium water into a rarer medium air). Another ray of light *OD* gets refracted in the direction *DY*. The two refracted rays *CX* and *DY*, when produced backwards, appear to meet at point *I*, nearer to the water surface than point *O* (see Figure 10). Thus, *I* is the virtual image of the end *O* of the stick which is formed by the refraction of light on going from water to air. Thus, an eye at position *E* sees the end *O* of the stick at position *I* which is nearer to the water surface.

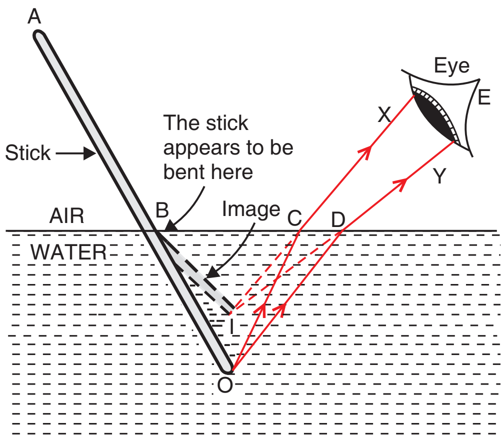


Figure 10. A straight stick *AO* appears bent at point *B* where it enters water.

We can extend this reasoning to all the points which make up part *BO* of the stick under water. Thus, due to the refraction of light, a virtual image of the part *BO* of the stick is formed at *BI*. So, what we see under water is actually the virtual image *BI* of the part *BO* of the stick under water. Since the part *AB* of the stick which is above water and the image *BI* under water are not in the same straight line, the stick *AO* appears to be bent at point B along *BI*. Thus, though the actual stick is *ABO*, it appears to be *ABI*. Please note that it is not the stick that is really bent. It is actually the light passing from water to air that is bent (or refracted) (see Figure 11).

Figure 11. The stick is partly immersed in water. Due to the refraction of light coming from the part of the stick that is under water, the stick appears bent.

Figure 12. The pencil is partly immersed in water. Because of the refraction of light coming from the part of the pencil that is under water, the pencil appears bent.

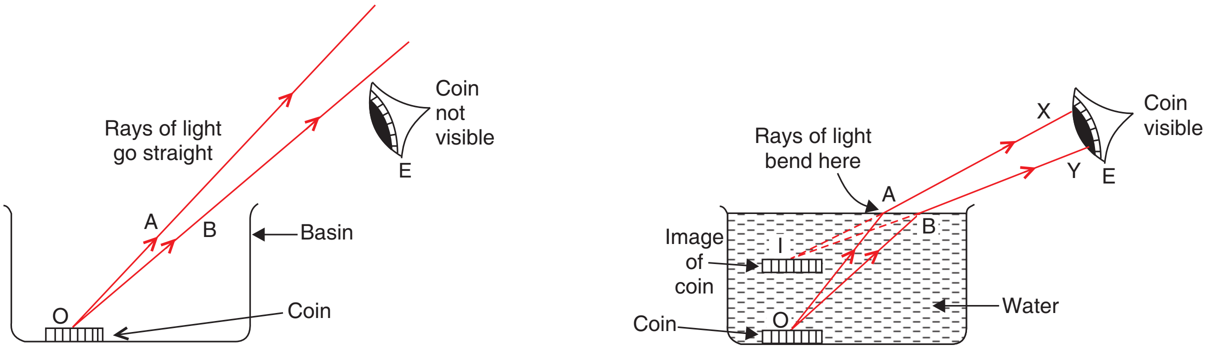
When a pencil is partly immersed in water and held obliquely to the surface, the pencil appears to bend at the water surface (when viewed from the side) (see Figure 12). This apparent bending of the pencil is due to the refraction of light when it passes from water into air. We can use Figure 10 for explaining the bending of pencil in water. Just make a pencil in place of stick.

2. An Object Placed Under Water Appears to be Raised

We will perform an experiment to show that an object placed under water appears to be raised. This can be done as follows : We place a coin at the bottom of an empty basin (a shallow vessel). Let us move our head away from the basin slowly, till the coin disappears from our view and we cannot see it [see

Figure 13(*a*)]. Now, without moving our head, we pour water into the basin. We will find that on adding water, the coin appears to rise and we are able to see it [see Figure 13(*b*)]. The coin under water appears to be raised (and becomes visible) due to the refraction of light which takes place when it goes from water into air. We will now understand all this more clearly with the help of a ray-diagram.

Figure 13(*a*) shows a coin *O* placed in an empty basin (having no water). In this case the rays of light *OA* and *OB* coming from the coin travel in straight line paths in air and do not enter our eye *E* (because the eye is at a lower level). Since the rays of light coming from the coin do not enter our eye, we cannot see the coin from this position of our eye.



(*a*) The coin placed in empty basin is not visible to the eye from this particular position.

(*b*) On adding water in the basin, the coin appears raised and becomes visible to the eye from the same position.

Figure 13.

When the coin is under water, then the rays *OA* and *OB* coming from the coin travel in water in straight line paths until they reach the surface of water. When the rays of light *OA* and *OB* travelling in water, go out into air, they get refracted (they change their directions). The ray of light *OA* gets refracted at point *A*, bends away from the normal, and goes in the direction *AX* [see Figure 13(*b*)]. Similarly, the ray of light *OB* gets refracted at point *B*, bends away from the normal, and goes in the direction *BY*.

If we extend the refracted rays *AX* and *BY* backwards (to the left side), then a virtual image of the coin is formed at point *I*, nearer to the surface of water [see Figure 13(*b*)]. The refracted rays *AX* and *BY*, which appear to be coming from the virtual image of the coin can enter our eye at position *E* due to which the coin becomes visible to us. Thus, **when the coin is under water then due to refraction of light, a virtual image of the coin is formed nearer to the water surface. And since the virtual image of coin which we see, is nearer to the water surface, so the coin appears to rise on adding water in the basin.** Thus, it is due to the refraction of light that a coin placed at the bottom of a container appears to rise as the container is slowly filled with water.

If instead of water, we take some other transparent liquid such as kerosene or turpentine in the above two experiments, then the bending of stick or raising of coin will appear to take place by different amounts than that in water. This is because light is refracted by different amounts in different liquids.

3. A Pool of Water Appears to be Less Deep than it Actually is

If we look into a pool of water (or tank of water), it appears to be less deep than it really is. This is due to the refraction of light which takes place when light rays pass from the pool of water into the air. Let us understand it more clearly with the help of a ray-diagram.

Figure 14 shows a pool of water (or a tank of water). Let us take any point *O* at the bottom of this pool. This point is under the surface of water. Our eye sees this point by the light rays coming from it. Now, a ray of light *OA* coming from the point *O* is travelling in water and it comes out into the air at point *A*. It gets refracted away from the normal in the direction *AX* (see Figure 14.) Similarly, another ray of light *OB*, coming from the point *O* gets refracted at point *B* and goes away from the normal in the direction *BY*. The two refracted rays AX and BY, when produced backwards, meet at point I under water. In fact, when the rays AX and BY enter the eye E, they appear to be coming from point I. So, point I is the virtual image of point O (which is at the bottom of the pool). It is clear from Figure 14 that the image I is nearer to the surface of water than the point O. Thus, a point O at the bottom of a pool appears to be much nearer at position I.

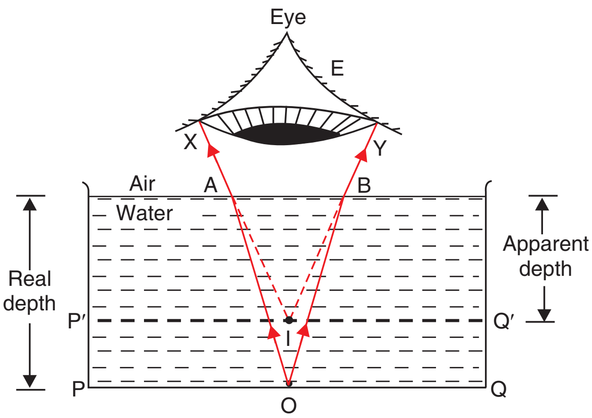


Figure 14. The bottom PQ of the pool of water appears to be raised at $P'Q'$ due to refraction of light. The pool thus appears to be less deep.

This reasoning can be applied to all the points which make up the bottom PQ of the pool, so that due to refraction of light, the bottom PQ of the pool will appear to be much nearer at the position $P'Q'$ (see Figure 14). Due to this, the pool of water will appear less deep than it actually is. Please note that **when we look into a pool of water, we do not see the actual bottom of the pool, we see a virtual image of the bottom of the pool which is formed by the refraction of light coming from the pool water into the air.** And since the image of the bottom of the pool is formed nearer to us, we feel that the pool is less deep. From this discussion we conclude that the bottom of a pool of water appears raised due to refraction of light. And the pool of water appears to be less deep than it actually is. *We should be careful while entering a swimming pool because the water in it will be deeper than it appears to be.*

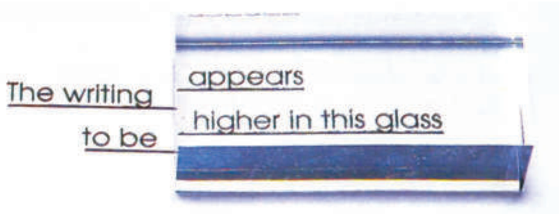


Figure 15. Those words of writing which are below the glass slab appear raised (or higher) due to refraction of light as it comes out of glass slab.

It is also due to the refraction of light that a thick glass slab appears to be less thick (when seen from above), than it actually is. Similarly, an ink mark or the writing on a piece of paper appears to be raised and much nearer than it actually is, when viewed by keeping a glass slab over it (see Figure 15). This also happens due to refraction of light. As we will study in the next Chapter, the stars appear to twinkle on a clear night due to the refraction of light in the atmosphere. Before we go further and discuss the laws of refraction of light, **please answer the following questions :**

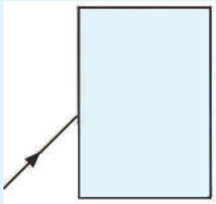
Very Short Answer Type Questions

1. If a ray of light goes from a rarer medium to a denser medium, will it bend towards the normal or away from it ?
2. If a ray of light goes from a denser medium to a rarer medium, will it bend towards the normal or away from the normal ?
3. A beam of light travelling in a rectangular glass slab emerges into air. Draw a ray-diagram indicating the change in its path.
4. A beam of light travelling in air is incident on water. Draw a ray-diagram indicating the change in its path in water.
5. A ray of light travelling in water emerges into air. Draw a ray-diagram indicating the change in its path.
6. A ray of light travelling in air is incident on a parallel-sided glass slab (or rectangular glass slab). Draw a ray-diagram indicating the change in its path in glass.
7. A ray of light travelling in glass emerges into air. State whether it will bend towards the normal or away from the normal.
8. A ray of light travelling in air enters obliquely into water. Does the ray of light bend towards the normal or away from the normal ? Why ?
9. A ray of light goes from water into air. Will it bend towards the normal or away from the normal ?
10. State two effects caused by the refraction of light.
11. Name the phenomenon due to which a swimming pool appears less deep than it really is.
12. When a ray of light passes from air into glass, is the angle of refraction greater than or less than the angle of incidence ?

13. A ray of light passes from air into a block of glass. Does it bend towards the normal or away from it ?
14. As light rays pass from water into glass, are they refracted towards the normal or away from the normal ?
15. In which material do you think light rays travel faster–glass or air ?
16. Which phenomenon of light makes the water to appear shallower than it really is ?
17. State whether the following statement is true or false :
Refraction occurs because light slows down in denser materials.
18. Why does a ray of light bend when it travels from one medium to another ?
19. Fill in the following blanks with suitable words :
(*a*) Light travelling along a normal is ....refracted.
(*b*) Light bends when it passes from water into air. We say that it is..............

Short Answer Type Questions

20. What is meant by 'refraction of light' ? Draw a labelled ray diagram to show the refraction of light.
21. A ray of light travelling in air is incident on a rectangular glass block and emerges out into the air from the opposite face. Draw a labelled ray diagram to show the complete path of this ray of light. Mark the two points where the refraction of light takes place. What can you say about the final direction of ray of light ?
22. Draw a labelled ray diagram to show how a ray of light is refracted when it passes :
(*a*) from air into an optically denser medium.
(*b*) from an optically denser medium into air.
23. The diagram given alongside shows a ray of light entering a rectangular block of glass.
(*a*) Copy the diagram and draw the normal at the point of entry.
(*b*) Draw the approximate path of the ray of light through the glass block and out of the other side.



24. What is meant by the 'angle of incidence' and the 'angle of refraction' for a ray of light ? Draw a labelled ray diagram to show the angle of incidence and the angle of refraction for a refracted ray of light.
25. Light travels more quickly through water than through glass.
(*a*) Which is optically denser : water or glass ?
(*b*) If a ray of light passes from glass into water, which way will it bend : towards the normal or away from the normal ?
26. Draw a labelled ray diagram to show how a ray of light passes through a parallel sided glass block :
(*a*) if it hits the glass block at 90° (that is, perpendicular to the glass block)
(*b*) if it hits the glass block at an angle other than 90° (that is, obliquely to the glass block).
27. When a light ray passes from air into glass, what happens to its speed ? Draw a diagram to show which way the ray of light bends.

Long Answer Type Questions

28. (*a*) Explain why, a stick half immersed in water appears to be bent at the surface. Draw a labelled diagram to illustrate your answer.
(*b*) A coin in a glass tumbler appears to rise as the glass tumbler is slowly filled with water. Name the phenomenon responsible for this effect.
29. (*a*) With the help of a labelled diagram, explain why a tank full of water appears less deep than it actually is.
(*b*) Name the phenomenon due to which a pencil partly immersed in water and held obliquely appears to be bent at the water surface.
30. (*a*) With the help of a diagram, show how when light falls obliquely on the side of a rectangular glass slab, the emergent ray is parallel to the incident ray.
(*b*) Show the lateral displacement of the ray on the diagram.
(*c*) State two factors on which the lateral displacement of the emergent ray depends.
31. Explain with the help of a labelled ray diagram, why a pencil partly immersed in water appears to be bent at the water surface. State whether the bending of pencil will increase or decrease if water is replaced by another liquid which is optically more dense than water. Give reason for your answer.

Multiple Choice Questions (MCQs)

32. Light travelling from a denser medium to a rarer medium along a normal to the boundary :
(*a*) is refracted towards the normal (*b*) is refracted away from the normal
(*c*) goes along the boundary (*d*) is not refracted

33. A ray of light passes from glass into air. The angle of refraction will be :
(*a*) equal to the angle of incidence (*b*) greater than the angle of incidence
(*c*) smaller than the angle of incidence (*d*) 45°

34. A ray of light travelling in air goes into water. The angle of refraction will be :
(*a*) 90° (*b*) smaller than the angle of incidence
(*c*) equal to the angle of incidence (*d*) greater than the angle of incidence

35. The speed of light in air is :
(*a*) 3×10^8 cm/s (*b*) 3×10^8 mm/s
(*c*) 3×10^8 km/s (*d*) 3×10^8 m/s

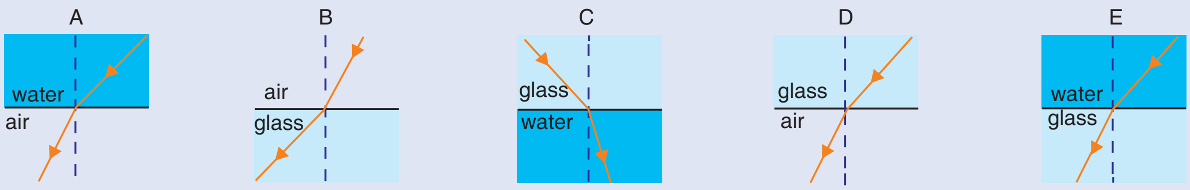
36. When a ray of light travelling in glass enters into water obliquely :
(*a*) it is refracted towards the normal (*b*) it is not refracted at all
(*c*) it goes along the normal (*d*) it is refracted away from the normal

37. A ray of light travelling in water falls at right angles to the boundary of a parallel-sided glass block. The ray of light :
(*a*) is refracted towards the normal (*b*) is refracted away from the normal
(*c*) does not get refracted (*d*) is reflected along the same path.

38. A ray of light passes from a medium *X* to another medium *Y*. No refraction of light occurs if the ray of light hits the boundary of medium *Y* at an angle of :
(*a*) 0° (*b*) 45° (*c*) 90° (*d*) 120°

Questions Based on High Order Thinking Skills (HOTS)

39. Which of the following diagrams shows the ray of light refracted correctly ?



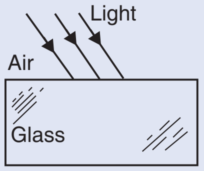
40. A vertical ray of light strikes the horizontal surface of some water :
(*a*) What is the angle of incidence ?
(*b*) What is the angle of refraction ?

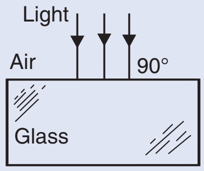
41. How is the reflection of light ray from a plane mirror different from the refraction of light ray as it enters a block of glass ?

42. How does the light have to enter the glass :
(*a*) to produce a large amount of bending ?
(*b*) for no refraction to happen ?

43. (*a*) How can you bend light away from the normal ?
(*b*) How must light travel out of a substance if it is not going to be refracted ?

44. Draw and complete the following diagrams to show what happens to the beams of light as they enter the glass block and then leave it :





45. Why does a beam of light bend when it enters glass at an angle ? Why does it not bend if it enters the glass at right angles ?

ANSWERS

12. Angle of refraction is less than the angle of incidence **17.** True **19.** (*a*) not (*b*) refracted **28.** (*b*) Refraction of light (as it comes out from water into air) **31.** The bending of pencil will increase; The optically denser medium will cause more refraction (or more bending) of light rays **32.** (*d*) **33.** (*b*) **34.** (*b*) **35.** (*d*) **36.** (*d*) **37.** (*c*) **38.** (*c*) **39.** E **40.** (*a*) 0° (*b*) 0° **41.** The angle of reflection is equal to the angle of incidence but the angle of refraction is not equal to the angle of incidence **42.** (*a*) Obliquely ; Making a large angle of incidence (*b*) Perpendicularly (at right angles) to the glass surface **43.** (*a*) Make the light enter from a denser medium to a rarer medium (*b*) At right angles (90°) to the surface of substance.

LAWS OF REFRACTION OF LIGHT

The refraction of light on going from one medium to another takes place according to two laws which are known as the laws of refraction of light. These are given below.

1. According to the first law of refraction of light : **The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane.** For example, in Figure 16, the incident ray *AO*, the refracted ray *OB*, and the normal *ON*, all lie in the same plane (which is the plane of the paper here).

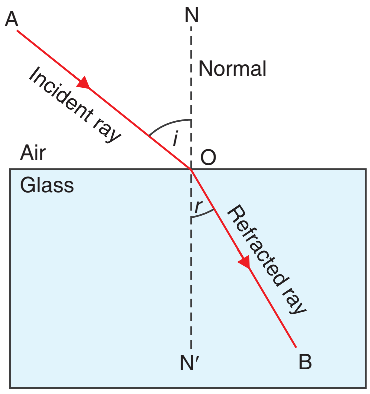


Figure 16.

2. The second law of refraction gives a relationship between the angle of incidence and the angle of refraction. This relationship was discovered by Snell experimentally in 1621, so the second law of refraction is called Snell's law of refraction. According to Snell's law of refraction of light : **The ratio of sine of angle of incidence to the sine of angle of refraction is constant for a given pair of media** (such as 'air and glass' or 'air and water'). That is :

$$\frac{\text{sine of angle of incidence}}{\text{sine of angle of refraction}} = \text{constant}$$

or $$\frac{\sin i}{\sin r} = \text{constant}$$

This constant is called refractive index. We will now discuss the refractive index in somewhat detail.

Suppose a ray of light travelling in air enters into another medium and gets refracted. Let the angle of incidence in air be *i* and the angle of refraction in that medium be *r* (see Figure 16). **The value of the constant $\frac{\sin i}{\sin r}$ for a ray of light passing from air into a particular medium is called the refractive index of that medium.** The refractive index is usually denoted by the symbol *n*. So :

Refractive index, $$n = \frac{\sin i}{\sin r}$$

where $\sin i$ = sine of the angle of incidence (in air)

and $\sin r$ = sine of the angle of refraction (in medium)

Suppose the angle of incidence (*i*) for a ray of light in air is 37° and the angle of refraction (*r*) in glass be 24°. Then :

Refractive index of glass, $$n = \frac{\sin 37°}{\sin 24°}$$

Now, if we look up the sine tables we will find that the value of sin 37° = 0.60 and sin 24° = 0.40. Putting these values in the above relation, we get :

$$n = \frac{0.60}{0.40}$$

$$n = 1.50$$

Thus, the refractive index of this glass is 1.50.

Please note that **since the refractive index is a ratio of two similar quantities (the sines of angles), it has no units**. It is a pure number. The refractive index of a substance does not depend on the angle of incidence. When we talk of refractive index of a substance, say glass, we mean the value of $\frac{\sin i}{\sin r}$ for light passing from air to glass. Strictly speaking, it should mean the value of $\frac{\sin i}{\sin r}$ for light passing from vacuum to glass. But the difference in using air in place of vacuum is so small that it is ignored.

When light rays go from air (or vacuum) into another medium, then they bend (or refract) to some extent. Now, some media bend the light rays more than the others. **The refractive index of a medium gives an indication of the light-bending ability of that medium.** For example, the refractive index of glass is greater than the refractive index of water, therefore, the light rays bend more on passing from air into glass than from air into water. We will now solve one problem based on refractive index.

Sample Problem. A beam of light passes from air into a substance *X*. If the angle of incidence be 72° and the angle of refraction be 40°, calculate the refractive index of substance *X*. (Given : sin 72° = 0.951 and sin 40° = 0.642)

Solution. We know that :

$$\text{Refractive index} = \frac{\text{Sine of angle of incidence}}{\text{Sine of angle of refraction}}$$

or $$n = \frac{\sin i}{\sin r}$$

Here, Angle of incidence, $i = 72°$

And, Angle of refraction, $r = 40°$

So, $$n = \frac{\sin 72°}{\sin 40°}$$

We are given that sin 72° = 0.951 and sin 40° = 0.642. So, putting these values of sin 72° and sin 40° in the above relation, we get :

$$n = \frac{0.951}{0.642}$$

or $$n = 1.48$$

Thus, the refractive index of substance *X* is 1.48.

So far we have denoted the refractive index of a substance just by the letter *n*. In its full form, the refractive index *n* has, however, two subscripts (lower words or letters) which show the two substances or media between which the light travels. For example, the refractive index for light going from *air* into *glass* is written as ${}_{\text{air}}n_{\text{glass}}$ (or ${}_{\text{a}}n_{\text{g}}$ where a = air and g = glass). We will discuss this in more detail after a while.

Refractive Index and Speed of Light

The material (or substance) through which light travels is called medium. Light is refracted (or bent) in going from one medium to another because its speed changes (it slows down or speeds up). Due to this, **the refractive index (*n*) can also be written as a ratio of speeds of light in the two media.**

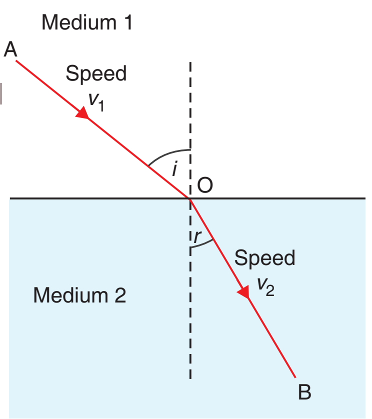


Figure 17.

Look at Figure 17 in which a ray of light *AO* is going from medium 1 to medium 2 as *OB*. The speed of light in medium 2 is different from that in medium 1. Let the speed of light in medium 1 be v_1 and that in medium 2 be v_2. Now, **the refractive index of medium 2 with respect to medium 1 is equal to the ratio of speed of light in medium 1 to the speed of light in medium 2.**

This can be written as :

$$_{\text{medium 1}}n_{\text{medium 2}} = \frac{\text{Speed of light in medium 1}}{\text{Speed of light in medium 2}}$$

or $$_1n_2 = \frac{v_1}{v_2}$$

where $_1n_2$ = Refractive index of medium 2 with respect to medium 1

v_1 = Speed of light in medium 1

and v_2 = Speed of light in medium 2

Please note that the symbol $_{\text{medium 1}}n_{\text{medium 2}}$ or $_1n_2$ means that it is the refractive index of medium 2 with respect to medium 1 (for the light entering from medium 1 into medium 2). We have represented the refractive index of medium 2 with respect to medium 1 by the symbol $_1n_2$. In some books, however, the refractive index of medium 2 with respect to medium 1 is represented by the symbol n_{21} (read as n-two-one and not as n-twenty one). We have not used this notation because we find it a bit confusing.

When light is going from one medium (other than vacuum or air) to another medium, then the value of refractive index is called *relative* refractive index. For example, when the light is going from water into glass, then the value of refractive index will be the relative refractive index of glass with respect to water. The relative refractive index has always 'two subscripts' with its symbol n which indicate the two media in which the light travels. For example, for the light going from water to glass, the refractive index is written as $_{\text{water}}n_{\text{glass}}$ (or $_wn_g$). The symbol $_{\text{water}}n_{\text{glass}}$ means that it is the refractive index of glass with respect to water, that is, it is the refractive index of glass for light entering from water into glass.

When light is going from vacuum to another medium, then the value of refractive index is called the *absolute* refractive index. The absolute refractive index has only one subscript with its symbol n on its right side which indicates the name of the medium (the word vacuum is not written as a subscript). For example, for the light going from vacuum into glass, the absolute refractive index of glass is represented as n_{glass} (and not as $_{\text{vacuum}}n_{\text{glass}}$). The symbol n_{glass} means that it is the refractive index of glass with respect to vacuum, that is, it is the refractive index of glass for light entering from vacuum into glass. Please note that the symbol n_{glass} is also written in short as n_g.

The exact speed of light in vacuum is 2.9979×10^8 m/s and that in air is 2.9970×10^8 m/s. We can see that the speed of light in air is almost the same as that in vacuum, so for the purpose of determining refractive index we can also treat air as if it were vacuum. So, **the refractive index of a medium (or substance) with respect to air is also considered to be its *absolute* refractive index.** Thus, $_{\text{air}}n_{\text{glass}}$ can also be written as n_{glass}. The absolute refractive index of a medium (or substance) is just called its refractive index.

We will now write some simplified formulae for calculating the refractive index from the given values of the speed of light in the two media. These are given below.

The ratio of speed of light in vacuum to the speed of light in a medium, is called the refractive index of that medium. That is :

$$\begin{array}{l}\text{Refractive index}\\\text{(of a medium)}\end{array} = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}}$$

Since the speed of light in air is almost equal to the speed of light in vacuum, so for all practical purposes we can also say that : **The ratio of speed of light in air to the speed of light in a medium, is called refractive index of that medium.** That is :

$$\begin{array}{l}\text{Refractive index}\\\text{(of a medium)}\end{array} = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}}$$

Let us take 'glass' as the medium and write a relation for its refractive index. Now, the speed of light in air is 3×10^8 m/s and the speed of light in common glass is 2×10^8 m/s. So :

$$\text{Refractive index of glass, } n_g = \frac{\text{Speed of light in air (or vacuum)}}{\text{Speed of light in glass}}$$

or $$n_g = \frac{3 \times 10^8}{2 \times 10^8}$$

or $$n_g = \frac{3}{2}$$

or $$n_g = 1.5$$

Thus, the refractive index of this glass is 1.5. **By saying that the refractive index of glass is 1.5 we mean that the ratio of the speed of light in air (or vacuum) to the speed of light in glass is equal to 1.5.** Let us solve one problem now.

Sample Problem. Light enters from air into a glass plate having refractive index 1.50. What is the speed of light in glass ? (The speed of light in vacuum is 3×10^8 m s^{-1}). **(NCERT Book Question)**

Solution. We know that :

$$\text{Refractive index of glass} = \frac{\text{Speed of light in air (or vacuum)}}{\text{Speed of light in glass}}$$

So, $$1.50 = \frac{3 \times 10^8}{\text{Speed of light in glass}}$$

or $$\text{Speed of light in glass} = \frac{3 \times 10^8}{1.50} \text{ m s}^{-1}$$

$$= 2 \times 10^8 \text{ m s}^{-1}$$

Thus, the speed of light in glass is 2×10^8 m s^{-1} (or 2×10^8 m/s).

The refractive index depends on the nature of the material of the medium and on the wavelength (or colour) of the light used. The value of refractive index of a substance is a characteristic property of that substance which can be used to identify it. The refractive indices of some of the common substances are given below (indices is the plural of index). These refractive index values have been obtained by using yellow sodium light of wavelength 589 nm (or 5.89×10^{-7} m).

Refractive Index of Some Common Substances

(with respect to air or vacuum)

Substance (or Medium)	*Refractive index (n)*	*Substance (or Medium)*	*Refractive index (n)*
1. Air	1.0003	8. Benzene	1.50
2. Ice	1.31	9. Crown glass	1.52
3. Water	1.33	10. Carbon disulphide	1.63
4. Alcohol	1.36	11. Dense flint glass	1.65
5. Sulphuric acid	1.43	12. Ruby	1.71
6. Kerosene	1.44	13. Sapphire	1.77
7. Turpentine oil	1.47	14. Diamond	2.42

Please note that different types of glass have different chemical compositions due to which they have somewhat different values of refractive indices. Because of this reason no single value can be given for the refractive index of all types of glass. The refractive index of glass usually varies from 1.5 to 1.9. Another point to be noted is that diamond has a very high refractive index of 2.42.

The construction of lenses of the optical instruments like cameras, microscopes and telescopes, etc., depends on an accurate knowledge of the refractive index of glass used for making lenses. Please note that **if any two media are optically exactly the same, then no bending occurs when light passes from one medium to another**. In other words, if the refractive indices of two media are equal, then there will be no bending of light rays when they pass from one medium to another. The ability of a substance to refract light is also expressed in terms of its optical density. The optical density of a substance (or medium) is the degree to which it retards (or slows down) the rays of light passing through it. **A substance having higher refractive index is optically denser than another substance having lower refractive index.** For example, the refractive index of one type of glass is 1.52 and that of water is 1.33. Since glass has a higher refractive index than water, therefore, glass is optically denser than water, and more bending of light rays takes place in glass than in water. From this we conclude that **higher the refractive index of a substance, more it will change the direction of a beam of light passing through it.**

Figure 18. Diamonds sparkle partly because of their high refractive index. The shape to which they are cut also helps them to sparkle.

Please note that **the optical density of a substance is different from its mass density.** A substance may have a higher optical density than another substance but its mass density may be less. For example, kerosene having a higher refractive index than water is optically denser than water though its mass density is less than that of water. We have been using the terms 'rarer medium' and 'denser medium' in our discussions. It actually means 'optically rarer medium' and 'optically denser medium'.

We will now show that **the refractive index for light going from medium 1 to medium 2 is equal to the reciprocal of the refractive index for light going from medium 2 to medium 1.** Suppose we have two media : medium 1 and medium 2. We can find out the refractive index in two ways : one for the light going from medium 1 to medium 2 (as shown in Figure 19) and the other for light going in the reverse direction, from medium 2 to medium 1 (as shown in Figure 20).

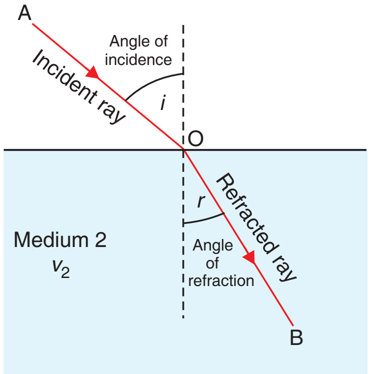


Figure 19. A ray of light going from medium 1 into medium 2

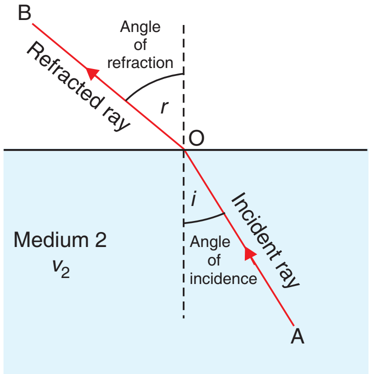


Figure 20. A ray of light going from medium 2 into medium 1

Suppose the speed of light in medium 1 is v_1 and that in medium 2 is v_2. Now :

(*i*) For the light going from medium 1 to medium 2 (Figure 19), the refractive index is given by :

$$_1n_2 = \frac{v_1}{v_2} \qquad ....(1)$$

(*ii*) And for the light going from medium 2 to medium 1 (Figure 20), the refractive index is given by :

$$_2n_1 = \frac{v_2}{v_1}$$

Let us take the reciprocal of this equation. This will give us :

$$\frac{1}{{}_2n_1} = \frac{v_1}{v_2} \qquad ....(2)$$

Now, if we compare equations (1) and (2), we find that their right hand sides are equal, so their left hand sides should also be equal. Thus,

$${}_1n_2 = \frac{1}{{}_2n_1}$$

This can also be written as :

$${}_{\text{medium 1}}n_{\text{medium 2}} = \frac{1}{{}_{\text{medium 2}}n_{\text{medium 1}}}$$

This means that the refractive index for light going from medium 1 to medium 2 is equal to the reciprocal of refractive index for light going from medium 2 to medium 1.

If medium 1 is air and medium 2 is glass, then the above relation can be written as :

$${}_{\text{air}}n_{\text{glass}} = \frac{1}{{}_{\text{glass}}n_{\text{air}}}$$

or

$${}_{\text{a}}n_{\text{g}} = \frac{1}{{}_{\text{g}}n_{\text{a}}}$$

Thus, the refractive index of glass for light going from *air* to *glass* is the reciprocal of the refractive index for light going from *glass* to *air.* Let us solve some problems now.

Sample Problem 1. If the refractive index of water for light going from air to water be 1.33, what will be the refractive index for light going from water to air ?

Solution. Here, $${}_{\text{a}}n_{\text{w}} = 1.33$$

Now, $${}_{\text{w}}n_{\text{a}} = \frac{1}{{}_{\text{a}}n_{\text{w}}}$$

$$= \frac{1}{1.33}$$

$$= 0.75$$

Sample Problem 2. The refractive indices of kerosene, turpentine and water are 1.44, 1.47 and 1.33, respectively. In which of these materials does light travel fastest ? **(NCERT Book Question)**

Solution. We know that :

$$\text{Refractive index} = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}}$$

So, $$\text{Speed of light in medium} = \frac{\text{Speed of light in air}}{\text{Refractive index}}$$

It is obvious from the above relation that the speed of light will be the *maximum* in that medium (or substance) which has the *lowest* refractive index. Now, out of kerosene, turpentine and water, water has the lowest refractive index of 1.33. So, the light will have maximum speed in water or light will travel fastest in water.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. What name is given to the ratio of sine of angle of incidence to the sine of angle of refraction ?
2. Write the relation between the angle of incidence and the angle of refraction for a medium.

3. What is the unit of refractive index ?

4. Which has higher refractive index : water or glass ?

5. Refractive indices of carbon disulphide and ethyl alcohol are 1.63 and 1.36 respectively. Which is optically denser ?

6. The refractive index of diamond is 2.42. What is the meaning of this statement in relation to the speed of light ?

7. If the refractive index for light going from air to diamond be 2.42, what will be the refractive index for light going from diamond to air ?

8. How is the refractive index of a material related to the speed of light in it ?

9. Fill in the following blank with a suitable word :

When a ray of light goes from air into a clear material, you see the ray bend. How much the ray bends is determined by the.............of the material.

Short Answer Type Questions

10. Give three examples of materials that refract light rays. What happens to the speed of light rays when they enter these materials ?

11. Define Snell's law of refraction. A ray of light is incident on a glass slab at an angle of incidence of 60°. If the angle of refraction be 32.7°, calculate the refractive index of glass. (Given : sin 60° = 0.866, and sin 32.7° = 0.540).

12. The speed of light in vacuum and in two different glasses is given in the table below :

Medium	*Speed of light*
Vacuum	3.00×10^8 m/s
Flint glass	1.86×10^8 m/s
Crown glass	1.97×10^8 m/s

(*a*) Calculate the absolute refractive indexes of flint glass and crown glass.

(*b*) Calculate the relative refractive index for light going from crown glass to flint glass.

13. The speed of light in air is 3×10^8 m/s. In medium X its speed is 2×10^8 m/s and in medium Y the speed of light is 2.5×10^8 m/s. Calculate:

(*a*) ${}_{\text{air}}n_X$ (*b*) ${}_{\text{air}}n_Y$ (*c*) ${}_{X}n_Y$

14. What is the speed of light in a medium of refractive index $\frac{6}{5}$ if its speed in air is 3,00,000 km/s ?

15. The refractive index of glass is 1.5. Calculate the speed of light in glass. The speed of light in air is 3.0×10^8 ms^{-1}.

16. The speed of light in water is 2.25×10^8 m/s. If the speed of light in vacuum be 3×10^8 m/s, calculate the refractive index of water.

17. Light enters from air into diamond which has a refractive index of 2.42. Calculate the speed of light in diamond. The speed of light in air is 3.0×10^8 ms^{-1}.

Long Answer Type Question

18. (*a*) State and explain the laws of refraction of light with the help of a labelled diagram.

(*b*) What is meant by the refractive index of a substance ?

(*c*) Light travels through air at 300 million ms^{-1}. On entering water it slows down to 225 million ms^{-1}. Calculate the refractive index of water.

Multiple Choice Questions (MCQs)

19. The refractive indices of four substances *P*, *Q*, *R* and *S* are 1.50, 1.36, 1.77 and 1.31 respectively. The speed of light is the maximum in the substance :

(*a*) *P* (*b*) *Q* (*c*) *R* (*d*) *S*

20. The refractive indices of four materials A, B, C and D are 1.33, 1.43, 1.71 and 1.52 respectively. When the light rays pass from air into these materials, they refract the maximum in :

(*a*) material A (*b*) material B (*c*) material C (*d*) material D

21. The refractive index of glass for light going from air to glass is $\frac{3}{2}$. The refractive index for light going from glass to air will be :

(*a*) $\frac{1}{3}$ (*b*) $\frac{4}{5}$ (*c*) $\frac{4}{6}$ (*d*) $\frac{5}{2}$

22. The refractive indices of four media A, B, C and D are 1.44, 1.52, 1.65 and 1.36 respectively. When light travelling in air is incident in these media at equal angles, the angle of refraction will be the minimum :

(*a*) in medium A (*b*) in medium B (*c*) in medium C (*d*) in medium D

23. The speed of light in substance X is 1.25×10^8 m/s and that in air is 3×10^8 m/s. The refractive index of this substance will be :

(*a*) 2.4 (*b*) 0.4 (*c*) 4.2 (*d*) 3.75

24. The refractive indexes of four substances *P, Q, R* and *S* are 1.77, 1.50, 2.42 and 1.31 respectively. When light travelling in air is incident on these substances at equal angles, the angle of refraction will be the maximum in :

(*a*) substance *P* (*b*) substance *Q* (*c*) substance *R* (*d*) substance *S*

25. The refractive index of water is :

(*a*) 1.33 (*b*) 1.50 (*c*) 2.42 (*d*) 1.36

26. The refractive index of water with respect to air is $\frac{4}{3}$. The refractive index of air with respect to water will be :

(*a*) 1.75 (*b*) 0.50 (*c*) 0.75 (*d*) 0.25

27. Refractive indices of water, sulphuric acid, glass and carbon disulphide are 1.33, 1.43, 1.53 and 1.63 respectively. The light travels slowest in :

(*a*) sulphuric acid (*b*) glass (*c*) water (*d*) carbon disulphide

28. The refractive index of glass with respect to air is $\frac{3}{2}$ and the refractive index of water with respect to air is $\frac{4}{3}$. The refractive index of glass with respect to water will be :

(*a*) 1.525 (*b*) 1.225 (*c*) 1.425 (*d*) 1.125

Questions Based on High Order Thinking Skills (HOTS)

29. The following table gives the refractive indices of a few media :

	1	2	3	4	5
Medium :	Water	Crown glass	Rock salt	Ruby	Diamond
Refractive index :	1.33	1.52	1.54	1.71	2.42

Use this table to give an example of :

(*i*) a medium pair so that light speeds up when it goes from one of these medium to another.

(*ii*) a medium pair so that light slows down when it goes from one of these medium to another.

30. Refractive indices of four media A, B, C and D are given below :

Medium	*Refractive index*
A	1.33
B	1.44
C	1.52
D	1.65

In which of these four media is the speed of light (*i*) maximum, and (*ii*) minimum ?

ANSWERS

7. 0.41 **9.** refractive index **11.** 1.60 **12.** (*a*) Flint glass : 1.61 ; Crown glass : 1.52 (*b*) 1.059 **13.** (*a*) 1.5 (*b*) 1.2 (*c*) 0.8 **14.** 2,50,000 km/s **15.** 2.0×10^8 ms^{-1} **16.** 1.33 **17.** 1.24×10^8 ms^{-1} **18.** (*c*) 1.33 **19.** (*d*) **20.** (*c*) **21.** (*c*) **22.** (*c*) **23.** (*a*) **24.** (*d*) **25.** (*a*) **26.** (*c*) **27.** (*d*) **28.** (*d*) **29.** (*i*) Crown glass to Water (*ii*) Water to Diamond **30.** (*i*) A (*ii*) D

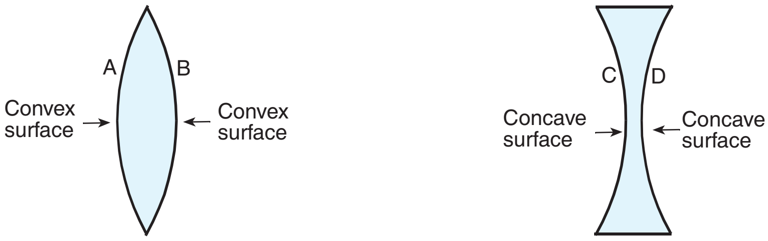
REFRACTION OF LIGHT BY SPHERICAL LENSES

We have all seen a palmist using a lens (called magnifying glass) for seeing the details of the lines of a person's palm. A watch maker also uses a lens to see the extremely small parts of a watch clearly. In fact, lenses play a very important role in our everyday life. Lenses are used in making spectacles, cameras, microscopes, telescopes, film projectors, and many, many other optical instruments. We have already studied that the working of a mirror is based on the reflection of light rays from its surface. **The working of a lens is based on the refraction of light rays when they pass through it.** We will now study the formation of images by lenses in detail. Before we do that, we should know the various types of spherical lenses and the terms like optical centre, principal axis, principal focus (or just focus), and focal length, etc., which are used in the study of refraction of light by lenses. These are discussed below.

Figure 21. This is a microscope. Lenses are used in making microscopes.

A lens is a piece of transparent glass bound by two spherical surfaces. There are two types of lenses : Convex lens and Concave lens.

(*i*) A convex lens is thick at the centre but thinner at the edges. Figure 22(*a*) shows a convex lens in which the two surfaces *A* and *B* are convex or bulging out at the centre.



(*a*) Convex lens (*b*) Concave lens

Figure 22.

(*ii*) A concave lens is thin in the middle but thicker at the edges. Figure 22(*b*) shows a concave lens in which the two surfaces *C* and *D* are concave or bent inward.

(*a*) Convex lens (*b*) Concave lens

Figure 23. Front view of spherical lenses.

Figure 22(*a*) shows the side view of a convex lens. When we look at a convex lens from the front side, it looks like a piece of transparent spherical glass (round glass) having a bulge in the middle [see Figure 23(*a*)]. We can feel the bulge in the middle of the convex lens by touching it. Similarly, Figure 22(*b*) shows the side view of a concave lens. When we look at a concave lens from the front side, it looks like a piece of transparent spherical glass (round glass) having a 'depression' in the middle [see Figure 23(*b*)]. We can feel the depression in the middle of a concave lens by touching it. Please note that the lenses (convex lens and concave lens) work on the refraction of light through them.

Optical Centre and Principal Axis of a Lens

The centre point of a lens is known as its optical centre. The optical centre of a lens is usually denoted by the letter *C*. In Figure 24, *C* is the optical centre of the convex lens. The optical centre of a lens has a property that a ray of light passing through it does not suffer any deviation and goes straight. The optical centre of a lens is sometimes also denoted by the letter *O*.

The principal axis of a lens is a line passing through the optical centre of the lens and perpendicular

to both the faces of the lens. In Figure 24, the line *F′F* is the principal axis of the convex lens and it passes through the optical centre *C*.

Principal Focus and Focal Length of a Convex Lens

Suppose a parallel beam of light rays falls on a convex lens as shown in Figure 24. These light rays are parallel to one another and also parallel to the axis of the lens. The incident rays pass through the convex lens and get refracted (or bent) according to the laws of refraction. All the rays, after passing through the convex lens, converge at the same point *F* on the other side (right side) of the lens. The point *F* is called principal focus (or just focus) of the convex lens. We can now say that : **The principal focus of a convex lens is a point on its principal axis to which light rays parallel to the principal axis converge after passing through the lens.** In Figure 24, point *F* is the principal focus for the light rays coming from the left side. If the incident light rays fall on the convex lens from the right hand side, they will converge to a point *F′* on the left side of the lens. Thus, *F′* is the second focus of the convex lens. From this discussion we conclude that **a lens has two foci. The two foci of a lens are at equal distances from the optical centre, one on either side of the lens** (The word *'foci'* is the plural form of *'focus'*). The two foci of a lens are usually denoted by the letters *F* and *F′*. Since all the light rays actually pass through the focus of a convex lens, therefore, **a convex lens has real focus.**

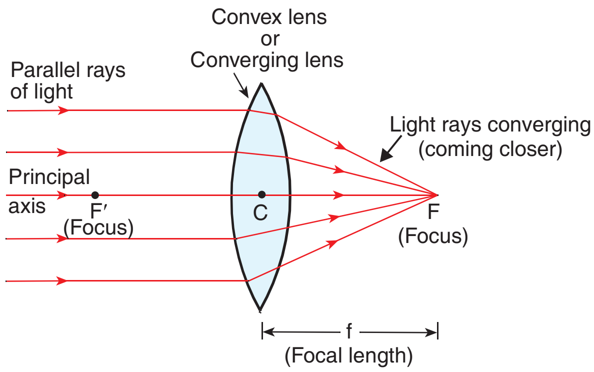


Figure 24. A convex lens converges (brings closer) a parallel beam of light rays to a point *F* on its other side (right side).

We are now in a position to define the focal length of a lens. **The focal length of a lens is the distance between optical centre and principal focus of the lens.** In Figure 24, the distance *CF* is the focal length of the convex lens. It should be noted that the distance *CF′* is also equal to the focal length of the lens. The focal length of a lens is denoted by the letter *f*. The focal length of a lens depends on the refractive index of the glass from which it is made, and the curvature of its two surfaces. Higher the refractive index, shorter will be the focal length. Similarly, more the curvature, shorter is the focal length.

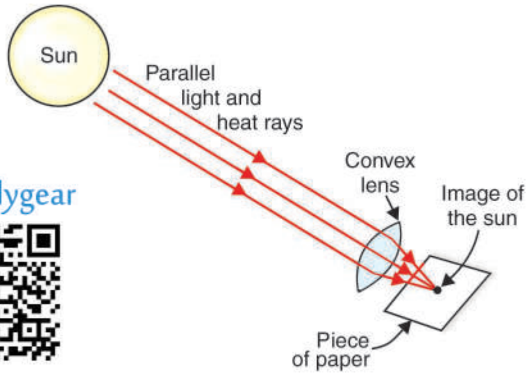


Figure 25. A convex lens forms a real image of the sun on a piece of paper.

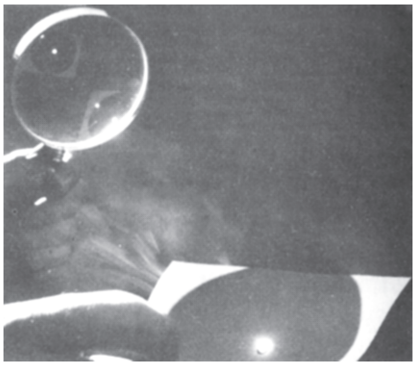


Figure 26. A picture showing the formation of image of the sun by a convex lens.

A convex lens is also known as a converging lens because it converges (brings to a point), a parallel beam of light rays passing through it (see Figure 24)**.** The fact that a convex lens converges (or focusses) parallel rays of light to a single point can be shown as follows : Place a piece of paper on the ground in bright sunshine (see Figure 25). Hold a convex lens some distance above the piece of paper in such a way that a sharp image of the sun is formed on the piece of paper. Here the convex lens is converging the parallel rays of sunlight due to which the sun's rays get concentrated on a small part of the paper (where image is formed). The heat energy of focussed sunlight rays burns a hole in the piece of paper (where sun's image is formed). Please note that we should never look at the sun through a convex lens. It can damage our eyes permanently by focussing a lot of sunlight energy into our eyes.

Principal Focus and Focal Length of a Concave Lens

We have just studied that **a convex lens converges a parallel beam of light rays.** A concave lens has just the opposite effect on such rays of light. **A concave lens diverges a parallel beam of light rays.** The action of a concave lens on a parallel beam of light rays is shown in Figure 27. When a parallel beam of light rays falls on a concave lens, the rays will spread out (or diverge) after passing through the lens. Since the refracted rays are diverging away from one another, they do not actually meet at a point. The diverging rays when produced backwards (as shown by dotted lines in Figure 27) appear to meet at a point *F* on the left side of the lens. To a person on the right hand side, the refracted rays appear to be diverging (or coming) from a point *F* on the principal axis of the concave lens. This point is the principal focus of the concave lens. Thus, **the principal focus of a concave lens is a point on its principal axis from which light rays, originally parallel to the axis, appear to diverge after passing through the concave lens.** In Figure 27, the parallel rays of light appear to be diverging from point *F* after refraction. So, *F* is the principal focus of the concave lens for the light rays coming from the left side. Like a convex lens, a concave lens also has two foci, one on each side of the concave lens. For example, if the parallel rays fall on the concave lens from the right side, then they will appear to diverge from a point *F′*. Thus, *F′* is the second focus of the concave lens. **A concave lens is also known as a diverging lens because it diverges a parallel beam of light rays** (see Figure 27). Since the light rays do not actually pass through the focus of a concave lens, **a concave lens has a virtual focus.** In Figure 27, the distance *CF* is the focal length of concave lens. The distance *CF′* is also equal to the focal length.

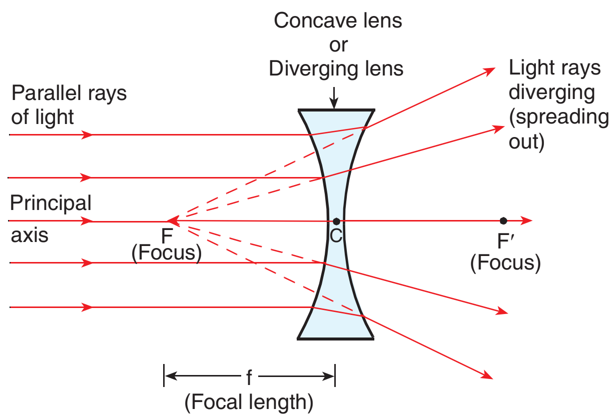


Figure 27. A concave lens diverges (spreads out) a parallel beam of light rays.

A yet another term which is used in the study of spherical lenses is 'aperture'. The aperture of a spherical lens (convex lens or concave lens) is the surface from which refraction of light takes place through the lens. The aperture of spherical lens is represented by its diameter. In most simple words, aperture tells us the size of the lens.

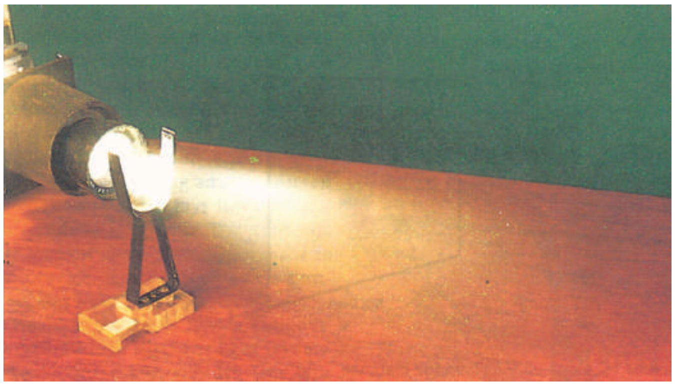


Figure 28. This picture shows that light diverges (or spreads) after passing through a concave lens.

Rules for Obtaining Images Formed by Convex Lenses

When an object is placed in front of a convex lens, an image is formed. **The image is formed at that point where at least two refracted light rays meet (or appear to meet).** To find out the position and nature of the image formed by a convex lens, we will use only those two rays of light (coming from the top of the object) whose paths after refraction from the lens are known to us and easy to draw (the bottom of the object is always assumed to be on the principal axis of the lens). Any two of the following rays of light are usually used to locate the images formed by convex lenses. We call them rules for obtaining images in convex lenses.

Rule 1. **A ray of light which is parallel to the principal axis of a convex lens, passes through its focus after refraction through the lens.** This is shown in Figure 29. Here we have a convex lens *L* and its principal axis is $X'Y'$. Now, a ray of light *AD* (coming from an object) is parallel to the principal axis of the convex lens. It enters the convex lens and gets refracted (or bends) at point *D* inside it. After refraction its path changes, it passes through focus *F* and goes in the direction *DX* (see Figure 29).

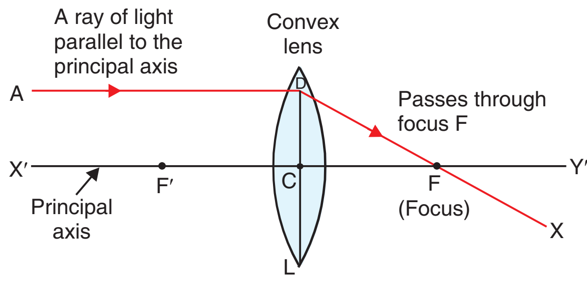


Figure 29.

Rule 2. **A ray of light passing through the optical centre of a convex lens goes straight after refraction through the lens.** It does not get deviated (or bent). This is shown in Figure 30. A ray of light *AC* is passing through the optical centre *C* of a convex lens. It goes straight in the direction *CY* after passing through the lens. It does not get deviated (or bent) from its original path (see Figure 30). Please note that a ray of light going along the principal axis of a convex lens also passes straight through the lens without any deviation. In Figure 30, the principal axis of the convex lens is $X'Y'$. So, a ray of light going along the principal axis $X'Y'$ of this convex lens will also go straight (without bending). We should keep this point in mind because in drawing ray-diagrams, an object is always placed above the principal axis of a lens so that a ray of light coming from its bottom always goes straight through the lens (along the principal axis).

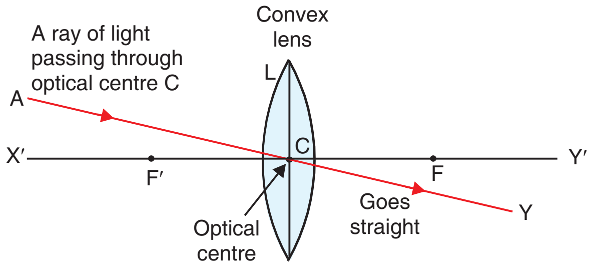


Figure 30.

Rule 3. **A ray of light passing through the focus of a convex lens becomes parallel to its principal axis after refraction through the lens.** This rule is just the reverse case of the first rule and it is shown in Figure 31. Here a ray of light *AD* (coming from the object) is passing through the focus F' of the convex lens. It enters the convex lens and gets refracted (or bends) at point *D* inside it. After passing through the convex lens, it becomes parallel to the principal axis of the lens and goes in the direction *DX* (see Figure 31).

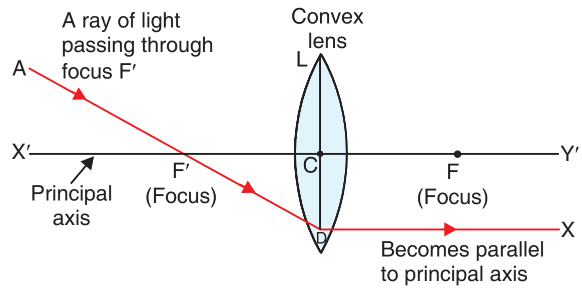


Figure 31.

Please note that in this case the ray of light has to pass through the second focus F' of the convex lens which lies on its left side.

We should remember the paths of the three rays of light described above because these will be used to construct ray-diagrams for finding the position and nature of images formed by convex lenses. At any given time, we will use only two of the above three types of light rays to find the position of image formed by a convex lens. We will now discuss the various positions at which an object can be placed in front of a convex lens to form images.

FORMATION OF DIFFERENT TYPES OF IMAGES BY A CONVEX LENS

The type of image formed by a convex lens depends on the position of the object in front of the lens. We can place the object at different positions (or distances) from a convex lens to get different types of images. We can place the object :

(*i*) between the optical centre (*C*) and focus (F') (see Figure 32)
(*ii*) at the focus (F')
(*iii*) between F' and $2F'$
(*iv*) at $2F'$
(*v*) beyond $2F'$, and
(*vi*) at infinity.

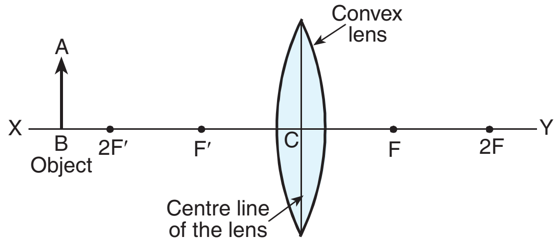


Figure 32.

We will consider all these six positions one by one.

Case 1. Image formed by a convex lens when the object is placed between optical centre and focus (Object between C and F′)

In Figure 33 we have a convex lens with optical centre C and two foci F and F'. The object AB has been placed between the optical centre C and focus F' so that it is at a distance less than the focal length f of the convex lens. In other words, the object AB is within the focus of the convex lens. A ray of light AD starting from the top of the object and parallel to the axis, passes through the other focus F after refraction through the lens and goes in the direction DX. Another ray of light AC passing through the optical centre C of the lens goes straight in the direction CY. The two refracted rays DX and CY diverge away from one another and, therefore, they cannot meet at a point on the right side to form a real image. We produce the refracted rays DX and CY backwards (to the left side) by dotted lines. They appear to meet at point A' on the left side. Thus, A' is the virtual image of point A of the object. To get the complete image of the object, we draw $A'B'$ perpendicular to the axis from point A'. Thus, $A'B'$ is the complete image of object AB. When our eye looks into the lens from the right side, it appears as if the light rays are coming from A' and B' instead of A and B. Thus, $A'B'$ is the virtual image. It is erect, larger than the object and can be seen only by looking through the lens. It is formed on the same side of the lens as the object. From the above discussion we conclude that **when the object is placed within the focus of a convex lens, the image formed is :**

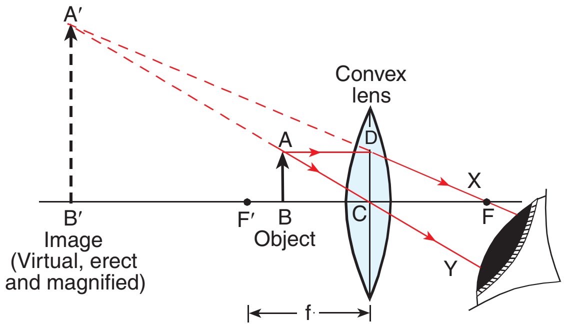


Figure 33. Formation of image by a convex lens when the object is placed between its optical centre (C) and focus (F').

(*i*) **behind the object (on the left side of lens),**
(*ii*) **virtual and erect,** and
(*iii*) **larger than the object (enlarged or magnified).**

Figure 33 explains the use of a convex lens as a magnifying glass (or simple microscope). It should be noted that to use a convex lens as a magnifying glass, the object to be viewed should be placed within its focus, so that a magnified and erect image of the object is obtained. That is, the object should be placed at a distance less than the focal length of the convex lens. For example, if the focal length of a convex lens is 5 centimetres, then the object to be magnified with it should be kept at a distance of less than 5 centimetres from this convex lens. So, if we look at a comb through this convex lens (by keeping the comb within 5 centimetres from it), then the part of comb seen through the convex lens appears much bigger in size than it actually is (see Figure 34). We actually see the magnified image of the comb through the convex lens. Figure 35 shows a convex lens being used as a magnifying glass to read the small print of a book.

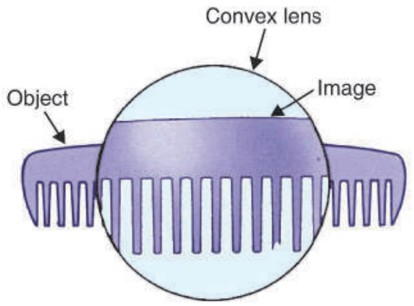


Figure 34. A convex lens is producing a magnified image of the middle part of the comb.

Figure 35. A convex lens being used as a magnifying glass to read the small print of a book.

Please note that **smaller the focal length of a convex lens, greater will be its magnifying power.** So, we should use a convex lens of short focal length as a magnifying glass. It will produce large magnification and hence the object will appear much bigger when seen through it. For example, a convex lens of 5 cm focal length will have a greater magnifying power than a convex lens of 50 cm focal length. So, we should use the convex lens having a shorter focal length of 5 cm as the magnifying glass. Thus, if we are given two convex lenses of focal lengths 5 cm and 50 cm respectively, then we should prefer to use the convex lens having 5 cm focal length as a magnifying glass (to see small things or read small letters of a dictionary).

Case 2. When the object is placed at the focus of a convex lens (Object at F′)

By saying that the object is at the focus of a convex lens, we mean that the object is at a distance equal to the focal length *f* of the lens. Figure 36 shows an object *AB* placed at the focus *F′* of a convex lens. A parallel ray of light *AD* passes through the focus *F* after refraction and goes along the path *DX*. Another ray *AC* passing through the centre *C* of the lens goes straight in the direction *CY*. The two refracted rays *DX* and *CY* are parallel to one another. These parallel rays will intersect (or meet) at a far off distance to form an image 'at infinity'. And since the image is formed at infinity, it is not possible to show it in our diagram. It will be real and inverted, and highly magnified or highly enlarged. From this discussion we conclude that **when an object is placed at the focus of a convex lens, the image formed is :**

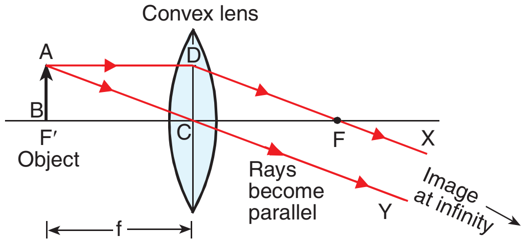


Figure 36. Formation of image by a convex lens when the object is placed at its focus (*F′*)

(*i*) **at infinity,**
(*ii*) **real and inverted,** and
(*iii*) **highly enlarged.**

Suppose we have a convex lens of focal length 5 cm, then its focus (*F′*) will be at a distance of 5 cm from it. So, by saying that the object is placed at the focus of this convex lens, we mean that the object is placed at a distance of 5 cm from the convex lens on its left side. In this case the convex lens converts the diverging rays of light coming from the object into a parallel beam of light rays which form an image at infinity (or very large distance).

Case 3. When the object is between F′ and 2F′ (Object between f and 2f)

By saying that the object is between *F′* and 2*F′*, we mean that the object is at a distance greater than focal length *f* but less than twice the focal length 2*f*. So, whether we say that the object is between *F′* and 2*F′* or between *f* and 2*f*, it means the same thing. Figure 37 shows an object *AB* placed between *F′* and 2*F′* of a convex lens. A ray of light *AD* which is parallel to the principal axis passes through the focus *F* after refraction and goes in the direction *DF* (see Figure 37). Another ray of light *AC* passing through the centre *C* of the lens goes straight and meets the first refracted ray at point *A′* on the right side of the lens. Thus, *A′* is the real image of point *A* of the object. Draw *A′B′* perpendicular to the axis to get the complete image *A′B′*. If we place a screen at *B′*, we can receive the image *A′B′* on the screen. It should be noted that the image is larger than the object (or magnified) and it is formed beyond 2*F* on the right side of the convex lens. From this discussion we conclude that **when an object is placed between *F′* and 2*F′* in front of a convex lens, the image formed is :**

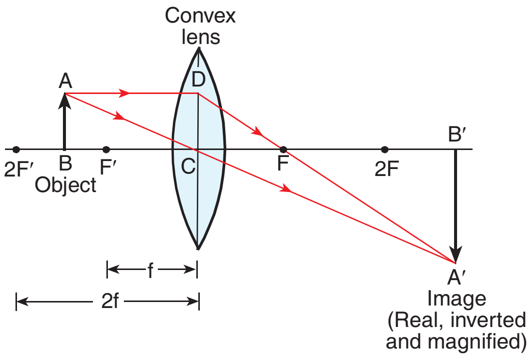


Figure 37. Formation of image by a convex lens when the object is placed between F′ and 2F′ (or between *f* and 2*f*)

(*i*) **beyond 2*F*,**
(*ii*) **real and inverted,** and
(*iii*) **larger than the object (or magnified).**

Figure 37 shows how a convex lens is used as a projection lens for the purpose of projecting a magnified real image of a slide (or a film) on a screen. The slide (or film) is kept between F' and $2F'$ of a convex lens and illuminated by a source of light (such as an electric lamp). A magnified image of the picture on the slide (or film) is produced on a screen placed on the other side of the convex lens.

Suppose we have a convex lens of 5 cm focal length, then its focus (F') will be at a distance of 5 cm from it. So, by saying that the object is between F' and $2F'$ from this convex lens, we will mean that the object is between 5 cm and $2 \times 5 = 10$ cm from the convex lens on its left side. And by saying that the image is formed beyond $2F$ on the other side, we mean that the image is formed at a distance of more than 10 cm from convex lens on its right side.

Case 4. When the object is at 2F′ (Object at 2f)

By saying that the object is placed at $2F'$, we mean that the object is at a distance equal to twice the focal length of the convex lens. In other words, the object is placed at a distance $2f$ from the convex lens. Figure 38 shows an object AB placed at a distance $2f$ (twice the focal length), from a convex lens. A ray of light AD which is parallel to the principal axis passes through the focus F after refraction and goes in the direction DF (see Figure 38). Another ray of light AC passing through the optical centre C of the lens, goes straight and meets the first refracted ray at point A', on the right side of the lens. Thus, A' is the real image of point A of the object. We draw $A'B'$ perpendicular to the axis to get the complete image $A'B'$. We find that the image $A'B'$ is formed at $2F$, at a distance $2f$ on the right side of the convex lens. So, in this case, the object and its image are at equal distance ($2f$ each) from the convex lens, but they are on opposite sides of the lens. Thus, **when an object is placed at a distance $2f$ in front of a convex lens, then the image formed is :**

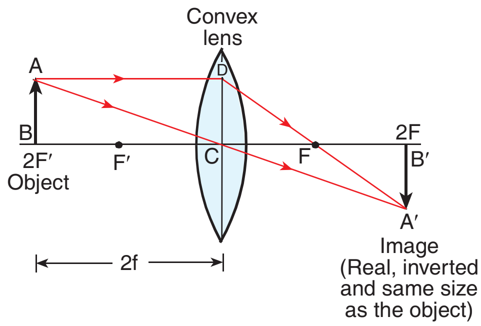


Figure 38. Formation of image by a convex lens when the object is placed at $2F'$ (at a distance $2f$ from the lens).

(*i*) **at a distance $2f$ on the other side of the lens,**
(*ii*) **real and inverted,** and
(*iii*) **of the same size as the object.**

Suppose we have a convex lens of focal length 5 cm, then its focus (F') will be at a distance of 5 cm from it. So, by saying that the object is at $2F'$ of this convex lens, we will mean that the object is at a distance of $2 \times 5 = 10$ cm from this convex lens on its left side. And by saying that the image is formed at $2F$ on the other side, we will mean that the image is formed at a distance of $2 \times 5 = 10$ cm from the convex lens on its right side.

Case 5. When the object is beyond 2F′ (Object beyond 2f)

Figure 39 shows an object AB placed beyond $2f$ in front of a convex lens. To construct the ray diagram, we first take a ray of light AD parallel to the principal axis. After refraction, it will pass through focus F and go in the direction DF. A second ray of light AC, passing through the optical centre C will go straight in the direction CA'. The two refracted rays meet at point A', so A' is the real image of point A of the object. To get the complete image, we draw $A'B'$ perpendicular to the axis. Thus, $A'B'$ is the complete image of the object AB. And it is formed between f and $2f$ on the other side of the lens. The image is real, inverted and smaller than the object. From the above discussion we conclude that **when an object is placed beyond $2f$ in front of a convex lens, then the image formed is :**

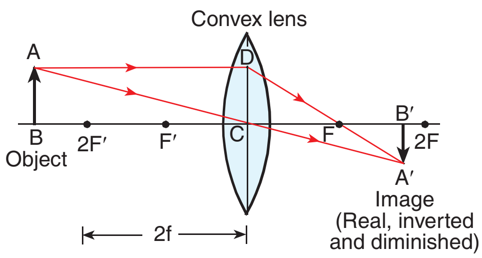


Figure 39. Formation of image by a convex lens when the object is placed beyond $2F'$ (at a distance more than $2f$).

(*i*) **between f and $2f$ on the other side of the lens,**
(*ii*) **real and inverted,** and

(*iii*) smaller than the object (or diminished).

Figure 39 shows the action of a simple camera lens in producing a small, real and inverted image of an object on the film. A simple camera has a convex lens in it. The object to be photographed is at a distance of more than twice the focal length of the convex lens. The convex lens forms a real, inverted and small image (diminished image) of the object on the film.

Suppose we have a convex lens of focal length 5 cm. Then its focus (F') will be at a distance of 5 cm on its left side, and its $2F'$ will be at a distance of $2 \times 5 = 10$ cm on the left side. So, by saying that the object is beyond $2F'$ of this convex lens, we will mean that the object is beyond 10 cm from convex lens on the left side. And by saying that the image is formed between F and $2F$ on the other side, we will mean that the image is formed at a distance between 5 cm and 10 cm from the convex lens on the right hand side of the lens. Figure 40 shows an actual picture of the formation of a real, inverted and diminished image by a convex lens of the filament of a lighted bulb on a screen.

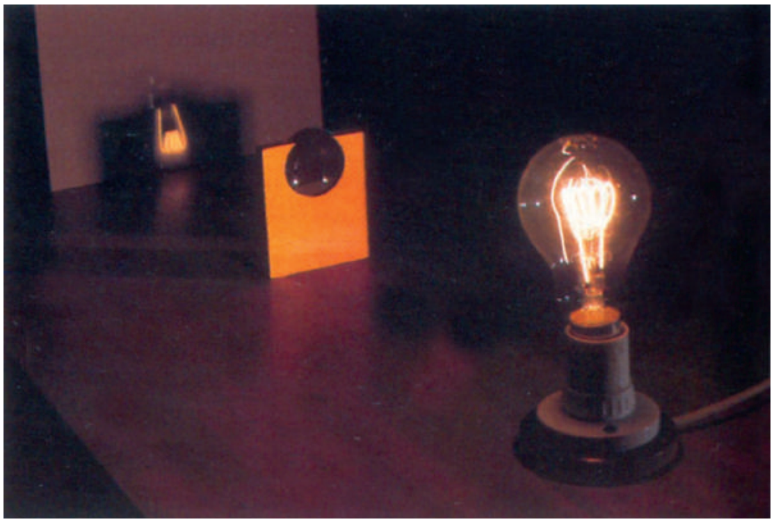


Figure 40. This picture shows a convex lens forming a real, inverted and diminished image of the filament of a light bulb. The bulb is placed at a distance more than twice the focal length from the convex lens.

Case 6. When the object is at infinity

When the object is at a considerable distance, we say that the object is at infinity. Suppose an object AB (in the form of an arrow pointing upwards) is at a considerable distance from a convex lens. Since the object is very far off from the lens, it has not been shown in Figure 41. Now, when the object is at infinity, then all the rays from a given point of the object, which are diverging in the beginning, become parallel to one another when they reach the lens after travelling a long distance. So, in Figure 41, we have two rays AD and AC coming from the same point A of the object. The incident rays AD and AC are parallel to one another but at an angle to the principal axis. The incident ray AD gets refracted along DX. The second ray AC passing through the optical centre C of the lens goes straight along CY and meets the first refracted ray at A'. Thus, A' is the real image of the top point A of the object. We draw $A'B'$ perpendicular to the axis from A'. Thus, $A'B'$ is the complete image of the object AB placed at infinity. It is clear from Figure 41, that the image is formed at the focus of the lens. It is real, inverted and much smaller than the object. From this discussion we conclude that **when an object is at infinity from a convex lens, then the image formed is :**

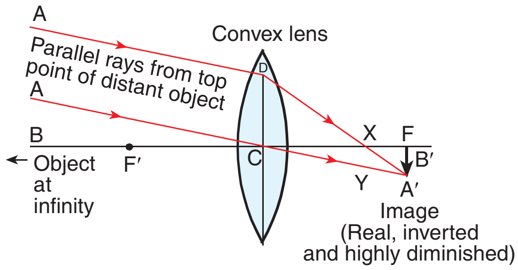


Figure 41. Formation of image by a convex lens when the object is placed at infinity (very large distance) from the lens.

(*i*) **at the focus,**

(*ii*) **real and inverted,** and

(*iii*) **much smaller than the object (or highly diminished).**

Figure 41 represents the action of the objective lens of a telescope. Because in a telescope, the objective lens is a convex lens which forms a real, inverted and diminished image of the distant object at its focus. Please note that when the object kept at infinity in front of a convex lens is assumed to be a big arrow pointing upwards, then its image is formed at focus according to the ray-diagram shown in Figure 41. If, however, the object kept at infinity in front of a convex lens is round in shape (like the sun), then its image is formed at the focus according to the ray-diagram shown in Figure 24 on page 231.

To Determine the Focal Length of a Convex Lens Quickly but Approximately

When the object is at infinity, the distance of image from the lens will be equal to the focal length of the lens. This fact is used to find out the focal length of a convex lens quickly but approximately. Let us see how this is done.

To determine the focal length of a convex lens, we put the convex lens in a holder (or stand) and keep it in front of a distant object like a window (or a tree), so that the rays coming from the window pass through it. A cardboard screen is put behind the lens. We change the distance of the screen from the convex lens until a clear inverted image of the window is formed on the screen. Measure the distance of the screen from the lens with a scale. This distance will be the focal length of convex lens. For example, if the image of a distant window is formed at a distance of 20 cm from a convex lens, then the focal length of this convex lens will be 20 cm. And before we end this discussion, here is a summary of the images formed by a convex lens.

Summary of the Images Formed by a Convex Lens

Position of object	*Position of image*	*Size of image*	*Nature of image*
1. Between f and lens	On the same side as object	Enlarged	Virtual and erect
2. At f (at focus)	At infinity	Highly enlarged	Real and inverted
3. Between f and $2f$	Beyond $2f$	Enlarged	Real and inverted
4. At $2f$	At $2f$	Same size as object	Real and inverted
5. Beyond $2f$	Between f and $2f$	Diminished	Real and inverted
6. At infinity	At f (at focus)	Highly diminished	Real and inverted

Uses of Convex Lenses

(*i*) Convex lenses are used in spectacles to correct the defect of vision called hypermetropia (or long-sightedness).
(*ii*) Convex lens is used for making a simple camera.
(*iii*) Convex lens is used as a magnifying glass (or magnifying lens) (by palmists, watchmakers, etc.).
(*iv*) Convex lenses are used in making microscopes, telescopes and slide projectors (or film projectors).

We will now solve some problems based on the formation of images by a convex lens.

Sample Problem 1. Where should an object be placed so that a real and inverted image of the same size is obtained by a convex lens ?

(*a*) at the focus of the lens.

(*b*) at twice the focal length.

(*c*) at infinity.

(*d*) between the optical centre of lens and its focus. **(NCERT Book Question)**

Answer. (*b*) at twice the focal length.

Sample Problem 2. A convex lens has a focal length of 20 cm. Where should an object be placed in front of this convex lens so as to obtain an image which is real, inverted and same size as the object ? Draw the ray diagram to show the formation of image in this case. **(NCERT Book Question)**

Solution. When the image formed by a convex lens is real, inverted and *same size* as the object, then the distance of the object from the lens is $2f$ (twice the focal length). Here,

Focal length, $f = 20$ cm
So, $2f = 2 \times 20$ cm
$= 40$ cm

Thus, the object should be placed at a distance of 40 cm in front of the convex lens. (Please draw the ray diagram yourself).

Sample Problem 3. An object is placed at the following distances from a convex lens of focal length 10 cm :

(*a*) 8 cm (*b*) 15 cm (*c*) 20 cm (*d*) 25 cm

Which position of the object will produce :

(*i*) a diminished real image ?
(*ii*) a magnified real image ?
(*iii*) a magnified virtual image ?
(*iv*) an image of the same size as the object ?

Solution. The focal length of this convex lens is 10 cm. This means that $f = 10$ cm.

(*i*) A diminished real image is formed by a convex lens when the object is beyond 2*f*, that is beyond 2×10 cm or beyond 20 cm. In this problem, the distance which is beyond 20 cm (or more than 20 cm) is 25 cm. Thus, 25 cm position of the object will produce a diminished real image.

(*ii*) A magnified real image is formed by a convex lens when the object is between *f* and 2*f*, that is between 10 cm and 20 cm. In this problem, the distance which is between 10 cm and 20 cm is 15 cm. So, 15 cm position of the object will produce a magnified real image.

(*iii*) A magnified virtual image is formed by a convex lens when the object is within focus, at a distance less than the focal length *f* or less than 10 cm. In this problem, the distance which is less than the focal length of 10 cm is 8 cm. Thus, 8 cm position of object will produce a magnified virtual image.

(*iv*) An image of the same size as the object is formed by a convex lens when the object is at 2*f* or twice the focal length from lens. Here $2f = 2 \times 10 = 20$ cm. So, the 20 cm position of the object will produce an image of the same size as the object.

If this question is asked in the examination, then the answer can just be written as :

(*i*) 25 cm (*ii*) 15 cm (*iii*) 8 cm (*iv*) 20 cm

Sample Problem 4. Which of the following lens would you prefer to use while reading small letters found in a dictionary ?

(*a*) A convex lens of focal length 50 cm.
(*b*) A concave lens of focal length 50 cm.
(*c*) A convex lens of focal length 5 cm.
(*d*) A concave lens of focal length 5 cm. **(NCERT Book Question)**

Answer. (*c*) A convex lens of focal length 5 cm.

Before we go further and discuss sign convention for lenses and the lens formula, **please answer the following questions :**

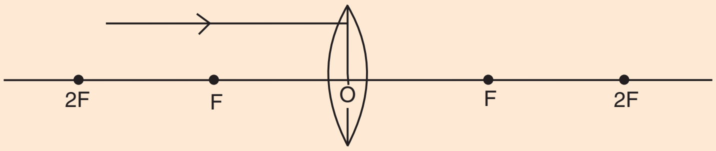
Very Short Answer Type Questions

1. Name the lens which can concentrate sun's rays to a point and burn a hole in a piece of paper.
2. Give the usual name for the following :
   A point inside a lens through which the light passes undeviated.
3. A 1 cm high object is placed at a distance of 2*f* from a convex lens. What is the height of the image formed ?
4. If the image formed by a convex lens is of the same size as that of the object, what is the position of the image with respect to the lens ?
5. If an object is placed at the focus of a convex lens, where is the image formed ?
6. Where should an object be placed in order to use a convex lens as a magnifying glass ?
7. Where should an object be placed in front of a convex lens so as to obtain its virtual, erect and magnified image ?
8. Where should an object be placed in front of a convex lens so as to obtain its real, inverted and magnified image ?

9. For what position of an object a real, diminished image is formed by a convex lens ?

10. If an object is at a considerable distance (or infinity) in front of a convex lens, where is the image formed ?

11. Draw the given diagram in your answer book and complete it for the path of a ray of light after passing through the lens.



12. What type of lens would you use as a magnifying glass ? How close must the object be to the lens ?

13. Name two factors on which the focal length of a lens depends.

14. State any two uses of convex lenses.

15. Fill in the following blanks with suitable words :

(*a*) Parallel rays of light are refracted by a convex lens to a point called the...........

(*b*) The image in a convex lens depends upon the distance of the...............from the lens.

Short Answer Type Questions

16. What is a lens ? Distinguish between a convex lens and a concave lens. Which of the two is a converging lens : convex lens or concave lens ?

17. (*a*) Explain with the help of a diagram, why the convex lens is also called a converging lens.

(*b*) Define principal axis, principal focus and focal length of a convex lens.

18. (*a*) Explain with the help of a diagram, why the concave lens is also called a diverging lens.

(*b*) Define the principal focus of a concave lens.

19. Draw a ray diagram to show the formation of a real magnified image by a convex lens. (In your sketch the position of object and image with respect to the principal focus of lens should be shown clearly).

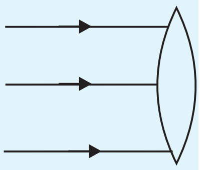
20. Describe with the help of a ray-diagram, the formation of image of a finite object placed in front of a convex lens between *f* and 2*f*. Give two characteristics of the image so formed.

21. Describe with the help of a ray diagram the nature, size and position of the image formed when an object is placed in front of a convex lens between focus and optical centre. State three characteristics of the image formed.

22. An object is placed at a distance equal to 2*f* in front of a convex lens. Draw a labelled ray diagram to show the formation of image. State two characteristics of the image formed.

23. Describe with the help of a ray-diagram, the size, nature and position of the image formed by a convex lens when an object is placed beyond 2*f* in front of the lens.

24. Describe with the help of a ray diagram the nature, size and position of the image formed when an object is placed at infinity (considerable distance) in front of a convex lens. State three characteristics of the image so formed.



25. (*a*) What type of lens is shown in the diagram on the right ? What will happen to the parallel rays of light ? Show by completing the ray diagram.

(*b*) Your eye contains a convex lens. Why is it unwise to look at the sun ?

26. Where must the object be placed for the image formed by a converging lens to be :

(*a*) real, inverted and smaller than the object ?

(*b*) real, inverted and same size as the object ?

(*c*) real, inverted and larger than the object ?

(*d*) virtual, upright and larger than the object ?

27. Draw a diagram to show how a converging lens held close to the eye acts as a magnifying glass. Why is it usual to choose a lens of short focal length for this purpose rather than one of long focal length ?

28. How could you find the focal length of a convex lens rapidly but approximately ?

Long Answer Type Questions

29. (*a*) With the help of a labelled diagram explain how a convex lens converges a beam of parallel light rays. Mark the principal axis, optical centre, principal focus and focal length of the convex lens on the diagram.

(*b*) State whether convex lens has a real focus or a virtual focus.
(*c*) List some things that convex lens and concave mirror have in common.

30. (*a*) With the help of a labelled diagram, explain how a concave lens diverges a beam of parallel light rays. Mark the principal axis, optical centre, principal focus and focal length of the concave lens on the diagram.
(*b*) State whether concave lens has a real focus or a virtual focus.
(*c*) List some things that concave lens and convex mirror have in common.

31. Draw ray diagrams to represent the nature, position and relative size of the image formed by a convex lens for the object placed :
(*a*) at $2F_1$,
(*b*) between F_1 and the optical centre *O* of the lens.
Which of the above two cases shows the use of convex lens as a magnifying glass ? Give reasons for your choice.

32. (*a*) An object is placed well outside the principal focus of a convex lens. Draw a ray diagram to show how the image is formed, and say whether the image is real or virtual.
(*b*) What is the effect on the size and position of the image of moving the object (*i*) towards the lens, and (*ii*) away from the lens ?

33. (*a*) Explain what is meant by a virtual, magnified image.
(*b*) Draw a ray diagram to show the formation of a virtual magnified image of an object by a convex lens. In your diagram, the position of object and image with respect to the principal focus should be shown clearly.
(*c*) Three convex lenses are available having focal lengths of 4 cm, 40 cm and 4 m respectively. Which one would you choose as a magnifying glass and why ?

34. (*a*) Explain why, a real image can be projected on a screen but a virtual image cannot.
(*b*) Draw a ray diagram to show the formation of a real diminished image of an object by a convex lens. In your diagram, the position of object and image with respect to the principal focus should be shown clearly.
(*c*) Name one simple optical instrument in which the above arrangement of convex lens is used.

Multiple Choice Questions (MCQs)

35. A convex lens has a focal length of 10 cm. At which of the following position should an object be placed so that this convex lens may act as a magnifying glass ?
(*a*) 15 cm (*b*) 7 cm (*c*) 20 cm (*d*) 25 cm

36. Which one of the following materials cannot be used to make a lens ?
(*a*) Water (*b*) Glass (*c*) Plastic (*d*) Clay

37. A small bulb is placed at the focal point of a converging lens. When the bulb is switched on, the lens produces :
(*a*) a convergent beam of light (*b*) a divergent beam of light
(*c*) a parallel beam of light (*d*) a patch of coloured light

38. An illuminated object is placed at a distance of 20 cm from a converging lens of focal length 15 cm. The image obtained on the screen is :
(*a*) upright and magnified (*b*) inverted and magnified
(*c*) inverted and diminished (*d*) upright and diminished

39. An object is placed between *f* and 2*f* of a convex lens. Which of the following statements correctly describes its image ?
(*a*) real, larger than the object (*b*) erect, smaller than the object
(*c*) inverted, same size as object (*d*) virtual, larger than the object

40. Which of the following can make a parallel beam of light when light from a bulb falls on it ?
(*a*) concave mirror as well as concave lens (*b*) convex mirror as well as convex lens
(*c*) concave mirror as well as convex lens (*d*) convex mirror as well as concave lens

41. In order to obtain a real image twice the size of the object with a convex lens of focal length 15 cm, the object distance should be :
(*a*) more than 5 cm but less than 10 cm (*b*) more than 10 cm but less than 15 cm
(*c*) more than 15 cm but less than 30 cm (*d*) more than 30 cm but less than 60 cm

42. A converging lens is used to produce an image of an object on a screen. What change is needed for the image to be formed nearer to the lens ?

(*a*) increase the focal length of the lens

(*b*) insert a diverging lens between the lens and the screen

(*c*) increase the distance of the object from the lens

(*d*) move the object closer to the lens

43. A convex lens of focal length 8 cm forms a real image of the same size as the object. The distance between object and its image will be :

(*a*) 8 cm (*b*) 16 cm (*c*) 24 cm (*d*) 32 cm

44. A virtual, erect and magnified image of an object is to be obtained with a convex lens. For this purpose, the object should be placed :

(*a*) between 2F and infinity (*b*) between F and optical centre

(*c*) between F and 2F (*d*) at F

45. A burning candle whose flame is 1.5 cm tall is placed at a certain distance in front of a convex lens. An image of candle flame is received on a white screen kept behind the lens. The image of flame also measures 1.5 cm. If f is the focal length of convex lens, the candle is placed :

(*a*) at f (*b*) between f and $2f$ (*c*) at $2f$ (*d*) beyond $2f$

Questions Based on High Order Thinking Skills (HOTS)

46. A lens of focal length 12 cm forms an erect image three times the size of the object. The distance between the object and image is :

(*a*) 8 cm (*b*) 16 cm (*c*) 24 cm (*d*) 36 cm

47. If an object is placed 21 cm from a converging lens, the image formed is slightly smaller than the object. If the object is placed 19 cm from the lens, the image formed is slightly larger than the object. The approximate focal length of the lens is :

(*a*) 5 cm (*b*) 10 cm (*c*) 18 cm (*d*) 20 cm

48. An object is placed at the following distances from a convex lens of focal length 15 cm :

(*a*) 35 cm (*b*) 30 cm (*c*) 20 cm (*d*) 10 cm

Which position of the object will produce :

(*i*) a magnified real image ?

(*ii*) a magnified virtual image ?

(*iii*) a diminished real image ?

(*iv*) an image of same size as the object ?

49. When an object is placed at a distance of 36 cm from a convex lens, an image of the same size as the object is formed. What will be the nature of image formed when the object is placed at a distance of :

(*a*) 10 cm from the lens ? (*b*) 20 cm from the lens ?

50. (*a*) Draw a diagram to show how a converging lens focusses parallel rays of light.

(*b*) How would you alter the above diagram to show how a converging lens can produce a beam of parallel rays of light.

ANSWERS

2. Optical centre **3.** 1 cm **4.** At 2F (at twice the focal length) **5.** At infinity (very large distance) **6.** At a distance less than focal length **7.** Within focus **8.** Between F and 2F (or Between f and $2f$)

9. Beyond 2F **10.** At focus (F) **15.** (*a*) focus (*b*) object **26.** (*a*) Beyond 2F (*b*) At 2F (*c*) Between F and 2F (*d*) Between F and Optical centre **33.** (*c*) Convex lens having 4 cm focal length ; It will produce greatest magnification **34.** (*c*) A simple camera **35.** (*b*) **36.** (*d*) **37.** (*c*) **38.** (*b*) **39.** (*a*) **40.** (*c*) **41.** (*c*) **42.** (*c*) **43.** (*d*) **44.** (*b*) **45.** (*c*) **46.** (*b*) **47.** (*b*) **48.** (*i*) 20 cm (*ii*) 10 cm (*iii*) 35 cm (*iv*) 30 cm **49.** (*a*) Virtual, erect and magnified (*b*) Real, inverted and magnified **50.** (*b*) Place a source of light (say, a lighted bulb) at the focus of the converging lens.

SIGN CONVENTION FOR SPHERICAL LENSES

These days New Cartesian Sign Convention is used for measuring the various distances in the ray diagrams of spherical lenses (convex lenses and concave lenses). According to the New Cartesian Sign Convention :

(*i*) All the distances are measured from the *optical centre* of the lens.
(*ii*) The distances measured in the *same* direction as that of incident light are taken as *positive*.
(*iii*) The distances measured *against* the direction of incident light are taken as *negative*.
(*iv*) The distances measured *upward* and perpendicular to the principal axis are taken as *positive*.
(*v*) The distances measured *downward* and perpendicular to the principal axis are taken as *negative*.

The New Cartesian Sign Convention for lenses is shown in Figure 42. **The object is always placed on the left side of the lens** (as shown in Figure 42), so that the direction of incident light is from left to right. All the distances measured from the optical centre (*C*) of the lens to the right side will be considered positive (because they will be in the same direction as the incident light). On the other hand, all the distances measured from the optical centre (*C*) of the lens to the left side are considered negative (because they are measured against the direction of incident light). On the basis of New Cartesian Sign Convention, **the focal length of a convex lens is considered positive** (and written with a plus sign). On the other hand, **the focal length of a concave lens is considered negative** (and written with a minus sign). Please note that the sign convention for *spherical lenses* is very similar to the sign convention for *spherical mirrors* which we have already studied.

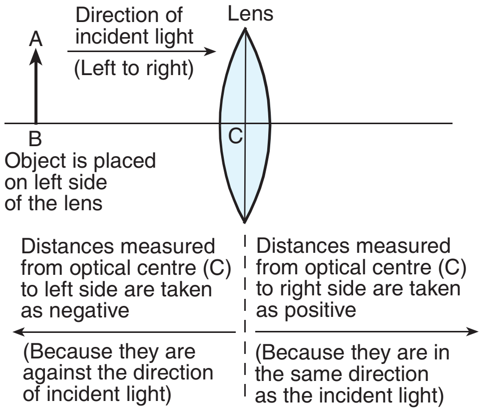


Figure 42. Sign convention for lenses.

Lens Formula

A formula which gives the relationship between image distance (v), object distance (u), and focal length (f) of a lens is known as the lens formula. The lens formula can be written as :

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

where v = image distance
u = object distance
and f = focal length

This lens formula applies to both types of spherical lenses : convex lenses as well as concave lenses. Please note that the lens formula differs from the mirror formula only in the sign between $\frac{1}{v}$ and $\frac{1}{u}$. The mirror formula is $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ whereas the lens formula is $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$. It is clear that the mirror formula has a plus sign (+) between $\frac{1}{v}$ and $\frac{1}{u}$ whereas the lens formula has a minus sign (–) between $\frac{1}{v}$ and $\frac{1}{u}$. The values of v and u should be substituted in the lens formula with their proper signs.

Magnification Produced by Lenses

The size of image formed by a lens depends on the position of the object from the lens. For example, the image formed by a convex lens can be smaller than the object, equal to the object or bigger than the object. The size of the image relative to the object is given by the linear magnification. **The linear magnification is the ratio of the height of the image to the height of the object.** That is :

$$\text{Magnification} = \frac{\text{height of image}}{\text{height of object}}$$

or $$m = \frac{h_2}{h_1}$$

where m = magnification

h_2 = height of image

and h_1 = height of object

We will now write another formula for the magnification produced by a lens in terms of the image distance and object distance.

The linear magnification produced by a lens is equal to the ratio of image distance to the object distance. That is :

$$\text{Magnification} = \frac{\text{Image distance}}{\text{Object distance}}$$

or $$m = \frac{v}{u}$$

where m = magnification

v = image distance

and u = object distance

It should be noted that this second magnification formula for lenses differs only in sign from the magnification formula for mirrors. The magnification formula for the mirrors is, $m = -\frac{v}{u}$ whereas that for lenses is, $m = \frac{v}{u}$. It is clear that the magnification formula for mirrors has a minus (–) sign but the magnification formula for lenses has no minus sign.

If the magnification m has a positive value, the image is virtual and erect. And if the magnification m has a negative value, the image will be real and inverted. Since a convex lens can form virtual images as well as real images, therefore, the magnification produced by a convex lens can be either positive or negative. A concave lens, however, forms only virtual images, so the magnification produced by a concave lens is always positive. A convex lens can form images which are smaller than the object, equal to the object or bigger than the object, therefore, the magnification (m) produced by a convex lens can be less than 1, equal to 1 or more than 1. On the other hand, a concave lens forms images which are always smaller than the object, so the magnification (m) produced by a concave lens is always less than 1.

Numerical Problems Based On Convex Lenses

We will now solve some numerical problems based on convex lenses by using the lens formula and the magnification formulae. Here are some examples.

Sample Problem 1. A convex lens of focal length 10 cm is placed at a distance of 12 cm from a wall. How far from the lens should an object be placed so as to form its real image on the wall ?

Solution. Here, the real image is formed on the wall which is at a distance of 12 cm from the convex lens. This means that the distance of image from the convex lens or image distance will be 12 cm. Since a real image is formed on the right side of the lens, so this image distance will be positive.

Now, Image distance, $v = +12$ cm (A real image)

Object distance, $u = ?$ (To be calculated)

Focal length, $f = +10$ cm (It is a convex lens)

Putting these values in the lens formula :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

we get : $$\frac{1}{12} - \frac{1}{u} = \frac{1}{10}$$

$$\frac{1}{12} - \frac{1}{10} = \frac{1}{u}$$

$$\frac{5-6}{60} = \frac{1}{u}$$

$$-\frac{1}{60} = \frac{1}{u}$$

So, Object distance, $u = -60$ cm

Thus, the object should be placed at a distance of 60 cm in front of the convex lens. The minus sign shows that the object is on the left side of the lens.

Sample Problem 2. If an object of 7 cm height is placed at a distance of 12 cm from a convex lens of focal length 8 cm, find the position, nature and height of the image.

Solution. First of all we will find out the position of the image. By the position of image we mean the distance of image from the lens.

Here, Object distance, $u = -12$ cm (It is to the left of lens)

Image distance, $v = ?$ (To be calculated)

Focal length, $f = +8$ cm (It is a convex lens)

Putting these values in the lens formula :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

we get : $$\frac{1}{v} - \frac{1}{-12} = \frac{1}{8}$$

or $$\frac{1}{v} + \frac{1}{12} = \frac{1}{8}$$

$$\frac{1}{v} = \frac{1}{8} - \frac{1}{12}$$

$$\frac{1}{v} = \frac{3-2}{24}$$

$$\frac{1}{v} = \frac{1}{24}$$

So, Image distance, $v = +24$ cm

Thus, the image is formed at a distance of 24 cm from the convex lens. The plus sign for image distance shows that the image is formed on the right side of the convex lens. Only a real and inverted image is formed on the right side of a convex lens, so the image formed is real and inverted.

Let us calculate the magnification now. We know that for a lens :

$$\text{Magnification, } m = \frac{v}{u}$$

Here, Image distance, $v = 24$ cm

Object distance, $u = -12$ cm

So, $$m = \frac{24}{-12}$$

or $$m = -2$$

Since the value of magnification is more than 1 (it is 2), so the image is larger than the object or magnified. The minus sign for magnification shows that the image is formed below the principal axis. Hence the image is real and inverted. Let us calculate the size of the image by using the formula :

$$m = \frac{h_2}{h_1}$$

Here, Magnification, $m = -2$ (Found above)

Height of object, $h_1 = +7$ cm (Measured upwards)

Height of image, $h_2 = ?$ (To be calculated)

Now, putting these values in the above formula, we get :

$$-2 = \frac{h_2}{7}$$

or $$h_2 = -2 \times 7$$

Thus, Height of image, $h_2 = -14$ cm

Thus, the height or size of the image is 14 cm. The minus sign shows that this height is in the downward direction, that is, the image is formed below the axis. Thus, the image is real and inverted.

Sample Problem 3. The magnification produced by a spherical lens is +2.5. What is the :

(*a*) nature of image ?

(*b*) nature of lens ?

Answer. (*a*) When the magnification is positive, then the image is virtual and erect. In this case, the magnification has a positive sign, so the nature of image is virtual and erect.

(*b*) The value of magnification given here is 2.5 (which is more than 1). So, the image is larger than the object or magnified. A virtual, erect and magnified image can be formed only by a convex lens, therefore, the nature of lens is convex.

We are now in a position to **answer the following questions and problems :**

Very Short Answer Type Questions

1. Write the formula for a lens connecting image distance (v), object distance (u) and the focal length (f). How does the lens formula differ from the mirror formula ?
2. Write down the magnification formula for a lens in terms of object distance and image distance. How does this magnification formula for a lens differ from the corresponding formula for a mirror ?
3. What is the nature of the image formed by a convex lens if the magnification produced by the lens is +3 ?
4. What is the nature of the image formed by a convex lens if the magnification produced by the lens is, – 0.5 ?
5. What is the position of image when an object is placed at a distance of 10 cm from a convex lens of focal length 10 cm ?
6. Describe the nature of image formed when an object is placed at a distance of 30 cm from a convex lens of focal length 15 cm.
7. At what distance from a converging lens of focal length 12 cm must an object be placed in order that an image of magnification 1 will be produced ?

Short Answer Type Questions

8. State and explain the New Cartesian Sign Convention for spherical lenses.
9. An object 4 cm high is placed at a distance of 10 cm from a convex lens of focal length 20 cm. Find the position, nature and size of the image.
10. A small object is so placed in front of a convex lens of 5 cm focal length that a virtual image is formed at a distance of 25 cm. Find the magnification.
11. Find the position and nature of the image of an object 5 cm high and 10 cm in front of a convex lens of focal length 6 cm.
12. Calculate the focal length of a convex lens which produces a virtual image at a distance of 50 cm of an object placed 20 cm in front of it.
13. An object is placed at a distance of 100 cm from a converging lens of focal length 40 cm.
    (*i*) What is the nature of image ?
    (*ii*) What is the position of image ?
14. A convex lens produces an inverted image magnified three times of an object placed at a distance of 15 cm from it. Calculate focal length of the lens.

15. A converging lens of focal length 5 cm is placed at a distance of 20 cm from a screen. How far from the lens should an object be placed so as to form its real image on the screen ?

16. An object 5 cm high is held 25 cm away from a converging lens of focal length 10 cm. Find the position, size and nature of the image formed. Also draw the ray diagram.

17. At what distance should an object be placed from a convex lens of focal length 18 cm to obtain an image at 24 cm from it on the other side ? What will be the magnification produced in this case ?

18. An object 2 cm tall is placed on the axis of a convex lens of focal length 5 cm at a distance of 10 m from the optical centre of the lens. Find the nature, position and size of the image formed. Which case of image formation by convex lenses is illustrated by this example ?

19. The filament of a lamp is 80 cm from a screen and a converging lens forms an image of it on a screen, magnified three times. Find the distance of the lens from the filament and the focal length of the lens.

20. An erect image 2.0 cm high is formed 12 cm from a lens, the object being 0.5 cm high. Find the focal length of the lens.

21. A convex lens of focal length 0.10 m is used to form a magnified image of an object of height 5 mm placed at a distance of 0.08 m from the lens. Calculate the position, nature and size of the image.

22. A convex lens of focal length 6 cm is held 4 cm from a newspaper which has print 0.5 cm high. By calculation, determine the size and nature of the image produced.

23. Determine how far an object must be placed in front of a converging lens of focal length 10 cm in order to produce an erect (upright) image of linear magnification 4.

24. A lens of focal length 20 cm is used to produce a ten times magnified image of a film slide on a screen. How far must the slide be placed from the lens ?

25. An object placed 4 cm in front of a converging lens produces a real image 12 cm from the lens.

(*a*) What is the magnification of the image ?

(*b*) What is the focal length of the lens ?

(*c*) Draw a ray diagram to show the formation of image. Mark clearly F and 2F in the diagram.

Long Answer Type Questions

26. (*a*) An object 2 cm tall stands on the principal axis of a converging lens of focal length 8 cm. Find the position, nature and size of the image formed if the object is :

(*i*) 12 cm from the lens

(*ii*) 6 cm from the lens

(*b*) State one practical application each of the use of such a lens with the object in position (*i*) and (*ii*).

27. (*a*) An object 3 cm high is placed 24 cm away from a convex lens of focal length 8 cm. Find by calculations, the position, height and nature of the image.

(*b*) If the object is moved to a point only 3 cm away from the lens, what is the new position, height and nature of the image ?

(*c*) Which of the above two cases illustrates the working of a magnifying glass ?

28. (*a*) Find the nature, position and magnification of the images formed by a convex lens of focal length 0.20 m if the object is placed at a distance of :

(*i*) 0.50 m (*ii*) 0.25 m (*iii*) 0.15 m

(*b*) Which of the above cases represents the use of convex lens in a film projector, in a camera, and as a magnifying glass ?

Multiple Choice Questions (MCQs)

29. A spherical mirror and a spherical lens each have a focal length of, –15 cm. The mirror and the lens are likely to be :

(*a*) both concave.

(*b*) both convex.

(*c*) the mirror is concave but the lens is convex.

(*d*) the mirror is convex but the lens is concave.

30. Linear magnification produced by a convex lens can be :

(*a*) less than 1 or more than 1

(*b*) less than 1 or equal to 1
(*c*) more than 1 or equal to 1
(*d*) less than 1, equal to 1 or more than 1

31. Magnification produced by a concave lens is always :
(*a*) more than 1 (*b*) equal to 1 (*c*) less than 1 (*d*) more than 1 or less than 1

32. In order to obtain a magnification of, – 3 (minus 3) with a convex lens, the object should be placed :
(*a*) between optical centre and F (*b*) between F and 2F
(*c*) at 2F (*d*) beyond 2F

33. A convex lens produces a magnification of +5. The object is placed :
(*a*) at focus (*b*) between *f* and 2*f*
(*c*) at less than *f* (*d*) beyond 2*f*

34. If a magnification of, –1 (minus 1) is obtained by using a converging lens, then the object has to be placed :
(*a*) within *f* (*b*) at 2*f*
(*c*) beyond 2*f* (*d*) at infinity

35. To obtain a magnification of, – 0.5 with a convex lens, the object should be placed :
(*a*) at F (*b*) between optical centre and F
(*c*) between F and 2F (*d*) beyond 2F

36. An object is 0.09 m from a magnifying lens and the image is formed 36 cm from the lens. The magnification produced is :
(*a*) 0.4 (*b*) 1.4 (*c*) 4.0 (*d*) 4.5

37. To obtain a magnification of, –2 with a convex lens of focal length 10 cm, the object should be placed :
(*a*) between 5 cm and 10 cm (*b*) between 10 cm and 20 cm
(*c*) at 20 cm (*d*) beyond 20 cm

38. A convex lens of focal length 15 cm produces a magnification of + 4. The object is placed :
(*a*) at a distance of 15 cm (*b*) between 15 cm and 30 cm
(*c*) at less than 15 cm (*d*) beyond 30 cm

39. If a magnification of, –1 is to be obtained by using a converging lens of focal length 12 cm, then the object must be placed :
(*a*) within 12 cm (*b*) at 24 cm (*c*) at 6 cm (*d*) beyond 24 cm

40. In order to obtain a magnification of, – 0.75 with a convex lens of focal length 8 cm, the object should be placed :
(*a*) at less than 8 cm (*b*) between 8 cm and 16 cm
(*c*) beyond 16 cm (*d*) at 16 cm

Questions Based on High Order Thinking Skills (HOTS)

41. A student did an experiment with a convex lens. He put an object at different distances 25 cm, 30 cm, 40 cm, 60 cm and 120 cm from the lens. In each case he measured the distance of the image from the lens. His results were 100 cm, 24 cm, 60 cm, 30 cm and 40 cm, respectively. Unfortunately his results are written in wrong order.
(*a*) Rewrite the image distances in the correct order.
(*b*) What would be the image distance if the object distance was 90 cm ?
(*c*) Which of the object distances gives the biggest image ?
(*d*) What is the focal length of this lens ?

42. A magnifying lens has a focal length of 100 mm. An object whose size is 16 mm is placed at some distance from the lens so that an image is formed at a distance of 25 cm in front of the lens.
(*a*) What is the distance between the object and the lens ?
(*b*) Where should the object be placed if the image is to form at infinity ?

43. A lens forms a real image 3 cm high of an object 1 cm high. If the separation of object and image is 15 cm, find the focal length of the lens.

44. An object 50 cm tall is placed on the principal axis of a convex lens. Its 20 cm tall image is formed on the screen placed at a distance of 10 cm from the lens. Calculate the focal length of the lens.

ANSWERS

3. Virtual and erect **4.** Real and inverted **5.** At infinity **6.** Real and inverted. **7.** 24 cm **9.** $v = -20$ cm ; The image is 20 cm in front of convex lens (on its left side) ; Virtual and erect; 8 cm **10.** +6 **11.** $v = +15$ cm ; The image is formed 15 cm behind the convex lens (on its right side); Real and inverted **12.** 33.3 cm **13.** (*i*) Real and inverted (*ii*) $v = +66.6$ cm ; The image is formed 66.6 cm behind the convex lens (on its right side) **14.** 11.2 cm **15.** 6.6 cm **16.** $v = +16.6$ cm ; The image is 16.6 cm behind the convex lens ; 3.3 cm ; Real and inverted **17.** 72 cm from convex lens ; $-\frac{1}{3}$ **18.** Real and inverted ; $v = +5$ cm ; The image is formed 5 cm behind the convex lens ; 0.01 cm **19.** 20 cm ; + 15 cm **20.** + 4.0 cm **21.** $v = -0.40$ m ; The position of image is 0.40 m from the lens on the same side as the object (on the left of lens) ; The nature of image is virtual and erect ; The size of image is 25 mm **22.** 1.5 cm high ; Virtual, erect and magnified (3 times) **23.** 7.5 cm **24.** 220 cm behind the lens **25.** (*a*) 3 (*b*) + 3 cm **26.** (*a*) (*i*) $v = +24$ cm ; The image is 24 cm behind the lens ; Real and inverted ; 4 cm (*ii*) $v = -24$ cm ; The image is 24 cm in front of the lens ; Virtual and erect ; 8 cm (*b*) (*i*) Used in film projector (*ii*) Used as a magnifying glass **27.** (*a*) $v = +12$ cm ; The image is formed 12 cm behind the lens ; 1.5 cm high ; Real and inverted (*b*) $v = -4.8$ cm ; The image is formed 4.8 cm in front of the lens (on its left side); 4.8 cm high ; Virtual and erect (*c*) Case *b* **28.** (*a*) (*i*) $v = +0.33$ m ; The image is formed 0.33 m behind the lens ; $m = -0.66$; Real and inverted (*ii*) $v = +1.00$ m ; The image is formed 1.00 m behind the lens ; $m = -4.0$; Real and inverted (*iii*) $v = -0.60$ m ; The image is formed 0.60 m in front of the lens ; $m = +4.0$; Virtual and erect (*b*) Film projector : Case (*ii*) ; Camera : Case (*i*) ; Magnifying glass : case (*iii*) **29.** (*a*) **30.** (*d*) **31.** (*c*) **32.** (*b*) **33.** (*c*) **34.** (*b*) **35.** (*d*) **36.** (*c*) **37.** (*b*) **38.** (*c*) **39.** (*b*) **40.** (*c*) **41.** (*a*) 100 cm ; 60 cm ; 40 cm ; 30 cm ; 24 cm (*b*) 25.7 cm (*c*) 25 cm (*d*) 20 cm **42.** (*a*) 7.14 cm (*b*) 10 cm **43.** + 2.81 cm **44.** 7.14 cm

RULES FOR OBTAINING IMAGES FORMED BY CONCAVE LENSES

We have already studied some rules for the formation of images by convex lenses. There are similar rules for constructing ray-diagrams for obtaining images with concave lenses. These are given below.

Rule 1. **A ray of light which is parallel to the principal axis of a concave lens, appears to be coming from its focus after refraction through the lens.** This is shown in Figure 43. Here we have a concave lens *L* and its principal axis is *X′Y′*. A ray of light *AD* parallel to the principal axis enters the concave lens, gets refracted at point *D* and goes in the direction *DX*. To a person looking into the concave lens from the right side, the refracted ray of light *DX* appears to be coming from the focus *F* of concave lens situated on its left side (as shown by dotted line) (see Figure 43).

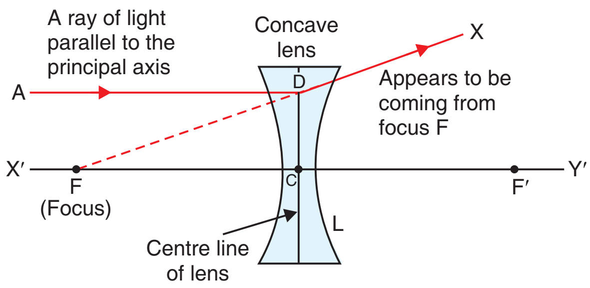


Figure 43.

Rule 2. **A ray of light passing through the optical centre of a concave lens goes straight after passing through the lens.** This is shown in Figure 44. The ray of light *AC* is passing through the optical centre *C* of concave lens. This ray of light goes straight in the direction *CY* after passing through the concave lens. It does not bend at all. Please note that a ray of light along the principal axis of a conave lens also goes straight.

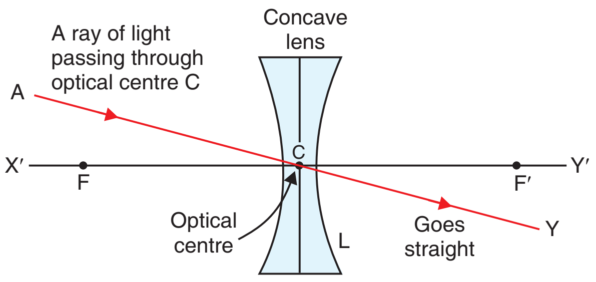


Figure 44.

Rule 3. **A ray of light going towards the focus of a concave lens, becomes parallel to its principal axis after refraction through the lens.** This rule is just the reverse case of the first rule and it is shown in Figure 45. Here a ray of light *AD* (coming from the object) is going towards the focus F' of the concave lens. It enters the concave lens and gets refracted (or bends) at point D. After passing through the concave lens, it becomes parallel to the principal axis of the lens and goes in the direction DX (see Figure 45).

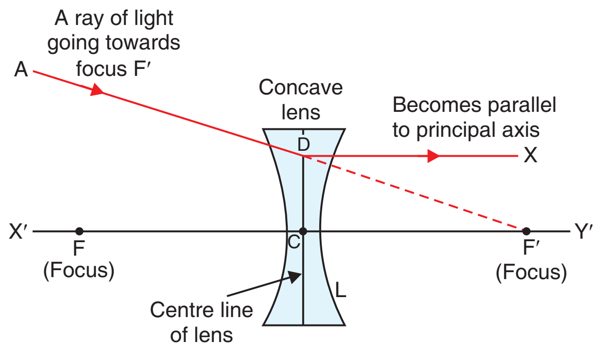


Figure 45.

At any given time, we will use only two of the above three types of light rays to draw the ray-diagrams to find the position of image formed by a concave lens.

Please note that **no matter where the object is placed in front of a concave lens, the concave lens always forms a virtual, erect and diminished image of the object.** When the distance of an object from a concave lens is changed, then only the position and size of the image changes. There are two main positions of an object in the case of a concave lens from the point of view of position and size of image. The object can be :

(*i*) anywhere between optical centre (C) and infinity, and

(*ii*) at infinity.

We will discuss both these cases one by one. Let us first describe the formation of image by a concave lens when the object is anywhere between optical centre (C) and infinity.

Formation of Image by a Concave Lens

In Figure 46, we have a concave lens with optical centre C. And F is the focus of this lens. The arrow AB pointing upwards represents the object. Now, we want to find out the position, nature and size of the image of this object which will be formed by the concave lens. The method used for obtaining the images with concave lenses is very similar to the one we have used in the case of convex lenses. This is as follows.

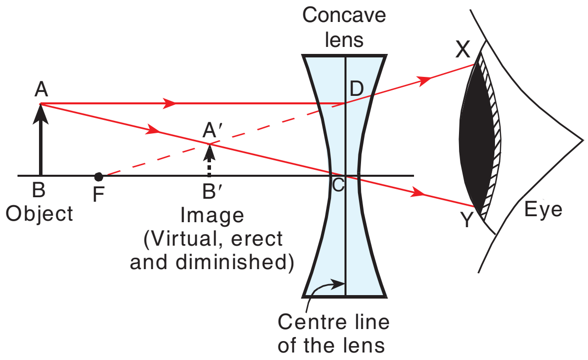


Figure 46. Diagram to show the formation of image by a concave lens.

Starting from the upper point A of the object AB, we draw a line AD parallel to the principal axis. Now, according to the first rule of image formation, this parallel ray AD should appear to be coming from focus F after refraction. So, we join DF by a dotted line and produce FD upwards in the direction DX by a solid line. Now, DX is the first refracted ray which appears to be coming from focus F of the concave lens.

We have now to draw a second ray of light starting from the same point A and passing through the optical centre C. For this we join the points A and C by a line. Thus, the line AC represents a ray of light passing through the optical centre C of the lens. Now, according to the second rule of image formation, this ray should go straight. So, we extend the line AC further in the direction CY. Thus, CY is the second refracted ray. The two refracted rays DX and CY are diverging rays and appear to intersect at point A' on the left side of the lens, only when they are produced backwards. So, to an eye placed on the right side of the concave lens (as shown in Figure 46), the top of arrow appears to be at A'. Thus, A' is the virtual image of the top point A of the object. To get the complete image of the object, we draw $A'B'$ perpendicular to the axis from point A'. Thus, $A'B'$ is the image of the object AB. The image is virtual, erect and smaller than the object. It is situated between

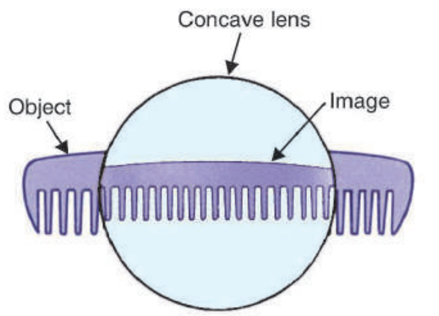


Figure 47. A concave lens always produces a smaller image than the object. Here a concave lens is producing a smaller image of the middle part of the comb.

the optical centre and focus (in front of the concave lens). From the above discussion we conclude that : **When an object is placed anywhere between optical centre (*C*) and infinity in front of a concave lens, the image formed is :**

(*i*) **between optical centre (*C*) and focus (*F*),**

(*ii*) **virtual and erect,** and

(*iii*) **diminished (smaller than the object).**

If we move the object more and more away from the optical centre of the concave lens, the image becomes smaller and smaller in size and moves away from the lens towards its focus. And when the object is at infinity, the image is formed at the focus (see Figure 27 on page 232). From this discussion we conclude that : **When an object is at infinity from a concave lens, the image formed is :**

(*i*) **at focus (*F*),**

(*ii*) **virtual and erect,** and

(*iii*) **highly diminished (much smaller than the object).**

And before we conclude this discussion, here is a summary of the images formed by a concave lens.

Summary of the Images Formed by a Concave Lens

Position of object	*Position of image*	*Size of image*	*Nature of image*
1. Anywhere between optical centre (*C*) and infinity.	Between optical centre (*C*) and focus (*F*)	Diminished	Virtual and erect
2. At infinity	At focus (*F*)	Highly diminished	Virtual and erect

How to Distinguish Between a Convex Lens and a Concave Lens Without Touching Them

We keep the lens close to the page of a book and see the image of the writing of the book through it. If the letters of the book appear enlarged, then it is a convex lens; and if the letters appear diminished, then it is a concave lens. This is due to the fact that when an object is within the focus of a convex lens, it produces an enlarged image. But a concave lens produces a diminished image for all positions of the object. So, in this case the object (the book) has been placed within focus of the lens.

Uses of Concave Lenses

(*i*) Concave lenses are used in spectacles to correct the defect of vision called myopia (or short-sightedness).

(*ii*) Concave lens is used as eye-lens in Galilean telescope.

(*iii*) Concave lenses are used in combination with convex lenses to make high quality lens systems for optical instruments.

(*iv*) Concave lens is used in wide-angle spyhole in doors.

Before we go further and discuss the mirror formula and magnification formulae for a concave lens, **please answer the following questions :**

Very Short Answer Type Questions

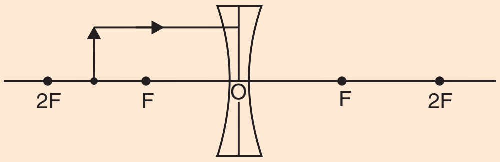
1. If the image formed by a lens is always diminished and erect, what is the nature of the lens ?
2. Copy and complete the diagram below to show what happens to the rays of light when they pass through the concave lens :

3. Which type of lenses are :
(*a*) thinner in the middle than at the edges ?
(*b*) thicker in the middle than at the edges ?

4. A ray of light is going towards the focus of a concave lens. Draw a ray diagram to show the path of this ray of light after refraction through the lens.

5. (*a*) What type of images can a convex lens make ?
(*b*) What type of image is always made by a concave lens ?

6. Take down this figure into your answer book and complete the path of the ray.



7. Fill in the following blanks with suitable words :
(*a*) A convex lens...........rays of light, whereas a concave lens...........rays of light.
(*b*) Lenses refract light to form images : a............lens can form both real and virtual images, but a diverging lens forms only.............images.

8. Things always look small on viewing through a lens. What is the nature of the lens ?

Short Answer Type Questions

9. An object lies at a distance of $2f$ from a concave lens of focal length f. Draw a ray-diagram to illustrate the image formation.

10. Show by drawing a ray-diagram that the image of an object formed by a concave lens is virtual, erect and diminished.

11. Give the position, size and nature of image formed by a concave lens when the object is placed :
(*a*) anywhere between optical centre and infinity.
(*b*) at infinity.

12. Which type of lens is : (*a*) a converging lens, and which is (*b*) a diverging lens ? Explain your answer with diagrams.

13. With the help of a diagram, explain why the image of an object viewed through a concave lens appears smaller and closer than the object.

14. How would a pencil look like if you saw it through (*a*) a concave lens, and (*b*) a convex lens ? (Assume the pencil is close to the lens). Is the image real or virtual ?

Long Answer Type Questions

15. (*a*) An object is placed 10 cm from a lens of focal length 5 cm. Draw the ray diagrams to show the formation of image if the lens is (*i*) converging, and (*ii*) diverging.
(*b*) State one practical use each of convex mirror, concave mirror, convex lens and concave lens.

16. (*a*) Construct ray diagrams to illustrate the formation of a virtual image using (*i*) a converging lens, and (*ii*) a diverging lens.
(*b*) What is the difference between the two images formed above ?

Multiple Choice Questions (MCQs)

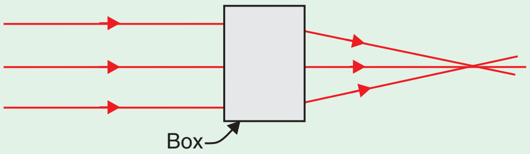
17. A diverging lens is used in :
(*a*) a magnifying glass
(*b*) a car to see objects on rear side
(*c*) spectacles for the correction of short sight
(*d*) a simple camera

18. When an object is kept at any distance in front of a concave lens, the image formed is always :
(*a*) virtual, erect and magnified
(*b*) virtual, inverted and diminished.
(*c*) virtual, erect and diminished
(*d*) virtual, erect and same size as object

19. When sunlight is concentrated on a piece of paper by a spherical mirror or lens, then a hole can be burnt in it. For doing this, the paper must be placed at the focus of :

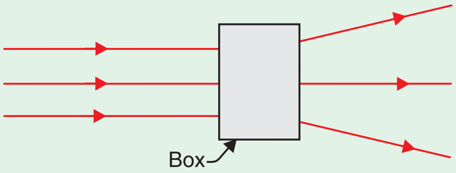
(*a*) either a convex mirror or convex lens (*b*) either a concave mirror or concave lens
(*c*) either a concave mirror or convex lens (*d*) either a convex mirror or concave lens

20. A beam of parallel light rays is incident through the holes on one side of a box and emerges out through the holes on its opposite side as shown in the diagram below :



Which of the following could be inside the box ?
(*a*) a rectangular glass block (*b*) a concave lens
(*c*) a convex lens (*d*) a glass prism

21. A beam of light is incident through the holes on one side of a box and emerges out through the holes on its opposite side as shown in the following figure :



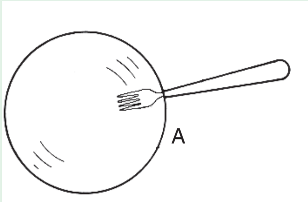
The box contains :
(*a*) a glass prism (*b*) a concave lens
(*c*) a convex lens (*d*) a parallel-sided glass slab

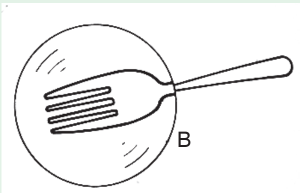
22. Which of the following can form a virtual image which is always smaller than the object ?
(*a*) a plane mirror (*b*) a convex lens
(*c*) a concave lens (*d*) a concave mirror

Questions Based on High Order Thinking Skills (HOTS)

23. When an object is placed 10 cm in front of lens *A*, the image is real, inverted, magnified and formed at a great distance. When the same object is placed 10 cm in front of lens *B*, the image formed is real, inverted and same size as the object.
(*a*) What is the focal length of lens *A* ?
(*b*) What is the focal length of lens *B* ?
(*c*) What is the nature of lens *A* ?
(*d*) What is the nature of lens *B* ?

24. When a fork is seen through lenses *A* and *B* one by one, it appears as shown in the diagrams. What is the nature of (*i*) lens *A*, and (*ii*) lens *B* ? Give reason for your answer.





25. What kind of lens can form :
(*a*) an inverted magnified image ?
(*b*) an erect magnified image ?
(*c*) an inverted diminished image ?
(*d*) an erect diminished image ?

ANSWERS

1. Concave lens **3.** (*a*) Concave lenses (*b*) Convex lenses **5.** (*a*) Real and Virtual (*b*) Virtual **7.** (*a*) converges; diverges (*b*) converging ; virtual **8.** Concave lens **14.** (*a*) Smaller (*b*) Bigger ; Virtual **16.** (*b*) The virtual image formed by a converging lens is magnified whereas that formed by a diverging lens is diminished **17.** (*c*) **18.** (*c*) **19.** (*c*) **20.** (*c*) **21.** (*b*) **22.** (*c*) **23.** (*a*) 10 cm (*b*) 5 cm (*c*) Convex lens (*d*) Convex lens **24.** (*i*) Concave lens (*ii*) Convex lens **25.** (*a*) Convex lens (*b*) Convex lens (*c*) Convex lens (*d*) Concave lens.

LENS FORMULA AND MAGNIFICATION FORMULAE FOR A CONCAVE LENS

The lens formula for a concave lens is the same as that for a convex lens, which is :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

The magnification formulae for a concave lens are also just the same as that for convex lens, which are :

$$m = \frac{h_2}{h_1} \quad \text{and} \quad m = \frac{v}{u}$$

Numerical Problems Based on Concave Lenses

We will now solve some numerical problems based on concave lenses by using the lens formula and the magnification formulae. Here are some examples.

Sample Problem 1. An object is placed at a distance of 50 cm from a concave lens of focal length 20 cm. Find the nature and position of the image.

Solution. First of all we will find out the position of image which is given by the image distance v.

Here, Object distance, $u = -50$ cm (It is to the left of lens)
Image distance, $v = ?$ (To be calculated)
Focal length, $f = -20$ cm (It is a concave lens)

Putting these values in the lens formula :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

we get : $$\frac{1}{v} - \frac{1}{-50} = \frac{1}{-20}$$

or $$\frac{1}{v} + \frac{1}{50} = -\frac{1}{20}$$

or $$\frac{1}{v} = -\frac{1}{20} - \frac{1}{50}$$

or $$\frac{1}{v} = \frac{-5-2}{100}$$

or $$\frac{1}{v} = \frac{-7}{100}$$

or $$v = -\frac{100}{7}$$

So, Image distance, $v = -14.3$ cm

Thus, the image is formed at a distance of 14.3 cm from the concave lens. The minus sign for image distance shows that the image is formed on the left side of the concave lens. We know that a concave lens always forms a virtual and erect image, so the nature of image is virtual and erect.

Sample Problem 2. An object placed 50 cm from a lens produces a virtual image at a distance of 10 cm in front of the lens. Draw a diagram to show the formation of image. Calculate focal length of the lens and magnification produced.

Solution. First of all we will find out the focal length of the lens. We know that the object is always placed in front of the lens on the left side, so the object distance is always taken as negative. Here the image is also formed in front of the lens on the left side, so the image distance will also be negative. Thus,

Object distance, $u = -50$ cm (To the left of lens)
Image distance, $v = -10$ cm (To the left of lens)
Focal length, $f = ?$ (To be calculated)

Putting these values in the lens formula :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

we get :

$$\frac{1}{-10} - \frac{1}{-50} = \frac{1}{f}$$

$$-\frac{1}{10} + \frac{1}{50} = \frac{1}{f}$$

$$\frac{-5+1}{50} = \frac{1}{f}$$

$$-\frac{4}{50} = \frac{1}{f}$$

$$f = -\frac{50}{4}$$

So, Focal length, $f = -12.5$ cm

The minus sign for focal length shows that it is a concave lens. Please draw the ray diagram yourself.

We will now calculate the magnification produced by concave lens. We know that for a lens :

$$\text{Magnification, } m = \frac{v}{u}$$

Here, Image distance, $v = -10$ cm

And, Object distance, $u = -50$ cm

So,

$$m = \frac{-10}{-50}$$

$$m = +\frac{1}{5}$$

$$m = +0.2$$

Thus, the magnification produced by this concave lens is + 0.2. Since the value of magnification is less than 1 (it is 0.2), therefore, the image is smaller than the object (or diminished). The plus sign for the magnification shows that the image is virtual and erect.

Sample Problem 3. The magnification produced by a spherical lens is + 0.75. What is the :

(*a*) nature of image ?

(*b*) nature of lens ?

Answer. (*a*) When the magnification is positive, the nature of image is virtual and erect. In this case, the magnification is positive, so the nature of image is virtual and erect.

(*b*) The value of magnification given here is 0.75 (which is less than 1), so the image is smaller than the object or diminished. A virtual, erect and diminished image can be formed only by a concave lens, so the nature of lens is concave.

We are now in position to **answer the following questions and problems :**

Very Short Answer Type Questions

1. The lens *A* produces a magnification of, – 0.6 whereas lens *B* produces a magnification of + 0.6.
   (*a*) What is the nature of lens *A* ?
   (*b*) What is the nature of lens *B* ?
2. A 50 cm tall object is at a very large distance from a diverging lens. A virtual, erect and diminished image of the object is formed at a distance of 20 cm in front of the lens. How much is the focal length of the lens ?

Short Answer Type Questions

3. An object is placed at a distance of 4 cm from a concave lens of focal length 12 cm. Find the position and nature of the image.

4. A concave lens of focal length 15 cm forms an image 10 cm from the lens. How far is the object placed from the lens ? Draw the ray-diagram.

5. An object 60 cm from a lens gives a virtual image at a distance of 20 cm in front of the lens. What is the focal length of the lens ? Is the lens converging or diverging ? Give reasons for your answer.

6. A concave lens of 20 cm focal length forms an image 15 cm from the lens. Compute the object distance.

7. A concave lens has focal length 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens ? Also find the magnification produced by the lens.

8. Calculate the image distance for an object of height 12 mm at a distance of 0.20 m from a concave lens of focal length 0.30 m, and state the nature and size of the image.

9. A concave lens has a focal length of 20 cm. At what distance from the lens a 5 cm tall object be placed so that it forms an image at 15 cm from the lens ? Also calculate the size of the image formed.

10. An object is placed 20 cm from (*a*) a converging lens, and (*b*) a diverging lens, of focal length 15 cm. Calculate the image position and magnification in each case.

11. A 2.0 cm tall object is placed 40 cm from a diverging lens of focal length 15 cm. Find the position and size of the image.

Long Answer Type Questions

12. (*a*) Find the position and size of the virtual image formed when an object 2 cm tall is placed 20 cm from :

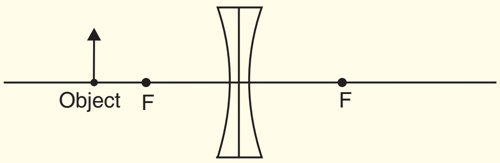
(*i*) a diverging lens of focal length 40 cm.

(*ii*) a converging lens of focal length 40 cm.

(*b*) Draw labelled ray diagrams to show the formation of images in cases (*i*) and (*ii*) above (The diagrams may not be according to scale).

13. (*a*) A small object is placed 150 mm away from a diverging lens of focal length 100 mm.

(*i*) Copy the figure below and draw rays to show how an image is formed by the lens.



(*ii*) Calculate the distance of the image from the lens by using the lens formula.

(*b*) The diverging lens in part (*a*) is replaced by a converging lens also of focal length 100 mm. The object remains in the same position and an image is formed by the converging lens. Compare two properties of this image with those of the image formed by the diverging lens in part (*a*).

Multiple Choice Questions (MCQs)

14. A concave lens produces an image 20 cm from the lens of an object placed 30 cm from the lens. The focal length of the lens is :

(*a*) 50 cm (*b*) 40 cm (*c*) 60 cm (*d*) 30 cm

15. Only one of the following applies to a concave lens. This is :

(*a*) focal length is positive
(*b*) image distance can be positive or negative
(*c*) height of image can be positive or negative
(*d*) image distance is always negative

16. The magnification produced by a spherical mirror and a spherical lens is + 0.8.

(*a*) The mirror and lens are both convex
(*b*) The mirror and lens are both concave
(*c*) The mirror is concave but the lens is convex
(*d*) The mirror is convex but the lens is concave

17. The magnification produced by a spherical lens and a spherical mirror is + 2.0.

(*a*) The lens and mirror are both concave
(*b*) The lens and mirror are both convex
(*c*) The lens is convex but the mirror is concave
(*d*) The lens is concave but the mirror is convex

Questions Based on High Order Thinking Skills (HOTS)

18. A camera fitted with a lens of focal length 50 mm is being used to photograph a flower that is 5 cm in diameter. The flower is placed 20 cm in front of the camera lens.

(*a*) At what distance from the film should the lens be adjusted to obtain a sharp image of the flower ?

(*b*) What would be the diameter of the image of the flower on the film ?

(*c*) What is the nature of camera lens ?

19. An object is 2 m from a lens which forms an erect image one-fourth (exactly) the size of the object. Determine the focal length of the lens. What type of lens is this ?

20. An image formed on a screen is three times the size of the object. The object and screen are 80 cm apart when the image is sharply focussed.

(*a*) State which type of lens is used.

(*b*) Calculate focal length of the lens.

ANSWERS

1. (*a*) Convex lens (*b*) Concave lens **2.** 20 cm **3.** $v = -3$ cm ; The image is formed at 3 cm in front of the concave lens (on its left side) ; Virtual and erect **4.** $u = -30$ cm ; The object is at 30 cm from the concave lens on its left side **5.** $f = -30$ cm ; Diverging lens : Negative sign of focal length **6.** 60 cm on left side of lens **7.** $u = -30$ cm ; $m = +0.33$ **8.** $v = -0.12$ m ; Virtual and erect ; 7.2 mm tall **9.** $u = -60$ cm ; 1.25 cm **10.** (*a*) $v = +60$ cm; $m = -3$ (*b*) $v = -8.5$ cm; $m = +0.42$; **11.** $v = -10.90$ cm ; 0.54 cm tall **12.** (*a*) (*i*) $v = -13.3$ cm ; 1.33 cm tall (*ii*) $v = -40$ cm ; 4 cm tall **13.** (*a*) (*ii*) $v = -60$ mm (*b*) $v = +300$ mm ; The image formed by converging lens is real, inverted and magnified (2 times). It is formed behind the converging lens. On the other hand, the image formed by diverging lens is virtual, erect and diminished. It is formed in front of the diverging lens. **14.** (*c*) **15.** (*d*) **16.** (*d*) **17.** (*c*) **18.** (*a*) $v = +6.66$ cm ; The film should be at a distance of 6.66 cm behind the camera lens (*b*) 1.66 cm (*c*) Convex lens **19.** $f = -66.7$ cm ; Concave lens **20.** (*a*) Convex lens (*b*) + 15 cm

POWER OF A LENS

A convex lens converges the light rays falling on it whereas a concave lens diverges the light rays falling on it. **The power of a lens is a measure of the degree of convergence or divergence of light rays falling on it.** If a convex lens converges a beam of parallel light rays more strongly by focussing them closer to the optical centre, it is said to have greater power (than another convex lens which focusses the same parallel light rays at a greater distance from the optical centre). Similarly, a concave lens which diverges a parallel beam of light rays more strongly is said to have a greater diverging power than another concave lens which diverges the light rays less strongly. *The power of a lens depends on its focal length*. We can define the power of a lens as follows :

The power of a lens is defined as the reciprocal of its focal length in metres.

Thus, $$\text{Power of a lens} = \frac{1}{\text{focal length of the lens } (\textit{in metres})}$$

or $$P = \frac{1}{f}$$

where P = Power of the lens

and f = focal length of the lens (*in metres*)

Since the power of a lens is *inversely proportional* to its focal length, therefore, **a lens of short focal length has more power whereas a lens of long focal length has less power**. For example, a lens of 5 cm focal length will have more power than a lens of 20 cm focal length. A more powerful lens is one that bends the light rays more ; and has a shorter focal length (see Figure 48).

The unit of the power of a lens is dioptre, which is denoted by the letter D. **One dioptre is the power of a lens whose focal length is 1 metre.** The power of a lens can be measured directly by using an instrument called dioptremeter. It is used by opticians to measure the power of spectacle lenses (see Figure 49). A convex lens has a positive focal length, so **the power of a convex lens is positive** (and written with a

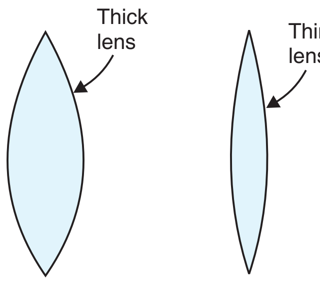


Figure 48. A thick lens has short focal length but more power. A thin lens has large focal length but less power.

Figure 49. An optician measuring the power of a spectacle lens by using an instrument called dioptremeter.

+ sign). A concave lens has a negative focal length, so **the power of a concave lens is negative** [and written with a minus (–) sign]. Since a convex lens is also known as a converging lens and a concave lens is also known as a diverging lens, we can also say that the power of a converging lens is positive whereas the power of a diverging lens is negative. When an optician, after testing the eyes of a person, prescribes the corrective lenses of say, + 2.0 D and + 1.5 D for the left eye and right eye, respectively, he actually refers to the power of convex lenses required for making eye-glasses or spectacles to make him see clearly.

In order to calculate the power of a lens, we need its focal length in metres. In many problems, the focal length of a lens is usually given to us in 'centimetres'. So, to calculate the power of such a lens, we should first convert the focal length of the lens into 'metres' by dividing the given 'centimetre' value by 100. If, however, the focal length is already in metres, then there is no need to change it. We will now solve some problems based on the calculation of power of lenses.

Sample Problem 1. A convex lens is of focal length 10 cm. What is its power ?

Solution. Here, the focal length of the lens is given in 'centimetres' so to calculate the power of this lens, we should first convert the focal length into 'metres' because our formula uses the focal length in 'metres'.

Now, $10 \text{ cm} = \dfrac{10}{100} \text{ m}$

$= 0.1 \text{ m}$

So, Focal length, $f = 0.1$ m (A convex lens has positive focal length)

Now, putting this value of focal length in the formula for the power of a lens :

$$P = \frac{1}{f\,(\text{in metres})}$$

we get : $P = \dfrac{1}{0.1}$

or $P = \dfrac{1 \times 10}{1}$

Thus, Power, $P = +10$ dioptres (or +10 D)

Thus, the power of this convex lens is +10 dioptres which is also written as +10 D. The plus sign with the power indicates that it is a converging lens or convex lens.

Sample Problem 2. A person having a myopic eye uses a concave lens of focal length 50 cm. What is the power of the lens ?

Solution. Here we have a concave lens. Now, the focal length of a concave lens is considered negative, so it is to be written with a minus sign.

Thus, Focal length, $f = -50$ cm

$$= -\frac{50}{100} \text{ m}$$

$$= -0.5 \text{ m}$$

Now, Power, $P = \dfrac{1}{f\,(\text{in metres})}$

$$P = \frac{1}{-0.5}$$

$$P = -\frac{1 \times 10}{5}$$

$$P = -2 \text{ dioptres} \qquad (\text{or } -2\text{ D})$$

Thus, the power of this concave lens is, – 2 dioptres which can also be written as, – 2 D. The minus sign with the power indicates that it is a diverging lens or concave lens.

Sample Problem 3. A thin lens has a focal length of, – 25 cm. What is the power of the lens and what is its nature ?

Solution. Since the focal length is negative, it is a concave lens or diverging lens. Calculate the power yourself as shown in the above question. The power will be, – 4 D.

Sample Problem 4. The power of a lens is + 2.5 D. What kind of lens it is and what is its focal length ?

Solution. The power of this lens has positive sign, so it is a convex lens. Now,

Power, $P = \dfrac{1}{f\,(\text{in metres})}$

So, $+2.5 = \dfrac{1}{f}$

and $f = \dfrac{1}{2.5}$ m

$$= \frac{1}{2.5} \times 100 \text{ cm}$$

So, Focal length, $f = 40$ cm (or + 40 cm)

Sample Problem 5. A lens has a power of, – 2.5 D. What is the focal length and nature of the lens ?

Solution. The power of this lens has minus sign, so it is a concave lens. Calculate the focal length yourself as shown in the above question. The focal length will be, – 40 cm.

Sample Problem 6. Find the power of a concave lens of focal length 2 m. **(NCERT Book Question)**

Solution. A concave lens has negative focal length, so it is to be written with a minus sign. Thus,

Focal length, $f = -2$ m (It is in metres)

Now, Power, $P = \dfrac{1}{f\,(\text{in metres})}$

$$P = \frac{1}{-2}$$

$$P = -0.5 \text{ D}$$

Thus, the power of this concave lens is, – 0.5 dioptre.

Sample Problem 7. A convex lens forms a real and inverted image of a needle at a distance of 50 cm from the lens. If the image is of the same size as the needle, where is the needle placed in front of the lens? Also, find the power of the lens. **(NCERT Book Question)**

Solution. (*i*) In this case needle is the object. Since the image is real, inverted and of same size as the needle (or object), the needle must be at the same distance (50 cm) in front of lens, as the image is behind the lens. Thus, the needle is placed at a distance of 50 cm from lens in the front.

(*ii*) When the image formed by a convex lens is of the same size as the needle (or object), then the distance of needle from the lens is $2f$ (twice the focal length). In this case :

$$2f = 50 \text{ cm}$$

So,
$$f = \frac{50}{2} \text{ cm}$$
$$f = 25 \text{ cm}$$

Thus, the focal length of this convex lens is +25 cm. This is equal to $\frac{+25}{100}$ m or + 0.25 m. Now,

$$\text{Power, } P = \frac{1}{f \text{ (in metres)}}$$
$$= \frac{1}{+0.25} = +4.0 \text{ D}$$

So, the power of this convex lens is + 4.0 dioptres.

Power of a Combination of Lenses

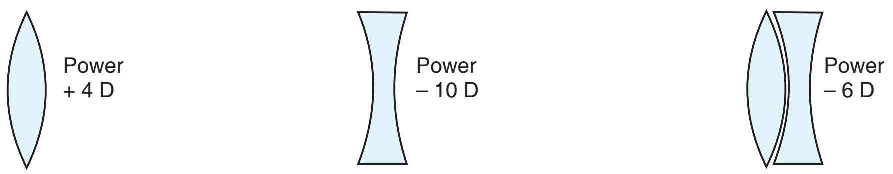
If a number of lenses are placed in close contact, then the power of the combination of lenses is equal to the algebraic sum of the powers of individual lenses. Thus, if two lenses of powers p_1 and p_2 are placed in contact with each other, then their resultant power P is given by :

$$P = p_1 + p_2$$

For example, if a convex lens of power, + 4 D and a concave lens of power, –10 D are placed in contact with each other, then their resultant power will be :

$$P = p_1 + p_2$$
$$= +4 + (-10)$$
$$= 4 - 10$$
$$= -6 \text{ D}$$

This shows that a combination of convex lens of power + 4 D and a concave lens of power, – 10 D has a resultant power of , – 6 D. So, this combination of convex lens and concave lens behaves like a concave lens (of power, – 6 dioptres). This is shown clearly in the Figure given below :



(*a*) Convex lens (*b*) Concave lens (*c*) Combination of convex lens and concave lens

Figure 50. A combination of convex lens of power +4 D and a concave lens of power, –10 D kept in close contact has a resultant power of, – 6 D.

In general, if a number of thin lenses having powers p_1, p_2, p_3, ...etc., are placed in close contact with one another, then their resultant power P is given by :

$$P = p_1 + p_2 + p_3 + \ldots\ldots\ldots\ldots$$

Please note that the individual powers p_1, p_2, p_3, etc., of the lenses should be put in the above formula with their proper signs.

The use of powers of lenses (instead of their focal lengths) makes the work of opticians very simple and straightforward. For example, when an optician places two convex lenses of powers +2.0 D and +0.25 D in front of a person's eye during eye-testing, he immediately knows that this convex lens combination is equivalent to a single convex lens of power +2.25 D.

The lens systems consisting of several lenses in contact are used in designing the optical instruments like cameras, microscopes and telescopes, etc. The use of a combination of lenses increases the sharpness of the image. The image produced by using a combination of lenses is also free from many defects which otherwise occur while using a single lens. We will now solve a problem based on combination of lenses.

Sample Problem. Two thin lenses of power, + 3.5 D and, – 2.5 D are placed in contact. Find the power and focal length of the lens combination. **(NCERT Book Question)**

Solution. We know that :

Power of combination of lenses, $P = p_1 + p_2$

So, $P = +3.5 + (-2.5)$

$P = +3.5 - 2.5$

$P = +1.0$ D

Thus, the power of this combination of lenses is, +1.0 dioptre.

We will now calculate the focal length of this combination of lenses. We know that :

Power, $P = \frac{1}{f}$

or $+1 = \frac{1}{f}$

And, $f = +1$ m

So, the focal length of this combination of lenses is, +1 metre.

We are now in a position to **answer the following questions and problems :**

Very Short Answer Type Questions

1. The lens *A* has a focal length of 25 cm whereas another lens *B* has a focal length of 60 cm. Giving reason state, which lens has more power : *A* or *B*.
2. Which causes more bending (or more refraction) of light rays passing through it : a convex lens of long focal length or a convex lens of short focal length ?
3. Name the physical quantity whose unit is dioptre.
4. Define 1 dioptre power of a lens.
5. Which type of lens has (*a*) a positive power, and (*b*) a negative power ?
6. Which of the two has a greater power : a lens of short focal length or a lens of large focal length ?
7. How is the power of a lens related to its focal length ?
8. Which has more power : a thick convex lens or a thin convex lens, made of the same glass ? Give reason for your choice.
9. The focal length of a convex lens is 25 cm. What is its power ?
10. What is the power of a convex lens of focal length 0.5 m ?
11. A converging lens has a focal length of 50 mm. What is the power of the lens ?
12. What is the power of a convex lens whose focal length is 80 cm ?
13. A diverging lens has a focal length of 3 cm. Calculate the power.
14. The power of a lens is + 0.2 D. Calculate its focal length.
15. The power of a lens is, – 2 D. What is its focal length ?
16. What is the nature of a lens having a power of + 0.5 D ?
17. What is the nature of a lens whose power is, – 4 D ?
18. The optician's prescription for a spectacle lens is marked + 0.5 D. What is the :
    (*a*) nature of spectacle lens ?
    (*b*) focal length of spectacle lens ?
19. A doctor has prescribed a corrective lens of power, –1.5 D. Find the focal length of the lens. Is the prescribed lens diverging or converging ?

20. A lens has a focal length of, –10 cm. What is the power of the lens and what is its nature ?

21. The focal length of a lens is +150 mm. What kind of lens is it and what is its power ?

22. Fill in the following blanks with suitable words :

(*a*) The reciprocal of the focal length in metres gives you the ....of the lens, which is measured in.........

(*b*) For converging lenses, the power is............while for diverging lenses, the power is..............

Short Answer Type Questions

23. An object of height 4 cm is placed at a distance of 15 cm in front of a concave lens of power, –10 dioptres. Find the size of the image.

24. An object of height 4.25 mm is placed at a distance of 10 cm from a convex lens of power +5 D. Find (*i*) focal length of the lens, and (*ii*) size of the image.

25. A convex lens of power 5 D and a concave lens of power 7.5 D are placed in contact with each other. What is the :

(*a*) power of this combination of lenses ?

(*b*) focal length of this combination of lenses ?

26. A convex lens of focal length 25 cm and a concave lens of focal length 10 cm are placed in close contact with one another.

(*a*) What is the power of this combination ?

(*b*) What is the focal length of this combination ?

(*c*) Is this combination converging or diverging ?

27. The power of a combination of two lenses *X* and *Y* is 5 D. If the focal length of lens *X* be 15 cm :

(*a*) calculate the focal length of lens *Y*.

(*b*) state the nature of lens *Y*.

28. Two lenses *A* and *B* have focal lengths of + 20 cm and, –10 cm, respectively.

(*a*) What is the nature of lens *A* and lens *B* ?

(*b*) What is the power of lens *A* and lens *B* ?

(*c*) What is the power of combination if lenses *A* and *B* are held close together ?

Long Answer Type Questions

29. (*a*) What do you understand by the power of a lens ? Name one factor on which the power of a lens depends.

(*b*) What is the unit of power of a lens ? Define the unit of power of a lens.

(*c*) A combination of lenses for a camera contains two converging lenses of focal lengths 20 cm and 40 cm and a diverging lens of focal length 50 cm. Find the power and focal length of the combination.

30. (*a*) Two lenses *A* and *B* have power of (*i*) + 2 D and (*ii*) – 4 D respectively. What is the nature and focal length of each lens ?

(*b*) An object is placed at a distance of 100 cm from each of the above lenses *A* and *B*. Calculate (*i*) image distance, and (*ii*) magnification, in each of the two cases.

Multiple Choice Questions (MCQs)

31. The focal lengths of four convex lenses *P*, *Q*, *R* and *S* are 20 cm, 15 cm, 5 cm and 10 cm, respectively. The lens having greatest power is :

(*a*) *P* (*b*) *Q* (c) *R* (*d*) *S*

32. A converging lens has a focal length of 50 cm. The power of this lens is :

(*a*) + 0.2 D (*b*) – 2.0 D (*c*) + 2.0 D (*d*) – 0.2 D

33. A diverging lens has a focal length of 0.10 m. The power of this lens will be :

(*a*) + 10.0 D (*b*) + 1.0 D (*c*) – 1.0 D (*d*) – 10.0 D

34. The power of a lens is + 2.0 D. Its focal length should be :

(*a*) 100 cm (*b*) 50 cm (*c*) 25 cm (*d*) 40 cm

35. If a spherical lens has a power of, – 0.25 D, the focal length of this lens will be :

(*a*) – 4 cm (*b*) – 400 mm (*c*) – 4 m (*d*) – 40 m

36. The power of a concave lens is 10 D and that of a convex lens is 6 D. When these two lenses are placed in contact with each other, the power of their combination will be :

(*a*) + 16 D (*b*) + 4 D (*c*) –16 D (*d*) – 4 D

37. The power of a converging lens is 4.5 D and that of a diverging lens is 3 D. The power of this combination of lenses placed close together is :

(*a*) + 1.5 D (*b*) + 7.5 D (*c*) – 7.5 D (*d*) – 1.5 D

38. A convex lens of focal length 10 cm is placed in contact with a concave lens of focal length 20 cm. The focal length of this combination of lenses will be :

(*a*) + 10 cm (*b*) + 20 cm (*c*) – 10 cm (*d*) – 20 cm

Questions Based on High Order Thinking Skills (HOTS)

39. The optical prescription for a pair of spectacles is :

Right eye : – 3.50 D Left eye : – 4.00 D

(*a*) Are these lenses thinner at the middle or at the edges ?

(*b*) Which lens has a greater focal length ?

(*c*) Which is the weaker eye ?

40. A person got his eyes tested by an optician. The prescription for the spectacle lenses to be made reads :

Left eye : + 2.50 D Right eye : + 2.00 D

(*a*) State whether these lenses are thicker in the middle or at the edges.

(*b*) Which lens bends the light rays more strongly ?

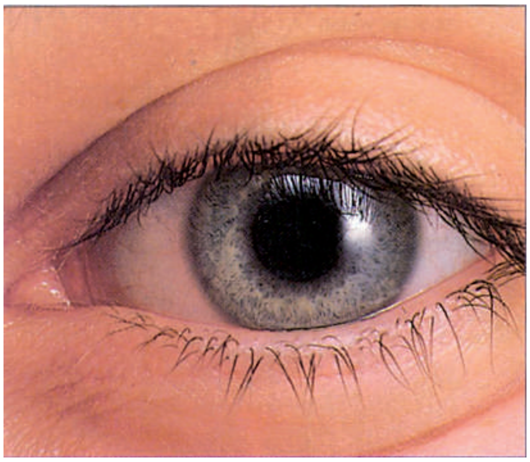
(*c*) State whether these spectacle lenses will converge light rays or diverge light rays.

ANSWERS

1. Lens *A* has more power ; It has shorter focal length. **2.** Convex lens of short focal length **6.** Lens of short focal length **8.** Thick convex lens ; It has shorter focal length **9.** + 4 D **10.** + 2 D **11.** + 20 D **12.** + 1.25 D **13.** – 33.3 D **14.** + 5 m **15.** – 50 cm **16.** Convex lens **17.** Concave lens **18.** (*a*) Convex lens (*b*) 2 m **19.** – 66.6 cm ; Diverging lens **20.** –10 D ; Concave lens **21.** Convex lens ; + 6.6 D **22.** (*a*) power ; dioptres (*b*) positive ; negative **23.** 1.6 cm **24.** (*i*) 20 cm (*ii*) 8.50 mm **25.** (*a*) –2.5 D (*b*) – 40 cm **26.** (*a*) – 6 D (*b*) –16.66 cm (*c*) Diverging **27.** (*a*) – 60 cm (*b*) Concave lens **28.** (*a*) Lens *A* is convex ; Lens *B* is concave (*b*) Power of lens $A = +5$ D ; Power of lens $B = -10$ D (*c*) – 5 D **29.** (*c*) $P = +5.5$ D ; $f = +18.18$ cm **30.** (*a*) Lens *A* is convex ; $f = +50$ cm ; Lens *B* is concave ; $f = -25$ cm (*b*) Lens A : $v = +100$ cm ; $m = -1$; Lens B : $v = -20$ cm ; $m = 0.2$ **31.** (*c*) **32.** (*c*) **33.** (*d*) **34.** (*b*) **35.** (*c*) **36.** (*d*) **37.** (*a*) **38.** (*b*) **39.** (*a*) Thinner at the middle (*b*) Lens of lower power : – 3.50 D (*c*) Left eye **40.** (*a*) Thicker in the middle (*b*) Lens having greater power of + 2.50 D (*c*) Converge light rays.

CHAPTER

6



The Human Eye And The Colourful World

In the previous Chapter we have studied the refraction of light by lenses (convex lenses and concave lenses). The optical instruments such as cameras, microscopes, telescopes, film projectors and spectacles, etc., work on the refraction of light through various types of artificial lenses (man-made lenses) made of transparent glass. **The human eye works on the refraction of light through a natural convex lens made of transparent living material and enables us to see things around us**. Our eye is the most important optical instrument gifted to us by the God. Without eye, all other optical instruments would have no value at all. In this chapter we will study the structure and working of the human eye. We will also describe the common defects of eye (or defects of vision) and how they are corrected by using various types of lenses (in the form of spectacles). And finally, we will discuss the refraction of light through a glass prism, atmospheric refraction and scattering of light by atmosphere. Let us start with the human eye.

THE HUMAN EYE

The main parts of the human eye are : Cornea, Iris, Pupil, Ciliary muscles, Eye lens, Retina and Optic nerve (see Figure 1). The eye-ball is approximately spherical in shape having a diameter of about 2.5 cm. We will now describe the construction and working of the eye.

Construction of the Eye

The front part of the eye is called cornea. It is made of a transparent substance and it is bulging outwards. The outer surface of cornea is convex in shape. The light coming from objects enters the eye through cornea. Just behind the cornea is the iris (or coloured diaphragm). Iris is a flat, coloured, ring-shaped membrane behind the cornea of the eye. There is a hole in the middle of the iris which is called pupil of the eye. Thus, *pupil is a hole in the middle of the iris.* The pupil appears black because no light is reflected from it.

The eye-lens is a convex lens made of a transparent, soft and flexible material like a jelly made of proteins. Being flexible, the eye-lens can change its shape (it can become thin or thick) to focus light on to the retina. The eye-lens is held in position by suspensory ligaments. One end of suspensory ligaments is attached to the eye-lens and their other end is attached to ciliary muscles (see Figure 1). Ciliary muscles change the thickness of eye-lens while focusing. In other words, the focal length of eye-lens (and hence its converging power) can be changed by changing its shape by the action of ciliary muscles. In this respect an eye differs from a camera. The focal length of the convex lens used in a camera is fixed and cannot be changed but the focal length of the convex lens present inside the eye can be changed by the action of ciliary muscles.

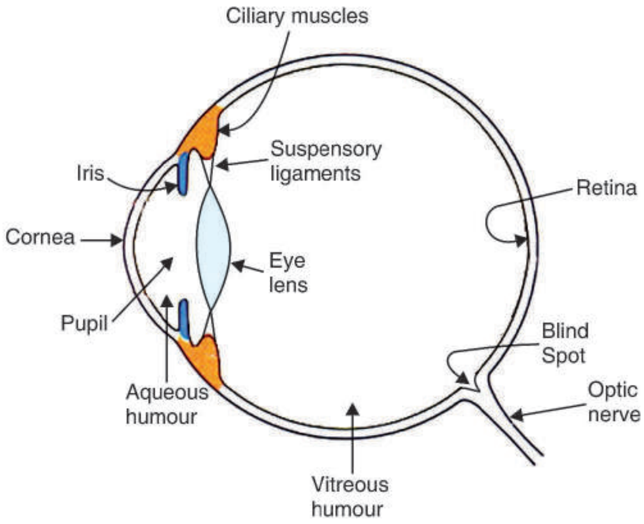


Figure 1. The structure of human eye.

The screen on which the image is formed in the eye is called retina. The retina is behind the eye-lens and at the back part of the eye. The retina of an eye is just like the film in a camera. The retina is a delicate membrane having a large number of light sensitive cells called 'rods' and 'cones' which respond to the 'intensity of light' and 'colour of objects' respectively, by generating electrical signals. At the junction of optic nerve and retina in the eye, there are no light sensitive cells (no rods or cones) due to which no vision is possible at that spot. This is called blind spot. Thus, **blind spot is a small area of the retina insensitive to light where the optic nerve leaves the eye** (see Figure 1). When the image of an object falls on the blind spot, it cannot be seen by the eye. It should be noted that there is an eye-lid in front of the eye which is just like the shutter in a camera. When eye-lid is open, light can enter the eye but when eye-lid is closed, no light enters the eye. The space between cornea and eye-lens is filled with a watery liquid called 'aqueous humour'. And the space between eye-lens and retina is filled with a transparent jelly like substance called 'vitreous humour' which supports the back of the eye.

Working of the Eye

The light rays coming from the object kept in front of us enter through the cornea of the eye, pass through the pupil of the eye and fall on the eye-lens. The eye-lens is a convex lens, so it converges the light rays and produces a real and inverted image of the object on the retina. (Actually, the outer surface of cornea also acts as a convex lens due to which cornea converges most of the light rays entering the eye. Only the final convergence of light rays is done by the eye-lens to focus the image of an object exactly on the retina). The image formed on the retina is conveyed to the brain by the optic nerve and gives rise to the sensation of vision. Actually, the retina has a large number of light-sensitive cells. When the image falls on the retina then these light-sensitive cells get activated and generate electrical signals. The retina sends these electrical signals to the brain through the optic nerve and gives rise to the sensation of vision. Although the image formed on the retina is inverted, our mind interprets the image as that of an erect object. **As far as physics is concerned, the eye consists of a convex lens (called eye-lens) and a screen (called retina). The eye-lens forms a real image of the objects on the retina of the eye and we are able to see the objects.**

The human eye is like a camera. In the eye, a convex lens (called eye-lens) forms a real and inverted image of an object on the light-sensitive screen called retina whereas in a camera, the convex lens (called camera-lens) forms a real and inverted image of an object on the light sensitive photographic film.

The Function of Iris and Pupil

The iris controls the amount of light entering the eyes. The iris automatically adjusts the size of the pupil according to the intensity of light received by the eye. **If the amount of light received by the eye is large (as during the day time), then the iris contracts the pupil (makes the pupil small) and reduces the amount of light entering the eye** (see Figure 2). On the other hand, **if the amount of light received by the**

eye is small (as in a dark room or during night), the iris expands the pupil (makes the pupil large) so that more light may enter the eyes (see Figure 3). Thus, the iris regulates (or controls) the amount of light entering the eye by changing the size of the pupil. The iris makes the pupil 'expand' or 'contract' according to the intensity of light around the eye. If the intensity of the outside light is low, then the pupil expands to allow more light to enter the eye. On the other hand, if outside intensity of light is high, then the pupil contracts so that less light enters the eye.

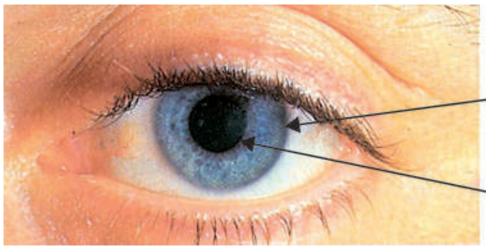


Figure 2. When outside light is bright, pupil becomes small, so that less light goes into the eye.

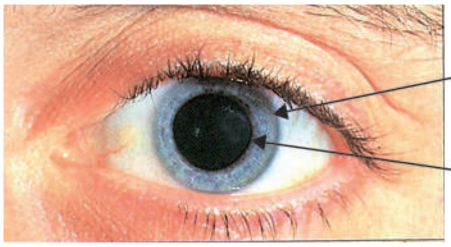


Figure 3. When outside light is dim, pupil becomes large, so that more light enters the eye.

It should be noted that **the adjustment of the size of the pupil takes some time**. For example, when we go from a bright light to a darkened cinema hall, at first we cannot see our surroundings clearly. After a short time our vision improves, and we can see the persons sitting around us. This is due to the fact that in bright sunlight the pupil of our eye is small. So, when we enter the darkened cinema hall, very little light enters our eye and we cannot see properly. After a short time, the pupil of our eye expands and becomes large. More light then enters our eye and we can see clearly. On the other hand, if we go from a dark room into bright sunlight or switch on a bright lamp, then we feel the glare in our eyes. This is due to the fact that in a dark room, the pupil of our eye is large. So, when we go out from a dark room into bright sunlight or switch on a bright lamp, a large amount of light enters our eyes and we feel the glare. Gradually, the pupil of our eye contracts. Less light then enters our eye and we can see clearly. In this way, the iris also protects our eyes from the glare of bright lights.

Rods and Cones

The retina of our eye has a large number of light-sensitive cells. There are two kinds of light-sensitive cells on the retina : rods and cones.

(*i*) **Rods are the rod-shaped cells present in the retina of an eye which are sensitive to dim light**. Rods are the most important for vision in dim light (as during the night). We can see things to some extent in a dark room or in the darkness of night due to the presence of rod cells in the retina of our eyes. Nocturnal animals (animals which sleep during the day and come out at night) like the owl have a large number of rod cells in their retina which help them see properly during the night when there is not much light (see Figure 4). In fact, our night vision is relatively poor as compared to the night vision of an owl due to the presence of relatively smaller number of rod cells in the retinas of our eyes. Rod cells of the retina, however, do not provide information about the colour of the object.

Figure 4. An owl has very large number of 'rod' cells in the retina of its eyes. These help the owl to see properly even in dim light during the night.

Figure 5. We can see the various colours in this picture due to the presence of 'cone' cells in the retina of our eyes.

(*ii*) Cones are the cone-shaped cells present in the retina of an eye which are sensitive to bright light (or normal light). The cone cells of our retina also respond to colours. In other words, **cone cells cause the sensation of colour of objects in our eyes**. The cone-shaped cells of the retina make us see colours and also make us distinguish between various colours (see Figure 5). Cone cells of the retina function only in bright light. **The cones do not function in dim light**. This is why when it is getting dark at night, it becomes impossible to see colours of cars on the road.

An Important Discussion

A normal eye can see the *distant* objects as well as the *nearby* objects clearly due to its power of accommodation. Before we discuss the power of accommodation of the eye, we should know the difference between the *distant* objects and *nearby* objects from the point of view of light rays received from them. This is described below.

(*i*) The rays of light coming from a distant object (at infinity) are parallel to one another when they reach the eye [see Figure 6(*a*)]. Actually, the rays of light given out by the distant object are diverging in the beginning but they become parallel when they reach the eye after travelling a large distance. The parallel rays of light coming from a distant object need a convex eye-lens of *low converging power* to converge them or focus them to form an image on the retina of the eye. The convex eye-lens of low converging power is the one having a *large* focal length and it is quite *thin.*

(*a*) The light rays coming from a distant object are parallel

(*b*) The light rays coming from a nearby object are diverging

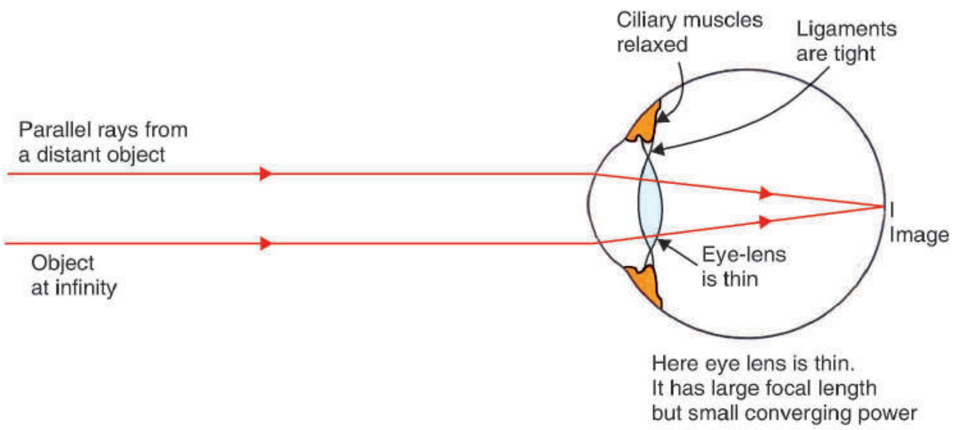
Figure 6.

(*ii*) The rays of light coming from a nearby object are diverging (or spreading out) when they reach the eye [see Figure 6(*b*)]. The diverging rays coming from a nearby object need a convex eye-lens of *high converging power* to converge them or focus them to form an image on the retina of the eye. The convex eye-lens of high converging power is the one having a *short* focal length and it is quite *thick.* Keeping these points in mind, it will now be easy for us to understand the power of accommodation of the eye.

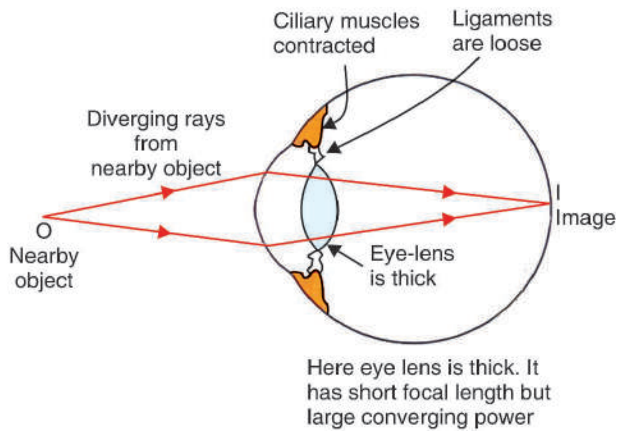
Accommodation

A normal eye can see the *distant* objects as well as the *nearby* objects clearly. We will now discuss how the eye is able to focus the objects lying at various distances. **An eye can focus the images of the distant objects as well as the nearby objects on its retina by changing the focal length (or converging power) of its lens.** The focal length of the eye-lens is changed by the action of ciliary muscles. The ciliary muscles can change the thickness of the soft and flexible eye-lens and hence its focal length which, in turn, changes the converging power of the eye-lens. Let us see how it happens.

When the eye is looking at a distant object (at infinity), then the ciliary muscles of the eye are fully relaxed. The relaxed ciliary muscles of the eye pull the suspensory ligaments attached to the eye-lens tightly. The suspensory ligaments, in turn, pull the eye-lens due to which the eye-lens gets stretched and becomes thin (or less convex) [see Figure 7 (*a*)]. The thin eye-lens has large focal length but its converging power is small. The small converging power of thin eye-lens is sufficient to converge the parallel rays of light coming from a distant object to form an image on the retina of the eye [see Figure 7(*a*)]. When the eye is looking at a distant object, the eye is said to be *unaccommodated* because it is the relaxed state of the eye.



(*a*) An eye focused on a distant object (at infinity).



(*b*) An eye focused on a nearby object

Figure 7. Diagrams to show how an eye can focus the distant objects as well as nearby objects by changing the thickness (or converging power) of its lens.

The thin eye-lens is not powerful enough to converge the diverging light rays coming from the nearby objects onto the retina. So, to look at the nearby objects, the eye-lens has to change its shape and become thick (or more convex) to increase its converging power. This happens as follows :

When the same eye has to look at a nearby object, the ciliary muscles of the eyes contract. The contracted ciliary muscles make the suspensory ligaments loose. When the suspensory ligaments become loose, they stop pulling the eye-lens. The eye-lens bulges under its own elasticity and becomes thick (or more convex) [see Figure 7(*b*)]. The thick eye-lens has small focal length but its converging power is large. Since the converging power of eye-lens increases, the thick eye-lens can converge the diverging light rays coming from the nearby object to form an image on the retina of the eye. This is shown in Figure 7(*b*) in which an object *O* is near to the eye. It has been focused by the thick eye-lens to form an image *I* on the retina. *When the eye-lens becomes more convex to focus the nearby objects, the eye is said to be 'accommodated'*. We can now say that : **The ability of an eye to focus the distant objects as well as the nearby objects on the retina by changing the focal length (or converging power) of its lens is called accommodation.**

The maximum "accommodation" of a normal eye is reached when the object is at a distance of about 25 cm from the eye. After this the ciliary muscles cannot make the eye-lens more thick (or more convex). So, an object placed at a distance of less than 25 cm cannot be seen clearly by a normal eye because all the power of accommodation of the eye has already been exhausted. Thus, **a normal eye has a power of accommodation which enables objects as far as infinity and as close as 25 cm to be focused on the retina.** The power of accommodation of the eye for a person having normal vision (normal eyesight) is about 4 dioptres.

Range of Vision of a Normal Human Eye

We will first understand the meaning of far point and near point of an eye. **The farthest point from the eye at which an object can be seen clearly is known as the "far point" of the eye.** The far point of a normal human eye is at **infinity** (see Figure 8). This means that the far point of a normal human eye is at a very large distance. **The nearest point up to which the eye can see an object clearly without any strain, is called the "near point" of the eye.** The near point of a normal human eye is at a distance of **25 centimetres** from the eye.

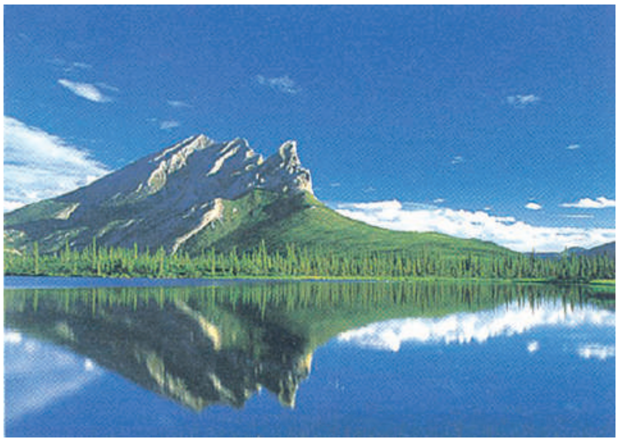


Figure 8. We can see the distant mountains, clouds and sky because the far point of our eye is at infinity.

The near point of an eye is also known by another name as the least distance of distinct vision. **The minimum distance at which an object must be placed so that a normal eye may see it clearly without any strain, is called the least distance of distinct vision.** The least distance of distinct vision for a normal human eye is about **25 centimetres.** For example, to read a book clearly and comfortably without putting a strain on the eyes, it must be held at a distance of 25 centimetres from our eyes. If we try to read a book by holding it very close to our eyes, we will feel a lot of strain on the eyes and the image of printed matter of the book will also look blurred.

From the above discussion we conclude that **the range of vision of a normal human eye is from infinity to about 25 centimetres.** That is, a normal human eye can see the objects clearly which are lying anywhere between infinity to about 25 centimetres. Let us answer one question now.

Sample Problem. What happens to the image distance in the eye when we increase the distance of an object from the eye ? **(NCERT Book Question)**

Answer. In the eye, the image distance (distance between eye-lens and retina) is fixed by the God which cannot be changed. So, when we increase the distance of an object from the eye, there is no change in the image distance inside the eye.

Before we go further and study the common defects of vision, **please answer the following questions :**

Very Short Answer Type Questions

1. What kind of lens is present in the human eye ?

2. Name two parts of the eye which refract light rays (or bend light rays).

3. Name the part of the eye :
   (*a*) which controls the amount of light entering the eye.
   (*b*) on which the image is formed.
   (*c*) which changes the focal length of eye-lens.

4. What is the name of :
   (*a*) the curved, transparent front surface of the eye ?
   (*b*) the light-sensitive layer in the eye ?

5. Where is the image formed in a human eye ?

6. What is the function of the lens in the human eye ?

7. What job does the pupil of the eye do ?

8. How does the eye adjust to take account of an increase in brightness ?

9. Name that part of the eye which is equivalent to the photographic film in a camera.

10. Name the part of the retina which is insensitive to light.

11. Which part of the eye contains cells which are sensitive to light ?

12. Name two types of cells in the retina of an eye which respond to light.

13. Out of rods and cones in the retina of your eye :
(*a*) which detect colour ?
(*b*) which work in dim light ?

14. State whether the following statement is true or false :
The image formed on our retina is upside-down

15. What is the principal function of the eye-lens ?

16. Where does the greatest degree of refraction of light occur in the eye ?

17. What changes the shape of lens in the eye ?

18. What do the ciliary muscles do when you are focusing on a nearby object ?

19. What is the least distance of distinct vision for a normal human eye ?

20. What is the :
(*a*) far point of a normal human eye ?
(*b*) near point of a normal human eye ?

21. What is the range of vision of a normal human eye ?

22. Name the part of our eyes which helps us to focus near and distant objects in quick succession.

23. Define the term "power of accommodation" of human eye.

24. Give the scientific names of the following parts of the eye :
(*a*) carries signals from an eye to the brain.
(*b*) muscles which change the shape of the eye-lens.
(*c*) a hole in the middle of the iris.
(*d*) a clear window at the front of the eye.
(*e*) changes shape to focus a picture on the retina.

25. Fill in the following blanks with suitable words :
(*a*) Most of the refraction of light rays entering the eye occurs at the outer surface of the............
(*b*) The part of eye sensitive to light is..................
(*c*) The part of eye which alters the size of the pupil is..............
(*d*) When light is dim, the pupil becomes...............
(*e*) The iris controls the amount of..................entering the eye.
(*f*) The ciliary muscles control the shape of the ....
(*g*) To bring light from a distant object to a focus on the retina of the eye, the convex eye-lens needs to be made..........
(*h*) To bring light from a near object to a focus on the retina of the eye, the convex eye-lens needs to be made.......

Short Answer Type Questions

26. Why is a normal eye not able to see clearly the objects placed closer than 25 cm ?

27. What changes take place in the shape of eye-lens :
(*a*) when the eye is focused on a near object ?
(*b*) when the eye is focused on a distant object ?

28. The eyes of a person are focused (*i*) on a nearby object, and (*ii*) on a distant object, turn by turn. In which case :
(*a*) the focal length of eye-lens will be the maximum ?
(*b*) the converging power of eye-lens will be the maximum ?

29. What change is made in the eye to enable it to focus on objects situated at different distances ? Illustrate your answer with the help of diagrams.

30. How is the amount of light entering the eye controlled ?

31. What happens to the eye when you enter a darkened cinema hall from bright sunshine ? Give reason for your answer.

32. Why does it take some time to see objects in a dim room when you enter the room from bright sunshine outside ?

33. A person walking in a dark corridor enters into a brightly lit room :
(*a*) State the effect on the pupil of the eye.
(*b*) How does this affect the amount of light entering the eye ?

34. Ciliary muscles of human eye can contract or relax. How does it help in the normal functioning of the eye ?

35. Describe and explain, how a normal eye can see objects lying at various distances clearly.

36. There are two types of light-sensitive cells in the human eye :
(*a*) Where are they found ?
(*b*) What is each type called ?
(*c*) To what is each type of cell sensitive ?

37. What are rods and cones in the retina of an eye ? Why is our night vision relatively poor compared to the night vision of an owl ?

38. (*a*) How does the convex eye-lens differ from the ordinary convex lens made of glass ?
(*b*) List, in order, the parts of the eye through which light passes to reach the retina.

39. (*a*) What happens to the size of pupil of our eye (*i*) in dim light (*ii*) in bright light ?
(*b*) Name the cells on the retina of an eye which are sensitive to (*i*) bright light (*ii*) dim light (*iii*) sensation of colour.

Long Answer Type Questions

40. (*a*) Draw a simple diagram of the human eye and label clearly the cornea, iris, pupil, ciliary muscles, eye-lens, retina, optic nerve and blind spot.
(*b*) Describe the working of the human eye with the help of the above diagram.
(*c*) How does the eye adjust itself to deal with light of varying intensity ?

41. (*a*) Explain the functions of the following parts of the eye :
(*a*) cornea (*b*) iris (*c*) pupil (*d*) ciliary muscles (*e*) eye-lens
(*f*) retina (*g*) optic nerve
(*b*) If you walk from a dark room into sunlight and back again into dark room, how would your pupils alter in size ? What makes this happen ?
(*c*) Explain why, we cannot see our seats first when we enter a darkened cinema hall from bright light but gradually they become visible.

Multiple Choice Questions (MCQs)

42. The human eye forms the image of an object at its :
(*a*) cornea (*b*) iris (*c*) pupil (*d*) retina

43. The change in focal length of an eye-lens is caused by the action of the :
(*a*) pupil (*b*) retina (*c*) ciliary muscles (*d*) iris

44. The least distance of distinct vision for a young adult with normal vision is about :
(*a*) 25 m (*b*) 2.5 cm (*c*) 25 cm (*d*) 2.5 m

45. Refraction of light in the eye occurs at :
(*a*) the lens only (*b*) the cornea only (*c*) both the cornea and the lens (*d*) the pupil

46. To focus the image of a nearby object on the retina of an eye :
(*a*) the distance between eye-lens and retina is increased
(*b*) the distance between eye-lens and retina is decreased
(*c*) the thickness of eye-lens is decreased
(*d*) the thickness of eye-lens is increased

47. The term "accommodation" as applied to the eye, refers to its ability to :
(*a*) control the light intensity falling on the retina
(*b*) erect the inverted image formed on the retina
(*c*) vary the focal length of the lens
(*d*) vary the distance between the lens and retina

48. Which of the following controls the amount of light entering the eye ?
(*a*) ciliary muscles (*b*) lens (*c*) iris (*d*) cornea

49. The human eye possesses the power of accommodation. This is the power to :
(*a*) alter the diameter of the pupil as the intensity of light changes
(*b*) distinguish between lights of different colours
(*c*) focus on objects at different distances
(*d*) decide which of the two objects is closer.

50. How does the eye change in order to focus on near or distant objects ?
(*a*) The lens moves in or out (*b*) The retina moves in or out
(*c*) The lens becomes thicker or thinner (*d*) The pupil gets larger or smaller

51. Which of the following changes occur when you walk out of bright sunshine into a poorly lit room ?
(*a*) the pupil becomes larger (*b*) the lens becomes thicker
(*c*) the ciliary muscle relaxes (*d*) the pupil becomes smaller

52. The size of the pupil of the eye is adjusted by :
(*a*) cornea (*b*) ciliary muscles (*c*) optic nerve (*d*) iris

Questions Based on High Order Thinking Skills (HOTS)

53. The descriptions of five kinds of images are given below :
(*a*) diminished and virtual (*b*) enlarged and real
(*c*) enlarged and erect (*d*) real and inverted
(*e*) virtual and the same size
Which one of these describes the image formed :
(*i*) on the retina of the eye ? (*ii*) by a magnifying glass ?
(*iii*) by a convex driving mirror on a car ? (*iv*) by a plane mirror ?
(*v*) on the screen of a slide projector ?

54. What shape are your eye-lenses :
(*a*) when you look at your hand ?
(*b*) when you look at a distant tree ?

55. Suggest how your irises help to protect the retinas of your eyes from damage by bright light.

56. (*a*) Which parts of the eye cause rays of light to converge on the retina ?
(*b*) Which part causes the greatest convergence ?
(*c*) Which part brings the image into sharp focus on the retina ? How does it do this ?

57. An object is moved closer to an eye. What changes must take place in the eye in order to keep the image in sharp focus ?

58. Why does the eye-lens not have to do all the work of converging incoming light rays ?

59. Explain why, when it is getting dark at night, it is impossible to make out the colour of cars on the road.

60. Nocturnal animals (animals which sleep during the day and come out at night) tend to have wide pupils and lot of rods in their retinas. Suggest reasons for this.

ANSWERS

2. Cornea and Eye-lens **3.** (*a*) Iris (*b*) Retina (*c*) Ciliary muscles **4.** (*a*) Cornea (*b*) Retina **10.** Blind spot **11.** Retina **14.** True **16.** At cornea **17.** Ciliary muscles **18.** Make the eye-lens thicker (more converging) **22.** Ciliary muscles **24.** (*a*) Optic nerve (*b*) Ciliary muscles (*c*) Pupil (*d*) Cornea (*e*) Eye-lens **25.** (*a*) cornea (*b*) retina (*c*) iris (*d*) large (*e*) light (*f*) eye-lens (*g*) thinner (*h*) thicker **27.** (*a*) Eye-lens becomes thicker (more convex) (*b*) Eye-lens becomes thinner (less convex) **28.** (*a*) When the eye is focused on a distant object (*b*) When the eye is focused on a nearby object **33.** (*a*) Pupil becomes smaller (*b*) Amount of light entering the eye is reduced **39.** (*i*) Becomes large (*ii*) Becomes small (*b*) (*i*) Cones (*ii*) Rods (*iii*) Cones **42.** (*d*) **43.** (*c*) **44.** (*c*) **45.** (*c*) **46.** (*d*) **47.** (*c*) **48.** (*c*) **49.** (*c*) **50.** (*c*) **51.** (*a*) **52.** (*d*) **53.** (*i*) *d* (*ii*) *c* (*iii*) *a* (*iv*) *e* (*v*) *b* **54.** (*a*) Thick (more convex) (*b*) Thin (less convex) **56.** (*a*) Cornea and Eye-lens (*b*) Cornea (*c*) Eye-lens ; By changing its thickness and hence converging power **57.** Ciliary muscles should change the shape of eye-lens to make it thicker and increase its converging power **58.** Because cornea of the eye also converges light rays entering the eye **59.** The colour detecting cells of the retina of eye called 'cones' do not work well in dim light **60.** Wide pupils allow more light to enter the eye during night ; Rod cells in the retina are sensitive to dim light and hence help in seeing properly at night.

DEFECTS OF VISION AND THEIR CORRECTION

The ability to see is called vision. It is also called eyesight. Vision is known as *'drishti'* in Hindi. Sometimes the eye of a person cannot focus the image of an object on the retina properly. In such cases the vision of a person becomes blurred and he cannot see either the distant objects or nearby objects (or both) clearly and comfortably. The person is said to have a *defect* of vision. The defects of vision are also known as defects of eye. There are three common defects of vision (or defects of eye). These are :

1. **Myopia** (Short-sightedness or Near-sightedness)
2. **Hypermetropia** (Long-sightedness or Far-sightedness), and
3. **Presbyopia.**

These are the *refractive* defects of vision because they are caused by the incorrect refraction of light rays by the eye-lens. These defects of vision can be corrected by using suitable spherical lenses (convex lenses or concave lenses). These lenses are usually used in the form of eye-glasses or spectacles (see Figure 9). We will now describe all these defects of vision and their correction, one by one. Let us start with myopia.

Figure 9. If the lenses in our eyes don't focus properly, wearing spectacles with appropriate lenses helps us see clearly.

1. Myopia (Short-sightedness or Near-sightedness)

A short-sighted person means that the short sight of the person (to see nearby objects) is normal but his long-sight (to see distant objects) is defective. **Myopia (or short-sightedness) is that defect of vision due to which a person cannot see the distant objects clearly (though he can see the nearby objects clearly).** For example, a child having the defect called myopia (or short-sightedness) and sitting on the back benches in the class cannot read the writing on blackboard clearly though he can read his book comfortably. **The far point of an eye suffering from myopia is less than infinity.** Such a person can see clearly only up to a distance of few metres (or even less).

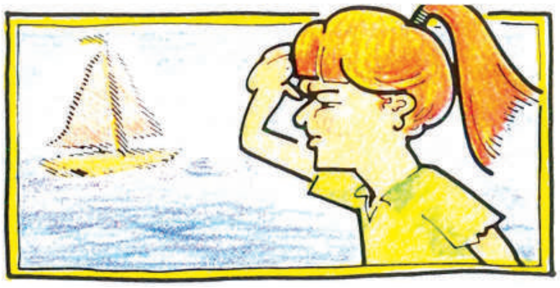


Figure 10. This girl is having the eye-defect called myopia (short-sightedness). She cannot see the distant ship clearly.

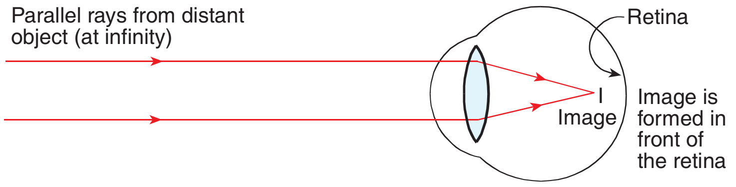
The defect of eye called myopia (or short-sightedness) is caused :

(*i*) due to *high* converging power of eye-lens (because of its *short* focal length), or

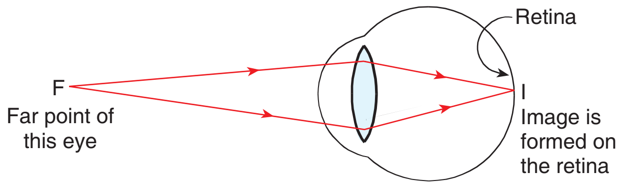
(*ii*) due to eye-ball being too *long*.

In some cases, in an eye suffering from myopia, the ciliary muscles attached to the eye-lens do not relax sufficiently to make the eye-lens thinner to reduce its converging power. So, due to the greater converging power of the eye-lens in myopic eye, the image of a distant object is formed in *front* of the retina and hence the eye cannot see it clearly. In other cases, in the eye suffering from myopia, the eye-ball is too long due to which the retina is at a larger distance from the eye-lens. This condition also results in the formation of the image of a distant object in *front* of the retina (even though the eye-lens may have correct converging power).

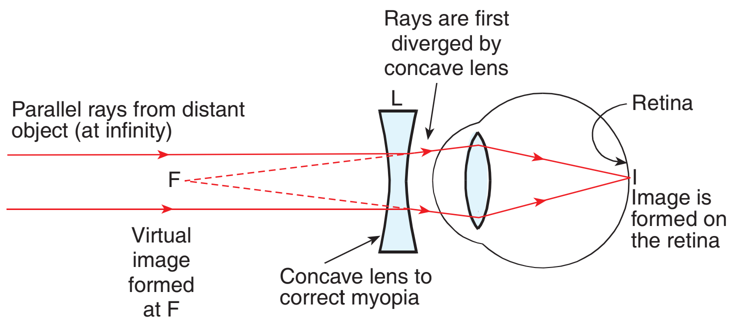
Figure 11(*a*) shows an eye having the defect called myopia (or short-sightedness). In this case, the parallel rays of light coming from the distant object *O* (at infinity) are converged to form an image *I* in front of the retina due to which the eye cannot see the distant object clearly [see Figure 11(*a*)] (The object is at a large distance called infinity from the eye, so it has not been shown in this Figure). The image is formed in front of the retina either due to *high* converging power of eye-lens or due to eye-ball being too *long.*



(*a*) In a myopic eye, image of distant object is formed in front of the retina (and not on the retina)



(*b*) The far point (*F*) of a myopic eye is less than infinity



(*c*) *Correction of myopia*. The concave lens placed in front of the eye forms a virtual image of distant object at far point (*F*) of the myopic eye

Figure 11. Myopia and its correction by using concave lens.

The far point of eye having myopia (or short-sightedness) is at point *F* which is less than infinity [see Figure 11(*b*)]. Please note that the rays of light coming from the person's far point *F* can just be focused by his eye on the retina as shown in Figure 11(*b*). This means that if the distant object can be made to appear as if it were at the far point *F* of this eye, then the eye can see it clearly. This is done by putting a concave lens in front of the eye (as described below).

Myopia (short-sightedness or near-sightedness) is corrected by using spectacles containing concave lenses. When a concave lens (diverging lens) *L* of suitable power is placed in front of the myopic eye as shown in Figure 11(*c*), then the parallel rays of light coming from the distant object (at infinity) are first diverged by the concave lens. Due to this the concave lens forms a virtual image of the distant object at the far point *F* of this myopic eye [see Figure 11(*c*)]. Since the rays of light now appear to be coming from the eye's far point (*F*), they can be easily focused by the eye-lens to form an image on the retina [see Figure 11(*c*)]. **Please note that the concave lens used for correcting myopia should be of such a focal length (or power) that it produces a virtual image of the distant object (lying at infinity) at the far point of the myopic eye.**

It should also be noted that **the whole purpose of using a concave lens here is to reduce the converging power of the eye-lens.** The concave lens used here decreases the converging power of the eye-lens and helps in forming the image of distant object on the retina of the myopic eye.

Calculation of Power of Concave Lens to Correct Myopia. The focal length of concave lens needed to correct myopia (or short-sightedness) in a person is calculated by using the lens formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}\cdot$ In this formula, the object distance u is to be taken as infinity (∞), and the image distance v will be the distance of person's far point (which is different for different persons). Knowing the focal length of the concave lens, we can calculate its power. This will become more clear from the following example.

Sample Problem. The far point of a myopic person is 80 cm in front of the eye. What is the nature and power of the lens required to correct the defect ? **(NCERT Book Question)**

Solution. The defect called myopia is corrected by using a concave lens. So, the person requires concave lens spectacles. We will now calculate the focal length of the concave lens required in this case. The far point of the myopic person is 80 cm. This means that this person can see the distant object (kept at infinity) clearly if the image of this distant object is formed at his far point (which is 80 cm here). So, in this case :

Object distance, $u = \infty$ (Infinity)

Image distance, $v = -80$ cm (Far point, in front of lens)

And, Focal length, $f = ?$ (To be calculated)

Putting these values in the lens formula :

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

we get

$$\frac{1}{-80}-\frac{1}{\infty}=\frac{1}{f}$$

or

$$-\frac{1}{80}-0=\frac{1}{f} \qquad \left(\text{Because } \frac{1}{\infty}=0\right)$$

$$-\frac{1}{80}=\frac{1}{f}$$

$$f = -80 \text{ cm}$$

Thus, the focal length of the required concave lens is 80 cm. We will now calculate its power. Please note that the focal length of, – 80 cm is equal to $\frac{-80}{100}$ m or – 0.8 m. Now,

$$\text{Power, } P = \frac{1}{f\,(\text{in metres})}$$

$$= \frac{1}{-0.8}$$

$$= -\frac{10}{8}$$

$$= -1.25 \text{ D}$$

So, the power of concave lens required is, –1.25 dioptres.

2. Hypermetropia (Long-sightedness or Far-sightedness)

A long-sighted person means that the long-sight of the person (to see distant objects) is normal but his short-sight (to see nearby objects) is defective. **Hypermetropia (or long-sightedness) is that defect of vision due to which a person cannot see the nearby objects clearly (though he can see the distant objects clearly).** For example, a person having the defect hypermetropia cannot read a book clearly and comfortably though he can read the number of a distant bus clearly. **The near-point of a hypermetropic eye is more than 25 centimetres away.** Such a person has to hold the reading material (like a book or newspaper) at an arm's length, much beyond 25 cm from the eye for comfortable reading. Please note that **hypermetropia is just the opposite of myopia.**

The defect of eye called hypermetropia (or long-sightedness) is caused :

(*i*) due to *low* converging power of eye-lens (because of its *large* focal length), or

(*ii*) due to eye-ball being too *short*.

In some cases, the ciliary muscles attached to the eye-lens become weak and cannot make the eye-lens thicker to increase its converging power. So, due to the low converging power of eye-lens in an eye suffering from hypermetropia, the image of nearby object is formed *behind* the retina and hence the eye cannot see it clearly. In other cases, in an eye suffering from hypermetropia, the eye-ball is too short due to which the retina is at a smaller distance from the eye-lens. This condition also results in the formation of the image of a nearby object *behind* the retina (even though the eye-lens may have correct converging power).

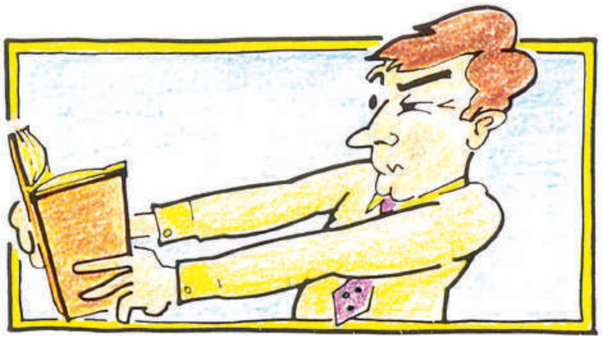
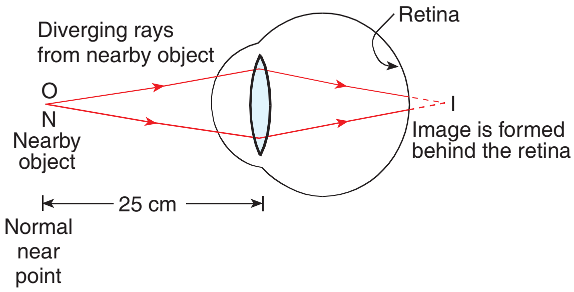
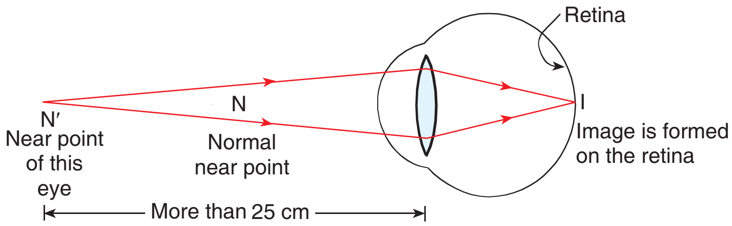


Figure 12. This man is having the eye-defect called hypermetropia (long-sightedness). He cannot read a book clearly by holding it at the normal distance of 25 cm. He has to hold the book at a much larger distance (at arm's length) to be able to read it.

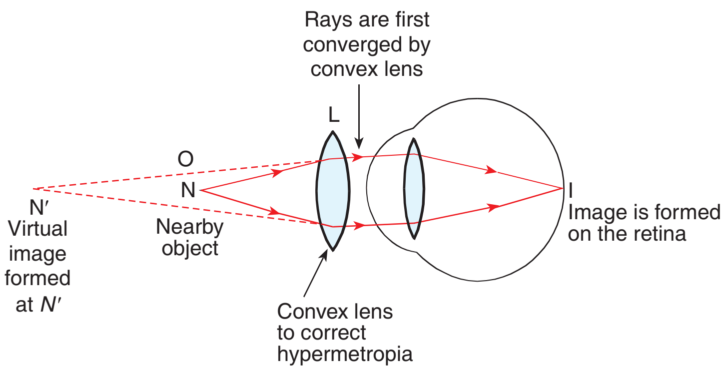
Figure 13(*a*) shows an eye having the defect called hypermetropia (or long-sightedness). In this case the



(*a*) In a hypermetropic eye, the image of nearby object lying at normal near point *N* (at 25 cm) is formed behind the retina.



(*b*) The near point *N′* of hypermetropic eye is farther away from the normal near point *N*



(*c*) *Correction of hypermetropia*. The convex lens forms a virtual image of the object (lying at normal near point *N*) at the near point *N′* of this eye.

Figure 13. Hypermetropia and its correction by using convex lens.

diverging rays of light coming from a nearby object *O* placed at the normal near point *N* (25 cm from the eye) are converged to form an image *I* behind the retina due to which the eye cannot see the nearby object clearly [see Figure 13(*a*)]. The image is formed behind the retina either due to *low* converging power of eye-lens or because of eye-ball being too *short*.

The near-point of an eye having hypermetropia (or long-sightedness) is at point *N*′ which is more than 25 centrimetres away [see Figure 13(*b*)]. The diverging rays of light coming from a hypermetropic person's near point can just be focused by his eye on the retina as shown in Figure 13(*b*). This means that if the object placed at the normal near point *N* (25 cm) can be made to appear as if it were placed at this eye's near point *N*′, then the eye will be able to see it clearly. This can be done by putting a convex lens in front of the eye.

Hypermetropia (long-sightedness or far-sightedness) is corrected by using spectacles containing convex lenses. When a convex lens (converging lens) *L* of suitable power is placed in front of the hypermetropic eye as shown in Figure 13(*c*), then the diverging rays of light coming from the nearby object (at 25 cm) are first converged by this convex lens. Due to this, the convex lens forms a virtual image of the nearby object (which is lying at the normal near point *N*) at the near point *N*′ of the hypermetropic eye [see Figure 13(*c*)]. Since the rays of light now appear to be coming from this eye's near point *N*′, they can be easily focused by the eye-lens to form an image on the retina [see Figure 13(*c*)]. **Please note that the convex lens used for correcting hypermetropia (or long-sightedness) should be of such a focal length (or power) that it forms a virtual image of the object (placed at the normal near point *N* of 25 cm), at the near point *N*′ of the hypermetropic eye.**

It should also be noted that **the whole purpose of using a convex lens here is to increase the converging power of the eye-lens.** The convex lens used in spectacles increases the converging power of eye-lens and helps in forming the image of a nearby object on the retina of the eye.

Calculation of the Power of Convex Lens to Correct Hypermetropia. The focal length of convex lens needed to correct hypermetropia (or long-sightedness) can be calculated by using the lens formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$. In this formula, the object distance *u* is to be taken as the normal near point of the eye (which is 25 cm) and the image distance *v* will be the distance of the near point of the hypermetropic eye. Knowing the focal length of the convex lens, its power can be calculated. This will become more clear from the following example.

Sample Problem. The near point of a hypermetropic eye is 1 m. What is the nature and power of the lens required to correct this defect ? (Assume that the near point of the normal eye is 25 cm).

(NCERT Book Question)

Solution. The eye defect called hypermetropia is corrected by using a convex lens. So, the person requires convex lens spectacles. We will first calculate the focal length of the convex lens required in this case. This hypermetropic eye can see the nearby object kept at 25 cm (at near point of normal eye) clearly if the image of this object is formed at its own near point which is 1 metre here. So, in this case :

Object distance, u = –25 cm (Normal near point)

Image distance, v = –1 m (Near point of this defective eye)

= –100 cm

And, Focal length, f = ? (To be calculated)

Putting these values in the lens formula,

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

We get :

$$\frac{1}{-100}-\frac{1}{-25}=\frac{1}{f}$$

or

$$-\frac{1}{100}+\frac{1}{25}=\frac{1}{f}$$

$$\frac{-1+4}{100} = \frac{1}{f}$$

$$\frac{3}{100} = \frac{1}{f}$$

$$f = \frac{100}{3}$$

$$f = 33.3 \text{ cm}$$

Thus, the focal length of the convex lens required is +33.3 cm. We will now calculate the power. Please note that 33.3 cm is equal to $\frac{33.3}{100}$ m or 0.33 m. Now,

$$\text{Power,} \quad P = \frac{1}{f\,(\text{in metres})}$$

$$= \frac{1}{+0.33}$$

$$= +\frac{100}{33}$$

$$= +3.0 \text{ D}$$

So, the power of convex lens required is +3.0 dioptres.

Myopia and hypermetropia are the two most common defects of vision (or defects of eye). We will now study another defect of vision which occurs in old age. It is called presbyopia.

3. Presbyopia

In old age, due to ciliary muscles becoming weak and the eye-lens becoming inflexible (or rigid), the eye loses its power of accommodation. Because of this an old person cannot see the nearby objects clearly. This leads to the defect called presbyopia. **Presbyopia is that defect of vision due to which an old person cannot see the nearby objects clearly due to loss of power of accommodation of the eye**. For example, an old person having presbyopia cannot read a book or newspaper comfortably and clearly without spectacles. Presbyopia occurs in old age due to the gradual weakening of the ciliary muscles and diminishing flexibility of the eye-lens. **The near-point of the old person having presbyopia gradually recedes and becomes much more than 25 centimetres away.** Actually, presbyopia is a special kind of hypermetropia. We can call it old age hypermetropia. Presbyopia is the hypermetropia (or long-sightedness) caused by the loss of power of accommodation of the eye due to old age. **Presbyopia defect is corrected in the same way as hypermetropia by using spectacles having convex lenses** (see Figure 13).

It is also possible that the same person has both the defects of vision – myopia as well as hypermetropia. A person suffering from myopia as well as hypermetropia uses spectacles having bifocal lenses in which upper part consists of a concave lens (to correct myopia) used for distant vision and the lower part consists of a convex lens (to correct hypermetropia) used for reading purposes (see Figure 14).

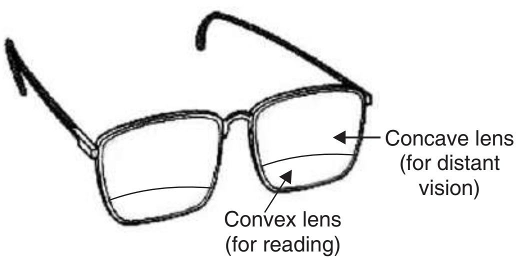


Figure 14. Spectacles having bifocal lenses.

These days it is possible to correct the refractive defects of the eye (such as myopia and hypermetropia) by using contact lenses or by undergoing surgical procedures. Then there is no need to wear spectacles.

Cataract

A yet another defect of the eye which usually comes in old age is the cataract. **The medical condition in which the lens of the eye of a person becomes progressively cloudy resulting in blurred vision is**

called cataract. Cataract develops when the eye-lens of a person becomes cloudy (or even opaque) due to the formation of a membrane over it. Cataract decreases the vision of the eye gradually. It can even lead to total loss of vision of the eye. The vision of the person can be restored after getting **surgery** done on the eye having cataract. The opaque lens is removed from the eye of the person by surgical operation and a new artificial lens is inserted in its place. Please note that the eye-defect called 'cataract' cannot be corrected by any type of spectacle lenses. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Name one of the common defects of vision and the type of lens used to remove it.

2. Name the defect of vision in a person :

(*a*) whose near point is more than 25 cm away.

(*b*) whose far point is less than infinity

3. Which defect of vision can be rectified :

(*a*) by using a concave lens ?

(*b*) by using a convex lens ?

4. What type of lens is used to correct (*a*) hypermetropia (*b*) myopia ?

5. What is the other name for (*a*) myopia (*b*) hypermetropia ?

6. What is the scientific name of (*a*) short-sightedness, and (*b*) long-sightedness ?

7. What kind of lens is used to correct (*a*) short-sightedness (*b*) long-sightedness ?

8. State whether the following statement is true or false :

Short-sightedness can be cured by using a concave lens.

9. Name the defect of vision in which the eye-lens loses its power of accommodation due to old age.

10. Name the defect of vision which makes the eye-lens cloudy resulting in blurred vision.

11. What is the other name of old age hypermetropia ?

12. Name any two defects of vision which can be corrected by using spectacles.

13. Name one defect of vision (or eye) which cannot be corrected by any type of spectacle lenses.

14. Name the body part with which the terms myopia and hypermetropia are connected.

15. What is the far point of a person suffering from myopia (or short-sightedness) ?

16. Where is the near point of a person suffering from hypermetropia (or long-sightedness) ?

17. Your friend can read a book perfectly well but cannot read the writing on blackboard unless she sits on the front row in class.

(*a*) Is she short-sighted or long-sighted ?

(*b*) What type of lenses–converging or diverging–would an optician prescribe for her ?

18. A man can read the number of a distant bus clearly but he finds difficulty in reading a book.

(*a*) From which defect of the eye is he suffering ?

(*b*) What type of spectacle lens should he use to correct the defect ?

19. A student sitting in the last row of the class-room is not able to read clearly the writing on the blackboard.

(*a*) Name the type of defect he is suffering from.

(*b*) How can this defect by corrected ?

20. Complete the following sentences :

(*a*) A short-sighted person cannot see .... objects clearly. Short-sightedness can be corrected by using ....lenses.

(*b*) A long-sighted person cannot see .... objects clearly. Long-sightedness can be corrected by using .... lenses.

Short Answer Type Questions

21. What are the two most common defects of vision (or defects of eye) ? How are they corrected ?

22. Differentiate between myopia and hypermetropia. What type of spectacles should be worn by a person having the defects of myopia as well as hypermetropia ? How does it help ?

23. Name the defect of vision which can be corrected by a converging lens. Show clearly by a ray diagram how the lens corrects the defect.

24. Name the defect of vision which can be corrected by a diverging lens. Show clearly by a ray diagram how the lens corrects the defect.

25. Explain with the help of labelled ray diagram, the defect of vision called myopia and how it is corrected by a lens.

26. Explain with the help of labelled ray-diagram, the defect of vision called hypermetropia, and how it is corrected by a lens.

27. A person suffering from the eye-defect myopia (short-sightedness) can see clearly only up to a distance of 2 metres. What is the nature and power of lens required to rectify this defect ?

28. The near-point of a person suffering from hypermetropia is at 50 cm from his eye. What is the nature and power of the lens needed to correct this defect ? (Assume that the near-point of the normal eye is 25 cm).

29. A person needs a lens of power, – 5.5 dioptres for correcting his distant vision. For correcting his near vision, he needs a lens of power, +1.5 dioptres. What is the focal length of the lens required for correcting (*i*) distant vision, and (*ii*) near vision ?

30. What is presbyopia ? Write two causes of this defect. Name the type of lens which can be used to correct presbyopia.

31. When is a person said to have developed cataract in his eye ? How is the vision of a person having cataract restored ?

32. Fill in the following blanks with suitable words :

A person is short-sighted if his eyeball is too................Spectacles with a ....lens are needed. A person is long-sighted if his eyeball is too................Spectacles with a ....lens are needed. These focus light rays exactly on to the.............

Long Answer Type Questions

33. (*a*) What is short-sightedness ? State the two causes of short-sightedness (or myopia). With the help of ray diagrams, show :

(*i*) the eye-defect short-sightedness.

(*ii*) correction of short-sightedness by using a lens.

(*b*) A person having short-sight cannot see objects clearly beyond a distance of 1.5 m. What would be the nature and power of the corrective lens to restore proper vision ?

34. (*a*) What is long-sightedness ? State the two causes of long-sightedness (or hypermetropia). With the help of ray diagrams, show :

(*i*) the eye-defect long-sightedness.

(*ii*) correction of long-sightedness by using a lens.

(*b*) An eye has a near point distance of 0.75 m. What sort of lens in spectacles would be needed to reduce the near point distance to 0.25 m ? Also calculate the power of lens required. Is this eye long-sighted or short-sighted ?

(*c*) An eye has a far point of 2 m. What type of lens in spectacles would be needed to increase the far point to infinity ? Also calculate the power of lens required. Is this eye long-sighted or short-sighted ?

Multiple Choice Questions (MCQs)

35. The human eye can focus objects at different distances by adjusting the focal length of the eye-lens. This is due to :

(*a*) presbyopia (*b*) accommodation (*c*) near-sightedness (*d*) far-sightedness

36. The defect of vision which cannot be corrected by using spectacles is :

(*a*) myopia (*b*) presbyopia (*c*) cataract (*d*) hypermetropia

37. A person cannot see the distant objects clearly (though he can see the nearby objects clearly). He is suffering from the defect of vision called :

(*a*) cataract (*b*) hypermetropia (*c*) myopia (*d*) presbyopia

38. Though a woman can see the distant objects clearly, she cannot see the nearby objects clearly. She is suffering from the defect of vision called :

(*a*) long-sight (*b*) short-sight (*c*) hind-sight (*d*) mid-sight

39. A young man has to hold a book at arm's length to be able to read it clearly. The defect of vision is :

(*a*) astigmatism (*b*) myopia (*c*) presbyopia (*d*) hypermetropia

40. After testing the eyes of a child, the optician has prescribed the following lenses for his spectacles :
Left eye : + 2.00 D Right eye : + 2.25 D
The child is suffering from the defect of vision called :
(*a*) short-sightedness (*b*) long-sightedness
(*c*) cataract (*d*) presbyopia

41. A person got his eyes tested. The optician's prescription for the spectacles reads :
Left eye : – 3.00 D Right eye : – 3.50 D
The person is having a defect of vision called :
(*a*) presbyopia (*b*) myopia (*c*) astigmatism (*d*) hypermetropia

42. A student sitting on the last bench in the class cannot read the writing on the blackboard clearly but he can read the book lying on his desk clearly. Which of the following statement is correct about the student ?
(*a*) The near point of his eyes has receded away.
(*b*) The near point of his eyes has come closer to him.
(*c*) The far point of his eyes has receded away.
(*d*) The far point of his eyes has come closer to him.

43. A man driving a car can read a distant road sign clearly but finds difficulty in reading the odometer on the dashboard of the car. Which of the following statement is correct about this man ?
(*a*) The near point of his eyes has receded away.
(*b*) The near point of his eyes has come closer to him.
(*c*) The far point of his eyes has receded away.
(*d*) The far point of his eyes has come closer to him.

44. The defect of vision in which the eye-lens of a person gets progressively cloudy resulting in blurred vision is called :
(*a*) myopia (*b*) presbyopia (*c*) colourblindness (*d*) cataract

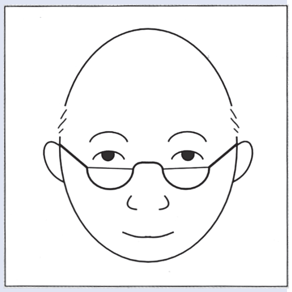
45. A person cannot see distant objects clearly. His vision can be corrected by using the spectacles containing :
(*a*) concave lenses (*b*) plane lenses (*c*) contact lenses (*d*) convex lenses

46. A person finds difficulty in seeing nearby objects clearly. His vision can be corrected by using spectacles containing :
(*a*) converging lenses (*b*) diverging lenses (*c*) prismatic lenses (*d*) chromatic lenses

Questions Based on High Order Thinking Skills (HOTS)

47. In a certain murder investigation, it was important to discover whether the victim was long-sighted or short-sighted. How could a detective decide by examining his spectacles ?

48. The picture given here shows a person wearing 'half-moon' spectacles. What sort of eye-defect do you think he has ? Why are these particular spectacles useful to him ?



49. A short-sighted person has a near point of 15 cm and a far point of 40 cm.
(*a*) Can he see clearly an object at a distance of :
(*i*) 5 cm ? (*ii*) 25 cm ? (*iii*) 50 cm ?
(*b*) To see clearly an object at infinity, what kind of spectacle lenses does he need ?

50. The near point of a long-sighted person is 50 cm from the eye.
(*a*) Can she see clearly an object at :
(*i*) a distance of 20 cm ? (*ii*) at infinity ?
(*b*) To read a book held at a distance of 25 cm, will she need converging or diverging spectacle lenses ?

51. A person can read a book clearly only if he holds it at an arm's length from him. Name the defect of vision :
(*a*) if the person is an old man (*b*) if the person is a young man

ANSWERS

2. (*a*) Hypermetropia (*b*) Myopia **8.** True **9.** Presbyopia **11.** Presbyopia **13.** Cataract **14.** Eye **17.** (*a*) Short-sighted (*b*) Diverging lenses **18.** (*a*) Hypermetropia (Long-sightedness) (*b*) Convex lens **19.** (*a*) Myopia (Short-sightedness) (*b*) Concave lens **20.** (*a*) distant ; concave (*b*) nearby ; convex **22.** Spectacles having bifocal lenses in which upper part consists of concave lens and lower part consists of convex lens **27.** Concave lens ; – 0.5 D **28.** Convex lens; + 2 D **29.** (*i*) –18.18 cm (*ii*) + 66.6 cm **32.** long ; concave; short ; convex ; retina **33.** (*b*) Concave lenses ; – 0.67 D **34.** (*b*) Convex lenses ; + 2.67 D ; Long-sighted (*c*) Concave lenses ; – 0.5 D ; Short-sighted **35.** (*b*) **36.** (*c*) **37.** (*c*) **38.** (*a*) **39.** (*d*) **40.** (*b*) **41.** (*b*) **42.** (*d*) **43.** (*a*) **44.** (*d*) **45.** (*a*) **46.** (*a*) **47.** If spectacle lenses are convex, the person was long-sighted ; If spectacle lenses are concave, then the person was short-sighted **48.** Long-sightedness (Hypermetropia) ; The convex lenses of spectacles form the image of nearby object at the near point of his eye. **49.** (*a*) (*i*) No (*ii*) Yes (*iii*) No (*b*) Concave lenses **50.** (*a*) (*i*) No (*ii*) Yes (*b*) Converging lenses **51.** (*a*) Presbyopia (*b*) Hypermetropia

WHY DO WE HAVE TWO EYES FOR VISION AND NOT JUST ONE

There are many advantages of having two eyes instead of one. Some of these are given below.

1. Having Two Eyes Gives a Wider Field of View. A human being has a horizontal field of view of about 150° with one eye open but with two eyes open, the field of view becomes 180°. Thus, having two eyes gives a wider field of view. This means that with two eyes open, we can see a much larger area in front of us (than can be seen with only one eye).

Figure 15. The human beings have two eyes at the front of their head.

The human beings have two eyes at the front of their head, so their field of view is limited to about 180° (see Figure 15). Some animals, however, have their two eyes located on the opposite sides of their head. Those animals who have two eyes on the opposite sides of their head have the widest possible field of view. They can see much larger area around them than the human being can see. The animals of prey (like rabbit, deer, chicken, fish, etc.) have their two eyes on the opposite sides of their heads so that they can see their enemies (predators) in a very large area around them and try to escape from them (see Figure 16). A domestic animal having its two eyes on the opposite sides of the head is horse.

Figure 16. Rabbits are animals of prey. They have two eyes on the sides of their head.

2. Having Two Eyes Enables Us to Judge Distances More Accurately. Our two eyes are a few centimetres apart from each other (see Figure 15). Due to this, the two eyes see the same object from two slightly different angles and send two slightly different images of the same object to the brain. The brain combines these two slightly different images to build a three-dimensional picture of the object which enables us to judge the distance of the object more accurately.

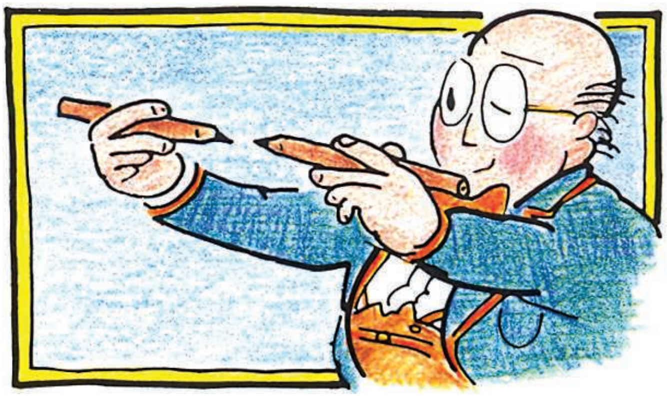


Figure 17. It is difficult to touch the tips of two pencils with one eye open (but much easier when both the eyes are open).

Figure 18. Tiger is a predator. It has two eyes at the front of its head.

This will become clear from the following example. Let us take two sharpened pencils, one in each hand. Stretch the arms forward and try touching the tips of pencils first with one eye open and then with both eyes open. We will find that it is difficult to touch the tips of two pencils with one eye open but it is much more easy when both the eyes are open (see Figure 17). This is because with both the eyes open, we can judge the distances of the pencil tips more accurately. Human beings (and all other animals having their eyes at the front of their head) are said to have *stereoscopic vision* (or *stereopsis)* which gives the perception of depth. All the predators (like tiger, lion, etc.) have their eyes at the front of head so that they can judge the distance of their prey accurately and catch them easily (see Figure 18).

The Gift of Vision

There are millions of blind people in our country who cannot see at all. The eyesight of most of these blind people can be restored if they are given the eyes donated by other persons after their death. In this way, our eyes can live even after our death. In fact, our two eyes can give eyesight to two blind persons (each getting one eye), and make them see this beautiful world.

Some of the important points to be noted about the donation of eyes are the following :

1. Any person of any age or sex (male or female) can donate eyes. People who wear spectacles or have undergone cataract operations can also donate eyes. Even the persons having ailments such as diabetes (sugar), hypertension (blood pressure) and asthma can donate eyes. But they should not have any communicable diseases. The persons who were infected with or died because of diseases such as AIDS, hepatitis B or C, rabies, leukaemia, tetanus, cholera, meningitis, or encephalitis, however, cannot donate eyes.

2. After the death of the person (who had registered for eye donation), the eye bank should be informed immediately. This is because eyes must be removed within 4 to 6 hours of a person's death.

3. The doctors of the eye bank team will remove the eyes at the home of the dead person or at the hospital. It takes only 10 to 15 minutes to remove the eyes. There is no disfigurement of the face in this process.

4. The eye bank distributes the donated eyes to various eye hospitals where these are transplanted in the blind people through surgical operation.

5. Those donated eyes which are not suitable for transplantation, are used for doing research and for teaching purposes in medical colleges.

We can, even today, make a pledge in writing, with the eye bank of our area that (God forbid) whenever we die our eyes should be removed and given to the blind persons to light up their dark world ! We should be grateful to God that he has given us the gift of vision to see this wonderful world. Let us pass on this priceless gift of vision to our less fortunate blind brothers and sisters by registering our name for eye donation. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. How much is our field of view :
(*a*) with one eye open ?
(*b*) with both eyes open ?

2. Which of the following have a wider field of view ?
(*a*) Animals having two eyes on the opposite sides of their head.
(*b*) Animals having two eyes at the front of their head.

3. Out of animals of prey and predators, which have their eyes :
(*i*) at the front of their head ?
(*ii*) on the opposite sides of their head ?

4. State whether the following statement is true or false :
Rabbit has eyes which look sideways.

5. Fill in the following blanks with suitable words :
   (*a*) Having two eyes gives a ....field of view.
   (*b*) Having two eyes enables us to judge................more accurately.

Short Answer type Questions

6. What are the advantages of having two eyes instead of just one ?
7. Explain clearly why, a person who has lost the sight of one eye is at a disadvantage compared with the normal person who has two good eyes.
8. Name two animals having eyes :
   (*a*) on the sides of the head.
   (*b*) at the front of the head.
9. Among animals, the predators (like lions) have their eyes facing forward at the front of their heads, whereas the animals of prey (like rabbit) usually have eyes at the sides of their head. Why is this so ?
10. Five persons A, B, C, D and E have diabetes, leukaemia, asthma, meningitis and hepatitis, respectively.
   (*a*) Which of these persons can donate eyes ?
   (*b*) Which of these persons cannot donate eyes ?

Multiple Choice Questions (MCQs)

11. The animal which does not have eyes that look sideways is :
   (*a*) Horse (*b*) Chicken (*c*) Lion (*d*) Fish
12. With both eyes open, a person's field of view is about :
   (*a*) 90° (*b*) 150° (*c*) 180° (*d*) 360°
13. Having two eyes gives a person :
   (*a*) deeper field of view (*b*) coloured field of view
   (*c*) rear field of view (*d*) wider field of view
14. The animals of prey have :
   (*a*) two eyes at the front (*b*) two eyes at the back
   (*c*) two eyes on the sides (*d*) one eye at the front and one on the side
15. The animals called predators have :
   (*a*) both the eyes on the sides (*b*) one eye on the side and one at the front
   (*c*) one eye on the front and one at the back (*d*) both the eyes at the front

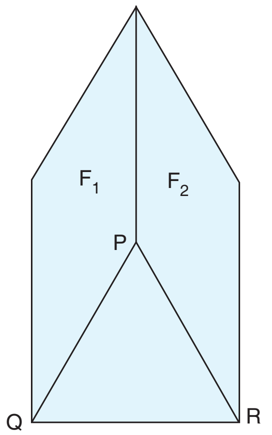
ANSWERS

1. (*a*) About 150° (*b*) About 180° **2.** (*a*) **3.** (*i*) Predators (*ii*) Animals of prey **4.** True **5.** (*a*) wider (*b*) distances **8.** (*a*) Rabbit ; Deer (*b*) Tiger ; Lion **10.** (*a*) A and C (*b*) B, D and E **11.** (*c*) **12.** (*c*) **13.** (*d*) **14.** (*c*) **15.** (*d*)

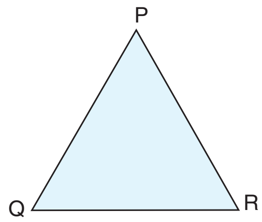
GLASS PRISM

We have already studied the refraction of light through a rectangular glass slab. In a rectangular glass slab, the emergent light rays are parallel to the incident light rays because the opposite faces of a rectangular glass slab (where refraction takes place) are parallel to one another. We will now discuss the refraction of light through a glass object whose opposite faces (where refraction takes place) are not parallel to one another. A triangular glass prism is such an object. A triangular glass prism is shown in Figure 19(*a*). The triangular glass prism is a transparent object made of glass having two triangular ends and three rectangular sides (or rectangular faces). Please note that the opposite faces of a triangular glass prism are not parallel to one another. For example, in Figure 19(*a*), the opposite faces of the glass prism F_1 and F_2 (where the refraction of light takes place) are not parallel to one another. They are inclined at an angle to one another. The angle between its opposite faces is called the angle of the prism. In Figure 19(*a*), angle QPR is the angle of this prism. Though an actual triangular glass prism looks like that shown in Figure 19(*a*), but for the sake of convenience in drawing ray-diagrams, a triangular glass prism is represented by drawing a triangle as shown in Figure 19(*b*). Please note that a 'triangular glass prism' is usually called 'glass prism' and sometimes even just 'prism'.

As we will study after a while the refraction of light on passing through a glass prism is different from that in a glass slab. This is because **in refraction through a glass slab, the emergent ray is parallel to the incident ray** but **in refraction through a glass prism, the emergent ray is not parallel to the incident ray.** *The emergent ray of light in a glass prism is not parallel to the incident ray of light because the opposite faces of the glass prism (where refraction takes place) are not parallel to one another.* Actually, in refraction through a glass prism, the emergent ray is *deviated* from its original direction by a certain angle. And we say that light rays get deviated on passing through a glass prism. We will now study the refraction of light through a glass prism in somewhat detail.



(*a*) A triangular glass prism.



(*b*) This is how a triangular glass prism is represented in ray-diagrams.

Figure 19.

REFRACTION OF LIGHT THROUGH A GLASS PRISM

When a ray of light passes through a glass prism, refraction (or bending) of light occurs both, when it enters the prism as well as when it leaves the prism. Since the refracting surfaces (*PQ* and *PR*) of the prism are *not* parallel, therefore, the emergent ray and incident ray are *not* parallel to one another (see Figure 20). In this case the ray of light is deviated on passing through the prism. Let us see how it happens.

In Figure 20, a glass prism *PQR* has been kept on its base *QR*. A ray of light *AB* is incident on the face *PQ* of the prism. The *incident* ray *AB* is going from air (rarer medium) into glass (denser medium), so it bends towards the normal *BN′* and goes along the direction *BC* inside the glass prism. Thus, *BC* is the *refracted* ray of light which bends towards the base *QR* of the prism.

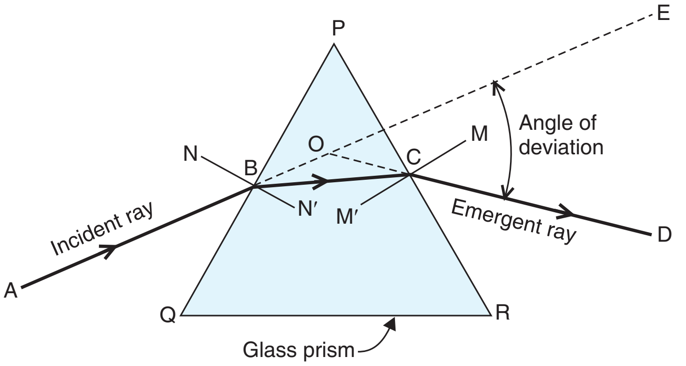


Figure 20. Refraction of light through a glass prism. Here the emergent ray *CD* is not parallel to the incident ray *AB*. It gets deviated.

When the ray of light *BC* travelling in the glass prism comes out into air at point *C*, refraction takes place again (see Figure 20). Since the ray *BC* is going from glass (denser medium) into air (rarer medium), so it bends away from the normal *MC* and goes along the direction *CD* in the form of *emergent* ray. Here also, the emergent ray of light *CD* bends towards the base *QR* of the prism. From this discussion we conclude that **when a ray of light passes through a prism, it bends towards the *base* of prism.** In other words, **when a ray of light passes through a prism, it bends towards the *thicker* part of the prism.**

If we look carefully at Figure 20, we will see that the emergent ray *CD* is not parallel to the incident ray *AB*. There has been a deviation (or change) in the path of light in passing through the prism. Let us produce the incident ray *AB* upwards towards the point *E* by a dotted line. Now, *AE* represents the original direction of the ray of light. Similarly, let us produce the emergent ray *CD* backwards by a dotted line so that it cuts the line *AE* at point *O* (see Figure 20). We can now say that the original direction of the ray of light is *AE* but after passing through the prism, it deviates from its path and goes in the direction *OD.* **The angle between incident ray and emergent ray is called angle of deviation.** In Figure 20, the angle *EOD* is the angle of deviation. Please note that *it is the peculiar shape (triangular shape) of the glass prism which makes the emergent ray bend with respect to the incident ray.*

DISPERSION OF LIGHT

In the year 1665, Newton discovered by his experiments with glass prisms that white light (like sunlight) consists of a mixture of seven colours. By saying that white light is a mixture of seven colours we mean that white light is a mixture of lights of seven colours. Newton found that if a beam of white light is passed through a triangular glass prism, the white light splits to form a band of seven colours on a white screen (see Figure 21). **The band of seven colours formed on a white screen, when a beam of white light is passed through a glass prism, is called spectrum of white light.** The seven colours of the spectrum are : Red, Orange, Yellow, Green, Blue, Indigo, and Violet. The seven colours of the spectrum can be denoted by the word *VIBGYOR* where *V* stands for Violet, *I* for Indigo, *B* for Blue, *G* for Green, *Y* for Yellow, *O* for Orange and *R* for Red.

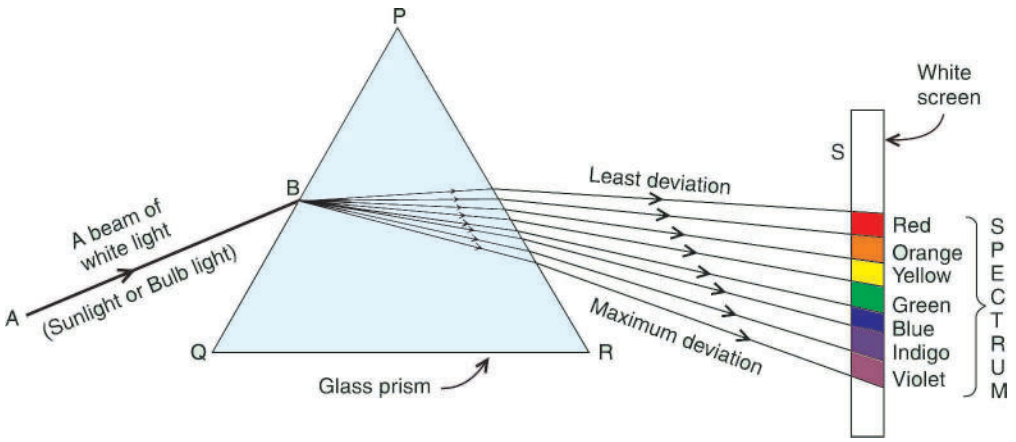


Figure 21. A glass prism splits the white light into lights of seven colours.

In Figure 21, a beam of white light *AB* is passed into a glass prism *PQR*. This beam of white light splits on entering the glass prism and forms a broad patch of seven colours on a white screen *S* placed on the other side of the prism. Please note that when the glass prism is kept on its base as shown in Figure 21, then the red colour is at the top and violet colour is at the bottom of the spectrum. **The splitting up of white light into seven colours on passing through a transparent medium like a glass prism is called dispersion of light.** The formation of spectrum of seven colours shows that white light is made up of lights of seven different colours mixed together. That is, **white light is a mixture of seven colours** (or seven coloured lights). The effect of glass prism is only to *separate* the seven colours of white light. A similar band of seven colours is produced when a beam of white light from an electric bulb falls on a triangular glass prism. We can explain the dispersion of light by a glass prism as follows.

Figure 22. It is usually not possible to distinguish all the seven colours of the spectrum easily due to the overlapping of various colours. So, the spectrum is not really seven separate colours.

White light is a mixture of lights of seven colours : red, orange, yellow, green, blue, indigo and violet. **The dispersion of white light occurs because colours of white light travel at different speeds through the glass prism.** The amount of refraction (or bending) depends on the speed of coloured light in glass. Now, since the different colours travel at different speeds, they are refracted (or bent) by different angles on passing through the glass prism (some colours are bent less whereas others are bent more). So, **when white light consisting of seven colours falls on a glass prism, each colour in it is refracted (or deviated) by a different angle, with the result that seven colours are spread out to form a spectrum.** The red colour has the maximum speed in glass prism, so **the red colour is deviated the least**. Due to this the red colour forms the upper part of the spectrum. On the other hand, the violet colour has the minimum speed in glass prism, so **the violet colour is deviated the maximum**. Due to this violet colour appears at the bottom of the spectrum. Please note that the seven colours of spectrum differ only in their frequencies. These colours in the order of increasing frequency (but decreasing wavelengths) are : Red, Orange, Yellow, Green, Blue, Indigo and Violet. Any light that gives spectrum similar to that of sunlight is called white light.

Re-Combination of Spectrum Colours to Give White Light

We have just seen that white light can be dispersed into its seven constituent colours. Newton showed that the reverse of this is also true. That is, **the seven coloured lights of the spectrum can be recombined to give back white light**. This can be done as follows.

A triangular glass prism *PQR* is placed on its base *QR* as shown in Figure 23, and another similar prism *P′Q′R′* is placed alongside it in the inverted position on its vertex *P′* so that its refracting surface is in the

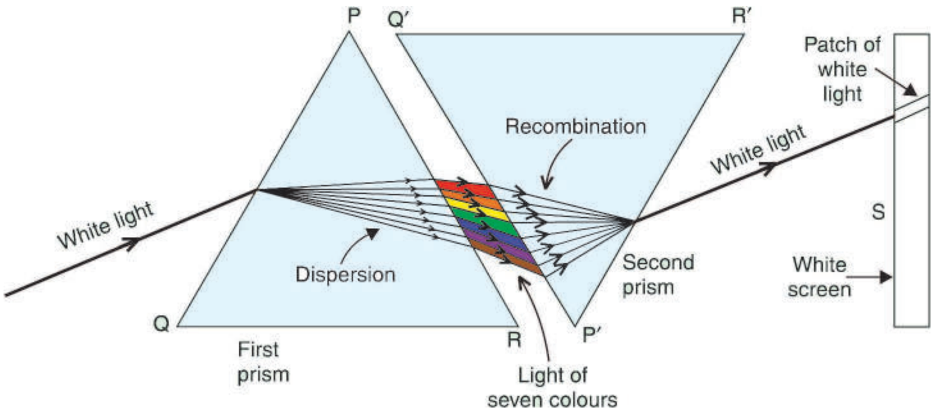


Figure 23. The first glass prism disperses (splits) white light into seven colours. The second glass prism (which has been placed upside down) recombines the seven colours of spectrum to give back white light.

opposite direction. When a beam of white light is allowed to fall on the first prism *PQR*, then a patch of ordinary white light is obtained on a screen *S* placed behind the second prism *P′Q′R′* (see Figure 23). Newton explained these observations as follows.

The first glass prism *PQR* disperses (splits) the white light into seven coloured rays. The second glass prism *P′Q′R′* receives all the seven coloured rays from the first prism and recombines them into original white beam of light which falls on the screen *S*. The recombination of seven colours, produced by first prism, is due to the fact that the second prism has been placed in reversed position due to which the refraction produced by the second prism is equal and opposite to that produced by the first prism.

Figure 24. A rainbow.

The Rainbow

One of the most beautiful examples of spectrum formed by the dispersion of sunlight is provided by nature in the form of rainbow. **The rainbow is an arch of seven colours visible in the sky which is produced by the dispersion of sun's light by raindrops in the atmosphere** (see Figure 24). The rainbow is actually a *natural spectrum* of sunlight in the sky. The rainbow is formed in the sky when the sun is *shining* and it is *raining* at the same time. We can see the rainbow if we stand with our back towards the sun and rain in front of us. A rainbow is always formed in a direction *opposite* to that of the sun. **A rainbow is produced by the dispersion of white sunlight by raindrops (or water drops) in the atmosphere. Each raindrop acts as a tiny glass**

prism splitting the sunlight into a spectrum. This will become more clear from the following discussion.

The raindrops in the atmosphere act like many small prisms. As white sunlight enters and leaves these raindrops (or water drops), the various coloured rays present in white light are refracted by different amounts due to which an arch of seven colours called rainbow is formed in the sky. The formation of rainbow can be explained with the help of a diagram shown in Figure 25. A ray of white sunlight *AB* enters the raindrop at point *B* and undergoes refraction and dispersion to form a spectrum. This spectrum undergoes total internal reflection at point *C* within the raindrop and finally refracted out of the raindrop at point *D* (see Figure 25). This spectrum produced by the raindrops in the atmosphere is seen from the earth. The red colour of spectrum appears at the *top* of the rainbow whereas violet colour appears at its *bottom.*

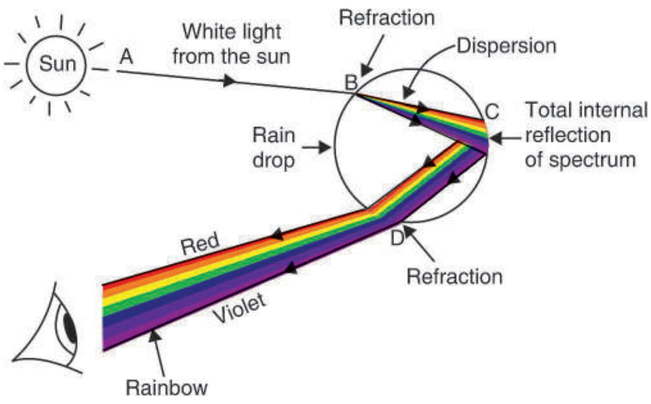


Figure 25. Formation of a rainbow.

The formation of seven-coloured rainbow in the sky shows that white sunlight consists of a mixture of seven coloured lights. We can also see a rainbow on a sunny day if we look through a spray of water from a fountain (or through a waterfall) with the sun behind us. Before we go further and discuss atmospheric refraction, **please answer the following questions :**

Very Short Answer Type Questions

1. As light rays pass from air into a glass prism, are they refracted towards or away from the normal ?
2. As light rays emerge from a glass prism into air, are they refracted towards or away from the normal ?
3. Name a natural phenomenon which is caused by the dispersion of sunlight in the sky.
4. What information do we get about sunlight from the formation of a rainbow ?
5. What did Newton demonstrate by his experiments with the prism ?
6. What colours make up white light ?
7. Give the meaning of the term VIBGYOR. With which phenomenon is it connected ?
8. In the formation of spectrum of white light by a prism :
   (*i*) which colour is deviated least ?
   (*ii*) which colour is deviated most ?
9. What colours lie on the two sides of the 'green colour' in the spectrum of white light ?
10. Name the scientist who discovered that sunlight consists of seven colours.
11. What is the order of colours in a rainbow, from the outside to the inside ?
12. Which colour of the spectrum has (*a*) longest wavelength, and (*b*) shortest wavelength ?
13. Which light has the longer wavelength : red light or blue light ?
14. Which colour of light has the shorter wavelength – red or violet ?
15. Fill in the blanks with suitable words :
    (*a*) When a ray of light enters a prism, it bends................the normal ; as it leaves the prism, it bends .... the normal.
    (*b*) White light is composed of.............colours. The colour of white light deviated through the largest angle by a prism is..............

Short Answer Type Questions

16. (*i*) A ray of white light breaks up into its components while passing through a glass prism. Draw a ray diagram to show the path of rays.
    (*ii*) Mark the least deviated colour in your diagram.
    (*iii*) Why do different coloured rays deviate differently in a prism ?

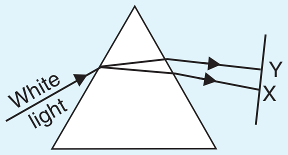
17. (*a*) What happens when a ray of ordinary light is passed through a triangular glass prism ?
(*b*) What will happen if another similar glass prism is placed upside down behind the first prism ?

18. When a beam of white light is passed through a prism, it splits to form lights of seven colours. Is it possible to recombine the lights of seven colours to obtain the white light again ? Explain your answer.

19. (*a*) What is spectrum ? What is the name of glass shape used to produce a spectrum ?
(*b*) How many colours are there in a full spectrum of white light ? Write the various colours of spectrum in the order, starting with red.

20. What is meant by dispersion of white light ? Describe the formation of rainbow in the sky with the help of a diagram.

21. In the figure given alongside, a narrow beam of white light is shown to pass through a triangular glass prism. After passing through the prism, it produces a spectrum YX on the screen.



(*a*) State the colour seen (*i*) at X, and (*ii*) at Y.
(*b*) Why do different colours of white light bend through different angles with respect to the incident beam of light ?

22. Draw a diagram to show how white light can be dispersed into a spectrum by using a glass prism. Mark the various colours of the spectrum.

23. Make two diagrams to explain refraction and dispersion.

24. Describe how you could demonstrate that white light is composed of a number of colours.

25. How could you show that the colours of the spectrum combine to give white light ?

26. Which is refracted most by a prism : red light or violet light ? Explain why ?

Long Answer Type Question

27. (*a*) Draw a diagram to show the refraction of light through a glass prism. On this diagram, mark (*i*) incident ray (*ii*) emergent ray, and (*iii*) angle of deviation.
(*b*) What is a rainbow ? What are the two conditions necessary for the formation of a rainbow in the sky ?
(*c*) What acts as tiny prisms in the formation of a rainbow ?
(*d*) Name the process which is involved in the formation of a rainbow.
(*e*) What are the seven colours seen in a rainbow ?

Multiple Choice Questions (MCQs)

28. A beam of white light is shone onto a glass prism. The light cannot be :
(*a*) deviated (*b*) dispersed (*c*) focused (*d*) refracted

29. A beam of white light falls on a glass prism. The colour of light which undergoes the least bending on passing through the glass prism is :
(*a*) violet (*b*) red (*c*) green (*d*) blue

30. The colour of white light which suffers the maximum bending (or maximum refraction) on passing through a glass prism is :
(*a*) yellow (*b*) orange (*c*) red (*d*) violet

31. Which of the following colour of white light is least deviated by the prism ?
(*a*) green (*b*) violet (*c*) indigo (*d*) yellow

32. The colour of white light which is deviated the maximum on passing through the glass prism is :
(*a*) blue (*b*) indigo (*c*) red (*d*) orange

33. The splitting up of white light into seven colours on passing through a glass prism is called :
(*a*) refraction (*b*) deflection (*c*) dispersion (*d*) scattering

34. Which of the following coloured light has the least speed in glass prism ?
(*a*) violet (*b*) yellow (*c*) red (*d*) green

35. The coloured light having the maximum speed in glass prism is :
(*a*) blue (*b*) green (*c*) violet (*d*) yellow

36. Which of the following colour of white light has the least wavelength ?
(*a*) red (*b*) orange (*c*) violet (*d*) blue

37. Out of the following, the colour of light having the maximum wavelength is :
(*a*) violet (*b*) indigo (*c*) green (*d*) orange

Questions Based on High Order Thinking Skills (HOTS)

38. Why do you not see a spectrum of colours when light passes through a flat pane of glass ?

39. Name some everyday objects :
(*a*) which reflect all the colours in sunlight
(*b*) which absorb all the colours in sunlight

40. Where in nature can you find evidence that white sunlight may be made of different colours ?

ANSWERS

1. Towards the normal **2.** Away from the normal **3.** Rainbow **4.** Sunlight consists of 7 colours **8.** (*i*) Red (*ii*) Violet **9.** Yellow and Blue **12.** (*a*) Red (*b*) Violet **13.** Red light **14.** Violet **15.** (*a*) towards ; away from (*b*) seven; violet **21.** (*i*) Violet (*ii*) Red **26.** Violet light **28.** (*c*) **29.** (*b*) **30.** (*d*) **31.** (*d*) **32.** (*b*) **33.** (*c*) **34.** (*a*) **35.** (*d*) **36.** (c) **37.** (*d*) **38.** Because a flat pane of glass has parallel sides **39.** (*a*) White paper (*b*) Blackboard **40.** Formation of rainbow in the sky.

ATMOSPHERIC REFRACTION

We know that when light goes from one medium to another medium having different optical densities, then refraction of light rays (or bending of light rays) takes place. Now, in the atmosphere, we have air everywhere. But all the air in the atmosphere is not at the same temperature. Some of the air layers of the atmosphere are cold whereas other air layers of the atmosphere are comparatively warm (or hotter). Now, the cooler air layers of the atmosphere behave as optically denser medium for light rays whereas the warmer air layers (or hotter air layers) of the atmosphere behave as optically rarer medium for the light rays. So, **in the same atmosphere we have air layers having different optical densities.** And when light rays pass through the atmosphere having air layers of different optical densities, then refraction of light takes place. **The refraction of light caused by the earth's atmosphere (having air layers of varying optical densities) is called atmospheric refraction.**

We can see the effect of atmospheric refraction by a simple observation as follows : If we look at objects through the hot air over a fire, the objects appear to be moving slightly. This can be explained as follows : The air just above the fire becomes hotter (than the air further up). This hotter air is optically rarer but the colder air further up is optically denser. So, when we see the objects by the light coming from them through hot and cold air layers having different optical densities, then refraction of light takes place randomly due to which the objects appear to be moving slightly. This is an example of atmospheric refraction on a small scale.

Please note that under normal circumstances, the air in the upper atmosphere is optically rarer and as we come down, the air in the lower atmosphere is optically denser. This arrangement of optical densities of air in the atmosphere can, however, change according to the local conditions such as temperature, etc., at a particular place. We will now describe **some of the optical phenomena in nature which occur due to the atmospheric refraction of light.**

1. Twinkling of Stars

We know that stars emit their own light (called star-light). Due to this light, the stars shine in the night sky. Now, when we look at a star in the sky on a clear night, we observe that the intensity of light coming from it changes continuously. At one moment the star appears to be very bright, and the next moment it becomes very dim. In fact, the stars go on becoming bright and dim, bright

Figure 26. The twinkling of stars is due to the atmospheric refraction of their light.

and dim, again and again. And we say that the stars twinkle at night. **The twinkling of a star is due to the atmospheric refraction of star's light.** This can be explained as follows :

When the light coming from a star enters the earth's atmosphere, it undergoes refraction due to the varying optical densities of air at various altitudes. The atmosphere is continuously changing (due to which the optical densities of air at different levels in the atmosphere keep on changing). **The continuously changing atmosphere refracts the light from the stars by different amounts from one moment to the next.** When the atmosphere refracts more star-light towards us, the star appears to be bright and when the atmosphere refracts less star-light, then the star appears to be dim. In this way, **the star-light reaching our eyes increases and decreases continuously due to atmospheric refraction. And the star appears to twinkle at night.**

We know that **though stars twinkle at night but planets do not twinkle at all.** This can be explained as follows : The stars appear very, very small to us (because they are very, very far off). So, stars can be considered to be point sources of light. **The continuously changing atmosphere is able to cause variations in the light coming from a point-sized star (due to refraction) because of which the star appears to be twinkling.** On the other hand, the planets appear to be quite big to us (because they are much nearer to the earth). So, a planet can be considered to be a collection of a very large number of point sources of light. The dimming effect produced by some of the point sources of light in one part of the planet is nullified by the brighter effect produced by the point sources of light in its other part. Thus, on the whole, the brightness of a planet always remains the same and hence it does not appear to twinkle. We can now say that : **The continuously changing atmosphere is unable to cause variations in the light coming from a big-sized planet (due to refraction) because of which the planet does not twinkle at all.**

2. The Stars Seem Higher Than They Actually Are

Due to atmospheric refraction, the stars seem to be higher in the sky than they actually are. This can be explained as follows : Light from a star is refracted (bent) as it leaves space (a vacuum) and enters the earth's atmosphere. Air higher up in the sky is rarer but that nearer the earth's surface is denser. So, as the light from a star comes down, the dense air bends the light more. Due to this refraction of star's light, the star appears to be at a higher position. For example, in Figure 27, though the actual position of a star is at *A*, but due to atmospheric refraction, it seems higher in the sky at position *B* (This is because our eye will see the star at that position from where light enters it in the straight line direction). Our nearest star, the sun, also seems higher than it actually is, due to atmospheric refraction.

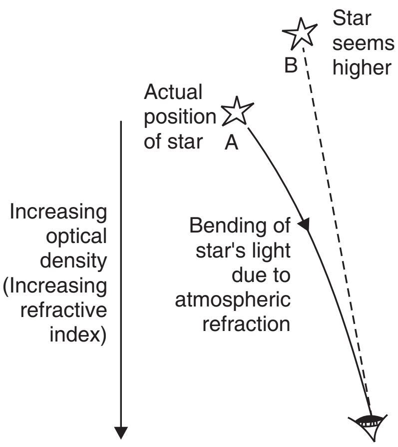


Figure 27. A star seems to be higher in the sky (than it actually is) due to atmospheric refraction.

3. Advance Sunrise and Delayed Sunset

Sometimes the refraction (or bending) of the light rays tend to bring into view the objects which are actually below the horizon (and cannot be seen otherwise). This happens in the case of the sun just before sunrise and just after sunset. Thus, **we can see the sun about 2 minutes before the actual sunrise and 2 minutes after the actual sunset because of atmospheric refraction.** Let us take the case of sunrise.

The actual sunrise takes place when the sun is just above the horizon. But due to refraction of sunlight caused by the atmosphere, we can see the rising sun about 2 minutes before it is actually above the horizon. This happens as follows : When the sun is slightly below the horizon, then the sun's light coming from less dense air to more dense air is refracted downwards as it passes through the atmosphere. Because of this atmospheric refraction, the sun appears to be raised above the horizon when actually it is slightly below the horizon. For example, in Figure 28, the actual position of the sun is at *A* just below the horizon but it appears to be at position *B* above the horizon, due to atmospheric refraction of light rays coming from it (This is because our eye will see the sun at that position from where light enters it in the straight line direction).

It is also due to atmospheric refraction that we can still see the sun for about 2 minutes even after the sun has set below horizon. From the above discussion we conclude that we can see the sun 2 minutes before the actual sunrise time and for 2 minutes after the actual sunset time. So, **the time from sunrise to sunset is lengthened by about 2 + 2 = 4 minutes because of atmospheric refraction**. Thus, the day would have been shorter by about 4 minutes if the earth had no atmosphere. The sun appears flattened (or oval) at sunrise and sunset. The apparent flattening of the sun's disc at sunrise and sunset is also due to atmospheric refraction. We will study this in detail in higher classes. Before we go further and discuss scattering of light, **please answer the following questions :**

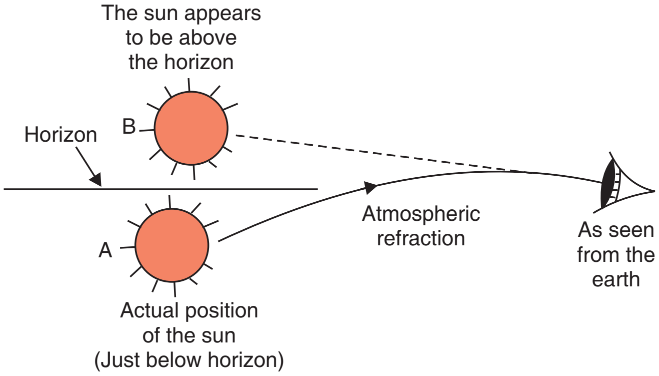


Figure 28. Effect of atmospheric refraction at sunrise.

Very Short Answer Type Questions

1. Name the phenomenon which causes the twinkling of stars.
2. Name two effects produced by the atmospheric refraction.
3. Which phenomenon makes us see the sun :
   (*a*) a few minutes before actual sunrise ?
   (*b*) a few minutes after actual sunset ?
4. Atmospheric refraction causes advance sunrise and delayed sunset. By how much time is :
   (*a*) sunrise advanced ?
   (*b*) sunset delayed ?
5. State whether the following statement is true or false :
   The planets twinkle at night due to atmospheric refraction of light.
6. Name the phenomenon due to which the stars seem higher in the sky than they actually are.
7. Fill in the following blanks with suitable words :
   We can see the sun about............minutes before the actual sunrise and about............minutes after the actual sunset because of atmospheric..............

Short Answer Type Questions

8. Why do stars seem higher than they actually are ? Illustrate your answer with the help of a diagram.
9. Explain why, the sun can be seen about two minutes before actual sunrise. Draw a diagram to illustrate your answer.
10. Explain why, if we look at objects through the hot air over a fire, the objects appear to be moving (or shaking) slightly.

Long Answer Type Question

11. (*a*) What is atmospheric refraction ? What causes atmospheric refraction ?
    (*b*) Why do stars twinkle on a clear night ?
    (*c*) Explain why, the planets do not twinkle at night.

Multiple Choice Questions (MCQs)

12. The twinkling of stars is due to atmospheric :
    (*a*) reflection of light (*b*) dispersion of light
    (*c*) interference of light (*d*) refraction of light

13. The atmospheric refraction of light causes the twinkling of :
(*a*) planets only (*b*) stars only
(*c*) planets and stars (*d*) stars and satellites

14. The stars appear higher in the sky than they actually are, due to :
(*a*) diffraction of light (*b*) scattering of light
(*c*) refraction of light (*d*) reflection of light

15. The stars twinkle but the planets do not twinkle at night because :
(*a*) the stars are small but the planets are large
(*b*) the stars are very large but planets are small
(*c*) the stars are much nearer but planets are far off
(*d*) the stars are far off but planets are nearer to earth

16. As light from a far off star comes down towards the earth :
(*a*) it bends away from the normal
(*b*) it bends towards the normal
(*c*) it does not bend at all
(*d*) it is reflected back

17. We can see the sun before the actual sunrise by about :
(*a*) 5 minutes (*b*) 2 minutes (*c*) 2 hours (*d*) 20 minutes

18. Due to atmospheric refraction of sunlight, the time from sunrise to sunset is lengthened by about :
(*a*) 6 minutes (*b*) 2 minutes (*c*) 4 minutes (*d*) 5 minutes

19. The day is longer on the earth by about 4 minutes because :
(*a*) the earth is round in shape (*b*) the earth rotates on its axis
(*c*) the earth revolves around the sun (*d*) the earth has atmosphere

Questions Based on High Order Thinking Skills (HOTS)

20. We know that light refracts (or bends) when it goes from one medium to another. Now, the atmosphere contains only air. Then how does light get refracted on passing through only air in the atmosphere ?

21. By how much time the day would have been shorter if the earth had no atmosphere ?

22. A student claims that because of atmospheric refraction, the sun can be seen after it has set, and the day is, therefore, longer than if the earth had no atmosphere.
(*a*) What does the student mean by saying that the sun can be seen after it has set ?
(*b*) Do you think that the students' conclusion is correct ?

ANSWERS

1. Atmospheric refraction of light **2.** Twinkling of stars ; Advance sunrise and delayed sunset **3.** (*a*), (*b*) Atmospheric refraction of sunlight **4.** (*a*), (*b*) About 2 minutes **5.** False **6.** Atmospheric refraction of light **7.** two ; two ; refraction **12.** (*d*) **13.** (*b*) **14.** (*c*) **15.** (*d*) **16.** (*b*) **17.** (*b*) **18.** (*c*) **19.** (*d*) **21.** By about 4 minutes **22.** (*b*) Yes

SCATTERING OF LIGHT

Scattering of light means to *throw* light in various random directions. Light is scattered when it falls on various types of suspended particles in its path. Depending on the size of particles, the scattering can be of white sunlight as such or of the coloured lights which make up the white sunlight. As we will study after a while, the blue colour of the sky and the red colour of the sun at sunrise and at sunset can be explained on the basis of scattering of light caused by the earth's atmosphere (or air) (see Figure 29). We will first describe the Tyndall effect.

(*a*) The sky is blue

(*b*) The sunset (and sunrise) are red

Figure 29. The effects produced by the scattering of sunlight by the earth's atmosphere.

Tyndall Effect

The scattering of light by particles in its path is called Tyndall effect. When a beam of sunlight enters a dusty room through a window, then its path becomes visible to us. This is because the tiny dust particles present in the air of room scatter the beam of light all around the room. And when this scattered light enters our eyes, we can see the beam of light. Thus, an example of Tyndall effect is the way a beam of sunlight becomes visible as it passes through dust particles in the air of a room. Tyndall effect can also be observed when sunlight passes through the canopy of a dense forest. Here, tiny water droplets in the mist scatter sunlight (see Figure 30).

Figure 30. The scattering of sunlight passing through the canopy of a forest.

We have just studied the spectrum of sun's white light which consists of seven coloured lights. If we look at the spectrum of white sunlight, we will observe that the reds and blues are very predominent in it. Red coloured light has a longer wavelength but the blue coloured light has a shorter wavelength. In fact, the wavelength of blue light is almost half that of the red light. In 1859, in an attempt to explain the blue colour of the sky, **Tyndall discovered that when white light consisting of seven colours is passed through a clear liquid having small suspended particles in it, then the blue colour of white light having shorter wavelength is scattered much more than the red colour having longer wavelength.**

Blue light has shorter wavelength, so it is scattered more easily. On the other hand, red light has longer wavelength, so it is not scattered much. In other words, **the blue coloured light present in white sunlight is scattered much more easily than the red light.** In fact, the blue light present in sunlight is scattered 10 times more than the red light.

The Colour of Scattered Light Depends on the Size of Scattering Particles

The earth's atmosphere is a heterogeneous mixture of minute particles. These particles include suspended particles of dust, tiny water droplets and molecules of air (the molecules of air means the molecules of gases like nitrogen and oxygen which make up the air). When light coming from the sun strikes the particles present in the atmosphere (or air), then what happens to the light depends on its wavelength and the size of the particles it hits. This will become clear from the following discussion.

(*i*) Dust particles and water droplets suspended in the atmosphere are much larger than the wavelength range of visible light. When white light coming from the sun hits these larger particles, it gets reflected or scattered in different directions. The different colours of white light are reflected by the dust and water particles in the same way. Due to this, the scattered light appears white (because it still contains all the colours of white light). Thus, when white sunlight falls on larger particles (like dust particles and water droplets) present in the atmosphere, it is scattered as such, so the scattered light also appears white.

(*ii*) The air molecules (nitrogen and oxygen gas molecules) present in the atmosphere are smaller than the wavelength range of visible light. So, when light coming from the sun hits these very small air molecules, it behaves differently. Since the different colours of white light have different wavelengths, so they are affected differently. The lower wavelength lights (blues) are scattered much more by the air molecules but the higher wavelength lights (reds) are scattered much less. Thus, when white sunlight falls on the extremely small particles like air molecules present in the atmosphere, it is *not* scattered as white light. The molecules of air scatter mainly the lower wavelengths of light which have blue shades.

From the above discussion we conclude that **the colour of the scattered light depends on the size of the scattering particles in the atmosphere** :

(*a*) The larger particles of dust and water droplets present in the atmosphere scatter the light as such due to which the scattered light also appears white.

(*b*) The extremely minute particles such as the air molecules present in the atmosphere scatter mainly the blue light present in the white sunlight.

Why the Sky is Blue

The scattering of blue component of the white sunlight by air molecules present in the atmosphere causes the blue colour of the sky. This can be explained as follows.

The sunlight is made up of seven coloured lights mixed together. When sunlight passes through the atmosphere, most of the longer wavelength lights (such as red, orange, yellow, etc.) present in it *do not* get scattered much by the air molecules and hence pass straight through. The shorter wavelength blue light is, however, scattered all around the sky by air molecules in the atmosphere (see Figure 31). Whichever direction we look, some of this scattered blue light enters our eyes. Since we see the blue light from everywhere overhead, the sky looks blue.

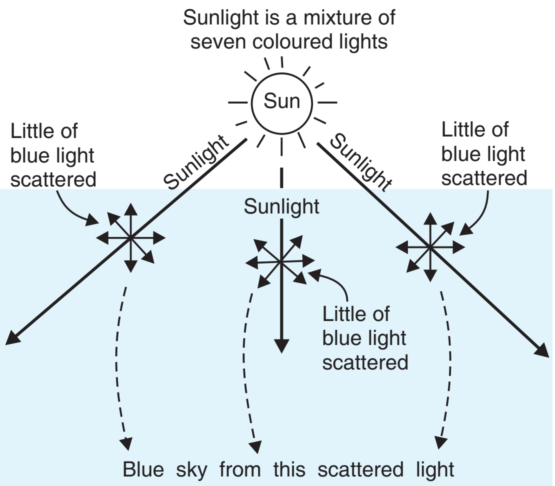


Figure 31. The scattering of a little of blue light (present in white sunlight) by air molecules in the atmosphere makes the sky appear blue.

Thus, the sky appears blue because the molecules in the air (nitrogen and oxygen molecules) scatter blue part of the sunlight much more than they scatter red light (or other shades). Please note that only a little of the blue light present in white sunlight is scattered by the atmosphere which makes the sky appear blue. Most of the blue light remains behind unscattered due to which the composition of sunlight remains almost unaltered. Because of this the direct sunlight coming through the blue sky still appears to be white.

If the earth had no atmosphere consisting of air, there would have been *no scattering* of sunlight at all. In that case no light from the sky would have entered our eyes and the sky would have looked dark and black to us.

In outer space, the sky looks dark and black instead of blue. This is because there is no atmosphere containing air in the outer space to scatter sunlight. Since there is no scattered light to reach our eyes in outer space, therefore, the sky looks dark and black there. This is why the astronauts who go to outer space find the sky to be dark and black instead of blue.

We know that the *'danger'* signal lights are red in colour. This is because the red coloured light having longer wavelength is the least scattered by fog or smoke particles. Due to this the red light can be seen in the same colour even from a distance.

Why the Sun Appears Red at Sunrise and Sunset

The sun and the surrounding sky appear red at sunrise and at sunset because at that time most of the blue colour present in sunlight has been scattered out and away from our line of sight, leaving behind mainly red colour in the direct sunlight beam that reaches our eyes. This can be explained as follows.

At the time of sunrise and sunset when the sun is near the horizon, the sunlight has to travel the *greatest* distance through the atmosphere to reach us. During this long journey of sunlight, most of the shorter wavelength blue-colour present in it is scattered out and away from our line of sight. So, the light reaching us directly from the rising sun or setting sun consists mainly of longer wavelength red colour due to which the sun appears red (see Figure 32). Due to the same reason, the sky surrounding the rising sun and setting sun also appears red. Thus, at sunrise and sunset, the sun itself as well as the surrounding sky appear red.

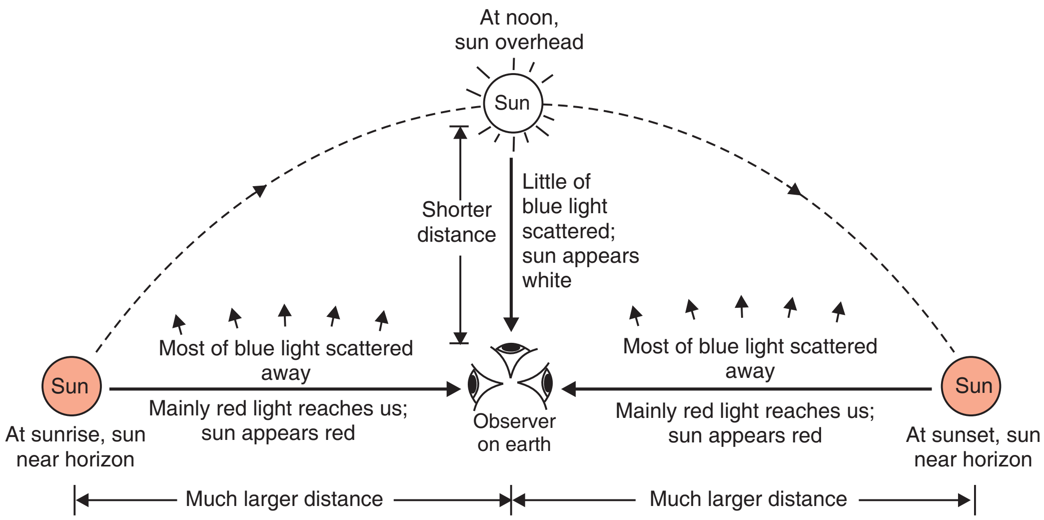


Figure 32. The sun appears red at sunrise and sunset (but white at noon).

We will now discuss **why the sun appears white when it is overhead in the sky.** When the sun is overhead (as at noon), then the light coming from the sun has to travel a relatively shorter distance through the atmosphere to reach us. During this shorter journey of sunlight, only a little of the blue colour of the white light is scattered (most of the blue light remains in it). Since the light coming from the overhead sun has almost all its component colours in the right proportion, therefore, the sun in the sky overhead appears white to us (see Figure 32).

Experiment to Study the Scattering of Light

We will now perform an experiment to understand how the scattering of light leads to the blue colour of the sky, and the red appearance of the sun at sunrise and sunset. In this experiment we will prepare a colloidal solution containing tiny particles of sulphur required for scattering the light by the action of sulphuric acid on sodium thiosulphate solution.

Set up the apparatus as shown in Figure 33. *S* is a strong source of white light. We will consider this source of light to be the sun. The source of light *S* is placed at the focus of a convex lens (converging lens) L_1 so as to produce a parallel beam of light rays. A transparent glass tank *T* is filled with about 2 litres of clear water. A cardboard disc *D* having a circular hole *C* at its centre is kept on the other side of the water tank. Another convex lens L_2 is kept behind the cardboard disc to focus the light rays (coming from the glass tank and passing through the circular hole of cardboard disc) to form an image on the screen *R*. We will now describe how the experiment is actually performed.

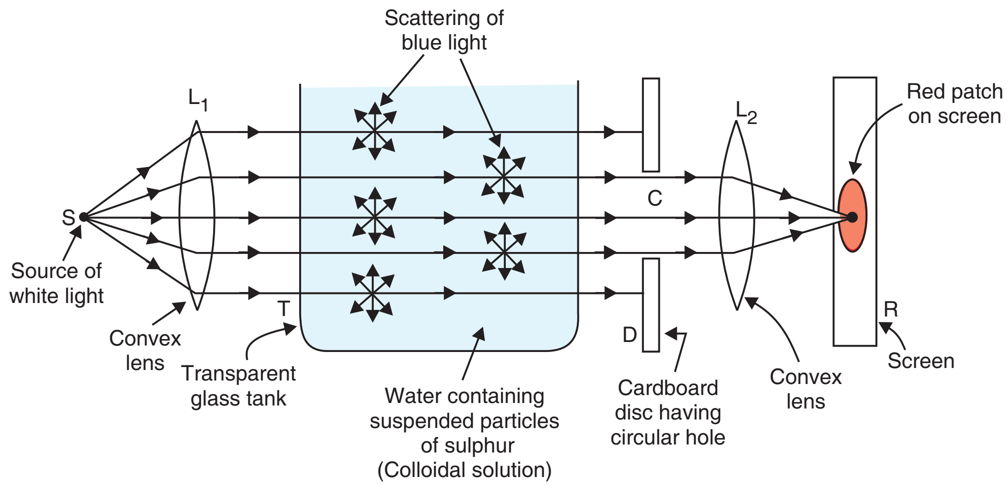


Figure 33. An arrangement for observing the scattering of light in a colloidal solution to show how the sky appears blue, and the sun appears red at sunrise and sunset.

Switch on the source of light *S*. We will find that a beam of light passes through water in the glass tank and forms a circular patch of white light on the screen *R*. We can, however, not see the path of the beam of light inside the water of the tank (because there are no suspended particles in water to scatter the beam of light). Let us now dissolve about 200 grams of sodium thiosulphate (called 'hypo') in water of the glass tank. Then add 1 to 2 mL of concentrated sulphuric acid to the water. We will see that fine microscopic particles of sulphur begin to form in water and a colloidal solution is obtained. As the sulphur particles begin to form in water, we will see the blue light coming from the *sides* of the glass tank (see Figure 33). This is due to the scattering of short wavelength blue light (present in the beam of white light) by the minute colloidal sulphur particles. This is how the sky looks blue (when the blue light present in sunlight is scattered by the molecules of air in the atmosphere).

If we look at the screen on the *front* side of the glass tank containing colloidal solution of sulphur, we will see a red patch on the screen. This is because mainly the red colour of the beam of white light reaches the screen after passing through the colloidal sulphur solution in the glass tank (the blue colour being scattered away and hence eliminated on the way). This is how the sun looks red at sunrise and sunset when mainly the red colour of sunlight reaches our eyes after the elimination of blue colour through scattering along the way. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. What is the colour of the sunlight :
   (*a*) scattered by the dust particles in the atmosphere ?
   (*b*) scattered by the air molecules in the atmosphere ?

2. Which of the two is scattered more easily : light of shorter wavelengths or light of longer wavelengths ?

3. State whether the following statements are true or false :
   (*a*) The scattering away of red light makes the sky appear blue during the day time.
   (*b*) The scattering away of blue light makes the sun appear red at sunset.

4. What colour does the sky appear to an astronaut ?

5. Which effect is illustrated by the observation that when a beam of sunlight enters a dusty room, then its path becomes visible to us.

6. State two effects produced by the scattering of light by the atmosphere.

Short Answer Type Questions

7. What is tyndall effect ? Explain with an example.

8. What happens when a beam of sunlight enters a dusty room through a window ? Explain your answer.

9. Why does the sky appear blue on a clear day ?
10. Why does the sky appear dark (or black) to an astronaut instead of blue ?
11. Why does the sun appear red at sunrise ?
12. Why does the sun appear red at sunset ?
13. Why are the 'danger signal' lights red in colour ?

Long Answer Type Question

14. (*a*) Draw a neat and labelled diagram of the experimental set up for observing the scattering of light in a colloidal solution of sulphur to show how the sky appears blue, and the sun appears red at sunrise and sunset.
(*b*) Out of blue light and red light, which one is scattered more easily ?
(*c*) Which component of sunlight is scattered away when the sun appears red at sunrise or sunset ?
(*d*) What causes the scattering of blue component of sunlight in the atmosphere ?

Multiple Choice Questions (MCQs)

15. The blue colour of sky is due to :
(*a*) refraction of light (*b*) dispersion of light
(*c*) diffraction of light (*d*) scattering of light
16. The red colour of the sun at the time of sunrise and sunset is because :
(*a*) red colour is least scattered (*b*) blue colour is least scattered
(*c*) red colour is most scattered (*d*) blue colour is most scattered
17. Which of the following is not caused by the atmospheric refraction of light ?
(*a*) twinkling of stars at night
(*b*) sun appearing higher in the sky than it actually is
(*c*) sun becoming visible two minutes before actual sunrise
(*d*) sun appearing red at sunset
18. The sky appears blue because some of the blue component of sunlight is scattered by :
(*a*) gas molecules present in air (*b*) dust particles present in air
(*c*) water droplets suspended in air (*d*) soot particles present in air
19. Sunset is red because at that time the light coming from the sun has to travel :
(*a*) lesser thickness of earth's atmosphere (*b*) greater thickness of earth's atmosphere
(*c*) varying thickness of earth's atmosphere (*d*) along the horizon

Questions Based on High Order Thinking Skills (HOTS)

20. In an experiment to study the scattering of light by passing a beam of white light through a colloidal solution of sulphur in a transparent glass tank :
(*a*) Which colour is observed from the front of the glass tank ? Does this colour correspond to the colour of sky on a clear day or the colour of sky around the sun at sunset ?
(*b*) Which colour is observed from the sides of the glass tank ? Does this colour correspond to the colour of sky on a clear day or the colour of sky around the sun at sunset ?
21. Explain why, when the sun is overhead at noon, it appears white, but when the same sun is near the horizon at sunset, it appears red.
22. Complete the following statements :
When the sun is setting, the light from it has to travel a ....thickness of the earth's atmosphere and only...........wavelength...........light is able to reach us. Sunset is therefore..........

ANSWERS

1. (*a*) White (*b*) Blue **2.** Light of shorter wavelength **3.** (*a*) False (*b*) True **4.** Dark (or Black) **5.** Tyndall effect (Scattering of light) **6.** Sky appears blue ; Sun appears red at sunrise and sunset **14.** (*b*) Blue light (*c*) Blue (*d*) Gas molecules present in air **15.** (*d*) **16.** (*d*) **17.** (*d*) **18.** (*a*) **19.** (*b*) **20.** (*a*) Red ; Colour of sky around the sun at sunset (*b*) Blue ; Colour of sky on a clear day **22.** greater ; longer ; red ; red

Multiple Choice Questions (MCQs)

(Based on Practical Skills in Science)

Multiple choice questions based on the experiment :

To study the dependence of current (I) on the potential difference (V) across a resistor and determine its resistance. Also plot a graph between V and I.

1. To study the dependence of current (I) on the potential difference (V) across a resistor, the correct way of connecting the ammeter and voltmeter in the circuit is :

(1) ammeter and voltmeter both are connected in series

(2) ammeter is connected in parallel and voltmeter in series

(3) ammeter is connected in series and voltmeter in parallel

(4) ammeter and voltmeter both are connected in parallel

2. The following four circuits have been made for studying the dependence of current on the potential difference across a resistor.

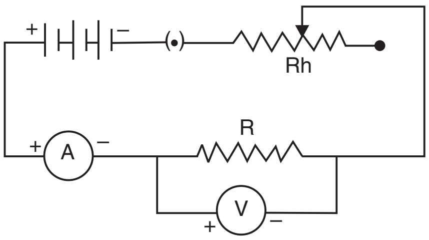
The correct circuit is :

(1) A

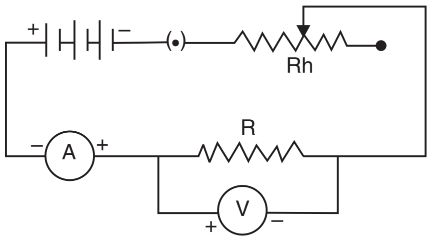
(2) B

(3) C

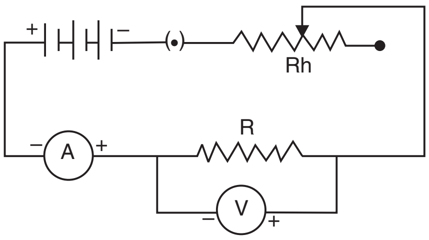
(4) D



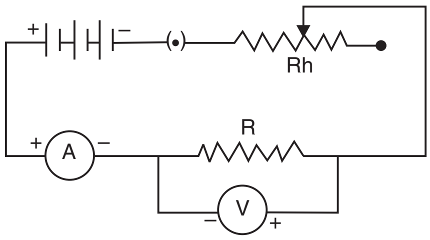
(A)



(B)



(C)



(D)

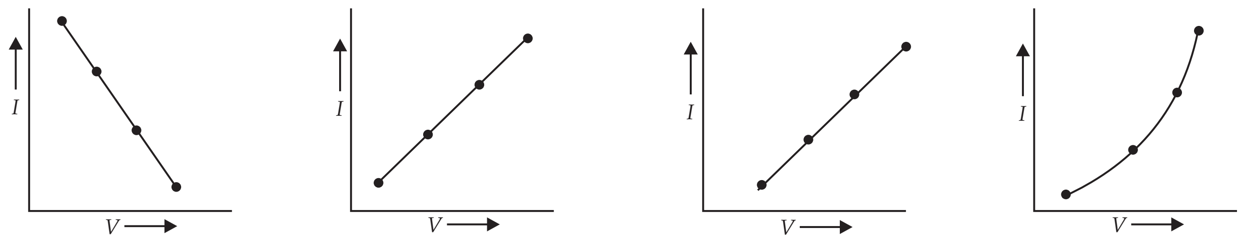
3. To study the dependence of current (I) on the potential difference (V) across a resistor, the following observations were made by four students A, B, C and D.

Student	Reading No. 1	Reading No. 2	Reading No. 3
A	V = 0.5 V I = 0.1 A	V = 1.0 V I = 0.2 A	V = 1.5 V I = 0.3 A
B	V = 0.8 V I = 0.4 A	V = 1.6 V I = 0.8 A	V = 2.4 V I = 1.2 A
C	V = 1.0 V I = 0.5 A	V = 1.2 V I = 1.4 A	V = 1.4 V I = 1.0 A
D	V = 2.4 V I = 0.8 A	V = 2.7 V I = 0.9 A	V = 3.0 V I = 1.0 A

The teacher found that one of the students has made wrong observations. The student who made the mistake is :

(1) A (2) B (3) C (4) D

4. Graphs plotted by four students A, B, C and D for the experiment "To study the dependence of current (*I*) on the potential difference (*V*) across a resistor" are shown below :



(A) (B) (C) (D)

The correct *V–I* graph is :

(1) A (2) B (3) C (4) D

5. The following 'precautions' were listed by a student in the experiment on study of 'Dependence of current on potential difference'.

(A) Use copper wires as thin as possible for making connections.

(B) All the connections should be kept tight.

(C) The positive and negative terminals of the voltmeter and the ammeter should be correctly connected.

(D) The 'zero error' in the ammeter and the voltmeter should be noted and taken into consideration while recording the measurements.

(E) The 'key' in the circuit, once plugged in, should not be taken out till all the observations have been completed.

The 'precautions' that need to be corrected and revised are :

(1) (A), (C) and (E) (2) (C) and (E) (3) (B) and (E) (4) (A) and (E)

6. An ammeter has 20 divisions between 0 mark and 2 A mark on its scale. The least count of this ammeter is :

(1) 0.01 A (2) 0.02 A (3) 0.1 A (4) 0.2 A

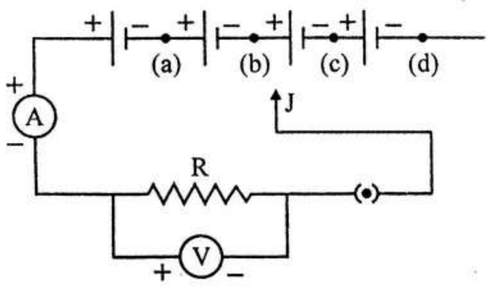
7. A student finds that there are 20 divisions between the 0 mark and 1 V mark of a voltmeter. What is the least count of this voltmeter ?

(1) 0.50 V (2) 0.02 V (3) 0.2 V (4) 0.05 V

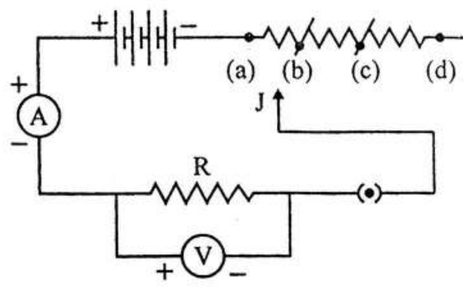
8. Which of the following instruments does not have plus (+) or minus (–) sign marked on it while representing in a circuit diagram ?

(1) Rheostat (2) Voltmeter (3) Ammeter (4) Cell

9. To study the dependence of current (I) on the potential difference (V) across a resistor R, two students used the two set ups shown in Figures A and B respectively. They kept the contact point J in four different positions, marked (a), (b), (c) and (d) in the two figures.



(A)



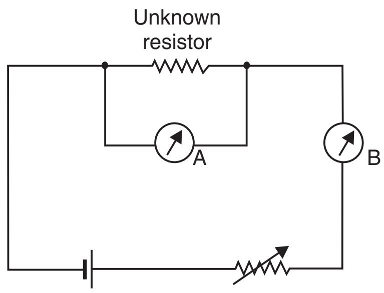
(B)

For the two students, the ammeter and voltmeter readings will be maximum when the contact J is in the position :

(1) (d) in both the set ups (2) (a) in both the set ups

(3) (d) in set up A and (a) in set up B (4) (a) in set up A and (d) in set up B

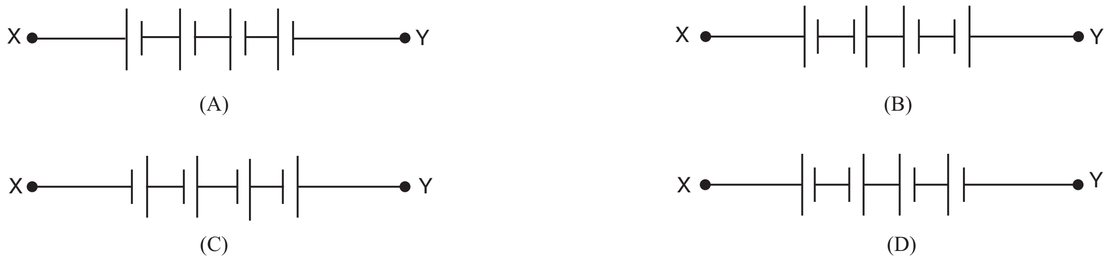
10. In the circuit given below, the instrument B reads 0.93 and the instrument A reads 1.80 in their respective SI units.



The value of unknown resistor will be :

(1) 0.51 Ω (2) 1.63 Ω (3) 1.93 Ω (4) 19.3 Ω

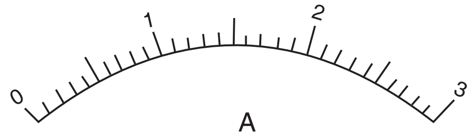
11. Four identical cells of emf 1.5 V each were connected in four different ways as shown below :



The potential difference between the points X and Y would be equal to 6.0 V in case/cases :

(1) A and B (2) A and C (3) A and D (4) A only

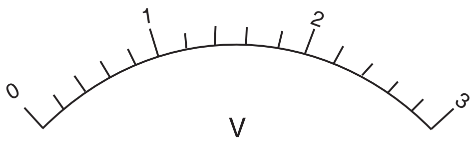
12. The scale of an ammeter is shown below :



The least count of this ammeter is :

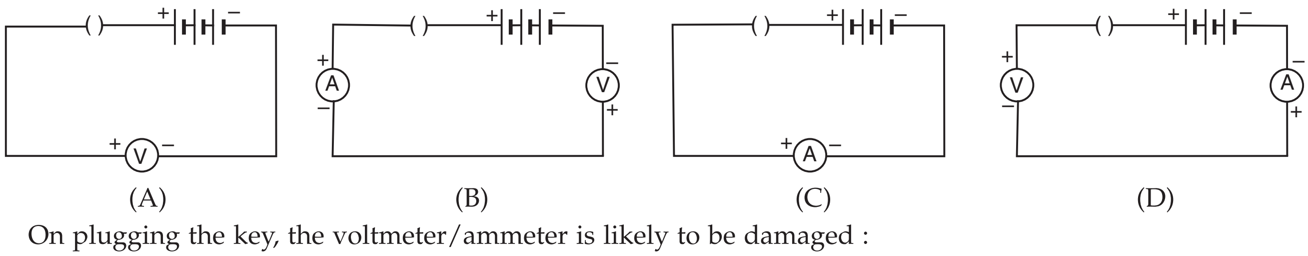
(1) 0.05 A (2) 0.5 A (3) 0.1 A (4) 1 A

13. The least count of the voltmeter shown below is :



(1) 0.1 V (2) 0.01 V (3) 0.02 V (4) 0.2 V

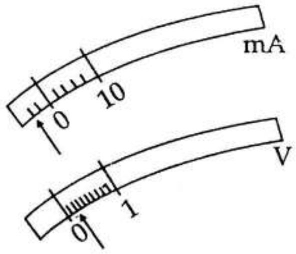
14. Consider the following circuits :



On plugging the key, the voltmeter/ammeter is likely to be damaged :

(1) in circuit A (2) in circuit B (3) in circuit C (4) in circuit D

15. The rest positions of the needles in a Milliammeter and Voltmeter when not being used in a circuit are as shown in the figure. The 'zero error' and 'least count' of these two instruments are :



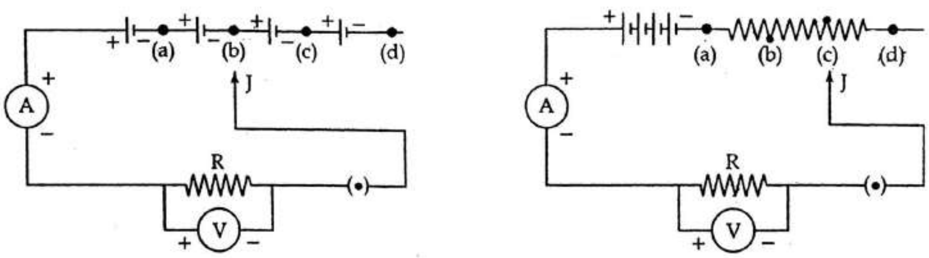
(1) (+4 mA, – 0.2 V) and (1 mA, 0.1 V) respectively
(2) (+4 mA, – 0.2 V) and (2 mA, 0.2 V) respectively
(3) (– 4 mA, + 0.2 V) and (2 mA, 0.2 V) respectively
(4) (– 4 mA, + 0.2 V) and (2 mA, 0.1 V) respectively

16. A student has to connect 4 cells of 2 V each to form a battery of voltage 8 V. The correct way of connecting these cells is shown in figure :

(1) A (2) B (3) C (4) D

(A) (B) (C) (D)

17. To study the dependence of current (I) on the potential difference (V) across a resistor, two students used the two set ups shown in figs (A) and (B) respectively. They kept the contact J in four different positions, marked (a), (b), (c), (d) in the two figures.

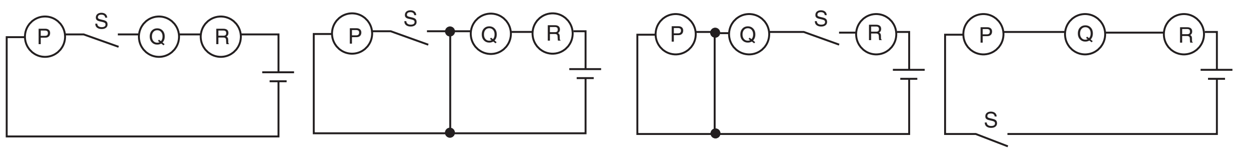


(A) (B)

For the two students, their Ammeter and Voltmeter readings will be minimum when the contact J is in the position :

(1) (a) in both the set ups
(2) (d) in both the set ups
(3) (d) in set up (A) and (a) in set up (B)
(4) (a) in set up (A) and (d) in set up (B)

18. In the circuits A, B, C and D, with switch S open, the lamps Q and R would light up but not lamp P in :

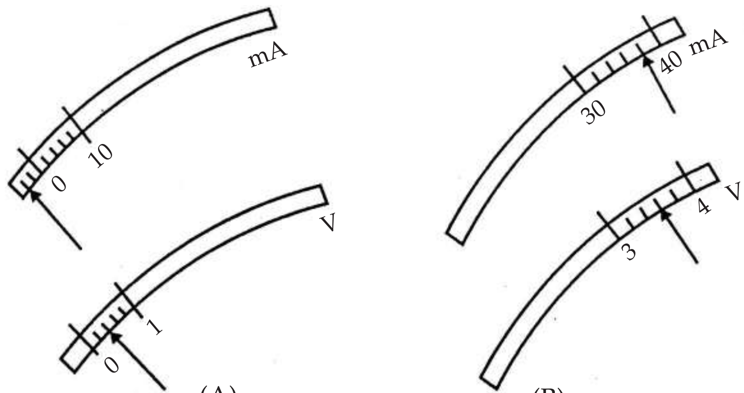


(A) (B) (C) (D)

(1) circuit A (2) circuit B (3) circuit C (4) circuit D

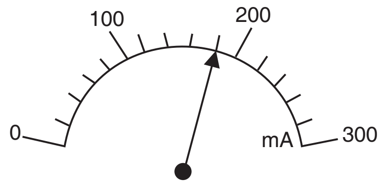
19. The rest positions of the needles in a milliammeter and voltmeter not in use are as shown in Fig. A. When a student uses these in his experiment, the readings of the needles are in the positions shown in Fig. B. The corrected values of current and voltage in the experiment are

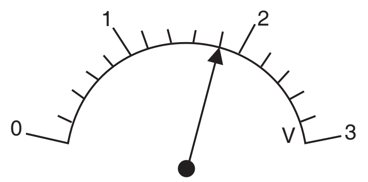
(1) 42 mA and 3.2 V
(2) 42 mA and 4.0 V
(3) 34 mA and 3.2 V
(4) 34 mA and 4.0 V



(A) (B)

20. The current flowing through a resistor connected in an electric circuit and the potential difference applied across its ends are shown in the figures below :

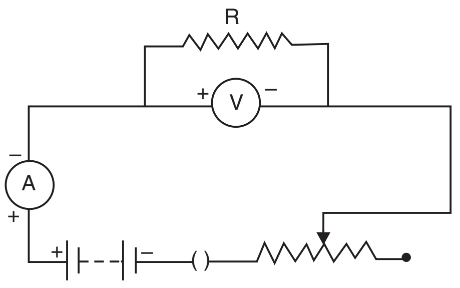




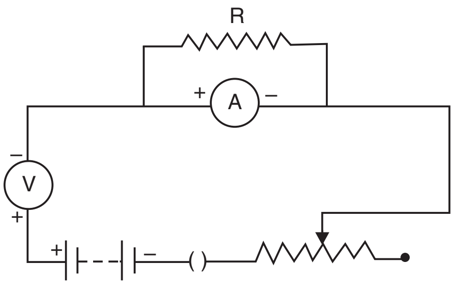
The value of the resistance of the resistor is :

(1) 10 Ω (2) 15 Ω (3) 20 Ω (4) 25 Ω

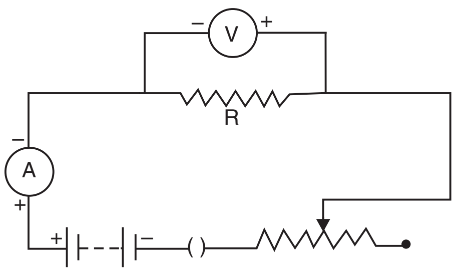
21. Consider the following circuit diagrams drawn by four students :



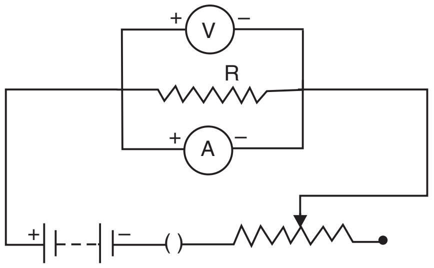
(A)



(B)



(C)

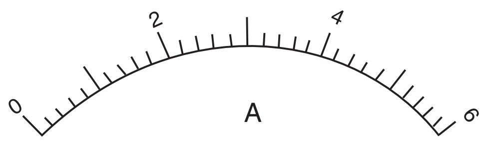


(D)

The correct circuit diagram for studying the dependence of current on the potential difference across a resistor is :

(1) A (2) B (3) C (4) D

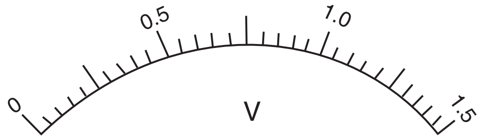
22. The scale of an ammeter is shown below :



The least count of this ammeter is :

(1) 0.1 A (2) 0.01 A (3) 0.02 A (4) 0.2 A

23. The figure below shows the scale of a voltmeter.

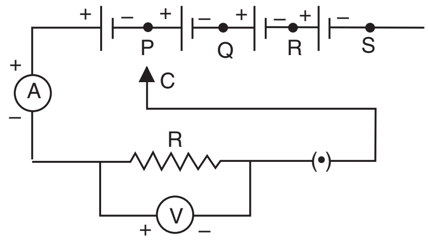


The least count of this voltmeter is :

(1) 1 V (2) 0.5 V (3) 5 V (4) 0.05 V

24. A student used the set up given here to study the dependence of current (I) on the potential difference (V) across a resistor.

He kept the contact C in four different positions marked as P,Q, R and S in the figure. On calculating the values of the ratio $\frac{V}{I}$ for his four readings, he would find that the value of this ratio :



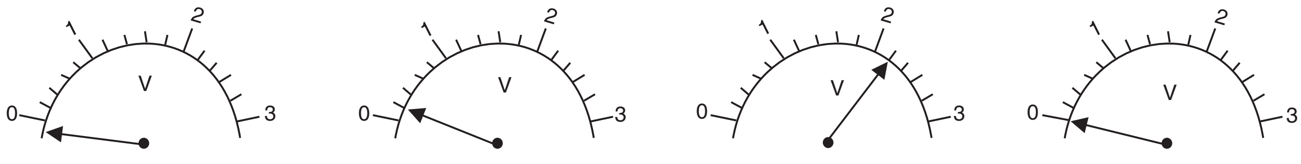
(1) for contact at point P is $\frac{1}{4}$th of that for contact at point S.

(2) for contact at point Q is $\frac{2}{4}$th of that for contact at point S.

(3) for contact at point R is $\frac{3}{4}$th of that for contact at point S.

(4) is the same for all the four readings

25. You are given the following four voltmeters to study the dependence of current (I) on the potential difference (V) across a resistor.

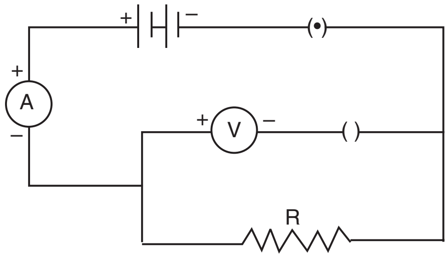


(A) (B) (C) (D)

Which one of the above voltmeters would you prefer to use in the circuit to begin your experiment ?

(1) A (2) B (3) C (4) D

26. A student arranged an electric circuit as shown alongside :



He would observe :

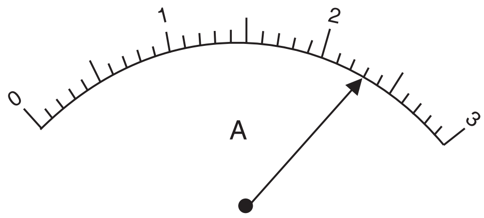
(1) no reading in either the ammeter or the voltmeter

(2) no reading in the voltmeter but a reading in the ammeter

(3) no reading in the ammeter but a reading in the voltmeter

(4) readings in both the ammeter and the voltmeter

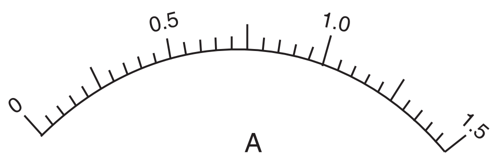
27. Four students recorded the readings of the current by observing the position of pointer on the ammeter scale given below :



If there is no zero error, the correct reading of current is :

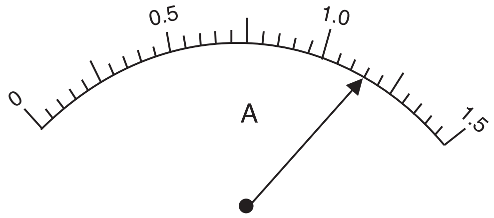
(1) 2.3 A (2) 5 A (3) 2.0 A (4) 2.05 A

28. The least count of the ammeter shown below is :



(1) 0.05 A (2) 0.5 A (3) 0.1 A (4) 1 A

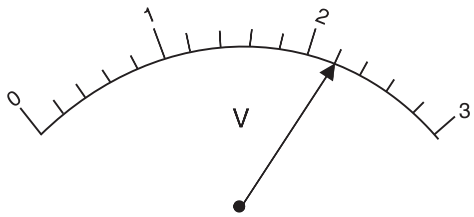
29. Four students measured the reading by observing the position of pointer on the ammeter scale as shown below :



Assuming that the ammeter has no zero error, the correct reading is :

(1) 1.25 A (2) 1.30 A (3) 1.15 A (4) 1.1 A

30. Four students recorded the readings of the potential differece by observing the position of the pointer of an ideal voltmeter as shown below :



The correct reading is :

(1) 2.5 V (2) 2.0 V (3) 2.2 V (4) 2.4 V

Multiple Choice questions based on the experiments :

To determine the equivalent resistance of two resistors (i) when connected in series (ii) when connected in parallel.

31. In an experiment to find the equivalent resistance of two resistors connected in series, a student uses the circuit shown :

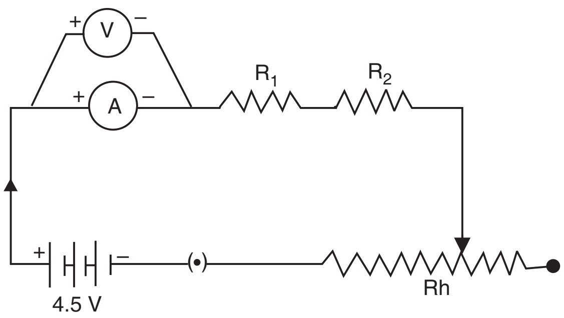
This circuit will give :

(1) correct reading for voltage V but incorrect reading for current I

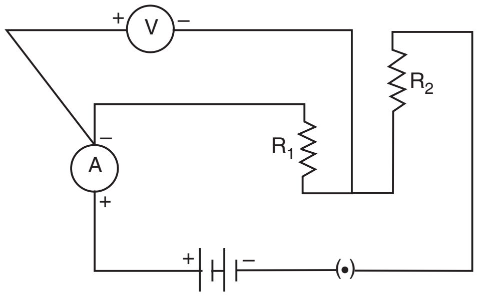
(2) correct reading for current I but incorrect reading for voltage V

(3) correct readings for both voltage V and current I

(4) Incorrect readings for both current I and voltage V



32. A student sets up an electric circuit shown here for finding the equivalent resistance of two resistors in series :



In this circuit, the :

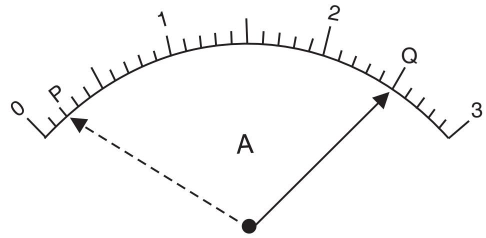
(1) resistors have been connected correctly but the voltmeter has been wrongly connected

(2) resistors have been connected correctly but the ammeter has been wrongly connected

(3) resistors as well as the voltmeter have been wrongly connected

(4) resistors as well as the ammeter have been wrongly connected

33. A student while performing the experiment to find the resultant resistance of two resistors connected in series observes the ammeter pointer at position P when the key is 'off' and the same pointer at position Q when the key is 'on'.

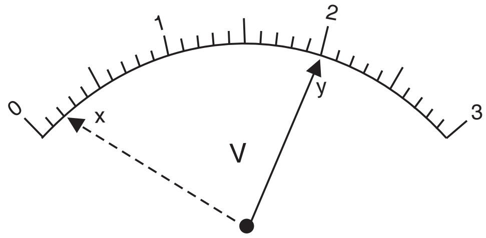


The correct reading of ammeter is :

(1) 0.2 A (2) 2.5 A

(3) 2.3 A (4) 2.7 A

34. While performing an experiment to determine the equivalent resistance of two resistors connected in parallel, a student observes the pointer of voltmeter at position X when the key is 'off' and the same pointer at position Y when the key is 'on'.



The correct voltmeter reading is :

(1) 0.2 V (2) 2 V

(3) 2.2 V (4) 1.8 V

35. Choose the appropriate set of apparatus for performing the experiment to determine the equivalent resistance of two resistors when connected in series :

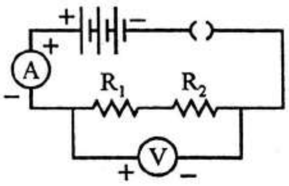
(1) Voltmeter, Ammeter, Two resistors, Key, Battery

(2) Ammeter, Two resistors, Key, Connecting wires, Rheostat, Battery

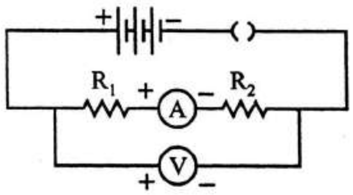
(3) Key, Rheostat, Voltmeter, Two resistors, Battery, Connecting wires

(4) Battery, Ammeter, Connecting wires, Rheostat, Voltmeter, Two resistors, Key

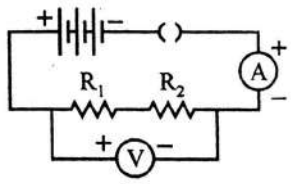
36. In the experiment on finding the equivalent resistance of two resistors connected in series, three students connected the ammeter in their circuits in the three ways X, Y and Z shown here.



(X)



(Y)

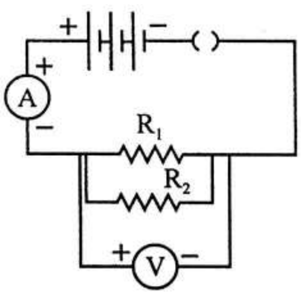


(Z)

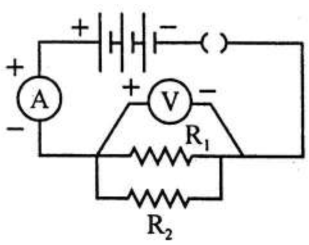
Assuming their ammeters to be ideal, the ammeters have been correctly connected in

(1) cases X and Y only (2) cases Y and Z only (3) cases Z and X only (4) all the three cases

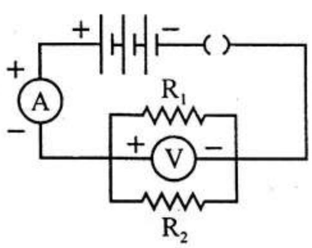
37. In the experiment on finding the equivalent resistance of two resistors, connected in parallel, three students connected the voltmeter in their circuits, in the three ways X, Y and Z shown here.



(X)



(Y)

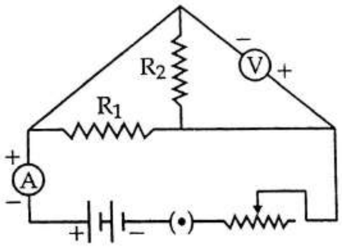


(Z)

The voltmeter has been correctly connected in

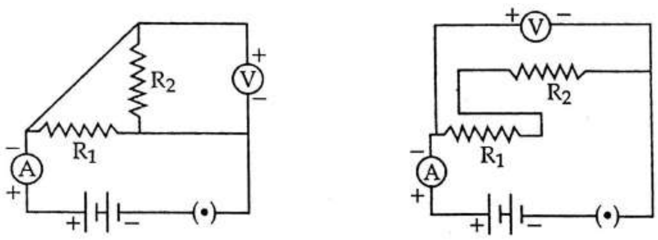
(1) cases X and Y only (2) cases Y and Z only (3) cases Z and X only (4) all the three cases

38. The only *correct* statement for the following electric circuit is :



(1) The Voltmeter has been correctly connected in the circuit
(2) The Ammeter has been correctly connected in the circuit
(3) The Resistors R_1 and R_2 have been correctly connected in series
(4) The Resistors R_1 and R_2 have been correctly connected in parallel

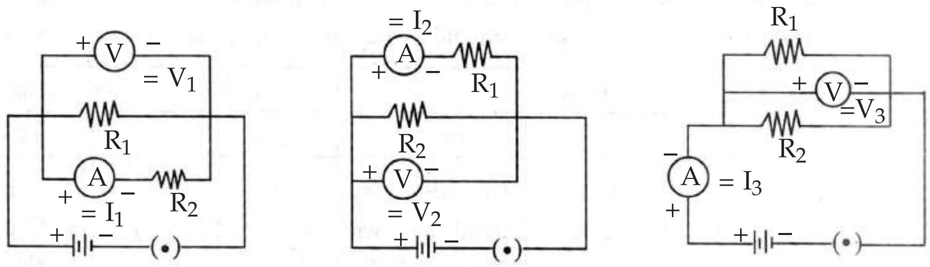
39. The only *correct* statement for the two circuits (X) and (Y) shown below is :



(X) (Y)

(1) The resistors R_1 and R_2 have been connected in series in both the circuits
(2) The resistors R_1 and R_2 have been connected in parallel in both the circuits
(3) In the circuit (X) the resistors have been connected in parallel whereas these are connected in series in circuit (Y).
(4) In the circuit (X) the resistors R_1 and R_2 are connected in series while these are connected in parallel in circuit (Y)

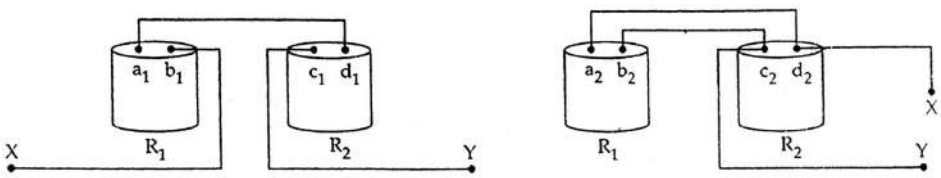
40. For three circuits, shown here



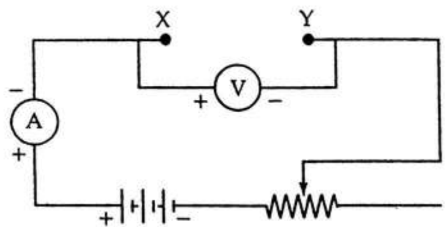
the same two resistors R_1 and R_2 have been connected in parallel in all the circuits but the voltmeter and the ammeter have been connected in three different positions. The relation between the three voltmeter and ammeter readings would be :

(1) $V_1 = V_2 = V_3$ and $I_1 = I_2 = I_3$
(2) $V_1 \neq V_2 \neq V_3$ and $I_1 = I_2 = I_3$
(3) $V_1 = V_2 = V_3$ and $I_1 \neq I_2 \neq I_3$
(4) $V_1 \neq V_2 \neq V_3$ and $I_1 \neq I_2 \neq I_3$

41. Two students (A) and (B) connect their two given resistors R_1 and R_2 in the manners shown below :



(A) (B)



Student (A) connects the terminals marked (b_1) and (c_1) while student (B) connects the terminals marked (d_2) and (c_2) in their respective circuits at the points marked X and Y.

Which one of the following is correct in relation to above arrangements ?

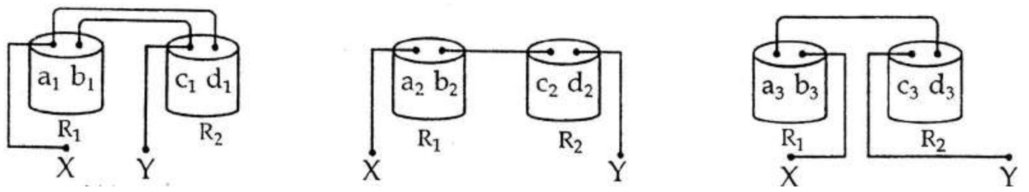
(1) both the students will determine the equivalent resistance of the series combination of the two resistors.

(2) both the students will determine the equivalent resistance of the parallel combination of the two resistors.

(3) student (A) will determine the equivalent resistance of the series combination while student (B) will determine the equivalent resistance of the parallel combination of the two resistors.

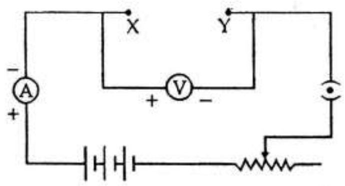
(4) student (A) will determine the equivalent resistance of the parallel combination while student (B) will determine the equivalent resistance of the series combination of the two resistors.

42. Three students (A), (B) and (C) connect their two given resistors R_1 and R_2 in the manners shown below :



(A) (B) (C)

They connect the terminals marked X and Y above to the terminals marked X and Y in the circuit given below :

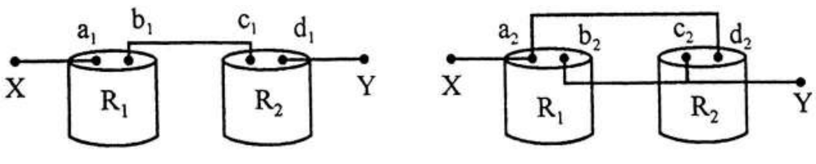


They record the Ammeter readings (I) for different positions of the rheostat and the corresponding Voltmeter readings (V).

The average value of the ratio V/I in their observations would be minimum for :

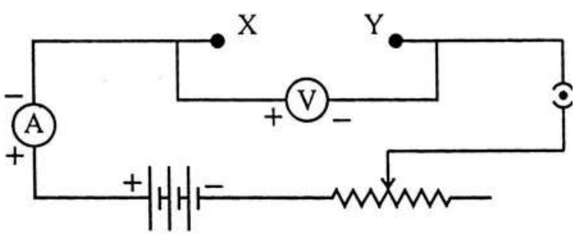
(1) students (A) and (B) only
(2) students (B) and (C) only
(3) students (C) and (A) only
(4) student (A) only

43. Students A and B connect the two resistors R_1 and R_2 given to them in the manners shown below :



(A) (B)

and then insert them at X and Y into the measuring circuit shown below :



We can then say that

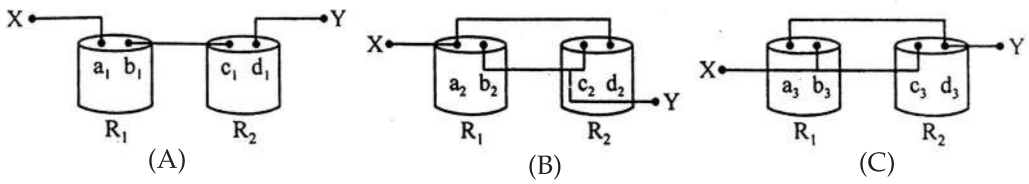
(1) both the students will determine the equivalent resistance of the series combination of R_1 and R_2

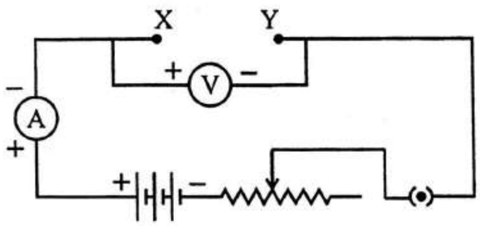
(2) both the students will determine the equivalent resistance of the parallel combination of R_1 and R_2

(3) student A will determine the equivalent resistance of the series combination while student B will determine the equivalent resistance of the parallel combination of R_1 and R_2

(4) student A will determine the equivalent resistance of the parallel combination while student B will determine the equivalent resistance of the series combination of R_1 and R_2

44. A student carries out the experiment for studying the dependence of current (I) flowing through a resistor system of R_1 and R_2 on the potential difference (V) applied to it by connecting the resistor system to points X and Y of the measuring circuit as shown :

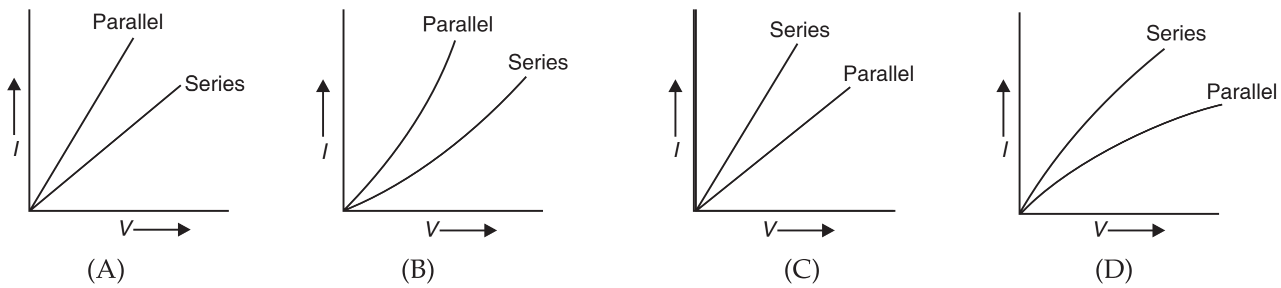




The average value of the ratio V/I, of his observations, would then be equal

(1) only in cases A and B
(2) only in cases B and C
(3) only in cases C and A
(4) all the three cases

45. Four students performed experiments on series and parallel combination of two given resistors R_1 and R_2 which obey Ohm's law and plotted the following V–I graphs :



Which of the graphs is correctly labelled in terms of 'series' and 'parallel' ?

(1) graph A
(2) graph B
(3) graph C
(4) graph D

46. You are given four ammeters A, B, C and D having the least counts mentioned below :

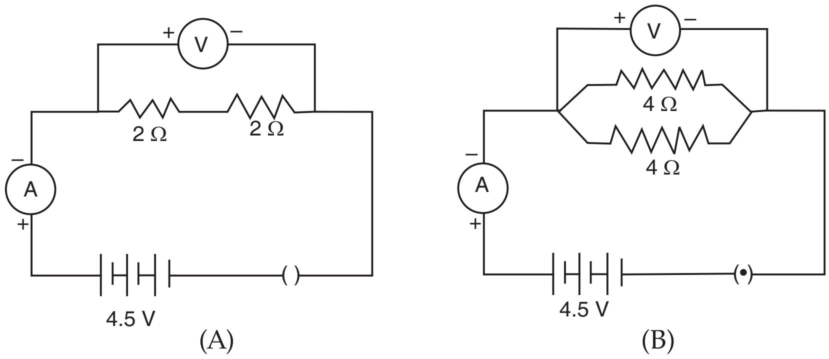
(a) Ammeter A with least count 0.25 A
(b) Ammeter B with least count 0.5 A
(c) Ammeter C with least count 0.05 A
(d) Ammeter D with least count 0.1 A

Which of the ammeters would you prefer for doing an experiment to determine the equivalent resistance of two resistances most accurately, when connected in parallel ?

(1) A
(2) B
(3) C
(4) D

47. Consider the two circuits A and B given alongside :

In the circuits A and B shown here, the voltmeter reading would be :



(1) nearly 4.5 V in both the circuits
(2) 0 V in both the circuits
(3) nearly 1 V for circuit A and nearly 4.5 V for circuit B.
(4) 0 V for circuit A and nearly 4.5 V for circuit B.

48. The values of resistances marked on the coils R_1 and R_2 are found to be correct. A student connects the given resistors in the following manner (as shown in Figure 1).

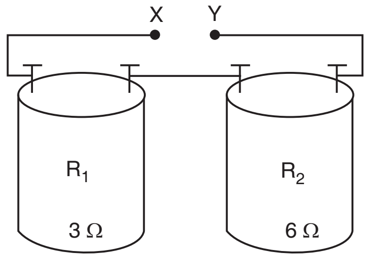


Figure 1.

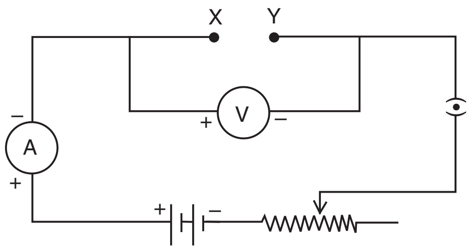


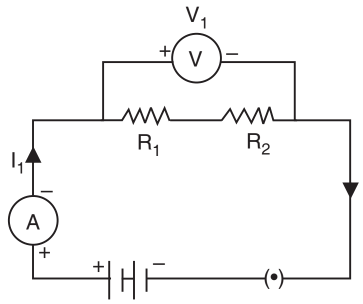
Figure 2.

He then connects the terminals marked X and Y of the above combination of resistors R_1 and R_2 to the terminals marked X and Y in the circuit (shown in Figure 2).

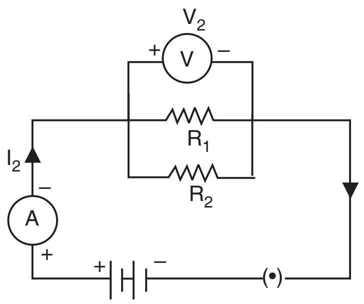
The average value of the ratio V/I in the observations recorded in the circuit would be :

(1) 9 Ω (2) 6 Ω (3) 3 Ω (4) 2 Ω

49. A student using the same two resistors, ammeter, voltmeter and battery, sets up two circuits A and B connecting the two resistors first in series and then in parallel.



(A)

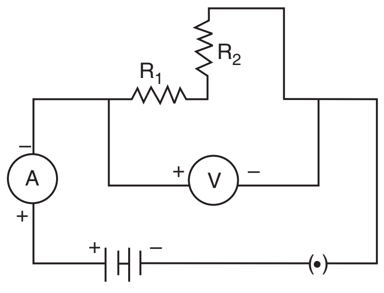


(B)

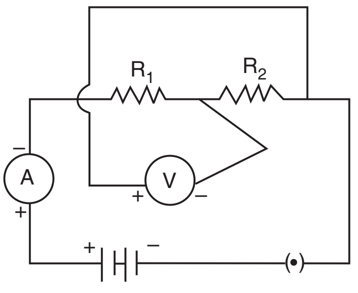
If the ammeter and voltmeter readings in the two cases be I_1, I_2 and V_1, V_2 respectively, he is likely to observe that :

(1) $I_1 = I_2$ but $V_1 \neq V_2$ (2) $I_1 < I_2$ but $V_1 = V_2$
(3) $I_1 > I_2$ but $V_1 = V_2$ (4) $I_1 = I_2$ and $V_1 = V_2$

50. Two students made two circuits A and B to determine the resultant resistance of two resistors R_1 and R_2 connected in series :



(A)

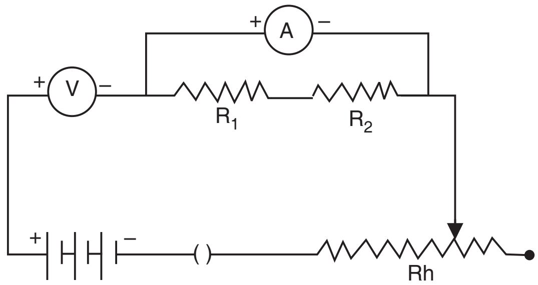


(B)

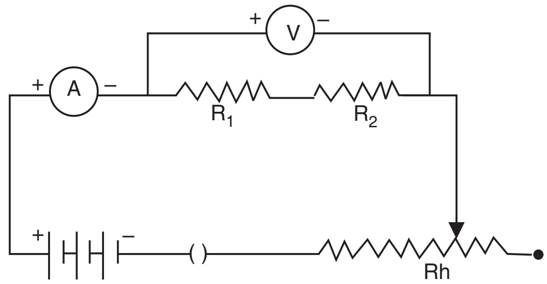
All the components have been connected correctly in :

(1) circuit A only (2) circuit B only
(3) both circuits A and B (4) neither of the two circuits

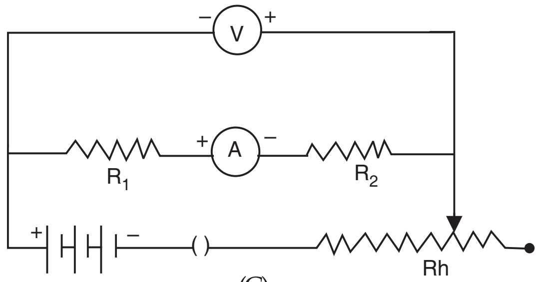
51. Four students have made the following circuit diagrams for determining the equivalent resistance of two resistors connected in series :



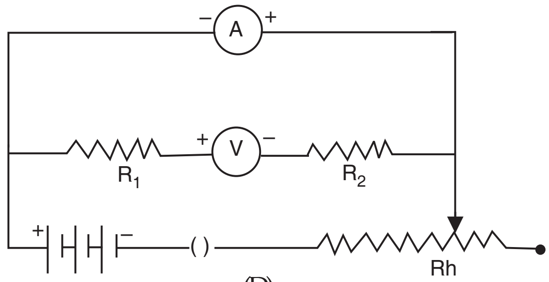
(A)



(B)



(C)

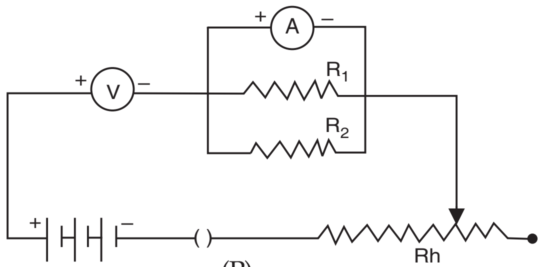


(D)

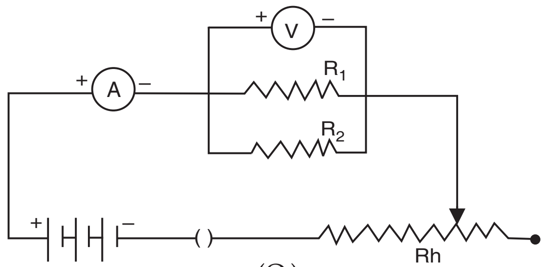
The correct circuit diagram is :

(1) A (2) B (3) C (4) D

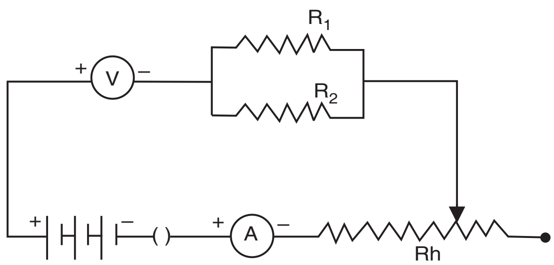
52. Consider the following four circuits P, Q, R and S which have been set up to find the resultant resistance of two resistors combined in parallel :



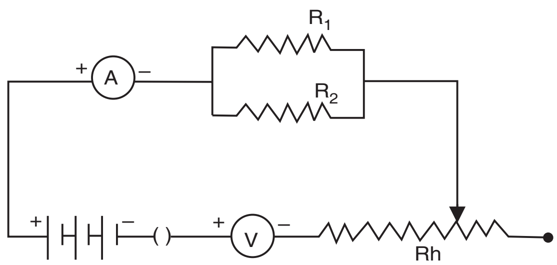
(P)



(Q)



(R)

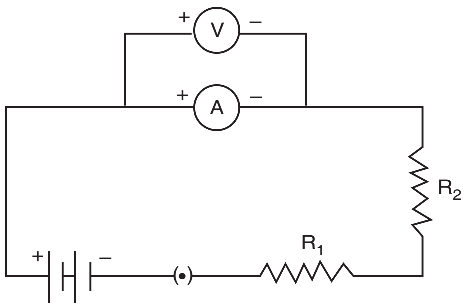


(S)

The correct way of connecting the ammeter and voltmeter in the circuit is :

(1) P (2) Q (3) R (4) S

53. In order to determine the equivalent resistance of two resistors R_1 and R_2 connected in series, a student made this circuit for his experiment.



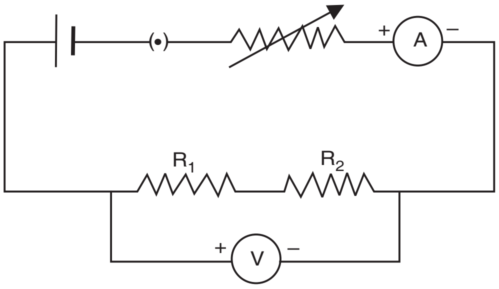
The only statement which is true for this circuit is that it gives :

(1) incorrect readings for current I as well as for potential difference V

(2) correct reading for current I but incorrect reading for potential difference V

(3) incorrect reading for current I but correct reading for potential difference V
(4) correct readings for both current I and potential difference V.

54. To find the resultant resistance of two resistors when connected in series, a student arranged the various components according to the circuit shown alongside :



The student, however, did not succeed in his objective. Which of the following mistake has been made by the student in setting up the circuit ?

(1) position of voltmeter is wrong
(2) position of ammeter is wrong
(3) terminals of voltmeter are wrongly connected
(4) terminals of ammeter are wrongly connected

55. The following apparatus is available in the school laboratory :

Battery	:	4.5 V
Rheostat	:	Varies battery voltage from 0 to 4.5 V
Resistors	:	1 Ω and 2 Ω
Ammeters	:	A_1 of range 0 to 1 A ; Least count 0.05 A
	:	A_2 of range 0 to 3 A ; Least count 0.1 A
Voltmeters	:	V_1 of range 0 to 5 V ; Least count 0.1 V
		V_2 of range 0 to 10 V ; Least count 0.5 V

The best combination of ammeter and voltmeter for finding the resultant resistance of the two given resistors connected in series would be :

(1) ammeter A_1 and voltmeter V_1 (2) ammeter A_1 and voltmeter V_2
(3) ammeter A_2 and voltmeter V_1 (4) ammeter A_2 and voltmeter V_2

56. The science laboratory in a school has the following apparatus available in it :

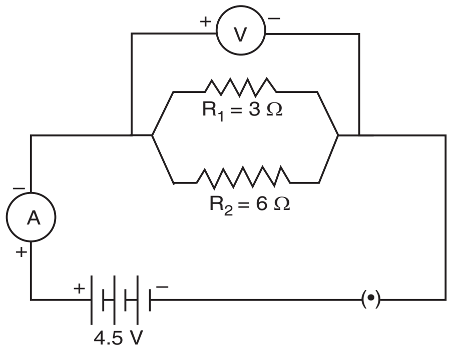
Battery	:	6 V
Rheostat	:	Varies battery voltage from 0 to 6 V
Resistors	:	3 Ω and 6 Ω
Ammeters	:	A_1 of range 0 to 5 A ; Least count 0.25 A
	:	A_2 of range 0 to 3 A ; Least count 0.1 A
Voltmeters	:	V_1 of range 0 to 10 V ; Least count 0.5 V
	:	V_2 of range 0 to 5 V ; Least count 0.1 V

For the experiment to determine the equivalent resistance of the two given resistors connected in parallel, the best combination would be :

(1) ammeter A_1 and voltmeter V_2 (2) ammeter A_2 and voltmeter V_1
(3) ammeter A_1 and voltmeter V_1 (4) ammeter A_2 and voltmeter V_2

57. The ammeter, voltmeter and, resistors R_1 and R_2 connected in the circuit as shown below have been checked and found to be correct.

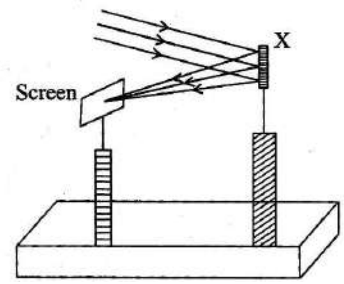
On plugging the key, the voltmeter reads 4.5 V but the ammeter reads 1.5 A. This is most likely because the wires joined to :



(1) resistor R_1 are loose
(2) resistor R_2 are loose
(3) both the resistors R_1 and R_2 are loose
(4) ammeter terminals are loose

Multiple choice questions based on the experiment :

To determine the focal length of a concave mirror.



58. A student determines the focal length of a device X, by focussing the image of a far off object on the screen positioned as shown in the figure alongside.

The device X is a :

(1) Convex lens

(2) Concave lens

(3) Convex mirror

(4) Concave mirror

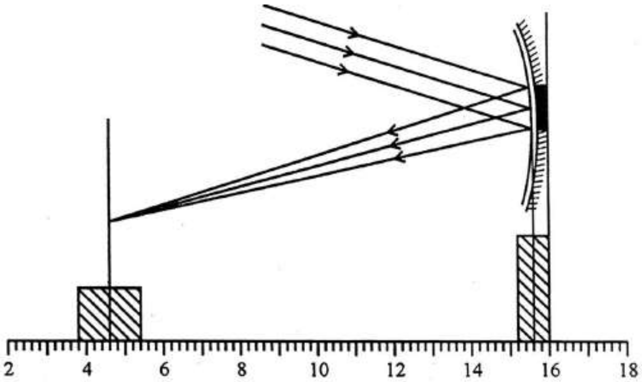
59. The focal length of the concave mirror in the experimental set up, shown alongside, equals :

(1) 10.3 cm

(2) 11.0 cm

(3) 11.7 cm

(4) 12.2 cm



60. While determining the focal length of a concave mirror, a student obtained the image of a distant object on a screen. In order to get the focal length of the mirror, the student should measure the distance :

(1) between the object and the mirror only (2) between the screen and the mirror only

(3) between the object and the screen only

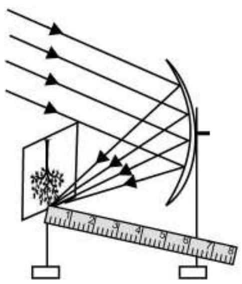
(4) between the screen and mirror as well as between the screen and the object

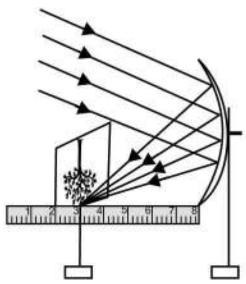
61. A student gets a blurred image of a distant object on a screen which is fixed at a place. In order to obtain a sharp image on the screen, he will have to shift the mirror :

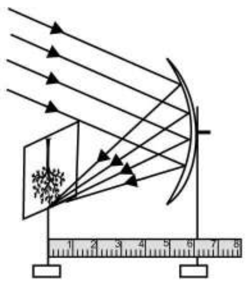
(1) towards the screen (2) away from the screen

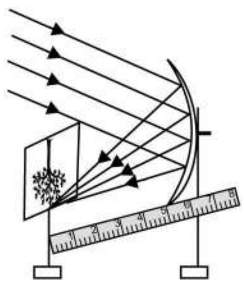
(3) either towards or away from the screen (4) very far away from the screen

62. Four students A, B, C and D performed the experiment to determine the focal length of a concave mirror by obtaining the image of a distant tree on a screen. They measured the distances between the screen and the mirror as shown in the diagrams given below :


(A)


(B)


(C)


(D)

The correct value for focal length will be obtained by the student :

(1) A (2) B (3) C (4) D

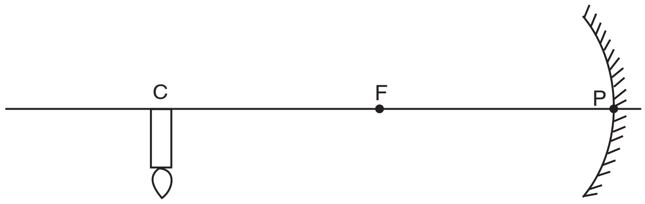
63. A student has to do the experiment on finding the focal length of a given concave mirror by using a distant object. Out of the following 'set-ups' A, B, C and D available to him :

A : a screen, a mirror holder and a scale
B : a mirror holder, a screen holder and a scale
C : a screen holder and a scale
D : a mirror holder and a scale

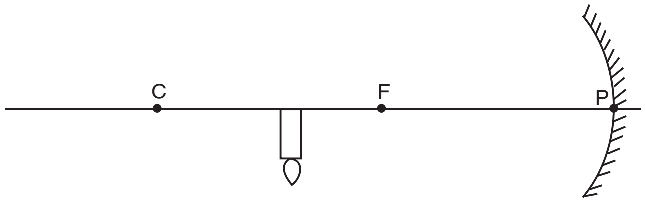
The 'set-up' which is likely to give him the best result is :

(1) A (2) B (3) C (4) D

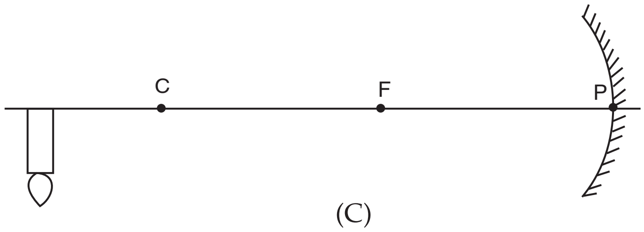
64. Four students A, B, C and D performed an experiment to determine the focal length of a concave mirror by using a lighted candle kept at a considerable distance as the object. They represented the position of image by drawing the following diagrams :



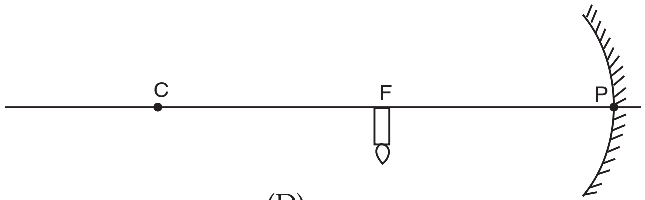
(A)



(B)



(C)

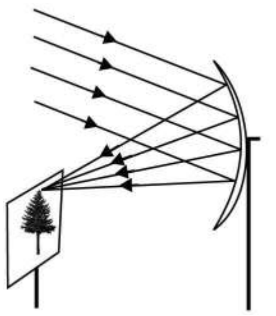


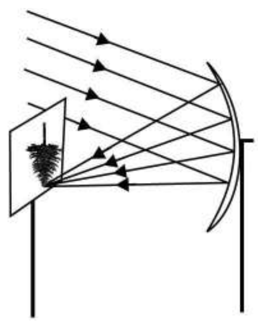
(D)

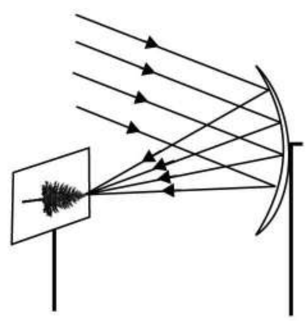
Which diagram describes the correct position of the image of the candle ?

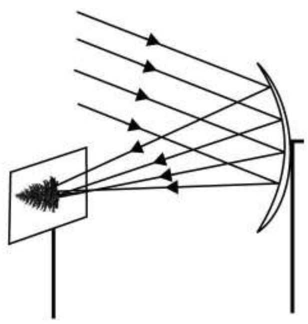
(1) A (2) B (3) C (4) D

65. The parallel rays from the top of a distant tree are incident on a concave mirror forming its image on a screen.


(A)


(B)


(C)


(D)

The diagram which shows the image of the tree on the screen correctly is :

(1) A (2) B (3) C (4) D

66. In order to determine the focal length of a concave mirror, a student obtained a sharp image of the grill of a window in the laboratory wall on a screen. His teacher suggested that to get better result for focal length, he should focus a distant tree instead of the window grill. In which direction should the mirror be moved for this purpose so as to get a sharp image of the tree on the screen ?

(1) behind the screen (2) away from the screen
(3) towards the screen (4) very far away from the screen

67. In order to determine the focal length of a concave mirror, a student obtained the sharp image of a distant tree on a screen. In order to obtain a sharp image of a window grill of the laboratory on the same screen, in which direction should the screen be moved ?

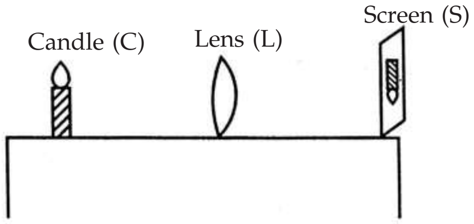
(1) very close to the mirror (2) very far away from the mirror
(3) slightly nearer to the mirror (4) slightly farther away from the mirror

Multiple choice questions based on the experiment :

To determine the focal length of a convex lens.

68. A student performs an experiment on finding the focal length of a convex lens by keeping a lighted candle on one end of laboratory table, a screen on its other end and the lens between them as shown in the figure. The positions of the three are adjusted to get a sharp image of the candle flame on the screen.

If now the candle flame were to be replaced by a distant lamp on a far away electric pole, the student would be able to get a sharp image of this distant lamp on the screen by moving :



(1) the screen in the direction of the lens or the lens in the direction of the screen
(2) the screen in the direction of the lens or the lens away from the screen
(3) the screen away from the lens or the lens in the direction of the screen
(4) neither the screen nor the lens.

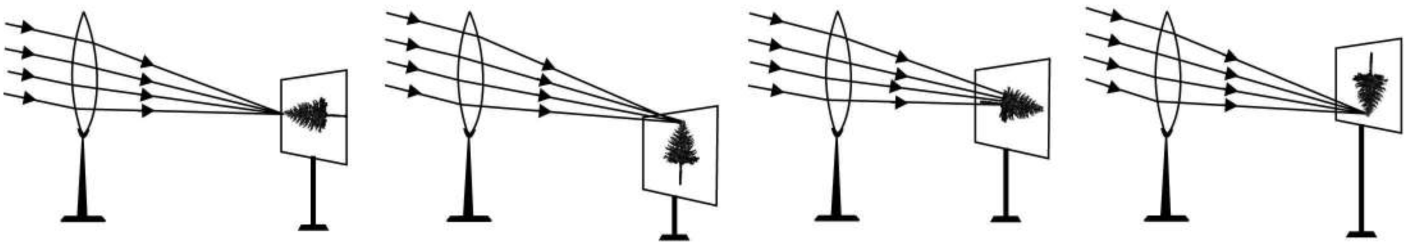
69. A student obtained a sharp image of the grill of a window in the laboratory on a screen, using a convex lens. For getting better results, her teacher suggested focussing of a distant tree instead of the grill. In which direction should the lens be moved for this purpose to get a sharp image on the screen ?
(1) Towards the screen (2) Away from the screen
(3) Behind the screen (4) Very far away from the screen

70. A sharp image of a distant object is obtained on a screen by using a convex lens. In order to determine the focal length of the lens, you need to measure the distance between the :
(1) lens and the object (2) lens and the screen
(3) object and the screen (4) lens and the screen and also between object and the screen

71. While performing the experiment to determine the focal length of a convex lens by using the sun as the distant object, a student could not find a screen with stand. In the absence of a good screen, which of the following method is the most appropriate and safe to be used by the student ?
(1) He should focus the image of the sun on his hand
(2) He should focus the image of the sun on his nylon shirt
(3) He should focus the image of the sun on a wall of the room
(4) He should focus the image of the sun on a carbon paper

72. While performing an experiment on determining the focal length of a convex lens, a student obtains a sharp inverted image of the laboratory window grill on the screen and measures the distance between the screen and the lens. She then repeats the experiment and takes a distant tree as the object in the second case. In order to get a sharp image of the tree on the screen, she will now have to move the screen :
(1) slightly nearer to the lens (2) slightly farther away from the lens
(3) very close to the lens (4) very far away from the lens

73. While performing the experiment on the determination of focal length of a convex lens, four students obtained the image of the same distant tree on the screen :



(A) (B) (C) (D)

Which diagram shows the formation of image correctly ?
(1) A (2) B (3) C (4) D

74. A student was given the following suggestions by his classmates for performing the experiment on finding the focal length of a convex lens :
(A) Select any object very far away from the laboratory window
(B) Select a well illuminated object far (but not very far) from the laboratory window
(C) Keep all the lights of the laboratory on
(D) Place the lens between the object and the screen

(E) Place the screen between the object and the lens

(F) Obtain the sharpest image of the object on the screen

He can perform the experiment better by following the suggestions :

(1) A, D, F (2) B, C, E (3) C, F, B (4) D, F, B

75. For performing an experiment, a student was asked to choose one concave mirror and one convex lens from a lot of mirrors and lenses of different kinds. The correct procedure adopted by her will be :

(1) To choose a mirror and lens which can form an enlarged and erect image of an object.

(2) To choose a mirror which can form a diminished and erect image and a lens which can form an enlarged and erect image of the object.

(3) To choose a mirror which can form an enlarged and erect image and a lens which can form a diminished and erect image of an object.

(4) To choose a mirror and a lens which can form a diminished and erect image of an object.

76. A teacher gives a convex lens and a concave mirror of focal length of about 20 cm each to his student and asks him to find their focal lengths by obtaining the image of a distant object. The student uses a distant tree as the object and obtains its sharp image, one by one, on a screen. The distances d_1 and d_2 between the lens/mirror and the screen in the two cases and the nature of their respective sharp images are likely to be :

(1) (20 cm, 40 cm) and (erect, erect) (2) (20 cm, 40 cm) and (inverted, erect)

(3) (20 cm, 20 cm) and (inverted, inverted) (4) (20 cm, 20 cm) and (erect, inverted)

77. Three students measured the focal length of a convex lens using parallel rays from a distant object. All of them measured the distance between the lens and the inverted image on the screen.

(*i*) Student A saw a sharp image on the screen and labelled the distance as f_1

(*ii*) Student B saw a slightly larger blurred image on the screen and labelled the distance as f_2

(*iii*) Student C saw slightly smaller blurred image on the screen and labelled the distance as f_3

The relation between the three measurements would most likely be :

(1) $f_1 = f_2 = f_3$ (2) $f_1 < f_2 < f_3$ (3) $f_3 < f_1 < f_2$ (4) $f_1 < f_2$ and $f_1 = f_3$

78. A student has to do the experiment on finding the focal length of a given convex lens by using a distant object. She can do her experiment if she is also made available :

(1) a lamp and a screen (2) a scale and a screen

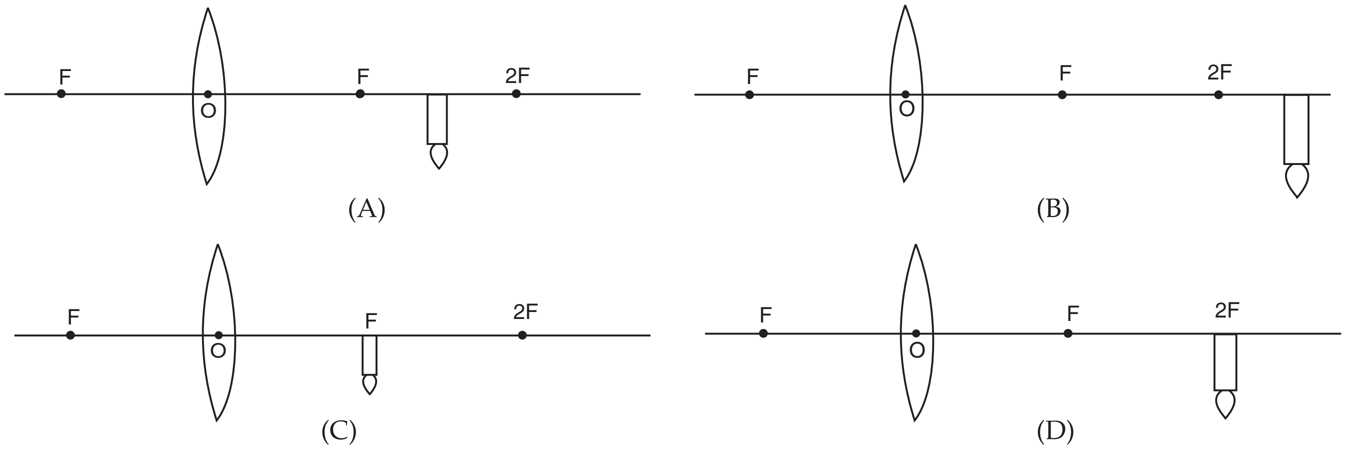
(3) a lamp and a scale (4) only a screen

79. A student performs an experiment to estimate the focal length of a convex lens by obtaining the image of a distant window on a white screen. The image formed on the white screen is :

(1) virtual, erect and magnified (2) real, erect and magnified

(3) real, inverted and diminished (4) virtual, inverted and diminished

80. Four students A, B, C and D performed an experiment to determine the focal length of a convex lens by using a lighted candle kept at a considerable distance as the object. They represented the position of image by drawing the following diagrams :



Which diagram describes the correct position of image of the candle ?

(1) A (2) B (3) C (4) D

Multiple choice questions based on the experiment :

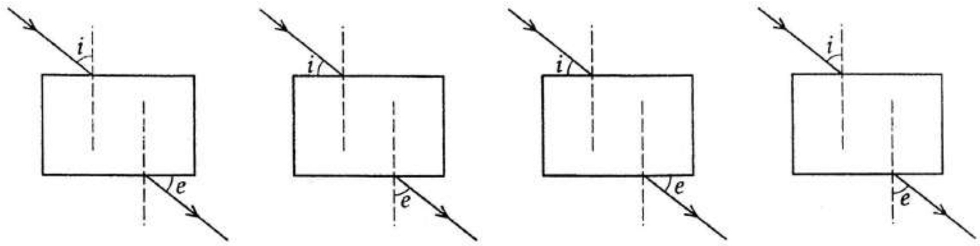
To trace the path of a ray of light through a rectangular glass slab for different angles of incidence. Measure the angle of incidence, angle of refraction, angle of emergence and interpret the results.

81. A student performs the experiment on tracing the path of a ray of light passing through a rectangular glass slab for different angles of incidence. He measures the angle of incidence $\angle i$, angle of refraction $\angle r$ and angle of emergence $\angle e$ for all his observations. He would find that in all cases :

(1) $\angle i$ is more than $\angle r$ but (nearly) equal to $\angle e$ (2) $\angle i$ is less than $\angle r$ but (nearly) equal to $\angle e$

(3) $\angle i$ is more than $\angle e$ but (nearly) equal to $\angle r$ (4) $\angle i$ is less than $\angle e$ but (nearly) equal to $\angle r$

82. A student does the experiment on tracing the path of a ray of light passing through a rectangular glass slab for different angles of incidence. He can get a correct measure of the angle of incidence and the angle of emergence by following the labelling indicated in figure :



(A) (B) (C) (D)

(1) A (2) B (3) C (4) D

83. A student suggested the following 'guidelines' to his friend for doing the experiment on tracing the path of a ray of light passing through a rectangular glass slab for three different angles of incidence :

A. Draw the 'outline' of the glass slab at three positions on the drawing sheet.

B. Draw 'normals' on the top side of these 'outlines' very near their left end.

C. Draw the incident rays on the three 'outlines' in directions making angles of 30°, 45°, 60° with the normals drawn.

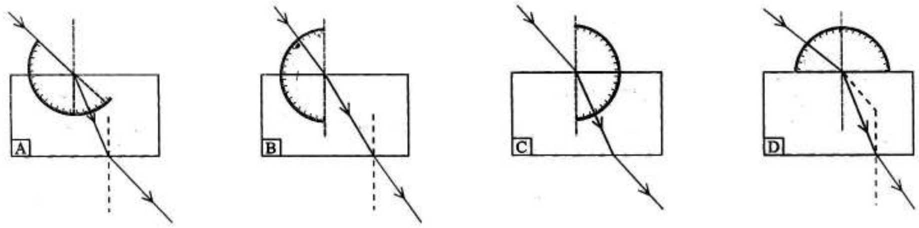
D. Fix two pins vertically on each of these incident rays at two points nearly 1 cm apart.

E. Look for the images of the 'heads' of these pins while fixing two pins from the other side, to get the refracted rays.

When he showed these 'guidelines' to his teacher, the teacher corrected and modified the 'guidelines' labelled as

(1) B, C, E (2) B, D, E (3) B, C, D (4) C, D, E

84. A student traces the path of a ray of light passing through a rectangular glass slab.



For measuring the angle of incidence, he must position the protractor in the manner shown in figure :

(1) A (2) B (3) C (4) D

85. A student performed the experiment of glass slab and with different angles of incidence measured the angles of refraction and emergence in each case. He then recorded his observations as given in the table.

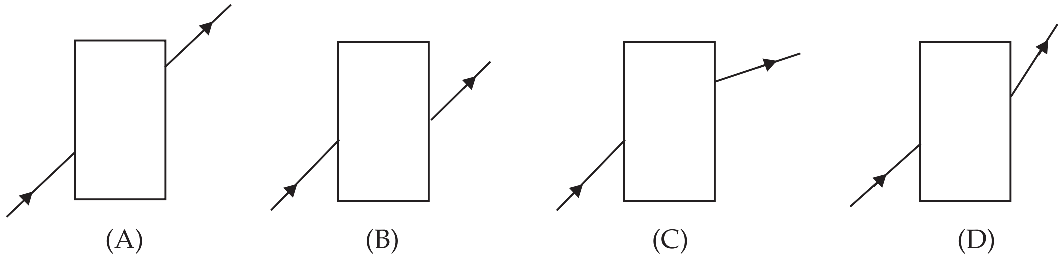
The correct observation is :

(1) A (2) B

(3) C (4) D

S.No.	*Angle of incidence*	*Angle of refraction*	*Angle of emergence*
A	30°	25°	30°
B	40°	42°	40°
C	50°	50°	50°
D	60°	60°	62°

86. Four students A, B, C and D showed the following traces of the path of a ray of light passing through a rectangular glass slab.



The trace most likely to be correct is that of student :

(1) A (2) B (3) C (4) D

87. In an experiment on tracing the path of a ray of light through a rectangular glass slab, four students A, B, C and D used the following values of the angle of incidence and the distance between the feet of the two pins (fixed on the incident rays) :

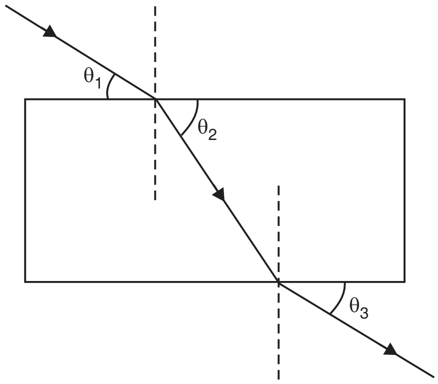
(A) 30°, 45°, 60° and 1 cm (B) 30°, 45°, 60° and 6 cm

(C) 20°, 50°, 80° and 10 cm (D) 20°, 50°, 80° and 15 cm

Out of these, the best choice is that of the student :

(1) A (2) B (3) C (4) D

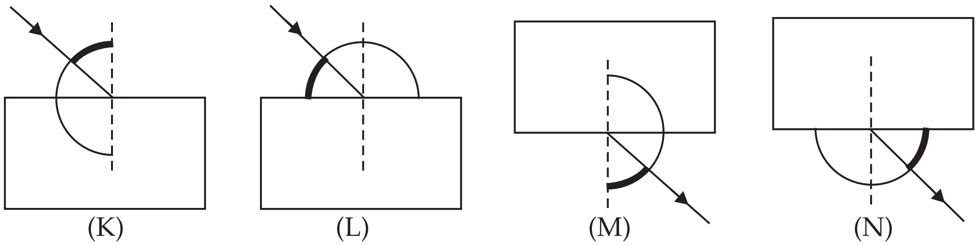
88. A student while doing the experiment on tracing the path of a ray of light passing through a rectangular glass slab measured the three angles marked as θ_1, θ_2 and θ_3 in the figure.



His measurements could be correct if he were to find :

(1) $\theta_1 < \theta_2 < \theta_3$ (2) $\theta_1 < \theta_2$ but $\theta_1 = \theta_3$ (3) $\theta_1 > \theta_2 > \theta_3$ (4) $\theta_1 > \theta_2$ but $\theta_2 = \theta_3$

89. In the experiment on tracing the path of a ray of light passing through a rectangular glass slab, the correct setting of the protractor (D), for measuring the angle of incidence ($\angle i$), and the angle of emergence ($\angle e$) correspond, respectively, to diagrams :



(1) K and M (2) K and N (3) L and M (4) L and N

90. Four students A, B, C and D selected the following items from the materials available in the science laboratory to perform an experiment to study the refraction of light through a glass slab :

(A) convex lens, glass slab, pins, drawing board, white paper, scale

(B) glass slab, pins, drawing board, scale, white paper, protractor

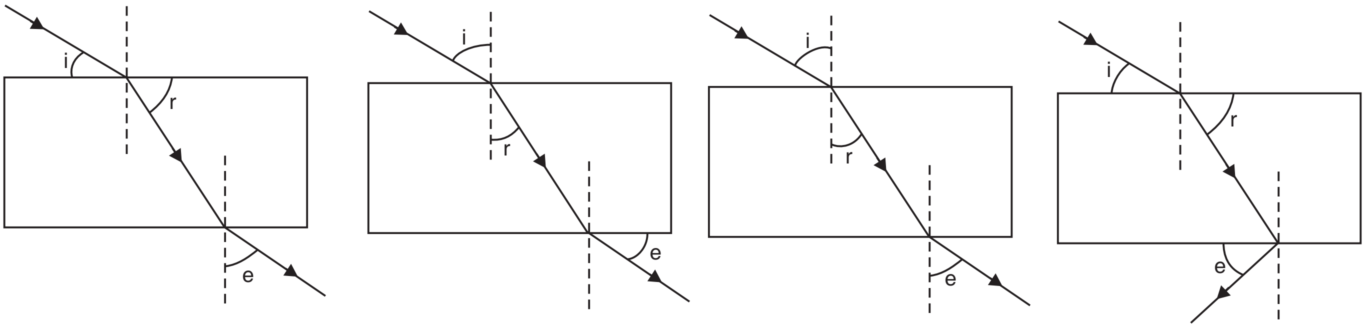
(C) glass slab, glass prism, candle, screen, pins, scale, drawing board, protractor

(D) concave mirror, pins, glass slab, protractor, white paper, drawing board

Correct choice of the items required is made by the student :

(1) A (2) B (3) C (4) D

91. In an experiment to trace the path of a ray of light passing through a rectangular glass slab, four students measured the angles of incidence (i), angles of refraction (r) and angles of emergence (e) as shown in the diagrams :



(A) (B) (C) (D)

The correct measurement is given in the diagram :

(1) A (2) B (3) C (4) D

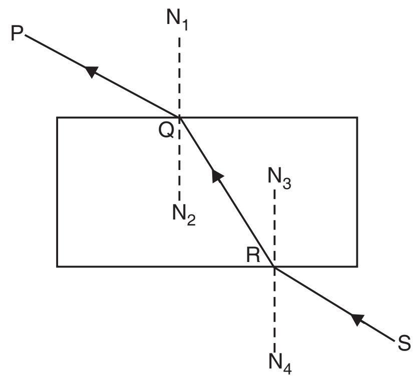
92. A teacher asked four students to record the observations of the experiment on tracing the path of a ray of light through a rectangular glass slab. The students recorded their observations under the following headings :

(1) Angle of incidence, Angle of refraction, Angle of reflection
(2) Angle of incidence, Angle of deviation, Angle of emergence
(3) Angle of incidence, Angle of reflection, Angle of emergence
(4) Angle of incidence, Angle of refraction, Angle of emergence

The correct observations were recorded by the student :

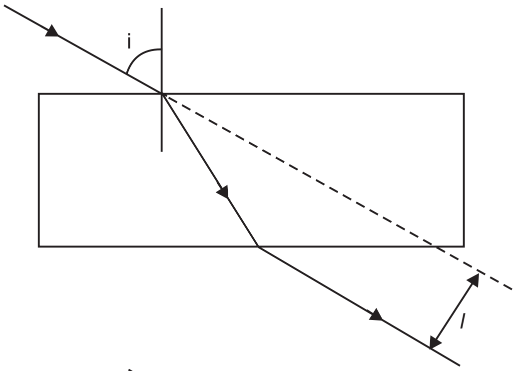
(1) A (2) B
(3) C (4) D

93. An experiment for tracing the path of a ray of light through a glass slab was set up in the laboratory and ray diagram was drawn as shown here. The teacher asked the students to identify the refracted ray. The correct answer is :



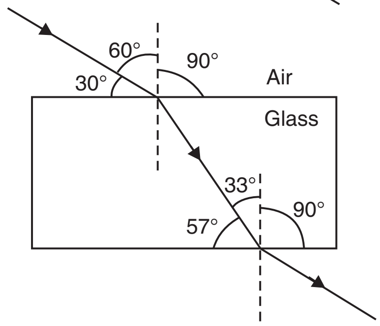
(1) SR (2) RQ
(3) N_1N_2 (4) QP

94. A student traces the path of a ray of light passing through a rectangular glass slab for three different values of angle of incidence ($\angle i$) namely 30°, 45° and 60°. He extends the direction of incident ray by a dotted line and measures the perpendicular distance 'l' between the extended incident ray and the emergent ray. He will observe that :



(1) 'l' keeps on increasing with increase in angle of incidence
(2) 'l' keeps on decreasing with increase in angle of incidence
(3) 'l' remains the same for all three angles of incidence.
(4) 'l' is the maximum for $\angle i = 45°$ and is less than this value both for $\angle i = 30°$ and $\angle i = 60°$

95. A ray of light is incident on a parallel-sided glass slab as shown in the figure. The angle of refraction for this ray of light is likely to be :



(1) 60° (2) 33°
(3) 57° (4) 30°

96. In an experiment to study the refraction of light through a rectangular glass slab, a student measured the angle of incidence, angle of refraction and the angle of emergence. The student lost the reading of angle of incidence but noted the readings of angle of refraction to be 35° and angle of emergence to be 65°. The angle of incidence is likely to be :

(1) 45° (2) 55° (3) 35° (4) 65°

97. In the glass slab experiment, a student measures the angle of incidence ($\angle i$) in air and finds it to be 40°. He also measured the corresponding angle of refraction as well as the angle of emergence for this ray of light but lost their record. The most likely record of readings for the angle of incidence and angle of emergence will be :

(1) $\angle r = 40°$ and $\angle e = 50°$ (2) $\angle r > 40°$ and $\angle e = 50°$

(3) $\angle r = 50°$ and $\angle e = 40°$ (4) $\angle r < 40°$ and $\angle e = 40°$

98. In the experiment to trace the path of a ray of light through a parallel sided glass slab, a student measured the angles of refraction for three different angles of incidence. He will find that :

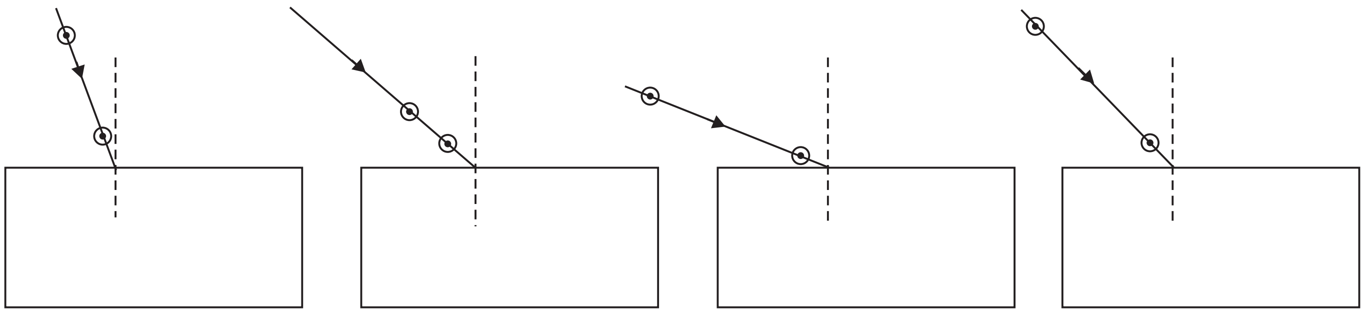
(1) angle of refraction is always equal to the angle of incidence

(2) angle of refraction is always smaller than the angle of incidence

(3) angle of refraction is always greater than the angle of incidence

(4) angle of refraction can be smaller or greater than the angle of incidence depending on the refractive index of glass slab

99. Which of the following is the best set-up for tracing the path of a ray of light through a rectangular glass slab ?



(A) (B) (C) (D)

(1) A (2) B (3) C (4) D

100. A student performs an experiment with glass slab to trace the path of a ray of light entering from air into glass slab and emerging into air again. On looking carefully at the trace obtained on paper, he will observe that the emergent ray and the incident ray :

(1) are converging (coming closer to each other) (2) are diverging (moving away from each other)

(3) are perpendicular (at right angles to each other) (4) are parallel (at equidistant from each other)

ANSWERS

01. 3	02. 1	03. 3	04. 2	05. 4	06. 3	07. 4
08. 1	09. 3	10. 3	11. 2	12. 3	13. 4	14. 3
15. 4	16. 1	17. 4	18. 2	19. 1	20. 1	21. 1
22. 4	23. 4	24. 4	25. 4	26. 2	27. 1	28. 1
29. 3	30. 3	31. 2	32. 1	33. 3	34. 4	35. 4
36. 1	37. 4	38. 4	39. 3	40. 3	41. 3	42. 2
43. 1	44. 2	45. 1	46. 3	47. 4	48. 1	49. 2
50. 1	51. 2	52. 2	53. 2	54. 4	55. 3	56. 2
57. 2	58. 4	59. 2	60. 2	61. 3	62. 3	63. 1
64. 4	65. 2	66. 3	67. 4	68. 1	69. 1	70. 2
71. 3	72. 1	73. 4	74. 4	75. 1	76. 3	77. 3
78. 2	79. 3	80. 3	81. 1	82. 4	83. 2	84. 2
85. 1	86. 2	87. 2	88. 2	89. 1	90. 2	91. 3
92. 4	93. 2	94. 1	95. 2	96. 4	97. 4	98. 2
99. 4	100. 4					

NCERT BOOK QUESTIONS AND EXERCISES (with answers)

Chapter : ELECTRICITY

NCERT Book, Page 200

Q. 1. What does an electric circuit mean ?

Ans. A continuous conducting path consisting of wires and other resistances (like electric bulb, etc.) and a switch, between the two terminals of a cell or battery, along which an electric current flows, is called a circuit.

Q. 2. Define the unit of current.

Ans. The SI unit of electric current is ampere (which is denoted by the letter A). When 1 coulomb of charge flows through any cross-section of a conductor in 1 second, the current flowing through it is said to be 1 ampere.

Q.3. Calculate the number of electrons constituting one coulomb of charge.

Ans. See Sample Problem on page 2 of this book.

NCERT Book, Page 202

Q. 1. Name a device that helps to maintain a potential difference across a conductor.

Ans. An electric cell (or a battery).

Q.2. What is meant by saying that the potential difference between two points is 1 V ?

Ans. The potential difference between two points is said to be 1 volt (1 V) if 1 joule of work is done in moving 1 coulomb of electric charge from one point to the other.

Q. 3. How much energy is given to each coulomb of charge passing through a 6 V battery ?

Ans. See Sample Problem 2 on page 5 of this book.

NCERT Book, Page 209

Q.1. On what factors does the resistance of a conductor depend ?

Ans. The electrical resistance of a conductor (or a wire) depends on the following factors :

(*i*) length of the conductor,

(*ii*) area of cross-section of the conductor (or thickness of the conductor),

(*iii*) nature of the material of the conductor, and

(*iv*) temperature of the conductor.

Q.2. Will current flow more easily through a thick wire or a thin wire of the same material, when connected to the same source ? Why ?

Ans. The current will flow more easily through a thick wire than through a thin wire of the same material when connected to the same source (like a battery). This is due to the fact that the resistance of a wire is inversely proportional to the square of its diameter. A thick wire has greater diameter and hence lesser resistance making the current to flow through it more easily. On the other hand, a thin wire has smaller diameter and hence greater resistance to the flow of current through it.

Q.3. Let the resistance of an electrical component remain constant while the potential difference across the two ends of the component decreases to half of its former value. What change will occur in the current through it ?

Ans. The current through the component will also decrease to half of its former value.

Q.4. Why are coils of electric toasters and electric irons made of an alloy rather than a pure metal ?

Ans. The coils (or heating elements) of toasters and electric irons are made of an alloy rather than a pure metal because :

(*i*) the resistivity of an alloy is much higher than that of a pure metal, and

(*ii*) an alloy does not undergo oxidation (or burn) easily even at high temperature, when it is red hot.

Q.5. Use the data in Table on page 23 of this book to answer the following :
(*a*) Which among iron and mercury is a better conductor ?
(*b*) Which material is the best conductor ?

Ans. (*a*) The electrical resistivity of iron is $10.0 \times 10^{-8}\ \Omega$ m whereas that of mercury is $94.0 \times 10^{-8}\ \Omega$ m. Since the resistivity of iron is less than that of mercury, therefore, iron is a better conductor than mercury.
(*b*) Silver metal has the lowest electrical resistivity (of $1.60 \times 10^{-8}\ \Omega$ m), therefore, silver metal is the best conductor of electricity.

NCERT Book, Page 213

Q.1. Draw a schematic diagram of a circuit consisting of a battery of three cells of 2 V each, a 5 Ω resistor, an 8 Ω resistor, and a 12 Ω resistor, and a plug key, all connected in series.

Ans. See Sample Problem 3(*a*) on page 32 of this book.

Q.2. Redraw the circuit of Question 1 putting an ammeter to measure the current through the resistors and a voltmeter to measure the potential difference across the 12 Ω resistor. What would be the reading in the ammeter and the voltmeter ?

Ans. See Sample Problem 3(*b*) on page 32 of this book.

NCERT Book, Page 216

Q.1. Judge the equivalent resistance when the following are connected in parallel :
(*a*) 1 Ω and 10^6 Ω (*b*) 1 Ω, 10^3 Ω and 10^6 Ω

Ans. (*a*) The equivalent resistance of two resistances 1 Ω and 10^6 Ω connected in parallel will be less than 1 Ω. This is because when a number of resistances are connected in parallel, then their equivalent resistance is less than the smallest individual resistance (which is 1 Ω in this case).
(*b*) The equivalent resistance of three resistances 1 Ω , 10^3 Ω and 10^6 Ω connected in parallel will be less than 1 Ω.

Q.2. An electric lamp of 100 Ω, a toaster of resistance 50 Ω, and a water filter of resistance 500 Ω are connected in parallel to a 220 V source. What is the resistance of an electric iron connected to the same source that takes as much current as all three appliances, and what is the current through it ?

Ans. The combined resistance R of three resistors (or electrical devices) R_1, R_2 and R_3, connected in parallel is given by the formula :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Here, Resistance of electric lamp, $R_1 = 100\ \Omega$
Resistance of toaster, $R_2 = 50\ \Omega$
And, Resistance of water filter, $R_3 = 500\ \Omega$

Putting these values of R_1, R_2 and R_3 in the above formula, we get :

$$\frac{1}{R} = \frac{1}{100} + \frac{1}{50} + \frac{1}{500}$$

$$\frac{1}{R} = \frac{5 + 10 + 1}{500}$$

$$\frac{1}{R} = \frac{16}{500}$$

$$R = \frac{500}{16}$$

$$R = 31.25\ \Omega$$

Thus, the resistance of electric iron will also be 31.25 Ω.

Now, Potential difference, $V = 220$ V
Current, I = ? (To be calculated)
And, Resistance, R = 31.25 Ω (Calculated above)

By Ohm's law : $$\frac{V}{I} = R$$

$$\frac{220}{I} = 31.25$$

$$I = \frac{220}{31.25}$$

$$I = 7.04 \text{ A}$$

Thus, the current passing through the electric iron is 7.04 amperes.

Q. 3. What are the advantages of connecting electrical devices in parallel with the battery instead of connecting them in series ?

Ans. The advantages of connecting electrical devices in parallel are the following :

(*i*) In parallel circuits, if one electrical appliance stops working due to some defect, then all other appliances keep working normally. On the other hand, in series circuit, if one electrical appliance stops working due to some defect, then all other appliances also stop working (because the whole circuit is broken).

(*ii*) In parallel circuits, each electrical appliance has its own switch due to which it can be turned on or turned off independently, without affecting other appliances. In series circuit, all the electrical appliances have only one switch due to which they cannot be turned on or turned off independently.

(*iii*) In parallel circuits, each electrical appliance gets the same voltage as that of the battery due to which all the appliances work properly. In series circuit, the appliances do not get the same voltage as that of the battery because the voltage is shared by all the appliances.

(*iv*) In the parallel connection of electrical appliances, the overall resistance of the circuit is reduced due to which the current from the battery is high and hence each electrical appliance can draw the required amount of current. In the series connection of electrical appliances, the overall resistance of the circuit increases too much due to which the current from the battery is low and hence all the electrical appliances cannot draw sufficient current for their proper working.

Q.4. How can three resistors of resistances 2 Ω, 3 Ω, and 6 Ω be connected to give a total resistance of (*a*) 4 Ω, and (*b*) 1 Ω ?

Ans. (*a*) In order to obtain a total resistance of 4 Ω from three resistors of 2 Ω, 3 Ω and 6 Ω :

(*i*) First connect the two resistors of 3 Ω and 6 Ω in parallel to get a total resistance of 2 Ω . This is because in parallel combination :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

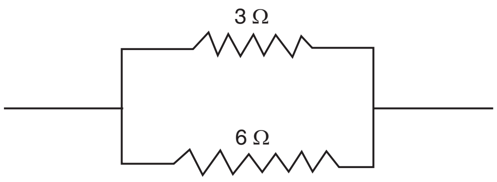
$$\frac{1}{R} = \frac{1}{3} + \frac{1}{6}$$

$$\frac{1}{R} = \frac{2+1}{6}$$

$$\frac{1}{R} = \frac{3}{6}$$

$$R = \frac{6}{3}$$

$$R = 2\ \Omega$$



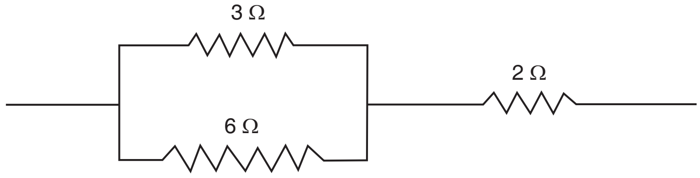
(*ii*) Then the parallel combination of 3 Ω and 6 Ω resistors (which is equivalent to 2 Ω resistance) is connected in series with the remaining 2 Ω resistor to get a total resistance of 4 Ω. This is because in series combination :

$$R = R_1 + R_2$$

$$R = 2 + 2$$

$$R = 4\ \Omega$$

The arrangement of three resistors of 2 Ω , 3 Ω and 6 Ω which gives a total resistance of 4 Ω can now be represented as follows :



Thus, we can obtain a total resistance of 4 Ω by connecting a parallel combination of 3 Ω and 6 Ω resistors in series with 2 Ω resistor.

(*b*) In order to obtain a total resistance of 1 Ω from three resistors of 2 Ω, 3 Ω and 6 Ω, all the three resistors should be connected in parallel. This is because in parallel combination :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

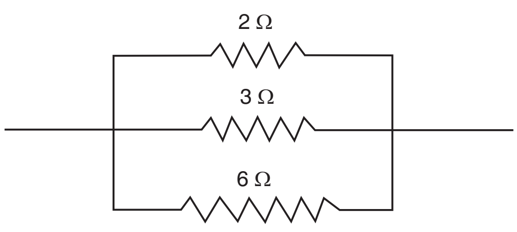
$$\frac{1}{R} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$$

$$\frac{1}{R} = \frac{3 + 2 + 1}{6}$$

$$\frac{1}{R} = \frac{6}{6}$$

$$R = \frac{6}{6}$$

$$R = 1\ \Omega$$



Q.5. What is (*a*) the highest, and (*b*) the lowest, total resistance that can be secured by the combination of four coils of resistances 4 Ω, 8 Ω, 12 Ω and 24 Ω ?

Ans. (*a*) The highest resistance can be secured (or obtained) by connecting all the four coils in series. In this case :

$$R = R_1 + R_2 + R_3 + R_4$$

$$R = 4 + 8 + 12 + 24$$

$$R = 48\ \Omega$$

Thus, the highest resistance which can be secured is 48 ohms.

(*b*) The lowest resistance can be secured by connecting all the four coils in parallel. In this case :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$\frac{1}{R} = \frac{1}{4} + \frac{1}{8} + \frac{1}{12} + \frac{1}{24}$$

$$\frac{1}{R} = \frac{6 + 3 + 2 + 1}{24}$$

$$\frac{1}{R} = \frac{12}{24}$$

$$\frac{1}{R} = \frac{1}{2}$$

$$R = 2\ \Omega$$

Thus, the lowest resistance which can be secured is 2 ohms.

NCERT Book, Page 218

Q. 1 Why does the cord of an electric heater not glow while the heating element does ?

Ans. The heating element of an electric heater is made of an alloy (such as nichrome) which has high resistance whereas the cord is made of copper metal which has very, very low resistance. Now, the heating element of an electric heater made of nichrome glows because it becomes red-hot due to the large amount of heat produced on passing current (because of its high resistance). On the other hand, the connecting cord of the electric heater made of copper does not glow because negligible heat is produced in it by passing the same current (due to its extremely low resistance).

Q.2. Compute the heat generated while transferring 96000 coulombs of charge in one hour through a potential difference of 50 V.

Ans. First of all we will calculate the current (I) by using the given values of charge (Q) and time (t). We know that :

$$\text{Current, } I = \frac{Q}{t} = \frac{96000\ \text{C}}{1\ \text{h}} = \frac{96000\ \text{C}}{60 \times 60\ \text{s}}$$

or $\quad I = 26.67$ A ....(1)

We will now calculate the resistance by using Ohm's law :

$$\text{Resistance, } R = \frac{V}{I} = \frac{50 \text{ V}}{26.67 \text{ A}}$$

or $R = 1.87\ \Omega$ ....(2)

And, Time, $t = 1 \text{ h} = 60 \times 60 \text{ s}$

$= 3600 \text{ s}$ .... (3)

Heat generated, $H = I^2 \times R \times t$

$= (26.67)^2 \times 1.87 \times 3600 \text{ J}$

$= 4788397 \text{ J}$

$= 4.79 \times 10^6 \text{ J}$ or $4.8 \times 10^6 \text{ J}$

Thus, the heat generated is 4.8×10^6 joules.

Q.3. An electric iron of resistance 20 Ω takes a current of 5 A. Calculate the heat developed in 30 s.

Ans. Here, Current, $I = 5 \text{ A}$

Resistance, $R = 20\ \Omega$

And, Time, $t = 30 \text{ s}$

Now, Heat produced, $H = I^2 \times R \times t$

$H = (5)^2 \times 20 \times 30$

$H = 25 \times 20 \times 30$

$H = 15000 \text{ J}$

Thus, the heat developed is 15000 joules.

NCERT Book, Page 220

Q.1. What determines the rate at which energy is delivered by a current ?

Ans. Electric power of the appliance.

Q.2. An electric motor takes 5 A from a 220 V line. Determine the power of the motor and the energy consumed in 2 h.

Ans. Here, Voltage, $V = 220 \text{ V}$

And, Current, $I = 5 \text{ A}$

Now, Power, $P = V \times I$

So, $P = 220 \times 5 \text{ W}$

$P = 1100 \text{ W}$

Thus, the power of the motor is 1100 watts.

Now, Power, $P = 1100 \text{ W}$ (Calculated above)

Time, $t = 2 \text{ h}$

$= 2 \times 60 \times 60 \text{ s}$

$= 7200 \text{ s}$

So, Energy, $E = P \times t$

$E = 1100 \times 7200 \text{ J}$

$E = 7.92 \times 10^6 \text{ J}$

Thus, the energy consumed is 7.92×10^6 joules.

NCERT Book, Pages 221-222

Q.1. A piece of wire of resistance R is cut into five equal parts. These parts are then connected in parallel. If the equivalent resistance of this combination is R', then the ratio R/R' is :

(*a*) 1/25 (*b*) 1/5 (*c*) 5 (*d*) 25

Ans. The resistance of wire is R. This wire is cut into five equal pieces, so the resistance of each piece of the wire will be $\frac{R}{5}$. Now, five pieces of wire, each piece of wire having resistance of $\frac{R}{5}$ are connected in parallel to give the equivalent resistance R′. So,

$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R'} = \frac{5}{R} + \frac{5}{R} + \frac{5}{R} + \frac{5}{R} + \frac{5}{R}$$

$$\frac{1}{R'} = \frac{5 + 5 + 5 + 5 + 5}{R}$$

$$\frac{1}{R'} = \frac{25}{R}$$

To obtain the ratio $\frac{R}{R'}$ we multiply both sides of the above equation by R. This will give us :

$$\frac{R}{R'} = \frac{25 \times R}{R}$$

or $$\frac{R}{R'} = 25$$

Thus, the correct answer is : (*d*) 25.

Q.2. Which of the following terms does not represent electrical power in a circuit ?

(*a*) I^2R (*b*) IR^2 (*c*) VI (*d*) V^2/R

Ans. (*b*) IR^2

Q.3. An electric bulb is rated 220 V and 100 W. When it is operated on 110 V, the power consumed will be :

(*a*) 100 W (*b*) 75 W (*c*) 50 W (*d*) 25 W

Ans. See Sample Problem 2 on page 53 of this book.

Q.4. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in series and then in parallel in a circuit across the same potential difference. The ratio of heat produced in series and parallel combination would be :

(*a*) 1 : 2 (*b*) 2 : 1 (*c*) 1 : 4 (*d*) 4 : 1

Ans. See Sample Problem 3 on page 64 of this book.

Q.5. How is a voltmeter connected in the circuit to measure the potential difference between two points ?

Ans. The voltmeter is always connected in parallel across the two points (in the circuit) where the potential difference is to be measured.

Q. 6. A copper wire has diameter 0.5 mm and resistivity of $1.6 \times 10^{-8}\ \Omega$ m. What will be the length of this wire to make its resistance 10 Ω ? How much does the resistance change if the diameter is doubled ?

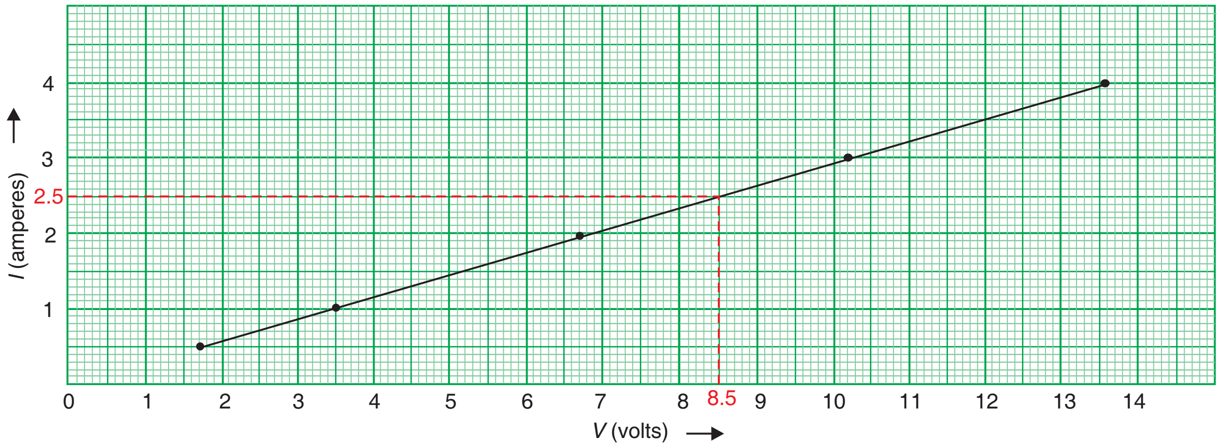
Ans. See Sample Problem 2 on page 24 of this book.

Q.7. The values of current *I* flowing in a given resistor for the corresponding values of potential difference *V* across the resistor are given below :

***I* (amperes) :**	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**
***V* (volts) :**	**1.6**	**3.4**	**6.7**	**10. 2**	**13.2**

Plot a graph between *V* and *I* and calculate the resistance of the resistor.

Ans. The graph between *V* and *I* plotted by using the given data is shown below :



If we look at the above graph, we find that when potential difference *V* is 8.5 volts, then the corresponding current value is 2.5 amperes. Now,

$$\text{Resistance, } R = \frac{V}{I}$$

$$R = \frac{8.5}{2.5}$$

$$R = 3.4\ \Omega$$

Thus, the resistance of the resistor is 3.4 ohms.

Q.8. When a 12 V battery is connected across an unknown resistor, there is a current of 2.5 mA in the circuit. Find the value of the resistance of the resistor.

Ans. In this problem, the current is given in the units of milliamperes (mA), so the current is to be converted into the units of amperes (A) by dividing the given milliamperes value by 1000.

Here, Potential difference, $V = 12$ V

Current, $I = 2.5$ mA

$$= \frac{2.5}{1000}\ \text{A}$$

$$= 0.0025\ \text{A}$$

And, Resistance, $R = ?$ (To be calculated)

From Ohm's law : $\frac{V}{I} = R$

So, $\frac{12}{0.0025} = R$

And, Resistance, $R = 4800\ \Omega$ (or 4.8 kΩ)

Q.9. A battery of 9 V is connected in series with resistors of 0.2 Ω, 0.3 Ω, 0.4 Ω , 0.5 Ω and 12 Ω respectively. How much current would flow through the 12 Ω resistor ?

Ans. All the resistors are connected in series. So,

Combined resistance, $R = 0.2 + 0.3 + 0.4 + 0.5 + 12$

$= 13.4\ \Omega$

Potential difference, $V = 9$ V

And, Current, $I = ?$ (To be calculated)

Current flowing through the whole circuit can be calculated by using Ohm's law :

Now, $\frac{V}{I} = R$

So, $\frac{9}{I} = 13.4$

And, $I = \frac{9}{13.4}$

Current, $I = 0.67$ A

Since the same current flows through all the resistors connected in series in a circuit, therefore, 0.67 ampere of current would flow through the 12 Ω resistor.

Q.10. How many 176 Ω resistors in parallel are required to carry 5 A on a 220 V line ?

Ans. Here, Potential difference (V) is 220 V and current (I) is 5 A.

So, Resistance , $R = \frac{V}{I}$

$$R = \frac{220}{5}$$

$$R = 44\ \Omega$$

Thus, the total resistance of the circuit is 44 ohms. Now, all that we have to do is to find out how many 176 ohm resistors should be connected in parallel to obtain a resultant resistance of 44 Ω. Suppose the number of 176 Ω resistors required is x.

Then : $\frac{1}{44} = \frac{1}{176} \times x$ (Resistances in parallel)

$$44\,x = 176$$

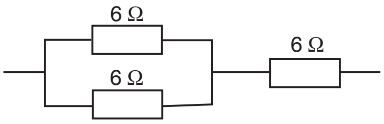
$$x = \frac{176}{44}$$

$$x = 4$$

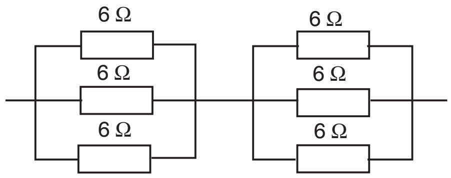
Thus, 4 resistors of 176 Ω each should be connected in parallel.

Q.11. Show how you would connect three resistors, each of resistance 6 Ω, so that the combination has a resistance of (*i*) 9 Ω, and (*ii*) 4 Ω.

Ans. (*i*) In order to get a resistance of 9 Ω from three resistors of 6 Ω each, we connect two 6 Ω resistors in parallel and then this parallel combination is connected in series with the third 6 Ω resistor [as shown in Figure (*i*)]. This is because : $\frac{1}{R} = \frac{1}{6} + \frac{1}{6} = \frac{1+1}{6} = \frac{2}{6} = \frac{1}{3}$ or $R = 3\ \Omega$; And 3 Ω + 6 Ω = 9 Ω.



(*i*)



(*ii*)

(*ii*) In order to get a resistance of 4 Ω from three resistors of 6 Ω each, we connect all the three 6 Ω resistors in parallel and then connect two such parallel combinations in series [as shown in Figure (*ii*)]. This is because :

$$\frac{1}{R} = \frac{1}{6} + \frac{1}{6} + \frac{1}{6} = \frac{1+1+1}{6} = \frac{3}{6} = \frac{1}{2} \quad \text{or} \quad R = 2\ \Omega\ ;\ \text{And } 2\ \Omega + 2\ \Omega = 4\ \Omega\ .$$

Q.12. Several electric bulbs designed to be used on a 220 V electric supply line are rated 10 W each. How many bulbs can be connected in parallel with each other across the two wires of 220 V line if the maximum allowable current is 5 A ?

Ans. First we will calculate the resistance (R) of one bulb by using the given power (P) and voltage (V) values.

Now, Power, $P = \frac{V^2}{R}$

So, $10 = \frac{(220)^2}{R}$

And, $R = \frac{220 \times 220}{10}$

Resistance of 1 bulb, $R = 4840\ \Omega$ ....(1)

We will now calculate the total resistance of the circuit by using the given V (voltage) and I (current) values. Now,

$$\frac{V}{I} = R$$

So, $\frac{220}{5} = R$

Total resistance, $R = 44\ \Omega$

Thus, the total resistance of the circuit is 44 ohms. Now, all that we have to do is to find out how many 4840 Ω bulbs should be connected in parallel to obtain a total resistance of 44 Ω. Suppose the number of 4840 Ω bulbs required is x. Then :

$$\frac{1}{44} = \frac{1}{4840} \times x \qquad \text{(Resistances in parallel)}$$

$$x = \frac{4840}{44}$$

$$x = 110$$

Thus, 110 bulbs can be connected in parallel in this circuit.

Q.13. A hot plate of an electric oven connected to a 220 V line has two resistance coils A and B, each of 24 Ω resistance, which may be used separately, in series or in parallel. What are the currents in the three cases ?

Ans. **(*i*)** *Calculation of current when each coil is used separately*

Here, Potential difference, $V = 220$ V

And, Resistance, $R = 24\ \Omega$ (One coil only)

Now, Current, $I = \frac{V}{R}$

$$I = \frac{220}{24}$$

$$I = 9.17 \text{ A} \quad \ldots (1)$$

(*ii*) *Calculation of current when the two coils are connected in series*

When the two coils of 24 Ω each are connected in series, then their combined resistance will be 24 Ω + 24 Ω = 48 Ω

Here, Potential difference, $V = 220$ V

And, Resistance, $R = 48\ \Omega$ (Two coils in series)

Now, Current, $I = \frac{V}{R}$

$$I = \frac{220}{48}$$

$$I = 4.58 \text{ A} \quad \ldots (2)$$

(*iii*) *Calculation of current when the two coils are connected in parallel*

When the two coils of 24 Ω each are connected in parallel, then their combined resistance will be 12 Ω. This is because :

$$\frac{1}{R} = \frac{1}{24} + \frac{1}{24} = \frac{1+1}{24} = \frac{2}{24} = \frac{1}{12} \quad \text{So, } R = 12\ \Omega$$

Here, Potential difference, $V = 220$ V

Resistance, $R = 12\ \Omega$ (Two coils in parallel)

Now, Current, $I = \frac{V}{R}$

$$I = \frac{220}{12}$$

$$I = 18.34 \text{ A} \quad \ldots (3)$$

Q.14. Compare the power used in the 2 Ω resistor in each of the following circuits :

(*i*) a 6 V battery in series with 1 Ω and 2 Ω resistors.

(*ii*) a 4 V battery in parallel with 12 Ω and 2 Ω resistors.

Ans. (*i*) *In the First Case :*

Potential difference, $V = 6$ V

Current, $I = ?$ (To be calculated)

And, Resistance, $R = 1\ \Omega + 2\ \Omega$ (Resistors in series)

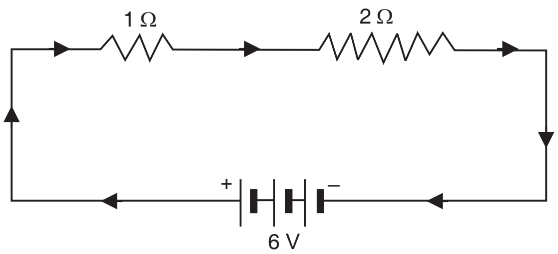
$R = 3\ \Omega$

Now, by Ohm's law : (for whole circuit) $\frac{V}{I} = R$

So, $\frac{6}{I} = 3$

And, Current, $I = \frac{6}{3}$

$I = 2$ A



(*i*)

Thus, the current flowing in the circuit containing 1 Ω and 2 Ω resistors in series is 2 A. In a series circuit, the same current flows throughout the circuit. So, the current flowing through the 2 Ω resistor is also 2 A [see Figure (*i*)]. Now, we know that the current (in 2 Ω resistor) is 2 A and its resistance is 2 Ω.

So, Power used in 2 Ω resistor, $P_1 = I^2 \times R$

(In first case) $P_1 = (2)^2 \times 2$

$P_1 = 4 \times 2$

$P_1 = 8$ W ... (1)

Thus, the power P_1 used in 2 Ω resistor in the first case is 8 watts.

(*ii*) *In the Second Case :*

Here, 4 V battery is attached across the parallel combination of 12 Ω and 2 Ω resistors, so the potential difference across the 2 Ω resistor will also be 4 V [see Figure (*ii*)].

Now, Potential difference, $V = 4$ V (Across the 2 Ω resistor)

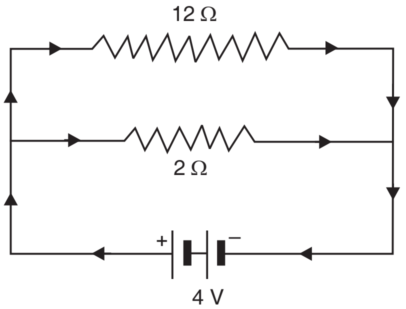
And Resistance, $R = 2\ \Omega$

So, Power used in 2 Ω resistor, $P_2 = \dfrac{V^2}{R}$
(in second case)

$$P_2 = \frac{(4)^2}{2}$$

$$P_2 = \frac{16}{2}$$

$P_2 = 8$ W ... (2)



(*ii*)

Thus, the power P_2 used in the 2 Ω resistor in the second case is also 8 watts.

In order to compare the power used in 2 Ω resistor in the two circuits, let us divide P_1 by P_2.

So, $$\frac{P_1}{P_2} = \frac{8\text{ W}}{8\text{ W}}$$

or $$\frac{P_1}{P_2} = 1$$

or $P_1 = P_2$

The 2 Ω resistor uses equal power in both the circuits.

Q.15. Two lamps, one rated 100 W at 220 V and the other 60 W at 220 V are connected in parallel to electric mains supply. What current is drawn from the line if the supply voltage is 220 V ?

Ans. In order to solve this problem, first we have to calculate the resistances R_1 and R_2 of two lamps separately.

Now, Power, $P = \dfrac{V^2}{R}$

For first lamp : $100 = \dfrac{(220)^2}{R_1}$

Resistance of first lamp, $R_1 = \dfrac{(220)^2}{100} = \dfrac{220 \times 220}{100} = \dfrac{48400}{100}$

$= 484\ \Omega$ ... (1)

Again, Power, $P = \dfrac{V^2}{R}$

For second lamp : $60 = \dfrac{(220)^2}{R_2}$

Resistance of second lamp, $R_2 = \dfrac{(220)^2}{60} = \dfrac{220 \times 220}{60} = \dfrac{48400}{60}$

$= 806.7\ \Omega$ ... (2)

The two lamps of resistances 484 Ω and 806.7 Ω are connected in parallel. So, the combined resistance of two lamps can be calculated as follows :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R} = \frac{1}{484} + \frac{1}{806.7}$$

$$\frac{1}{R} = \frac{806.7 + 484}{484 \times 806.7} = \frac{1290.7}{390442.8}$$

$$R = \frac{390442.8}{1290.7}$$

Total resistance, $R = 302.5\ \Omega$

Current drawn from the line can now be calculated by using Ohm's law as follows :

$$\frac{V}{I} = R$$

$$\frac{220}{I} = 302.5$$

$$I = \frac{220}{302.5}$$

$$I = 0.727\text{ A} \quad \text{or} \quad 0.73\text{ A}$$

Thus, the current drawn from line is 0.73 ampere.

Q.16. Which uses more energy, a 250 W TV set in 1 hr or a 1200 W toaster in 10 minutes ?

Ans. (*i*) *For TV set :* Power, $P = 250\text{ W} = \frac{250}{1000}\text{ kW} = 0.25\text{ kW}$

Time, $t = 1$ h

So, Electric energy, $E = P \times t$

(used by TV set) $E = 0.25 \times 1$ kWh

$E = 0.25$ kWh ... (1)

(*ii*) *For toaster :* Power, $P = 1200\text{ W} = \frac{1200}{1000}\text{ kW} = 1.2\text{ kW}$

Time, $t = 10\text{ min} = \frac{10}{60}\text{ h} = 0.167\text{ h}$

So, Electric energy, $E = P \times t$

(used by toaster) $E = 1.2 \times 0.167$ kWh

$E = 0.20$ kWh ... (2)

From the above calculations, it is clear that the TV set uses more energy (0.25 kWh) whereas toaster uses less energy (0.20 kWh).

Q.17. An electric heater of resistance 8 Ω draws 15 A from the service mains for 2 hours. Calculate the rate at which heat is developed in the heater.

Ans. The rate at which heat is developed in the electric heater will be given by the power of the heater.

Now, Power, $P = I^2 \times R$

$P = (15)^2 \times 8$

$P = 225 \times 8$

$P = 1800\text{ W} \quad \text{or} \quad 1800\text{ J/s}$

Thus, the rate at which heat is developed in the heater is 1800 joules per second.

Q.18 Explain the following :

(*a*) Why is the tungsten used almost exclusively for the filament of electric lamps ?

(*b*) Why are the conductors of electric heating devices such as bread toasters and electric irons made of an alloy rather than a pure metal ?

(*c*) Why is the series arrangement not used for domestic circuits ?

(*d*) How does the resistance of a wire vary with its area of cross-section ?

(*e*) Why are copper and aluminium wires usually employed for electricity transmission ?

Ans. (*a*) Tungsten is used almost exclusively for making the filaments of electric lamps (or electric bulbs) because it has very high melting point (of 3380°C) due to which the tungsten filament can be kept white-hot without melting away. Moreover, tungsten has high flexibility and low rate of evaporation at high temperature.

(*b*) See Q. 4 on page 321 of this book.

(*c*) The series arrangement is not used for domestic circuits because of the following disadvantages :

(*i*) In series arrangement, if one electrical appliance stops working due to some defect, then all other appliances also stop working (because the whole circuit is broken).

(*ii*) In series arrangement, all the electrical appliances can have only one switch due to which they cannot be turned 'on' or 'off' independently.

(*iii*) In series arrangement, all the appliances do not get the same voltage (220 V) as that of the power supply line (because the line voltage is shared by all the appliances). Due to this, the appliances do not work properly.

(*iv*) In series arrangement of electrical appliances, the overall resistance of the circuit increases too much due to which the current from power supply is low. Because of this, all the appliances of different power ratings cannot draw sufficient current for their proper working.

(*d*) The resistance of a wire is inversely proportional to its area of cross-section. That is : $R \propto \frac{1}{A}$. So, when the area of cross-section of wire increases (or thickness of wire increases), then its resistance decreases. And when the area of cross-section of wire decreases (or thickness of wire decreases), then its resistance increases.

(*e*) Copper and aluminium wires are usually employed for transmission of electricity because copper and aluminium have low electrical resistivity (due to which they are very good conductors of electricity).

Chapter : MAGNETIC EFFECT OF ELECTRIC CURRENT

NCERT Book, Page 224

Q.1. Why does a compass needle get deflected when brought near a bar magnet ?

Ans. A compass needle gets deflected when brought near a bar magnet because the bar magnet exerts a magnetic force on the compass needle which is itself a tiny pivoted magnet (free to move in the horizontal plane).

NCERT Book, Page 228

Q.1. Draw magnetic field lines around a bar magnet.

Ans. See Figure 8 on page 71 of this book.

Q.2. List the properties of magnetic lines of force.

Ans. (*i*) The magnetic lines of force originate from the north pole of a magnet and end at its south pole.

(*ii*) The magnetic lines of force come closer to one another near the poles of a magnet but they are widely separated at other places.

(*iii*) The magnetic lines of force do not intersect (or cross) one another.

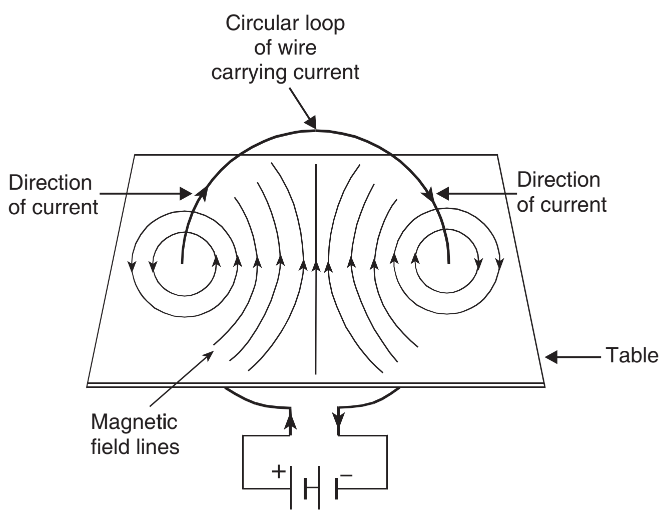
Q.3. Why don't two magnetic lines of force intersect with each other ?

Ans. The two magnetic lines of force do not intersect each other because the resultant force on a north pole at any point on a magnetic line of force can be only in one direction. If, however, the two magnetic lines of force intersected (or crossed) each other, it would mean that at the point of intersection, the compass needle would point in two directions at the same time, which is not possible.

NCERT Book, Pages 229-230

Q.1. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right hand rule to find out the direction of the magnetic field inside and outside the loop.

Ans. A circular loop of wire lying in the plane of the table is shown in Figure given alongside. A battery is passing current through the loop of wire in the clockwise direction. Now, by applying Right-hand thumb rule to the left side of circular loop, we find that the direction of magnetic field around it is anticlockwise but the magnetic field is perpendicular to the plane of table (or plane of paper). And by applying Right-hand thumb rule to the right side of circular loop, we find that the direction of magnetic field around it is clockwise but again, the magnetic field is perpendicular to the plane of table (or plane of paper).



Q.2. The magnetic field in a given region is uniform. Draw a diagram to represent it.

Ans. See Sample Problem on page 81 of this book.

Q.3. Choose the correct option :

The magnetic field inside a long, straight solenoid carrying current :

(*a*) is zero

(*b*) decreases as we move towards its end

(*c*) increases as we move towards its end

(*d*) is the same at all points

Ans. (*d*) is the same at all points.

NCERT Book, Pages 231-232

Q.1. Which of the following property/properties of a proton can change while it moves freely in a magnetic field ? (There may be more than one correct answer) :

(*a*) mass **(*b*) speed** **(*c*) velocity** **(*d*) momentum**

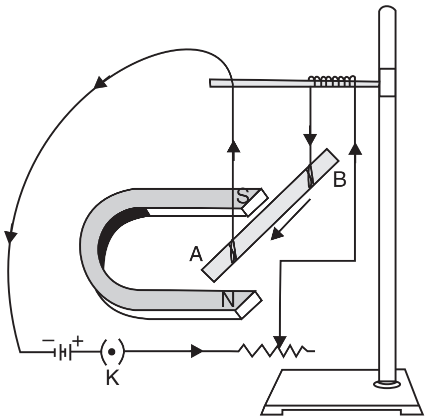
Ans. (*c*) velocity, and (*d*) momentum.

Q.2. A small aluminium rod AB is suspended horizontally from a stand by the ends of two connecting wires as shown in the Figure given here. A horseshoe magnet is placed in such a way that north pole of the magnet is vertically below and its south pole vertically above the aluminium rod. The aluminium rod is connected in series with a battery, a key and a rheostat. How do you think the displacement of rod AB will be affected if :

(*i*) current in rod AB is increased ?

(*ii*) a stronger horseshoe magnet is used ?

(*iii*) length of the rod AB is increased ?



Ans. In order to answer this question, we have to remember that : When a current-carrying conductor is perpendicular to the magnetic field, the force acting on it is directly proportional to (*a*) magnitude of current flowing in the conductor (*b*) strength of magnetic field applied, and (*c*) length of the conductor. And greater the force, greater will be the displacement of the conductor (which is an aluminium rod in this case). Now :

(*i*) if the current in rod AB is increased, then more force will act on the rod and hence the displacement of rod will also be more.

(*ii*) if a stronger horseshoe magnet is used, then the strength of magnetic field will increase leading to greater force on the rod. And due to greater force, the displacement of rod will also be more.

(*iii*) If the length of rod AB is increased, then more force will act on the rod and hence the displacement of rod will also be more.

Q.3. A positively charged particle (alpha particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is :

(*a*) towards south **(*b*) towards east** **(*c*) downward** **(*d*) upward**

Ans. (*d*) upward (For details, see Sample Problem 1 on page 88 of this book).

NCERT Book, Page 233

Q.1. State Flemings left-hand rule.

Ans. See page 87 of this book.

Q.2. What is the principle of an electric motor ?

Ans. See page 89 of this book.

Q.3. What is the role of the split ring in an electric motor ?

Ans. The role of the split ring (called commutator) in an electric motor is to reverse the direction of current flowing through the motor coil after every half rotation of the coil. Due to this reversing of current, the direction of force remains unchanged on the two sides of the coil and hence the coil continues to rotate in the same direction.

NCERT Book, Page 236

Q.1. State different ways to induce current in a coil.

Ans. (*i*) The current can be induced in a coil by rotating it in the magnetic field between the poles of a U-shaped magnet.

(*ii*) The current can be induced in the coil by keeping it stationary and rotating a magnet inside it.

(*iii*) The current can be induced in a coil by changing the current continuously in 'another coil' kept near it.

NCERT Book, Page 237

Q.1. State the principle of an electric generator.

Ans. The electric generator works on the principle that when a straight conductor is moved in a magnetic field, then current is induced in the conductor.

Q.2. Name some sources of direct current.

Ans. Dry cell, Dry cell battery, Car battery, Solar cell and D.C. generator.

Q.3. Which sources produce alternating current ?

Ans. A.C. generators (or Power house generators), Car alternators and Bicycle dynamos.

Q.4. Choose the correct option :

A rectangular coil of copper wires is rotated in a magnetic field. The direction of the induced current changes once in each :

(*a*) two revolutions (*b*) one revolution (*c*) half revolution (*d*) one-fourth revolution

Ans. (*c*) half revolution.

NCERT Book, Page 238

Q.1. Name two safety measures commonly used in electric circuits and appliances.

Ans. See Sample Problem 4 on page 112 of this book.

Q.2. An electric oven of 2 kW power rating is operated in a domestic electric circuit (220 V) that has a current rating of 5 A. What result do you expect ? Explain.

Ans. See Sample Problem 1 on page 111 of this book.

Q.3. What precautions should be taken to avoid the overloading of domestic electric circuits ?

Ans. See Sample Problem 3 on page 112 of this book.

NCERT Book, Pages 240-241

Q.1. Which of the following correctly describes the magnetic field near a long straight wire ?

(*a*) The field consists of straight lines perpendicular to the wire

(*b*) The field consists of straight lines parallel to the wire

(*c*) The field consists of radial lines, originating from the wire

(*d*) The field consists of concentric circles centred on the wire

Ans. (*d*) The field consists of concentric circles centred on the wire.

Q.2. The phenomenon of electromagnetic induction is :

(*a*) the process of charging a body

(*b*) the process of generating magnetic field due to a current passing through a coil

(*c*) producing induced current in a coil due to relative motion between a magnet and the coil

(*d*) the process of rotating a coil of an electric motor

Ans. (*c*) producing induced current in a coil due to relative motion between a magnet and the coil.

Q.3. The device used for producing electric current is called a :

(*a*) generator (*b*) galvanometer (*c*) ammeter (*d*) motor

Ans. (*a*) generator

Q.4. The essential difference between an AC generator and a DC generator is that :

(*a*) AC generator has an electromagnet while a DC generator has permanent magnet

(*b*) DC generator will generate a higher voltage

(*c*) AC generator will generate a higher voltage

(*d*) AC generator has slip rings while the DC generator has a commutator

Ans. (*d*) AC generator has slip rings while the DC generator has a commutator.

Q.5. At the time of short circuit, the current in the circuit :

(*a*) reduces substantially (*b*) does not change

(*c*) increases heavily (*d*) varies continuously

Ans. (*c*) increases heavily.

Q.6. State whether the following statements are true or false :

(*a*) An electric motor converts mechanical energy into electrical energy

(*b*) An electric generator works on the principle of electromagnetic induction
(*c*) The field at the centre of a long circular coil carrying current will be parallel straight lines
(*d*) A wire with a green insulation is usually the live wire of an electric supply

Ans. (*a*) False (*b*) True (*c*) True (*d*) False

Q.7. List three sources of magnetic fields.

Ans. Magnetic fields can be produced :
(*i*) by using a permanent magnet
(*ii*) by passing electric current through a straight wire or a circular coil (solenoid)
(*iii*) by using an electromagnet

Q.8. How does a solenoid behave like a magnet ? Can you determine the north and south poles of a current carrying solenoid with the help of a bar magnet ? Explain.

Ans. (*a*) One end of a current-carrying solenoid acts like a north pole (N-pole) and the other end a south pole (S-pole). So, if a current-carrying solenoid is suspended freely by tying a thread in the middle, it will come to rest pointing in the north and south directions (just like a freely suspended bar magnet).

(*b*) We can determine the north and south poles of a current-carrying solenoid by using a bar magnet. This can be done as follows : We bring the north pole of a bar magnet near both the ends of a freely suspended current-carrying solenoid. The end of solenoid which will be repelled by the north pole of bar magnet and move away from it, will be its north pole. And the end of solenoid which will be attracted by the north pole of the bar magnet and move towards it, will be its south pole.

Q.9. When is the force experienced by a current-carrying conductor placed in a magnetic field largest ?

Ans. The force experienced by a current-carrying conductor placed in a magnetic field is the largest when the current-carrying conductor is perpendicular to the direction of magnetic field.

Q.10. Imagine that you are sitting in a chamber with your back to one wall. An electron beam, moving horizontally from back wall towards the front wall is deflected by a strong magnetic field to your right side. What is the direction of magnetic field ?

Ans. See Sample Problem 2 on page 88 of this book.

Q.11. Draw a labelled diagram of an electric motor. Explain its principle and working. What is the function of a split ring in an electric motor ?

Ans. See page 89 of this book.

Q.12. Name some devices in which electric motors are used.

Ans. Electric motors are used in electric fans, coolers, refrigerators, mixer and grinders, washing machines, water pumps and electric cars.

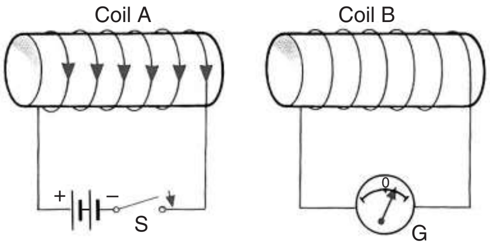
Q.13. A coil of insulated copper wire is connected to a galvanometer. What will happen if a bar magnet is (*i*) pushed into the coil (*ii*) held stationary inside the coil (*iii*) withdrawn from inside the coil ?

Ans. See Sample Problem 1 on page 102 of this book.

Q.14. Two circular coils A and B are placed close to each other. If the current in the coil A is changed, will some current be induced in the coil B ? Give reason.

Ans. If the current in coil A is 'switched on' or 'switched off', then an electric current is induced in the coil B (see Figure given here). This can be explained as follows :

(*i*) When we switch on current in coil A, it becomes an electromagnet and produces a magnetic field around coil B. The effect is just the same as pushing a magnet into coil B. So, an induced current flows in coil B for a moment. When the current in coil A becomes steady, its magnetic field also becomes steady and the current in coil B stops.



(*ii*) When we switch off the current in coil A, then its magnetic field in coil B stops quickly. This effect is just the same as pulling a magnet quickly out of coil B. So, in this case an induced current flows in coil B in the opposite direction.

Q.15. State the rule to determine the direction of a :

(*i*) magnetic field produced around a straight conductor carrying current.

(*ii*) force experienced by a current-carrying straight conductor placed in a magnetic field which is perpendicular to it.

(*iii*) current induced in a straight conductor moving in a magnetic field.

Ans. (*i*) The direction of magnetic field produced around a straight current-carrying conductor is determined by using Maxwell's right hand thumb rule (For statement, see page 76 of this book).

(*ii*) The direction of force experienced by a current-carrying straight conductor placed in a magnetic field is determined by Fleming's left-hand rule (For statement, see page 87 of this book).

(*iii*) The direction of current induced in a straight conductor moving in a magnetic field is determined by Fleming's right-hand rule (For statement, see page 96 of this book).

Q.16. Explain the underlying principle and working of an electric generator by drawing a labelled diagram. What is the function of brushes ?

Ans. See page 98 of this book.

Q.17. When does an electric short circuit occur ?

Ans. An electric short circuit takes place when the live wire and the neutral wire of electricity supply line touch each other directly. This occurs when the plastic insulation of live wire and neutral wire get torn or when there is a fault in the electrical appliance.

Q.18. Why is it necessary to earth metallic appliances ? What is the function of an earth wire ?

Ans. The metal body of an electrical appliance is 'earthed' or connected by means of a metal wire to the earth (which is at zero potential) to avoid the risk of electric shocks. This is because if, by chance, the live wire at the high potential of 220 volts touches the metal case of the electrical appliance, then the current passes from the electrical appliance directly to the earth through the low resistance earth wire. Since the current does not pass through our body, we do not get an electric shock. Thus, the function of an earth wire is to provide an easy passage to the leaking current from an electrical appliance to go into the earth and hence prevent electric shocks to the user of electrical appliance.

Chapter : SOURCES OF ENERGY

NCERT Book, Page 243

Q.1. What is a good source of energy ?

Ans. A good source of energy is one :

(*i*) which would give a large amount of energy per unit mass (or per unit volume)

(*ii*) which is cheap and easily available

(*iii*) which is easy to store and transport

(*iv*) which is safe to handle and use, and

(*v*) which does not cause environmental pollution.

Q.2. What is a good fuel ?

Ans. A good fuel is one :

(*i*) which has a high calorific value,

(*ii*) which has a proper ignition temperature,

(*iii*) which burns without giving out any smoke or harmful gases,

(*iv*) which burns smoothly and does not leave behind much ash after burning, and

(*v*) which is cheap, easily available, easy to handle, safe to transport and convenient to store.

Q.3. If you could use any source of energy for heating your food, which one would you use and why ?

Ans. I would use LPG (cooking gas) for heating food because :

(*i*) LPG has a high calorific value. It gives a lot of heat (per unit mass) on burning.

(*ii*) LPG burns with a smokeless flame and hence does not cause any air pollution.

(*iii*) LPG does not produce any poisonous gases on burning

(*iv*) LPG does not leave behind any ash after burning

NCERT Book, Page 248

Q.1. What are the disadvantages of fossil fuels ?

Ans. Coal, petroleum and natural gas are fossil fuels. The burning of fossil fuels has the following disadvantages :

(*i*) Fossil fuels are non-renewable sources of energy. Once exhausted, fossil fuels will not be available to us in the near future.

(*ii*) The burning of fossil fuels causes a lot of air pollution. This is described below :

(*a*) The burning of fossil fuels produces acidic gases such as sulphur dioxide and nitrogen oxides which cause acid rain. The acid rain damages plants (crops, etc.) , reduces fertility of soil by making it acidic, poses a danger to aquatic life (like fish) by making the water of lakes and rivers acidic, and damages buildings by corroding them slowly.

(*b*) The burning of fossil fuels produces large amount of carbon dioxide gas which goes into air. The presence of increasing amounts of carbon dioxide gas in air is causing increased greenhouse effect leading to excessive heating of the earth. This global warming is harmful for all the life on earth.

(*c*) The burning of fossil fuels (especially coal) produces smoke which pollutes the air. The burning of coal leaves behind a lot of ash. It also puts tiny particles of ash (called fly-ash) into the air causing air pollution.

Q.2. Why are we looking at alternative sources of energy ?

Ans. We are looking at alternative sources of energy mainly due to two reasons :

(*i*) because the fossil fuels and nuclear fuels present in the earth are limited which may not last for long, and

(*ii*) because of the undesirable effects of pollution both from the burning of fossil fuels and from the radioactive wastes of the nuclear power plants.

Q.3. How has the traditional use of wind and water energy been modified for our convenience ?

Ans. (*i*) The traditional use of wind energy has been modified by the improvements in technology to generate electricity through wind-powered generators.

(*ii*) The traditional use of energy of flowing water has been modified by improvements in technology to generate electricity through flowing water-powered generators (by establishing hydropower plants).

NCERT Book, Page 253

Q.1. What kind of mirror–concave, convex or plane–would be best suited for use in a solar cooker ? Why ?

Ans. A concave mirror reflector would be best suited for use in a solar cooker. This is because a concave reflector converges a large amount of sun's heat rays to a small area at its focus due to which a high temperature is produced in its focus area (which is suitable for baking and frying). Such a high temperature cannot be achieved in a solar cooker by using a plane mirror reflector. Convex mirror reflector, being a diverging mirror, cannot be used at all in a solar cooker.

Q.2. What are the limitations of energy that can be obtained from the oceans ?

Ans. The energy from the oceans can be obtained mainly in three forms : Tidal energy, Wave energy and Ocean thermal energy. Some of the important limitations of these forms of energy are as follows :

(*i*) There are very few places around the world where barrages (or dams) can be built to harness tidal energy. Moreover, the rise and fall of water during high and low tides is not enough to generate electricity on a large scale.

(*ii*) The wave energy can be harnessed only at those places where the sea-waves are very strong. The efficiency of power plants based on wave energy is very low. Moreover, the power plants built in oceans or at sea-shores have high cost of installation, corrode easily and need a lot of maintenance.

(*iii*) A temperature difference of 20°C (or more) between the surface water of ocean and deeper water is necessary to harness ocean thermal energy. The efficiency of OTEC power plants which work by utilising ocean thermal energy, is very low. Moreover, it is very expensive to establish OTEC power plants.

Q.3. What is geothermal energy ?

Ans. Geothermal energy is the heat energy from hot rocks present inside the earth. This heat comes from the fission of radioactive materials which are naturally present in these rocks. Geothermal energy is available only at some places in the world. Geothermal energy can be used to produce electricity.

Q.4. What are the advantages of nuclear energy ?

Ans. See page 156 of this book.

NCERT Book, Page 253

Q.1. Can any source of energy be pollution free ? Why or why not ?

Ans. In reality, no source of energy can be said to be pollution free. The use of each and every source of energy disturbs the environment in one way or the other. For example, though the use of a wind generator, solar cooker and solar cells for obtaining energy is pollution free but the processes involved in making the materials for these energy devices must have caused some pollution and damaged the environment in one way or the other.

Q.2. Hydrogen has been used as a rocket fuel. Would you consider it a cleaner fuel than CNG ? Why or why not ?

Ans. See Sample Problem on page 160 of this book.

NCERT Book, Page 254

Q.1. Name two energy sources that you would consider to be renewable. Give reasons for your choices.

Ans. Hydroenergy (Energy from flowing water) and Biomass energy (Energy from biofuels such as wood) are the renewable sources of energy.

(*i*) Hydroenergy is a renewable source of energy because it is supplied by the water cycle in nature (powered by sun's energy) and it will never get exhausted.

(*ii*) Biomass energy contained in wood is a renewable source of energy because if trees are cut from the forest for obtaining wood, then more trees will grow in the forest in due course of time.

Q.2. Give the names of two energy sources that you would consider to be exhaustible. Give reasons for your choices.

Ans. Exhaustible sources of energy means non-renewable sources of energy. Coal and petroleum are the two exhaustible sources of energy (or non-renewable sources of energy). This is due to the following reasons : Coal and petroleum are fossil fuels which were formed in the earth very, very slowly. The coal and petroleum which are present in the earth today have taken millions of years to form and get accumulated. So, if all the coal and petroleum present in earth get exhausted, they cannot be produced quickly in nature. We will not get any coal or petroleum in the near future.

NCERT Book, Pages 254-255

Q.1. A solar water heater cannot be used to get hot water on :

(*a*) a sunny day **(*b*) a cloudy day** **(*c*) a hot day** **(*d*) a windy day**

Ans. (*b*) a cloudy day.

Q.2. Which of the following is not an example of a bio-mass energy source ?

(*a*) wood **(*b*) gobar gas** **(*c*) nuclear energy** **(*d*) coal**

Ans. (*c*) nuclear energy

Q.3. Most of the sources of energy we use represent stored solar energy. Which of the following is not ultimately derived from the sun's energy ?

(*a*) geothermal energy **(*b*) wind energy** **(*c*) fossil fuels** **(*d*) biomass**

Ans. (*a*) geothermal energy

Q.4. Compare and contrast fossil fuels and the sun as direct sources of energy.

Ans. See page 140 of this book.

Q.5. Compare and contrast bio-mass and hydroelectricity as sources of energy.

Ans. See page 146 of this book.

Q.6. What are the limitations of extracting energy from :

(*a*) wind ? **(*b*) waves ?** **(*c*) tides ?**

Ans. *(a) Limitations of extracting energy from wind :*

(*i*) Wind generators to produce electricity can be established only at those places where wind blows for the greater part of the year.

(*ii*) The wind speed should be higher than 15 km/h to maintain the required speed of wind turbines for generating electricity.

(*iii*) There should be some back-up facilities like storage cells to take care of energy needs during the period there is no wind.

(*iv*) A large area of land is required for establishing wind energy farms

(*v*) The initial cost of establishing wind energy farms is quite high.

(b) Limitations of extracting energy from waves (or sea-waves) :

(*i*) The wave energy can be harnessed at only those places where the sea-waves are very strong.

(*ii*) The efficiency of power plants based on wave energy is very low.

(*iii*) The power plants built in oceans or at sea-shores have high cost of installation, corrode easily and need a lot of maintenance.

(c) Limitations of extracting energy from tides :

(*i*) There are very few sites around the world which are suitable for building tidal barrages (or tidal dams).

(*ii*) The rise and fall of sea-water during high and low tides is not enough to generate electricity on a large scale.

Q.7. On what basis would you classify energy sources as :

(*a*) renewable and non-renewable ?

(*b*) inexhaustible and exhaustible ?

Are the options given in (*a*) and (*b*) the same ?

Ans. The options given in (*a*) and (*b*) are the same. This is because renewable sources of energy are also known as inexhaustible sources of energy whereas non-renewable sources of energy are also called exhaustible sources of energy.

(*i*) Those sources of energy which are being produced in nature continuously and can be used again and again for ever, are called renewable sources of energy (or inexhaustible sources of energy). These sources of energy will never get exhausted. For example, wood is a renewable source of energy (or inexhaustible source of energy), because if some trees are cut down from forests for obtaining firewood, then more trees will grow in the forest on their own or can be replanted by man. This will ensure continuous supply of wood for obtaining heat energy.

(*ii*) Those sources of energy which have accumulated in the earth over very, very long time of millions of years and cannot be made quickly when used up completely, are called non-renewable sources of energy (or exhaustible sources of energy). These sources of energy will get exhausted sooner or later. For example, coal is a non-renewable source of energy (or exhaustible source of energy) because coal has accumulated in the earth over a very, very long time, and if all the coal gets used up completely, it cannot be produced quickly in nature.

Q.8. What are the qualities of an ideal source of energy ?

Ans. An ideal source of energy has the following qualities :

(*i*) It gives a large amount of energy per unit mass (or per unit volume).

(*ii*) It does not cause any environmental pollution.

(*iii*) It is easy to store and safe to transport

(*iv*) It is safe to handle and use

(*v*) It is cheap and easily available.

Q.9. (*a*) What are the advantages and disadvantages of using a solar cooker ?

(*b*) Are there any places where solar cookers would have limited utility ?

Ans. (*a*) See page 138 of this book.

(*b*) The solar cookers have limited utility at those places which usually remain cloudy and have long winters. An example of such places are hilly areas.

Q.10. (*a*) What are the environmental consequences of the increasing demand for energy ?

(*b*) What steps would you suggest to reduce energy consumption ?

Ans. (*a*) *Some of the environmental consequences of the increasing demand for energy are the following :*

(*i*) The combustion of fossil fuels is producing acid rain and damaging plants (crops), soil, aquatic life and buildings.

(*ii*) The burning of fossil fuels is increasing the amount of greenhouse gas carbon dioxide in the atmosphere leading to global warming.

(*iii*) The cutting down of forest trees (deforestation) for obtaining firewood is causing soil erosion and destroying wildlife.

(*iv*) The construction of hydropower plants is disturbing ecological balance.

(*v*) Nuclear power plants are increasing radioactivity in the environment.

(*b*) *Some of the steps which can be taken to reduce energy consumption are as follows :*

(*i*) Switch off lights, fans, TV and other such electrical appliances when not needed, to save electricity.

(*ii*) Use energy efficient electrical appliances such as compact fluorescent lamps (CFLs) and tube-lights to save electricity.

(*iii*) Good quality stoves should be used to burn fuels like kerosene and LPG so as to obtain maximum heat.

(*iv*) Pressure cookers should be used for cooking food to save fuel.

(*v*) Solar cookers should be used to cook food wherever possible and solar water heaters should be used to get hot water.

(*vi*) Bicycles should be used for short distances instead of scooters, motorcycles and cars so as to save petrol.

Chapter : LIGHT– REFLECTION AND REFRACTION

NCERT Book, Page 168

Q.1. Define the principal focus of a concave mirror.

Ans. The principal focus of a concave mirror is a point on its principal axis to which all the light rays which are parallel and close to the axis, converge after reflection from the concave mirror.

Q.2. The radius of curvature of a spherical mirror is 20 cm. What is its focal length ?

Ans. See Sample Problem on page 178 of this book.

Q.3. Name a mirror that can give an erect and enlarged image of an object.

Ans. Concave mirror.

Q.4. Why do we prefer a convex mirror as a rear-view mirror in vehicles ?

Ans. We prefer a convex mirror as a rear-view mirror in vehicles because of the following reasons :

(*i*) A convex mirror always produces an erect image (right side up image) of the objects.

(*ii*) The image formed in a convex mirror is highly diminished or much smaller than the object, due to which a convex mirror gives a wide field of view (of the traffic behind).

NCERT Book, Page 171

Q.1. Find the focal length of a convex mirror whose radius of curvature is 32 cm.

Ans.

$$\text{Focal length} = \frac{\text{Radius of curvature}}{2}$$

or

$$f = \frac{R}{2}$$

$$f = \frac{32}{2}\text{ cm}$$

$$f = 16\text{ cm}$$

Thus, the focal length of convex mirror is 16 centimetres.

Q.2. A concave mirror produces three times magnified (enlarged) real image of an object placed at 10 cm in front of it. Where is the image located ?

Ans. See Sample Problem 3 on page 197 of this book.

NCERT Book, Page 176

Q.1. A ray of light travelling in air enters obliquely into water. Does the light ray bend towards the normal or away from the normal ? Why ?

Ans. When a ray of light travelling in air enters obliquely into water, it bends towards the normal. This is because water is optically denser (than air) due to which the speed of light waves decreases on entering water, making the light bend towards the normal.

Q.2. Light enters from air to glass having refractive index 1.50. What is the speed of light in the glass ? The speed of light in vacuum is 3×10^8 m s^{-1}.

Ans. See Sample Problem on page 225 of this book.

Q. 3. Find out from Table on page 225 the medium having highest optical density. Also find the medium with lowest optical density.

Ans. (*a*) The medium having highest refractive index has the highest optical density. Since diamond has the highest refractive index (2.42), therefore, diamond has the highest optical density.

(*b*) The medium having lowest refractive index has the lowest optical density. Since air has the lowest refractive index (1.0003), therefore, air has the lowest optical density.

Q.4. You are given kerosene, turpentine and water. In which of these the light travels fastest ? Use the information given in Table on page 225.

Ans. The light travels fastest in that medium which has the lowest refractive index. Now, the refractive index of kerosene is 1.44, the refractive index of turpentine is 1.47 whereas the refractive index of water is 1.33. Here water has the lowest refractive index (of 1.33), so light travels fastest in water.

Q.5. The refractive index of diamond is 2.42. What is the meaning of this statement ?

Ans. By saying that the refractive index of diamond is 2.42, we mean that the ratio of speed of light in air (or vacuum) to the speed of light in diamond is equal to 2.42.

NCERT Book, Page 184

Q.1. Define 1 dioptre of power of a lens.

Ans. 1 dioptre is the power of a lens whose focal length is 1 metre.

Q.2. A convex lens forms a real and inverted image of a needle at a distance of 50 cm from it. Where is the needle placed in front of the convex lens if the image is equal in size to the object ? Also find the power of the lens.

Ans. See Sample Problem 7 on page 259 of this book.

Q.3. Find the power of a concave lens of focal length 2 m.

Ans. The focal length of a concave lens is considered negative and hence written with a minus sign.

So, Focal length of concave lens, $f = -2$ m (or -2 metres)

Now, Power, $P = \frac{1}{f\,(\text{in metres})}$

or $P = \frac{1}{-2}$

Thus, Power, $P = -\,0.5$ dioptre (or, $-\,0.5$ D)

NCERT Book, Pages 185-186

Q.1. Which one of the following materials cannot be used to make a lens ?

(*a*) water (*b*) glass (*c*) plastic (*d*) clay

Ans. (*d*) clay.

Q.2. The image formed by a concave mirror is observed to be virtual, erect and larger than the object. Where should be the position of the object ?

(*a*) between the principal focus and the centre of curvature

(*b*) at the centre of curvature

(*c*) beyond the centre of curvature

(*d*) between the pole of the mirror and its principal focus.

Ans. (*d*) between the pole of the mirror and its principal focus

Q.3. Where should an object be placed in front of a convex lens to get a real image of the size of the object ?

(*a*) at the principal focus of the lens

(*b*) at twice the focal length

(*c*) at infinity

(*d*) between the optical centre of the lens and its principal focus

Ans. (*b*) at twice the focal length.

Q.4. A spherical mirror and a thin spherical lens each have a focal length of, –15 cm. The mirror and the lens are likely to be :

(*a*) both concave

(*b*) both convex

(*c*) the mirror is concave and the lens is convex

(*d*) the mirror is convex but the lens is concave

Ans. (*a*) both concave.

Q.5. No matter how far you stand from a mirror, your image appears erect. The mirror is likely to be :

(*a*) plane (*b*) concave (*c*) convex (*d*) either plane or convex

Ans. (*d*) either plane or convex

Q.6. Which of the following lenses would you prefer to use while reading small letters found in a dictionary ?
(*a*) A convex lens of focal length 50 cm
(*b*) A concave lens of focal length 50 cm
(*c*) A convex lens of focal length 5 cm
(*d*) A concave lens of focal length 5 cm

Ans. **(*c*)** A convex lens of focal length 5 cm

Q.7. We wish to obtain an erect image of an object using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror ? What is the nature of the image ? Is the image larger or smaller than the object ? Draw a ray diagram to show the image formation in this case.

Ans. See Sample Problem 1 on page 187 of this book.

Q.8. Name the type of mirror used in the following situations :
(*a*) Headlights of a car
(*b*) Side/rear view mirror of a vehicle
(*c*) Solar furnace
Support your answer with reason.

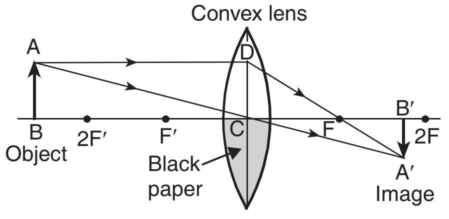
Ans. (*a*) A concave mirror is used in the headlights of a car. This is because when, a lighted bulb is placed at the focus of the concave reflector, then the concave reflector produces a powerful beam of parallel light rays. This beam of light helps us to see things up to a considerable distance in the darkness of night.

(*b*) A convex mirror is used as side-view mirror (or rear-view mirror) in a vehicle. This is because (*i*) a convex mirror always produces an erect image of the objects, and (*ii*) the image formed in a convex mirror is highly diminished due to which a convex mirror gives a wide field of view (of the traffic behind).

(*c*) A concave mirror is used in a solar furnace. This is because when the solar furnace is placed at the focus of a large concave reflector, then the concave reflector converges and focuses the sun's heat rays on the furnace due to which the solar furnace gets very hot.

Q.9. One half of a convex lens is covered with a black paper. Will this lens produce a complete image of the object ? Verify your answer experimentally. Explain your observations.

Ans. The convex lens half covered with a black paper will produce a complete image of an object (as shown in the Figure alongside). We can verify this by obtaining the image of a tree (or a window) on a screen by using this half covered convex lens. The full image of an object is produced by this convex lens (which is half covered with a black paper) because light rays can still pass through its optical centre (as shown in Figure given here).



Q.10. An object 5 cm in length is held 25 cm away from a converging lens of focal length 10 cm. Draw the ray diagram and find the position, size and nature of the image formed.

Ans. A converging lens means a convex lens. Now, first of all we will find the position of image by calculating the image distance v.

Here, Object distance, u = –25 cm (It is to the left of lens)
Image distance, v = ? (To be calculated)
And, Focal length, f = + 10 cm (It is a converging lens or convex lens)

Now, putting these values in the lens formula :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

We get :
$$\frac{1}{v} - \frac{1}{-25} = \frac{1}{10}$$

$$\frac{1}{v} + \frac{1}{25} = \frac{1}{10}$$

$$\frac{1}{v} = \frac{1}{10} - \frac{1}{25}$$

$$\frac{1}{v} = \frac{5-2}{50}$$

$$\frac{1}{v} = \frac{3}{50}$$

$$v = +\frac{50}{3}$$

$$v = + 16.67 \text{ cm}$$

Thus, the position of image is at a distance of 16.67 cm from the lens. The plus sign for image distance shows that the image is formed on the right side of lens (or behind the lens) and that the nature of image is real and inverted.

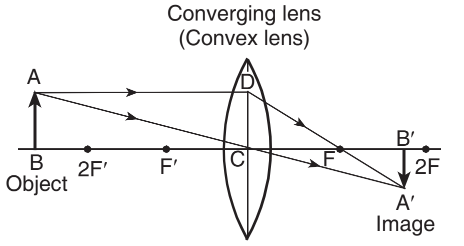
Let us calculate the magnification now. For a lens :

$$\text{Magnification, } m = \frac{v}{u}$$

$$m = \frac{16.67}{-25}$$

$$m = -0.66$$

We will now calculate the size of image h_2 by knowing the size of object h_1 and value of m.



Now, $m = \dfrac{h_2}{h_1}$

So, $-0.66 = \dfrac{h_2}{5}$

$$h_2 = -0.66 \times 5$$

$$h_2 = -3.3 \text{ cm}$$

Thus, the size of image is 3.3 cm. The negative sign of the size of image shows that the image is inverted.

Q.11. A concave lens of focal length 15 cm forms an image 10 cm from the lens. How far is the object from the lens ? Draw the ray diagram.

Ans. In this question, we have to calculate the object distance u.

Here, Object distance, u = ? (To be calculated)

Image distance, $v = -10$ cm (To the left of concave lens)

And, Focal length, $f = -15$ cm (It is a concave lens)

Now, putting these values in the lens formula :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

We get :

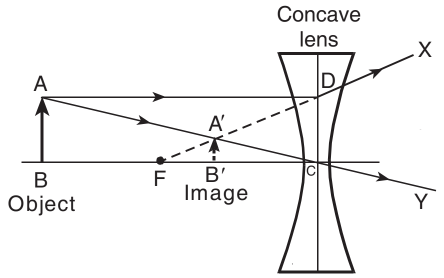
$$\frac{1}{-10} - \frac{1}{u} = \frac{1}{-15}$$

$$-\frac{1}{u} = -\frac{1}{15} + \frac{1}{10}$$

$$-\frac{1}{u} = \frac{-2+3}{30}$$

$$-\frac{1}{u} = \frac{1}{30}$$

Object distance, $u = -30$ cm



Thus, the object is placed at a distance of 30 cm from the concave lens. The minus sign with object distance shows that the object is on its left side.

Q.12. An object is placed at a distance of 10 cm from a convex mirror of focal length 15 cm. Find the position and nature of the image.

Ans. We can find the position of image by calculating the image distance, v.

Here, Object distance, $u = -10$ cm (To the left of mirror)
Image distance, $v = ?$ (To be calculated)
And, Focal length, $f = +15$ cm (It is a convex mirror)
Putting these values in the mirror formula :

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

We get :
$$\frac{1}{v} + \frac{1}{-10} = \frac{1}{15}$$

$$\frac{1}{v} - \frac{1}{10} = \frac{1}{15}$$

$$\frac{1}{v} = \frac{1}{15} + \frac{1}{10}$$

$$\frac{1}{v} = \frac{2+3}{30}$$

$$\frac{1}{v} = \frac{5}{30}$$

$$\frac{1}{v} = \frac{1}{6}$$

So, Image distance, $v = +6$ cm
Thus, the position of image is at a distance of 6 cm from the convex mirror on its right side (behind the mirror). Since the image is formed behind the convex mirror, therefore, the nature of image is virtual and erect.

Q.13. The magnification produced by a plane mirror is +1. What does this mean ?

Ans. See Sample Problem 4 on page 197 of this book.

Q.14. An object 5.0 cm in length is placed at a distance of 20 cm in front of a convex mirror of radius of curvature 30 cm. Find the position of the image, its nature and size.

Ans. Here, Object distance, $u = -20$ cm (To the left of mirror)
Image distance, $v = ?$ (To be calculated)
Radius of curvature, $R = +30$ cm (It is a convex mirror)

So, Focal length, $f = \frac{R}{2} = \frac{30}{2} = +15$ cm

Now, putting these values of u and f in the mirror formula :

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

We get :
$$\frac{1}{v} + \frac{1}{-20} = \frac{1}{15}$$

$$\frac{1}{v} - \frac{1}{20} = \frac{1}{15}$$

$$\frac{1}{v} = \frac{1}{15} + \frac{1}{20}$$

$$\frac{1}{v} = \frac{4+3}{60}$$

$$\frac{1}{v} = \frac{7}{60}$$

$$v = \frac{60}{7}$$

or
$$v = +8.57 \text{ cm}$$

Thus, the position of image is 8.57 cm behind the mirror (on its right side). Since the image is formed behind the convex mirror, therefore, the nature of image is virtual and erect.

Now, For a mirror, Magnification, $m = -\frac{v}{u}$

So, $m = -\frac{+8.57}{-20}$

$m = +0.42$

Also, $\text{Magnification} = \frac{\text{height of image}}{\text{height of object}}$

or $m = \frac{h_2}{h_1}$

So, $+0.42 = \frac{h_2}{5.0}$

$h_2 = 0.42 \times 5.0$

Height of image, $h_2 = 2.1$ cm

Thus, the size of image is 2.1 cm.

Q.15. An object of size 7.0 cm is placed at 27 cm in front of a concave mirror of focal length 18 cm. At what distance from the mirror should a screen be placed so that a sharp focussed image can be obtained ? Find the size and nature of the image.

Ans. Here, Object distance, $u = -27$ cm (To the left side of mirror)

Image distance, $v = ?$ (To be calculated)

Focal length, $f = -18$ cm (It is a concave mirror)

Height of object, $h_1 = 7.0$ cm

And, Height of image, $h_2 = ?$ (To be calculated)

Now, For a mirror : $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

So, $\frac{1}{v} + \frac{1}{-27} = \frac{1}{-18}$

$$\frac{1}{v} - \frac{1}{27} = -\frac{1}{18}$$

$$\frac{1}{v} = -\frac{1}{18} + \frac{1}{27}$$

$$\frac{1}{v} = \frac{-3+2}{54}$$

$$\frac{1}{v} = -\frac{1}{54}$$

Image distance, $v = -54$ cm

Since the image distance is minus 54 cm, therefore, the screen should be placed at a distance of 54 cm in front of the concave mirror (on its left side). The nature of image obtained on the screen is real and inverted.

Also, For a mirror, $\frac{h_2}{h_1} = -\frac{v}{u}$

So, $\frac{h_2}{7.0} = -\frac{-54}{-27}$

$$\frac{h_2}{7.0} = -2$$

$$h_2 = -2 \times 7.0$$

Height of image, $h_2 = -14.0$ cm

Thus, the size of image is 14.0 cm.

Q.16. Find the focal length of a lens of power, –2.0 D. What type of lens is this ?

Ans. The power of this lens has a negative sign (or minus sign), so this is a concave lens. Now,

$$\text{Power, } P = \frac{1}{f\,(\text{in metres})} \qquad (f = \text{focal length})$$

So, $$-2.0 = \frac{1}{f}$$

And, $$f = -\frac{1}{2.0} \text{ m}$$

Or $$f = -\frac{1}{2.0} \times 100 \text{ cm}$$

So, Focal length of lens, $f = -50$ cm

Q.17. A doctor has prescribed a corrective lens of power + 1.5 D. Find the focal length of the lens. Is the prescribed lens diverging or converging ?

Ans. The power of this lens is positive (with a plus sign), therefore, this is a convex lens or converging lens. Now,

$$\text{Power, } P = \frac{1}{f\,(\text{in metres})}$$

So, $$+1.5 = \frac{1}{f}$$

or $$f = \frac{1}{+1.5} \text{ m}$$

$$f = +\frac{1}{1.5} \times 100 \text{ cm}$$

So, Focal length of lens, $f = +\ 66.7$ cm

Chapter : THE HUMAN EYE AND THE COLOURFUL WORLD

NCERT Book, Page 190

Q.1. What is meant by the power of accommodation of the eye ?

Ans. The ability of an eye to focus the distant objects as well as the nearby objects on the retina by changing the focal length (or converging power) of its lens is called accommodation.

Q.2. A person with a myopic eye cannot see objects beyond 1.2 m distinctly. What should be the type of the corrective lens used to restore proper vision ?

Ans. The proper vision of a myopic eye can be restored by using concave lens of suitable power.

Q.3. What are the far point and near point of the human eye with normal vision ?

Ans. The far point of human eye with normal vision is at infinity and the near point is at a distance of 25 centimetres from the eye.

Q.4. A student has difficulty in reading the blackboard while sitting in the last row. What could be the defect the child is suffering from ? How can it be corrected ?

Ans. Since the child cannot see the distant objects (like blackboard writing) clearly, he is suffering from the defect of vision (or defect of eye) called 'myopia' or 'short-sightedness'. Myopia can be corrected by using spectacles containing concave lenses of suitable power.

NCERT Book, Pages 197-198

Q.1. The human eye can focus objects at different distances by adjusting the focal length of the eye-lens. This is due to :

(*a*) presbyopia **(*b*) accommodation** **(*c*) near-sightedness** **(*d*) far-sightedness**

Ans. (*b*) accommodation

Q.2. The human eye forms the image of an object at its :

(*a*) cornea **(*b*) iris** **(*c*) pupil** **(*d*) retina**

Ans. (*d*) retina

Q.3. The least distance of distinct vision for a young adult with normal vision is about :

(*a*) 25 m **(*b*) 2.5 cm** **(*c*) 25 cm** **(*d*) 2.5 m**

Ans. (*c*) 25 cm

Q.4. The change in focal length of an eye-lens is caused by the action of the :

(*a*) pupil **(*b*) retina** **(*c*) ciliary muscles** **(*d*) iris**

Ans. (*c*) ciliary muscles

Q.5. A person needs a lens of power, –5.5 dioptres for correcting his distant vision. For correcting his near vision, he needs a lens of power +1.5 dioptres. What is the focal length of the lens required for correcting (*i*) distant vision, and (*ii*) near vision ?

Ans. (*i*) *For distant vision* : Power of lens, $P = -5.5$ D

Now, Power, $P = \dfrac{1}{f\text{(in metres)}}$ (where f = focal length)

So, $-5.5 = \dfrac{1}{f}$

And, $f = \dfrac{1}{-5.5}$ m

Or, $f = -\dfrac{1}{5.5} \times 100$ cm

So, Focal length, $f = -18.18$ cm (or -18.2 cm)

Thus, the focal length of lens required for correcting distant vision is, –18.2 cm. Minus sign of focal length tells us that it is a concave lens.

(*ii*) *For near vision* : Power of lens, $P = +1.5$ D

Now, Power, $P = \frac{1}{f(\text{in metres})}$

So, $+1.5 = \frac{1}{f}$

And, $f = \frac{1}{+1.5}$ m

Or, $f = +\frac{1}{1.5} \times 100$ cm

So, Focal length, $f = +66.66$ cm (or + 66.7 cm)

Thus, the focal length of lens required for correcting near vision is + 66.7 cm. Plus sign of focal length tells us that it is a convex lens.

Q.6. The far point of a myopic person is 80 cm in front of the eye. What is the nature and power of the lens required to correct the problem ?

Ans. See Sample Problem on page 275 of this book.

Q.7. (*a*) Make a diagram to show how hypermetropia is corrected.

(*b*) The near point of a hypermetropic eye is 1 m. What is the power of the lens required to correct this defect ? Assume that the near point of the normal eye is 25 cm.

Ans. (*a*) See Figure 13(*c*) on page 276 of this book.

(*b*) See Sample Problem on page 277 of this book.

Q.8. Why is a normal eye not able to see clearly the objects placed closer than 25 cm ?

Ans. A normal eye can see nearby objects because the ciliary muscles make the eye-lens more convex (or thick) thereby increasing its converging power. This increased converging power of eye-lens can make a normal eye see objects clearly only when placed up to 25 cm from the eye. However, when objects are placed closer than 25 cm, then the ciliary muscles cannot make the eye-lens more convex to increase its converging power further so as to focus them sharply on the retina. Due to this, such objects are not seen clearly. In other words, a normal eye is not able to see clearly the objects placed closer than 25 cm because all its power of accommodation (or ability to increase converging power of eye-lens by making it more convex) has already been exhausted.

Q.9. What happens to the image distance in the eye when we increase the distance of an object from the eye ?

Ans. See Sample Problem on page 269 of this book.

Q.10. Why do stars twinkle ?

Ans. See page 290 of this book.

Q.11. Explain why the planets do not twinkle.

Ans. See page 291 of this book.

Q.12. Why does the sun appear reddish in the morning ?

Ans. See page 296 of this book.

Q.13. Why does the sky appear dark instead of blue to an astronaut ?

Ans. This is because in outer space, there is no atmosphere to scatter sunlight. Since there is no scattering of blue component of white sunlight which can reach the eyes of an astronaut in outer space, therefore, the sky appears dark to the astronaut, instead of blue.

Value Based Questions
(with Answers)
FIRST TERM

Q.1. Raman is a student of class X. Raman's mother was making tea in an old electric kettle having metal case. She switched on the power supply to the electric kettle. When Raman's mother touched the metal case of working electric kettle unknowingly, she got a severe electric shock. Raman put off the main switch quickly. After removing the kettle plug from socket, Raman found that the connecting cord was torn where it touched the metal case of the kettle. He also found that though the red and black wires of connecting cord were firmly connected to the two lower terminals of the power plug but the green wire of cord was not connected to the upper terminal of the plug. Raman replaced the torn connecting cord and also connected the three wires of cord firmly to the power plug terminals.

(*a*) Why did Raman put off the main switch quickly ?

(*b*) What name is given to (*i*) red wire (*ii*) black wire, and (*iii*) green wire, of the connecting cord ?

(*c*) Which wire, red, black or green, touched the metal case of electric kettle when Raman's mother got electric shock ?

(*d*) Which safety device was not working in electric kettle circuit which could have prevented the electric shock ?

(*e*) What values are displayed by Raman in this incident ?

Ans. (*a*) Raman put off the main switch to cut off the electricity supply to faulty electric kettle so as to save his mother.

(*b*) (*i*) Red wire is live wire (*ii*) Black wire is neutral wire, and (*iii*) Green wire is earth wire.

(*c*) Red wire (or live wire) which is at a high potential of 220 volts was touching the metal case of electric kettle.

(*d*) Earth wire.

(*e*) The values displayed by Raman are (*i*) Presence of mind (in putting off the main switch) (*ii*) Concern for mother (to save her life) (*iii*) Knowledge of household electric wiring, and (*iv*) Application of knowledge (in daily life situations).

Q.2. Vikalp's father had constructed a new room in their house. An electrician was called in to do the electric wiring. The electrician was asked to do wiring for two fans, two bulbs, a light socket and a power socket. Vikalp studies in tenth standard. Just when the electrician had completed the wiring, Vikalp returned home from school. Vikalp wanted to check the wiring by using all the switches and sockets. Vikalp found that the two fans and two sockets worked properly, each having a separate switch but there was a problem in the working of bulbs. Both the bulbs could be switched on and switched off with the same switch. Vikalp explained the mistake in wiring to electrician and then two separate switches were provided for the two bulbs.

(*a*) In what way were the two fans and two sockets connected in the household circuit by the electrician ?

(*b*) What mistake was made by electrician in connecting the two bulbs in the circuit ?

(*c*) In addition to the problem of not being able to be switched on and switched off independently, what other problem could be observed easily in the working of two electric bulbs, if the mistake had not been corrected ?

(*d*) What values were displayed by Vikalp during this incident ?

Ans. (*a*) The two fans and two sockets were connected correctly in parallel circuits.

(*b*) The two electric bulbs were connected wrongly in series in the circuit.

(*c*) The two electric bulbs would glow less brightly when connected in series because they would not get the same voltage of 220 volts of the mains supply line.

(*d*) Vikalp showed the values of (*i*) Curiosity to check whether things worked properly or not (*ii*) Knowledge of household wiring, and (*iii*) Application of knowledge.

Q.3. Rahul went to an electronics shop to get his father's old radio set repaired. The radio mechanic required resistances of 1.5 Ω and 10 Ω to repair the radio set properly but he had only a large number of 3 Ω resistors. The radio mechanic made many attempts but could not get the right combinations of 3 Ω resistors to obtain 1.5 Ω and 10 Ω resistances. Rahul had studied combination of resistors in class X. Rahul thought for a while and then joined some 3 Ω resistors in two different ways to obtain the required resistances.

(*a*) How did Rahul obtain 1.5 Ω resistance by joining a number of 3 Ω resistors ?

(*b*) How many 3 Ω resistors were combined together to obtain 1.5 Ω resistance ?

(*c*) How did Rahul obtain 10 Ω resistance by joining a number of 3 Ω resistors ?

(*d*) How many 3 Ω resistors were combined together by Rahul to obtain 10 Ω resistance ?

(*e*) What values are shown by Rahul in this episode ?

Ans. (*a*) In order to obtain 1.5 Ω resistance, Rahul first combined three 3 Ω resistors in parallel to obtain a resistance of 1 Ω. He then connected six 3 Ω resistors in parallel to obtain a resistance of 0.5 Ω. These two parallel combinations were then connected in series to obtain a resistance of 1 + 0.5 = 1.5 Ω (see Figure 1)

(*b*) Nine 3 Ω resistors.

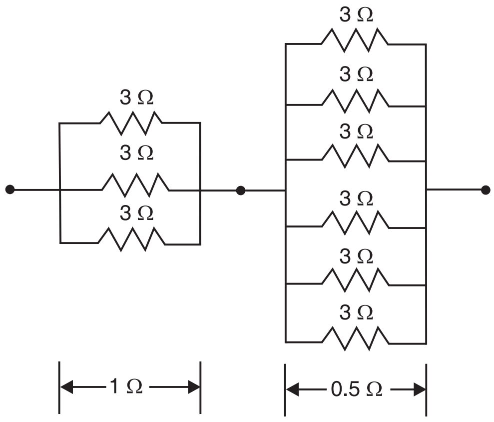


Figure 1.

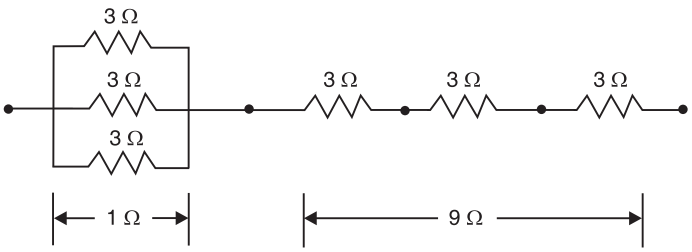


Figure 2.

(*c*) In order to obtain 10 Ω resistance, Rahul first connected three 3 Ω resistors in parallel to obtain a resistance of 1 Ω. He then connected three 3 Ω resistors in series to get a resultant resistance of 9 Ω. The parallel combination and series combination were then connected in series to obtain a final resistance of 1 + 9 = 10 Ω (see Figure 2).

(*d*) Six 3 Ω resistors.

(*e*) Rahul showed the values of (*i*) Knowledge of combination of resistors (*ii*) Application of knowledge, and (*iii*) Desire to help others.

Q.4. Aslam is a welder by profession who was working at Mohan's house. After making a 'railing' by using electric welding with naked eyes, Aslam was using a grinder on it to smoothen the welding joints. Just then some particle fell into Aslam's eye. He started crying with pain. Mohan hired an auto and took him to an eye hospital. In the hospital, doctor used a device connected to two electric wires to remove the particle from Aslam's eye. Aslam asked Mohan what had fallen into his eye and what device was used by the doctor to remove that particle from the eye. Being a science student of class X, Mohan explained everything to Aslam and asked him to be careful in future.

(*a*) What could be the particle which fell into Aslam's eye ?

(*b*) What device was used by the doctor to remove the particle and how it worked ?

(*c*) What precautions should be observed by Aslam while doing electric welding and grinding work ?

(*d*) What values are shown by Mohan during this episode ?

Ans. (*a*) An iron particle fell into Aslam's eye while using the grinder on iron railing.

(*b*) The doctor used an electromagnet to remove the tiny iron particle from Aslam's eye. Electromagnet is a powerful magnet and the iron particle in the eye is strongly attracted by the electromagnet, sticks to the electromagnet and gets removed.

(*c*) Aslam should use some device to protect his eyes while doing electric welding or using a grinder. Such an eye-protecting device can be welding helmet, hand held shield or welding goggles.

(*d*) Mohan showed the values of (*i*) Ability to handle a serious situation with calmness, and (*ii*) Desire to help others (by rushing Aslam to an eye hospital).

Q.5. Rajan constructed a small house. He used good quality and well insulated copper wires for wiring. He also used good quality switches, sockets and plugs. Rajan, however, had a very old room heater. On one winter night, Rajan was sleeping in a closed room with his family with the room heater switched on. During sleep, Rajan felt suffocated and woke up to see the room heater on fire. Rajan's son Arvind got up quickly and put off the main switch. Arvind also made a telephone call to Fire Brigade. The Fire Brigade men reached quickly and extinguished fire in the room. Rajan and his family thanked the firemen.

(*a*) What was the cause of fire in Rajan's house ?

(*b*) Name the safety device which was missing in the electric wiring of Rajan's house ?

(*c*) How could the above device prevent fire in Rajan's house ?

(*d*) What values are displayed by Arvind in this whole incident ?

Ans. (*a*) The cause of fire in Rajan's house was short-circuiting (due to the working of an old room heater having connecting cord with torn insulation, etc.).

(*b*) Electric fuse is the safety device which was missing in the wiring of Rajan's house.
(*c*) During short-circuiting, when the live wire and neutral wire touch each other directly, then the resistance of the circuit formed becomes very low due to which too much current passes through the household circuit (including the thin fuse wire). When too much current passes through fuse wire, the fuse wire gets heated too much, melts and breaks, cutting off the electricity supply in the household circuit. This prevents the electric fire in the house.
(*d*) The values displayed by Arvind in this incident are (*i*) General awareness (that electric fire can be prevented from spreading by putting off the main switch), and (*ii*) Presence of mind (in calling the Fire Brigade to extinguish fire).

Q.6. Vaibhav had gone to his uncle's home in a foreign country where the domestic electric supply is D.C. (Direct Current). An electrician was working in his uncle's kitchen who was trying to find out the location of electric wiring in a particular wall for further electrical work. Failing to do so, the electrician recommended the breaking of substantial portion of the kitchen wall. Vaibhav told his uncle that he could locate the position of current-carrying wires in the kitchen wall without breaking the kitchen wall. In order to do this, Vaibhav purchased a small device from the market and moved it slowly over the whole kitchen wall. After about ten minutes, Vaibhav could locate the position of all the current-carrying wires in this kitchen wall. His uncle was happy that now only a small portion of the kitchen wall will have to be dismantled.
(*a*) What was the small device purchased by Vaibhav ?
(*b*) What was noticed by Vaibhav when this device was moved slowly over the current-carrying wires embedded in the wall ?
(*c*) What name was given to the effect which helped Vaibhav to locate the concealed current-carrying wires in the wall ?
(*d*) Name the Scientist who discovered the above effect.
(*e*) What values are shown by Vaibhav in this episode ?

Ans. (*a*) Vaibhav purchased a plotting compass.
(*b*) When Vaibhav moved the plotting compass over the wall slowly, the compass needle was deflected from its usual north-south position whenever compass came over the current-carrying wires.
(*c*) Magnetic effect of electric current.
(*d*) Oersted.
(*e*) The values shown by Vaibhav are (*i*) Knowledge of scientific facts (that even a concealed current- carrying wire in a wall can create magnetic field around it and deflect compass needle), and (*ii*) Application of knowledge in everyday situations.

Q.7. Farid was given two thin wires X and Y in the science laboratory. The teacher asked Farid to find out (by performing suitable activities) which wire was 'fuse wire' and which one a 'nichrome wire'. Farid was given batteries of 3 V and 12 V, and some copper connecting wires alongwith crocodile clips. The teacher had himself performed this activity earlier and knew that the batteries of 3 V and 12 V were appropriate for this activity. The teacher also advised Farid to put off fan while performing the activites and take necessary precautions to avoid burns. Farid performed the activities and concluded that wire X is nichrome wire whereas wire Y is the fuse wire.
(*a*) Describe briefly the activity which Farid could have performed to conclude that wire X is nichrome wire.
(*b*) Describe briefly the activity which Farid could have performed to conclude that wire Y is fuse wire.
(*c*) Why did teacher advise Farid to switch off the fan during these activities ?
(*d*) What values are shown by Farid in performing these activities ?

Ans. (*a*) Farid first connected the wire X in series circuit with 3 V battery. He found that the wire got heated and became dull red. Farid then connected wire X in series circuit with 12 V battery. He found that wire X got heated too much and started glowing bright red. This showed that wire X is like the heating element of an electric heater and hence made of nichrome.
(*b*) Farid now connected the wire Y in series circuit with 3 V battery. The wire got heated a little but did not glow. Farid then connected wire Y in series circuit with 12 V battery. He found that wire Y got heated too much, melted and broke into two pieces. Now, when a thin wire gets heated too much and breaks on passing excessive electric current, it behaves like a fuse wire. So, wire Y is the fuse wire.
(*c*) The teacher advised Farid to switch off the fan while performing these activities because the fan's air could cool the hot wires due to which the fuse wire will not get heated to its melting point and hence not break.
(*d*) The values shown by Farid in performing these activities are (*i*) Knowledge of the heating effect of electric current and working of fuse, and (*ii*) Ability to apply knowledge in real life situations.

Q.8. Mr. Dogra lives in a very old house. The electric wiring in this house was done more than 50 years ago. Mr. Dogra purchased an air conditioner recently. One day Mr. Dogra was sitting in a closed room with all his family members with air conditioner switched on. A geyser was also working on the same socket as the air conditioner. Suddenly, everyone in the room heard a little explosion and saw that the electric wires in the air conditioner socket had caught fire. Mr. Dogra was so shocked that he did not know what to do. Mr. Dogra's son Rajesh who is studying in Class X rushed out of the room and put off the main switch quickly. Before Mr. Dogra could call the Fire Brigade, Rajesh extinguished the fire with the help of a fire extinguisher which he had made in the school. An electrician was called. When he checked the main fuse, he found that someone had put a thick copper wire in the main fuse instead of a proper fuse wire. The electrician changed the whole wiring of the house by using good quality wires and fixed a proper fuse wire in the main fuse. He also made separate circuit for geyser and provided separate fuses for all the circuits.

(*a*) Why did the electric wires catch fire ?

(*b*) What is the condition of using an air conditioner and a geyser on the same socket known as ?

(*c*) Why did the fuse not blow off ?

(*d*) What would you recommend in place of old porcelain fuse holders in the house to protect the wiring more efficiently ?

(*e*) What values are displayed by Mr. Dogra's son Rajesh in this whole episode ?

Ans. (*a*) The wires caught fire due to overheating caused by the excessive current passing through them when two appliances, air conditioner and geyser, which draw heavy current were used on the same socket.

(*b*) This condition is called overloading.

(*c*) The fuse did not blow off because a thick copper wire had been used as a fuse wire in the fuse box which did not get heated too much, did not melt and hence did not break to cut off the electric supply.

(*d*) The old porcelain fuse holders should be replaced by MCBs (Miniature Circuit Breakers). And an additional MCB should be put in the air conditioner circuit alongwith its socket.

(*e*) The values displayed by Mr. Dogra's son Rajesh are (*i*) Presence of mind (in switching off the main switch to cut off electricity supply and prevent fire from spreading), and (*ii*) Concern for the family (to protect them by extinguishing the fire).

Q.9. Vinod went to his ancestral village alongwith his father during the summer holidays. He found that the women of the village still used dried cow-dung cakes (*uple*) as the fuel to cook food and for other heating purposes. One day Vinod went to *Panchayat* meeting in the village which is attended by all the village elders and requested them to instal '*Gobar* gas plant' in the village and use cow-dung in it to produce *gobar* gas, instead of burning cow-dung cakes directly. He explained the advantages of using *gobar* gas as a fuel instead of cow-dung cakes. Every one liked the idea and thanked Vinod for guidance.

(*a*) State two disadvantages of using dried cow-dung cakes as a fuel for cooking food.

(*b*) State two advantages of using *gobar* gas as a fuel for cooking food.

(*c*) What values are displayed by Vinod in this whole episode ?

Ans. (*a*) (*i*) Burning of dried cow-dung cakes as fuel produces a lot of smoke which causes air pollution in the house and damages the health of all the family members, especially women and children.

(*ii*) The burning of dried cow-dung cakes as fuel destroys the important plant nutrients (like nitrogen and phosphorus) present in them which could otherwise be used to increase the fertility of soil in the fields.

(*b*) (*i*) *Gobar* gas burns without producing any smoke and hence does not cause any air pollution. This ensures good health for village people, especially women and children (who spend most of their time inside the house).

(*ii*) The cow-dung slurry left behind after the extraction of *gobar* gas still contains the plant nutrients (like nitrogen and phosphorus) which can be used as a manure in fields to increase the fertility of soil.

(*c*) The values displayed by Vinod are (*i*) General awareness (or knowledge) of the alternative sources of energy (such as *gobar* gas), and (*ii*) Concern about the environment and health of village people (exemplified by his desire to reduce air pollution).

Q.10. Dinesh is a student of 10th standard. He went to a remote area of Rajasthan for trekking with his friends. Dinesh found that it was a sparsely inhabited area. He was surprised to know that there was still no electricity in this area. The people used kerosene oil lamps to light up their homes at night and there were no street lights. The children also had to study with kerosene lamps at night. The village farmers used diesel to run irrigation pumps. Actually, there were no power transmission lines which could bring electricity to this remote area. Dinesh was really disturbed by the living conditions of the people in this part of Rajasthan. One day Dinesh gathered all the people of village in the village school. He told them that if they put pressure on their area MLAs and MP for making available the required funds, then he could tell them about the devices to light up their homes and streets at night, play radio and television

and also run irrigation pumps with electricity without there being power transmission lines. All the people agreed and Dinesh described them the devices to get electricity in their area in detail. The village people were very happy to know this and soon they got electricity in their area.

(*a*) What was the device described by Dinesh to the village people to obtain electricity locally ?
(*b*) What source of energy is made use of in this device to obtain electricity ?
(*c*) Why do you think this device is more appropriate for an area like Rajasthan ?
(*d*) What is the name of the single unit of this device ?
(*e*) What values are shown by Dinesh in this incident ?

Ans. (*a*) Solar panels.
(*b*) Solar energy (Sun's energy or Sunlight energy).
(*c*) Because Rajasthan gets a lot of sunshine throughout the year.
(*d*) Solar cell.
(*e*) The values shown by Dinesh in this incident are (*i*) General awareness (knowledge) about the alternative sources of energy (here solar energy) (*ii*) Concern for the environment to improve it (by reducing air pollution), and (*iii*) Desire to help people improve their life (by providing electricity).

Q.11. Simranjit studies in tenth class in a school. There are fifty students in his class. Most of the students come to the school by school buses but four students (including Simranjit) live in an area where school buses do not ply. These four students come to school by separate cars driven by their parents and also go back by separate cars. One day their science teacher was teaching the chapter on sources of energy. He told the students that the fossil fuels are limited in nature and we should make efforts to conserve them by reducing their consumption. Hearing this, an idea came to Simranjit's mind which he shared with the three classmates who live in the same area. All these students liked the idea. These students talked to their parents, and even the parents liked the idea.

(*a*) What could be the idea mooted by Simranjit ?
(*b*) Why was this idea mooted ?
(*c*) How did this idea help the environment ?
(*d*) How did this idea help the individual parents ?
(*e*) What values are displayed by Simranjit in mooting this idea ?

Ans. (*a*) The idea mooted by Simranjit was that since four of them come to school from the same area, they should form a 'car pool' in which four of them come and go by one car, turn by turn.
(*b*) The idea of 'car pool' was mooted to conserve (or save) petrol fuel (which comes from a fossil fuel petroleum) because it is non-renewable and present in limited quantity in earth.
(*c*) The idea of 'car pool' helped the environment by decreasing air pollution because less fuel (like petrol) is burned in one car daily (than four cars).
(*d*) The idea of 'car pool' helped the individual parents by providing them more spare time for doing other work (because only one of the parents had to do the duty of taking all the four students to school and bring them back. The other three parents are free on this day).
(*e*) The values displayed by Simranjit in mooting the idea of 'car pool' are (*i*) To conserve (or save) the non-renewable and fast depleting fossil fuel petroleum (so that it could last for as long as possible) (*ii*) To reduce air pollution caused by the excessive burning of petroleum fuels, and (*iii*) Strengthening the bonds of friendship among classmates (by travelling together in one car daily).

Q.12. Mr. Firoze is a retired man who lives in a big house. He has recently replaced all the filament-type bulbs in his house by CFLs. His wife and children have a habit of keeping the lights and fans on (even when there is no one in the room) but Mr. Firoze keeps on going to every room periodically to switch them off. A few days back Mr. Firoze had purchased a device which can cook rice and *dal* without using any usual fuel. He has also installed an equipment on the roof of his house to obtain hot water. Mr. Firoze uses bicycle for short distances like going to nearby market, instead of scooter or car.

(*a*) What is CFL ? Why has Mr. Firoze replaced all the filament-type bulbs in his big house by CFLs ?
(*b*) Why does Mr. Firoze keep switching off lights and fans when no one is in the rooms ?
(*c*) Name the device which Mr. Firoze has purchased to cook rice and *dal* without using any usual fuel ?
(*d*) Name the equipment which Mr. Firoze has installed on the house-roof to obtain hot water ?
(*e*) Why does Mr. Firoze use bicycle for going through short distances ?
(*f*) What values are displayed by Mr. Firoze by all the above actions ?

Ans. (*a*) CFL stands for Compact Fluorescent Lamp. Mr. Firoze has replaced all the filament-type bulbs by CFLs to save electricity (or electrical energy) because CFLs consume much less electricity as compared to the traditional filament-type bulbs.
(*b*) Mr. Firoze keeps switching off lights and fans when no one is in the rooms to save electricity by preventing its wastage.
(*c*) Solar cooker.

(*d*) Solar water heater.

(*e*) Mr. Firoze uses bicycle for short distances to save petrol (which is used in scooter or car). Cycling also keeps him physically fit.

(*f*) The values displayed by Mr. Firoze by all his actions are (*i*) Conservation (or saving) of fossil fuels like coal and natural gas (which are used to produce electricity), LPG (which is used to cook food or heat water), petroleum (which gives petrol to run cars and scooters), and (*ii*) Concern for the environment to keep it pollution free (because burning of less fossil fuels produces less air pollution).

SECOND TERM

Q.13. Benny's mother was finding it difficult to cook food in the kitchen because there was no light in the kitchen due to a power cut. She complained about this to Benny. Benny took a big plane mirror from the house and made it stand in sunshine (outside the house) in such a way that sun's rays falling on it were diverted into the kitchen. This arrangement provided sufficient light in the kitchen due to which Benny's mother could finish her work in the kitchen comfortably.

(*a*) Which phenomenon of light is made use of by Benny in this case ?

(*b*) Benny's mother could also cook rice and *dal* by using a device kept in sunshine outside the kitchen in which a plane mirror is used as a reflector. Name the device.

(*c*) State four characteristics of images formed by a plane mirror.

(*d*) What values (or qualities) are displayed by Benny in this episode ?

Ans. (*a*) Benny makes use of the phenomenon of reflection of light from a plane mirror.

(*b*) Solar cooker.

(*c*) The image formed by a plane mirror is (*i*) virtual and erect (*ii*) same size as the object (*iii*) same distance behind the mirror as the object is in front of the mirror (*iv*) laterally inverted (or sideways reversed).

(*d*) The values (or qualities) displayed by Benny in this episode are (*i*) Awareness (or knowledge) about the reflection of light (*ii*) Ability to apply knowledge in real life situations, when needed, and (*iii*) Desire to help his mother.

Q.14. Sanjay was going to his office in his car. While driving his car, Sanjay saw a man behind him on a motorcycle through his rear-view mirror. A woman was also sitting behind the man on the motorcycle. Through his rear-view mirror, Sanjay noticed that the saree of the woman was almost touching the spokes of motorcycle wheel. He signalled the motorcyclist to stop and alerted the woman. She tied her saree properly and thanked Sanjay for the alert.

(*a*) What kind of mirror is used by Sanjay as rear-view mirror ?

(*b*) State two characteristics of the image formed by such a rear-view mirror ?

(*c*) What could have happened if Sanjay had not alerted the woman sitting at the back of motorcycle ?

(*d*) What values are displayed by Sanjay in this incident ?

Ans. (*a*) Convex mirror.

(*b*) The characteristics of the image formed by rear-view mirror (which is a convex mirror), are (*i*) virtual and erect, and (*ii*) diminished (smaller than the object).

(*c*) If Sanjay had not alerted the woman sitting at the back of motorcycle, then her saree could get entangled in the spokes of moving motorcycle wheel and cause a serious accident.

(*d*) The values displayed by Sanjay in this incident are (*i*) Vigilant (because he kept careful watch for possible danger around him) (*ii*) Concern about others (here he was concerned about the safety of the woman), and (*iii*) Responsible citizen (because he stopped the motorcycle and alerted the woman about impending danger to her life).

Q.15. Manoj is a twelve year old boy. He obtained a lens from one of his friends. Manoj held the lens towards the sun and started looking at the sun through it. On seeing this, Manoj's elder brother ran towards him and snatched away the lens from him. The brother firmly told Manoj not to do it again.

(*a*) What could be the nature of the lens ?

(*b*) Why did the brother snatch the lens from Manoj ?

(*c*) What could have happened to Manoj if his brother had not snatched away the lens from him ? Explain.

(*d*) What values are shown by Manoj's brother ?

Ans. (*a*) It is convex lens (which is a converging lens).

(*b*) The brother snatched away the convex lens from Manoj because looking at the sun through convex lens could damage the eyes of Manoj.

(*c*) Convex lens is a converging lens. It could converge (or concentrate) a lot of sun's rays or sun's energy into Manoj's eyes. This energy could damage the delicate retina of eyes and even make him blind.

(*d*) The values shown by Manoj's brother are (*i*) Awareness (having knowledge) of the properties of convex lens, and (*ii*) Concern for the eyes of his brother Manoj.

Q.16. Anahat is an eight year old girl who has just begun to learn swimming. At the moment she is in the swimming pool. Suddenly, Anahat finds that her earring has fallen into the water. It appears to her that the earring has not gone too deep. So, she begins to go further into swimming pool to retrieve her earring. Her trainer, who has been watching her movements, does not allow Anahat to go further and pulls her out of the swimming pool quickly.

(*a*) Why does it appear to Anahat that her earring has not gone too deep in water ? Name the phenomenon involved.

(*b*) Why does the trainer not allow Anahat to go further in the swimming pool ?

(*c*) Give one example of the effect of phenomenon involved in the above episode in which a glass slab is used.

(*d*) What values does the trainer show in the above episode ?

Ans. (*a*) The phenomenon involved is refraction of light. Due to refraction of light coming out through the water of swimming pool into air, the bottom of swimming pool appears raised. In other words, the swimming pool appears to be less deep to Anahat than it really is. Due to this, Anahat thinks that her earring has not gone too deep in water and tries to retrieve it.

(*b*) The trainer does not allow Anahat to go further in the swimming pool because the water there is much deeper than it appears to be and there is a risk of drowning

(*c*) Due to refraction of light, when a glass slab is placed over some printed matter, the letters appear to be raised when viewed from top.

(*d*) The trainer shows the values of (*i*) Sense of duty (*ii*) Presence of mind (*iii*) Concern for the safety of children, and (*iv*) Timely action.

Q.17. Seema's father Mr. Soni runs a cosmetics and perfumes shop in a crowded market place. Mr. Soni usually complains at home that there is lot of 'shop-lifting' in his shop which was causing loss to him. Seema used to hear such complaints of her father. One day Seema went to the market and purchased two big mirrors of a special kind. She then went to her father's shop and fixed the two big mirrors at two strategic positions inside the shop. Mr. Soni found that after the installation of these mirrors, the shop-lifting almost stopped. He was very happy and thanked Seema for making this possible.

(*a*) What type of mirrors were fixed by Seema in the shop ?

(*b*) How did these mirrors help in preventing shop-lifting ?

(*c*) What special name is given to such mirrors which help prevent shop-lifting ?

(*d*) Can you give one example of another use of such mirrors ?

(*e*) What values are exhibited by Seema in this episode ?

Ans. (*a*) Convex mirrors.

(*b*) Mr. Soni could see the virtual, erect and diminished images of the customers by looking at the two big convex mirrors. In this way, Mr. Soni was able to keep a watch on most of the customers present in the shop (with the help of these two big convex mirrors) and hence the shop-lifting almost stopped.

(*c*) Shop security mirrors.

(*d*) Convex mirrors are used as rear-view mirrors in vehicles such as cars, buses, trucks, motorcycles and scooters, etc.

(*e*) The values exhibited by Seema are (*i*) Knowledge about various types of mirrors (*ii*) Application of knowledge in everyday situations, and (*iii*) Desire to solve her father's problem.

Q.18. It was a bright, sunny day in the morning when the classes started in the school. Suddenly dark clouds appeared in the sky. Due to this the classroom became quite dark. The teacher asked a student to switch on all the lights in the classroom.

(*a*) Why did the teacher ask for all the lights to be switched on ?

(*b*) What was the size of the pupil of the eyes of the students :

(*i*) before the clouds appeared ?

(*ii*) when classroom became quite dark ?

(*iii*) when the lights were switched on ?

(*c*) In which of the above mentioned three situations, the students will feel glare in their eyes and why ?

(*d*) What values are exhibited by the teacher in this case ?

Ans. (*a*) The teacher asked all the lights in the classroom to be switched on because seeing the blackboard writing in dim light put a lot of strain on the eyes of the students.

(*b*) (*i*) Before the clouds appeared, there was sufficient light in the classroom due to which the size of pupil of eyes was small.

(*ii*) When classroom became quite dark, the light was dim, due to which the size of pupil of eyes was very large.

(*iii*) When the lights were switched on, the light was bright and hence the size of pupil of eyes became small again.

(*c*) The students will feel glare in their eyes when the lights are switched on in the dark classroom. This is because the size of pupil of eye is large in the dark room. So, when lights are switched on, then suddenly too much light enters the eyes (due to large size of pupil) causing the glare in the eyes.

(*d*) The values exhibited by the teacher are (*i*) General awareness or Knowledge (that it is necessary to study in sufficient light to keep the eyes healthy, and (*ii*) Concern for the students (that studying in dim light can harm the eyes of students).

Q.19. Mr. Vinay's 65 year old mother is complaining about blurred vision in both the eyes due to which she cannot see things clearly. Mr. Vinay took his mother to an eye hospital. The doctor examined the eyes of his mother carefully and concluded that she has a medical condition which could not be corrected by using any type of spectacle lenses and it required surgery. The mother's eyes were operated upon and she could see properly once again.

(*a*) What could be the defect in the eyes of Mr. Vinay's mother ?

(*b*) What has happened to the eye lens during this defect ?

(*c*) What is done during surgical operation of eyes to restore the correct vision ?

(*d*) What would happen if eye surgery of a person having this defect is not done ?

(*e*) What values are shown by Mr. Vinay in this episode ?

Ans. (*a*) The defect in the eyes of Mr. Vinay's mother is known as cataract.

(*b*) During the development of cataract, a membrane is gradually formed over both the eye-lenses making the eye-lenses cloudy. This makes the vision blurred.

(*c*) During surgical operation, the cloudy eye-lenses are removed from the eyes and suitable artificial lenses are inserted in their place.

(*d*) If the eye surgery of a person having cataract is not done then the vision of this person will go on becoming more and more blurred, and ultimately the person would not be able to see anything at all.

(*e*) Mr. Vinay shows the values of (*i*) Awareness or knowledge (that eye-defects can be cured by eye-specialist doctors) (*ii*) Desire to mitigate the sufferings of others (here mother), and (*iii*) Sense of responsibility (towards old mother).

Q.20. Vasantha is a domestic help (or maid) working at Mrs. Sharma's home. One day Vasantha complained to Mrs. Sharma that she had difficulty in reading the letter which she had received from her parents. Mrs. Sharma, realising that Vasantha had an eye defect, took her to an eye-specialist doctor. The doctor tested her eyes carefully and told Vasantha to wear spectacles containing certain type of lenses having specified power. Mrs. Sharma bought the required spectacles for Vasantha. By wearing these spectacles, Vasantha could read and write easily. She was very happy and thanked Mrs. Sharma.

(*a*) What could be the eye-defect Vasantha was suffering from ?

(*b*) What could be the two possible reasons responsible for her eye-defect.

(*c*) What type of lenses do you think doctor recommended for Vasantha's spectacles ? Why ?

(*d*) Do you think Vasantha has to wear the spectacles all the time ? Give reason for your answer.

(*e*) What values are displayed by Mrs. Sharma in this episode ?

Ans. (*a*) Vasantha was suffering from an eye defect called hypermetropia (long-sightedness or far-sightedness) in which a person cannot see the nearby things clearly (though he or she can see the distant things clearly).

(*b*) (*i*) Low converging power of eye lens (because of eye lens being less convex or less thick).
(*ii*) Eye-ball being too short (because of which the distance of retina from the eye lens is less than normal).

(*c*) The doctor recommended convex lenses for the spectacles of Vasantha. This is because convex lenses are converging lenses which will increase the converging power of the convex eye lenses.

(*d*) No, Vasantha does not have to wear these spectacles all the time. She has to wear these spectacles only while reading, writing, sewing, etc. (because only her near vision is defective).

(*e*) Mrs. Sharma displayed the values of (*i*) Awareness, which means having knowledge of a situation or facts (because she knew that Vasantha's eye defect can be rectified by using spectacles) (*ii*) Concern for others (to mitigate their suffering), and (*iii*) Kindness and generosity (because Mrs. Sharma bought spectacles for Vasantha by spending her own money).

Q.21. There was some construction work going on in the neighbourhood of Amar Singh. One day when Amar Singh came back from his office, he saw his ten year old son standing near the welder and looking at the electric welding being done with great curiosity. Amar Singh grabbed his son by the arm and brought him inside the house quickly. He firmly told his son not to look at electric welding being done again because it is extremely harmful. Amar Singh then went out and scolded the welder for allowing a child to stand near him and watch the electric welding being done. The welder said 'sorry' to Amar Singh for the lapse on his part.

(*a*) Why did Amar Singh bring his son inside the house quickly ?

(*b*) What harm could have been done to the child by staring at the electric welding and why ?
(*c*) Name a natural luminous object which can do the same damage when looked at straight with naked eyes for a considerable time.
(*d*) What other harm could have been done to the child by standing near the welder when electric welding was being done ?
(*e*) What values are exhibited by Amar Singh in this episode ?

Ans. (*a*) Amar Singh brought his son inside the house quickly to protect his son from damage to his eyes and possible burns.
(*b*) Electric welding produces enormously bright light. This extremely bright light could have damaged the retina of the eye.
(*c*) The sun is also an extremely bright object in the sky which can damage the retina of eyes if looked at straight with naked eyes for a considerable time.
(*d*) The electric welding produces sparks which fly off in all directions. The extremely hot sparks of electric welding could cause burns on the body of the child standing nearby.
(*e*) Amar Singh exhibited the values of (*i*) Awareness (that electric welding can damage the eyes and also cause burns) (*ii*) Concern for his son (to protect his eyes and prevent burns), and (*iii*) Teach lesson to wrong doer (by scolding the welder).

Q.22. Sunny Dayal is a car driver working for Mr. Khanna. One day Sunny Dayal complained that he had difficulty in driving car because he could not see the distant traffic (cars, buses, scooters, motorcycles and people) clearly though he could see the nearby things clearly. Mr. Khanna took Sunny Dayal to an eye hospital. The eye-specialist doctor checked and tested his eyes with various machines and gave him the name and power of lenses to be worn as spectacles. Mr. Khanna paid for the required spectacles for the driver. By wearing these spectacles, the driver could now see even the distant vehicles and people on the road clearly. He thanked Mr. Khanna for this.
(*a*) Name the eye defect Sunny Dayal is suffering from.
(*b*) What could be the two possible reasons for his eye defect ?
(*c*) What type of lenses do you think have been recommended for Sunny Dayal's spectacles and why ?
(*d*) Do you think Sunny Dayal has to wear these spectacles all the time ? Give reasons for your answer.
(*e*) What could have been the risk if Mr. Khanna had not taken Sunny Dayal to eye specialist doctor for the correction of vision by wearing spectacles ?
(*f*) What values (or qualities) are displayed by Mr. Khanna ?

Ans. (*a*) Myopia (Short-sightedenss or Near-sightedness).
(*b*) (*i*) One reason for this eye defect is the high converging power of eye lens (because of eye lens being too convex or too thick).
(*ii*) Another reason for this eye defect is that the eyeball may be too long (because of which the distance of retina from the eye lens is more than normal).
(*c*) The doctor recommended concave lenses for the spectacles of Sunny Dayal. This is because concave lenses are diverging lenses which will decrease the converging power of convex eye lenses.
(*d*) No, Sunny Dayal has not to wear these spectacles when reading or writing. This is because Sunny Dayal's near vision is normal. He can see the nearby objects clearly even with naked eyes.
(*e*) If Sunny Dayal had not worn spectacles to correct his myopic vision, then the risk was that he could have caused a car accident (because without spectacles he could not see distant vehicles and people clearly).
(*f*) Mr. Khanna displayed the values of (*i*) General awareness (that eye-defect can usually be corrected by wearing spectacles containing suitable lenses) (*ii*) Concern for others (because he wanted to mitigate or remove the suffering of driver) (*iii*) Concern for self and family (because he wanted to protect himself and his family from car accidents), and (*iv*) Kindness or Generosity (because he spent his own money in the hospital and for buying spectacles, which the driver could not afford).

Q.23. A social worker was addressing people at an eye donation camp organised in a colony. He said that there are millions of blind people in our country who cannot see at all. The eyesight of most of these blind people can be restored if we donate our eyes by making a pledge in writing to the eye bank that, after our death, our eyes should be removed and given to the blind people. He said, in this way we can pass on the priceless gift of vision to our blind brothers and sisters to light up their dark world, without losing anything. By listening to the social worker, many people (including some students) filled up the pledge forms to donate their eyes, after death.
(*a*) Within how much time of the death of a person, his donated eyes must be removed and preserved so as to remain good for transplantation ?
(*b*) What happens to those donated eyes which are not good for transplantation ?
(*c*) Can a person having AIDS disease donate eyes ?

(*d*) Can a person having diabetes disease donate eyes ?
(*e*) How many blind people can get eyesight if ten persons donate their eyes ?
(*f*) What values of social worker are exhibited by his address ?

Ans. (*a*) The eyes must be removed within 4 to 6 hours of a person's death.
(*b*) Those donated eyes which are not good for transplantation are used for doing research and for teaching purposes in medical colleges.
(*c*) No
(*d*) Yes
(*e*) One person donates two eyes, so ten persons donate $2 \times 10 = 20$ eyes. These 20 eyes can give eyesight to 20 blind persons (each blind person getting one eye).
(*f*) The social worker exhibits values of (*i*) Awareness (about the donation of eyes) (*ii*) Concern for blind people (that they get eyesight to see this beautiful world), and (*iii*) Motivational skill (to get the people pledge for eye donation).

Q.24. Pavni's mother had just washed all the white clothes. She was telling her friend that the whiteness of white clothes was decreasing with every wash and even new white clothes appeared to be like old ones after a few washings. Pavni, who is a student of class 10, was listening to her mother's complaint. Pavni then went to the market and purchased a particular 'dye'. She asked her mother to dissolve a little of this dye in a bucketful of water and soak the washed white clothes in the solution of dye for some time. Pavni's mother did the same. After sometime, the clothes were taken out of the bucket, rinsed well and spread on clothes line for drying. Pavni's mother observed that the whiteness of washed white clothes had increased a lot after applying a little of the dye. Pavni's mother did not know why on applying a little of a certain dye to washed white clothes, their whiteness had increased manifolds. Pavni explained everything to her mother.
(*a*) What could be the 'dye' applied by Pavni's mother to the washed white clothes by dissolving in water ?
(*b*) Why does the application of this dye make the washed white clothes look even more white (or shining white) ? Explain.
(*c*) What values are displayed by Pavni in this episode ?

Ans. (*a*) The dye applied by Pavni's mother to the washed white clothes is 'blue' ('blue colour' or '*neel*').
(*b*) The white sunlight is a mixture of seven coloured lights; violet, indigo, blue, green, yellow, orange and red (which is called spectrum). Now, when the white sunlight consisting of seven different colours comes down through the atmosphere, then some of its blue colour is scattered by air molecules present in the atmosphere (causing the blue colour of the sky). In this way, the white sunlight becomes somewhat deficient in blue colour. When this sunlight (having deficiency of blue colour) falls on washed white clothes to which 'blue colour' (or *neel*) has been applied, then the deficiency of blue colour in white sunlight is made up. The white sunlight reflected from the washed white clothes now has all the colours of the spectrum in the right proportions and this makes the white clothes appear extremely white.
(*c*) Pavni displayed the values of (*i*) Knowledge of scientific facts (such as composition of sunlight, spectrum and scattering of light) (*ii*) Application of knowledge in real life situations (such as to make washed white clothes look more white), and (*iii*) Desire to help mother by solving her problem.

Q.25. Sona was standing outside her house in the afternoon enjoying the light drizzle after the heavy rain. Suddenly she saw a rainbow in the sky. Sona called out her father and asked him what a rainbow is and how it is formed. Sona's father told her that rainbow is an arch of seven colours visible in the sky which is produced by the splitting of white sunlight by tiny raindrops in the atmosphere. He also told Sona that a similar phenomenon can also be observed in a science laboratory by passing white light through a transparent object.
(*a*) What is the name of the phenomenon which produces rainbow ?
(*b*) Name the seven colours of the rainbow. Which of them deviates the most ?
(*c*) When the rainbow is formed, state whether the sun is shining in the sky or not.
(*d*) Name the transparent object which can be used to observe the phenomenon similar to a rainbow in the science laboratory.
(*e*) What values are displayed by Sona's father ?

Ans. (*a*) Dispersion of light.
(*b*) Violet, Indigo, Blue, Green, Yellow, Orange and Red. The violet colour deviates the most.
(*c*) Yes, the sun is shining in the sky.
(*d*) Glass prism.
(*e*) The values displayed by Sona's father are (*i*) Understanding of scientific facts (such as the dispersion of light), and (*ii*) Desire to impart knowledge to his daughter.

PREMIUM NOTES