uses in our day-to-day life.

- One of the most important applications of electromagnetic waves is in communication.
- Some of the important applications of electromagnetic waves are:-
  1. We are able to see everything around us because of electromagnetic waves.
  2. It helps in aircraft navigation and helps the pilot for the smooth take-off and landing of aeroplanes. It also helps to calculate the speed of the aeroplane.
  3. In the medical field it has got very important applications. For example: - In laser eye surgery, in x-rays.
  4. In radio and television broadcasting signals. These signals are transmitted by electromagnetic waves.
  5. Electromagnetic waves helps in determining the speed of the passing vehicles.
  6. They are used in electronic appliances like T.V. remotes, remote cars, LED TV, microwave ovens etc.
  7. Voice transmission in mobile phones is possible because of electromagnetic waves.

What are Electromagnetic Waves?

- Electromagnetic (EM) waves are the waves which are related to both electricity and magnetism.
- Electromagnetic (EM) waves are the waves which are coupled time varying electric and magnetic fields that propagate in space.
- Waves associated with electricity and magnetism and as they are waves so they will propagate in the space.
- When the electric and magnetic fields combine together and when they are varying with time they both will give rise to electromagnetic waves.
- Electromagnetic equations emerged from Maxwell's equations.
- Maxwell found these EM waves have so many special properties which can be used for many practical purposes.
- Time varying electric field + Time varying magnetic field = Electromagnetic waves.

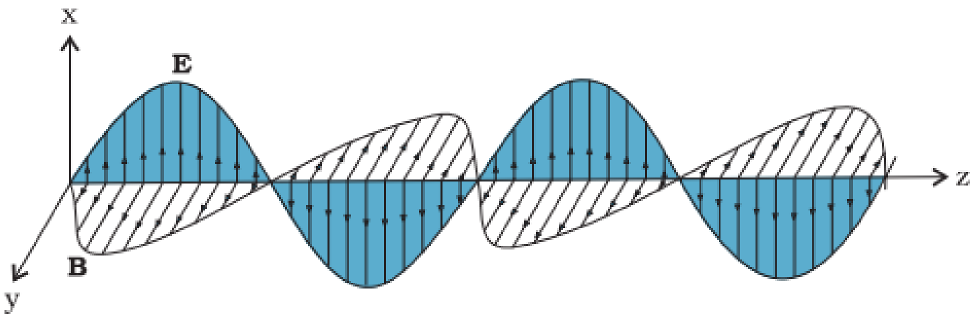


FIGURE 8.4 A linearly polarised electromagnetic wave, propagating in the *z*-direction with the oscillating electric field **E** along the *x*-direction and the oscillating magnetic field **B** along the *y*-direction.

Maxwell's Experiments

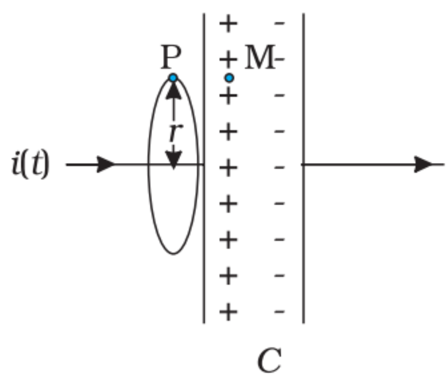
- Maxwell proposed that the time varying electric field can generate magnetic field.
- Time varying magnetic field generates electric field (Faraday-Lenz law).
  1. According to Faraday Lenz law an EMF is induced in the circuit whenever the amount of magnetic flux linked with a circuit changes.
  2. As a result electric current gets generated in the circuit which has an electric field associated with it.

Ampere's Circuit Law:

- According to Ampere's Circuital law, the line integral of magnetic field over the length element is equal to μ_0 times the total current passing through the surface $\int dl = \mu_0 I$
- According to Maxwell there was some inconsistency in the Ampere's circuital law.
- This means Ampere's circuital law was correct for some cases but not correct for some.
- Maxwell took different scenarios i.e. he took a capacitor and tried to calculate magnetic field at a specific point in a piece of a capacitor.
- Point P as shown in the figure is where he determined the value of B, assuming some current I is flowing through the circuit.
- He considered 3 different amperial loops as shown in the figs.
- Ampere's circuital law should be same for all the 3 setups.

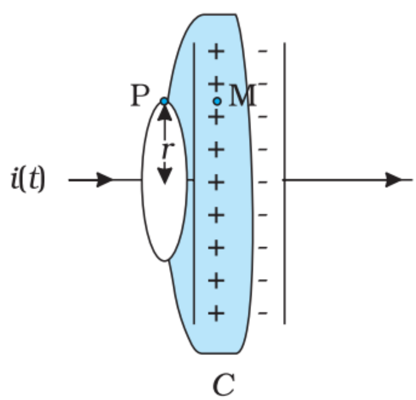
Case 1: Considered a surface of radius r & dl is the circumference of the surface, then from Ampere's circuital law

$$\int B.dl = \mu_0 l$$
$$or\ B(2\pi r) = \mu_0\ l$$
$$or\ B = \frac{\mu_0 l}{2\pi r}$$



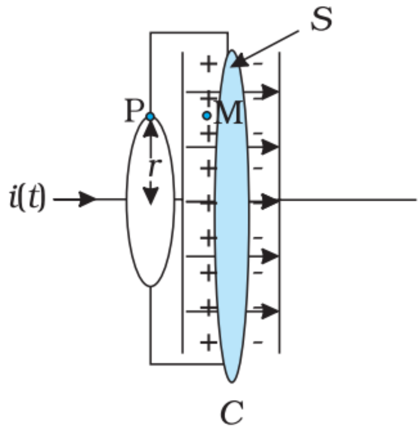
Case 2 : Considering a surface like a box & its lid is open and applying the Ampere's circuital law

$$\int B.dl = \mu_0 l$$



$$\int B.dl = 0$$

Case 3: Considering the surface between 2 plates of the capacitor, in this case also I=0, so B=0



- At the same point but with different amperial surfaces the value of magnetic field is not same. They are different for the same point.

Maxwell suggested that there are some gaps in the Ampere's circuital law. He corrected the Ampere's circuital law. And he made Ampere's circuital law consistent in all the scenarios.

<u>Maxwell's correction to Ampere's law</u>

- Ampere's law states that "the line integral of resultant magnetic field along a closed plane curve is equal to μ_0 time the total current crossing the area bounded by the closed curve provided the electric field inside the loop remains constant".
- Ampere's law is true only for steady currents.
- Maxwell found the shortcoming in Ampere's law and he modified Ampere's law to include time-varying electric fields.
- For Ampere's circuital law to be correct Maxwell assumed that there has to be some current existing between the plates of the capacitor.
- Outside the capacitor current was due to the flow of electrons.
- There was no conduction of charges between the plates of the capacitor.
- According to Maxwell between the plates of the capacitor there is an electric field which is directed from positive plate to the negative plate.
  - Magnitude of the electric field E =(V/d)

  Where V=potential difference between the plates, d = distance between the plates.

  E = (Q/Cd)

  where Q=charge on the plates of the capacitor, Capacitance of the capacitor=C

  =>E = (Q/ (Aε_0d/d)), where A =area of the capacitor.
  E=Q/(Aε_0)

  Direction of the electric field will be perpendicular to the selected surface i.e. if considering plate of the capacitor as surface.

- Electric Flux through the surface = Φ_E = (EA) =(QA)/ (Aε_0) =(Q/ ε_0)

- Assuming Q (charge on capacitor i.e. charging or discharging of the capacitor) changes with time current will be get generated.
  - Therefore current I_d =(dQ/dt)

  Where I_d =displacement current
  - =>Differentiating Φ_E =(Q/ ε_0) on both sides w.r.t time,
    ($d\Phi_E$/dt) =(1/ ε_0) (dQ/dt)

  where (dQ/dt) =current

  Therefore (dQ/dt) = ε_0 (d Φ_E/dt)

  =>Current was generated because of change of electric flux with time.
  - Electric flux arose because of presence of electric field in the plates of the capacitor.

    I_d = (dQ/dt) = Displacement current

  Therefore Change in electric field gave rise to Displacement current.
    - Current won't be 0 it will be I_d.
    - There is some current between the plates of the capacitor and there is some current at the surface.
    - At certain points there is no displacement current there is only conduction current and vice-versa.
  - Maxwell corrected the Ampere's circuital law by including displacement current.
  - He said that there is not only the current existed outside the capacitor but also current known as displacement current existed between the plates of the capacitor.
  - Displacement current exists due to the change in the electric field between the plates of the capacitor.
  - **Conclusion**:-Magnetic fields are produced both by conduction currents and by time varying fields.

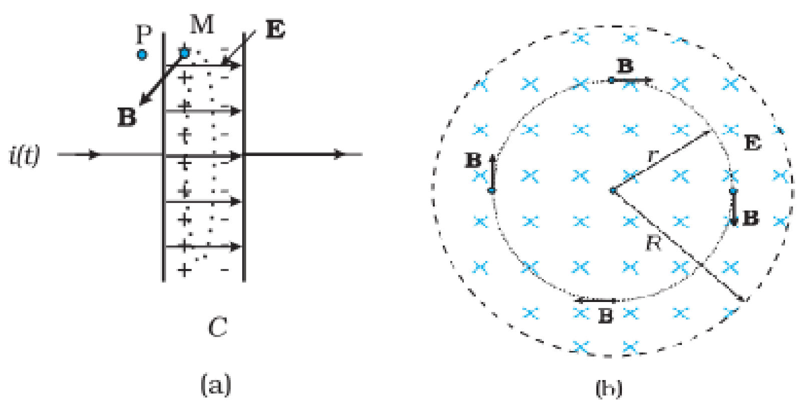


FIGURE (a) The electric and magnetic fields **E** and **B** between the capacitor plates, at the point M. (b) A cross sectional view of Fig. (a).

Ampere-Maxwell Law

- As Maxwell was able to correct the shortcomings of the Ampere's circuital law therefore the law came to known as Ampere-Maxwell law.
- Current which is arising due to the flow of charges is known as <u>conduction current</u>.
  It is denoted by I_C.
- Current which is arising due to change in electric field is known as <u>displacement current</u>.
  It is denoted by I_d.
- Therefore I = I_c + $I_{d,}$ where I = total current

- $\int dl = \mu_0 I_c + \mu_0 \varepsilon_0 (d\, \phi_E/dt)$
- The above expression is known as Modified Maxwell Law

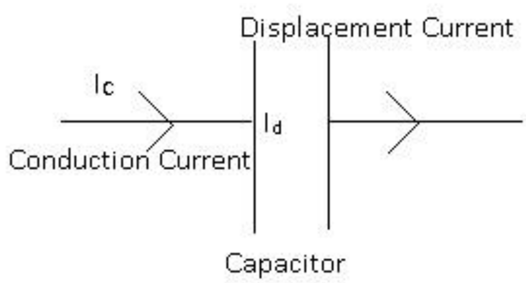
- Area between the plates i.e. inside the capacitor there is displacement current I_d.
- Physical behaviour of displacement current is same as that of induction current.
- Difference between Conduction current and Displacement current:-

Conduction Current	Displacement Current
It arises due to the fixed charges.	It arises due to the change in electric field.

- For Static electric fields:-

  $I_d=0$.
- For time varying electric fields:-

  $I_d \neq 0$.
- There can be some scenarios where there will be only conduction current and in some case there will be only displacement current.
- Outside the capacitor there is only conduction current and no displacement current.
- Inside the capacitor there is only displacement current and no conduction current.
- But there can be some scenario where both conduction as well as displacement current is present i.e. $I = I_C + I_d$.
- Applying modified Ampere-Maxwell law to calculate magnetic field at the same point of the capacitor considering different amperial loop, the result will be same.



Ampere – Maxwell law: Consequences
Case 1 : Magnetic field is given as

- $\int dl = \mu_0 I_c$
- $\int dl = \mu_0 I_c / 2\pi r$

Case 2 : Magnetic field is given as

- $\int dl = \mu_0 I_d$
- $\int dl = \mu_0 I_d / 2\pi r$

Conclusion: -

1. The value of B is same in both cases.
2. Total current should be the same.

- **Time varying electric field generates magnetic field given by (Ampere-Maxwell law)**
  - Consider 1^{st} step up there is electric field between the plates and this electric field is varying with time.
  - As a result there is displacement current and this displacement current gives rise to magnetic field.
- **Time varying magnetic field generates electric field given by (Faraday-Lenz law)**

- Electromagnetic waves are based on the above conclusion.

Maxwell's Equations

- Maxwell's equations describe how an electric field can generate a magnetic field and vice-versa. These equations describe the relationship and behaviour of electric and magnetic fields.
- Maxwell gave a set of 4 equations which are known as Maxwell's equations.
- According to Maxwell equations:-
  - A flow of electric current will generate magnetic field and if the current varies with time magnetic field will also give rise to an electric filed.
    - First equation (1) describes the surface integral of electric field.
    - Second equation (2) describes the surface integral of magnetic field.
    - Third equation (3) describes the line integral of electric field.
    - Fourth equation (4) describes line integral of magnetic field.

MAXWELL'S EQUATIONS

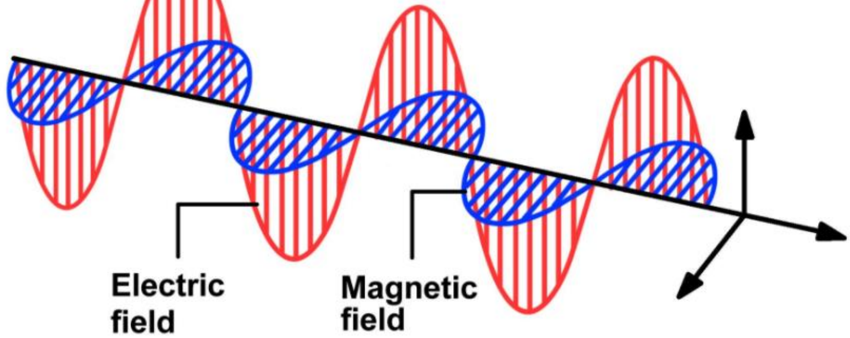
1. $\oint \mathbf{E} \cdot d\mathbf{A} = Q/\varepsilon_0$	(Gauss's Law for electricity)
2. $\oint \mathbf{B} \cdot d\mathbf{A} = 0$	(Gauss's Law for magnetism)
3. $\oint \mathbf{E} \cdot d\mathbf{l} = \frac{-d\Phi_B}{dt}$	(Faraday's Law)
4. $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$	(Ampere – Maxwell Law)

- Maxwell was the first to determine the speed of propagation of EM waves is same as the speed of light.

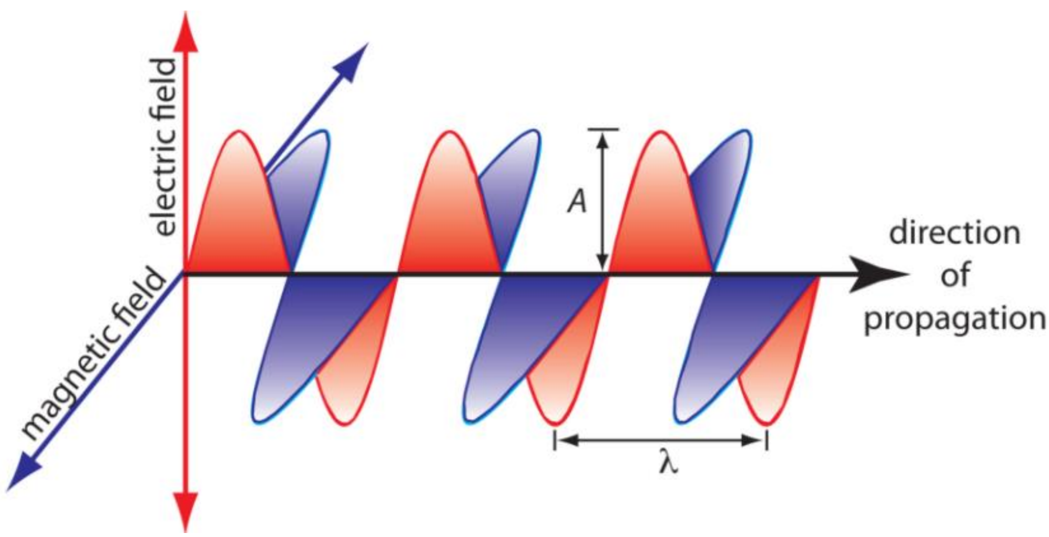
  Experimentally it was found that:-

  $$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

  Where μ_0(permeability) and ε_0(permittivity) and c= velocity of light.
- Maxwell's equations show that the electricity, magnetism and ray optics are all inter-related to each other.



- Electromagnetic waves are coupled time varying electric and magnetic fields that propagate in space.
- Electric field is varying with time, and it will give rise to magnetic field, this magnetic field is varying with time and it gives rise to electric field and the process continues so on.
- These electric and magnetic fields are time varying and coupled with each other when propagating together in space gives rise to electromagnetic waves.
- In the fig, red line represents the electric field and it varies in the form of a sine wave.
- The magnetic field as shown in the fig. represented by blue line.
- The magnetic field will be a sine wave but in a perpendicular direction to the electric field.
- These both give rise to electromagnetic field.
- If the electric field is along x-axis, magnetic field along y-axis, the wave will then propagate in the z-axis.
- Electric and magnetic field are perpendicular to each other and to the direction of wave propagation.
- Electric and magnetic fields which is time varying and coupled to each other they give rise to electromagnetic waves.



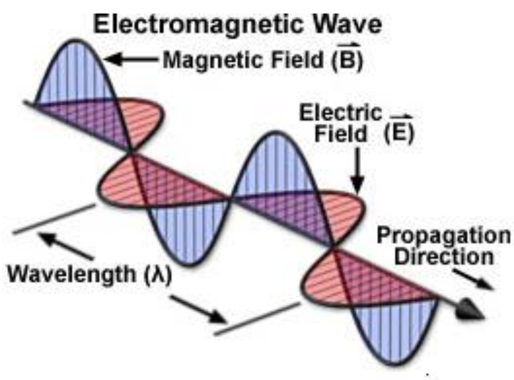
8.3.1 Sources of Electromagnetic Waves (EM)

- EM waves are generated by electrically charged particle oscillates (accelerating charges).
- The electric field associated with the accelerating charge vibrates which generates the vibrating magnetic field.
- These both vibrating electric and magnetic fields give rise to EM waves.

- When the charge is moving with uniform velocity, then the acceleration is 0. The change in electric field with time is also constant as a result again there will be no electromagnetic waves generated.
- This shows that only the accelerated charges alone can generate EM waves.
- For example:
  - Consider an oscillating charge particle, it will have oscillating electric field and which give rise to oscillating magnetic field.
  - This oscillating magnetic field in turn give rise to oscillating electric field and so on process continues.
  - The regeneration of electric and magnetic fields are same as propagation of the wave.
  - This wave is known as electromagnetic wave.
  - The frequency of EM waves= the frequency of the oscillating particle.

8.3.2 Nature of EM waves

- EM waves are transverse waves.
- The transverse waves are those in which direction of disturbance or displacement in the medium is perpendicular to that of the propagation of wave.
- The particles of the medium are moving in a direction perpendicular to the direction of propagation of wave.



- In case of EM waves the propagation of wave takes place along x-axis, electric and magnetic fields are perpendicular to the wave propagation.
- This means wave propagation → x-axis , electric field → y-axis, magnetic field → z-axis.
- Because of this EM waves are transverse waves in nature.
- Electric field of EM wave is represented as:

  $$E_y = E_0 \sin(kx - \omega t)$$

  Where Ey= electric field along y-axis and x=direction of propagation of wave.
- Wave number $k = (2\pi/\lambda)$
- Magnetic field of EM wave is represented as:

  $$B_z = B_0 \sin(kx - \omega t)$$

  Where B_z = electric field along z-axis and x=direction of propagation of wave.

in our day-to-day life.

- Energy in EM wave is partly carried by electric field and partly by magnetic field.
- Mathematically:
  - Total energy stored per unit volume in EM wave, E_T =Energy stored per unit volume by electric field + Energy stored per unit volume stored in magnetic field.

$$E_T = \left(\frac{1}{2}\right)(E^2\epsilon_0) + \left(\frac{1}{2}\right)(B^2\mu_0)$$

  - Experimentally it has been found that the; Speed of the EM wave =Speed of the light $c = \frac{E}{B}$

    => B=(E/c)

$$\therefore E_T = \left(\frac{1}{2}\right)(E^2\epsilon_0) + \left(\frac{1}{2}\right)(E^2/c^2\mu_0)$$

From Maxwell's equations :-

$$c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$$

$$\therefore E_T = \left(\frac{1}{2}\right)(E^2\epsilon_0) + \left(\frac{1}{2}\right)\left(\frac{E^2\mu_0\epsilon_0}{\mu_0}\right)$$

$$E_T = \left(\frac{1}{2}\right)(E^2\epsilon_0) + \left(\frac{1}{2}\right)(E^2\mu_0\epsilon_0)$$

$$\therefore E_T = E^2\epsilon_0$$

This is the amount of energy carried per unit volume by the EM wave.

8.3.4 Properties of EM waves

1. Velocity of EM waves in free space or vacuum is a fundamental constant.
- Experimentally it was found that the velocity of EM wave is same as speed of light(c=3x10^8m/s).
- The value of c is fundamental constant.

$$c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$$

2. No material medium is necessary for EM waves. But they can propagate within a medium as well.
- EM waves require time varying electric and magnetic fields to propagate.
- If the medium is present then velocity $v = \frac{1}{\sqrt{\mu\epsilon}}$

Where μ =permeability of the medium and ε=permittivity of the medium.

For example: -Spectacles. When light falls on glass of the spectacle, light rays pass through glass .i.e. Light waves propagate through medium which is glass here.

3. EM waves carry energy and momentum.
- Total energy stored per unit volume in EM wave, $E_T = E^2\epsilon_0$ (partly carried by electric field and partly by magnetic field).
- As EM waves carry energy and momentum, it becomes an important property for its practical purposes.
- EM waves are used for communication purposes, voice communication in mobile phones, telecommunication used in radio.

For example: -

The sunlight which we get from sun is in the form of visible light rays. These light rays are also part of EM waves. If we keep our palm in sun, after some time, palm becomes warm and starts sweating. This happens because sunlight is getting transferred in the form of EM waves and these EM waves carry energy.

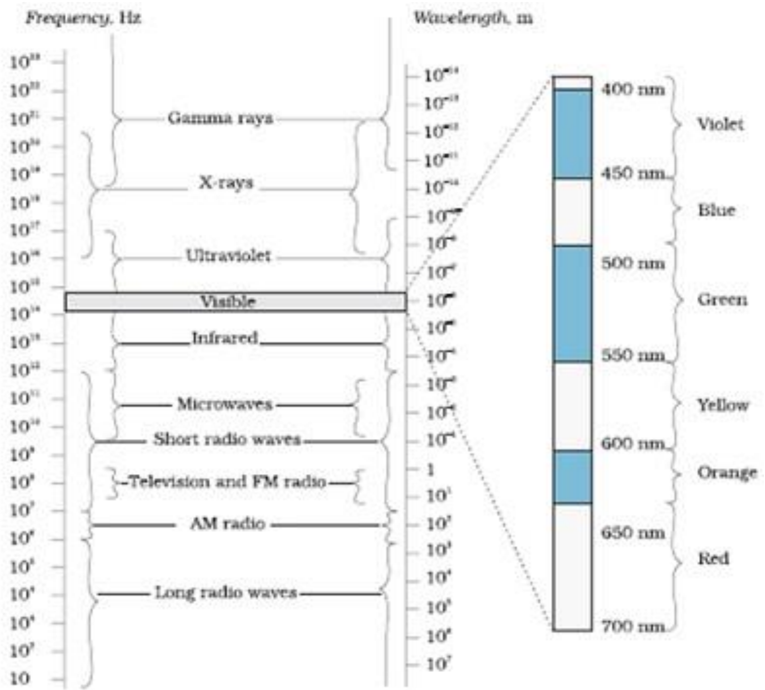
Suppose total energy transferred to the hand =E.

Momentum = (E/c) as c is extremely high, therefore momentum is very small. As momentum is very less, pressure experienced is also very less. This is the reason due to which the pressure exerted by the sun is not experienced by the hand.

- Based on the wavelength EM waves are classified into different categories. This classification is known as electromagnetic spectrum.
- Different categories of EM waves in decreasing order of their wavelength:-
  - Radio waves > 0.1m
  - Microwaves 0.1 m - 1mm
  - Infra-Red 1mm – 700 nm
  - Visible light 700nm – 400 nm
  - Ultraviolet 400nm- 1nm
  - X-rays 1nm – 10^{-3}nm
  - Gamma rays <10^{-3}nm
- These 7 waves together constitute the electromagnetic spectrum.

Tip:-

- To remember the order of wavelength of each wave, we can just write the initial letter of all the waves and they are in the order of decreasing wavelength.
- R (max wavelength), M, I, V, U, X and G (minimum wavelength).
- It can be remembered like this Red Man In Violet Uniform X Gun.

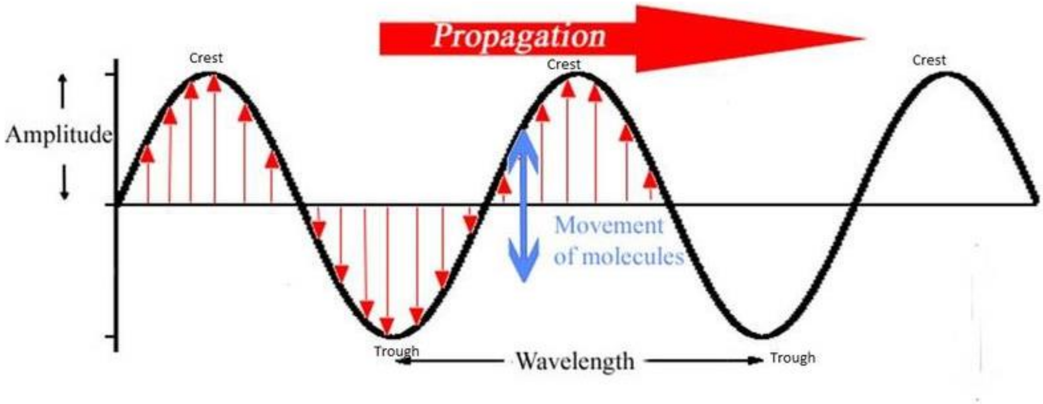


The electromagnetic spectrum, with common names for various part of it. The various regions do not have sharply defined boundaries.

Electromagnetic energy of each wave in Electromagnetic Spectrum

- Electromagnetic waves energy can be described by *frequency, wavelength or energy*.
  1. **Frequency-** Both micro and radio waves are described in terms of frequencies.
  - Frequency is number of crests that pass a given point within one second.
  - Consider a wave which has 3 crests which pass a point in 1 second. Therefore frequency=3Hz.

- Wavelength can vary from small value to a large value.
- SI unit: - meter.



3. **Energy-** X-rays and Gamma rays are described in terms of energies.
   - An EM wave can be described in terms of energy –in units of eV.
   - eV is the amount of kinetic energy needed to move 1 electron through a potential of 1 volt.

- Moving along the EM spectrum energy increases as the wavelength decreases.
- Relation between Wavelength and Frequency:

$c = \nu\lambda$

Where λ =wavelength and ν= frequency.

=>$\lambda = (c/\nu)$

$E = h\nu = (hc/\lambda)$

=> $E \propto \nu$ and $E \propto (1/\lambda)$

∴ from EM spectrum

- *Decreasing order of wavelength* → R, M, I, V, U, X and G
- In terms of *increasing order of frequency* → G, X, U, V, I, M, and R

8.4.1 Radio Waves

- Radio waves are produced by the accelerated motion of charges in conducting wires.
- Important application of radio waves is in:-
  i. Radio and television communication systems.
  ii. Mobile phones for voice communication.
- In electromagnetic spectrum the wavelength (λ) of radio waves is >0.1m.
- Radio waves are further classified into different bands:-
  i. (Amplitude Modulated)AM band 530 kHz to 1710 kHz (lowest frequency band).They are similar to FM channels.
  ii. Short wave band – up to 54MHz
  iii. TV waves band – 54MHz to 890MHz
  iv. (Frequency Modulated)FM band – 88MHz to 108MHz
  v. UHF band- Ultra high frequency(used for voice communication over cell phones)

- They are produced by special vacuum tubes (klystrons/magnetrons/Gunn diodes).
- They are used in microwave ovens, and radar system in aircraft navigation.

RADAR Technology:

RADAR- Radio detection and ranging.

Different applications of RADAR:

a) Air traffic control:

For example: - To manage air traffic. The pilot should know any other aeroplane is present nearby or not.

The pilot should know the climatic conditions during take-off and landing.

Radar plays very important role in aircraft navigation.

b) Speed detection:

The instruments which are used to detect the speed of the vehicles which move on the roads uses radar technology.

c) Military purposes

It helps to detect enemies and weapons.

d) Satellite tracking

In order to track satellites, radar technology is used.

Why Radio waves use micro waves:

- As they use short wavelength waves which are same as micro waves.
- They are invisible to humans. If we are able to see the waves which get transmitted it will be very irritating.
- Even the smallest presence of microwaves is easy to detect.

Working of Radar Set:-

It consists of:

1. Transmitter: It transmits the microwaves.
2. Receiver: It receives the echo produced by the microwaves when they strike any object. When the receiver receives the reflected ray then it is possible to track the presence of other object in the vicinity.

Microwave ovens

- The following are the properties because of which microwaves are very useful :-
- They have smaller wavelength.
- They get absorbed by water, fats and sugar.

Working of microwave oven:-

- In order to heat anything uniformly microwave ovens are used.
- Any food material will have water, sugar and fats in it.
- When we heat any food material inside the microwave, the microwaves penetrate inside the food.
- So the microwaves get absorbed by the water and the fat molecules.
- The molecules of the food material will start moving randomly with some frequency.
- This is same as providing some wave to the food material with the same frequency with which the molecules start vibrating.
- This shows that the frequency of microwave matches with the frequency of the molecules.
- As all the molecules are set in random motion, temperature increases and food material gets heated uniformly throughout.
- Object can be heated by 2 ways:

8.4.3 Infrared waves

- Infrared waves often known as heat waves as they are produced by hot bodies.
- Their wavelength is lesser than both radio and micro waves.
- They readily get absorbed by water.

Applications: Infrared lamps/Infrared detector/LED in remote switches of electronic devices/Greenhouse effect.

For example:

a) Fire gives out both visible light waves and infrared waves. The light rays are visible to us but the infrared waves cannot be seen by us.

b) Humans also generate some infrared waves.

- There are some special glasses which have infrared detector to view infrared waves.
- The infrared lamps are used to heat food materials and sometimes washrooms.
- When we switch on the TV with the help of remote, there is an LED both on TV and on remote.
- The signal gets transferred from remote to TV via infrared waves.

Greenhouse Effect: Green house effect is an atmospheric heating phenomenon that allows incoming solar radiation to pass through but blocks the heat radiated back from the Earth's surface.

- Consider that the sun gives radiation in the form of visible light to the earth.
- When the visible light reaches the earth's surface all the objects on the earth becomes hot.
- The visible light carries energy from sun and that energy gets transferred to all the objects present on the earth.
- As a result of heat transfer all the objects gets heated up.
- These hot objects transmit infrared waves.
- The earth will reradiate the infrared waves.
- When these infrared waves try to go out of the atmosphere they get trapped by the greenhouse gases (CO_2, CH_4, water vapour).
- As a result heat gets trapped inside the earth which results in an increase in temperature.
- The greenhouse effect makes earth warm because of which the temperature of the earth is suitable for the survival of life on earth.
- Global warming is due to an increase in temperature of the environment, due to pollution.

8.4.4 Visible or Light rays

- Light waves are the most common form of EM wave.
- Their wavelength range is 4×10^{14} Hz-7×10^{14}
- We are able to see everything because of light rays.
- The radiation which we get from sun is in the form of visible light.
- Most of the insects have compound eyes due to which they see not only the visible light but also the ultraviolet rays.
- Snakes can even see the infrared rays.

8.4.5 Ultraviolet rays(UV rays)

It covers wavelengths ranging from about 4×10^{-7} m (400 nm) down to 6×10^{-10}m (0.6 nm).

- The UVrays are produced by special lamps and very hot bodies (sun).
- UV rays have harmful effects on humans.
- UV lamps are used to kill germs in water purifiers.

which causes tanning of the skin.

- In order to protect from UV rays glasses are used, as they get absorbed by the glasses.
- UV rays help in LASER assisted eye surgery. As UV rays have very short wavelength so they can be focused into narrow beam of light.
- The ozone layer which is present outside the atmosphere protects us from the harmful UV rays.
- Ozone has a property of reflecting the harmful UV rays. But due to the use of CFC (chlorofluorocarbon) ozone layer is depleting. So if ozone layer gets depleted humans will get exposed to harmful UV rays coming from the sun.

8.4.6 X-Rays

- X-Rays are produced by bombarding a metal target by high energy electrons.
- It is very important diagnostic tool.
  - X-Rays have lesser wavelengths as compared to all other waves.
  - Because of this X-Rays can easily penetrate inside the skin (low density material). It either gets reflected or absorbed by the high density material (like bone).
  - In any X-Ray, bones look darker and lighter area is skin.
- It is also used for cancer treatment.
  - In cancer there is unwanted growth of the cells.
  - In order to treat cancer the abnormal growth of cells should be stopped.
  - The X-Rays have the ability to damage the living tissue.

This is how it helps in the treatment of cancer

8.4.7 Gamma Rays

- Gamma rays are produced in the nuclear reactions and also emitted by radioactive nuclei.
- It is also used in the treatment of the cancer.
- Gamma rays also have very small wavelength. So they help to kill the growth of unwanted living cells which grow when the body is suffering from cancer.