NINTH EDITION

ELECTRICAL INSTALLATION CALCULATIONS: BASIC

LEVEL 2

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AND A. J. WATKINS

ROUTLEDGE

Electrical Installation Calculations: Basic

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For technical certificate level 2

Christopher Kitcher and A. J. Watkins

Ninth Edition

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

Ninth edition published 2014
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
711 Third Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

First edition published 1957
Eighth edition published by Elsevier 2009

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data
Kitcher, Chris.
Electrical installation calculations. Basic : for technical certificate level 2 / Christopher Kitcher and A.J. Watkins. — Ninth edition.
pages cm
1. Electric wiring—Mathematics. 2. Electric wiring—Standards—Great Britain. 3. Buildings—Electric equipment—Installation—Mathematics. 4. Electrical engineers—Certification—Great Britain. 5. National Vocational Qualifications (Great Britain) I. Watkins, A. J. (Albert James), 1925- II. Title.
TK3221.K568 2014
621.319'24—dc23
2013019546

ISBN: 978–0–415–81004–3 (pbk)
ISBN: 978–1–315–87103–5 (ebk)

Typeset in Rotis Sans Serif
by RefineCatch Limited, Bungay, Suffolk

Contents

Preface

Being able to carry out mathematical calculations is a vital part of electrical installation courses and indeed electrical installation work.

The structure of electrical installation courses continually changes as do the course titles and numbers; however, electrical science remains the same and, like it or not, anyone wanting to become an electrician will need to have a good understanding of how to carry out electrical calculations.

The calculations which need to be performed vary from those which an electrician needs almost on a daily basis, such as cable calculation or the amount of energy required to run a particular piece of equipment, to more complex calculations such as those required for electromagnetism.

This book will show you how to carry out these calculations as simply as possible using electronic calculator methods. These methods will be useful both in the classroom and the workplace. It is not necessary for you to have a deep understanding of how the mathematical functions are performed. Each topic is shown using a step-by-step process with lots of exercises provided to give you the opportunity to test yourself at the end of each chapter.

This edition has been completely updated to the 17th edition of BS 7671 amendment 1: 2011 and the IET *On-Site Guide*; useful references are made to these documents throughout.

It does not matter which electrical course you are attending – this book along with the advanced calculations book will be invaluable.

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1 Use of Calculators

Throughout the 'Basic' and 'Advanced' books the use of a calculator is encouraged. Your calculator is a tool and like any tool, practice is required to perfect their use. A scientific calculator will be required, and although they differ in the way the functions are carried out, the end result is the same.

The examples are given using a Casio fx-83MS.

The figure printed on the button is the function performed when the button is pressed.

To use the function in small letters above any button the *shift* button must be used.

Practice is important.

A syntax error will appear when the figures are entered in the wrong order.

$\boldsymbol{x}^2$ will multiply a number by itself, i.e. $6 \times 6 = 36$. On the calculator this would be $6\ x^2 = 36$.

When a number is multiplied by itself it is said to be *squared*.

x^3 will multiply a number by itself and then the total by itself again.

For example, when we enter 4 on calculator $x^3 = 64$. When a number is multiplied in this way it is said to be *cubed*.

$\sqrt{}$: will give you the number which achieves your total by being multiplied by itself, i.e. $\sqrt{36} = 6$. This is said to be the *square root* of a number, and is the opposite of *squared*.

$\sqrt[3]{\ }$ will give you the number which when multiplied by itself three times will be your total, i.e. $\frac{100}{8.22} = 12.17A$. This is said to be the *cube root*.

X^{-1} will divide 1 by a number, i.e. $\frac{1}{4} = 0.25$. This is the *reciprocal* button and is useful in this book for finding the resistance of resistors in parallel and capacitors in series.

EXP is for the powers of 10 function, i.e. 25 × 1000 = 25 *EXP* × 10^3 = 25000.

Enter into calculator 25 *EXP* 3 = 25000. (Do not enter the *X* or the number 10.)

If a calculation shows 10^{-3} ie: – 25 × 10^{-3} enter 25 *EXP* – 3 = (0.025). (When using *EXP* if a minus is required use the button (-).)

Brackets should be used to carry out a calculation within a calculation.

EXAMPLE

Calculation: $\frac{32}{(0.8 \times 0.65 \times 0.94)} = 65.46$

Enter into calculator 32 ÷ (0.8 × 0.65 × 0.94) =

Remember *Practice makes Perfect*.

2

Simple Transposition of Formulae

To find an unknown value:

- The subject must be on the top line and must be on its own.
- The answer will always be on the top line.
- To get the subject on its own values must be moved.
- Any value that moves across the = sign must move from above the line to below line or from below the line to above the line.

EXAMPLE 1

$3 \times 4 = 2 \times 6$

$3 \times 4 = 2 \times ?$

Transpose to find? $\dfrac{2 \times 6}{4} = 3$

EXAMPLE 2

$\dfrac{2 \times 6}{?} = 4$

Step 1: $2 \times 6 = 4 \times ?$

Step 2: $\dfrac{2 \times 6}{4} = ?$

Answer: $\dfrac{2 \times 6}{4} = 3$

EXAMPLE 3

$5 \times 8 \times 6 = 3 \times 20 \times ?$

Step 1: move 3×20 away from unknown value, as the known values move across the = sign they must move to bottom of equation $\frac{5 \times 8 \times 4}{3 \times 20} = ?$

Step 2: carry out the calculation

$$\frac{5 \times 8 \times 6}{3 \times 20} = \frac{240}{60} = 4$$

Therefore $\begin{array}{c} 5 \times 8 \times 6 = 240 \\ 3 \times 20 \times 4 = 240 \end{array}$ or $5 \times 8 \times 6 = 3 \times 20 \times 4$

SI Units

3

In Europe and the United Kingdom, the units for measuring different properties are known as SI units.

SI stands for Système Internationale.

All units are derived from seven base units.

Base quantity	Base unit	Symbol
Time	second	s
Electrical current	ampere	A
Length	metre	m
Mass	kilogram	kg
Temperature	kelvin	K
Luminous Intensity	candela	cd
Amount of substance	mole	mol

SI DERIVED UNITS (USED IN BOOK 1 & 2)

Derived quantity	Name	Symbol
Frequency	hertz	Hz
Force	newton	N
Energy, work, quantity of heat	joule	J
Electric charge, quantity of electricity	coulomb	C
Power	watt	W
Potential difference, electromotive force	volt	V or U
Capacitance	farad	F
Electrical resistance	ohm	Ω
Magnetic flux	weber	Wb
Magnetic flux density	tesla	T
Inductance	henry	H
Luminous flux	lumen	cd
Area	square metre	m^2
Volume	cubic metre	m^3
Velocity, speed	metre per second	m/s
Mass, density	kilogram per cubic metre	kg/m^3
Luminance	candela per square metre	cd/m^2

SI UNIT PREFIXES

Name	Multiplier	Prefix	Power of 10
Tera	1000 000 000 000	T	1×10^{12}
Giga	1000 000 000	G	1×10^{9}
Mega	1000 000	M	1×10^{6}
Kilo	1000	k	1×10^{3}
Unit	1		
milli	0.001	m	1×10^{-3}
micro	0.000 001	μ	1×10^{-6}
nano	0.000 000 001	η	1×10^{-9}
pico	0.000 000 000 001	ρ	1×10^{-12}

EXAMPLES

mA milliamp = one thousandth of an ampere
km kilometre = one thousand metres
μv microvolt = one millionth of a volt
GW Gigawatt = one thousand million watts
kW kilowatt = one thousand watts

CALCULATOR EXAMPLE

1 kilometre is 1 metre $\times$ 10^{3}.

Enter into calculator 1 EXP 3 = (*1000*) metres

1000 metres is 1 kilometre $\times$ 10^{-3}

Enter into calculator 1000 EXP –3 = (*1*) kilometre

1 microvolt is 1 volt $\times$ 10^{-6}

Enter into calculator 1EXP –6 = (1^{-06} or 0.000001) volts. (Note 6th decimal place.)

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Conductor Colour Identification

4

3 phase a.c. systems, although known as 3 phase, each phase is now identified as a line.

Old reference	Old colour	New colour	New reference
Phase 1	Red	Brown	L 1
Phase 2	Yellow	Black	L 2
Phase 3	Blue	Grey	L 3
Neutral	Black	Blue	N

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Circuit Calculations

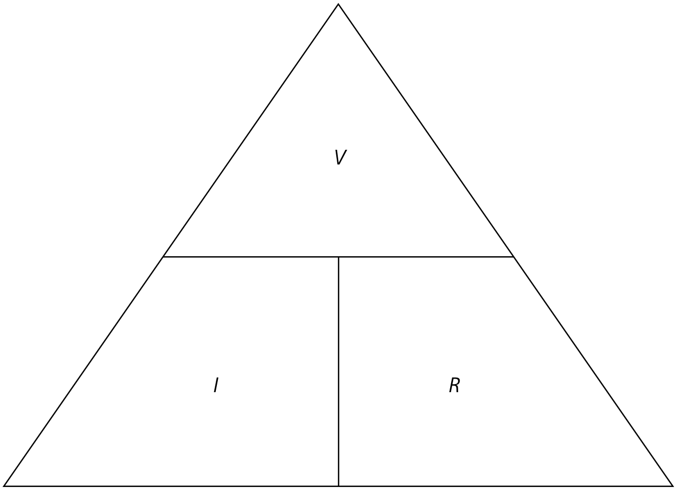
5

OHM'S LAW

Ohm's law is the first calculation which needs to be learnt and it is probably the one which is used most frequently.

The most common method of remembering to begin with is to use what is known as the Ohm's law triangle.

Figure 1 Ohm's law triangle



U	Voltage can be thought of as the pressure in the circuit
I	Current is the flow of electrons
R (Ω)	Resistance is anything which resists the flow of current i.e. cable resistance, load resistance or a specific value of resistance added to the circuit for any reason.

As you can see the symbol used for voltage is *U*. This will be used throughout the book although other publications may use *V*; of course *V* can be used when carrying out calculations if it is preferred.

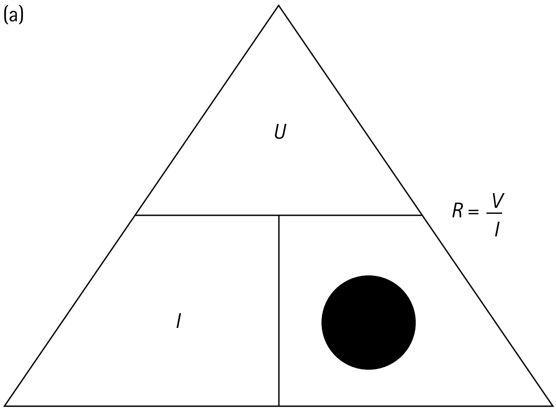
Using the triangle in Figure 2, to find the resistance of a circuit block out the *R*, this will indicate to you the formula to find out the resistance.

In a d.c. circuit the current is directly proportional to the applied voltage and inversely proportional to the resistance.

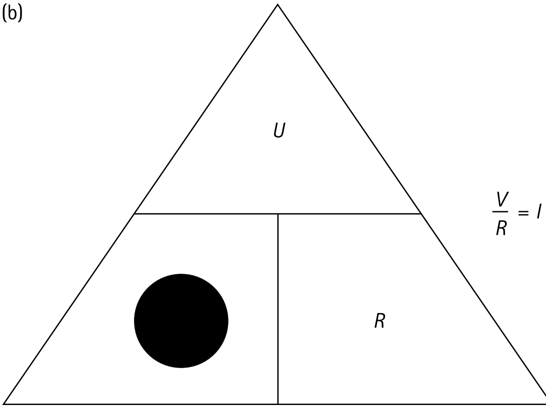
To put this simply, if the voltage is increased then the current will increase and if the resistance is increased the current will reduce.

Figure 2a, 2b, 2c Ways to calculate current voltage and resistance using the Ohm's law triangle

(a)



(b)



(c)

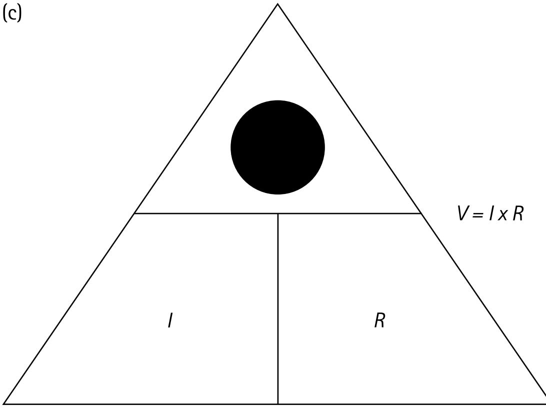


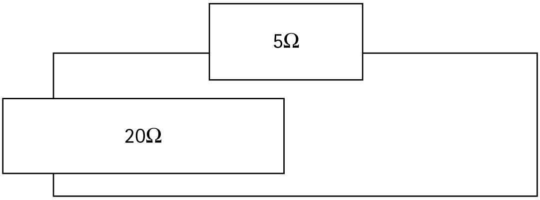
Figure 3 shows an example if a voltage of 20 volts is applied to a 5Ω resistor.

$\frac{U}{R} = I \qquad \frac{20}{5} = 4 \text{ amperes}$

If the resistance in the circuit is now increased to 10Ω it can be seen that the current flow is halved. $\frac{20}{10} = 2 \text{ amperes}$

To put it another way, double the resistance and the current will be halved.

Figure 3 20 volts applied to a 5Ω resistor



Where the resistance of a circuit is unknown, Ohm's law can be used to calculate it.

Where the measured voltage is 20V and the measured current is 4 amperes the calculation is:

$$\frac{U}{I} = R \qquad \frac{20}{4} = 5\Omega$$

Where the voltage is unknown and the measured resistance is 5Ω and the measured current is 4 amperes, Ohm's law can be used as follows:

$R \times I = U \quad 5 \times 4 = 20V$

RESISTORS IN SERIES

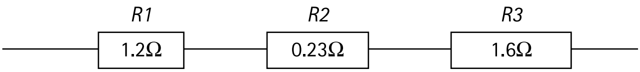
When a number of resistors are connected in series and the total value of resistance is required the values of the resistors are added together as the total resistance is equal to the sum of all of the resistance values.

So in Figure 4:

$R1 + R2 + R3 = R$

$1.2 + 0.23 + 1.6 = 3.03$

Figure 4 Resistors connected in a series



EXAMPLES

Ohm's law can be used to calculate values in series circuits.

Using the circuit in Figure 4 with an applied voltage of 20 volts, the total current can be calculated:

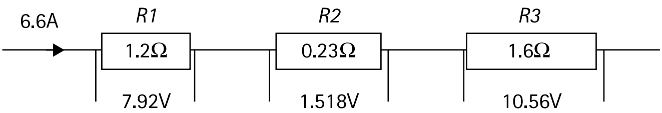
$$\frac{U}{R} = I \qquad \frac{20}{3.03} = 6.6\text{A}$$

This calculation shows that each resistance in a circuit will cause a reduction in the voltage (pressure). Ohm's law can be used to find the voltage at different parts of the circuit. In a series circuit the current will be the same wherever it is measured, it is the voltage which will change.

The calculation $I \times R$ can be used to calculate the voltage drop across each resistance.

Using values from Figure 4, the current in the circuit is 6.6A and the volt drop will be as shown in Figure 5.

Figure 5 Calculating the volt drop



Voltage drop across:

R1 6.6A × 1.2Ω = 7.92V
R2 6.6A × 0.23Ω = 1.518V
R3 6.6A × 1.6Ω = 10.56V

It can be seen that the sum of the voltage drop across all resistors is equal to the total voltage in the circuit and that the voltage after the last resistance is zero volts.

EXERCISE 1

1 Calculate the total resistance of each of the following groups of resistors in series. *(Values are in ohms unless otherwise stated.)*

(a) 12, 35, 59

(b) 8.4, 3.5, 0.6

(c) 19.65, 4.35

(d) 0.085, 1.12, 0.76

(e) 27.94, 18.7, 108.3

(f) 256.5, 89.7

(g) 1400, 57.9kΩ

(h) 1.5MΩ, 790 000

(i) 0.0047, 0.095

(j) 0.0568, 0.000 625 (*give answers in microhms)*

2 Determine the value of resistance which, when connected in series with the resistance given, will produce the required total.

(a) 92Ω to produce 114Ω

(b) 12.65Ω to produce 15Ω

(c) 1.5Ω to produce 3.25Ω

(d) 4.89Ω to produce 7.6Ω

(e) 0.9Ω to produce 2.56Ω

(f) 7.58Ω to produce 21Ω

(g) 3.47Ω to produce 10Ω

(h) 195Ω to produce 2000Ω

(i) 365μΩ to produce 0.5Ω (*answer in microhms*)

(j) 189 000Ω to produce 0.25MΩ (*answer in megohms*)

3 Calculate the total resistance when four resistors each of 0.84Ω are wired in series

4 Resistors of 19.5Ω and 23.7Ω are connected in series. Calculate the value of a third resistor which will give a total of 64.3Ω.

5 How many 0.58Ω resistors must be connected in series to make a total resistance of 5.22Ω?

6 A certain type of lamp has a resistance of 41Ω. What is the resistance of 13 such lamps in series? How many of these lamps are necessary to make a total resistance of 779Ω?

7 The four field coils of a motor are connected in series and each has a resistance of 33.4Ω. Calculate the total resistance. Determine also the value of an additional series resistance which will give a total resistance of 164Ω.

8 Two resistors connected in series have a combined resistance of 4.65Ω. The resistance of one of them is 1.89Ω. What is the resistance of the other?

9 Four equal resistors are connected in series and their combined resistance is 18.8Ω. The value of each resistor is:

(a) 9.4Ω

(b) 75.2Ω

(c) 4.7Ω

(d) 37.6Ω

10 Two resistors connected in series have a combined resistance of 159Ω. One resistor has a value of 84Ω. The value of the other is:

(a) 133.56Ω

(b) 1.89Ω

(c) 243Ω

(d) 75Ω

11 Two resistors of equal value are connected to three other resistors of value 33Ω, 47Ω and 52Ω to form a series group of resistors with a combined resistance of 160Ω.
What is the resistance of the two unknown resistors?

(a) 7Ω

(b) 14Ω

(c) 28Ω

(d) 42Ω

RESISTORS IN PARALLEL

When resistances are connected in parallel, the voltage is common across each resistance *(remember in series it was the current that was common)*.

Each resistance that is connected to a circuit in parallel will reduce the resistance of the circuit and will therefore increase the current flowing in the circuit.

Figure 6 shows a resistance of 6Ω connected to a voltage of 10V. Using Ohm's law the current in the circuit can be calculated:

$$\frac{U}{R} = I = \frac{10}{6} = 1.66\text{A}$$

When another resistance of 3Ω is connected to the circuit in parallel as Figure 7 shows, the total resistance can be calculated, again by using Ohm's law as follows.

Figure 6 Calculating resistance and voltage in parallel

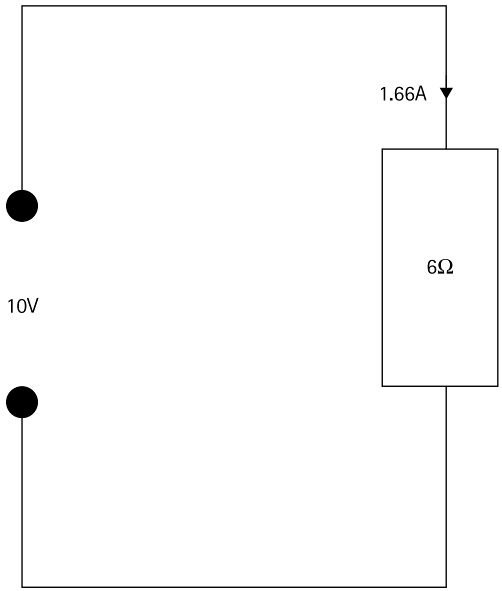
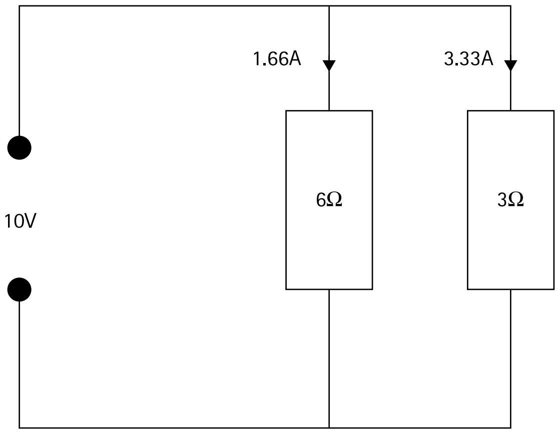


Figure 7 Adding another 3Ω to the circuit



The voltage across each resistance is 10 volts.

Therefore the current flowing through R_1 is $\frac{10}{6} = 1.66A$

The current flowing through R_2 is $\frac{10}{3} = 3.33A$

The total current in the circuit is the sum of the current flowing in R_1 & R_2: 1.66 + 3.33 = 4.99 amperes

But what happens if another resistance of 4Ω is connected in parallel to this circuit, as shown in Figure 8?

Current flowing in R_1 is 1.66A and R_2 is 3.33A.

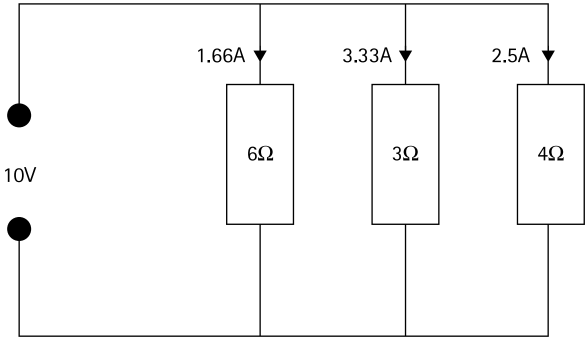
Using Ohm's law, current in R3 is $\frac{10}{4} = 2.5A$

(*Note higher resistance results in less current flow.*)

Total current in circuit is 1.66 + 3.33 + 2.5 = 7.49A

This can also be used to calculate the total resistance of the circuit.

Figure 8 Adding another 4Ω to the circuit



Using Ohm's law, the voltage is 10 volts, current is 7.49A, the calculation is:

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

$$\frac{10}{7.49} = 1.33\,\Omega$$

Clearly this method can only be used if the voltage is known.

CALCULATION OF TOTAL RESISTANCE OF RESISTORS IN PARALLEL

If only the resistances are known the total resistance can be calculated by using the following method with a calculator:

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

Using values from Figure 8:

$$\frac{1}{6} + \frac{1}{3} + \frac{1}{4} = \frac{1}{0.75} = 1.33\Omega$$

On calculator enter:

$6x^{-1} + 3x^{-1} + 4x^{-1} = x^{-1} =$ (1.33Ω *Answer*)

This can be proven to be correct by using Ohm's law again:

$$\frac{U}{R} = I \frac{10}{1.33} = 7.5\text{A}$$

The current will be the same as when the current passing through all of the individual resistances in Figure 8 are added together, i.e.

2.5 + 3.33 + 1.66 = 7.49 amperes (This is 0.01A different because I only used 2 decimal places.)

RESISTANCES IN PARALLEL USING PRODUCT OVER SUM METHOD

Another method of calculating the total resistance of resistances in parallel is by using the product over sum method.

If the resistances from Figure 8 are used, the total resistance can be found.

The resistances were 6Ω, 3Ω and 4Ω.

$$Step\ 1: \frac{6 \times 3}{6 + 3} = 2$$

$$Step\ 2: \frac{2 \times 4}{2 + 4} = 1.33$$

This method can be used for any number of resistances connected in parallel.

The calculation must be carried out using two resistances, then using the result of the calculation with the next resistance, then the next until all of the resistances are used.

EXERCISE 2

1 The following groups of resistors are connected in parallel. In each case calculate the equivalent resistance. Where necessary, make the answers correct to three significant figures. (*All values are in Ohm's.*)

(a) 2, 3, 6

(b) 3, 10, 5

(c) 9, 7

(d) 4, 6, 9

(e) 7, 5, 10

(f) 14, 70

(g) 12, 12

(h) 15, 15, 15

(i) 40, 40, 40, 40

2 In each case, calculate the value of a resistor which, when connected in parallel with the given resistor, will produce the value asked for. (*Give answers correct to three significant figures.*)

Question	Given resistance (Ω)	Resistance required (Ω)
(a)	48	12
(b)	20	5
(c)	9	4
(d)	6	3
(e)	7	6
(f)	500	400
(g)	0.6×10^3	200
(h)	75	25
(i)	38	19
(j)	52	13

3 A heating element is in two sections, each of 54Ω resistance. Calculate the current taken from a 230V supply when the sections are connected

(a) in series

(b) in parallel.

4 Two single-core cables, having resistances of 1.2Ω and 0.16Ω, are connected in parallel and are used to carry a total current of 30A. Calculate:

(a) the voltage drop along the cables

(b) the actual current carried by each cable.

5 A cable carries a current of 65A with a 13V drop. What must be the resistance of a cable which, when connected in parallel with the first cable, will reduce the voltage drop to 5V?

6 To vary the speed of a d.c. series motor it is usual to connect a diverter resistor in parallel with the field winding. The field of a series motor has a resistance of 0.6Ω and the diverter resistor has three steps, of 5Ω, 4Ω and 2Ω. Assuming that the total current is fixed at 28A, find out how much current flows through the field winding at each step of the diverter.

7 Resistors of 24Ω and 30Ω are connected in parallel. What would be the value of a third resistor to reduce the combined resistance to 6Ω?

8 Two cables having resistances of 0.03Ω and 0.04Ω between them carry a total current of 70A. How much does each carry?

9 When two equal resistors are connected in series to a 125V supply, a current of 5A flows. Calculate the total current which would flow from the same voltage supply if the resistors were connected in parallel.

10 A current of 50A is carried by two cables in parallel. One cable has a resistance of 0.15Ω and carries 20A. What is the resistance of the other cable?

11 Three cables, having resistances of 0.018Ω, 0.024Ω and 0.09Ω respectively, are connected in parallel to carry a total current of 130A. Calculate

(a) the equivalent resistance of the three in parallel

(b) the voltage drop along the cables

(c) the actual current carried by each cable.

12 Four resistance coils – A, B, C and D – of values 4Ω, 5Ω, 6Ω and 7Ω respectively are joined to form a closed circuit in the form of a square. A direct-current supply at 40V is connected across the ends of coil C. Calculate:

(a) the current flowing in each resistor

(b) the total current from the supply

(c) the potential difference across each coil

(d) the total current from the supply if a further resistance coil R of 8Ω is connected in parallel with coil A.

13 Resistors of 3Ω, 5Ω and 8Ω are connected in parallel. Their combined resistance is

(a) 1.6Ω

(b) 0.658Ω

(c) 16.0Ω

(d) 1.52Ω

14 Two resistors are connected in parallel to give a combined resistance of 3.5Ω. The value of one resistor is 6Ω. The value of the other is

(a) 8.4Ω

(b) 0.12Ω

(c) 1.2Ω

(d) 2.5Ω

15 The resistance of a cable carrying 43A is 0.17Ω. Calculate the resistance of a second cable which, if connected in parallel, would reduce the voltage drop to 5V.

16 A cable of resistance 1.92Ω carries a current of 12.5A. Find the voltage drop. If a second cable of 2.04Ω resistance is connected in parallel, what voltage drop will occur for the same value of load current?

17 Three cables, having resistances 0.0685Ω, 0.0217Ω and 0.1213Ω, are connected in parallel. Find

(a) the resistance of the combination

(b) the total current which could be carried by the cables for a voltage drop of 5.8V.

18 A load current of 250A is carried by two cables in parallel. If their resistances are 0.0354Ω and 0.046Ω, how much current flows in each cable?

19 Two cables in parallel between them carry a current of 87.4A. One of them has a resistance of 0.089Ω and carries 53A. What is the resistance of the other?

20 Resistors of 34.7Ω and 43.9Ω are connected in parallel. Determine the value of a third resistor which will reduce the combined resistance to 19Ω.

21 Three pvc-insulated cables are connected in parallel, and their resistances are 0.012Ω, 0.015Ω and 0.008Ω, respectively, With a total current of 500A flowing on a 240V supply,

(a) calculate the current in each cable

(b) calculate the combined voltage drop over the three cables in parallel

(c) calculate the individual voltage drop over each cable in the paralleled circuit.

22 Tests on a 300m length of single-core mineral-insulated cable produced the following results: conductor resistance 2.4Ω, insulation resistance 40MΩ. What will be the anticipated conductor and insulation resistance values of a 120m length of the cable?

(a) 16Ω, 0.96MΩ

(b) 0.96Ω, 100MΩ

(c) 0.96Ω, 40MΩ

(d) 16Ω, 16MΩ

23 A 250m reel of twin mineral-insulated cables is to be cut to provide two equal lengths. Before cutting the cable one core is tested and the insulation resistance is found to be 23MΩ and the conductor resistance found to be 2.9Ω. What will be the anticipated conductor and insulation resistance values of each of the two lengths?

(a) 46Ω, 1.45MΩ

(b) 1.45Ω, 46MΩ

(c) 0.145Ω, 11.5MΩ

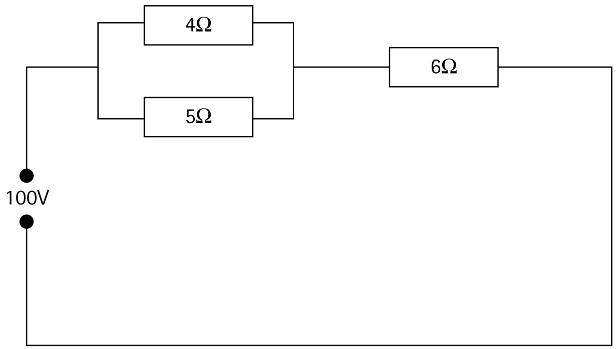
(d) 11.5Ω, 46MΩ

SERIES AND PARALLEL RESISTORS

EXAMPLE

Resistors of 4Ω and 5Ω are connected in parallel and a 6Ω resistor is connected in series with the group. The combination is connected to a 100 volt supply (see Figure 9). Calculate the total resistance, voltage drop and current in each resistor.

Figure 9 Series and parallel resistors in a circuit



To find a resistance for the parallel group,

$$\frac{1}{4}+\frac{1}{5}=\frac{1}{0.45}=2.22$$

Calculator method:

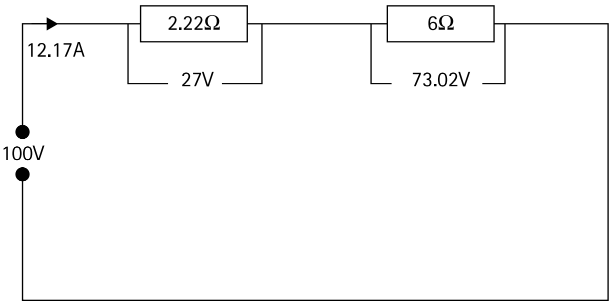
$4x^{-1} + 5x^{-1} = x^{-1} = 2.22$

This circuit may now be shown as Figure 10.

Total resistance in circuit can now be calculated as two resistances in series.

Total R = 2.22 + 6 = 8.22Ω

Figure 10 Series and parallel resistors in a circuit



To calculate total current,

Using Ohm's law $\frac{U}{R} = I$

$$\frac{100}{8.22} = 12.17\text{A}$$

Voltage drop across the 6Ω resistance is calculated $I \times R = U$

$12.17 \times 6 = 73.02\text{V}$

Voltage drop across parallel group is 100V – 73.02V = 26.98V

This voltage can now be used to calculate the current through each parallel resistance, again using Ohm's law.

Current through 4Ω resistor is

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

$$\frac{26.98}{4} = 6.745\text{A}$$

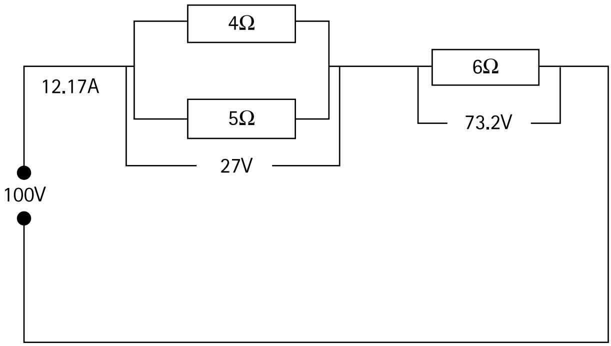
Current through 5Ω resistor is

$$\frac{26.98}{5} = 5.396\,A$$

As a check, the sum of the currents through the parallel resistances together should equal the total current in the circuit, as shown in Figure 11.

6.745A + 5.396A = 12.141A (allowing for only using 3 decimal places)

Figure 11 Checking the sum of the currents through the parallel resistances equals the total current



Voltage Drop

6

CONDUCTOR RESISTANCE AND VOLTAGE DROP USING OHM'S LAW

Appendix 4 Section 6.4 of BS 7671 states that the maximum voltage drop in any circuit from the origin of the supply to the terminals of the current-using equipment should not exceed 3% of the supply voltage in a lighting circuit or 5% of the supply voltage in all other circuits.

To calculate the percentage as a voltage the calculation is:

$$\frac{\text{Voltage} \times \%}{100} = \text{volt drop}$$

Where the supply voltage is 230V:

Lighting circuit $\frac{230 \times 3}{100} = 6.9\text{V}$

Other circuits $\frac{230 \times 5}{100} = 11.5\text{V}$

Calculator method:

Voltage × % shift = Ans

Lighting = 230 × 3 shift % = 6.9

Other = 230 × 5 shift % = 11.5

As described in the chapter on series resistances, there will be a voltage drop across any resistances in series. A conductor will be a resistance in series with the resistance of a load.

This voltage drop can be calculated using Ohm's law.

EXAMPLE

A circuit is wired using 70°C thermoplastic flat twin and earth cable with copper 2.5mm^2 live conductors and a 1.5mm^2 circuit protective conductor. The circuit is 30 metres long and will carry a current of 17 amperes, supply voltage is 230 volts.

From Table I1 in the *On-Site Guide* it can be seen that a 2.5mm^2 copper conductor has a resistance of 7.41mΩ per metre @ 20°C.

The current flowing in a circuit will be the same in the line and the neutral conductors (see Figure 12). Therefore the resistance of both live conductors must be taken into account.

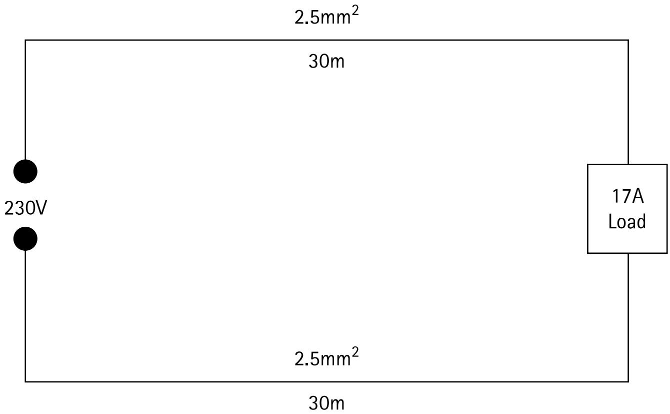
Phase conductor resistance is 7.41mΩ/m

Neutral conductor resistance is 7.41mΩ/m

$7.41 + 7.41 = 14.82$

The resistance of a twin 2.5mm^2 copper cable is 14.82mΩ/m. This can also be found using Table I1 of the *On-Site Guide*.

Figure 12 Circuit with 70°C thermoplastic flat twin and earth cable with copper 2.5mm^2 live conductors



The total resistance of this cable will be mΩ per metre $\times$ length.

$14.82 \times 30 = 444.6\text{m}\Omega$

This value is in milli ohms and should now be converted to ohms:

$$\frac{\text{m}\Omega}{1000} = \text{ohms}$$

$$\frac{444.6}{1000} = 0.444$$

When conductors are operating their maximum current rating, they can operate at 70°C. This will result in the resistance of the conductors increasing; this increased resistance must be used in the calculation for voltage drop.

To calculate the total resistance of the cables at their operating temperature a factor from Table I3 in the *On-Site Guide* should be used. It will be seen that a multiplier of 1.2 should be used for a conductor rated @ 70 °C.

To calculate the total resistance of the current-carrying conductors:

$\Omega \times$ multiplier = total resistance of conductors @ 70 °C

$0.444 \times 1.2 = 0.533\Omega$

These calculations can be carried out in one single calculation:

$$\frac{\text{m}\Omega \times \text{length} \times \text{multiplier}}{1000} = \text{total resistance}$$

$$\frac{14.82 \times 30 \times 1.2}{1000} = 0.533$$

Voltage drop can now be calculated using Ohm's law

$I \times R = U$

$17 \times 0.533 = 9.06$ volts

This voltage drop will be acceptable as it is below 11.5 volts.

VOLTAGE DROP USING TABLES FROM BS 7671

Using the same example:

A circuit is wired using 70°C thermoplastic flat twin and earth cable with copper 2.5mm^2 live conductors and a 1.5mm^2 circuit protective conductor. The circuit is 30 metres long and will carry a current of 17 amperes, supply voltage is 230 volts.

The voltage drop for this cable can be found using Table 4D5 from Appendix 4 of BS 7671 or Table F6 in the *On-Site Guide*.

Using these either of these tables it will be seen that the voltage drop for 2.5m^2 copper cable is 18mV/A/m (millivolts x amperes x distance in metres). (*As value is in millivolts it must be divided by 1000 to convert to volts*.)

Voltage drop for example circuit is $\frac{18 \times 17 \times 30}{1000} = 9.18$

It can be seen that the voltage drop is slightly higher than when Ohm's law was used in the previous calculation. This is because the volt drop value used in BS 7671 has been rounded up for ease of calculation.

When working on installations containing old and new colours, great care must be taken as the black and blue identification can be confusing. Also all current-carrying conductors are referred to as live conductors.

Areas, Perimeters and Volume

7

CALCULATION OF PERIMETERS

RECTANGLE, SQUARE OR TRIANGLE

Add the length of all of the sides.

For example the perimeter of a rectangle which is 150mm × 185mm would be 150 + 185 + 150 + 185 = 670mm.

For a triangle only add the three sides.

CIRCLE

Circumference = $\pi \times d$

As an example to calculate the circumference of a circle which has a diameter of 67mm,

$\pi \times d$ = circumference

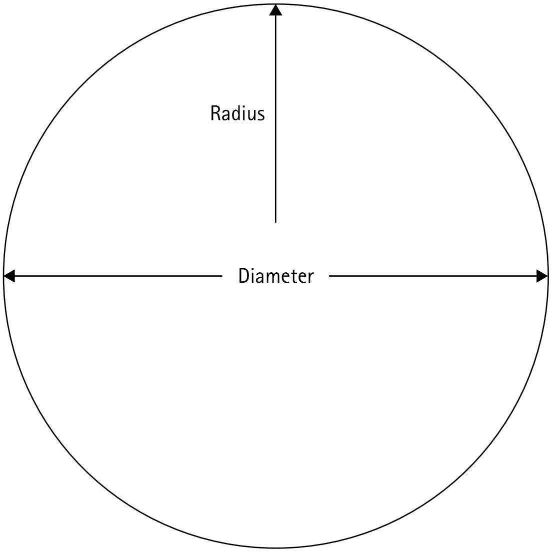
3.142 × 67 = 210.514mm

Calculator method, enter: shift $\pi \times d =$

Where the value is required in metres ÷ 1000

For example, $\frac{210.514}{1000} = 0.210\text{m}$

Figure 13 Radius and diameter of a circle



AREAS AND PERIMETERS

RECTANGLE, SQUARE

To find the area multiply the length by the breadth.

For example, a rectangle which is 150mm × 185mm:

$150 \times 185 = 27750\text{mm}^2$

Where the answer is required in metres ÷ 1000000

$$\frac{27750}{1000000} = 0.0277\text{m}$$

Figure 14 A rectangle

TRIANGLE

Area = half base × height

For example, a triangle which is 167mm wide by 212mm high.

$$\text{Area} = \frac{167}{2} = 83.5\text{mm}$$

83.5mm × 212mm = 17702mm^2

Calculator method: (base ÷ 2) × height

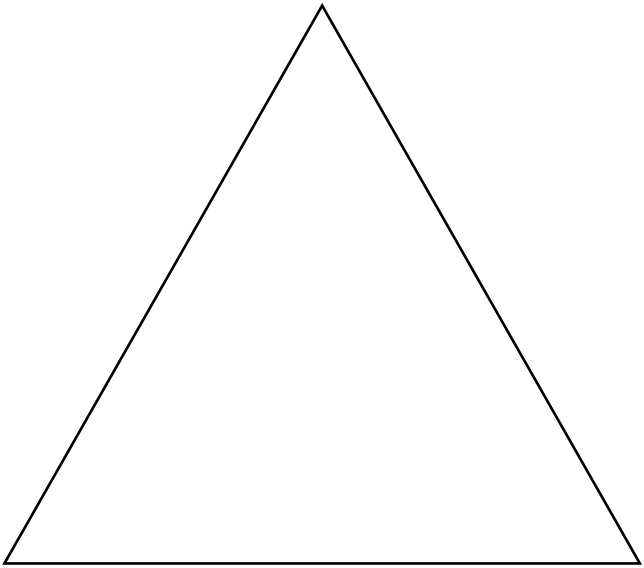
(167 ÷ 2) × 212 = 17702 mm^2

If the answer is required in m^2 ÷ 1000000

CIRCLE

$$\text{Area: } A = \frac{\pi \times d^2}{4}$$

Figure 15 A triangle



A circle with a circumference of 67mm will have an area of:

$$\frac{3.142 \times 67 \times 67}{4} = 3526.1\text{mm}^2$$

To convert to $m^2 \div 1000000$

Calculator method: enter, shift $\pi \times 67\ x^2 \div 4$. This would also be the cross-sectional area of a cable

VOLUMES

CUBE

Volume of a cube is width x breadth x height.

For example, a cube which is 500mm wide × 600mm long and 450mm high:

$500 \times 600 \times 450 = 135000000\text{mm}^3$

To convert to metres enter: 135000000 EXP – 9 = answer 0.135m^3

CYLINDER

The volume of a cylinder is $\pi \times \frac{1}{2}\text{base}^2 \times \text{height}$ *or*

$\pi \times \text{radius}^2 \times \text{height}$ *or* $\frac{\pi \times d^2}{4} \times \text{height}$

For example, a cylinder with a base diameter of 430mm and a height of 568mm would have a volume of:

$3.142 \times 215^2 \times 568 = 82495723\text{mm}^3$

Enter into a calculator: shift $\pi \times 215\ x^2 \times 568 =$

This calculation can also be carried out using area of base x height:

Example: $\frac{\pi \times d^2}{4} \times \text{height} = \text{volume}$

Figure 16 Measuring a cube

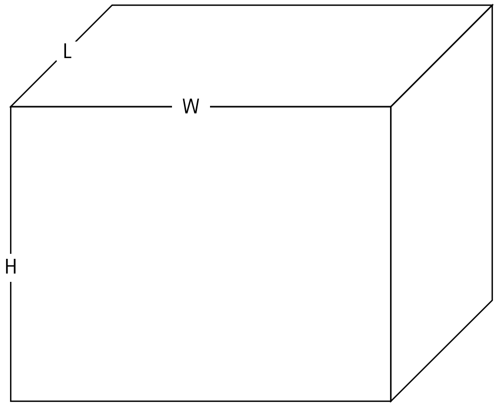
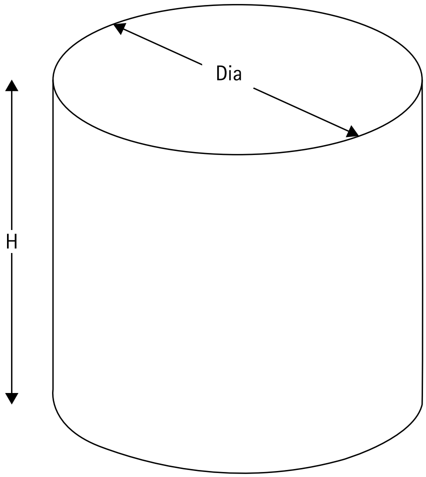


Figure 17 Measuring a cylinder



Enter into calculator: shift $\pi \times 430\ x^2 \div 4 \times 568 =$

To convert from mm^3 to m^3 enter into calculator mm^3 exp $-9 =$

In this case 82495723 EXP $-9 =$ ans is $0.082495723m^3$

EXAMPLE 1

Calculate the cross-sectional area of a trunking with dimensions of 50mm by 150mm.

Area = Length × breadth $50 \times 150 = 7500mm^2$

EXAMPLE 2

Calculate the area of a triangular space 6.75 metres wide and 7.6 metres high.

$$\text{Area} = \frac{1}{2} b \times h \text{ or } \frac{1}{2} \times 6.75 \times 8.6 = 29.025m^2$$

Enter on calculator $0.5 \times 6.75 \times 8.6 = 29.025\ m^2$

EXAMPLE 3

A cylinder has a diameter of 0.76m and a height of 1.43m. Calculate its volume and the length of weld around its base.

$$\text{Volume} = \frac{\pi \times d^2}{4} \times \text{height}$$

$$\frac{\pi \times 0.76^2}{4} \times 1.43 = 0.317\text{m}^3$$

Enter on calculator: shift $\pi \times 0.76\ x^2 \div (4 \times 1.43) = (0.317\ \text{m}^3)$

Length of weld = $\pi \times d$

= 3.142 × 0.76

= 2.38m

EXAMPLE 4

Calculate the volume of a rectangular tank with a base 1.3m long, 650mm wide, 2.18m high.

1.3 × (650mm convert to metres) 0.65 × 2.18 = 1.842m^3

Calculate the length of insulation required to wrap around the tank.

1.3 + 0.65 + 1.3 + 0.65 = 3.9 metres

EXERCISE 3

1 Find the volume of air in a room 3.4m by 3.5m by 2.7m.

2 Calculate the volume of a cylindrical tank 0.7m in diameter and 0.75m long.

3 Find the volume and total surface area of the following enclosed tanks:

(a) rectangular, 1m × 0.75m × 1.5m

(b) cylindrical, 0.4m in diameter and 0.6m high.

4 Find the volume of a copper bar 6m long and 25mm by 8mm CSA.

5 Calculate the volume per metre of a length of copper bar with a diameter of 35mm.

6 The gable end wall of a building is 19.5m wide and 6m high with a triangular area of the roof being 3m high. The building is 27m long. Calculate the volume of the building.

7 A triangular roof has a width of 2.8m and a height of 3m. Calculate the volume of the roof if the building were 10.6m long.

8 Calculate the area of material required to make a cylindrical steel tank with a diameter of 1.3m and a height of 1.85m. Calculation to include lid and base.

9 A storage tank has internal dimensions of 556mm × 680mm × 1270mm. Calculate the volume of the tank allowing an additional 25%.

10 A circular tank has an external diameter of 536mm and an external length of 1460mm. It is made from 1.5mm thick metal. Calculate the volume within the tank.

8

Space Factors

Our wiring regulations require that any cables installed into a duct trunking should not take up more than 45% of the space within the duct or trunking. This can be calculated by using the cross-sectional areas of the space available and the cross-sectional area of the cable, or the space factor tables from the *On-Site Guide* can be used.

Calculation

To find a percentage of an area the calculation is:

$$\frac{CSA \times \%}{100} = \textit{the percentage of the area.}$$

EXAMPLE

Calculate the area which could be used within a trunking which is 50mm × 100mm.

$50\text{mm} \times 100\text{mm} = 5000\text{mm}^2$ (CSA)

$$\text{Area available} = \frac{5000 \times 45}{100} = 2250\text{mm}^2$$

Or enter into a calculator 5000 × 45 *shift* % =

Table A Details of single core thermoplastic (pvc) cables

Nominal conductor size (mm^2)	Number and diameter of wires (no. of strands × mm^2)	Nominal overall diameter (mm)
1.0	1 × 1.13	2.9
1.5	1 × 1.38	3.1
2.5	1 × 1.78	3.5
2.5 stranded	7.067	3.8
4	7 × 0.85	4.3
6	7 × 1.04	4.9
10	7 × 1.35	6.2
16	7 × 1.70	7.3
25	7 × 2.14	9.0
35	19 × 1.53	10.3
50	19 × 1.78	12.0

Table B Dimensions of trunking (mm × mm)

50 × 37.5
50 × 50
75 × 25
75 × 37.5
75 × 50
75 × 75
100 × 37.5
100 × 50
100 × 75
100 × 100

To calculate the number of cables that it would be permissible to install into a trunking the calculation would be:

$$\frac{\textit{Usable area}}{\textit{CSA of cable}} = \textit{number of cables}$$

EXAMPLE 1

A trunking has a usable area of 1687.5mm^2 and we need to calculate how many 2.5mm^2 stranded cables we could install in it.

From Table A we can see that the cable has a diameter of 3.8mm. The calculation would be as follows.

The first step is to calculate the cross-sectional area of the cable:

$$\frac{\pi \times d^2}{4} = CSA$$

$$\frac{3.142 \times 3.8 \times 3.8}{4} = 11.34\text{mm}^2$$

The second step is to calculate the number of cables:

$$\frac{\textit{usable area}}{\textit{CSA of cable}} = \textit{number of cables}$$

$$\frac{1687.5}{11.34} = 148.8 \textit{ cables}$$

EXAMPLE 2

Calculate the maximum number of 10mm^2 cables that could be installed in a 50mm × 75mm trunking allowing for space factor.

Find area of trunking 50 × 75 = 3750mm^2

Usable area (45%) 3750 × 45% = 1687.50 (*calculator*)

$$or\ \frac{3750 \times 45}{100} = 1687.50$$

From Table A, the diameter of a 10mm^2 cable is 6.2mm.

The cross-sectional area of one cable is $\frac{\pi d^2}{4}$.

$$\frac{3.142 \times 6.2^2}{4} = 30.2\text{mm}^2$$

To calculate the number of cables that it would be permissible to install in the trunking:

$\frac{CSA \times \%}{100} = \textit{the percentage of the area}$. number of cables

Therefore 15 cables can be installed.

EXAMPLE 3

The following cables are to be installed in a single run of trunking:

twelve × 1mm^2, ten × 1.5mm^2, eight × 2.5mm^2 *stranded*, six × 25mm^2

Calculate the size of trunking required for this installation.

Step 1: calculate the cross-sectional area of cables using values from Table A.

CSA of 1mm^2 cable including insulation $\frac{\pi \times 2.9^2}{4} = 6.6\text{mm}^2$

Twelve 1mm^2 cables: 12 × 6.6 = 79.2mm^2

CSA of 1.5mm^2 cable including insulation $\frac{\pi \times 3.1^2}{4} = 7.54\text{mm}^2$

Ten 1.5mm^2 cables: 10 × 7.54 = 75.4mm^2

CSA of 2.5 mm^2 cable including insulation $\frac{\pi \times 3.8^2}{4}$ 11.34mm^2

Eight 2.5 mm^2 cables: 8 × 11.34 = 90.72mm^2

CSA of 25mm^2 cable including insulation $\frac{\pi \times 9^2}{4} = 63.61\text{mm}^2$

Six 25mm^2 cables: 6 × 63.61 = 381.66mm^2

Step 2: add all *CSA*s of cables together.

$79.2 + 75.4 + 90.72 + 381.66 = 629.98\text{mm}^2$

This is the total area required for the cables and it must be a maximum of 45% of total area in the trunking.

Step 3: calculate space required

$$\frac{629.98 \times 100}{45} = 1399.9\text{mm}^2.$$

Calculator method $629.98 \times 100 \div 45 = 1399.9\text{mm}^2$

A 37.5mm × 50mm trunking has an area of $37.5 \times 50 = 1875\text{mm}^2$.

This will be suitable and will also allow some space for future additions.

The method shown is perfectly acceptable for space factor calculation; however, it is a bit long winded and most electricians/designers would find it simpler to use the tables for space factor in trunking which are provided in the *On-Site Guide*.

Cable factors for trunking (OSG Table E5)

Type of conductor	Conductor cross-sectional area in mm^2	PVC BS 6004 Cable factor	Thermosetting BS 7211 Cable factor
Solid	1.5	8.0	8.6
	2.5	11.9	11.9
	1.5	8.6	9.6
Stranded	2.5	12.6	13.9
	4	16.6	18.1
	6	21.2	22.9
	10	35.3	36.3
	16	47.8	50.3
	25	73.9	75.4

Factors for trunking (OSG Table E6)

Dimensions for trunking (mm^2)	Factor	Dimensions for trunking (mm^2)	Factor
50 × 38	767	200 × 100	8572
50 × 50	1037	200 × 150	13001
75 × 25	738	200 × 200	17429
75 × 38	1146	225 × 38	3474
75 × 50	1555	225 × 50	
75 × 75	2371	225 × 75	
100 × 25	993	225 × 100	
100 × 38	1542	225 × 150	
100 × 50	2091	225 × 200	
100 × 75	3189	225 × 225	
100 × 100	4252	300 × 38	
150 × 38	2999	300 × 50	
150 × 50	3091	300 × 75	
150 × 75	4743	300 × 100	
150 × 100	6394	300 × 150	
150 × 150	9697	300 × 200	
200 × 38	3082	300 × 225	
200 × 50	4145	300 × 300	
200 × 75	6359		

EXAMPLE 1

A trunking is required to contain the following thermoplastic cables (singles):

26 × 1.5mm^2 stranded
12 × 2.5mm^2 stranded

$12 \times 6mm^2$
$3 \times 10mm^2$
$3 \times 25mm^2$

Calculate the minimum size trunking permissible for the installation of these cables.

From Table E5 of the *On-Site Guide* each cable has a factor as follows. Once found, the factors should be multiplied by the number of cables.

$1.5mm^2 = 8.6 \times 26 = 223.6$
$2.5mm^2 = 12.6 \times 12 = 151.20$
$6.0mm^2 = 21.2 \times 12 = 254.4$
$10.0mm^2 = 35.3 \times 3 = 105.9$
$25.0mm^2 = 73.9 \times 3 = 221.7$

Add the cable factors together: 956.8.

From Table E6 (factors for trunking) a factor larger than 956 must now be found.

It will be seen from the table that a trunking 100 × 25 has a factor of 993 therefore this will be suitable, although possibly a better choice would be 50 × 50 which has a factor of 1037 as this will allow for future additions.

It should be remembered that there are no space factors for conduit; the amount of cables that can be installed in a conduit is dependent on the length of conduit and the number of bends between drawing in points.

Appendix E of the *On-Site Guide* contains tables for the selection of single core insulated cables installed in conduit.

EXERCISE 4

1 The floor of a room is in the form of a rectangle 3m by 3.5m. Calculate its area.
2 A rectangular electrode for a liquid resistor is to have area $0.7m^2$. If it is 0.5m long, how wide must it be?

3 Complete the table below, which refers to various rectangles:

Length (m)	6		12	8	
Breadth (m)	2	2			
Perimeter (m)		10		24	32
Area (m^2)			84		48

4 The triangular portion of the gable end of a building is 6m wide and 3.5m high. Calculate its area.

5 The end wall of a building is in the form of a square with a triangle on top. The building is 4m wide and 5.5m high to the top of the triangle. Calculate the total area of the end wall.

6 Complete the table below, which refers to various triangles:

Base(m)	0.5	4	1.5		0.3
Height (m)	0.25		2.2	3.2	0.12
Area (m^2)		9		18	

7 Complete the following table:

Area(m^2)	0.015			0.00029	0.0016
Area (mm^2)		250	7500		

8 Complete the table below, which refers to various circles:

Diameter	0.5m				4mm
Circumference		1.0m			
Area (m^2)			0.5m^2	6mm^2	

9 A fume extract duct is to be fabricated on site from aluminium sheet. Its dimensions are to be 175mm diameter and 575mm length. An allowance of 25mm should be left for a riveted joint along its length. Establish the area of metal required and the approximate number of rivets required, assuming rivets at approximately 70mm spacing.

10 A square ventilation duct is to be fabricated on site from steel sheet. To avoid difficulty in bending, the corners are to be formed by 37.5mm × 37.5mm steel angle and 'pop' riveting. Its dimensions are to be 259mm × 220mm × 660mm length. Establish the area of sheet steel, length of steel angle and the approximate number of rivets required, assuming rivets at 60mm spacing.

11 A coil of wire contains 25 turns and is 0.25m in diameter. Calculate the length of wire in the coil.

12 Complete the table below, which refers to circular conductors:

Number and diameter of wires (mm)	1/1.13		7/0.85		
Nominal cross-sectional area of conductor (mm^2)		2.5		10	25

13 Complete the table below, which refers to circular cables:

Nominal overall diameter of cable(mm)	2.9	3.8	6.2	7.3	12.0
Nominal overall cross-sectional area (mm^2)					

14 Calculate the cross-sectional areas of the bores of the following heavy-gauge steel conduits, assuming that the wall thickness is 1.5 mm:

(a) 16mm

(b) 25mm

(c) 32mm

15 Complete the following table, using a space factor of 45% in each case:

Permitted number of pvc cables in trunking of size (mm)

Cable size	50×37.5	75×50	75×75
16mm²			
25mm²			
50mm²			

16 The following pvc cables are to be installed in a single run of trunking: twelve 16mm², six 35mm², twenty-four 2.5mm², and eight 1.5mm². Determine the size of trunking required, assuming a space factor of 45%.

17 Determine the size of square steel trunking required to contain the following pvc cables: fifteen 50mm², nine 25mm², eighteen 10mm². Take the space factor for ducts as 35%.

18 The nominal diameter of a cable is 6.2mm. Its cross-sectional area is

(a) 120.8mm²

(b) 19.5mm²

(c) 30.2mm²

(d) 61.2mm²

19 Allowing a space factor of 45%, the number of 50mm² cables that may be installed in a 50mm × 37.5mm trunking is

(a) 71

(b) 8

(c) 23

(d) 37

The following cable calculations require the use of data contained in documents based upon BS 7671, e.g. IET *On-Site Guide*, etc. In each case assume that the stated circuit design calculations and environmental considerations have been carried out to determine the necessary cable current ratings and type of wiring system.

20 A steel cable trunking is to be installed to carry eighteen 1.5mm^2 single-core pvc-insulated cables to feed nine floodlighting luminaires; a single 4mm^2 protective conductor is to be included in the trunking. Establish the minimum size of trunking required.

21 50mm × 38mm pvc trunking is installed along a factory wall to contain low-current control cables. At present there are 25 pairs of single-core 1.5mm^2 pvc-insulated cables installed. How many additional pairs of similar 1.5mm^2 control cables may be installed in the trunking?

22 A pvc conduit is to be installed to contain six 4mm^2 single-core pvc cables and one 2.5mm^2 stranded single-core pvc protective conductor. The total length of run will be 16m and it is anticipated that four right-angle bends will be required in the conduit run. Determine the minimum conduit size and state any special consideration.

23 An electric furnace requires the following wiring:

(i) three 6mm^2 stranded single-core pvc cables

(ii) four 2.5mm^2 stranded single-core pvc cables

(iii) four 1.5mm^2 stranded single-core pvc cables.

There is a choice between new steel conduit and using existing 50mm × 38mm steel trunking which already contains six 25mm^2 single-core pvc cables and four 10mm^2 single-core pvc cables. Two right-angle bends will exist in the 18m run.

(a) Determine the minimum size of conduit to be used, and

(b) state whether the new cables could be included within the existing trunking, and if they could be, what considerations must be given before their inclusion.

24 Select two alternative sizes of steel trunking which may be used to accommodate the following.

(a) (i) ten 16mm^2 single-core pvc-insulated cables

(ii) twelve 6mm^2 single-core pvc-insulated cables

(iii) sixteen 1.5mm^2 single-core pvc-insulated cables

(iv) three multicore pvc-insulated signal cables, assuming a cable factor of 130.

(b) An extension to the trunking contains ten of the 16mm^2 cables and 8 of the 1.5mm^2 cables. Establish the minimum size of conduit, assuming a 5m run with no bends.

(c) How may the conduit size selected affect the choice of trunking dimensions (assume that the two sizes of trunking cost the same)?

9

Coulombs and Current Flow

Current is a flow of electrons.

When 6240000000000000000 electrons flow in one second a current of one ampere is said to flow.

This quantity of electrons is called a coulomb (C) and is the unit used to measure electrical charge.

1 coulomb = 6.24×10^{18} electrons

Therefore 1 ampere = 1 coulomb per second.

The quantity of electrical charge $\boldsymbol{Q = I \times t}$ ***coulombs***

EXAMPLE 1

Calculate the current flow if 7.1 coulombs were transferred in 2.5 seconds.

$$I = \frac{Q}{t} = \frac{7.1}{2.5} = 2.84\text{A}$$

EXAMPLE 2

If a current of 14A flows for 5.5 minutes calculate the quantity of electricity that is transferred.

$Q = I \times t$

$Q = 14 \times (5.5 \times 60)$ 4620 coulombs

EXERCISE 5

1 Calculate the time taken for a current of 14A to flow at a charge of 45C.
2 How long must a current of 0.5A flow to transfer 60 coulombs?
3 If a current of 4.3A flows for 15 minutes calculate the charge transferred.

Internal Resistance

10

RESISTIVITY

The resistance of a conductor is:

$$R = \frac{\rho \times L}{A}\Omega$$

ρ is the resistivity (Ωm)
l is the conductor length (m)
A is the cross-sectional area (m^2)

EXAMPLE 1

Determine the resistance of 100m of 120mm^2 copper.

The resistivity of copper is 1.78×10^{-8} Ωm

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

$$\frac{1.78 \times 10^{-8} \times 100}{120 \times 10^{-6}} = 0.0148\Omega$$

(Note 10^{-6} to convert to sq m on some calculators the EXP button is shown as $\times$ **10^x**

Enter into calculator 1.78 *EXP* – 8 × 100 ÷ 120 *EXP* – 6 = 0.0148

EXAMPLE 2

Calculate the length of $2.5mm^2$ copper conductor that will have a resistance of 1.12Ω.

This requires the use of simple transposition. It is easier to start with the formulae that is known:

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

Replace the letters with numbers where possible:

$$1.12 = \frac{1.78 \times 10^{-8} \times L}{2.5 \times 10^{-6}}$$

The subject must be on its own, on the top line; this will require moving some of the values.

Remember when a value moves across the = sign it must move from bottom to top or top to bottom.

This will give us:

Step 1:

$2.5 \times 10 - 6 \times 1.12 = 1.78 \times 10^{-8} \times L$

Step 2:

$$\frac{2.5 \times 10^{-6} \times 1.12}{1.78 \times 10^{-8}} = L$$

This will leave L on its own and we can now carry out the calculation

Enter into calculator 2.5 *EXP* – 6 × 1.12 ÷ 1.78 *EXP* – 8 = 157.30m

EXAMPLE 3

Calculate the cross-sectional area of an aluminium cable 118m long which has a resistance of 0.209Ω.

The resistivity of aluminium is 2.84×10^{-8}Ωm.

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

Convert to values:

$$0.209 = \frac{2.84 \times 10^{-8} \times 118}{A \times 10^{-6}}$$

Transpose:

$$A \times 0.209 = \frac{2.84 \times 10^{-8} \times 118}{10^{-6}}$$

$$A = \frac{2.84 \times 10^{-8} \times 118}{0.209 \times 10^{-6}} = 16\text{mm}^2$$

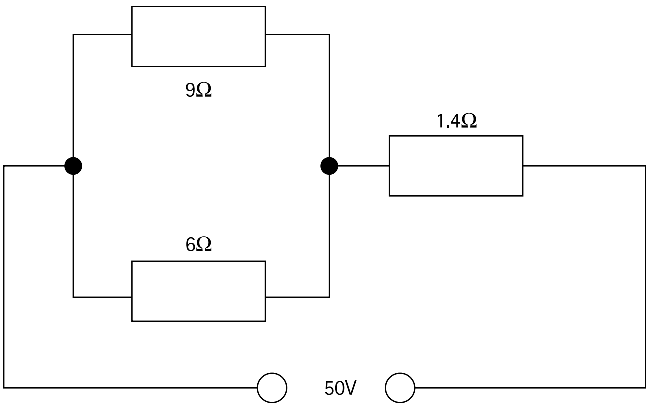
Enter into calculator:

2.84 *EXP* –8 × 118 ÷ 0.209 × *EXP* –6 = 16.03mm^2

EXERCISE 6

1 For the circuit of Figure 18, find

Figure 18



(a) the resistance of the parallel group

(b) the total resistance

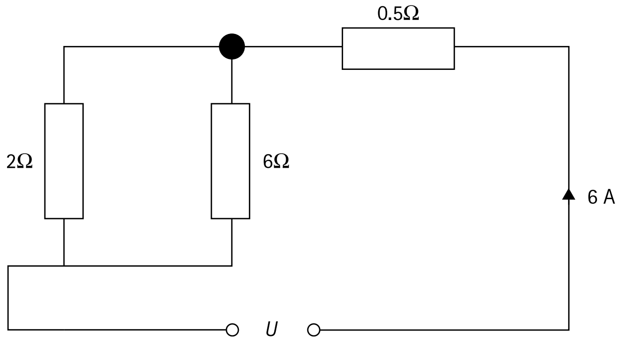
(c) the current in each resistor.

2 For the circuit of Figure 19, find

(a) the total resistance

(b) the supply voltage.

Figure 19



3 Find the value of the resistor *R* in the circuit of Figure 20.

4 Calculate the value of the resistor *r* in the circuit of Figure 21.

5 For the circuit of Figure 22, find

(a) the total resistance

(b) the total current.

Figure 20

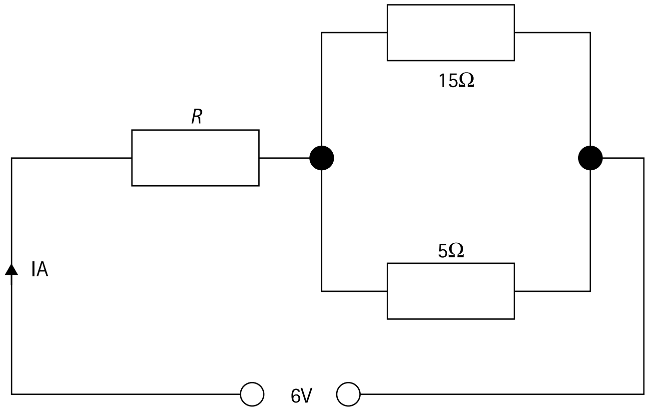
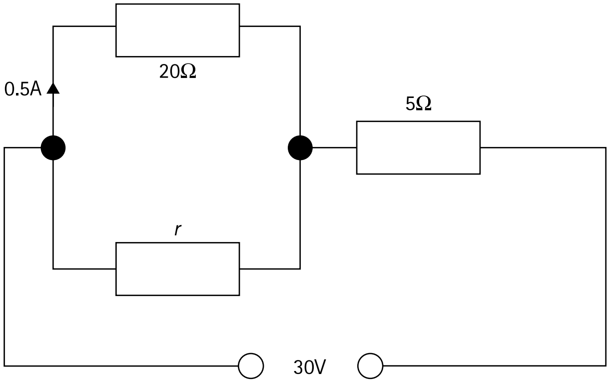


Figure 21



6 Determine the voltage drop across the 4.5Ω resistor in Figure 23.

7 Calculate the current in each resistor in Figure 24.

8 Determine the value of a resistor which when connected in parallel with the 70Ω resistor will cause a total current of 2.4A to flow in the circuit of Figure 25.

Figure 22

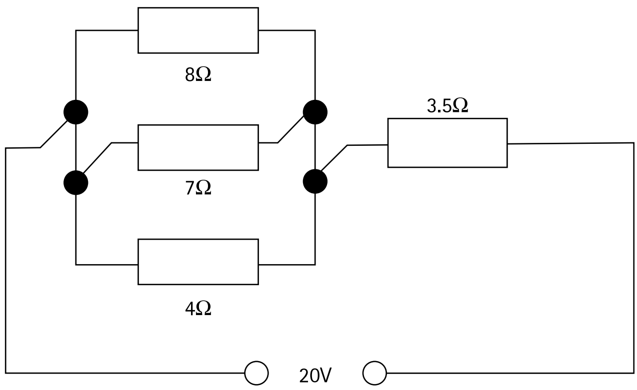
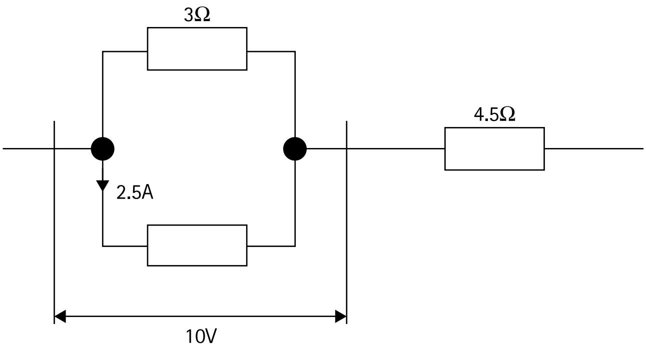


Figure 23



9 Two contactor coils of resistance 350 and 420Ω, respectively, are connected in parallel. A ballast resistor of 500Ω is connected in series with the pair. Supply is taken from a 220V d.c. supply. Calculate the current in each coil and the power wasted in the ballast resistor.

Figure 24

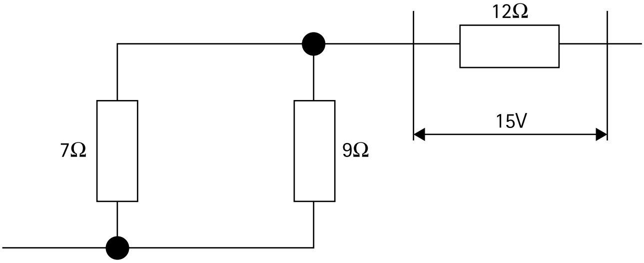
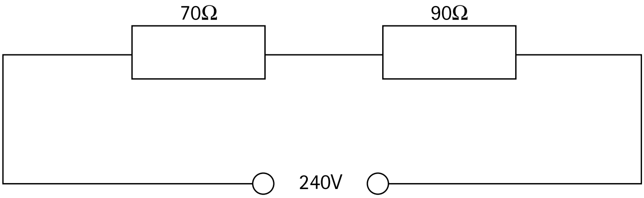


Figure 25



10 Two 110V lamps are connected in parallel. Their ratings are 150W and 200W. Determine the value of a resistor which when wired in series with the lamps will enable them to operate from the 230V mains.

11 A shunt motor has two field coils connected in parallel, each having a resistance of 235Ω. A regulating resistor is wired in series with the coils to a 200V supply. Calculate the value of this resistor when the current through each coil is 0.7A.

12 In a certain installation the following items of equipment are operating at the same time: (i) a 3kW immersion heater, (ii) two 100W lamps, (iii) one 2kW radiator. All these are rated at 240V.

The nominal supply voltage is stated to be 230V but it is found that the actual voltage at the origin of the installation is 5V less than this. Calculate:

(a) the total current

(b) the resistance of the supply cables

(c) the actual power absorbed by the immersion heater.

13 The overhead cable supplying an outbuilding from the 230V mains supply has a resistance of 0.96Ω. A 2kW radiator and a 1500W kettle, both rated at 230V, are in use at the time. Determine the voltage at the terminals of this apparatus. What would be the voltage if a 750W, 240V water heater were also switched on?

14 Two resistors in parallel, A of 20Ω and B of unknown value, are connected in series with a third resistor C of 12Ω. The supply to the circuit is direct current. If the potential difference across the ends of C is 180V and the power in the complete circuit is 3600W, calculate:

(a) the value of resistor B

(b) the current in each resistor

(c) the circuit voltage.

15 State Ohm's law in your own words, and express it in symbols. A d.c. supply at 240V is applied to a circuit comprising two resistors A and B in parallel, of 5Ω and 7.5Ω, respectively, in series with a third resistor C of 30Ω. Calculate the value of a fourth resistor D to be connected in parallel with C so that the total power in the circuit will be 7.2kW.

16 Three resistors of value 1.5Ω, 4Ω and 12Ω, are connected in parallel. A fourth resistor, of 6Ω, is connected in series with the parallel group. A d.c. supply of 140V is applied to the circuit.

(a) Calculate the current taken from the supply.

(b) Find the value of a further resistor to be connected in parallel with the 6Ω resistor so that the potential difference across it will be 84V.

(c) What current will now flow in the circuit?

17 An electric bell takes a current of 0.3A from a battery whose e.m.f. is 3V and internal resistance 0.12Ω. Calculate the terminal voltage of the battery when the bell is ringing.

18 Determine the voltage at the terminals of a battery of three cells in series, each cell having an e.m.f. of 1.5V and internal resistance 0.11Ω, when it supplies a current of 0.75A.

19 A car battery consists of six cells connected in series. Each cell has an e.m.f. of 2V and internal resistance of 0.008Ω. Calculate the terminal voltage of the battery when a current of 105A flows.

20 A battery has an open-circuit voltage of 6V. Determine its internal resistance if a load current of 54A reduces its terminal voltage to 4.35V.

21 Resistors of 5Ω and 7Ω are connected in parallel to the terminals of a battery of e.m.f. 6V and internal resistance of 0.3Ω. Calculate:

(a) the current in each resistor

(b) the terminal voltage of the battery

(c) the power wasted in internal resistance.

22 A battery is connected to two resistors, of 20Ω and 30Ω, which are wired in parallel. The battery consists of three cells in series, each cell having an e.m.f. of 1.5V and internal resistance 0.12Ω. Calculate:

(a) the terminal voltage of the battery

(b) the power in each resistor.

23 A battery of 50 cells is installed for a temporary lighting supply. The e.m.f. of each cell is 2V and the internal resistance is 0.0082Ω. Determine the terminal voltage of the battery when it supplies 25 lamps each rated at 150W, 110V.

24 The installation in a country house is supplied from batteries. The batteries have an open-circuit voltage of 110V and an internal resistance of 0.045Ω. The main cables from the batteries to the house have a resistance of 0.024Ω. At a certain instant the load consists of two 2kW radiators, three 100W lamps, and four 60W lamps. All this equipment is rated at 110V. Calculate the voltage at the apparatus terminals.

25 An installation is supplied from a battery through two cables in parallel. One cable has a resistance of 0.34Ω; the other has a resistance of 0.17Ω. The battery has an internal resistance of 0.052Ω and its open-circuit voltage is 120V. Determine the terminal voltage of the battery and the power wasted in each cable when a current of 60A is flowing.

26 A 12V battery needs charging and the only supply available is one of 24V. The battery has six cells, each of e.m.f. 1.8V and internal resistance 0.009Ω. Determine the value of a series resistor which will limit the current to 5A.

27 A circuit consists of a 7.2Ω resistor in parallel with one of unknown value. This combination is connected in series with a 4.5Ω resistor to a supply of direct current. The current flowing is 2.2A and the total power taken by the circuit is 35W. Calculate:

(a) the value of the unknown resistor

(b) the supply voltage

(c) the value of a resistor which if connected in parallel with the 4.5Ω resistor will cause a current of 4A to flow.

(Assume that the source of supply has negligible internal resistance.)

28 The combined resistance of the circuit in Figure 26 is:

(a) 0.333Ω

(b) 12.5Ω

(c) 30.0Ω

(d) 7.7Ω

Figure 26

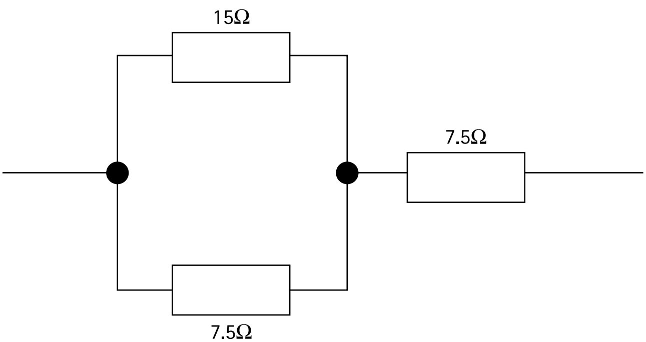
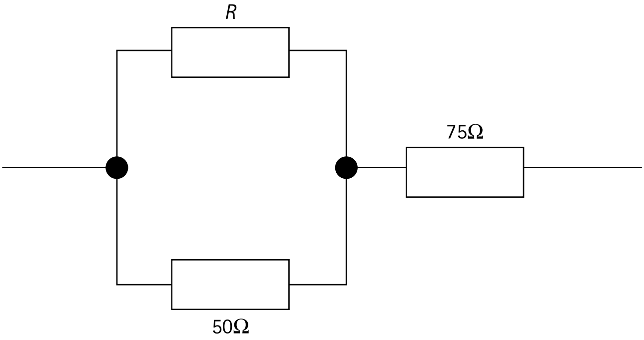


Figure 27



29 The combined resistance of the circuit in Figure 27 is 91.7. The value of resistor R is

(a) 33.3Ω

(b) 250Ω

(c) 0.04Ω

(d) 25Ω

30 The current flowing in the 0.4 resistor in Figure 28 is

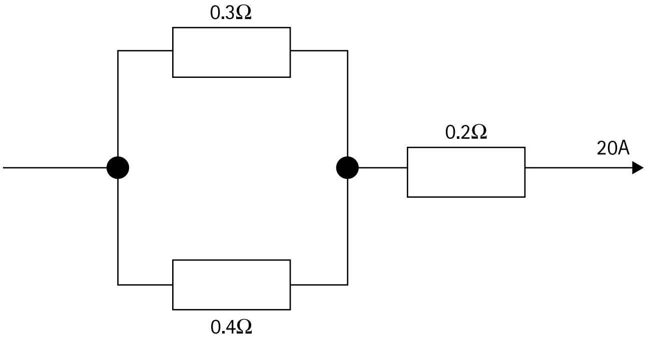
(a) 8.57A

(b) 11.43A

(c) 0.24A

(d) 0.73A

Figure 28



11

Power in a d.c. and Purely Resistive a.c. Circuit

METHOD 1

Power (watts) = voltage (volts) × current (amperes)

$P = U \times I$

EXAMPLE 1

The current in a circuit is 4.8A when the voltage is 240V. Calculate the power.

$P = U \times I$

$= 240 \times 4.8$

1152W

EXAMPLE 2

Calculate the current flowing when a 2kW heater is connected to a 230V supply.

$P = U \times I$

$2000 = 230 \times I$

$\therefore\ I = \dfrac{2000}{230}$

$= 8.7\text{A}$

EXAMPLE 3

The current in a certain resistor is 15A and the power absorbed is 200W. Find the voltage drop across the resistor.

$P = U \times I$

$200 = U \times 15$

$\therefore\ U = \dfrac{200}{15}$

$= 13.3\ \text{V}$

EXERCISE 7

1 Complete the following table:

P (watts)	3000	1600	1000	1000	2350		
I (amperes)	6	150	0.2	4.5			
U (volts)	240	250	240	100	220	460	240

2 The voltage drop in a cable carrying 12.5A is 2.4V. Calculate the power wasted.

3 A d.c. motor takes 9.5A from a 460V supply. Calculate the power input to the motor.

4 Calculate the current that flows when each of the following pieces of equipment is connected to the 230V mains:

(a) 3kW immersion heater

(b) 1500W kettle

(c) 450W electric iron

(d) 3.5kW washing machine

(e) 7kW cooker

(f) 60W lamp

(g) 100W lamp

(h) 2kW radiator

(i) 750W water heater

(j) 15W lamp.

5 Calculate the voltage drop in a resistor passing a current of 93A and absorbing 10kW.

6 A cable carries a current of 35A with a 5.8V drop. Calculate the power wasted in the cable.

7 A heater is rated at 4.5 kW, 240V. Calculate the current it takes from

(a) a 240V supply

(b) a 220V supply.

8 A motor-starting resistor passes a current of 6.5A and causes a voltage drop of 115 V. Determine the power wasted in the resistor.

9 Determine the current rating of the resistance wire which would be suitable for winding the element of a 1.5kW, 250V heater.

10 Calculate the current taken by four 750W lamps connected in parallel to a 230V main

11 A faulty cable joint causes an 11.5V drop when a current of 55A is flowing. Calculate the power wasted at the joint.

12 Two lamps, each with a rating of 100W 240V, are connected in series to a 230V supply. Calculate the current taken and the power absorbed by each lamp.

13 Determine the current rating of the cable required to supply a 4kW immersion heater from a 230V mains.

14 A generator delivers a current of 28.5A through cables having a total resistance of 0.103Ω. The voltage at the generator terminals is 225V. Calculate:

(a) the power generated

(b) the power wasted in the cables

(c) the voltage at the load.

15 Calculate the value of resistance which when connected in series with a 0.3W, 2.5V lamp will enable it to work from a 6V supply.

16 A motor takes a current of 15.5A at a terminal voltage of 455V. It is supplied through cables of total resistance 0.32Ω. Calculate:

(a) the voltage at the supply end

(b) the power input to the motor

(c) the power wasted in the cables.

17 Two coils, having resistances of 35Ω and 40Ω, are connected to a 100V d.c. supply (a) in series, (b) in parallel. For each case, calculate the power dissipated in each coil.

18 Two cables, having resistances of 0.036Ω and 0.052Ω, are connected in parallel to carry a total current of 190A. Determine the power loss in each cable.

19 If the power loss in a resistor is 750W and the current flowing is 18.5A, calculate the voltage drop across the resistor. Determine also the value of an additional series resistor which will increase the voltage drop to 55V when the same value of current is flowing. How much power will now be wasted in the original resistor?

20 A d.c. motor takes a current of 36A from the mains some distance away. The voltage at the supply point is 440V and the cables have a total resistance of 0.167Ω. Calculate:

(a) the voltage at the motor terminals

(b) the power taken by the motor

(c) the power wasted in the cables

(d) the voltage at the motor terminals if the current increases to 42A.

21 The voltage applied to a circuit is 240V and the current is 3.8A. The power is:

(a) 632W

(b) 63.2W

(c) 912W

(d) 0.016W

22 The power absorbed by a heating element is 590W at a p.d. of 235V. The current is:

(a) 13 865A

(b) 2.51A

(c) 0.34A

(d) 25.1A

23 A faulty cable joint carries a current of 12.5A, and a voltage drop of 7.5V appears across the joint. The power wasted at the joint is:

(a) 1.67W

(b) 0.6W

(c) 93.8W

(d) 60W

24 A heating element absorbs 2.5kW of power and the current is 10.5A. The applied voltage is:

(a) 238V

(b) 26.3V

(c) 2.38V

(d) 4.2V

METHOD 2

Power = current^2 × resistance

$P = I^2 R$

EXAMPLE 1

Calculate the power absorbed in a resistor of 8Ω when a current of 6A flows.

$P = I^2 R$

$= 6^2 \times 8$

$= 36 \times 8$

288W

EXAMPLE 2

A current of 12A passes through a resistor of such value that the power absorbed is 50W. What is the value of this resistor?

$P = I^2 R$

$50 = 12^2 \times \mathrm{R}$

$\therefore R = 50 \times 12 \times 12$

$= 0.347\Omega$

EXAMPLE 3

Determine the value of current which when flowing in a resistor of 400Ω causes a power loss of 1600W.

$P = I^2 R$

$\therefore 1600 = 12 \times 400$

$\therefore I^2 = \dfrac{1600}{400} = 4$

$\therefore \mathrm{I} = \sqrt{4} = 2\mathrm{A}$

EXERCISE 8

1 Complete the following table:

Power (W)		200		1440	100	2640	100	
Current (A)	10	5	15		4.2		0.42	1.3
Resistance (Ω)	15		8	10		20		25

2 A current of 20A flows in cable of resistance 0.325Ω. Calculate the power loss.

3 Determine the power loss in a cable having a resistance of 0.14Ω when passing a current of 14.5A.

4 Determine the value of current which, when flowing in a 40Ω resistor, dissipates 1000W.

5 An earth fault current of 38A passes through a conduit joint which has a resistance of 1.2Ω. Calculate the power dissipated at the joint.

6 A 100W lamp passes a current of 0.42A. Calculate its resistance.

7 In a certain installation the total length of cable is 90m and the resistance of this type of cable is 0.6Ω per 100m. Determine

(a) the voltage drop

(b) the power loss, when a current of 11.5A flows.

8 A resistor used for starting a d.c. motor has a value of 7.5Ω. Calculate the power wasted in this resistor when a starting current of 8.4A flows.

9 Determine the current rating of resistance wire which would be suitable for a 1000W heater element of resistance 2.5Ω.

10 An ammeter shunt carries a current of 250A and its resistance is 0.00095Ω. Calculate the power absorbed by the shunt.

11 What is the resistance of an electric-iron element of 450W rating and which takes a current of 1.9A?

12 A joint in a cable has a resistance of 0.045Ω. Calculate the power wasted at this joint when a current of 37.5A flows.

13 The resistance measured between the brushes of a d.c. motor is 2.3Ω. Calculate the power loss in the armature when the current is 13.5A.

14 Determine the rating in watts of a 1100Ω resistor which will carry 15mA.

15 Calculate the maximum current which a 250Ω resistor rated at 160W will carry.

METHOD 3

$$\text{Power} = \frac{\text{voltage}^2}{\text{resistance}} \text{ or } \frac{U^2}{R}$$

EXAMPLE 1

Calculate the power absorbed by a 60Ω resistor when connected to a 230V d.c. supply.

$$P = \frac{U^2}{R}$$

$$= \frac{230 \times 230}{60} = 881.86\text{W}$$

EXAMPLE 2

Determine the resistance of a heater which absorbs 3kW from a 230V d.c. supply.

$$P = \frac{U^2}{R}$$

$$3000 = \frac{230^2}{R}$$

Transposed

$$R = \frac{230^2}{3000}$$

$$R = \frac{230 \times 230}{3000} = 17.63\Omega$$

EXAMPLE 3

Determine the voltage which must be applied to a 10.7Ω resistor to produce 500W of power.

$$P = \frac{U^2}{R}$$

$$500 = \frac{U^2}{10.7}$$

Transposed

$$U^2 = 10.7 \times 500$$

$$= 5350$$

$$U = \sqrt{5350}$$

$$= 73.14$$

EXERCISE 9

1 A contactor coil has resistance of 800Ω. Calculate the power absorbed by the coil from a 230V d.c. supply.

2 A piece of equipment creates a voltage drop of 180V and the power absorbed by it is 240W. Determine its resistance.

3 Calculate the resistance of a 36W, 12V car headlamp bulb.

4 Determine the voltage to be applied to a 6Ω resistor to produce 2400W of power.

5 Complete the following table:

Power (W)		100	60	1800		36
Voltage (V)	80	240		220	3.5	
Resistance (Ω)	50		1042		0.29	4

6 Calculate the maximum voltage which may be applied to a 45Ω resistor rated at 5W.

7 Determine the power absorbed by the field coils of a 460V d.c. motor. The resistance of the coils is 380Ω.

8 Determine the resistance of a 230V, 1 kW heater.

9 The voltage drop in a cable of resistance 0.072Ω is 3.5V. Calculate the power wasted in the cable.

10 Determine the resistance of a 110V, 75W lamp.

11 The following items of equipment are designed for use on a 240V supply. Calculate the resistance of each item.

(a) 2kW radiator

(b) 3kW immersion heater

(c) 3.5kW washing machine

(d) 450W toaster

(e) 60W lamp

(f) 7kW cooker

(g) 100W lamp

(h) 1500W kettle

(i) 750W water heater

(j) 4 kW immersion heater.

12 Calculate the voltage drop in a resistor of 12.5Ω when it is absorbing 500W.

13 The power dissipated in a 57Ω resistor is 1000W. Determine the current.

14 Two lamps are connected in series to a 200V supply. The lamps are rated at 150W, 240V and 60W, 240V. Calculate:

(a) the current taken from the supply

(b) the total power.

15 Two 1000W, 230V heater elements are connected to a 230V d.c. supply (a) in series (b) in parallel. Calculate:

(a) the combined resistance in each case

(b) the power absorbed in each case.

16 Cables of resistance 0.35Ω and 0.082Ω are connected in parallel and they share a load of 100A. Determine the current and power loss in each.

17 The element of an immersion heater has a total resistance of 76.8Ω and is centre-tapped. Calculate the power absorbed from a 240V supply when the element sections are (a) in series (b) in parallel.

18 Complete the following table and then plot a graph of power (*vertically*) against current (*horizontally*). Try to make the axes of the graph of equal length, and join the points with a smooth curve.

Power (W)		250	400	600
Current (A)	0.8		3.15	
Resistance (Ω)	40	40		40

From the graph, state

(a) what power would be dissipated in a 40Ω resistor by a current of 3.7A

(b) how much current is flowing when the power is 770W?

19 Complete the following table and plot a graph of power against voltage. Join the points with a smooth curve.

Power (W)	2000	750		180
Voltage (V)	240		89.6	
Resistance (Ω)		19.2	19.1	19.2

(a) Read off the graph the voltage when the power is 1500W.

(b) Extend the graph carefully and find from it the power when the voltage is 250V.

20 The voltage applied to the field circuit of a motor can be varied from 250V down to 180V by means of a shunt field regulator. The resistance of the field coils is 360Ω. Plot a graph showing the relationship between the power and the applied voltage.

21 A cable of resistance 0.07Ω carries a current which varies between 0 and 90A. Plot a graph showing the power loss in the cable against the load current.

22 A current of 4.8A flows in a resistor of 10.5Ω. The power absorbed is

(a) 529.2W

(b) 24192W

(c) 2420W

(d) 242W

23 The power developed in a resistor of 24Ω is 225W. The current flowing is

(a) 9.68A

(b) 3.06A

(c) 0.327A

(d) 30.6A

24 The resistance of a 110V, 100W lamp is

(a) 1210Ω

(b) 0.011Ω

(c) 8.26Ω

(d) 121Ω

25 The voltage to be applied to a resistor of 55Ω in order to develop 50 watts of power is

(a) 0.95V

(b) 166V

(c) 52.4V

(d) 1.05V

MECHANICS

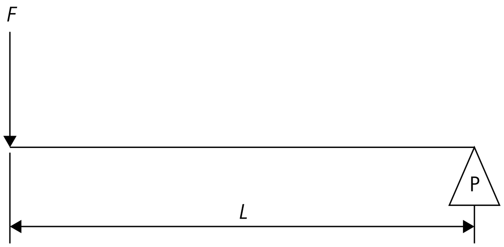
MOMENT OF FORCE

A force F newtons applied at right angles to a rod of length L metres pivoted at P (Figure 29) produces a turning moment M, where

$M = F \times L$ newton metres (Nm)

(Note that this turning moment is produced whether or not the bar actually free to turn.)

Figure 29 A force being applied to a rod



EXAMPLE 1

A horizontal bar 0.5m long is arranged as in Figure 29. Calculate the force required in order to produce a moment of 250Nm.

$M = F x L$

$\therefore$ 250Nm = F × 0.5m

$$\therefore F = \frac{250\text{Nm}}{0.5\text{m}}$$

$= 500\text{N}$

EXAMPLE 2

A horizontal bar 0.75m long is pivoted at a point 0.5m from one end, and a downward force of 100N is applied at right angles to this end of the bar. Calculate the downward force which must be applied at right angles to the other end in order to maintain the bar in a horizontal position. Neglect the weight of the bar.

The principle of moments applies; that is, for equilibrium (see Figure 30):

total clockwise moment = total anticlockwise moment

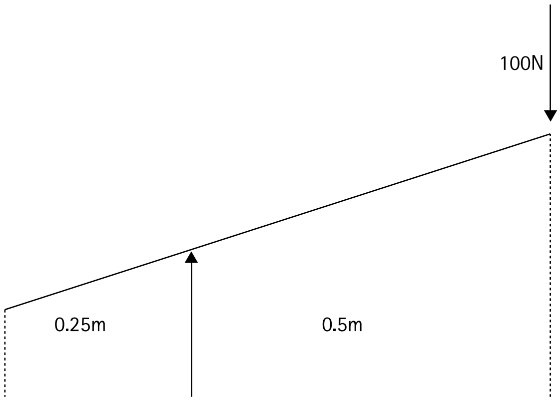
$F \times 0.25 = 100 \times 0.5$

$$\therefore \frac{100 \times 0.5}{0.25}$$

$= 200\text{N}$

(The principle of levers is twice the distance, half the force.)

Figure 30 Calculate the downward force



FORCE RATIO

If the bar of example 2 is considered as a lever, then all *effort* of 100N is capable of exerting a force of 200N on an object. The force *F* is then in fact the *load*.

By the principle of moments:

Load × distance from pivot = effort × distance from pivot

The force ratio is $\dfrac{\text{Load}}{\text{Effort}}$

$$\text{Or force ratio} = \frac{\text{Load}}{\text{Effort}} = \frac{\text{distance from effort to pivot}}{\text{distance from load to pivot}}$$

In the case of example 2:

$$\text{Force ratio} = \frac{0.5\text{m}}{0.25\text{m}} = 2$$

Note that force ratio is often also referred to as 'mechanical advantage'.

MASS, FORCE AND WEIGHT

Very often the load is an object which has to be raised to a higher level against the force of gravity.

The force due to gravity acting on a mass of 1kg is 9.81N.

The force to raise a mass of 1kg against the influence of gravity is therefore 9.81N, and this is called the weight of the 1kg mass.

Although the newton is the correct scientific unit of force and weight, for industrial and commercial purposes it is usual to regard a mass of 1kg as having a weight of 1 kilogram force (kgf), therefore

1kgf = 9.81N

The kilogram force is the 'gravitational' unit of weight and is often abbreviated to 'kilogram', or even 'kilo', in common usage.

EXAMPLE

A crowbar is arranged as shown in Figure 31 and for practical purposes the formula for force ratio may be applied to find the effort required to raise its load of 65 kgf:

$$\frac{\text{Load}}{\text{Effort}} = \frac{\text{distance from effort to pivot}}{\text{distance from load to pivot}}$$

$$\frac{65}{E} = \frac{1\text{m}}{0.125\text{m}}$$

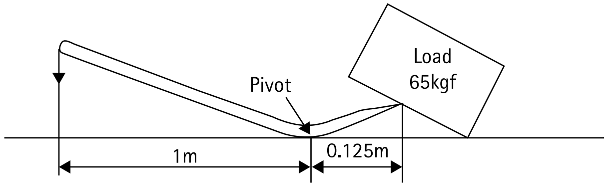
$$\frac{E}{65} = \frac{0.125}{1}$$

$E = 65 \text{ x } 0.125$

$= 8.125\text{kgf}$

(or quite simply one eighth of the force)

Figure 31 Crowbar lifting a load



WORK

When a force F newtons produces displacement of a body by an amount D metres in the direction of the force, the work done is

$W = F \times D$ newton metres or joules (J)

Work = Force × Distance

This is also the energy expended in displacing the body.

EXAMPLE 1

A force of 220N is required to move an object through a distance of 4.5m. Calculate the energy expended.

$W = F \times D$

$= 220\text{N} \times 4.5\text{m}$

$= 990\text{Nm or } 990\text{J}$

EXAMPLE 2

Calculate the energy required to raise a mass of 6kg through a vertical distance of 14.5m.

We have seen above that the force required to raise a mass of 1kg against the influence of gravity is 9.81N; therefore the force required to raise a mass of 6kg is:

$F = 6 \times 9.81\text{N}$

And the energy required is

$W = 6 \times 9.81\text{N} \times 14.5\text{m}$

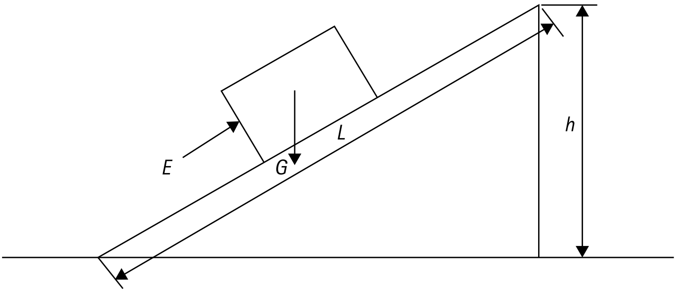
$= 853.47\text{Nm or } 853.47\text{J}$

THE INCLINED PLANE

Figure 32 illustrates a method of raising a load *G* through a vertical distance *h* by forcing it up a sloping plane of length *L* using an effort *E*.

Ignoring the effects of friction (which can be reduced by using rollers under the load),

Figure 32 The inclined plane method



Energy expended by the effort = energy absorbed by the load, that is,

effort × (distance through which the effort is exerted)

= load × (vertical distance through which the load is raised)

$E \times L = G \times h$

$$\text{Force ratio} = \frac{load}{effort} = \frac{G}{E} = \frac{L}{h}$$

EXAMPLE

A motor weighing 100kgf is to be raised through a vertical distance of 2m by pushing it up a sloping ramp 5m long. Ignoring the effects of friction, determine the, effort required.

$$\frac{G}{E} = \frac{L}{h}$$

$$\frac{100}{E} = \frac{5}{2}$$

$$\frac{E}{100} = \frac{2}{5}$$

$$E = 100 \times \frac{2}{5}$$

$$= 40\text{kgf}$$

THE SCREWJACK

A simplified arrangement of a screw type of lifting jack is shown in cross-section in Figure 33. A horizontal effort *E* is applied to the arm of radius *r* and this raises the load *G* by the action of the screw thread T.

If the effort is taken through a complete revolution, it acts through a distance equal to $2\pi \times r$ (or $\pi \times d^2 \div 4$) and the load rises through a vertical distance equal to the pitch of the screw thread, which is the distance between successive turns of the thread.

If *p* is the pitch of the thread, and ignoring friction,

(energy expended by the effort) = (energy absorbed by the load in rising through a distance *p*)

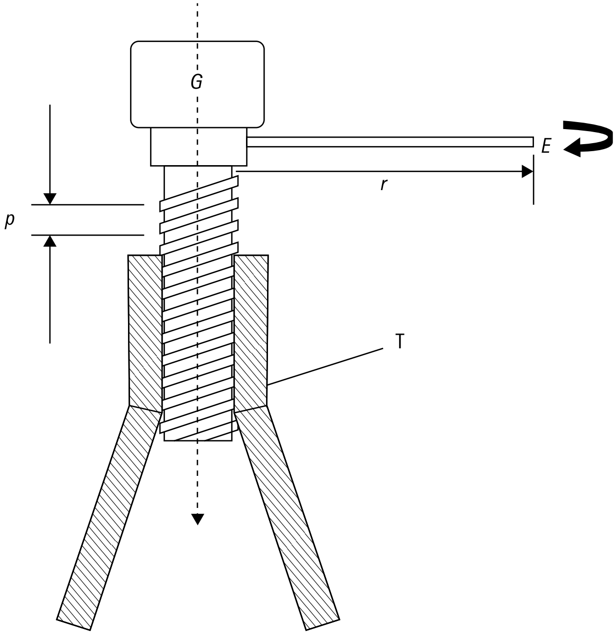
$E \times 2\varpi r = G \times p$

$$\frac{E \times 2\pi r}{p} = G$$

The force ratio is

$$\frac{load}{effort} = \frac{G}{E} = \frac{2\pi r}{p}$$

Figure 33 The screwjack method



EXAMPLE

If the pitch of the thread of a screwjack is 1cm and the length of the radius arm is 0.5m, find the load which can he raised by applying a force of 20kg.

$$\frac{G}{E} = \frac{2\pi r}{p}$$

$$\frac{G}{20} = \frac{2\pi \times 0.5}{1/100\text{m}} \ ((\textit{Conversion from cm to m})$$

$$G = \frac{20 \times 2\pi \times 0.5}{0.01} = 6283\text{kgf}$$

(This gives an enormous advantage but would be very slow.)

THE WHEEL-AND-AXLE PRINCIPLE

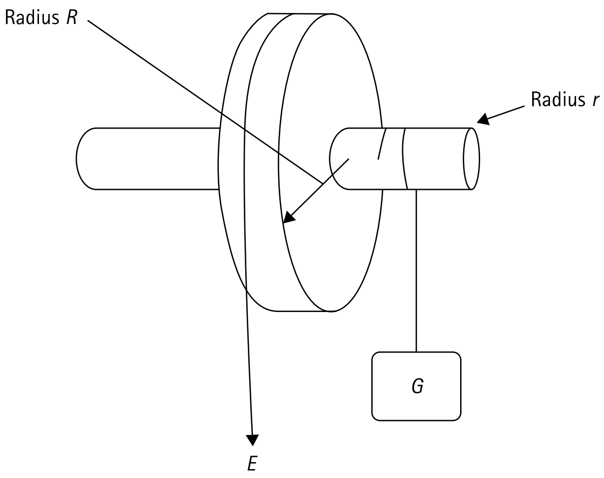
Figure 34 shows a simplified version of a common arrangement by means of which a load G is raised by applying an effort *E*.

By the principle of moments,

$$E \times R = G \times r$$

$$\textit{Force ratio} = \frac{\textit{load}}{\textit{effort}} = \frac{G}{E} = \frac{R}{r}$$

Figure 34 The wheel and axle principle



EXAMPLE

Calculate the effort required to raise a load of 250kgf using the arrangement shown in Figure 34 if the radius of the large wheel is 20cm and the radius of the axle is 8cm.

$$\frac{G}{E}=\frac{R}{r}$$
$$\frac{250}{E}=\frac{20\text{cm}}{8\text{cm}}$$

$$\frac{E}{250}=\frac{8}{20}$$
$$E=250\times\frac{8}{20}$$

$$=100\text{kgf}$$

THE BLOCK AND TACKLE

When a system of forces is in *equilibrium*, the sum of all forces acting downwards is equal to the sum of all forces acting upwards.

Figures 35(a), (b), (c) and (d) illustrate various arrangements of lifting tackle (rope falls) raising a load G by exerting an effort E. In each case the effort is transmitted throughout the lifting rope, giving rise to increasing values of force ratio. (The effects of friction are ignored.)

EXAMPLE

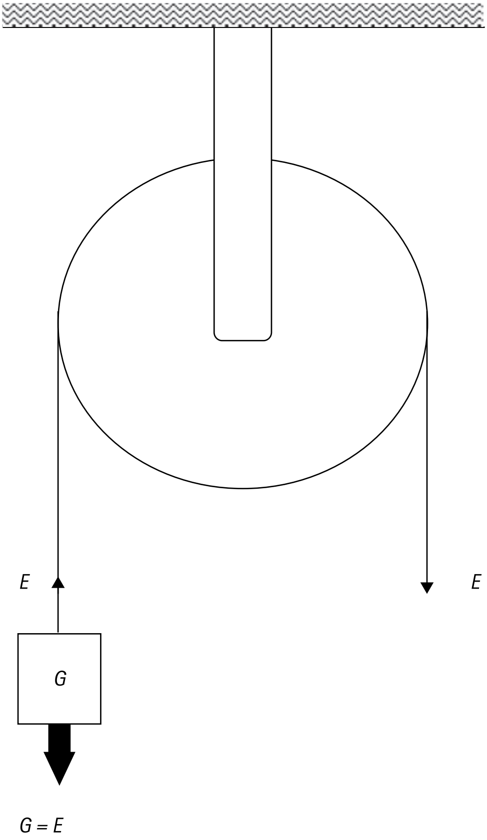
Determine the load which (ignoring friction) could be raised by exerting an effort of 60kgf using each of the arrangements illustrated in Figure 35. Look at the number of strings used to carry the load

For (a), 1 string

$G = E$

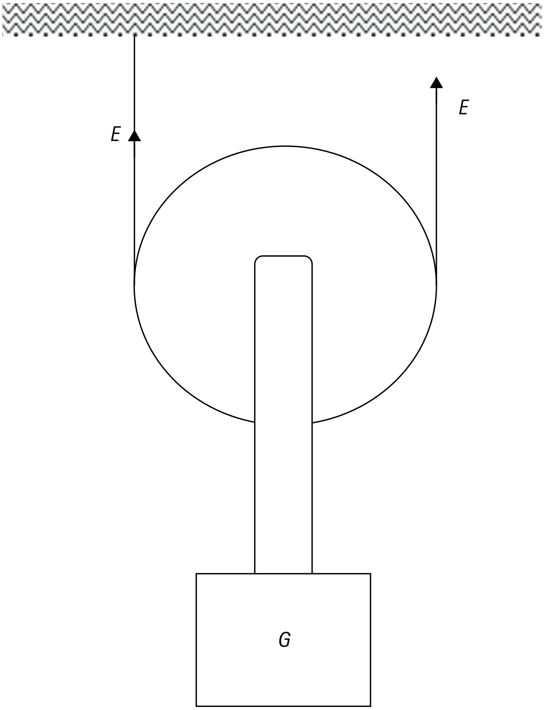
$= 60\text{kgf}$

Figures 35a Various arrangements of lifting tackle



(a) Force Ratio $= \frac{G}{E} = \frac{E}{E} = I$

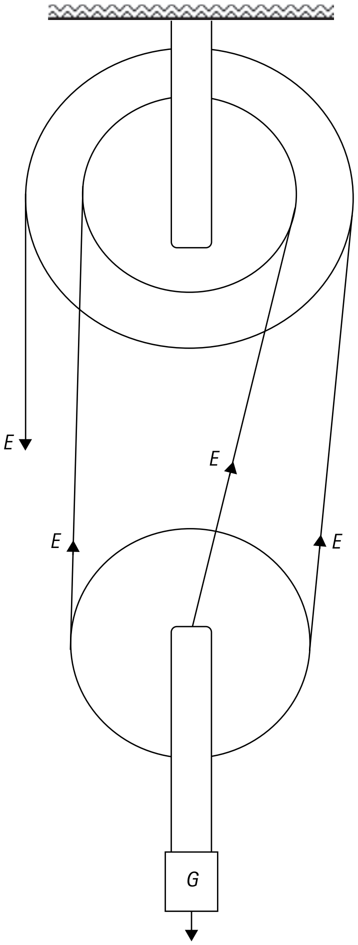
Figures 35b Various arrangements of lifting tackle



$G = 2E$

(b) Force Ratio $= \dfrac{2E}{E} = 2$

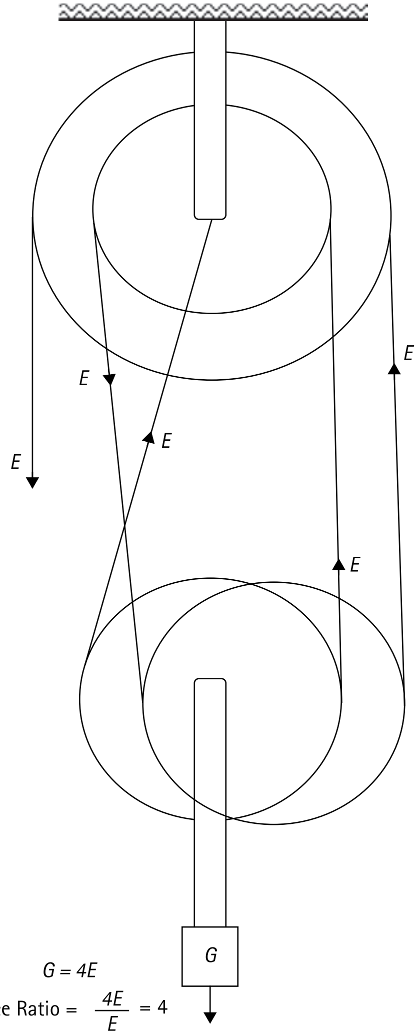
Figures 35c Various arrangements of lifting tackle



$G = 3E$

(c) Force Ratio $= \frac{3E}{E} = 3$

Figures 35d Various arrangements of lifting tackle



$G = 4E$

(d) Force Ratio $= \dfrac{4E}{E} = 4$

For (b), 2 strings

$G = 2E$

$= 2 \times 60$

$= 100\text{kgf}$

For (c), 3 strings

$G = 3E$

$= 3 \times 60$

$= 180\text{kgf}$

For (d), 4 strings

$G = 4E$

$4 \times 60 = 240\text{kgf}$

POWER

Power is the rate of doing work

$$\text{Power} = \frac{\textit{work done } (\textit{force x distance})}{\textit{time taken } (\textit{time in seconds})} \text{ or work done in one second}$$

EXAMPLE 1

The force required to raise a certain load through a vertical distance of 18m is 60N and the operation takes 30s. Calculate the power required.

$$\text{Power} = \frac{\textit{work done}}{\textit{time taken}} \qquad \text{1 watt} = \text{1 joule of work per second}$$

$$= \frac{18 \times 60}{30}$$

$$= \frac{1080}{30}$$

$$= 36\text{W}$$

EXAMPLE 2

Calculate the power required to raise a mass of 12kg through a vertical distance of 27m in a time of 25 secs.

Convert mass to weight 1kg = 9.81N (This is the force of gravity on 1kg.)

$12 \times 9.81 = 117.72\text{N}$

Work done (J) = force × distance $117.72 \times 27 = 3178.44$

$$\text{Power} = \frac{3178.44}{25} = 127.13 \text{ watts}$$

$$\text{Or as one calculation} = \frac{12 \times 9.81 \times 27}{25} = 127.13$$

EXAMPLE 3

Calculate the power required to raise 0.18m^3 of water per minute through a vertical distance of 35m. *(1 litre of water has a mass of 1kg)*

The mass of 1m^3 (*1000 litres)* of water is 10^3kg.

The force required to raise this mass of water is

$F = 0.18 \times 10^3 \times 9.81\text{N}$

$$\textit{The power required} = \frac{\textit{force} \times \textit{distance}}{\textit{time in seconds}} = \frac{\textit{work}}{\textit{time}}$$

$$\textit{As one calculation } \frac{0.18 \times 10^3 \times 9.81\text{N} \times 35}{60\text{s}} = \text{Nm or J} = 1030\text{W}$$

$= 1.03\text{kW}$

Enter into calculator 0.18 × *EXP* 3 (*or* × 10 x 3) × 9.81 × 35 ÷ 60 = *(ans)*

EFFICIENCY

If the pump performing the operation of the last example has an efficiency of 83%, the power required to drive the pump is then

$$P = \frac{1.03\text{kW} \times 100}{83} = 1.24\text{kW}$$

Enter into calculator 1.03 × 100 ÷ 83 =

EXAMPLE 1

A d.c. motor has a full load output of 5.4kW. The input to the motor is 230V and a current of 26A is drawn from the supply.

Calculate the efficiency.

$$Efficiency\ \eta = \frac{output\ power}{input\ power} \times 100$$

Output power = 5400W

Input power = volts × amperes 230 × 26 = 5980W

$$Efficiency = \frac{5400 \times 100}{5980} = 90.3\% =$$

EXAMPLE 2

Calculate the current taken by a 10kW 460V d.c. motor with an efficiency of 78%.

Output power = 10kW. For the calculation this should be converted to watts ie: 10000W.

The input power will always be greater than the output power.

$$\text{Input power } \frac{1000 \times 100}{78} = 12820W$$

To find current drawn from the supply $I = \frac{P}{U} or \frac{1280}{460} = 27.86A$

A simpler method would be:

$$I = \frac{P \times 100}{U \times \%} or \frac{10000 \times 100}{460 \times 78} = 27.86A$$

EXERCISE 10

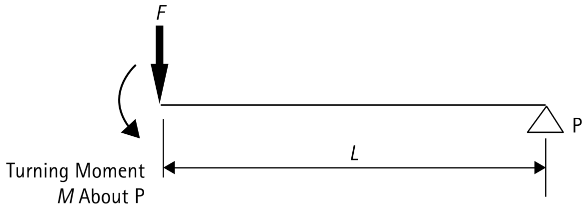
1 A force of 120N is applied at right angles to the end of a bar 1.75m long. Calculate the turning moment produced about a point at the other end of the bar.

2 Calculate the force required which when applied at right angles to the end of a bar 0.72m long will produce a turning moment of 150Nm about a point at the other end.

3 Complete the following table, which refers to Figure 36:

F (newtons)	85		0.25	6.5	
L (metres)	0.35	1.2		0.125	2.75
M (Newton metres)		50	0.15		500

Figure 36



4 A bar 1.5m long is pivoted at its centre. A downward force of 90N is applied at right angles 0.2m from one end. Calculate the downward force to be applied at right angles to the bar at the opposite end to prevent it from rotating. Neglect the weight of the bar.

5 A bar 0.8m long is pivoted at its centre. A downward force of 150N is applied at right angles to the bar at one end. At what distance from the opposite end of the bar should a vertically downwards force of 200N be applied to create equilibrium? Neglect the weight of the bar.

6 A force of 25N is used to move an object through a distance of 1.5m. Calculate the work done.

7 Energy amounting to 250J is available to move an object requiring a force of 12.5N. Through what distance will the object move?

8 Calculate the energy required to raise a load of 240kg through a vertical distance of 8.5m.

9 Calculate the energy required to raise 2.5m^3 of water from a well 12.5m deep.

10 A force of 0.15N is used to move an object through 75mm in 4.5s. Calculate

(a) the work done

(b) the power.

11 Calculate the power required to raise a load of 120kg through a vertical distance of 5.5m in 45s.

12 Complete the following table, which refers to Figure 31, page 81

Distance between effort and pivot (m)	1	1.5	1.25		1.8
Distance between load and pivot (m)	0.125		0.15	0.10	0.20
Load (kgf)		200		390	225
Effort (kgf)	20		50	65	
Force ratio		5			

13 Complete the following table, which refers to Figure 32, page 82

Load to be raised (kgf)	250	320	420		500
Effort required (kgf)		150	75	80	
Vertical height (m)	3	4		2.4	1.8
Length of inclined plane (m)	6		5	5.4	4.2

14 A screwjack as illustrated in Figure 33, page 84, has a thread of pitch 8mm and a radius arm of length 0.5m. Determine

(a) the effort required to raise a load of 1000 kgf

(b) the load which an effort of 5.5 kgf will raise.

(c) What length of radius arm would be required to raise a load of 2500 kgf using an effort of 7.5 kgf?

15 Complete the following table, which refers to the wheel and axle illustrated in Figure 34, page 85:

Radius of wheel *R* (cm)	25	16		17.5	30
Radius of axle *r* (cm)	8	6.5	6		8.5
Load *G* (kgf)	200		255	150	175
Effort *E* (kgf)		75	76.5	72.9	

16 A pump raises 0.15m^3 of water per minute from a well 7.5m deep.

Calculate

(a) the power output of the pump

(b) the power required to drive the pump, assuming an efficiency of 75%

(c) the energy supplied to the pump in one hour.

17 A test on a d.c. motor produced the following results:

Input	230V and 15A
Output	3200W

Calculate the efficiency.

18 Calculate the full-load current of the d.c. motors to which the following particulars refer:

	Supply e.m.f. (V)	Output power (kW)	Efficiency (%)
(a)	240	1	68
(b)	480	15	82
(c)	200	2	74
(d)	250	4	75
(e)	220	10	78

19 A pump which raises 0.12m^3 of water per minute through a vertical distance of 8.5m is driven by a 240V d.c. motor. Assuming that the efficiency of the pump is 72% and that of the motor is 78%, calculate the current taken by the motor.

20 A motor-generator set used for charging batteries delivers 24A at 50V. The motor operates from a 220V supply and its efficiency is 70%. The generator is 68% efficient. Calculate the cost of running the set per hour at full load if the electrical energy costs 4.79p per unit.

21 A pumping set delivers 0.6m^3 of water per minute from a well 5m deep. The pump efficiency is 62%, that of the motor is 74%, and the terminal voltage is 234V. Calculate

(a) the motor current

(b) the cost of pumping 100m^3 of water with energy at 5.18p per unit

(c) the cross-sectional area of the copper cable which will supply the set from a point 50m away with a voltage drop of not more than 6V. (The resistivity of copper is $1.78\times10^{-8}\Omega\text{m}$.)

22 A d.c. motor at 460V is required to drive a hoist. The load to be raised is 4000kg at a speed of 0.2m/s. Calculate the minimum power of motor needed to do this work and also the current it would take, assuming the respective efficiencies of hoist gearing and motor to be 85% and 70%. State the type of motor to be used, and give reasons for the choice.

23 A 50m length of two-core cable of cross-section 70mm^2 supplies a 240V, 30kW d.c. motor working at full load at 85% efficiency.

(a) Calculate the voltage drop in the cable.

(b) What steps would you take to reduce the voltage drop to half the above value, with the same load?

The resistivity of copper may be taken as $1.78\times10^{-8}\Omega\text{m}$.

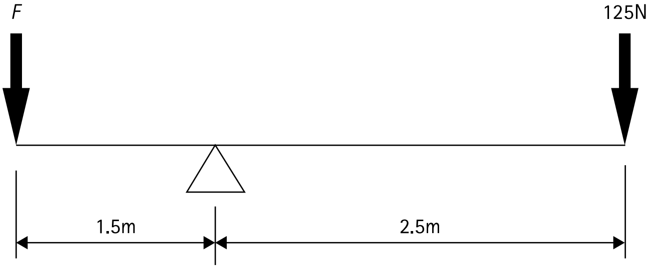
24 A conveyor moves 400kg upwards through a vertical distance of 14m in 50s. The efficiency of the gear is 38%. Calculate the power output of the driving motor. The motor is 78% efficient. Calculate the current it takes from a 250V d.c. supply.

25 The bar in Figure 37 is in equilibrium. The force *F* is

(a) 4.8N

(b) 2083N

Figure 37



(c) 208.3N

(d) 75N

26 A machine weighing 150kgf is raised through a vertical distance of 1.5m by forcing it up a sloping ramp 2.5m long. Neglecting friction, the effort required is

(a) 37.5kgf

(b) 90kgf

(c) 250kgf

(d) 562.5kgf

27 With reference to Figure 34, page 85, if the radius of the large wheel is 25cm and that of the axle is 8.5cm, the load which could be raised by exerting an effort of 95kgf is

(a) 2794kgf

(b) 279kgf

(c) 32.3kgf

(d) 323kgf

12 Power Factor

kVA, kVAr AND kW

In a purely resistive a.c. circuit the power drawn from the supply is generally the same as the energy produced at the load.

For example a 1kW electric fire will draw 1kW of power from the supply and produce 1kW of heat from the fire. This is because the current and voltage are in phase with each other (working together).

If we introduce inductance (magnetic effect) into the circuit, as we would in an electric motor, the voltage and current would be out of phase with each other, as the inductance would hold back the current.

Figure 38 A circuit with the current and voltage in phase with each other

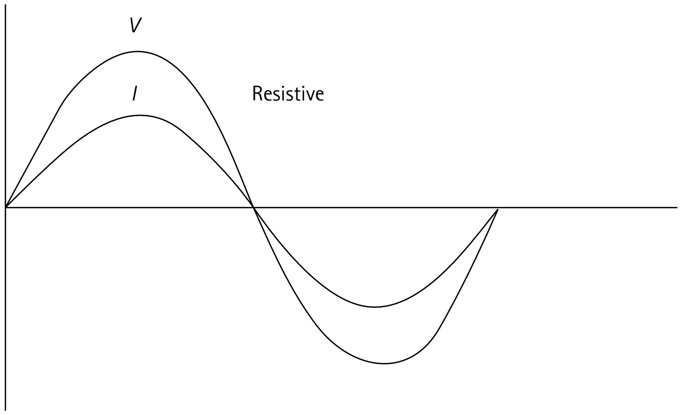
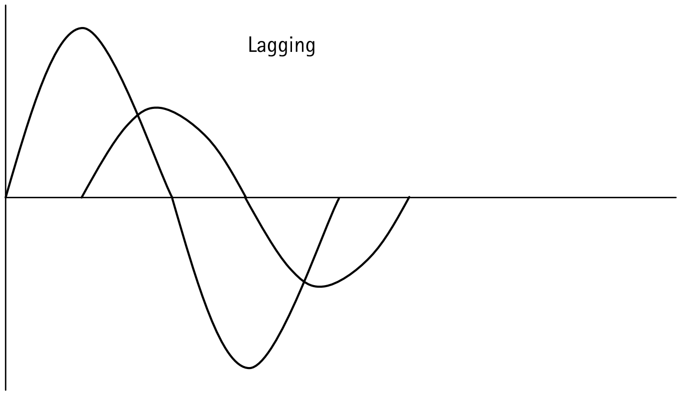


Figure 39 A lagging circuit



This would be known as a 'lagging circuit'.

If we introduced capacitance (electrostatic effect) into the circuit, the voltage and current would be out of phase, it would have the opposite effect to inductance and the voltage would be held back.

This would be known as a 'leading circuit'.

This happens because inductance or capacitance introduces reactance into the circuit. This is referred to as kVAr (reactive volt amperes).

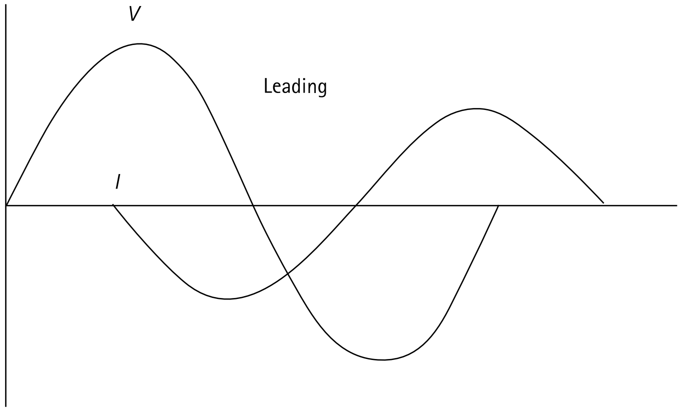
The effect of reactance on the circuit is that more power is drawn from the supply than is required. This is referred to as kVA (input power).

We already know that output power is referred to in kW (output power).

The power factor is the ratio between the kVA & the kW

$$\frac{kW}{kVA} = pf = \frac{\text{Real power (what we get)}}{\text{Apparent power (what we are taking from the supply)}}$$

Figure 40 A leading circuit



EXAMPLE 1

A single phase induction motor has an input power of 14.6 kVA and an output power of 13kW. Calculate the power factor

$$pf = \frac{kW}{kVA} or \frac{13}{14.6} = 0.89$$

Power factor does not have a unit, it is just a number and will always be less than 1.

A purely resistive circuit has no power factor and is known as unity 1.

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Transformers

13

TRANFORMER CALCULATIONS

Transformer calculations can be carried out using the ratio method or by transposition.

The formulae is $\frac{Up}{Us} = \frac{Np}{Ns} = \frac{Is}{Ip}$

(The connection to supply is always made on the primary side.)

Up is the voltage on the primary winding
Ip is the current at the secondary winding
Np is the number of primary turns
Us is the voltage at the secondary winding
Is is the current at the secondary winding
Ns is the number of secondary turns

A step-up transformer is one which has more windings on the secondary side than on the primary side and therefore increases the voltage.

A step-down transformer is one which has less windings on the secondary side that on the primary side and therefore reduces the voltage.

The type of transformer can be shown as a ratio.

(Note we always refer to what happens to the *voltage* in using the terms step up and step down; this is because the current does the opposite.)

EXAMPLE 1

A transformer that has 1000 primary turns and 10000 secondary turns.

The ratio is found $\frac{Ns}{Np} = \frac{10000}{1000} = 10$. As it has more secondary turns than primary it must be a step-up transformer and the ratio is shown to be 1:10.

If the transformer had 10000 primary turns and 1000 secondary turns the calculation would be the same. But because it has less secondary turns than it has primary turns it is a step-down transformer and would be shown as having a ratio of 10:1. *(Note ratio. Primary first: Secondary last.)*

EXAMPLE 2

A transformer has 27000 turns on the primary winding and 900 turns on the secondary. If a voltage of 230V was applied to the primary side, calculate

(a) the transformer ratio

(b) the secondary voltage.

a) The ratio is $\frac{Up}{Us}$ *or* $\frac{27000}{900} = 30$. As the secondary turns are less than the primary it must be a step-down transformer with a ratio of 30:1.

b) As the transformer is a step down with a ratio of 30:1 the secondary voltage will be 30 times less than the primary voltage.

$$\frac{230}{30} = 7.66V$$

EXAMPLE 3

A transformer has a step-up ratio of 1:16; it has 32000 turns on the secondary winding.

Calculate

a) the number of turns on the primary winding

b) the secondary voltage if 50V is supplied to the primary winding.

a) $\frac{Ns}{16} = \frac{32000}{16} = 2000$ Turns

b) Using the ratio 50 × 16 = 800 volts

TRANSFORMER CURRENT

The ratio of the transformer is the same for current although when carrying out transformer calculations it must be remembered:

If the voltage is stepped up the current is stepped down.
If the voltage is stepped down the current is stepped up.

$$\frac{Up}{Us} = \frac{Is}{Ip}$$

Using the values from example 3, if the current supplied from its secondary side is 5A

$$\frac{50}{800} = \frac{5}{Ip}$$

Using the ratio, if it is a step-up voltage transformer the current will step down by the same ratio.

If the secondary current is 5A the primary current is

secondary current x ratio = primary current

5 × 16 = 80A

If transposition is used, *Ip* must be on its own on the top line.

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Electromagnetic Effect

14

MAGNETIC FLUX AND FLUX DENSITY

The unit of magnetic flux is the *weber* (Wb). A magnetic field has a value of 1Wb if a conductor moving through it in one second has an e.m.f. of 1 volt induced in it.

Convenient units used are milliweber (mWb).

$1\text{Wb} = 10^3\text{mWb}$

And the microweber (μWb)

$1\text{Wb} = 10^6\mu\text{Wb}$

The symbol for magnetic flux is Φ.

The flux density in tesla (symbol *B*) is calculated by dividing the total flux by the CSA of the magnetic field.

$$B = \frac{\Phi}{A}$$

Φ is the total magnetic flux (Wb)
A is the CSA of the magnetic field (m^2)
B is the flux density (Wb/m^2 or tesla T)

EXAMPLE 1

The total flux in the air gap of an instrument is 0.15mWb and the CSA of the gap is $500mm^2$.

Calculate the flux density (*tesla*).

Φ in the calculation is in webers, we must convert milliwebers to webers by dividing by 1000. or multiply by (10^{-3}).

A is the CSA of the field in m^2. We must convert mm^2 to m^2, as there are one million mm^2 in $1m^2$ we must divide by 1000000 or multiply by (10^{-6}).

This can be carried out most simply in one calculation:

$$B = \frac{\Phi}{A}$$

$$\frac{0.15}{1000 \times 500 \times 10^{-6}} = 0.3 \textit{ tesla}$$

Enter in calculator 0.15 ÷ (1000 × *EXP* –6) =

Note use of brackets.

EXAMPLE 2

The air gap in a contactor is 12mm by 12mm, the flux density is 1.2T.

Calculate the total flux.

Total area = 12 × 12 = $144mm^2$

This requires simple transposition

$$B = \frac{\Phi}{A} \text{ or } 1.2 = \frac{\Phi}{144 \times 10^{-6}}$$

Transposed = $144 \times 10^{-6} \times 1.2 = \Phi$

(1.72×10^{-4} webers or 0.000172 webers which is 0.17 Wb)

FORCE ON A CURRENT CARRYING CONDUCTOR WITHIN A MAGNETIC FIELD

When a current carrying conductor is placed at right angles to a magnetic field, the force can be calculated by:

$F = BLI$ (Note it is taken for granted each letter has a multiplication sign between it and next letter.)

where F is the force in newtons (N)
B is the flux density (T)
L is the effective conductor length (m)
I is the current (A).

EXAMPLE 1

A conductor 300mm long is placed in and at right angles to a magnetic field with a flux density of 0.5 tesla. Calculate the force exerted on the conductor when a current of 36A is passed through it.

$F = B \times L \times I$

$F = 0.5 \times 0.3 \times 0.36$ (*note conversion from mm to m*) = 5.4N

EXAMPLE 2

A conductor 200mm long is placed in and at right angles to a magnetic field with a flux density of 0.35 tesla. Calculate the current required in the conductor to create a force of 5N on the conductor.

$F = B \times L \times I$

$5 = 0.35 \times 0.2 \times I$

Transpose for I

$$I = \frac{5}{(0.35 \times 0.2)} = 71.42\text{A}\ (\textit{note use of brackets})$$

Enter in calculator $5 \div (0.35 \times 0.2) =$

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Induced e.m.f.

15

When a conductor is moved through a magnetic field at right angles to it an e.m.f. is induced in the conductor.

$e = BlV$ volts $e = BlV$ (*ans in volts*)

where B is the flux density (T)
l is the length of conductor within the magnetic field (m)
V is the velocity of the conductor (metres per second m/s).

EXAMPLE 1

Calculate the induced e.m.f. in a conductor with an effective length of 0.25m moving at right angles, at a velocity of 5m/s. through a magnetic field with a flux density of 1.6 tesla.

$e = B \times l \, x \, V$
$e = 1.6 \times 0.25 \times 5 = 2$ *volts*

EXAMPLE 2

The e.m.f. in a conductor of effective length 0.25m moving at right angles through a magnetic field at a velocity of 5m/s is 1.375V. Calculate the magnetic flux density.

$e = BlV$ *(note e is volts in this equation not V)*
$1.375 = B \times 0.25 \times 5$

Transpose

$$B = \frac{1.375}{(0.25 \times 5)} = 1.1 \text{ tesla}$$

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Self-Inductance

16

If the self-inductance of a magnetic system is L henrys and the current changes from I_1 at time t_1 to I_2 at time t_2, the induced e.m.f. is

$$e = L \times \text{rate of change of current}$$

$$= L \times \frac{I_2 - I_1}{t_2 - t_1} \text{ volts}$$

where the current is in amperes and the time in seconds.

EXAMPLE 1

A coil has self-inductance 3H, and the current through it changes from 0.5A to 0.1A in 0.01s. Calculate the e.m.f. induced.

$$e = L \times \text{rate of change of current}$$

$$= 3 \times \frac{0.5 - 0.1}{0.01}$$

$$= 120\text{V}$$

The self-inductance of a magnetic circuit is given by

$$\text{Self-inductance} = \frac{\text{change in flux linkage}}{\text{corresponding change in current}}$$

$$L = N \times \frac{\Phi_2 - \Phi_1}{I_2 - I_1} \text{ henrys}$$

where N is the number of turns on the magnetizing coil and Φ_2, I_2; Φ_1, I_1 are corresponding values of flux and current.

EXAMPLE 2

The four field coils of a d.c. machine each have 1250 turns and are connected in series. The change in flux produced by a change in current of 0.25A is 0.0035Wb.

Calculate the self-inductance of the system.

$$L = N \times \frac{\Phi_2 - \Phi_1}{I_2 - I_1} \text{ henrys}$$

$$= 4 \times 1250 \times \frac{0.0035}{0.25}$$

$$= 70 \text{ H}$$

Mutual Inductance

17

If two coils A and B have mutual inductance M henrys, the e.m.f. in coil A due to current change in coil B is

$e_A = M \times$ rate of change of current in coil B

Thus, if the current in coil B has values I_1 and I_2 at instants of time t_1 and t_2,

$$e = M \times \frac{I_2 - I_1}{t_2 - t_1} \text{ volts}$$

EXAMPLE 1

Two coils have mutual inductance 3H. If the current through one coil changes from 0.1A to 0.4A in 0.15s, calculate the e.m.f. induced in the other coil.

$$e = 3 \times \frac{0.4 \times 0.1}{0.15} \ (t_2 - t_1 = 0.15)$$

$$= 6\text{V}$$

The mutual inductance between two coils is given by

$$M = N_A \times \frac{\Phi_2 - \Phi_1}{I_{B1} - I_{B2}} \text{ henrys}$$

where N_A is the number of turns on coil A and Φ_2 and Φ_1 are the values of flux linking coil A due to the two values of current in coil B, I_{B2} and I_{B1}, respectively.

EXAMPLE 2

The secondary winding of a transformer has 200 turns. When the primary current is 1A the total flux is 0.05Wb, and when it is 2A the total flux is 0.095Wb. Assuming that all the flux links both windings, calculate the mutual inductance between the primary and secondary.

$$M = N_A \times \frac{\Phi_2 - \Phi_1}{I_{B1} - I_{B2}}$$

$$= 200 \times \frac{0.095 - 0.05}{2 - 1}$$

$$= 9\text{H}$$

EXERCISE 11

1 Convert (a) 0.001 25Wb to milliwebers, (b) 795 000μWb to webers.

2 Complete the following table:

Wb	0.025			0.74
mWb		35		
μWb			59500	850000

3 The flux density in an air gap of cross-sectional area 0.0625m^2 is 1.1 Tesla Calculate the total flux.

4 Determine the flux density in an air gap 120mm by 80mm when the total flux is 7.68mWb.

5 An air gap is of circular cross-section 40mm in diameter. Find the total flux when the flux density is 0.75T.

6 Calculate the force on a conductor 150mm long situated at right angles to a magnetic field of flux density 0.85T and carrying a current of 15A.

7 Determine the flux density in a magnetic field in which a conductor 0.3m long situated at right angles and carrying a current of 15A experiences a force of 3.5N.

8 Complete the table below, which relates to the force on conductors in magnetic fields.

Flux density (T)	0.95	0.296	1.2	0.56	
Conductor length (m)	0.035		0.3	0.071	0.5
Current (A)		4.5		0.5	85
Force (N)	0.05	0.16	12		30

9 A conductor 250mm long is situated at right angles to a magnetic field of flux density 0.8T. Choose six values of current from 0 to 5A, calculate the force produced in each case, and plot a graph showing the relationship between force and current.

10 If the conductor of question 9 is to experience a constant force of 1.5N with six values of flux density ranging from 0.5T to 1.0T, calculate the current required in each case and plot a graph showing the relationship between current and flux density.

11 A conductor 250mm long traverses a magnetic field of flux density 0.8T at right angles. Choose six values of velocity from 5 to 10m/s. Calculate the induced e.m.f. in each case and plot a graph of e.m.f. against velocity.

12 If the conductor of question 11 is to experience a constant induced e.m.f. of 3V with values of flux density varying from 0.5T to 1.0T, choose six values of flux density, calculate in each case the velocity required, and plot a graph of velocity against flux density.

13 A conductor of effective length 0.2m moves through a uniform magnetic field of density 0.8T with a velocity of 0.5m/s. Calculate the e.m.f. induced in the conductor.

14 Calculate the velocity with which a conductor 0.3m long must pass at right angles through a magnetic field of flux density 0.65T in order that the induced e.m.f. shall be 0.5V.

15 Calculate the e.m.f. induced in a coil of 1200 turns when the flux linking with it changes from 0.03Wb to 0.045Wb in 0.1s.

16 The magnetic flux in a coil of 850 turns is 0.015Wb. Calculate the e.m.f. induced when this flux is reversed in 0.25s.

17 A coil has self-inductance 0.65H. Calculate the e.m.f. induced in the coil when the current through it changes at the rate of 10A/s.

18 A current of 5A through a certain coil is reversed in 0.1s, and the induced e.m.f. is 15V. Calculate the self-inductance of the coil.

19 A coil has 2000 turns. When the current through the coil is 0.5A the flux is 0.03Wb; when the current is 0.8A the flux is 0.045Wb. Calculate the self-inductance of the coil.

20 An air-cored coil has 250 turns. The flux produced by a current of 5A is 0.035Wb. Calculate the self-inductance of the coil. (Hint: in an air-cored coil, current and magnetic flux are directly proportional. When there is no current, there is no flux.)

21 Two coils have mutual inductance 2H. Calculate the e.m.f. induced in one coil when the current through the other changes at the rate of 25A/s.

22 Two coils have mutual inductance 0.15H. At what rate must the current through one change in order to induce an e.m.f. of 10V in the other?

23 Two coils are arranged so that the same flux links both. One coil has 1200 turns. When the current through the other coil is 1.5A, the flux is 0.045Wb; when the current is 2.5A the flux is 0.07Wb. Calculate the mutual inductance between the coils.

24 Calculate the e.m.f. induced in one of the coils of question 23 if a current of 0.2A in the other coil is reversed in 0.15s.

25 The total magnetic flux in an air gap is given as 200μW. In milliwebers this is

(a) 0.2

(b) 20

(c) 0.02

(d) 2

26 The total flux in a magnetic circuit is 0.375mWb and the cross-sectional area is 5cm^2. The flux density is

(a) 1.333T

(b) 0.075T

(c) 0.75T

(d) 7.5T

27 A force of 0.16N is experienced by a conductor 500mm long carrying a current of 0.375A and resting at right angles to a uniform magnetic field. The magnetic flux density is

(a) 0.117T

(b) 0.85T

(c) 8.5T

(d) 0.085T

28 The e.m.f. induced in a conductor of length 0.15m moving at right angles to a magnetic field with a velocity of 7.5m/s is 22.5mV. The magnetic flux density is

(a) 20T

(b) 25.3T

(c) 0.02T

(d) 0.0253T

29 The magnetic flux linking a coil of 150 turns changes from 0.05Wb to 0.075Wb in 5ms. The e.m.f. induced is

(a) 750V

(b) 0.75V

(c) 37.5V

(d) 37500V

30 When the current through a coil changes from 0.15A to 0.7A in 0.015s, the e.m.f. induced is 100V. The self-inductance of the coil is

(a) 367H

(b) 0.367H

(c) 2.73H

(d) 1.76H

31 Two coils have mutual inductance 0.12H. The current through one coil changes at the rate of 150A/s. The e.m.f. induced in the other is

(a) 1250V

(b) 0.0008V

(c) 180V

(d) 18V

18 Cable Selection

When a current is passed through a conductor it causes it to rise in temperature.

Heat in cables is the electrician's worst nightmare.

When installing circuits it is important that the correct size current-carrying conductor is selected to carry the current required without causing the cable to overheat and that the voltage drop caused by the resistance of the cable is not greater than is permissible.

The following calculations are designed to compensate for conductor temperature rise.

- We must first calculate the design current that the circuit will have to carry (I_b).
- Calculation is $\frac{P}{U} = I$ (I being design current).
- A protective device must now be selected (I_n); this must be equal to or greater than I_b.
- If the cable is to be installed in areas where environmental conditions will not allow the cable to cool, rating factors will be need to be used. This will ensure that the cable size selected will be suitable for installation and will not be adversely affected by the additional temperatures likely to be encountered.
- C_a is a rating factor to be used where ambient temperature is above or below 30 deg C. This factor can be found in Table 4B1 Appendix 4 of BS7671.

- C_g is a rating factor to be used where the cable is grouped or bunched (touching) with other cables. This factor can be found in Table 4C1 Appendix 4 of BS7671.
- C_i is a factor for use where a conductor is surrounded by thermal insulation and can be found in Table 52.2 part 5 of BS7671.
- C_f is a factor for rewirable fuses and is always 0.725. This factor must always be used when rewirable fuses protect a circuit. The reason for the factor will be explained at end of the chapter.
- These factors should be multiplied together and then divided into I_n.
- Therefore the calculation is $I_t \geq \dfrac{I_n}{C_a \times C_g \times C_i \times C_f}$.
- I_t is the value given in the current carrying tables in appendix 4 of BS 7671.
- The current carrying capacity of the cable must be equal to or greater than the result of this calculation.
- It should be remembered that all of the correction factors which affect the cable at the same section should be used.

EXAMPLE

A circuit is to be installed using 2.5mm^2 – 1.5mm^2 twin and earth 70°C thermoplastic cables; it is 32 metres long and protected by a BS 88 fuse. The load to be supplied is a 4.2kW kiln, the circuit is to be installed in mini trunking containing one other circuit at an ambient temperature of 35°C. Maximum permissible voltage drop is 7 volts. Supply is a TN-C-S system with a Z_e of 0.35**Ω**. Calculate the minimum cable that may be used.

$$\text{Design current}: I_b = \frac{P}{U}$$

$$\frac{42 \times 1000}{230} = 1826\,\text{A}$$

Protective device I_n (≥ 18.26) Nearest BS 88 is 20 amperes.

In the example the cable is installed in plastic trunking.

From BS 7671 Table 4A2 we must now select an installation method to use when we use the current carrying capacity table for selecting the cable size.

Number 6/7 method b matches the example used

The cable is installed in a trunking which will contain one other circuit.

The ambient temperature is 35°C. A correction factor for ambient temperature (C_a) from Table 4B1 must be used. For thermoplastic cable @ 35°C the factor is 0.94.

Correction factor for grouping (C_g) is required from BS 7671 Table 4C1; it can be seen that for two circuits in one enclosure a factor of 0.8 must be used.

Using these factors it is now possible to calculate the minimum size conductors required for this circuit.

$$I_t \geq \frac{I_n}{(C_a \times C_g)}$$

$$I_t \geq \frac{20}{(0.8 \times 0.94)} = 26.59\,\text{A}$$

Calculator method 20 ÷ (0.8 × 0.94) = 26.59

This is the minimum value of current that the cable must be able to carry to enable it to be installed in the environmental conditions affecting the cable.

From Table 4D5 columns 1 and 4 it can be seen that a 4mm^2 cable has an I_t (current carrying capacity) of 30 amperes.

A cable with 4mm^2 live conductors will carry the current in these conditions without overheating, but will it comply with the voltage drop requirements?

From Table 4D5 column 8 it can be seen that 4mm^2 cable has a voltage drop of 11 (mV/A/m) or millivolts x load current x length of circuit. As the value is in millivolts it must be converted to volts by dividing by 1000.

The circuit length is 32 metres and the load current is 18.26 amperes.

$$\text{Calculation } \frac{mV/A/m}{1000} = \frac{11 \times 18.26 \times 32}{1000} = 6.42 \text{ volts}$$

The voltage drop in this cable will be 6.42 volts which is acceptable as the maximum permissible for the circuit is 7 volts.

The calculations which have been carried out up to this point have been to select a cable to comply with the current and voltage drop requirements for the circuit.

This is only part of the calculation. It is now important that a calculation is carried out to prove that the protective device will operate within the time required if an earth fault were to occur on the circuit.

As the load is less than 32A the disconnection time must be 0.4 second (reg 411.3.2.2 and Table 41.1).

The resistance of the cable must now be calculated.

A 4mm^2 twin & earth cable will have a C.P.C of 1.5mm^2.

From Table I1 in the *On-Site Guide* it can be seen that this cable will have a resistance of 16.71 milli ohms per metre @ 20°C.

As the cable could operate at 70°C the multiplier from Table I3 in the *On-Site Guide* must be used to adjust the resistance value from 20°C to 70°C.

Calculation

$\text{m}\Omega \times$ length $\times$ multiplier 1.2 $\div$ 1000 (*to convert to ohms*)

$$\frac{16.71 \times 32 \times 1.2}{1000} = 0.64\Omega$$

The resistance of the cable at operating temperature of 70°C is 0.64Ω.

Z_s (*earth loop impedance*) must now be calculated.

$Z_s = Z_e + R_1 + R_2$

From the information given in the example, Z_e (*external earth loop impedance*) is 0.35Ω.

Therefore $Z_s = 0.35 + 0.64$ $Z_s = 0.99\Omega$

This value must now be checked against the value for maximum permissible Z_s. This is in BS 7671 Table 41.2 for a 0.4 second disconnection.

It can be seen that the maximum Z_s for a 20A BS 88-2 fuse is 1.77Ω.

As the circuit a has a calculated Z_s of 0.99 it will be satisfactory.

EXERCISE 12

1 The voltage drop figure for a certain cable is 44mV/A/m. Calculate the voltage drop in a 15m run of this cable when carrying a load of 6A.

2 The design current of a circuit protected by a BS 88 fuse is 28A, the grouping correction factor is 0.8, and the ambient temperature correction factor is 1.04. Calculate the minimum current-carrying capacity of the cable.

3 A circuit is protected by a BS EN 60898 circuit breaker rated at 32A. The grouping correction factor is 0.54 and the ambient temperature correction factor is 0.94. Calculate the minimum current capacity of the cable.

4 Calculate the effect on the minimum cable current rating required in question 3 if the circuit breaker is replaced by a BS 3036 semi-enclosed fuse.

5 A cable with a voltage drop figure of 6.4mV/A/m supplies a current of 24A to a point 18m away from a 230V supply source. Determine (a) the voltage drop in the cable and (b) the actual voltage at the load point.

6 There is a voltage drop limitation of 5V for a circuit wired in pvc-insulated twin and earth cable (clipped direct), having a length of run of 35m. The current demand is assessed as 36A. Protection is by a BS 88 fuse.

Establish the:

(a) fuse rating

(b) maximum mV/A/m value

(c) minimum cable cross-sectional area.

DISCONNECTION TIMES FOR FUSES

BS 7671 requirements part 4 chapters 41 and 47 give maximum disconnection times for circuits under earth fault conditions.

Regulation 411.3.2.2 tells us that the maximum disconnection times that must be applied to final circuits up to and including 32A must be as shown in Table 41.1.

Maximum disconnection times for final circuits not exceeding 32A

System	$50V < U_0 \leq 120V$ seconds		$120V < U_0 \leq 230V$ seconds		$230 < U_0 \leq 400V$ seconds		$U_0 > 400V$ seconds	
	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.
TN	0.8	Note	0.4	5	0.2	0.4	0.1	0.1
TT	0.3	Note	0.2	0.4	0.07	0.2	0.04	0.1

Note: Disconnection time is not required for protection against electric shock but it may be required for other reasons.

Maximum disconnection times for 230V circuits supplied by a TN system must not exceed 0.4 seconds and for 230V circuits supplied by a TT system the disconnection time must not exceed 0.2 seconds.

Table 41.2 provides the maximum Z_s values for circuit breakers and fuses for a 0.4 sec disconnection time and Table 41.3 provides the values for circuit breakers. RCDs will usually be required to provide a 0.2 second disconnection time for circuits supplied by TT systems.

Maximum disconnection time for distribution circuits and for final circuits greater than 32A is 5 seconds and the Z_s value for these circuits is provided by Table 41.4.

EXAMPLE

A 45A circuit will have a maximum disconnection time of 5 seconds, where it is protected by a BS 3036 fuse. Table 41.4 should be used to check the maximum permitted Z_s. It can be seen that for this circuit the max Z_s is 1.59Ω.

DISCONNECTION TIMES FOR CIRCUIT BREAKERS

When circuit breakers are used, it is important that the maximum Z_s values from Table 41.3 are used. When these values are used, compliance with regulations will be achieved as these devices are constructed to operate within 0.1 seconds providing the correct value of maximum Z_s is used.

BS7671 Requirements part 4, chapters 41 and 47 lay down maximum disconnection times for circuits under earth fault conditions.

Circuit breakers to BS EN 60898 are available as three types, B, C and D. It is important that the correct type is selected.

Type B will operate in 0.1s when a maximum current of 5 times its current rating passes through it.

Type C will operate in 0.1s when a maximum current of 10 times its current rating passes through it.

Type D will operate in 0.1s when a maximum current of 20 times its current rating passes through it.

To allow this amount of current to flow the resistance of the circuit ($R_1 + R_2$) must be low enough. For circuit breakers the maximum permissible Z_s can be calculated if required using Ohm's law.

EXAMPLE

A 20 amp BS EN 60898 device must operate at a maximum of 5 times its rating.

$5 \times 20 = 100A$

If this current value is now divided into the open circuit voltage U_{oc} the Z_s for the circuit will be calculated.

$$\frac{230}{100} = 2.3\Omega$$

This is the maximum Z_s for a 20 amp type B device.

For a 20 amp type C device

$10 \times 20 = 200A$

$$\frac{230}{200} = 1.15\Omega$$

For a 20 amp type D device

$20 \times 20 = 400A$

$$\frac{230}{400} = 0.57$$

This calculation can be used to calculate the Z_s for any BS EN 60898 device.

The overload characteristic for these devices is the same for each type, i.e. they will all operate at a maximum of 1.45 times their current rating.

FUSING FACTORS, FAULT CURRENT AND OVERLOAD

FUSE FACTOR (I_2)

Regulation 433.1.1 describes the characteristics required of them to comply with BS 7671.

The current causing effective operation for *overload* (I_2) of a protective device must not be greater than 1.45 times the current carrying capacity of the conductor that it is protecting.

Apart from BS 3036 semi-enclosed fuses all other protective devices are manufactured to comply with Regulation 433.1.1.

A BS 3036 semi-enclosed fuse will not operate on overload until the current passing through it reaches approximately 2 times its rating.

A fusing factor of 0.725 must be used when using BS 3036 fuses (Regulation 433.1.101).

EXAMPLE

A circuit is required to carry a load of 14 amperes.

The protective device must be ≥ 14A; the nearest rating BS 3036 fuse is 15A.

The cable selected for this circuit must be calculated using the following calculation.

Cable rating must be a minimum of $\frac{15}{0.725} = 20.69\text{A}$

The BS 3036 fuse will operate at 15 × 2 = 30

A cable with a minimum rating of 20.69A × 1.45 = 30A, this will satisfy Regulation 433.1.101.

This factor is to be used on all circuits using BS 3036 for overload protection and must be used with any other correction factors for circuits as described in the chapter for cable selection.

SHORT CIRCUIT CURRENT

This is a current which will flow in a circuit of negligible impedance between live conductors.

Figure 41 shows the supply phase and neutral each having a resistance of 0.02Ω and the final circuit phase and neutral each having a resistance of 0.23Ω.

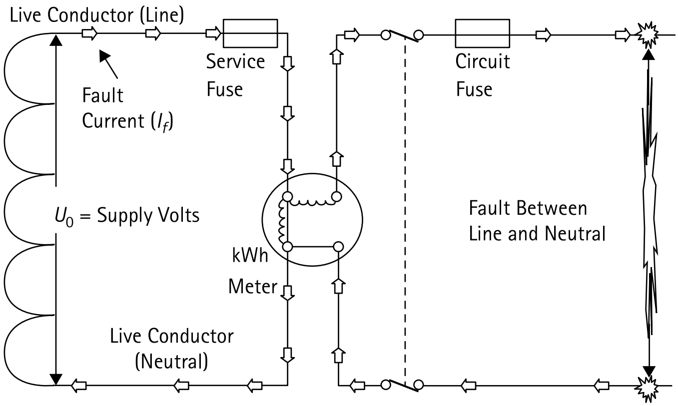
The total resistance of the supply and final circuit will be:

$0.02 + 0.02 + 0.11 + 0.11 = 0.26\Omega$

To calculate the short circuit current the open circuit current U_{oc} of the supply transformer is used. For a single phase supply this is taken to be 230V.

$$\frac{230}{026} = 923A$$

Figure 41 Short circuit current



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Earth Fault Loop Impedance

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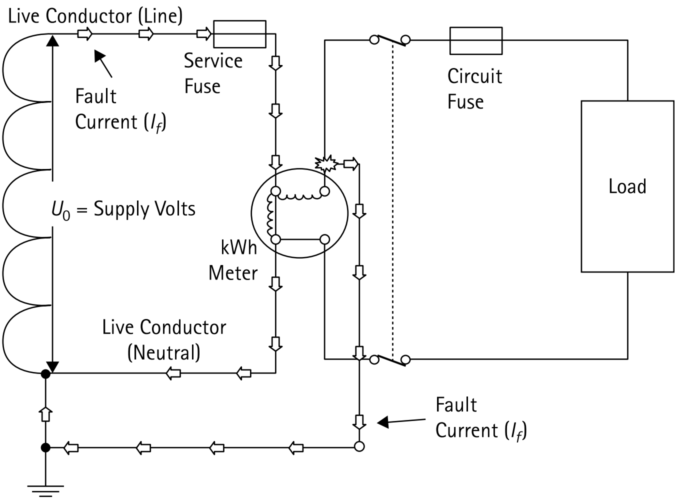
EARTH FAULT LOOP IMPEDANCE Z_e

Z_e is the external earth fault loop impedance (resistance) line conductor and earthing arrangement of the supply, see Figure 42.

Impedance of line conductor 0.02Ω

Impedance of earth path 0.78Ω

Figure 42 Earth fault loop impedance



Total external earth loop impedance $Z_e = 0.02 + 0.78 = 0.8\Omega$

Earth fault current if measured at the ends of the supply cable (origin) can be calculated:

$$\frac{230}{0.8} = 300\,A$$

EXAMPLE

The 100A high breaking current service fuse (BS 88-3) at the origin of an installation has a fusing factor of 1.4, the nominal voltage to earth U_o is 230V, and the tested value of Z_e at the origin of the installation is 0.38Ω.

(a) Calculate the minimum current required to blow the fuse.
(b) How much current will flow if the line conductor comes into contact with the earthed sheath of the supply cable at the origin of the installation?
(c) Using Appendix 3 from BS 7671 state approximately the current which would be required to operate the protective device in the required time under conditions described in (b).

(a) Minimum fusing current (I_2) = 100 × 1.4 = 140A

(b) Earth fault current (I_f) $= \dfrac{U_o}{Z_e}$

$$\frac{230}{0.38} = 631.6\,A$$

(c) Using the table attached to Figure 3.A1 from BS 7671 it can be seen that for a 5 second disconnection time a minimum current of 580A is required to operate the fuse.

EARTH FAULT LOOP IMPEDANCE Z_s

Z_s is the total earth fault loop impedance of the supply and the resistance of the final circuit cables, line conductor (*R1*) and circuit protective conductor (*R2*).

$Z_s = Z_e + R1 + R2$

If the loop impedance of a system (Z_s) is high, the fault current will be low and the device protecting the circuit may not operate within the required time. This will result in the extraneous and exposed conductive parts within the circuit rising in potential and becoming a serious shock risk.

EXAMPLE

A circuit is to be wired in 70°C thermoplastic cable with copper $2.5mm^2$ line, and $1.5mm^2$ circuit protective conductors. The circuit is 30 metres long and the Z_e for the circuit is measured at 0.35Ω.

(a) Calculate Z_s.
(b) Calculate earth fault current.

From Table I1 in the *On-Site Guide*, it can be found that a $2.5/1.5mm^2$ cable with copper conductors will have a ($R1 + R2$) value of 19.41mΩ/m.

The multiplier of 1.2 from Table I3 of the *On-Site Guide* must be used to correct operating resistance from 20°C to 70°C (operating temperature).

(a) Total resistance of final circuit cables $\frac{19.41 \times 30 \times 1.2}{1000} = 0.698\Omega$

$Z_s = Z_e + R1 + R2$

$Z_s = 0.35 + 0.698$

$Z_s = 1.04$

(b) Earth fault current $= \frac{230}{1.04} = 230.76$

EXERCISE 13

1. Complete the following table.

U (volts)	10	20		40	
I (amperes)	1		3	4	5
R (ohms)		10	10		10

2 Calculate the voltage when a current of 15.65A is following in a circuit with a resistance of 2.3Ω.

3 Complete the following table.

U (volts)		240		240	
I (amperes)	12	6	4	3	2.4
R (ohms)	20		60		100

4 When the table in question 3 has been correctly completed, plot a graph showing the relationship between current and resistance. Use the graph to find the value of the current when the resistance is 78Ω. State also the value of resistance required to give a current of 9.5A.

5 Complete the following table.

U (volts)	100	100		56	96	132	84	144		
I (amperes)	10		12	7	8	12		12	11	9
R (ohms)	10	8					12		11	7

6 Complete the following table.

I (amperes)	100		10		0.1	0.1		0.001	0.1	
R (ohms)	0.1	1000	0.1	1000	0.1		0.1			0.01
U (volts)		100		10		100	10	20	200	2

7 Complete the following table.

R (ohms)		14		16		0.07	12		0.75	15
I (amperes)	0.5	15	0.05		1.2	0.9		0.2		
U (volts)	240		25	96	132		8.4	100	6	120

8 A cable of resistance 0.029Ω carries a current of 83A. What will be the voltage drop?

9 To comply with BS 7671 regulations, the maximum value of voltage drop which can be tolerated in a circuit supplied from the 230V mains is 5%. Calculate the maximum resistance which can be allowed for circuits carrying the following currents: (a) 28A, (b) 53A, (c) 77A, (d)13A, (e) 203A.

10 The cable in a circuit has a resistance of 0.528Ω. What is the maximum current it can carry if the voltage drop is not to exceed 5.8V?

11 A 50V a.c. system supplies the following loads by means of a radial circuit:

Load A: 15A at a distance of 18m from the supply point S.

Load B: 25A at a distance of 35m from the supply point A.

Load C: 20A at a distance of 43m from the supply point B.

The type of cable used produces a voltage drop of 2.7mV per ampere per metre. Calculate the voltage drop in each section of the circuit and the voltage at each load point.

12 Assuming a fusing factor of 1.4, complete the following table, which refers to various sizes of fuse.

Nominal current (A)	5	15	30	60	100
Minimum fusing current (A)					

13 Repeat exercise 12 using a fusing factor of 1.2

14 A current of 1.5A flows in a 25Ω resistor. The voltage drop is:

(a) 0.06V

(b) 37.5V

(c) 16.67V

(d) 3.75V

15 If a cable must carry a current of 19.5A with a voltage drop of not more than 6V, its resistance must not exceed:

(a) 32.5Ω

(b) 117Ω

(c) 0.308Ω

(d) 3.25Ω

16 A fuse rated at 30A has a fusing factor of 1.4. The current required to blow the fuse is:

(a) 31.4A

(b) 21.4A

(c) 42A

(d) 30A

17 A faulty earthing conductor has a resistance of 12.5Ω, and the resistance of the remainder of the fault path is 1.5Ω. The supply voltage is 230V. The voltage appearing between metal parts and earth is:

(a) 205.4V

(b) 238.5V

(c) 24.6V

(d) 217.7V

20

Material Costs, Discounts and Value Added Tax

To find the Value Added Tax due on an item

EXAMPLE 1

If a consumer's unit with a main switch was quoted by the suppliers as costing £53.85 plus VAT, calculate the cost of the item including VAT.

$$\text{VAT on item} = \frac{53.85 \times 20}{100} = 10.77$$

Item including VAT £53.85 + £10.77 = £64.62

Or enter on calculator 53.85 × 20% = (10.77) + 53.85 = (£64.62) (Figures in brackets are the answers that you will get. Do not enter into calculator.)

A difficulty that often occurs is that a value is given including VAT and it is necessary to calculate the item cost without the VAT.

EXAMPLE 2

Using the values from example 2.

A consumer's unit costs £63.27 inclusive of VAT. Calculate the VAT content.

$$\frac{64.62}{1.2} = 53.85 \text{ or } \frac{64.62 \times 100}{120} = 53.85$$

Therefore the vat content is £64.62 – £53.85 = £10.77.

Or transpose formula from example 1 to find cost of unit without VAT

(53.85) × 1.20 = 64.62

Transpose $(53.85) = \dfrac{64.62}{1.20}$ Cost less VAT is £ 53.85

EXAMPLE 3

One hundred metres of 4 mm^2 3 core steel wired armoured cable costs 258.60 per 100 metres.

If a trade discount of 30% was allowed on this cable calculate the cost of 60 metres.

$$30\% \text{ of } 258.60 = \frac{30 \times 258.60}{100} = £77.58$$

Trade price of cable per 100 metres £258.60 – £77.58 = £181.02

Cost of 1 metre of this cable at trade price is $\dfrac{181.2}{100} = £1.81$

60 metres would cost £1.81 × 60m = £108.60

A far easier method would be to use a calculator and enter:

258.6 × 30 % = (77.58) = (181.02) ÷ 100 × 60 = (108.60) (Figures in brackets are the answers that you will get. Do not enter them in to calculator.)

If value added tax was needed to be added (current VAT rate is 20%)

$$\frac{108.6 \times 20}{100} = 21.72$$

£21.72 is the VAT on the cable and should be added to the trade cost

£108.6 + £21.72 = £130.32

Calculator method: enter 108.6 × 20 % + (130.32) answer in brackets.

EXERCISE 14

1. If 60 lengths of cable tray cost £732 including VAT, calculate (a) the cost of each length, (b) the cost of 17 lengths.
2. If 66m of black-enamelled heavy-gauge conduit cost £87 including VAT, calculate (a) the cost per metre, (b) the cost of 245m.

3 If 400 woodscrews cost £4.52, calculate (a) the cost of 250 screws, (b) the number of screws which could be purchased for £5.28.

4 If 100m of heavy gauge plastic conduit is listed at £103.20 plus VAT at 20%. Calculate the cost of 100m to the customer.

5 The list price of 1000m of 2.5mm^2 twin and earth cable is £430.00 plus VAT at 20% and a trade discount of 15%. Calculate the invoice price of 300m at the same terms.

6 An invoice was made out for 20 lengths of 50mm × 50mm of cable trunking. Each length costs £27.36 plus VAT at 20% less 35% trade discount. Calculate the total invoice cost.

7 An alteration to an existing installation requires the following material:

12m of plastic trunking at £6.23 per m

14.5m of plastic conduit at £86 per 100m

45m of cable at £14.60 per 100m

29 single socket-outlets at £12.15 each

saddles, screws, plugs, etc. £9.20.

Calculate the total cost of the materials. VAT is chargeable at 17.5%.

8 An order was placed one year ago for the following items:

135m MIMS cable at £217 per 100m

500 pot-type seals/glands at £26 per 10

200 one-hole clips at £29 per 100.

Calculate (a) the original cost of this order; (b) the present cost of the order, allowing 15% per annum for inflation. VAT is chargeable at 17.5% at both (a) and (b).

9 The materials list for an installation is as follows:

45m of 1.00mm^2 twin with earth cable at £19.30 per 100m

45m of 2.5mm^2 twin with earth cable at £28.20 per 100m

nine two-gang one-way switches at £3.50 each

two two-way switches at £2.12 each

six single switched socket outlets at £3.35 each

two twin switched socket outlets at £6.40 each

one consumer unit at £62.20

sheathing, screws, plugs, etc. £8.00.

Determine the total cost of the materials for this work, adding 17.5% VAT.

10 A contractor's order for conduit and fittings reads as follows:

360m of 20mm BEHG steel conduit at £147 per 90m

50 20mm BE standard circular terminal end boxes at £1.81 each

50 20mm BE standard through boxes at £2.17 each

50 20mm BE standard tee boxes at £2.57 each

50 20mm spacer-bar saddles at £23.20 per 100

50 20mm steel locknuts at £14.90 per 100

50 20mm brass hexagon male bushes at £38 per 100.

All prices are list, the contractor's discount on all items is 40%, and VAT is chargeable at 17.5%. Calculate the invoice total for this order.

11 It is necessary to install six tungsten-halogen floodlighting luminaires outside a factory and the following equipment is required.

Manufacturer's list prices are as shown:

6 off 500W 'Teck' T/H luminaries	£14.50 each*
1 off 'Teck' PIR sensor/relay unit	£24.10 each*
80m 20mm galvanized steel conduit	£186 per 100m
6 off 20mm galvanized tee boxes	£275 per 100
1 off 20mm galvanized angle box	£265 per 100
7 off galvanized box lids and screws	£11 per 100
8 off 20mm galvanized couplings	£19 per 100

30 off 20mm spacer saddles	£17.20 per 100
14 off 20mm brass male bushes	£38 per 100
1 off 'TYLOR' 20A switch-fuse	£24.50 each*
1 off 'TYLOR' 10A one-way switch	£3.20 each*
180m 1.5mm^2 pvc single cable	£12.15 per 100m
3m 0.75mm^2 three-core pvc flex	£26.30 per 100m
9 off 10A three-way porcelain connectors	£80 per 100
sundries taken from own stock	£15

The wholesaler offers a 25% discount on non-branded items and 10% on branded * items. Calculate

(a) the basic cost of the materials

(b) the total cost including VAT at 17.5%.

12 The list prices of certain equipment are as follows:

(a) £570.30 with 25% discount

(b) £886.20 with 40% discount

(c) £1357.40 with 10% discount

(d) £96.73 with 35% discount.

For each of the above establish:

(i) the basic cost price

(ii) the VAT chargeable.

13 For each of the following VAT inclusive prices establish the basic cost price:

(a) £656.25

(b) £735.33

(c) £895.43

(d) £1025.27

(e) £3257.72

14 A certain cable is priced at £19.50 per 100m plus 17.5% VAT. The cost of 65m is:

(a) £22.91

(b) £16.09

(c) £14.89

(d) £10.46

15 A certain item of equipment was invoiced at £ 25.75 and this included VAT at 17.5%. The list price of the item was:

(a) £3.84

(b) £21.91

(c) £30.26

(d) £43.25

Electrostatics

21

THE PARALLEL PLATE CAPACITOR

When a capacitor is connected to a d.c. supply it becomes charged; the quantity of charge is in coulombs.

$Q = CU$

where Q = quantity, C = capacitance in farads and U = voltage

EXAMPLE 1

A 70μF capacitor is connected to a 150 volt d.c. supply. Calculate the charge stored in the capacitor.

$Q = C \times U$

$= 70 \times 10^{-6} \times 150$

$= 0.105$ coulombs

Enter into calculator 70 × EXP^{-6} ×150 =

Energy stored is in watts or joules.

$$W = \frac{1}{2} CU^2$$

EXAMPLE 2

Calculate the energy stored in a 120μF capacitor when connected to a 110 volt d.c. supply.

$$W = \frac{120 \times 10^{-6} \times 110^2}{2}$$

0.726 joules

Enter into calculator 120 EXP – 6 × 110 EXP ÷ 2 =

SERIES ARRANGEMENT OF CAPACITORS

If a number of capacitors are connected in series, the total capacitance can be calculated.

$$\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{C_t} = \frac{1}{C}$$

The result will be as equivalent to a single capacitor.

EXAMPLE 1

Calculate the value of capacitance when capacitors of 23, 42 and 36μF are connected in series.

$$\frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{1}{C} = C$$

$$\frac{1}{23} + \frac{1}{42} + \frac{1}{36} = \frac{1}{C}$$

$= 10.51\ \mu F$

Enter on calculator $23X^{-1} + 42X^{-1} + 36X^{-1} = X^{-1} =$

EXAMPLE 2

Calculate the value of a capacitor which when connected in series with another of 20μF will give a resulting capacitance of 12μF.

$$\frac{1}{C} = \frac{1}{C} + \frac{1}{C}$$

$$\frac{1}{12} = \frac{1}{20} + \frac{1}{C}$$

$$\frac{1}{C} = \frac{1}{12} - \frac{1}{20}$$

$= 30\mu F$

Enter on calculator $12X^{-} - 20X^{-} = X^{-} =$

EXAMPLE 3

Capacitors of 4, 6 and 12μF are connected in series to a 300 volt d.c. supply. Calculate

(a) total capacitance
(b) the charge stored
(c) the energy stored.

(a)

$$\frac{1}{C} = \frac{1}{4} + \frac{1}{6} + \frac{1}{12}$$

$$= \frac{1}{0.5}$$

$= 2\mu F$

(b) Charge stored

$Q = CU$

$= 2 \times 300$

$= 600\mu F$

(c) Energy stored

$$W = \frac{1}{2} CU^2$$

$$= \frac{600 \times 10^{-6} \times 300^2}{2}$$

or $600 \times 10^{-6} \times 300^2 \times 0.5$

$= 27$ joules

PARALLEL ARRANGEMENT OF CAPACITORS

When a number of capacitors are connected in parallel they are equivalent to a single capacitor of value C given by:

$C = C_1 + C_2 + C_3$, etc.

When the arrangement is connected to a d.c. supply voltage, the total charge is the sum of the charges stored in each capacitor:

$Q = Q_1 + Q_2 + Q_3$

Q_1 is the charge on C_1, etc. The voltage is common to all capacitors.

EXAMPLE 1

Capacitors of 8 and 10μF are connected in parallel to a 20V supply. Calculate the charge stored on each and the total energy.

Charge on 8μF capacitor is

$Q = 8 \times 20$

$= 160\mu C$

Charge on 10μF capacitor is

$Q = 10 \times 20$

$= 200\mu C$ (microcoulombs as C is in μF)

Total energy is: $W = \frac{1}{2} CU^2$

$= \frac{1}{2} \times 18 \times 20^2$

$= 3600\mu J$ (as C is in microfarads)

EXAMPLE 2

Calculate the value of a single capacitor equivalent to the arrangement of capacitors of 4μF and 6μF in parallel and a 12μF capacitor in series with them. Capacitance of parallel group is

$$C_1 + C_2 = C$$

$$= 4 + 6$$

$$= 10\mu F$$

Treated as a single capacitor, this value can now be used with the capacitor in series to calculate the total capacitance.

$$\frac{1}{C} = \frac{1}{10} + \frac{1}{12}$$

$$= 5.45\mu F$$

EXERCISE 15

1 Complete the following table, which refers to a certain variable capacitor.

Applied volts (U)	50	25	80	45
Capacitance (μF)		0.3	0.4	0.8
Charge (μC)	10	18	48	

2 Capacitors of 3μF and 5μF are connected in series to a 240V d.c. supply. Calculate

(a) the resultant capacitance

(b) the charge on each capacitor

(c) the p.d. on each capacitor

(d) the energy stored in each capacitor

3 Calculate the value of a single capacitor equivalent to three 24μF capacitors connected in series. What would be the value of ten 24μF capacitors connected in series?

4 What value of capacitor connected in series with one of 20μF will produce a resultant capacitance of 15μF?

5 Three capacitors, of values 8μF, 12μF and 16μF, respectively, are connected across a 240V d.c. supply, (a) in series and (b) in parallel. For each case, calculate the resultant capacitance and also the potential difference across each capacitor.

6 A 12μF capacitor is charged to 25V. The energy stored is

(a) 150μJ

(b) 3750μJ

(c) 3750J

(d) 150J

7 Capacitors of 2μF and 4μF are connected in series. When an additional capacitor is connected in series, the combined capacitance falls to 1μF. The value of the third capacitor is

(a) 4μF

(b) 0.5μF

(c) 0.25μF

(d) 1.2μF

8 Capacitors of 8μFμ, 12μF, and 20μF are connected in parallel. For a total charge of 4000μC to be stored, the voltage to be applied to the combination is

(a) 0.01V

(b) 15 480V

(c) 100V

(d) 1034V

22 Formulae

$U = I \times R$	Voltage
$I = \frac{R}{U}$	Current
$R = \frac{U}{I}$	Resistance
$P = U \times I$	Power
$P = I^2 R$	Power loss
$I = \frac{R}{U}$	Current
$U = \frac{P}{I}$	Voltage
$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{R} \therefore R$	Resistors in parallel
$\frac{\pi \times d^2}{4} = CSA$	Area of a circle (mm^2 or m^2)
$\pi \times d = C$	Circumference of a circle (mm or m)
$\frac{1}{2}\, base \times height$	Area of triangle (mm^2 or m^2)
$\frac{1.78 \times 10^{-8} \times L}{CSA \times 10^{-6}} = R$	Resistance of a copper conductor (Ω)

(where CSA is in mm^2)

$\frac{2.84 \times 10^{-8} \times L}{CSA \times 10^{-6}} = R$	Resistance of an aluminium conductor (Ω)

(where CSA= is in mm^2)

Transformer calculation

$$\frac{Up}{Us} = \frac{Np}{Ns} = \frac{Is}{Ip}$$

Transformer efficiency

$$\frac{Power\,out}{Power} = per\,unit$$

$\times$ 100 *for* %

Work

$W = f \times d$ Work in N/m = force in Newtons $\times$ distance in mm or m

1kg = 9.81 Newtons

$$P = \frac{W}{t}\ or\ \frac{work\,done(\mathrm{Nm})}{Time(\mathrm{secs})} = \text{Power in watts}$$

$J = W \times t$ or Energy (joules) = watts $\times$ time in seconds

$$E = \frac{Input}{Output} \times 100 \text{ Efficiency in \%}$$

Capacitance

Charge of a capacitor is in coulombs $Q = CU$

Total charge of more than one capacitor $Q = Q_1 + Q_2 + Q_3\ etc. = Q_{\text{total}}$

Or capacitance is $\frac{Q}{U}$ Farads

Total capacitance of series connected $\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\ etc. = \frac{1}{C_t} = C$

Total capacitance of parallel connected $C_1 + C_2 + C_3\ etc. = C_{\text{total}}$

Energy stored in a capacitive circuit

Energy $W = \frac{1}{2}CV^2\ joules$

Energy stored in an inductive circuit

Energy $W = \frac{1}{2}LI^2$ joules *(where L is in henrys)*

Three phase calculations

I_p = Phase current
I_L = Line current
U_L = Line voltage
U_P = Phase voltage

In star *(Only one current)*

$$I_p = I_L$$

$$U_p = \frac{U_l}{\sqrt{3}}$$

$$U_L + U_p\sqrt{3}$$

$$P = \sqrt{3} \times U$$

$$I_L = \frac{P}{\sqrt{3} \times U_L}$$

In circuits with power factor

$$P = \sqrt{3} \times U_L \times I_L \times \cos\text{Ø}$$

$$I_L = \frac{P}{\sqrt{3} \times U_L \times \cos\text{Ø}}$$

In Delta *(only one voltage)*

$$U_L = U_P$$

$$I_P = \frac{I_L}{\sqrt{3}}$$

$$I_L = I_{P\times}\sqrt{3}$$

$$P = \sqrt{3} \times U_L \times I_L$$

In circuits with power factor

$$P = \sqrt{3} \times U_L \times I_L \times \cos\text{Ø}$$

$$I_L = \frac{P}{\sqrt{3} \times U_L \times \cos\text{Ø}}$$

$$\text{Power Factor } \cos \varnothing = \frac{\textit{True power}}{\textit{Apparent power}} = \frac{\textit{Watts}}{\textit{Volts} \times \textit{amps}}$$

Pythagoras type calculations

$$Z^2 = R^2 + X^2 \text{ or } Z = \sqrt{R^2 + X^2}$$

$$R = \sqrt{Z^2 - X^2} \text{ or } R^2 = Z^2 - X^2$$

$$X^2 = Z^2 - R^2 \text{ or } X = \sqrt{Z^2 - R^2}$$

$$kVa^2 = kW^2 + kVar^2 \text{ or kVa} = \sqrt{kW^2 + kVar^2}$$

$$kW^2 = kVa^2 - kVar^2 \text{ or } kW = \sqrt{kVa^2 - kVar^2}$$

$$kVar^2 = kVa^2 - kW^2 \text{ or } kVar = \sqrt{kVa^2 - kW^2}$$

Capacitive reactance

$$X_c = \frac{1}{2\pi f C \times 10^{-6}} \text{ or } \frac{1 \times 10^6}{2\pi f C}$$

$$C = \frac{1}{2\pi f X \times 10^{-6}} \text{ or } \frac{1 \times 10^6}{2\pi f X}$$

Inductive reactance

$$X_L = 2\mu f L$$

$$L = \frac{X_L}{2\pi f X}$$

Synchronous speed and slip calculations

N_S is synchronous speed in revs/sec or × 60 for revs/min
N_R is speed of rotor in revs/sec or × 60 for revs/min
f is frequency of supply
P is pairs of poles
Unit slip is shown as a decimal
Percentage slip is shown as %

Synchronous speed

$$N_s = \frac{f}{P} \text{ in revs per sec or} \times 60 \text{ for rpm}$$

Rotor speed

$$\frac{N_S - N_R}{N_S} = unit\ slip \times 100\ for\ \%$$

Calculations associated with cable selection

$$I_t \geq \frac{I_N}{Rating\ factors}$$

$$\text{Cable resistance @ 20 Deg C. R in ohms} = \frac{r_1 + r_2 \times length\ in\ m}{1000}$$

$$\text{Voltage drop in cable } \frac{mV \times Amperes \times Length\ (in\ metres)}{1000}$$

Earth fault loop impedance $Z_S = Z_e + R_1 + R_2$

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Electronic Symbols

23

BS 3939 graphical symbols used in electronics.

Figure 43 shows an a.c. relay

Figure 44 shows the symbol for a battery. The long line represents the positive terminal. Each pair of lines is one cell.

Figure 43 a.c. relay

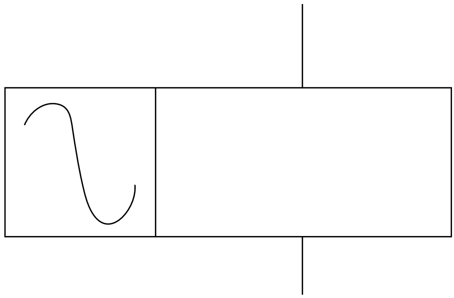


Figure 44 Symbol for a battery

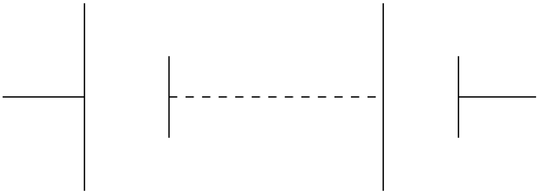


Figure 45 shows a primary cell, which supplies electrical energy.

Figure 46 shows a triac, a three terminal bi-directional device which contains back-to-back thyristors.

Figure 45 A primary cell

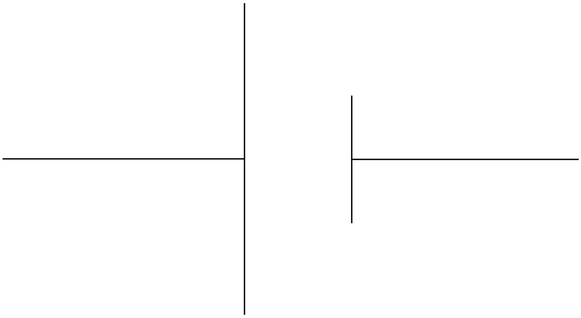


Figure 46 A triac

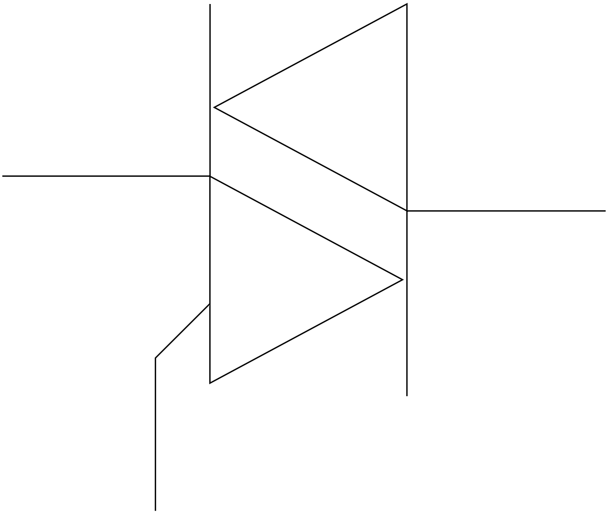


Figure 47 shows a polarized capacitor. This must be connected the correct way round or it will be damaged.

Figure 48 shows a variable capacitor.

Figure 47 A polarized capacitor

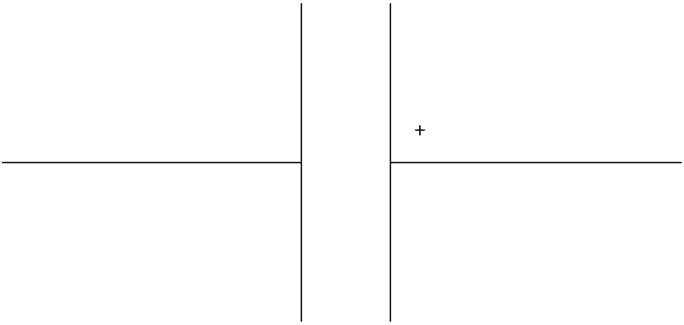


Figure 48 A variable capacitor

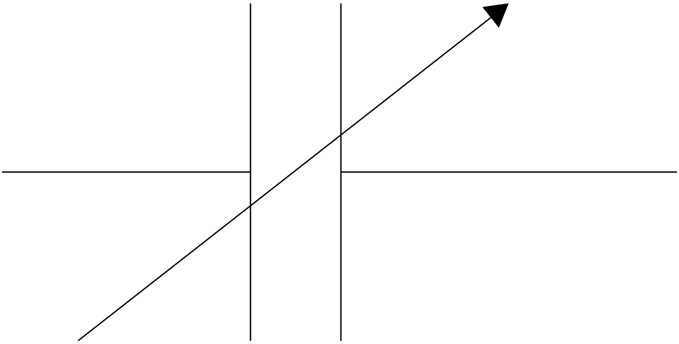


Figure 49 shows a preset variable capacitor (trimmer).

Figure 50 shows how a d.c. relay can be used for circuit control.

Figure 49 A preset variable capacitor

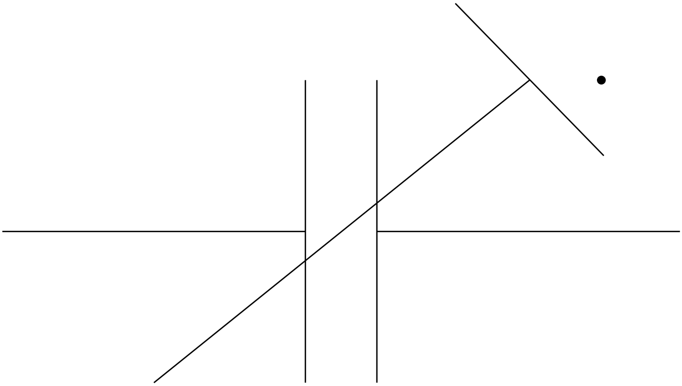


Figure 50 How to use a d.c. relay for circuit control

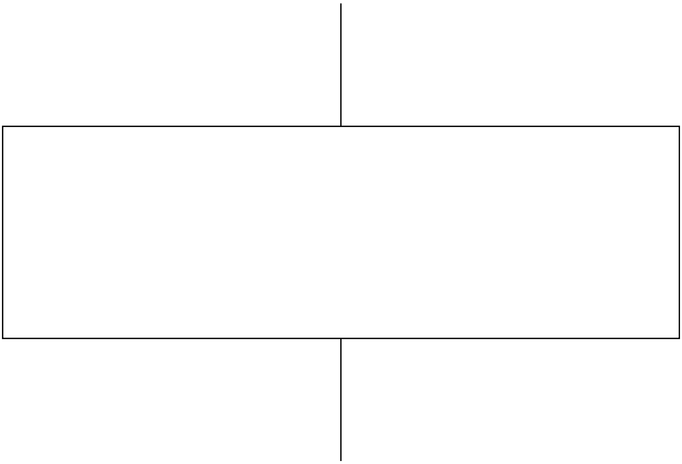


Figure 51 shows a diac, which is a two terminal device which contains back-to-back thyristors. This device is triggered on both halves of each cycle.

Figure 52 shows a light-sensitive diode.

Figure 51 A diac

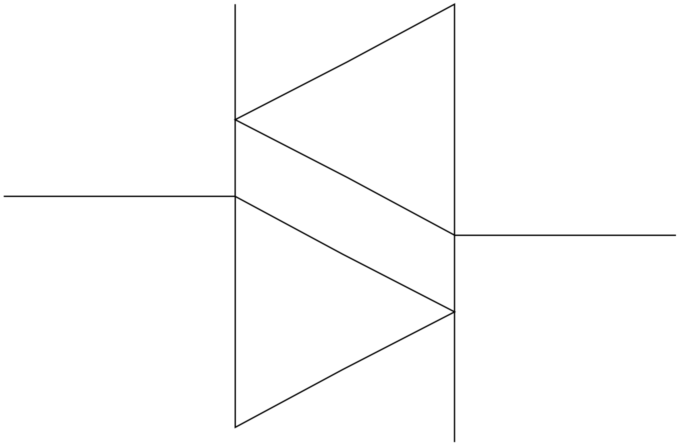


Figure 52 A light sensitive diode

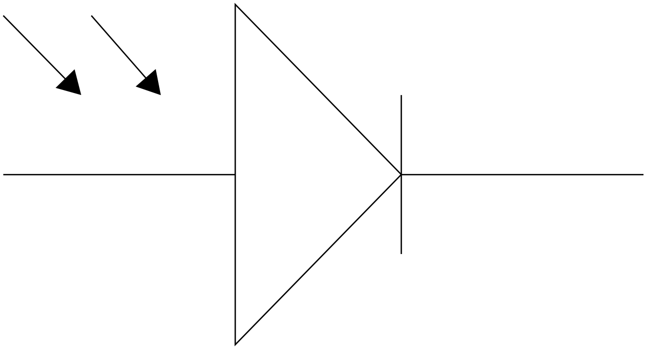


Figure 53 shows a light emitting diode (LED). This converts electrical energy to light.

Figure 54 shows a zener diode. This device acts in the same way as a diode, but will conduct in the reverse direction a predetermined voltage. It is used for voltage regulation.

Figure 55 shows that a diode will only conduct in one direction.

Figure 56 shows a fuse link.

Figure 57 shows an iron-cored inductor, a coil of wire which creates a magnetic field when a current is passed through it. It can be used on an a.c. circuit to create a high voltage when the magnetic field collapses or to restrict the flow of current (choke in fluorescent fitting).

Figure 53 LED

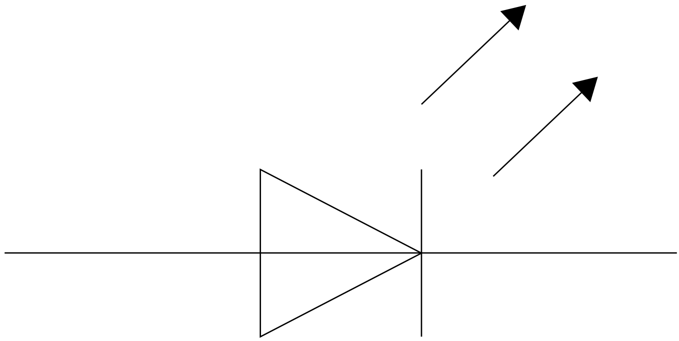


Figure 54 A zener diode

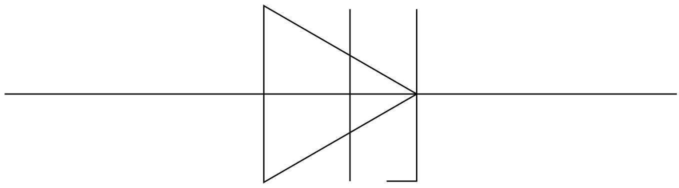


Figure 55 A diode

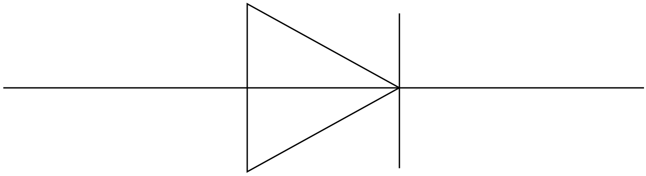


Figure 56 A fuse link

Figure 57 An iron-cored inductor

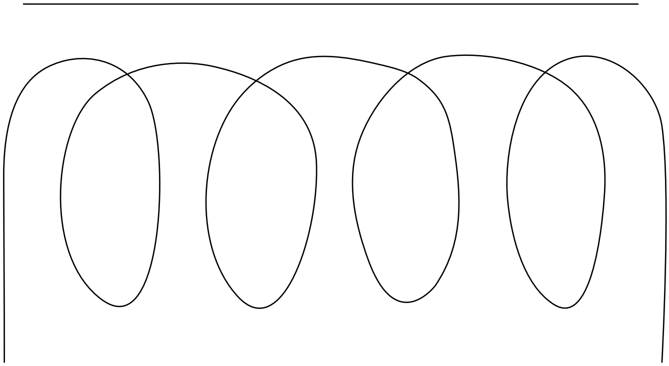


Figure 58 shows an air-cored inductor, which works in the same way as an iron-cored inductor.

Figure 59 shows an inverter. This changes d.c. to a.c. current. It is useful for motor control as the frequency can be altered. The waveform is rectangular but fortunately most a.c. motors and fluorescent lamps can accept these waveforms.

Figure 58 An air-cored inductor

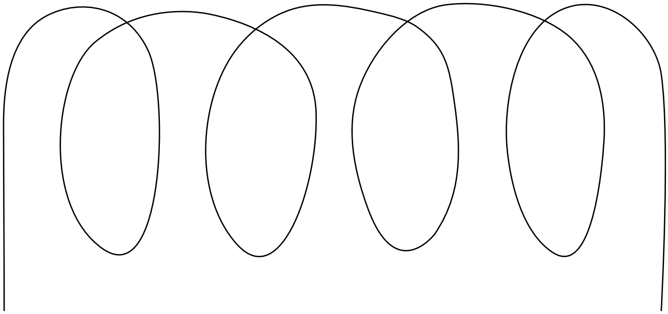


Figure 59 An inverter

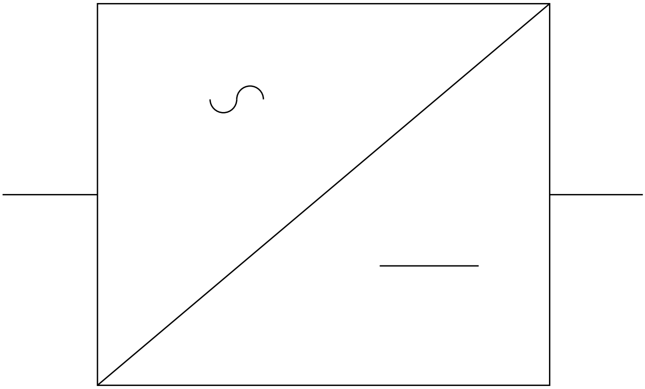


Figure 60 shows a variable resistor. This is a potentiometer, three contact device which is used to control voltage.

Figure 61 shows a fixed resistor.

Figure 62 shows a variable resistor, rheostat, two terminal device used to control current.

Figure 60 A variable resistor

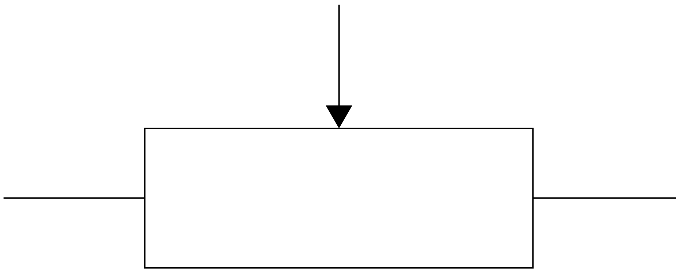


Figure 61 A fixed resistor

Figure 62 A rheostat variable resistor

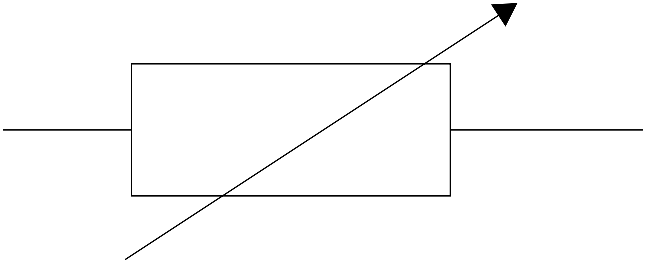


Figure 63 shows a preset resistor.

Figure 64 shows a thermistor. Resistance alters due to heat, a negative coefficient type reduces resistance as it gets hotter, a positive coefficient type increases resistance as it gets hotter.

Figure 65 shows a rectifier. This converts a.c. to d.c. current.

Figure 66 shows a solenoid valve.

Figure 63 A preset resistor

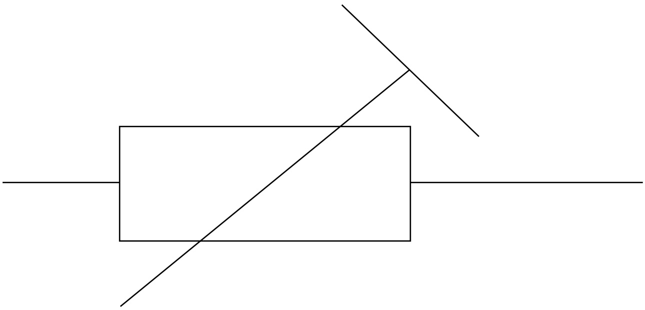


Figure 64 A thermistor

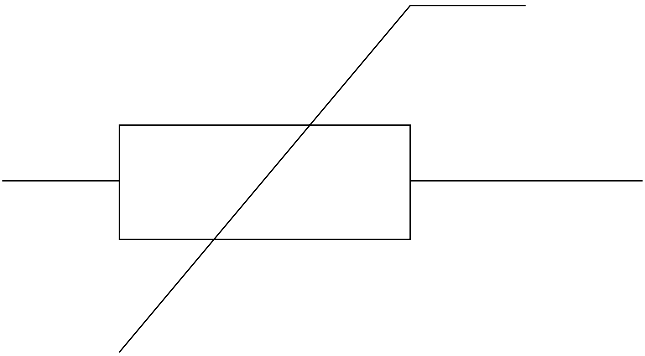


Figure 65 A rectifier

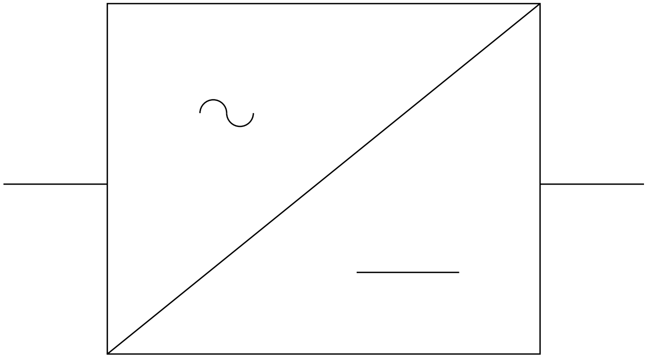


Figure 66 A solenoid valve

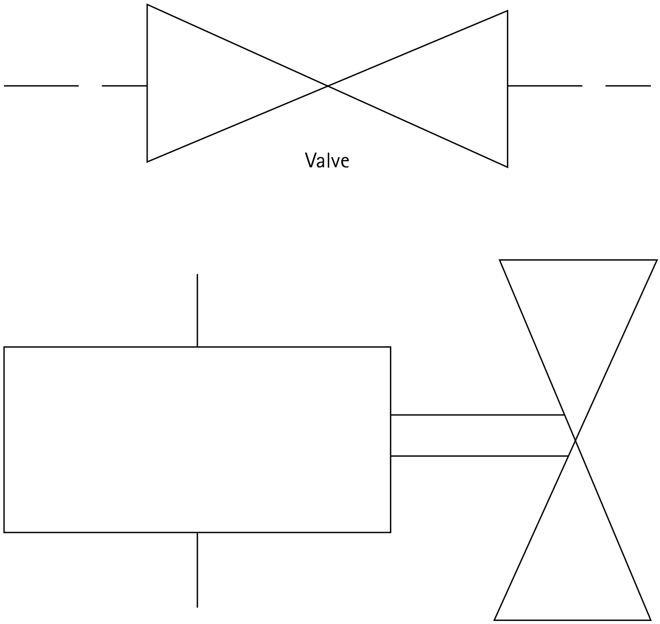


Figure 67 shows a three phase star supply.

Figure 68 shows a three phase delta supply.

Figure 69 shows an NPN transistor. This amplifies current or can be used with other electronic components to make a switch circuit.

Figure 70 shows a PNP transistor, which does the same thing as an NPN transistor.

Figure 71 shows a light-sensitive transistor.

Figure 72 shows a transformer.

Figure 67 A three phase star supply

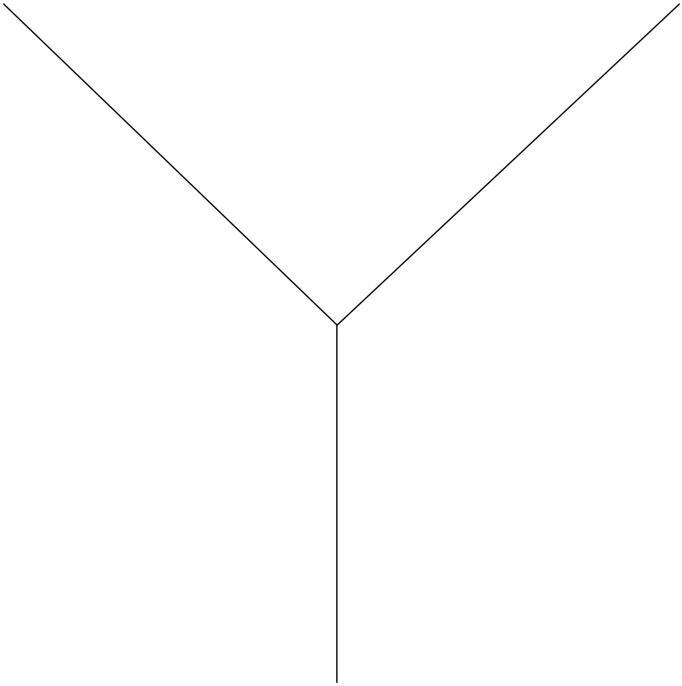


Figure 68 A three phase delta supply

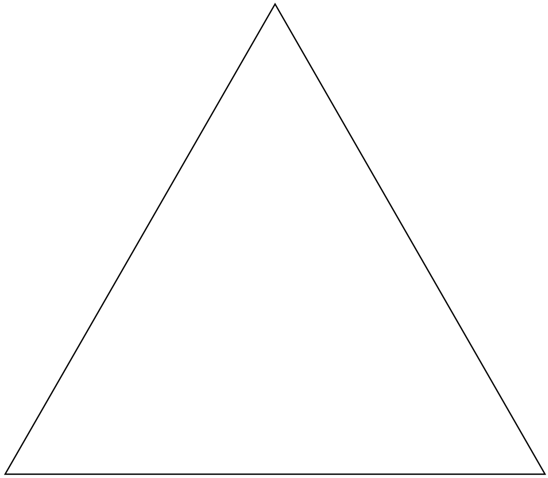


Figure 69 A NPN transistor

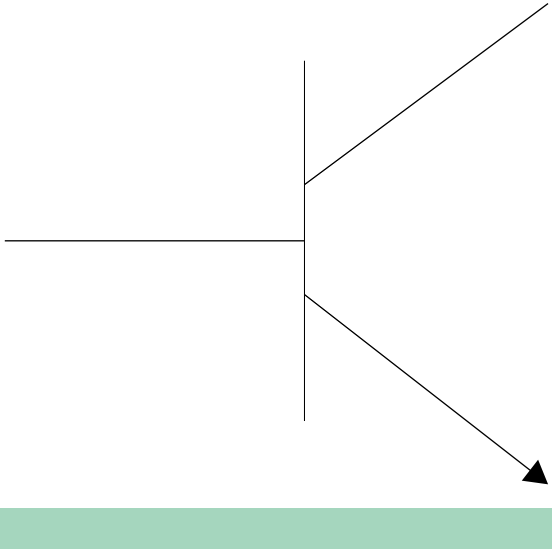


Figure 70 A PNP transistor

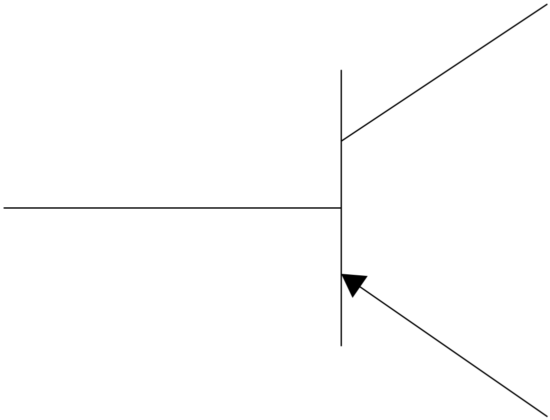


Figure 71 A light-sensitive transistor

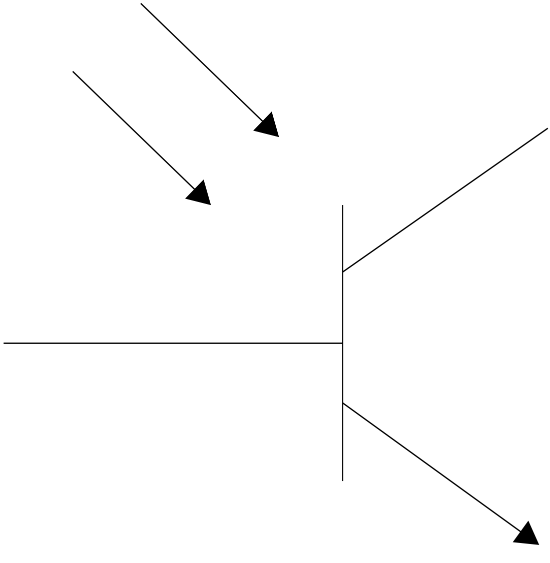
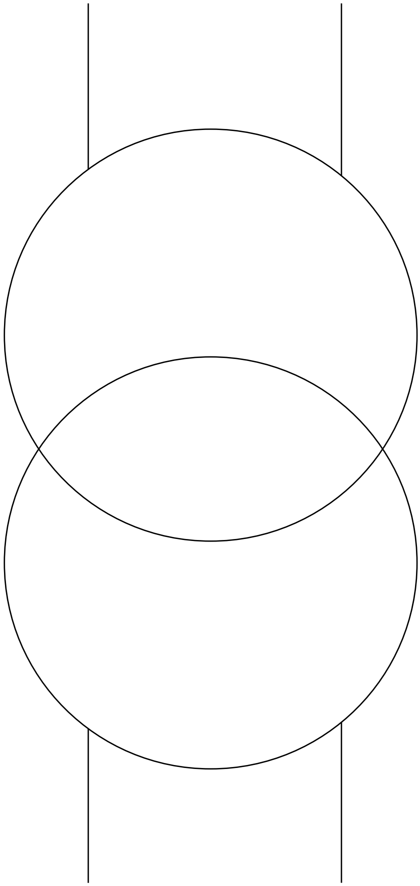


Figure 72 A transformer



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Glossary

24

a.c.:	Alternating current
Area:	Extent of a surface
BS 7671:	British Standard for electrical wiring regulations
Capacitive reactance:	The effect on a current flow due to the reactance of a capacitor
Circle:	Perfectly round figure
Circuit:	Assembly of electrical equipment which is supplied from the same origin and protected from overcurrent by a protective device
Circuit breaker:	A device installed into a circuit to automatically break a circuit in the event of a fault or overload and which can be reset
Circumference:	Distance around a circle
Conductor:	Material used for carrying current
Correction factor:	A factor used to allow for different environmental conditions of installed cables
Coulomb:	Quantity of electrons
CSA:	Cross-sectional area
Current:	Flow of electrons
Cycle:	Passage of an a.c. waveform through 360°

Cylinder:	Solid or hollow, roller-shaped body
d.c.:	Direct current
Dimension:	Measurement
Earth fault:	The current which flows between a live conductor to earth
Earth fault loop impedance:	Resistance of the conductors in which the current will flow in the event of an earth fault. This value includes the supply cable, supply transformer and the circuit cable up to the point of the fault
Efficiency:	The ratio of output and input power
e.m.f.:	Electromotive force in volts
Energy:	The ability to do work
Force:	Pull of gravity acting on a mass
Frequency:	Number of complete cycles per second of an alternating waveform
Fuse:	A device installed in a circuit which melts to break the flow of current in a circuit
Hertz:	Measurement of frequency
Impedance:	Resistance to the flow of current in an a.c. circuit
Impedance triangle:	Drawing used to calculate impedance in an a.c. circuit
Internal resistance:	Resistance within a cell or cells
Kilogram:	unit of mass
kVA:	Apparent power (× 1000)
kVAr:	Reactive power (× 1000)
kW:	True power (× 1000)
Load:	Object to be moved

Load:	The current drawn by electrical equipment connected to an electrical circuit
Magnetic flux:	Quantity of magnetism measured in webers
Magnetic flux density:	Is the density of flux measured in webers per metre squared or tesla
Mutual induction:	Effect of the magnetic field around a conductor on another conductor
Newton:	Pull of gravity (measurement of force)
Ohm:	Unit of resistance
On-Site Guide:	Publication by the IET containing information on electrical installation
Overload current:	An overcurrent flowing in a circuit which is electrically sound
Percentage efficiency:	The ratio of input and output power multiplied by 100
Perimeter:	Outer edge
Phasor:	Drawing used to calculate electrical values
Potential difference:	Voltage difference between conductive parts
Power:	Energy used doing work
Pressure:	Continuous force
Primary winding:	Winding of transformer which is connected to a supply
Prospective fault current:	The highest current which could flow in a circuit due to a fault
Prospective short circuit current:	The maximum current which could flow between live conductors
Protective device:	A device inserted into a circuit to protect the cables from overcurrent or fault currents

Rectangle:	Four-sided figure with right angles
Resistance:	Opposition to the flow of current
Resistivity:	Property of a material which affects its ability to conduct
Resistor:	Component which resists the flow of electricity
Secondary winding:	Winding of transformer which is connected to a load
Self-induction:	Effect of a magnetic field in a conductor
Series:	Connected end to end
Space factor:	Amount of usable space in an enclosure
Thermoplastic:	Cable insulation which becomes soft when heated and remains flexible when cooled down
Thermosetting:	Cable insulation which becomes soft when heated and is rigid when cooled down
Transformer:	A device which uses electromagnetism to convert a.c. current from one voltage to another
Transpose:	Change order to calculate a value
Triangle:	Three-sided object
Voltage drop:	Amount of voltage lost due to a resistance
Volume:	Space occupied by a mass
Watt meter:	Instrument used to measure true power
Waveform:	The shape of an electrical signal
Work:	Energy used moving a load (given in newton metres or joules)

25

Answers to Exercises

EXERCISE 1

1 a) 106Ω b) 12.5Ω c) 24Ω d) 1.965Ω
e) 154.94Ω f) 346.2Ω g) 59.3kΩ h) 2290000Ω
i) 0.0997Ω j) 57425 μΩ

2 a) 22Ω b) 2.35Ω c) 1.75Ω d) 2.71Ω
e) 1.66Ω f) 13.42Ω g) 6.53Ω h) 1805Ω
i) 499635μΩ j) 0.061MΩ

3 3.36Ω

4 21.1Ω

5 9

6 533Ω, 19

7 133.6Ω, 30.4Ω

8 2.76Ω

9 c

10 c

11 c

EXERCISE 2

1 a) 1Ω b) 1.58Ω c) 3.94Ω d) 1.89Ω
e) 2.26Ω f) 11.7Ω g) 6Ω h) 5Ω
i) 10Ω

2 a) 16Ω b) 6.67Ω c) 7.2Ω d) 6Ω
e) 42Ω f) 2000Ω g) 300Ω h) 37.5Ω
i) 38Ω j) 17.3Ω

3 a) 2.13A b) 8.52A
4 a) 4.2V b) 3.53A, 26.4A
5 0.125Ω
6 25A, 24.4A, 21.6A
7 10.9Ω
8 40A, 30A
9 20A
10 0.1Ω
11 a) 0.00923Ω b) 1.2V c) 66.7A, 50A, 13.3A
12 a) $I_A = I_B = I_D - 2.5A$, $I_C = 6.67A$ b) 9.17A
c) $U_A = 10V$, $U_B = 12.5V$, $U_C = 40V$, $U_D = 17.5V$ d) 9.4A
13 d
14 a
15 0.365Ω
16 24V, 12.4V
17 a) 0.0145Ω b) 400A
18 141A, 109A
19 0.137Ω
20 971Ω
21 a) 152A, 121A, 227A b) 1.82V c) 1.82V
22 b
23 b

EXERCISE 3

1 $32.3m^3$
2 $0.289m^3$
3 a) $1.125m^3$, $6m^2$ b) $0.074m^3$, $0.754m^2$
4 $0.000012m^3$
5 $962.2mm^3$
6 $2369.5m^3$
7 $44.52m^3$
8 $10.2m^2$
9 $0.6m^3$
10 $0.325m^3$

EXERCISE 4

1 10.5m^2

2 0.14mm

3

Length (m)	6	3	12	8	12
Breadth (m)	2	2	7	4	4
Perimeter (m)	16	10	38	24	32
Area (m^2)	12	6	84	32	48

4 10.5m^2

5 19m^2

6

Base (m)	0.5	4	1.5	11.25	0.3
Height (m)	0.25	4.5	2.2	3.2	0.12
Area (m^2)	0.0625	9	1.65	18	0.018

7

Area (m^2)	0.015	0.25×10^{-3}	7.5×10^{-3}	0.00029	0.0016
Area (mm^2)	15×10^3	250	7500	290	1.6×10^3

8

Diameter	0.5m	0.318m	0.7927m	2.76mm	4mm
Circumference	1.571m	1m	2.52m	8.67mm	12.57mm
Area	0.196m^2	0.079m^2	0.5m^2	5.98mm^2	12.57mm^2

9 0.331m^2 (575mm × 575mm), 9 rivets

10 0.633m^2 (600mm × 958mm), 2.64m angle, 80 rivets

11 19.6m

12

No. and diameter of wires (mm)	1/1.13	1/1.78	7/0.85	7/1.35	7/2.14
Nominal CSA (mm^2)	1	2.5	4	10	25

13

Nominal and overall diameter of cable (mm)	2.9	3.8	6.2	7.3	12
Nominal overall cross-sectional area (mm^2)	6.6	11.3	30.2	41.9	113

14 a) $133mm^2$ b) $380mm^2$ c) $660mm^2$

15

Cable size	50×37.5	75×50	75×75
$16mm^2$	20	40	60
$25mm^2$	13	27	40
$50mm^2$	8	15	22

16 75mm × 50mm or 100mm × 37.5mm

17 $8036mm^2$ (about 90mm × 90mm) use 100 mm × 100mm

18 c

19 d

20 75mm × 75mm trunking

21 19 pairs can be added

22 25mm conduit, draw in box after second bend

23 a) 32mm conduit b) adequate room exists but recalculation of new and existing cable rating will be necessary

24 a) 50mm × 50mm or 75mm × 38mm trunking b) 32mm conduit
c) difficulty may result when extending from stop end of 75mm × 38mm trunking

EXERCISE 5

1 3.21 sec

2 120 sec (2 min)

3 3870C

EXERCISE 6

1 a) 3.6Ω b) 5Ω
c) 4A in 9Ω resistance, 6A in 6Ω resistance, 10A in 1.4Ω resistance

2 a) 2Ω b) 12V

3 2.25Ω

4 2.86Ω

5 a) 5.43Ω b) 3.68A

6 26.2V

7 0.703A in 7Ω resistance, 0.547A in 9Ω resistance; 1.25A in 12Ω resistance

8 11.7Ω

9 0.174A, 0.145A, 50.6W

10 37.73Ω

11 25.4Ω

12 a) 20.31A b) 0.23Ω c) 2.64kW

13 216.3V, 213.37V

14 a) 5Ω b) I_A = 3A, I_B=12A, $I_{C=}$15A c) the circuit voltage is 240 volts

15 6Ω

16 a) 20A b) 2Ω c) 56A

17 2.96V

18 4.25V

19 6.96V

20 0.0306Ω

21 a) 1.09A, 0.78A b) 5.44V c) 1.05W

22 a) 4.37V b) 0.955W, 0.637W

23 88.7W

24 107V

25 117V, 136W, 272W

26 2.59Ω

27 a) 4.4Ω b) 15.9V c) 1.72Ω

28 b
29 d
30 a

EXERCISE 7

1

P (watts)	1440	3000	1600	1000	1000	2350	1080
I (amperes)	6	12	6.67	150	5.45	5.1	4.5
U (volts)	240	250	240	6.67	220	460	240

2 30W
3 4370W
4 a) 13.04A b) 6.52A c) 1.96A d) 15.22A
e) 30.44A f) 0.26A g) 0.43A h) 8.7A
i) 3.26A j) 0.065A
5 108V
6 203W
7 a) 18.75A b) 17.2A
8 748W
9 6A
10 13.04A
11 633W
12 0.2A, 23W
13 17.4A
14 a) 6.413kW b) 83.7W c) 222V
15 29.2Ω
16 a) 460V b) 7.05kW c) 76.9W
17 a) 62.1W, 70.9W b) 286W, 250W
18 453W, 315W
19 40.5V, 0.78Ω, 750W
20 a) 434V b) 15.6kW c) 216W d) 433V
21 c

22 b
23 c
24 a

EXERCISE 8

1

Power (W)	1500	200	1800	1440	1000	2640	100	42.25
Current (A)	10	5	15	12	4.2	11.49	0.42	1.3
Resistance (Ω)	15	8	8	10	56.7	20	567	25

2 130W
3 29.4W
4 5A
5 1.73kW
6 567Ω
7 a) 6.21V b) 71.4W
8 530W
9 20A
10 59.4W
11 125Ω
12 63.4W
13 419W
14 0.248W
15 0.8A

EXERCISE 9

1 66.12W
2 135Ω
3 4Ω
4 120V

5

Power (W)	128	100	60	1800	42.24	36
Voltage (V)	80	240	250	220	3.5	12
Resistance (Ω)	50	576	1042	26.9	0.29	4

6 15V

7 557W

8 52.9Ω

9 170W

10 161Ω

11 a) 28.8Ω b) 19.2Ω c) 16.5Ω d) 128Ω
e) 960Ω f) 8.23Ω g) 576Ω h) 38.4Ω
i) 76.8Ω j) 14.4Ω

12 79.1V

13 4.19A

14 a) 0.149A b) 29.8W

15 a) series – 106Ω, parallel – 26.5Ω b) series – 499W, parallel – 1996W

16 19A, 126W, 81A, 538W

17 750W, 3000W

18

Power (W)	25.6	250	400	600
Current (A)	0.8	2.5	3.15	3.87
Resistance (Ω)	40	40	40.3	40

a) 550W b) 4.4A

19

Power (W)	2000	750	420	180
Current (A)	240	120	89.6	58.8
Resistance (Ω)	28.8	19.2	19.1	19.2

a) 175V b) 3200W

20 180V = 90W, 190V = 100.27W, 200V = 111.11W, 210V = 122.50W, 220V = 134.44W, 230V = 160W, 240V = 160W, 250V = 173W

21 10A = 7W, 20A = 28W, 30A = 63W, 40A = 112W, 50A = 175W, 60A = 252W, 70A = 343W, 80A = 448W, 90A = 567W

22 d

23 b

24 d

25 c

EXERCISE 10

1 210Nm

2 208N

3

F (N)	85	41.7	0.25	6.5	182
L (m)	0.35	1.2	0.6	0.125	2.75
M (Nm)	29.8	50	0.15	0.813	500

4 66N

5 0.3m

6 37.5J

7 20m

8 20000J

9 306400J

10 a) 11.5mJ b) 2.5mW

11 144W

12

Distance between effort and pivot (m)	1	1.5	1.25	0.6	1.8
Distance between load and pivot (m)	0.125	0.3	0.15	0.1	0.2
Load (kgf)	160	200	416.5	390	225
Effort(kgf)	20	40	50	65	25
Force ratio	8	5	8.33	6	9

13

Load to be raised (kgf)	250	320	420	180	500
Effort required (kgf)	125	150	75	80	214.3
Vertical height (m)	3	4	0.89	2.4	1.8
Length of inclined plane (m)	6	8.53	5	5.4	4.2

14 a) 2.55kgf b) 2160kgf c) 0.424m

15

Radius of wheel *R* (cm)	25	16	20	17.5	30
Radius of axle *r* (cm)	8	6.5	6	8.5	8.5
Load *G* (kgf)	200	185	255	150	175
Effort *E* (kgf)	64	75	76.5	72.9	49.6

16 a) 184W b) 245W c) 882×10^3J

17 91%

18 a) 6.1A b) 38.1A c) 13.5A d) 21.3A
e) 58.3A

19 1.19A

20 12.58p

21 a) 4.57A b) 15.35p c) 1.36mm^2 (1.5mm^2)

22 13.2kW (15kW), 28.7A, a DC shunt wound motor as it can regulate its own speed under load.

23 a) 3.74V b) Increase the size of the cable

24 2.892kW, 14.8A

25 c

26 b

27 b

EXERCISE 11

1 a) 1.25mWb b) 0.795

2

Wb	0.025	0.035	0.059	0.74
mWb	25	35	59.5	740
Wb	25000	35000	59500	740000

3 0.0688Wb

4 0.792T

5 0.943mWb

6 1.913N

7 0.778T

8

Flux density (T)	0.95	0.295	1.2	0.56	0.706
Conductor length (m)	0.035	0.12	0.3	0.071	0.5
Current (A)	1.5	4.5	33.3	0.5	85
Force (N)	0.05	0.16	12	0.02	30

9 0.5A = 0.1N, 1.5A = 0.3N, 2A = 0.4N, 3A = 0.6N, 3.5A = 0.6N, 5A = 1N

10 0.5T = 12A, 0.6T = 10A, 0.7T = 8.57A, 0.8T = 7.5A, 0.9T = 6.66A, 1T = 6A

11 5m/s, = 1V, 6m/s = 1.34V, 7m/s = 1.4V, 8m/s = 1.4V, 9m/s = 1.8V, 10m/s = 2V

12 0.5T = 24m/s, 0.6T = 20m/s, 0.7T = 17.14m/s, 0.8T = 15m/s, 0.9T = 13.33m/s, 1T =12m/s

13 0.08V

14 2.56m/s

15 180V

16 102V

17 6.5V

18 0.15H

19 100H

20 1.75H

21 50V

22 66.7A/s
23 30H
24 80V
25 a
26 c
27 b
28 c
29 a
30 c
31 d

EXERCISE 12

1 3.96V
2 36.05A
3 59.1A
4 81.51A
5 a) 2.765V b) 227.23V
6 a) 45A b) 3.97 c) $16mm^2$

EXERCISE 13

1

U (volts)	10	20	30	40	50
I (amperes)	1	2	3	4	5
R (ohms)	10	10	10	10	10

2 36V
3

U (volts)	240	240	240	240	240
I (amperes)	12	6	4	3	2.4
R (ohms)	20	40	60	80	100

4 3A, 23Ω

5

U (volts)	100	100	96	56	96	132	84	144	121	63
I (amperes)	10	10	12	7	8	12	7	12	11	9
R (ohms)	10	10	8	8	12	11	12	12	11	7

6

I (amperes)	100	10	10	0.1	0.1	0.1	100	0.001	0.1	200
R (ohms)	0.1	1000	0.1	1000	0.1	1000	0.1	2000	2000	0.01
U (volts)	10	100	1	10	0.01	100	10	20	200	2

7

R (ohms)	480	14	500	16	110	0.07	12	500	0.75	15
I (amperes)	0.5	15	0.05	6	1.2	0.9	0.7	0.2	8	8
U (volts)	240	210	25	96	132	0.063	8.4	100	6	120

8 2.041V

9 a) 0.33Ω b) 0.17Ω c) 0.12Ω
d) 0.7Ω e) 0.045Ω

10 11A

11 Section SA 2.916 V, Section AB 4.253 V, Section AC 2.322 V; volts at A = 47.08V, volts at B = 42.83V, volts at C = 40.51V

12

Rated current (A)	5	15	30	60	100
Minimum fusing current (A)	7	21	42	84	140

13

Rated current (A)	5	15	30	60	100
Minimum fusing current (A)	6	18	36	72	120

14 b
15 c
16 c
17 a

EXERCISE 14

1 a) £12.20 b) £207.40
2 a) £1.32 b) £322.95
3 a) £2.83 b) 467
4 £123.84
5 £131.86
6 £426.96
7 £535.04
8 a) £1939.87 b) £2230.85
9 £188.25
10 £672.25
11 a) £416.61 b) £489.51
12 a) i) £427.73 ii) £74.85 b) i) £531.72 ii) £93.05
c) i) £1221.66 ii) £213.70 d) i) £62.87 ii) £11.00
13 a) £558.51 b) £625.81 c) £762.02 d) £872.57
e) £2787.85
14 c
15 b

EXERCISE 15

1

Applied volts	50	60	25	80	45
Capacitance (μF)	0.2	0.3	0.4	0.6	0.8
Charge (μC)	10	18	10	48	36

2 a) 1.88μF b) 450μC c) 150V, 90V d) 0.34J, 0.02J
3 8μF, 24μF

4 60 μF

5 a) 3.7μF, 111V, 74V, 56V b) 36μF, 240V

6 b

7 a

8 c

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Additional Questions and Answers

26

Answers are on page 208.

1 When working in areas which are very dusty, which of the following would not give a good level of protection?

A. Breathing apparatus

B. Positive pressure power respirator

C. Dust mask

D. Compressed airline breathing helmet

2 It is the duty of all employees to

A. Organise safety lectures

B. Carry out safe working practices

C. Provide suitable safety equipment

D. Carry out repairs to damaged equipment

3 Under which circumstances may an HSE improvement notice be issued?

A. When required by an architect

B. When legal requirements have not been met

C. When required by the building officer

D. After an accident

4 A satisfactory method of instructing a client in the use and maintenance of electrical equipment within an installation would be to

A. Leave manufacturers' instructions on site

B. Provide an operations and maintenance manual

C. Give verbal instructions while handing over the installation

D. Leave a manufacturers' catalogue

5 Ladders should not be painted because

A. The paint may be the wrong colour

B. It will need repainting after use

C. The paint will make the rungs slippery

D. The paint may cover up any damage to the ladder

6 Materials delivered to site must be checked against the original order and the

A. Time sheet

B. Variation order

C. Delivery note

D. Bill of quantities

7 The main reason that good housekeeping is important in the workplace is to

A. Improve the environment

B. Present a good appearance

C. Keep tools and equipment handy

D. Prevent accidents

8 When a job is completed any excess materials should be

A. Sold as scrap

B. Placed into a skip

C. Left on site

D. Returned to the stores

9 To protect against falling objects it is important to use

A. Goggles

B. Safety helmets

C. Gloves

D. High visibility clothing

10 Statutory regulations

A. State good practice

B. Must be obeyed

C. State safe procedures

D. Prevent accidents in the workplace

11 Which one of the following would not normally be considered as part of a risk assessment?

A. Enclosed spaces

B. Working at height

C. Delivery of materials

D. Manual handling

12 The correct method of checking if a circuit is safe to work on is to

A. Trace the circuit and withdraw the fuse

B. Connect an appliance and test for operation

C. Connect an approved test lamp between each conductor and earth

D. Switch off the main supply to the installation

13 Ladders used for access to scaffolding must be

A. Set at a ratio of 6 up to 1 out

B. Secured to the scaffold

C. Set at an angle of 65°

D. Extend above the scaffold platform by 0.43m

14 A safety harness would be worn when working

A. In a confined space

B. With lifting gear

C. Alone

D. Above ground

15 SWL stated on lifting equipment indicates the

A. Specified working load

B. Site working load

C. Safe working load

D. Standard working load

16 It is very important that the working area is left in a tidy and clean condition because it

A. Provides a safe environment

B. Reduces the costs

C. Saves on material

D. Allows better access

17 An employer must provide personal protective equipment

A. When it is required to control risk or harm

B. If a method statement would require it

C. When the main contractor specifies it

D. Every three months

18 A warning notice must be fixed to all

A. Equipment which is not earthed

B. Electric motors with a rating above 0.37kW

C. Any electrical equipment which has a voltage of above 250 volts where such voltage would not normally be expected

D. Where the isolator cannot be seen by persons working close by

19 A 13A socket outlet supplying portable equipment outdoors must be protected by an RCD with a trip current rating of

A. 100mA

B. 500mA

C. 0.3A

D. 0.03A

20 Protection against overcurrent is provided by

A. Fuses or circuit breakers of the correct type and size

B. Protective bonding

C. RCDs

D. Using large cables

21 Care of personal protective equipment (PPE) is the responsibility of the

A. Employer

B. Safety officer

C. Shop steward

D. Employee

22 'In' is a symbol used to denote the

A. Design current

B. Operating current of a fuse

C. Nominal rating of a protective device

D. Current rating of a cable

23 In a purely inductive circuit the current will

A. Lead the voltage by 90°

B. Increase

C. Lag the voltage by 90°

D. lead the voltage

24 A wall 3 metres long is to be represented on a drawing scaled at 1:50. What length will the wall be shown on the drawing?

A. 3.5cm

B. 3.0cm

C. 6.0cm

D. 9.0cm

25 In a d.c. motor a constant, stationary magnetic field will be found in the conductors connected to the

A. Stator

B. Yoke

C. Armature

D. Spindle

26 The Health and Safety at Work etc. Act 1974

A. Is for the guidance of employees only

B. Is for the guidance of employers and employees

C. Specifies the duties of employees only

D. Specifies the duties of employers and employees

27 Each set of windings in a 3 phase generator are set apart by

A. 120°

B. 90°

C. 360°

D. 180°

28 Apparent power is expressed as

A. kVAr

B. kW

C. kVA

D. kWh

29 The design current of a circuit is the

A. Rating of the protective device

B. Minimum current which is to be carried during normal service

C. Current which is intended to be carried during normal service

D. Current carrying capacity of the circuit

30 The main function of a transformer is to

A. Reduce the current

B. Change the voltage

C. Alter the frequency

D. Reduce cost

31 Which of the following is not a statutory document?

A. IEE Wiring Regulations BS 7671: 2001

B. Electricity Supply Regulations 1989

C. Electricity at Work Regulations 1989

D. Health and Safety at Work etc. Act 1974

32 The sign legally requiring the wearing of personal safety equipment is white text on a background of

A. Red

B. Blue

C. Green

D. Yellow

33 In a three phase four-wire circuit the neutral conductor will not carry current if the three load impedances are

A. Different

B. Unbalanced

C. Equal

D. Inductive

34 The colour of the cables in a three phase and neutral circuit should be

A. Red/yellow/blue and black

B. Brown/black/blue and grey

C. Black/blue/grey and brown

D. Brown/black/grey and blue

35 Which of the following components is not part of a d.c. motor?

A. Stator

B. Brushes

C. Armature

D. Commutator

36 First aid facilities are denoted by a

A. Red cross on a white background

B. Green cross on a white background

C. White cross on a black background

D. White cross on a green background

37 The IEE wiring regulations require that overload protection is provided for all motors with a rating of more than

A. 1kW

B. 1.37kW

C. 0.37kW

D. 1.25kW

38 The most suitable type of fire extinguisher for use on an oil fire is

A. Foam

B. Dry powder

C. CO_2

D. Water

39 The rotation speed of a magnetic field in an electric motor is known as the

A. Rotation speed

B. Synchronous speed

C. Top speed

D. Rotor speed

40 On finding a person in contact with live conductors the FIRST action is to

A. Pull the person away from the source of supply

B. Switch off the supply

C. Apply mouth to mouth resuscitation

D. Send for an ambulance

41 A star-connected motor has a line voltage of 600V, the phase voltage will be

A. 400V

B. 230V

C. 600V

D. 900V

42 During the handling of a battery, sulphuric acid is accidentally spilled onto a person's hands. The immediate first aid treatment is to

A. Apply an antiseptic

B. Go to a doctor

C. Wash the hands in running water

D. Apply butter

43 A delta-connected system has a line voltage of 600V. What is the phase voltage?

A. 1039V

B. 577V

C. 346V

D. 200V

44 The earth loop impedance of a circuit can be calculated by

A. $Z_s = R1 + R2 - Z_e$

B. $Z_s = Z_e + (R1 + R2)$

C. $Z_s = Z_e - (R1 + R2)$

D. $Z_s = R1 + R2 + X2$

45 An accident occurs, the cause of which is found to be a piece of faulty equipment. The action to be taken would be to

A. Remove the equipment and undertake the necessary repair

B. Retain the equipment in the original state for inspection by the Health and Safety Inspectorate

C. Prevent the use of the equipment by dismantling it

D. Return the equipment to the manufacturer for a report

46 When a BS 1361 fuse is replaced by a BS 3036 rewirable fuse it may have the effect of

A. Reducing the circuit current

B. Causing the cables to be under protected

C. Increasing the Z_s of the circuit

D. Increasing the load current

47 A high earth fault loop impedance may result in the following

A. The short circuit current not operating the protective device

B. The cable being damaged before the protective device operates

C. Having to increase the fault current rating of the protective device

D. The protective device operating faster than is required

48 The main body representing employers in the electrotechnical sector is the

A. JIB

B. NICEIC

C. NAPIT

D. IET

49 Protective bonding will

A. Ensure the correct operation of the protective device

B. Prevent static electricity

C. Reduce the risk of electric shock

D. Reduce disconnection times

50 When using a ladder, which of the following is not part of the equipment check procedure?

A. Check for damaged stiles

B. Check for missing rungs

C. Look for any defects

D. Check that the ladder is numbered

51 The sequence of control for a large installation can be MOST simply shown by a

A. Wiring diagram

B. Layout diagram

C. Circuit diagram

D. Bock diagram

52 A tender to apply to undertake work is normally completed by the

A. Design engineer

B. Estimator

C. Site electrician

D. Supervisor

53 The colour code for a powder type extinguisher is

A. Green

B. Blue

C. Black

D. Cream

54 When motor isolators are not adjacent to the motor they must be

A. Numbered

B. Placed 1200mm from the ground

C. Capable of being locked off

D. Painted in a bright colour

55 The maximum permissible working height of a tower scaffold is

A. 3 times the width of the base

B. 2 times the width of the base

C. 3.5 times the width of the base

D. 2.5 times the width of the base

56 Mechanical assistance should be used when intending to lift an object greater than

A. 35kg

B. 25kg

C. 20kg

D. 15kg

57 The reason for using high voltages for transmission is to

A. Increase the transmission current

B. Reduce the cable resistance

C. Decrease the transmission current

D. Increase the transmission speed

58 In a combined resistive and capacitive circuit the current

A. Leads the voltage between 0 and 90 degrees

B. Lags the voltage between 0 and 90 degrees

C. Leads the voltage by 90 degrees

D. Lags the voltage by 90 degrees

59 A protective device is in a circuit to

A. Indicate when the circuit is off

B. Avoid mechanical damage to appliances

C. Disconnect the circuit under fault conditions

D. Disconnect the circuit gradually

60 The main purpose of 'as fitted' drawings is to form part of the

A. Costing documentation

B. Network diagrams

C. Work study schedules

D. Records of work

61 Work on a circuit should only proceed when

A. The site foreman gives permission

B. The circuit is isolated and proved dead

C. Insulated tools are available

D. A qualified person gives permission

62 IP codes indicate how an enclosure can protect against

A. Vermin

B. Corrosion

C. Explosions

D. Foreign solid objects and moisture

63 The FIRST action to be taken when dealing with an electrical fire is to

A. Call for help

B. Dial 999

C. Use a fire extinguisher

D. Isolate the electrical supply

64 Earthing and bonding together with the correct operation of protective devices will

A. Eliminate all possible faults

B. Prevent direct contact

C. Significantly reduce the risk of electric shock

D. Stop circuits overloading

65 To check the presence of low voltage, use

A. An approved voltage indicator to GS38

B. A voltstick

C. A light touch with a wet finger

D. A neon screwdriver

66 Before any new wiring is connected to an existing system it must be established that

A. The electricity company is consulted

B. All of the wiring is less than 10 years old

C. The existing system is safe and can accommodate the new

D. The owners' consent is obtained

67 A cable connected to the terminals of a ring final socket outlet to a fused connection unit is known as

A. A fused spur

B. A radial circuit

C. A loop in circuit

D. A non-fused spur

68 A recognised method of storing a lot of technical information in a limited space for recording purposes is by

A. Filing

B. Electronically

C. Drawings

D. Microfilm

69 The results of an earth loop impedance test will indicate

A. That the sockets are looped together correctly

B. Correct polarity between neutral and earth

C. If the circuit protective devices will operate quick enough

D. Correct connection of equipment

70 Low voltage is in the range of

A. 0V to 50V

B. 50V to 1000V

C. 12V to 50V

D. 1000V to 1500V

71 The core of a transformer is used to provide a

A. Common connection for the transformer windings

B. Reduced magnetic field

C. Magnetic circuit for flux linkage

D. Cooling effect for the windings

72 The role of the contracts manager within a company would normally be within the

A. Company secretariat

B. Sales department

C. Design department

D. Advertising department

73 Which of the following would be described as an 'unsafe act' which could lead to an accident

A. Poor access to equipment

B. Poor lighting

C. Incorrect use of equipment

D. Equipment not maintained

74 The main source of symbols for use in electrical drawings is

A. BS 7671

B. Electricity at Work Regulations

C. Electricity Supply Regulations

D. BS EN 60617

75 A safe system of work is

A. Ensuring high standards of working

B. Ensuring that the work is carried out correctly

C. A risk assessment

D. A considered way of working which takes account of any potential hazards to employees and others

76 Fitting instructions for a component will normally be found in

A. British Standards

B. Manufacturers' data

C. Code of Practice

D. BS 7671

77 The main purpose of a circuit diagram is to show how an electrical system

A. Will function

B. Can be priced

C. Should be connected

D. Should be located

78 A location drawing shows a proposed route for a cable, if the scale is 1:50 and the route length on the drawing is 85mm the length of the cable will be

A. 4.25m

B. 17m

C. 42.5m

D. 58.9m

79 Which one of the following types of information would NOT be required when compiling a specification?

A. Clients' needs

B. Locations of equipment

C. Schedule of test results

D. Maximum demand

80 The main purpose of the manufacturer's data is to provide installation information and

A. A technical specification

B. The manufacturer's name

C. A list of other products

D. The date of production

ANSWERS

1 C
2 B
3 B
4 B
5 D
6 C
7 D
8 D
9 B
10 B
11 D
12 C
13 B
14 D
15 C
16 A
17 A
18 C
19 D
20 A
21 D
22 C
23 C
24 C
25 B
26 B
27 A
28 C
29 C
30 B
31 D
32 B
33 C
34 D
35 A
36 D
37 C
38 B
39 B
40 B
41 C
42 C
43 C
44 B
45 B
46 B
47 B
48 A
49 C
50 D
51 D
52 B
53 B
54 C
55 A
56 C
57 C
58 C
59 C
60 D
61 B
62 A
63 D
64 C

65 A	**69** C	**73** C	**77** C
66 C	**70** B	**74** D	**78** A
67 A	**71** C	**75** D	**79** C
68 B	**72** A	**76** B	**80** A

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