2365 Level 2

Electrotechnical Qualification

Unit 202: Principles of Electrical Science

Pre-attendance Workbook

v2.0

202: Principles of electrical science

Handout 1: Principles of electricity

Learning outcome
The learner will:
2. understand standard units of measurement used in electrical installation, maintenance and design work
4. understand the relationship between resistance, resistivity, voltage, current and power.

Assessment criteria
The learner can:
2.1 identify and use internationally recognised base and derived **(SI) units of measurement**
2.2 identify and determine values of base and derived SI units which apply specifically to **electrical quantities**
4.1 describe the basic principles of electron theory
4.2 identify and distinguish between materials which are good conductors and insulators
4.8 describe the chemical and thermal effects of electric currents.

Range
(SI) units of measurement: length, area, volume, mass, density, time, temperature, velocity
Electrical quantities (SI units): resistance, resistivity, power, frequency, current, voltage, energy, impedance, inductance and inductive reactance, capacitance and capacitive reactance, power factor

Principles of electricity

Electron theory – structure of matter

The smallest part of any material is called a **molecule**, yet the latter is made up of one or more **atoms**. For example, water is made up of H_2O (two atoms of hydrogen and one atom of oxygen).

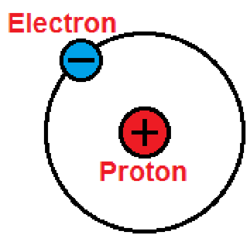
Basically, the atom is constructed of a central core containing **protons** surrounded by orbiting **electrons**.

Electrical nature of atoms

Protons are **positively charged**.
Electrons are **negatively charged**.

In an electrically neutral atom, the number of **protons** is equal to the number of **electrons**.

- The simplest atom is hydrogen (1 proton and 1 electron) – see right.
- The heaviest atom is uranium (92 protons balanced by 92 electrons).
- Helium atom (two protons and two electrons).

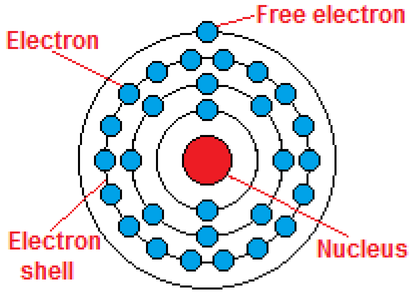


Copper atom – 29 protons and 29 electrons

An electrically neutral atom has as many (+ve positive) protons as there are (-ve negative) electrons.

The single electron in the outer orbit of the copper atom is only loosely attached to the atom because:

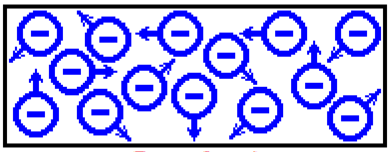
- it is so far away from the core (nucleus)
- inner electrons try to push it off (like charges repel).

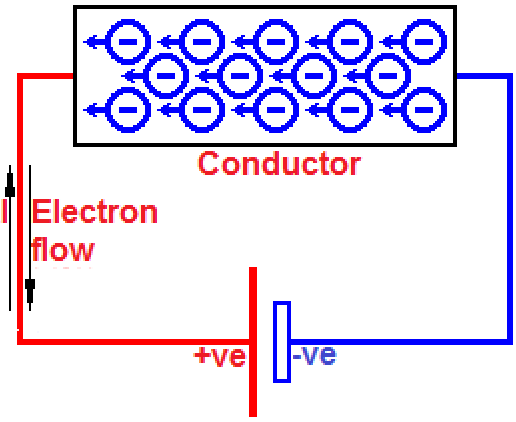


As a result, this electron may be easily detached. If the balance of protons and electrons is upset and the atom becomes positively charged it will then attract any nearby electron.

This process occurs millions of times every second; at any instant in time the material has a large number of free electrons moving in all directions.

Random free electron movement

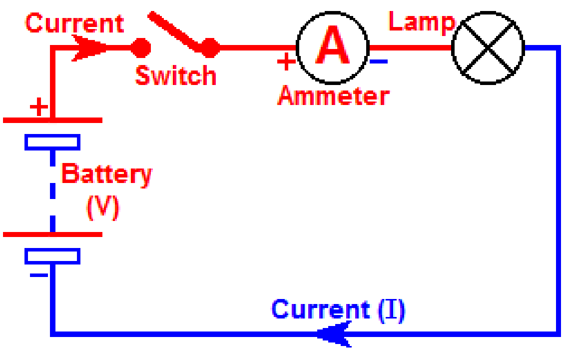




If the material is then connected across a battery, the positive plate (or terminal) attracts electrons, whilst the negative plate repels them.

The battery provides a source of electromotive force (EMF).

The resultant electron flow around the circuit is called an **electric current**.



Note: even when an appropriate EMF is applied, there must be a complete circuit for the electrons to flow; a break in the circuit will cause the electron flow to stop.

This aspect is useful, as we can use it to control the flow of electricity using, for example, a switch.

Conductors and insulators

A conductor is a material that has a loosely attached electron in its outer orbit that can be easily dislodged, as in copper. Any external influence which moves one of them will cause a repulsion of other electrons which spreads, 'domino fashion' through the conductor.

Simply stated, most metals are good electrical conductors, most non-metals are not. Metals are also generally good heat conductors, while non-metals are not. Examples of conductors are:

- silver
- gold
- copper
- aluminium
- mercury
- steel
- sea water
- concrete
- mercury
- platinum
- brass
- iron
- bronze
- graphite
- dirty water
- lemon juice.

Most solid non-materials are classified as insulators because they offer very large resistance to the flow of electric current. In an **insulator**, the outermost electrons are so tightly bound that there is essentially zero electron flow through them with ordinary voltages. Examples of insulators are:

- rubber
- glass
- pure water
- oil
- air
- diamond
- dry wood
- dry cotton
- plastic
- asphalt
- fibreglass
- dry paper
- porcelain
- ceramic
- quartz.

Effects of an electric current

When electricity flows, one or more effects occur as follows:

- thermal
- chemical
- magnetic.

Thermal effect

When an electric current is passed through a conductor, the conductor becomes hot after some time, and produces heat. This happens due to the conversion of some electric energy passing through the conductor into heat energy, by the collision of electrons with each other and the atom nuclei. This effect of electric current is called the heating effect of current.

The heating effect of current is used in various electrical heating appliances, such as electric lamps, electric irons, room heaters, water heaters, electric fuses, etc.

Chemical effect

We can use certain chemical reactions which produce electricity, as in a battery. But, it is interesting to note that when electric current is passed through certain liquids, a chemical reaction takes place. This is called the chemical effect of electric current and is referred to as electrolysis. For example, when an electric current is passed through acidified water, the water molecules split up to form hydrogen and oxygen gases.

Electrolysis is used to electroplate objects. This is useful for coating a cheaper metal with a more expensive one, such as copper or silver.

The negative electrode should be the object that is to be electroplated; the positive electrode should be the metal with which you want to coat the object. The electrolyte should be a solution of the coating metal, such as metal nitrate or sulphate.

Two examples are electroplating with silver (silver nitrate electrolyte) and electroplating with copper (copper sulphate electrolyte).

Magnetic effect

This will be covered later in the course.

Electrical quantities

Many different quantities are used in electrical systems and therefore need to be standardised. These units are standardised in an international system called the Système International d'Unités (abbreviated to SI units). SI units are based upon a small number of fundamental units from which all other units may be derived.

The table below shows a selection of units appropriate to the electrical industry, including the symbols used in formulae and also their abbreviation.

SI unit	Measure of	Symbol	Abbreviation
Metre	Length	l	m
Square metre	Area	a	m^2
Cubic metre	Volume	v	M^3
Kilogram	Mass	m	kg
Kilogram/metre^3	Density	ρ	kg/m^3
Second	Time	t	s
Degrees Celsius	Celsius temperature	t	°C
Metres/second	Velocity	v	m/s
Ohm	Electrical resistance	R	Ω
Rho	Resistivity	ρ	Ohm/m^3
Watts	Power	P	W
Hertz	Frequency – number of cycles per second	f	Hz
Ampere	Electric current	I	A
Volt	Electric potential/Potential difference/Electromotive force	V	V
Joule	Energy/work/quantity of heat	E	J
Ohm	Impedance	Z	Ω
Henry	Inductance	L	H
Ohm	Inductive reactance	X_L	Ω
Farad	Capacitance	C	F
Ohm	Capacitive reactance	X_C	Ω
cos θ	Power factor	pf	No unit

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Worksheet 1: Principles of electricity

Using your notes, answer the following questions.

1. **Name the two main parts of the atom.**

2. **Which part has a negative charge?**

3. **Which part has a positive charge?**

4. **In electron current theory, in which direction do the electrons flow?**

5. **What is the charge state of an atom with an extra electron?**

6. **What is conventional current flow?**

7. **State three effects of an electric current.**

202: Principles of electrical science

Handout 2: Mathematical principles

Learning outcome

The learner will:

1. understand mathematical principles which are appropriate to electrical installation, maintenance and design work.

Assessment criteria

The learner can:

1.1. identify and apply appropriate **mathematical principles** which are relevant to electrical work tasks.

Range

Mathematical principles: fractions and percentages, algebra, indices, transposition, triangles and trigonometry, statistics

Mathematical principles

One of the issues with working with electricity is that under normal circumstances we can't see it or hear it, although we can smell it if something goes wrong. If we are to understand the quantities involved we need to measure the relevant electrical quantities and, from these, calculate other quantities. So, if we are to understand electrical principles we need to have a good understanding of certain mathematical principles.

Fractions and percentages

A fraction represents a part of a whole. In everyday English, a fraction describes how many parts of a certain size there are, for example, one-half or 0.5, eight-fifths or 1.6, three-quarters or 0.75.

Fractions can be classified in two ways:

- vulgar fractions
- decimal fractions.

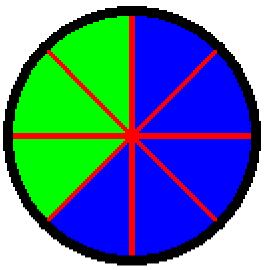
Vulgar fractions

A vulgar fraction consists of an integer (whole number) numerator displayed above a line (or before a slash), and a non-zero integer denominator, displayed below (or after) that line. Some examples are:

$$\frac{1}{2} \qquad 8/5 \qquad \frac{3}{4} \qquad 3/8$$

The number at the bottom (or to the right of the slash) is the denominator and tells us how many pieces an item is divided up by. The number on the top (or to the left of the slash) tells us how many of those pieces we have. Here are some examples.

- The picture to the right represents a cake.
- It has been divided into eight equal pieces.
- Because the cake has eight equal pieces the denominator will be 8.
- We are taking the green pieces of the cake and there are three of these.
- These three pieces will be the numerator, or the number of pieces we have.
- The resulting fraction will be:



$$\frac{3}{8} \quad \text{or} \quad 3/8$$

Fractions with the same denominator are referred to as like fractions. Add or subtract the numerators and write the answer as the new numerator above common denominator. For example:

$$\frac{2}{5}+\frac{1}{5}=\frac{3}{5} \quad \text{or} \quad \frac{9}{16}-\frac{3}{16}=\frac{6}{16}=\frac{3}{8}$$

Note that in the second example the answer was $6/16$ but this can be simplified to $3/8$ by cancelling.

If the fractions have different denominators we must first make the fractions equivalent by creating the same denominator. For example:

$$\frac{3}{8}+\frac{3}{12}=\frac{9+6}{24}=\frac{15}{24}=\frac{5}{8}$$

To solve this, we first had to find the lowest common multiple (LCM) which is the smallest number that all denominators will divide into without any remainder; in this case, 24. Next, the numerators need to be converted. Divide the original denominator in each case into the LCM and then multiply the respective numerator by the answer; 8 divided into 24 equals 3, 3 (numerator) times 3 equals 9; 12 divided into 24 equals 2; 3 (numerator) times 2 equals 6. We then add the new numerators together to give 15 which is then placed over the new denominator (24) to give $15/24$. This can then be simplified by cancelling to give $5/8$.

Decimal fractions
A decimal fraction is a fraction where the denominator (the bottom number) is a power of 10 (such as 10, 100, 1,000, etc).

You can write decimal fractions with a decimal point (and no denominator), which makes it easier to do calculations like addition and multiplication of fractions. For example:

$$\frac{43}{100}=0.43$$

Decimal fractions are ideal for use with calculators and they can be entered directly into the calculator. Vulgar fractions can be converted to decimal fractions by dividing the numerator by the denominator. For example:

$$\frac{17}{32}=17 \div 32=0.53125$$

Percentages
'Percent' means out of 100. The current basic income tax rate is 20 per cent taxable pay, this means that for £100 you will have to pay £20 in income tax. The symbol % means per cent.

How to calculate a percentage
A percentage is a fraction with a denominator of 100.

60% (60 in each 100) as a fraction is 60/100.

60% as a decimal is 0.6.

You will frequently need to find a percentage of a quantity. First, write the percentage as a fraction or a decimal, then multiply by the quantity.

Example: The maximum permitted voltage drop in a lighting circuit is 3% of the supply voltage. Calculate the maximum voltage drop if the supply voltage is 230 volts.

First, write 3% as a fraction: $3\% = 3/100$

Now multiply by the quantity: $3/100 \times 230 = 6.9 \text{ volts}$

Algebra

Algebra uses letters (like x or y) or other symbols in place of values; it is used to find unknown values, with rules for manipulating these symbols. For example, in electrical principles we can calculate the current flowing in a circuit if we know the applied voltage and the resistance of the circuit, using the formula:

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

Where:	I	=	Current in amperes
	V	=	Voltage in volts
	R	=	Resistance in ohms

Example

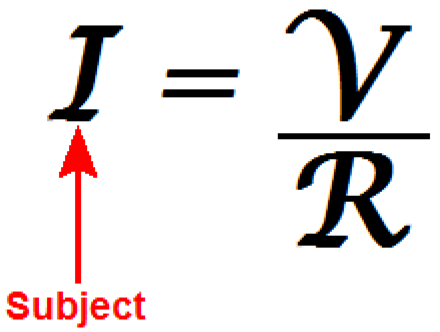
Calculate the current that will flow in a circuit of resistance of 460 ohms when a voltage of 230 volts is applied.

$$\begin{aligned} I &= \frac{V}{R} \\ &= \frac{230}{460} \\ &= 0.5 \text{ ohms} \end{aligned}$$

But what if we know, say, the current and resistance but not the voltage? We can still solve the equation by using transposition; this is explained in the next paragraph.

Transposition

This is also known as changing the subject of the formulae.



In the example on the left, I is the subject of the formula. By inserting the values for V and R, the value of the subject I can be calculated.

If we need to find V, for example, we must transpose the formula to make V the subject.

There is one fundamental rule for transposing a formula, as found below.

> Whatever you do to one side of the formula, you must do the same to the other side.

In other words:

- add the same quantity to both sides of the formula
- subtract the same quantity from both sides of the formula
- multiply both sides of the formula by the same quantity
- divide both sides of the formula by the same quantity
- take 'functions' of both sides of the formula; for example, square both sides or find the reciprocal of both sides.

Example 1

I = V/R – make V the subject of the formula.

$$I = \frac{V}{R}$$ (I is currently the subject of the formula.)

The question is: 'Make V the subject of the formula'. This means that 'V' must be put on its own on one side of the equals sign, with the other terms on the other side.

In order to do this, first multiply both sides by R. $$I \times R = \frac{V \times R}{R}$$

Now cancel through: $$I \times R = \frac{V \times \cancel{R}}{\cancel{R}}$$

$$I \times R = V$$

Now rearrange the formula: $$V = I \times R$$

Example 2

I = V/R – make R the subject of the formula.

$$I = \frac{V}{R}$$ (I is currently the subject of the formula.)

The question is: 'Make R the subject of the formula'. This means that 'R' must be put on its own on one side of the equals sign, with the other terms on the other side.

In order to do this, first multiply both sides by R. $$I \times R = \frac{V \times R}{R}$$

Now cancel through: $$I \times R = \frac{V \times \cancel{R}}{\cancel{R}}$$

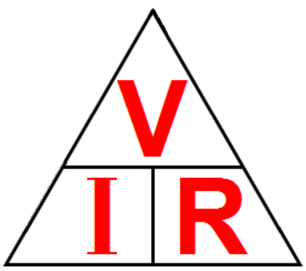
$$I \times R = V$$

Now divide both sides by I: $$\frac{I \times R}{I} = \frac{V}{I}$$

Now cancel through : $$\frac{\cancel{I} \times R}{\cancel{I}} = \frac{V}{I}$$

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

The formula used in examples 1 and 2 is the Ohm's law formula and is used to calculate the relationship between resistance (R), current (I) and voltage (V).



In formulae (the plural of formula) where there are three values, with two divided or multiplied by each other, the values can be put into a triangle that will allow you to determine easily which variation of the formula should be used.

If we need to find a value, simply cover it and what's left gives the formula. If the two values are side by side, multiply them; if the two values are one on top of the other then divide the bottom one into the top one to give the following:

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

Example 3
E = B x l x v – make v the subject of the formula.

$$E = B \times l \times v$$ (E is currently the subject of the formula.)

The question is: 'Make v the subject of the formula'. This means that 'v' must be put on its own on one side of the equals sign, with the other terms on the other side.

In order to do this, first divide both sides by B x l:

$$\frac{E}{B \times l} = \frac{B \times l \times v}{B \times l}$$

Now cancel through:

$$\frac{E}{B \times l} = \frac{\cancel{B \times l} \times v}{\cancel{B \times l}}$$

$$\frac{E}{B \times l} = v$$

Rearrange the formula:

$$v = \frac{E}{B \times l}$$

Indices

A knowledge of powers, or indices as they are often called, is essential for an understanding of most algebraic processes.

Basically, they are a shorthand way of writing multiplications of the same number.

So, suppose we have $4 \times 4 \times 4$

We write this as "4 to the power 3":

$$4^3$$

So:

$$4 \times 4 \times 4 = 4^3$$

The superscripted number 3 is called the power, or index. Note that the plural of index is indices.

Indices can be positive or negative and we generally use them in electrical science to express very large or very small numbers easily.

For example, a typical microwave motion detector uses a frequency of 2,420,000,000Hz. If you were to have to write numbers of this magnitude or input them into a calculator regularly it would be quite a chore. By using indices, the number could be written as:

$$2.42 \text{ x } 10^9 \text{ Hz}$$

Effectively, the 10^9 means that the decimal place, which is initially at the extreme right of the number, is moved nine places to the left.

Another example is that the resistivity of copper is 0.0000000172 ohm/metre^3. Again, to write and input these numbers would be quite a chore. By using negative indices, the number could be written as:

$$17.2\ 10^{-9} \text{ ohm/metre}^3$$

Effectively, the 10^{-9} means that the decimal place, which is initially at the left end of the number, is moved nine places to the right.

Standard form or scientific notation
A number written with one digit to the left of the decimal point and multiplied by 10 raised to some power is written in standard form or with scientific notation. For example:

$$43{,}712 = 4.3712 \times 10^{4}$$

$$0.036 = 3.6 \times 10^{-2}$$

Engineering notation
This is like scientific notation, except that the power of 10 is always a multiple of three. For example:

$$43712 = 43.712 \times 10^{3} = 0.043712 \times 10^{6}$$

$$0.036 = 36 \times 10^{-3} = 36000 \times 10^{-6}$$

In electrical installation, we generally use engineering notation.

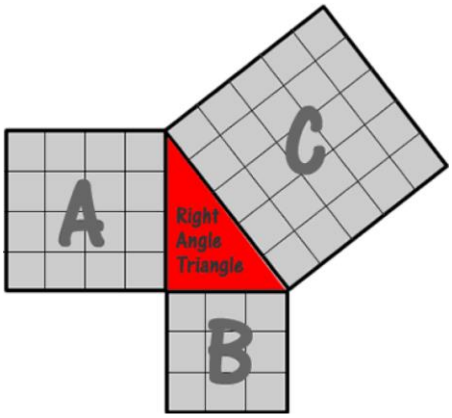
Triangles

When carrying out various calculations in electrical science we regularly make use of triangles, for example, to calculate impedance, power and power factor. To enable us to do these calculations we need to have a good understanding of Pythagoras' theorem and trigonometry.

Pythagoras' theorem states that for all right-angled triangles, the square on the hypotenuse is equal in area to the sum of the squares on the other two sides.

The hypotenuse is the longest side and it's always opposite the right angle.

If we draw a square on each side of a right-angled triangle, Pythagoras found that the combined areas of sides A and B (see the diagram to the right) will equal the area of the square on the hypotenuse, side C in this case.



This gives the relationship:

$$C^2 = A^2 + B^2$$

To calculate side C (the hypotenuse) the relationship would become the following equation:

$$C = \sqrt{A^2 + B^2}$$

To use Pythagoras' theorem we need to know the lengths of two of the sides to find the length of the third. The above equation can be transposed to enable us to find the other two sides as follows:

$$A = \sqrt{C^2 - B^2}$$

$$B = \sqrt{C^2 - A^2}$$

We use Pythagoras' theorem to calculate power and impedance in AC circuits (you will be shown how to apply the theorem later in your studies).

Trigonometry

Trigonometry is a branch of mathematics that studies relationships involving lengths and angles of triangles. Again, relating to right-angled triangles, if we know the length of one side and one angle we can calculate all the others.

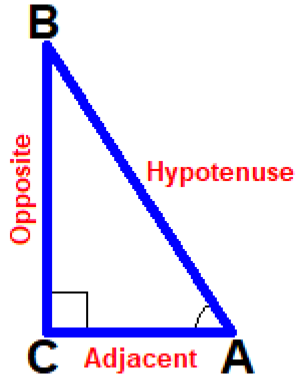
The ratios of the sides of a right-angled triangle are called trigonometric ratios. Three common trigonometric ratios are the sine (sin), cosine (cos) and tangent (tan).

These are defined for acute angle A below:

$$\sin(A) = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\cos(A) = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

$$\tan(A) = \frac{\text{Opposite}}{\text{Adjacent}}$$



We use trigonometry to calculate power factor in AC circuits (you will be shown how to apply this later in your studies).

Statistics

This is a branch of mathematics dealing with the collection, analysis, interpretation, presentation, and organisation of data. We would normally start with data collection which could be, for example, the number of people with red cars, blue cars, silver cars or white cars; this is referred to as the population.

Once the data has been collected it can then be analysed using simple statistical tools including range, average (mean), median and mode.

The range is the difference between the lowest and highest values. For example:

$\text{Data set: } 8, 11, 5, 9\ , 7, 6, 8, 10, 6$

- The lowest value is 5
- The highest value is 11

$$\text{So the range} = \text{Highest value} - \text{Lowest value} = 11 - 5 = 6$$

This appears very simple, but the result can be very misleading if there is an extraordinarily high or low value in the data set compared to the rest.

The average or mean value is defined as the number that measures the central tendency of a given set of numbers. You calculate this by adding up all the numbers in the data set and dividing this answer by the number of items in the data set. For example, using the numbers above:

$$\text{Average or mean} = \frac{(8 + 11 + 5 + 9 + 7 + 6 + 8 + 10 + 6)}{9} = \frac{70}{9} = 7.78$$

The median is the middle value of a data set. To find the median, list the values of the data set in numerical order and identify which value appears in the middle of the list. For example, again using the data set above:

The mode is the value that occurs the most; there can be more than one mode. For example, using the data set above it can be seen that the values that occur the most are 6 and 8, with two of each; both are the mode values.

Useful formulae

Voltage	=	I.R	=	P/I	=	$\sqrt{P.R}$
Current	=	V/R	=	P/V	=	$\sqrt{P/R}$
Resistance	=	V/I	=	V^2/P	=	P/I^2
Power	=	V.I	=	$I^2.R$	=	V^2/R

Resistors In series: $R_t = R_1 + R_2 + R_3$ etc

in parallel: $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ etc

Kirchhoff's laws

Voltage: VT = V1 + V2 + V3 + etc in a series circuit

Current: IT = I1 + I2 + I3 + etc in a parallel circuit

Resistivity $R = \rho \times \frac{l}{a}$ $R \propto L$ $R \propto 1/a$

Charge (Quantity) Q = It or Q = VC

Capacitors in parallel: $C_t = C_1 + C_2 + C_3$ etc

in series: $\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$ etc

Electro-magnetism $\Phi = B.A$ $B \propto H$

mmf = N x I

$H = \frac{n \times l}{L}$

Induced EMF $E = B \times l \times v$ (v = velocity)

$E = \frac{\Phi 2 - \Phi 1}{t}$

$E = -L \times \frac{(I2 - I1)}{t}$

Force on a conductor $F = B \times I \times l$ Newtons

Energy in a magnetic field: $½.L.I^2$ Joules

Stored in a capacitor: $½.C.V^2$ Joules

Efficiency $\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}}$

Mechanics	Force	=	Mass x Newtons
	Torque	=	Force x Distance
	Work Done (WD)	=	Force x Distance
	Energy	=	Joules
	Joules	=	Watts x Seconds
	Joules	=	Newton Metre
Pythagoras	Z	=	$\sqrt{R^2 + X^2}$
Power factor	pf	=	$\frac{R}{Z}$
Power factor	pf	=	$\frac{P}{VA}$

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Worksheet 2: Mathematical principles

Transpose the following formulae to make the stated value the subject (show all working).

1. $\mathbf{P = I \times V}$ **– make V the subject.**

2. $\mathbf{P = \frac{V^2}{R}}$ **– make V the subject.**

3. $\mathbf{p.f. = \frac{R}{Z}}$ **– make Z the subject.**

4. $\mathbf{Z = \sqrt{R^2 + X_L^2}}$ **– make R the subject.**

202: Principles of electrical science

Handout 3: Ohms law

Learning outcome

The learner will:

4. understand the relationship between resistance, resistivity, voltage, current and power.

Assessment criteria

The learner can:

4.4 explain the relationship between current, voltage and resistance in parallel and series DC circuits.

Ohm's law

Current

The uniform flow of electrons through a conductor is referred to as electric current.

The unit of electric current is the **ampere** (A).

In formulae, the symbol for electric current is **I**.

Electromotive force (EMF)

The EMF provides a difference in potential between two open terminals of an electrical circuit. When the circuit is complete, this potential difference causes the electrons to flow in a uniform direction around the circuit and produce a flow of current.

The unit of EMF is the **volt** (V).

In formulae, the symbol for EMF is **V**.

Resistance

Every circuit presents some opposition to the flow of current in the electric circuit, which has to be overcome by the electrical pressure applied. This opposition is called **resistance**.

The unit of resistance is the **ohm** (Ω)

In formulae, the symbol for resistance is **R**.

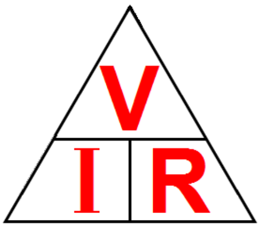
Ohm's law

In 1827 a man named Georg Ohm published his experiments regarding the relationship between current, voltage and resistance. His findings, referred to as **Ohm's law**, are shown below:

> The current flowing in any circuit is directly proportional to the applied voltage and inversely proportional to the resistance of the circuit, provided that the temperature of the circuit remains constant.

The simple relationship between symbols is shown on the right.

The simple method of transposing the symbols is to use the cover-up method, ie cover the symbol required; the answer is then given by the other two symbols.



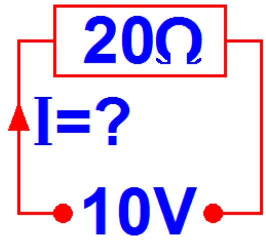
$$V = I \times R$$

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

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

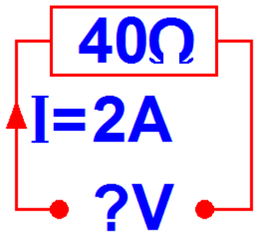
Example 1
An EMF of 10 volts is applied to a resistance of 20Ω. Calculate the current that will flow.

$$I = \frac{V}{R} = \frac{10}{20} = 0.5A$$



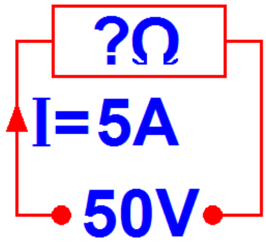
Example 2
Calculate the applied EMF when 2 amperes flows through a resistance of 40Ω.

$$V = I \times R = 2 \times 40 = 80 \text{ volts}$$



Example 3
When an EMF of 50 volts is applied to a circuit, a current of 5 amperes flows. Calculate the resistance of the circuit.

$$R = \frac{V}{I} = \frac{50}{5} = 10\ \Omega$$



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Worksheet 3: Basic electrical circuits and Ohm's law

1. **What potential is produced across a resistance of 15Ω if a current of 12A is flowing through it?**

2. **A current of 10A flows through a resistor and a voltage of 150V is measured across it. Calculate the value of the resistor.**

3. **When a current of 2.5A is flowing through a resistor, a voltage of 200V is measured across the resistor. Calculate the value of the resistor.**

4. **What is the current flowing in the circuit when a voltage of 198V is present across a resistance of 3.3Ω?**

5. **A voltage of 20V is measured across a resistor of 400Ω. Calculate the current flowing in the circuit.**

6. **Complete the following table:**

Voltage	15	10	20		40	50		96	
Current		1		3	4		5	8	0.1
Ohms	120		10	10		20	12		10

7. **A cable of resistance 0.043Ω carries a current of 139.5A. What will be the voltage drop in the cable?**

8. **A certain cable has a resistance of 1.6Ω. What is the maximum current it can carry if the voltage drop is not to exceed 14.4 volts?**

9. **Complete the following table:**

Voltage	84	10		230	0.7		110	0.02	
Current		0.1	0.2		0.9	0.05		0.01	0.166
Ohms	12		20	20		2.5	20		96

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Handout 4: Resistors in series

Learning outcome
The learner will:
4. understand the relationship between resistance, resistivity, voltage, current and power.

Assessment criteria
The learner can:
4.5 calculate the values of current, voltage and resistance in parallel and series DC circuits.

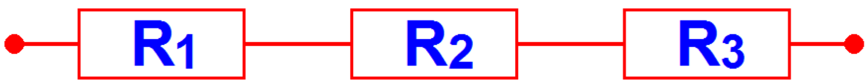
Resistors in series

When there is only one resistance in a circuit, the Ohm's law calculation is straightforward.

However, when there are two or more resistors in a circuit, the total effective resistance must be calculated first. Resistors can be connected in many configurations:

- series
- parallel
- series-parallel.

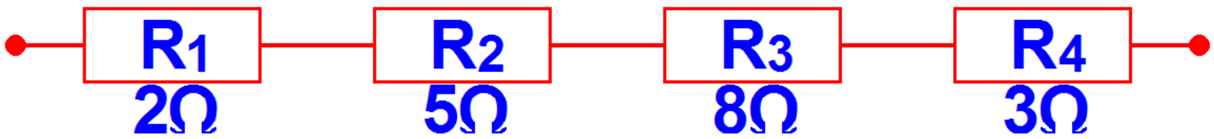
In order to find the total resistance of any series circuit, just add all the resistances together.



The formula for calculating the total resistance of resistors connected in series is given below:

$$\mathbf{R_t = R_1 + R_2 + R_3}$$

Example 1
Calculate the total resistance of the circuit shown below:

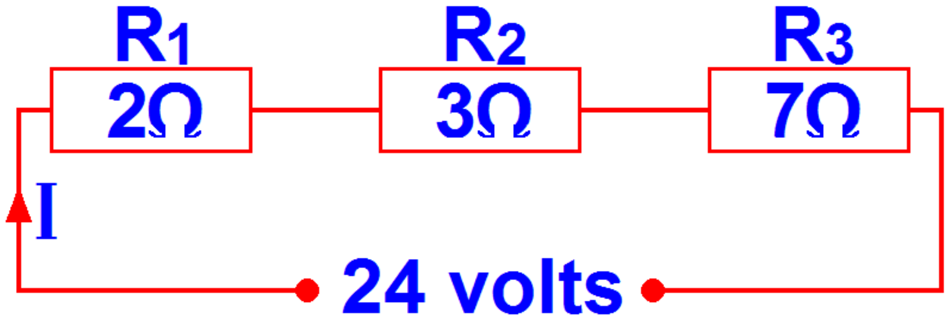


$$\begin{aligned} R_t &= R_1 + R_2 + R_3 + R_4 \\ &= 2 + 5 + 8 + 3 \\ &= \mathbf{18\Omega} \end{aligned}$$

Method of determining current flow in a series circuit

1. Calculate the total resistance of the circuit, using the series resistor formula.
2. Redraw the circuit diagram, using the equivalent total resistance.
3. Using Ohm's law, calculate the current flowing.

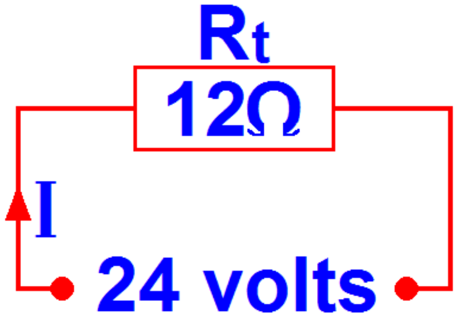
Example 2
Calculate the current that will flow in the circuit shown below:



$$R_t = R_1 + R_2 + R_3$$
$$= 2 + 3 + 7$$
$$= 12\Omega$$

Equivalent circuit

$$I = \frac{V}{R}$$
$$= \frac{24}{12}$$
$$= 2 \text{ amperes}$$



The current flowing in any series circuit will be the same wherever you measure it. In other words, the current coming from the supply will flow through resistance 1, then through resistance 2, followed by resistance 3, and so on, until it gets back to the supply terminal.

It does not matter where you measure the current in the series circuit, as it will always be the same.

Voltage drop

If a current is passed through a resistance then, according to Ohm's law, a voltage is produced across it, ie:

$$V = I \times R$$

This voltage is often referred to as a voltage drop but is calculated the same way as any other voltage.

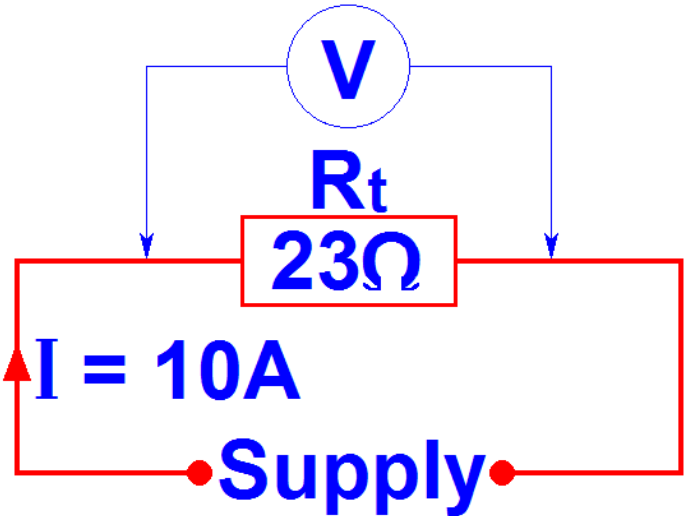
After you have read a question, the first thing that you should do is draw a diagram relating to the question, containing all the information.

Example 3
What potential is produced across a resistance of 23Ω if a current of 10 amps is flowing through it?

$V = I \times R$

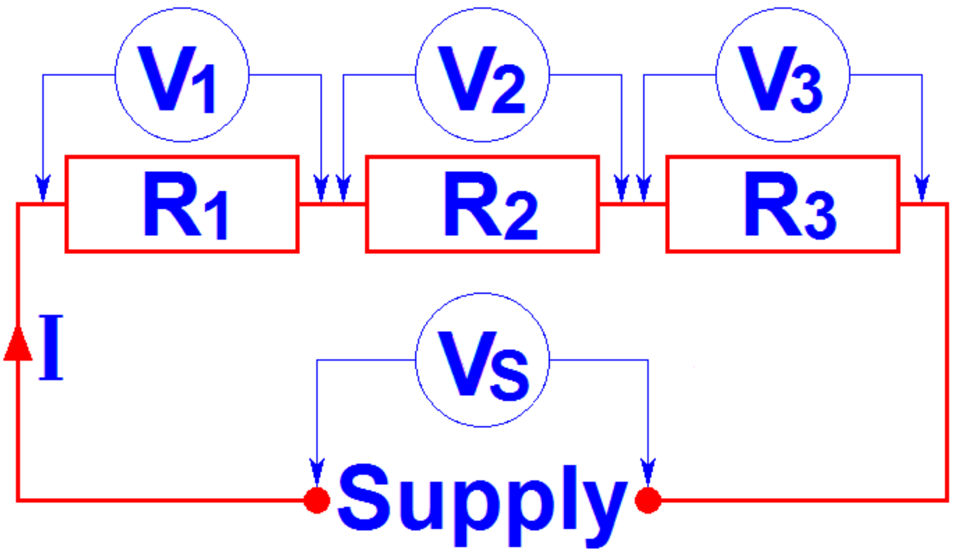
$V = 10 \times 23$

$V = 230 \text{ volts}$



Kirchhoff's voltage law

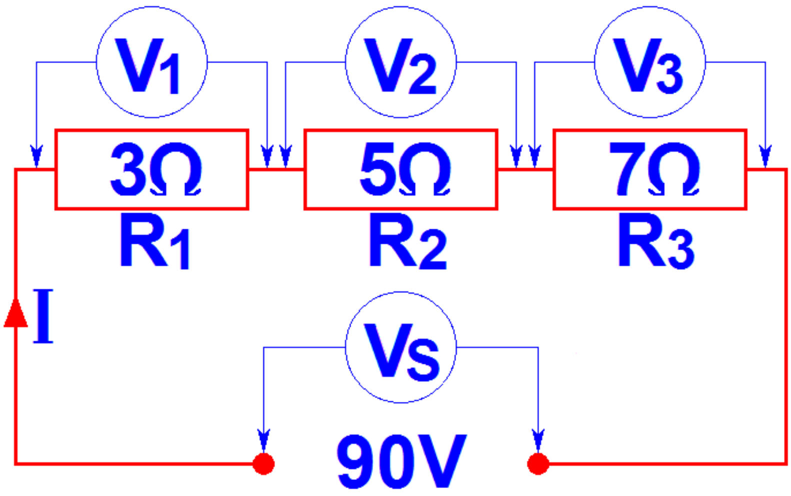
Kirchhoff's voltage law states that: the algebraic sum of the voltages around a circuit is equal to zero (or the supply voltage).



Putting Kirchhoff's statement into symbols, we get the formula:

$$V_S = V_1 + V_2 + V_3$$

Example 4
Calculate V_1, V_2, V_3, hence proving Kirchhoff's voltage law.



$$R_t = R_1 + R_2 + R_3$$
$$= 3 + 5 + 7$$
$$= \mathbf{15\Omega}$$
$$I = \frac{V}{R}$$
$$= \frac{90V}{15}$$
$$= 6 \text{ amperes}$$

Resistor 1	Resistor 2	Resistor 3
$V_1 = I \times R_1$ $= 6 \times 3$ $= 18V$	$V_2 = I \times R_2$ $= 6 \times 5$ $= 30V$	$V_3 = I \times R_3$ $= 6 \times 7$ $= 42V$

$$V_S = V_1 + V_2 + V_3$$
$$= 18 + 30 + 42$$
$$= 90V$$ – Kirchhoff's law is proved.

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Worksheet 4: Resistors in series

1. Complete the following table for resistors that are all connected in series.

	R1	R2	R3	R4	R_T
a	7 Ω	10 Ω	8 Ω	15 Ω	
b	7 Ω	16 Ω	8 Ω	19 Ω	
c	1.5 Ω	5.6 Ω	8.2 Ω	7.3 Ω	
d	0.03 Ω	0.105 Ω	1.06 Ω	2.007 Ω	
e	15 MΩ	21.3 MΩ	1.4 MΩ	5.3 MΩ	
f	15 mΩ	83 mΩ	26 mΩ	9 mΩ	
g	2 Ω	500 mΩ	1 kΩ	1.2 MΩ	

2. Calculate the value of resistor to be connected in series with two resistors of 1.8Ω and 5.6Ω, to give a total resistance of 10Ω.

3. How many resistors of 0.27Ω must be connected in series to give a total resistance of 3.51Ω?

4. Two resistors connected in series have a combined resistance of 89.75Ω. If the resistance of one resistor is 23.5Ω, what is the value of the other resistor?

5. Six resistors of equal value are connected in series. Calculate the value of the individual resistors if the total resistance is 14.4Ω.

6. Four resistors in series have voltage drops across them of 37V, 55V, 19V and 9V. Calculate the supply voltage.

7. Four resistors with values of 3Ω, 4Ω, 6Ω and 10Ω are connected in series to a supply of 230 volts. Calculate the voltage drop across each resistance in the circuit.

3Ω:

4Ω:

6Ω:

10Ω:

8. Four resistors with values of 8Ω, 17Ω, 9Ω and 6Ω are connected in series. The 9Ω resistor has a voltage drop of 27 volts across. Calculate: (a) the total current, (b) the total resistance, (c) the voltage drop across the other three resistors and (d) the supply voltage.

a)

b)

c)

d)

9. When four resistors are connected in series across a 110V supply, a current of 2A flows. Three of the resistors have values of 5Ω, 23Ω and 10Ω. Calculate: (a) the value of the fourth (unknown) resistor and (b) the voltage drop across all the resistors and prove Kirchhoff's law.

a)

b)

10. Four resistors, of 5Ω, 20Ω, 45Ω and 10Ω, are connected in series across a DC supply. If the voltage across the resistors is 15, 60 and 135 volts, respectively, calculate: (a) the voltage across the 10Ω resistor and (b) the supply voltage.

a)

b)

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Handout 5: Resistors in parallel

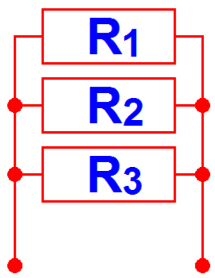
Learning outcome
The learner will:
4. understand the relationship between resistance, resistivity, voltage, current and power.

Assessment criteria
The learner can:
4.5 calculate the values of current, voltage and resistance in parallel and series DC circuits.

Resistors in parallel

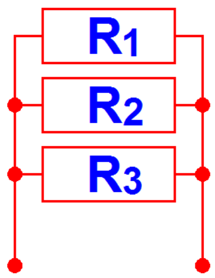
In order to find the total resistance of any parallel circuit, we must add the reciprocal $(1/x)$ of all the resistances together.

The formula for calculating the total resistance of resistors connected in parallel is given below.



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

Example 1
Calculate the total resistance of a parallel circuit if:
$R_1 = 9\Omega,\ R_2 = 12\Omega$ and $R_3 = 18\Omega$.



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

$$= \frac{1}{9} + \frac{1}{12} + \frac{1}{18}$$

Find the lowest common denominator, which is 36:

$$\frac{1}{R_t} = \frac{4 + 3 + 2}{36}$$

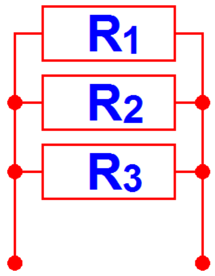
$$\frac{1}{R_t} = \frac{9}{36}$$

Inverting both sides of the equation will give us R_t:

$$R_t = \frac{36}{9}$$

$$= 4\Omega$$

The total resistance of the circuit will determine the amount of current that will flow in that circuit.



Example 2
Calculate the total resistance of a parallel circuit if $R_1 = 45\Omega$, $R_2 = 90\Omega$ and $R_3 = 30\Omega$

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$= \frac{1}{45} + \frac{1}{90} + \frac{1}{30}$$

Find the lowest common denominator, which is 90:

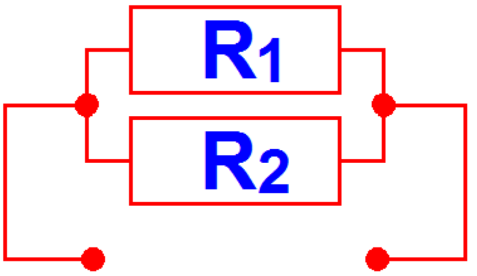
$$\frac{1}{R_t} = \frac{2+1+3}{90}$$
$$\frac{1}{R_t} = \frac{6}{90}$$

Inverting both sides of the equation will give us R_t:

$$R_t = \frac{90}{6}$$
$$= 15\Omega$$

It can be seen that in all parallel circuits the total resistance of the circuit is always less than the smallest resistance in that circuit.

Two resistors in parallel



When there are only two resistors in parallel, the equivalent total resistance of the combination may be found by using the product over sum method, as shown below.

- The product of two numbers is the multiplication of the two numbers.
- The sum of two numbers is the addition of the two numbers.

Example 3
Calculate the total resistance of two resistors connected in parallel if $R_1 = 6\Omega$ and $R_2 = 4\Omega$.

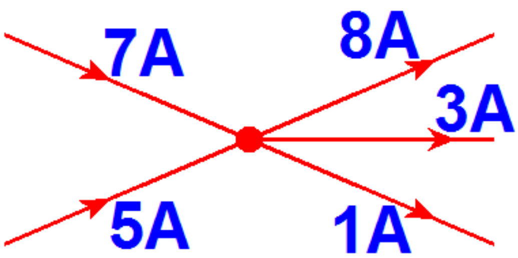
$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$= \frac{6 \times 4}{6 + 4}$$
$$= \frac{24}{10}$$
$$= 2.4\Omega$$

This method only works for two resistors in parallel.

If all the resistors in parallel are of the same value, then all that has to be done, in order to calculate the total resistance of the circuit, is to take any one resistor and divide its value by the number of resistors that are in the parallel combination.

Kirchhoff's current law

The sum of the currents arriving at a point must equal the sum of the currents leaving that point.

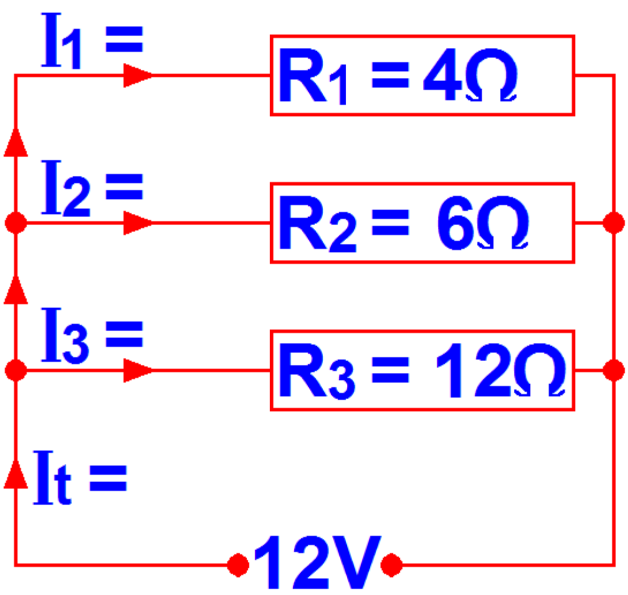


$$I_t = I_1 + I_2 + I_3 + \text{etc}$$

In any parallel branch/circuit, the voltage will always be the same across each individual resistor, but the current may be different depending on the value of the resistor.

Since the voltage is constant, it makes it easy to calculate the current flowing through each individual resistor.

Example 4



$$I_1 = \frac{V}{R_1} = \frac{12}{4} = 3 \text{ amps}$$

$$I_2 = \frac{V}{R_2} = \frac{12}{6} = 2 \text{ amps}$$

$$I_3 = \frac{V}{R_3} = \frac{12}{12} = 1 \text{ amp}$$

$$I_t = I_1 + I_2 + I_3$$

$$I_t = 3 + 2 + 1$$

$$I_t = 6 \text{ amps}$$

If we calculate the total resistance of the parallel network:

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

$$\frac{1}{R_t} = \frac{1}{4} + \frac{1}{6} + \frac{1}{12}$$

$$\frac{1}{R_t} = \frac{3 + 2 + 1}{12}$$

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

$$R_t = \frac{12}{6}$$

$$= 2\Omega$$

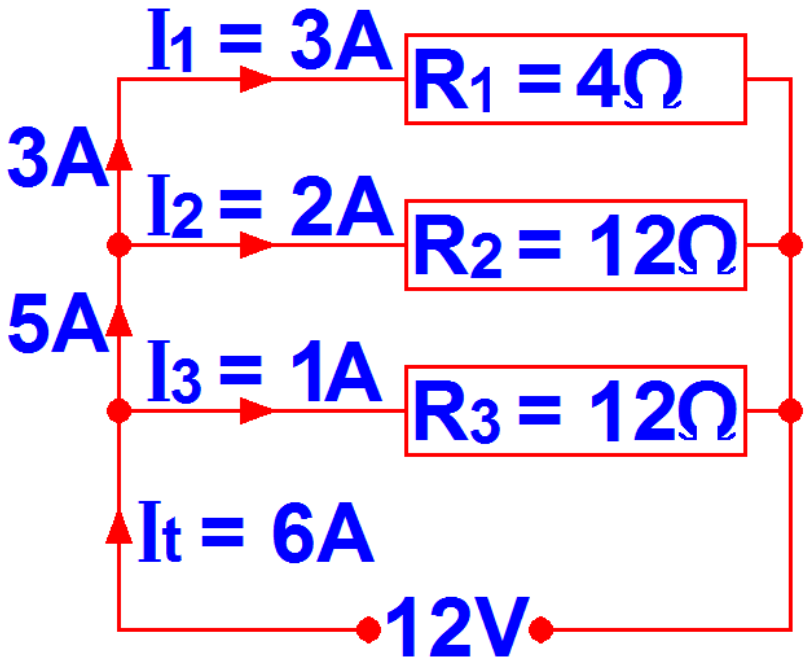
and then calculate the total current using Ohm's law:

$$I_t = \frac{V}{R_t}$$

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

$= 6 \text{ amps}$ – Kirchhoff's law is proved.

The sum of the currents through the resistors is the same as the current drawn from the supply; therefore, the solution is correct according to Kirchhoff's current law.



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Worksheet 5: Resistors in parallel

1. Calculate the total resistance of each branch if the following resistors are connected in parallel.

	R_1	R_2	R_3	R_T
a	12Ω	6Ω	4Ω	
b	30Ω	90Ω	45Ω	
c	120Ω	80Ω	48Ω	
d	6Ω	20Ω	30Ω	
e	1.5Ω	4Ω	12Ω	

2. Complete the following table, assuming that the resistors are connected in parallel.

	R_1	R_2	R_3	R_T
a	120Ω		-	48Ω
b		48Ω	-	12Ω
c		50Ω	-	40Ω
d	40Ω		20Ω	10Ω
e	60Ω		20Ω	10Ω

3. Two resistors of 48Ω and 80Ω are connected together in parallel. What would the value of a third resistor have to be, when connected in parallel with the first two, in order to give a combined resistance total of 15Ω?

4. A parallel circuit containing three resistors of 1.5Ω, 4Ω and 12Ω is connected across a 10 volt supply. Calculate the current flowing in each resistor and prove Kirchhoff's current law.

5. A parallel circuit containing three resistors of 18Ω, 20Ω and 30Ω is connected across a 144 volt supply. Calculate the current flowing in each resistor and prove Kirchhoff's current law.

6. A parallel circuit containing three resistors of 30Ω, 90Ω and 45Ω is connected across a 30 volt supply. Calculate the current flowing in each resistor and prove Kirchhoff's current law.

7. Three resistors of 0.012Ω, 0.015Ω and 0.008Ω, respectively, are connected in parallel across a 2.4 volt DC supply. Calculate:

a) the current flowing in each resistor:

b) the total current drawn from the supply:

8. Three resistors are connected in parallel across a DC supply. The values of two of the resistors are 12Ω and 18Ω, respectively. If the 18Ω resistor has a current of 18 amperes flowing through it and the total current drawn from the supply is 81 amperes, calculate:

a) the supply voltage:

b) the value of current flowing through each resistor:

c) the value, in ohms, of the third resistor:

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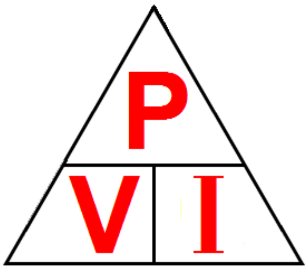
Handout 6: Power

Learning outcome
The learner will:
4. understand the relationship between resistance, resistivity, voltage, current and power.

Assessment criteria
The learner can:
4.6 calculate values of power in parallel and series DC circuits.

Power

- Electrical power is the rate of doing electrical work or of expenditure of electrical energy.
- The formula for power is obtained by using the power triangle, as shown on the right.
- From the triangle, it can be seen that:



$$\text{power} = \text{volts} \times \text{amps}$$

or

$$P = V \times I \text{ (DC only)}$$

Using Ohm's law and substituting for either voltage or current in the power equation, as shown below, you can find other formulae for power.

Ohm's law is: $V = I \times R$

Substituting I x R for V in the power equation we get:

$P = I \times I \times R$, giving:

$$P = I^2R \text{ (AC or DC)}$$

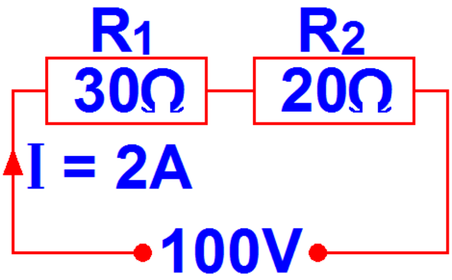
By substituting V/R for I in the power equation, we get:

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

This gives:

$$P = \frac{V^2}{R} \text{ (AC or DC)}$$

Example 1



$$\text{Total power} = V \times I = 100 \times 2 = 200 \text{ watts}$$

Power dissipated by $R_1 = P_1$:

$$P_1 = I^2R_1 = 2^2 \times 30 = 120 \text{ watts}$$

Power dissipated by $R_2 = P_2$:

$$P_2 = I^2R_2 = 2^2 \times 20 = 80 \text{ watts}$$

$$\text{Total power} = P_1 + P_2 = 120 + 80 = 200 \text{ watts}$$

Alternatively, since:

$$V = I \times R$$

then voltage across R_1 is V_1:

$$V_1 = I \times R_1 = 2 \times 30 = 60 \text{ volts}$$

$$P_1 = \frac{V_1^2}{R_1} = \frac{60^2}{30} = 120 \text{ watts}$$

or

$$P_1 = V_1 \times I = 60 \times 2 = 120 \text{ watts}$$

Voltage across R_2 is V_2:

$$V_2 = I \times R_2 = 2 \times 20 = 40 \text{ volts}$$

$$P_2 = \frac{V_2^2}{R_2} = \frac{40^2}{20} = 80 \text{ watts}$$

or

$$P_2 = V_2 \times I = 40 \times 2 = 80 \text{ watts}$$

Although the example shows how to calculate power in a series circuit the same method can be used for resistors in parallel, provided that you know two of the three values (resistance, current, voltage) of the individual resistance.

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Worksheet 6: Power

1. The voltage drop in a cable carrying 10.5 amperes is 4.6 volts. Calculate the power wasted in the cable.

2. A DC machine takes 18.6 amperes from a 220 volt supply. Calculate the machine's input power.

3. Complete the following table.

P		6,000	500		3,000	1,000		750	1,000
I	3		75	0.25		13.5	25		10
V	120	500		150	220		240	110	

4. Calculate the voltage drop in a resistor, when the power absorbed is 9kW and the current flowing is 63 amperes.

5. An appliance is rated at 3kW, 240 volts. Calculate the current drawn from the supply.

6. Two resistors of 25Ω and 95Ω are connected in series across a 240 volt DC supply. Calculate:

a) the power absorbed by each resistor:

b) the total power drawn from the supply:

7. Calculate the value of resistor that absorbs 1kW of power when a current of 10 amperes is flowing.

8. A joint in a cable has a resistance of 0.0236Ω. Calculate the power developed in the joint when a current of 40 amperes is flowing in the cable.

9. Determine what the rating of a 2kΩ resistor should be in watts, if it has to be capable of carrying a current of 30mA.

10. Calculate the power loss in a cable of 0.25Ω when a current of 30 amperes is flowing.

11. Three resistors of 1Ω, 0.005kΩ and 500mΩ are connected in series across a 52 volt DC supply. Calculate:

a) the power absorbed by each resistor:

b) the total power supplied to the circuit:

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Handout 7: Resistivity

Learning outcome

The learner will:

4. understand the relationship between resistance, resistivity, voltage, current and power.

Assessment criteria

The learner can:

4.3 describe what is meant by resistance and resistivity in relation to electrical circuits

4.7 state what is meant by the term voltage drop in relation to electrical circuits.

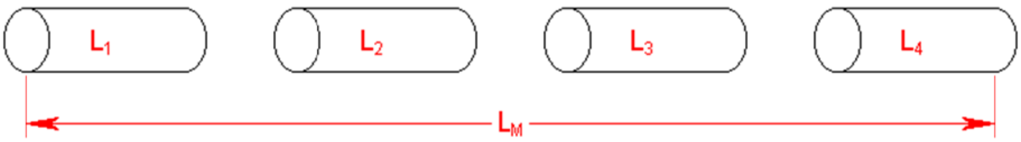
Resistivity

Up until now we have assumed that the conductors that form part of the circuit have no resistance. However, every conductor possesses resistance, the value of which depends on four factors:

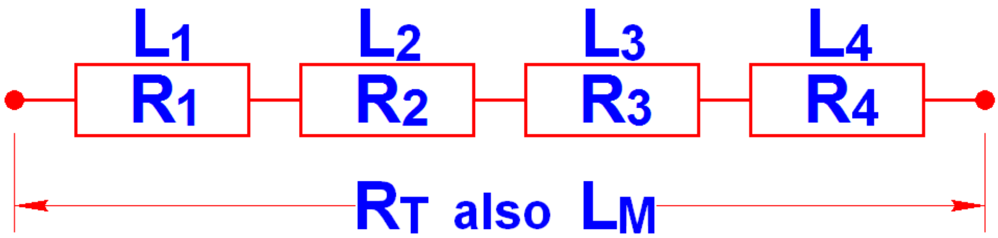
1. the length of the conductor (L metres)
2. the cross-sectional area of the conductors (CSA mm^2)
3. the type of conducting material (ρ Rho)
4. the temperature (t °C).

Length of conductor

The conductor length can be considered as being made up of a lot of resistors all in series. If the length of short conductors is L_1, L_2, L_3, and so on, then the total length (L_M) is made up of short lengths as shown:



$$L_M = L_1 + L_2 + L_3 \text{ etc}$$



Also, if the short conductors have resistances R_1, R_2, R_3 and R_4 then the total resistance of the length L_M is:

$$R_T = R_1 + R_2 + R_3 + R_4 \text{ etc}$$

It therefore follows that the resistance of a conductor is proportional to its length:

$$R \propto L$$

(resistance is proportional to length)

Example 1
If a cable has a resistance of 0.15Ω/m, what will be the resistance of 320m of the same cable?

Since resistance is proportional to length:

$$\begin{aligned} \text{Resistance} &= \Omega/\text{m} \times \text{length} \\ &= 0.15 \times 320 \\ &= 48\Omega \end{aligned}$$

Example 2
If a 50m length of a conductor has a resistance of 0.01Ω, what would be the resistance of 500m of the same cable?

$$\begin{aligned} \text{R} &= \frac{\text{new length}}{\text{old length}} \times \text{resistance} \\ &= \frac{500}{50} \times 0.01 \\ &= 0.1\Omega \end{aligned}$$

Example 3
If a 750m length of a conductor has a resistance of 0.013Ω, what will be the resistance of 150m of the same conductor?

Since resistance is proportional to length:

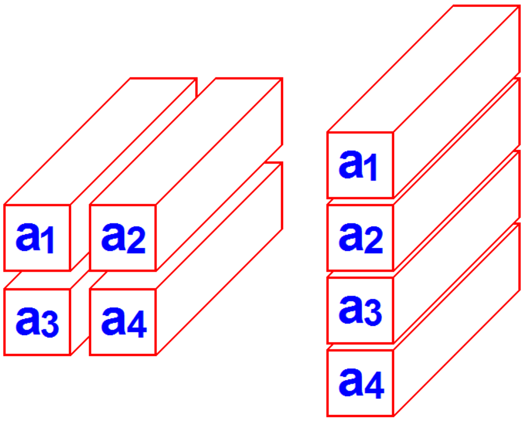
$$\begin{aligned} \text{R} &= \frac{\text{new length}}{\text{old length}} \times \text{resistance} \\ &= \frac{150}{750} \times 0.013 \\ &= 0.0026\Omega \end{aligned}$$

Cross-sectional area (CSA) of conductors

A conductor of cross-sectional area (a) can be regarded as being made up of a number of smaller conductors joined together in parallel, as shown.

If the areas of the small conductors are a_1, a_2, a_3, a_4, and so on, then the total area a_T, made up of small conductors, is calculated by:

$$\mathbf{a_T = a_1 + a_2 + a_3 + a_4}$$



If the resistances of the small conductors are R_1, R_2, R_3 and R_4 then the total resistance R_T is given by:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

Therefore, the resistance of a conductor is inversely proportional to its CSA.

$$R \propto \frac{1}{a}$$

(resistance is inversely proportional to area)

Example 4

If the resistance of 100m of a certain conductor is 0.076Ω, calculate the resistance of 100m of the same conductor, but with:

a) twice the CSA
b) four times the CSA
c) half the CSA
d) one quarter of the CSA.

a) Since R is $\propto$ to $1 \div a$, then:

$$R = 0.076 \div 2$$
$$= 0.038\Omega$$

b) Since R is $\propto$ to $1 \div a$, then:

$$R = 0.076 \div 4$$
$$= 0.019\Omega$$

c) Since R is $\propto$ to $1 \div a$, then:

$$R = 0.076 \div 1/2$$
$$= 0.152\Omega$$

d) Since R is $\propto$ to $1 \div a$, then:

$$R = 0.076 \div 1/4$$
$$= 0.304\Omega$$

Example 5

If the resistance of 100m of a certain conductor is 1.24Ω, calculate the resistance of 500m of the same conductor, but with twice the CSA.

$$R \propto L$$
$$= \frac{500}{100} \times 1.24$$
$$= 6.2\Omega$$

But:

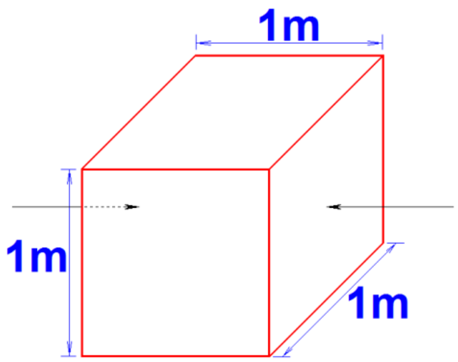
$$R \propto \frac{1}{a} \text{(therefore the resistance must be halved)}$$
$$= \frac{6.2}{2}$$
$$= 3.1\Omega$$

Type of conducting material and temperature

Since different materials have a different number of electrons in their structure, it must follow that they will not all have the same resistance to current flow. This resistance to current flow in a material is known as its resistivity (symbol ρ - RHO). A material that is a good conductor has a low resistivity, while a poorer conductor will have a higher value. The table below gives the resistivity of some commonly used materials in the electrical industry.

Material	**Resistivity at 20°C**
Copper	17.2 x 10^{-9} ohm metre
Aluminium	26.5 x 10^{-9} ohm metre
Silver	15.9 x 10^{-9} ohm metre
Gold	22.4 x 10^{-9} ohm metre
Brass (58% copper)	59.0 x 10^{-9} ohm metre
Brass (63% copper)	71.0 x 10^{-9} ohm metre

The table lists copper as 17.2 x 10^{-9} ohm metre at a temperature of 20°C. This means that the resistance of a cubic metre of copper – 1m long by 1m high and 1m deep – has a resistance of 0.0000000172Ω, or 17.2 x 10^{-9}Ω at a temperature of 20°C, when measured across two opposite faces. Conductors increase resistance with temperature increase, and vice versa; insulators decrease in resistance as temperature increases, and vice versa.



$$17.2 \times 10^{-9} \text{ is the same as } 17.2\text{Exp}^{-9}$$

Note: it will be written as 17.2E-9 for convenience.

Since the resistance of any conductor is directly proportional to length and inversely proportional to its CSA, the formula for calculating the resistance of any conductor is:

$$\text{Resistance} = \frac{\text{Resistivity} \times \text{Length}}{\text{Cross sectional area}} \quad \text{or} \quad R = \rho\frac{l}{a}$$

where:

R = conductor resistance in ohms

ρ = cable resistivity in Ω m

l = cable length in metres

a = cross sectional area (CSA) in m^2.

Cable CSA is usually quoted in mm^2 and this will need to be converted to m^2. In order to convert:

$$mm^2 \text{ to } m^2, \text{multiply by } 10^{-6}$$

Example 6

Calculate the resistance of 1,000m of $16mm^2$ (CSA) single copper conductor. Take ρ to be 17.2×10^{-9} ohm metre.

$$R = \rho\frac{l}{a}$$

$$= 17.2 \times 10^{-9} \times \frac{1{,}000}{16 \times 10^{-6}}$$

$$= \mathbf{1.075\Omega}$$

Example 7
Calculate the resistance of an aluminium wire 100m long and CSA of 25mm^2. Take the resistivity of aluminium to be 26.5 x 10^{-9} ohm metre.

$$R = \rho \frac{l}{a}$$

$$= 26.5 \times 10^{-9} \times \frac{100}{25 \times 10^{-6}}$$

$$= \mathbf{0.106\Omega}$$

Example 8
Calculate the resistance of 100m of copper conductor if ρ = 17.2 x 10^{-9} ohm metre for the material and the CSA is 2.5mm^2.

$$R = \rho \frac{l}{a}$$

$$= 17.2 \times 10^{-9} \times \frac{100}{2.5 \times 10^{-6}}$$

$$= \mathbf{0.688\Omega}$$

Example 9
Calculate the resistance of 100m of silver conductor if ρ = 15.9 x 10^{-9} ohm metre for the material and the CSA is 2.5mm^2.

$$R = \rho \frac{l}{a}$$

$$= 15.9 \times 10^{-9} \times \frac{100}{2.5 \times 10^{-6}}$$

$$= \mathbf{0.636\Omega}$$

Voltage drop

As we have demonstrated in this lesson, the conductors themselves will have resistance and, like any resistance will affect the current flow and voltage drop in the circuit. The magnitude of the voltage drop will not only depend on the resistance of the cable but also the amount of current being drawn by the load. The following example will help to demonstrate this.

Example 10
A load with a resistance of 23Ω is connected to 230V supply with a cable that has a total resistance of 0.7Ω. Calculate:

a) the voltage drop in the cable
b) the voltage that will appear across the load.

$$\begin{aligned} R &= \text{Resistance of load} + \text{resistance of cable} \\ &= 23 + 0.7 \\ &= 23.7\Omega \\ I &= \frac{V}{R} \\ &= \frac{230}{23.7} \\ &= 9.7\text{A} \end{aligned}$$

a)
$$\begin{aligned} \text{Cable voltage drop} &= \text{I} \times \text{cable resistance} \\ &= 9.7 \times 0.7 \\ &= \mathbf{6.79V} \end{aligned}$$

b)
$$\begin{aligned} \text{Voltage across load} &= \text{I} \times \text{load resistance} \\ &= 9.7 \times 23 \\ &= \mathbf{223.1V} \end{aligned}$$

As a check, according to Kirchhoff's voltage law:

$$\begin{aligned} V &= \text{Cable volt drop} + \text{voltage across load} \\ &= 6.79 + 223.1 \\ &= \mathbf{229.89V} \end{aligned}$$

Although not exactly 230 volts, the slight discrepancy can be explained because we rounded the answer for the total current. Kirchhoff's voltage law is proved.

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Worksheet 7: Resistivity

1. **If a coil of cable, 50m in length, has a conductor resistance of 0.275Ω, calculate the value for 800m of the same cable.**

2. **Calculate the resistance of a single core copper cable, 200m long and $25mm^2$ CSA. Take the resistivity of copper to be 17.2×10^{-9} ohm/metre^3.**

3. **Determine the resistance of 150m of single copper cable whose CSA is $10mm^2$. Take the resistivity of copper to be 17.2×10^{-9} ohm/metre^3.**

4. **Calculate the resistance of 75m of single aluminium cable whose CSA is $4mm^2$. Take the resistivity of aluminium to be 26.5×10^{-9} ohm/metre^3.**

5. **Find the CSA of a single copper cable, 500m long, which carries a current of 2.5 amperes and has a voltage drop of 3.58 volts. Take the resistivity of copper to be 17.2×10^{-9} ohm/metre^3.**

6. **Calculate the resistance of a $4mm^2$ CSA twin copper cable feeding a motor 150m away. Take the resistivity of copper to be 17.2×10^{-9} ohm/metre^3.**

7. **Calculate the resistance of 100m of the following sizes of twin copper cables. Take the resistivity of copper to be 17.2×10^{-9} ohm/metre^3:**
   - **a) $1mm^2$:**
   - **b) $1.5mm^2$:**
   - **c) $2.5mm^2$:**
   - **d) $4mm^2$:**
   - **e) $6mm^2$:**
   - **f) $10mm^2$:**

8. Complete the following table.

Resistance (R)	Ω	0.5	0.02		0.172
Resistivity (ρ)	Ω/m	$17.2E^{-9}$		$17.2E^{-9}$	$17.2E^{-9}$
Length (l)	M		4.23	85	250
CSA (a)	mm^2	1.0	6.0	2.5	

9. A motor takes 45A from a 230V supply. A twin aluminium cable, 40m in length, feeds the motor, each core having a CSA of 16mm^2. Calculate the voltage at the motor terminals. Take the resistivity of aluminium to be 26.5 x 10^{-9} ohm/metre^3.

10. Two cables have equal resistance but one has a CSA 2.5 times larger than the other. How much longer is the thicker cable than the thinner cable?

11. An immersion heater takes a current of 13A and is fed through a twin cable, each core having a CSA of 2.5mm^2. If the conductors are made of copper and have a resistivity of 17.2 x 10^{-9} Ω/m^3, calculate the greatest length of cable which may be used, if the cable voltage drop is not to exceed 11.5 volts.

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Handout 8: Connection of meters

Learning outcome
The learner will:
2. understand standard units of measurement used in electrical installation, maintenance and design work.

Assessment criteria
The learner can:
2.3 identify appropriate electrical instruments for the measurement of different **electrical quantities**.

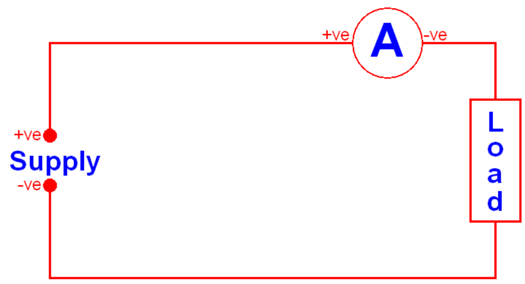
Range
Electrical quantities (measurement): resistance, power, current, voltage, energy

Connection of meters

It is often necessary to know how much voltage, current or energy is being used in any particular circuit. In order to do this, we use meters.

Since current flows in a cable, we must connect the ammeter in series with the circuit to measure this flow.

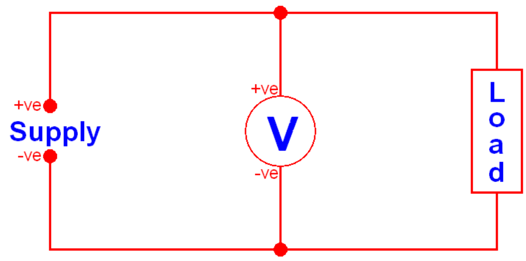
The ammeter, when connected, must not affect the current flow in any way. Because of this, the ammeter must have a very low resistance.



As voltage is the pressure in the system, in order to measure voltage we must connect the voltmeter in parallel with the system or load.

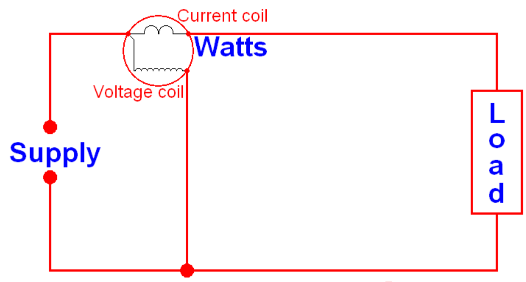
The voltmeter must also not affect the circuit in any way, when connected. Because of this, the voltmeter must have a very high resistance.

NB: +ve (pos) and –ve (neg) signs apply for DC instruments.

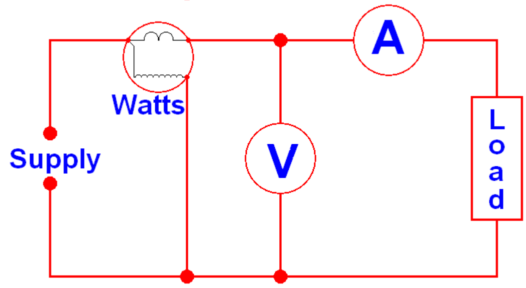


A wattmeter is an instrument which measures the amount of power being supplied to a circuit. A wattmeter measures DC and AC power.

The wattmeter is a combination of a voltmeter and an ammeter, and is connected into a circuit as shown.



It is sometimes required to take all three readings at the same time, for example to measure the power factor in a circuit. When this is the case, the instruments are connected as shown on the right.



Ohmmeters

When measuring resistance, we use an ohmmeter, which is simply connected across the circuit or piece of equipment to be tested. The ohmmeter requires its own internal supply, normally a battery. For this reason, the ohmmeter must never be connected across a circuit or piece of equipment that has a power supply connected to it, as this could cause damage to the meter and possibly the circuit or piece of equipment being tested.

When reading low values, a low reading ohmmeter should be used; for higher readings (thousands of ohms and above) a high reading ohmmeter (normally an insulation resistance tester) should be used.

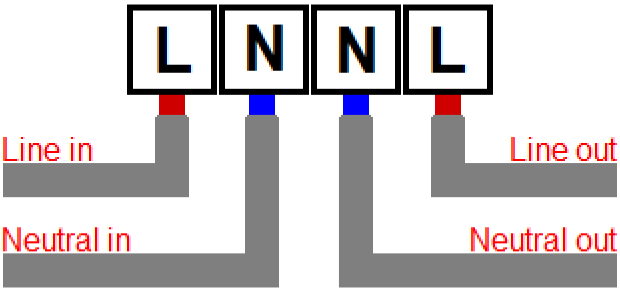
Energy meter

Electricity measurement in premises is carried out using an energy meter. The unit for energy is the joule, though for regular use the joule is too small a unit. An alternative means of measuring electrical energy is the watt-hour or, more commonly, the kilowatt-hour (kWh). One kWh refers to a unit of electricity and is used to charge the consumer for their electricity consumption.

If a 1kW appliance is operated for one hour it will use 1kWh of energy, which is one unit. To calculate the energy used by an appliance multiply its power rating by the duration of operation in hours.

For example, a 3kW appliance is operated for 6.5 hours continuously and the electricity cost 16p per unit. Calculate the cost of running this appliance for this duration.

$$\begin{aligned}
\text{kWh} &= \text{kW} \times \text{t (in hours)} \\
&= 3 \times 6.5 \\
&= 19.5 \text{ units} \\
\text{Cost} &= \text{units} \times \text{unit cost} \\
&= 19.5 \times 16 \\
&= \mathbf{312p \text{ or } £3.12}
\end{aligned}$$



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Worksheet 8: Connection of meters

1. **Complete the following diagram to show the connection of an ammeter.**

2. **Complete the following diagram to show the connection of a voltmeter.**

3. Complete the following diagram to show the connection of a wattmeter.

4. Complete the following diagram to show the connection of an ammeter, voltmeter and wattmeter, so that power factor can be calculated.

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Handout 9: Electro-magnetism

Learning outcome

The learner will:

5. understand the fundamental principles which underpin the relationship between magnetism and electricity.

Assessment criteria

The learner can:

5.1 describe the effects of magnetism in terms of attraction and repulsion

5.2 state the difference between magnetic flux and flux density.

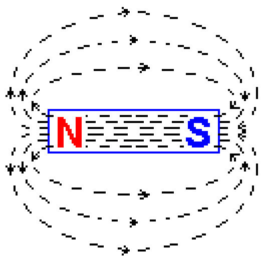
Electro-magnetism

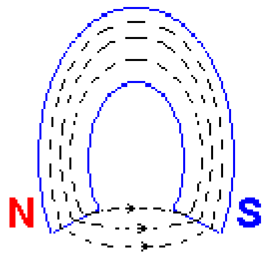
Magnetic field

This is the area around a magnet or electromagnet where the effects of the magnetic force produced can be felt. Magnetism is represented by unseen lines of flux that form closed loops, as shown in the following diagrams. Some conventions must be remembered:

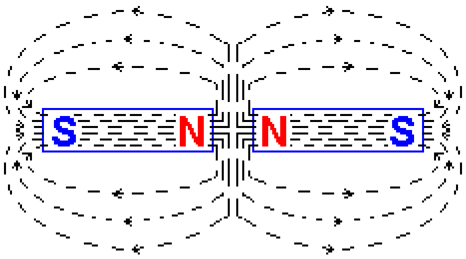
- Lines of flux cannot cross.
- Lines of flux flow externally from the north pole to the south pole.

Flux patterns for various arrangements of permanent magnets are shown below:



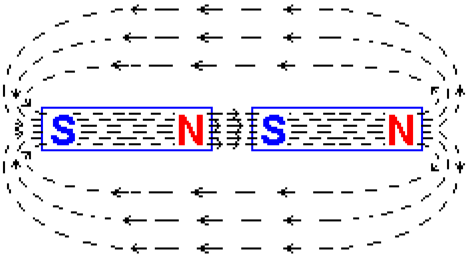


Two permanent magnets – north pole to north pole



Like poles repel.

Two permanent magnets – north pole to south pole



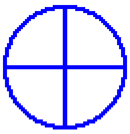
Unlike poles attract.

Electro-magnetism

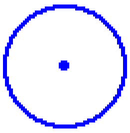
Electricity and magnetism are closely related.

An electrical current flowing through a conductor produces a magnetic field in the form shown below, around the conductor.

In order to help us to establish the direction of the magnetic fields around conductors, we must have a current direction convention, as shown below.



Current flowing into the conductor
(ie away from the observer)

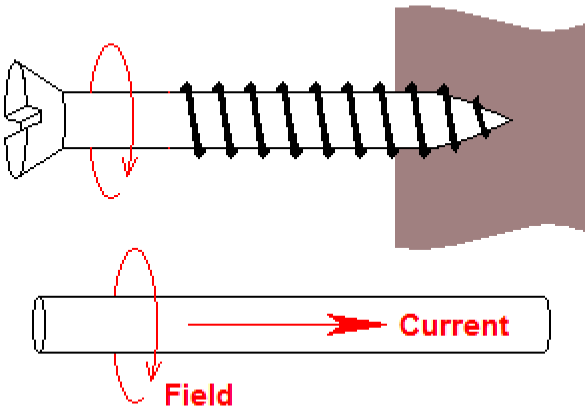


Current flowing out of the conductor
(ie towards the observer)

The direction of magnetic fields around cables can be found by using:

Maxwell's screw rule

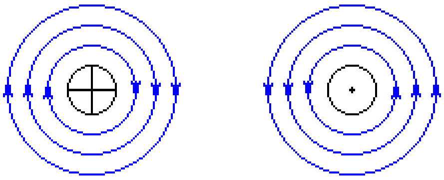
Maxwell's screw rule shows the relationship between the direction of the current flowing and the magnetic field produced by that current.



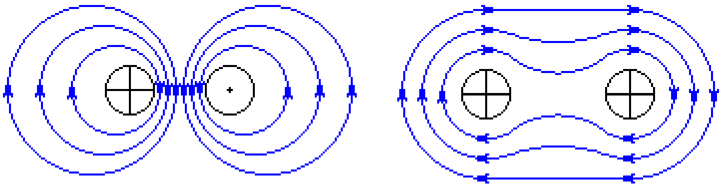
Imagine that you are driving a screw into the conductor in the direction of the current flow. The magnetic field produced by the current will form circular lines around the conductor, in the direction in which you have to drive the screw to advance it.

Magnetic fields due to electric current

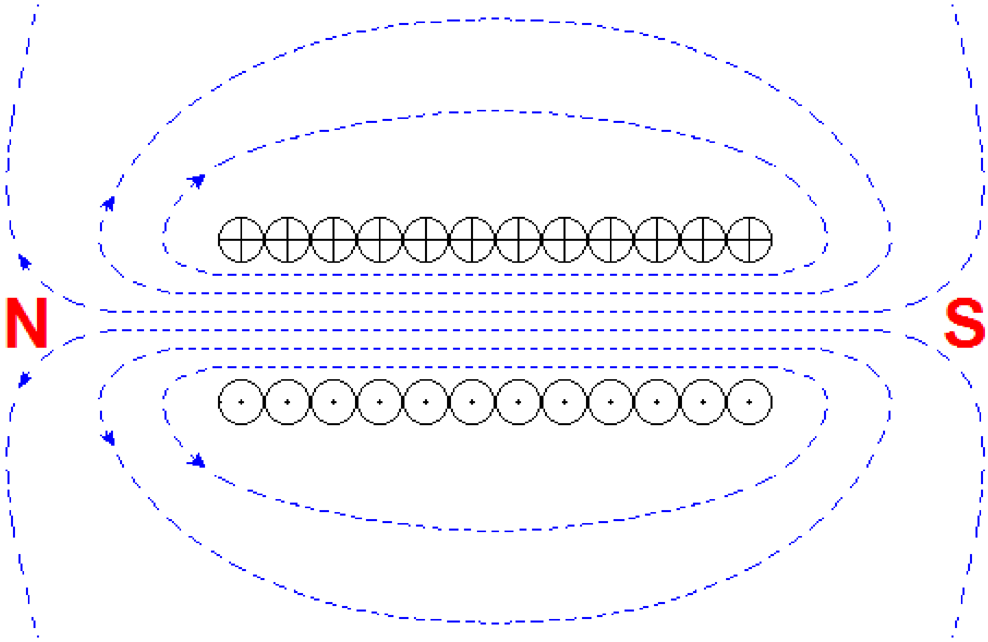
In straight conductors



In a flat coil



In a solenoid



Winding the conductors into a coil/solenoid increases the magnetic effect and produces a magnetic field similar to a bar magnet with north and south poles.

A solenoid is a coil wound into a tightly packed helix. In physics, the term solenoid refers to a long, thin loop of wire, often wrapped around a metallic core, which produces a magnetic field when an electric current is passed through it. Solenoids are important because they can create controlled magnetic fields and can be used as electromagnets. The term solenoid refers, specifically, to a coil designed to produce a uniform magnetic field in a volume of space.

A common use for a solenoid is in a relay (or contactor): an electrically operated switch. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits) or where several circuits must be controlled by one signal. The first relays were used in long-distance telegraph circuits, repeating the signal coming in from one circuit and retransmitting it to another.

A type of relay that can handle the high power required to directly control an electric motor or other loads is called a contactor.

There are two quantities relating to magnetism with which we need to be familiar when considering electrical science. These are detailed below.

Magnetic flux
The number of magnetic lines of force set up in a magnetic circuit is called magnetic flux. It is comparable to electric current in an electric circuit.

The unit is the Weber (Wb) and it is denoted by the symbol **Φ** in formulae.

Magnetic flux density
Whilst the magnetic flux is a measure of how many lines of flux there are, it gives us no indication of how compacted or spread out these lines are. The closer the lines are concentrated, the stronger will be the effect of the magnetic field; flux density is a measure of how compacted these lines of flux are.

Flux density is a measure of the number of lines of flux passing through an area of $1m^2$ and can be found by:

$$\text{Flux density, B} = \text{flux density (Weber)} \times \text{area } (\text{m}^2)$$

The unit for flux density is the tesla, abbreviated to T.

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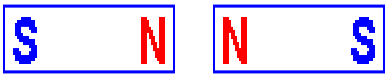
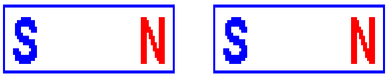
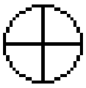
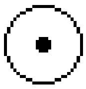
Worksheet 9: Electro-magnetism

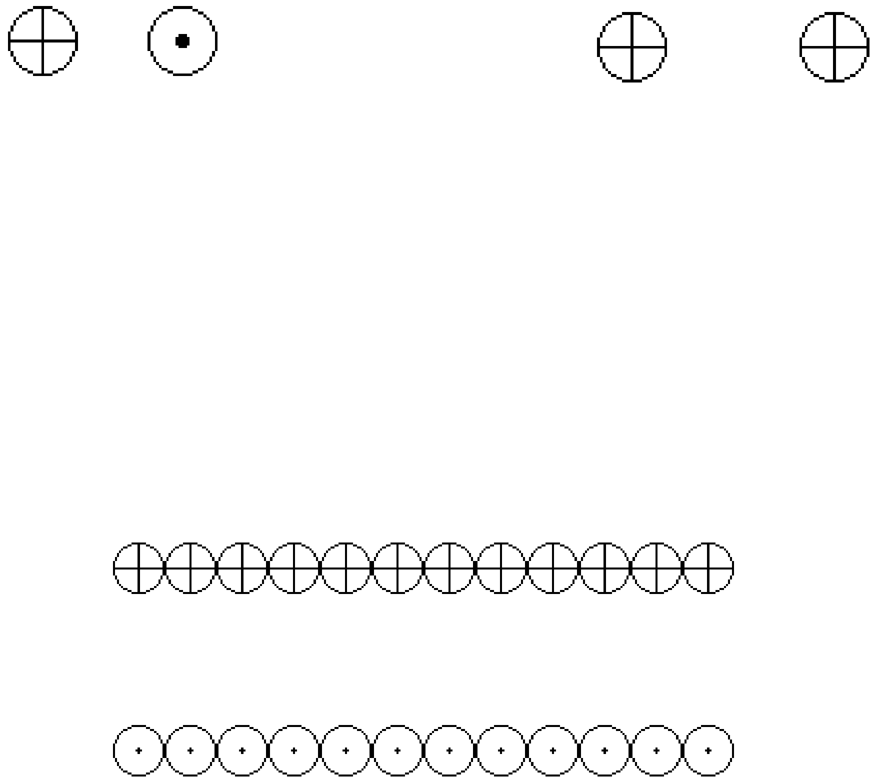
Complete the flux patterns for each of the following arrangements:











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Handout 10: Generation of an EMF

Learning outcome

The learner will:

5. understand the fundamental principles which underpin the relationship between magnetism and electricity.

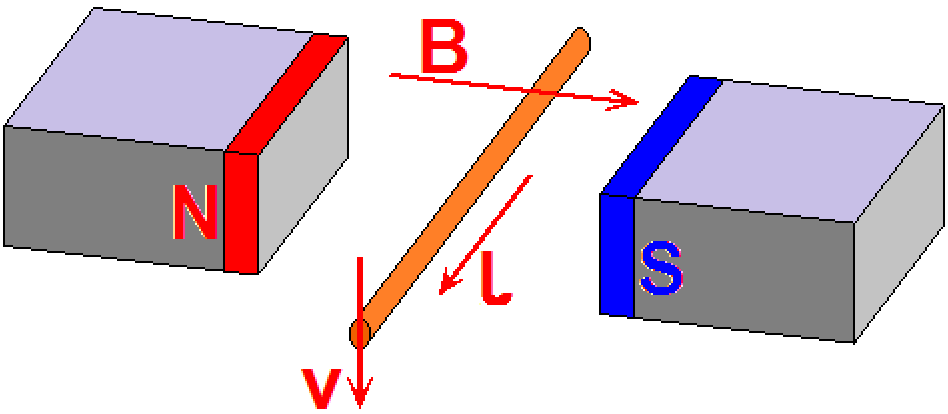
Assessment criteria

The learner can:

5.3 describe the magnetic effects of electrical currents in terms of:
   - a production of a magnetic field
   - b force on a current-carrying conductor in a magnetic field
   - c electromagnetism
   - d electromotive force.

Generation of an EMF

When a conductor cuts through a magnetic field, at right angles to the magnetic flux, an EMF (electromotive force) is induced in the conductor.



The strength of the induced EMF is determined by:

- the strength of the magnetic flux density (between pole faces) – B
- the length of the conductor in the magnetic field – l
- the velocity or speed of the conductor through the magnetic field – v

We can calculate the EMF by using the following formula.

$$e = B\,l\,v$$

Where:

e = induced EMF in volts

B = magnetic flux in tesla (T)

l = length of conductor in metres (m)

v = velocity of conductor in metres/sec (m/s)

$\therefore$ e (volts) = B (teslas) × l (metres) × v (metres/second)

Example 1
A conductor of 15cm in length is moved at 20 metres/second (m/s) perpendicularly through a magnetic field of flux density 2 teslas. Calculate the induced EMF.

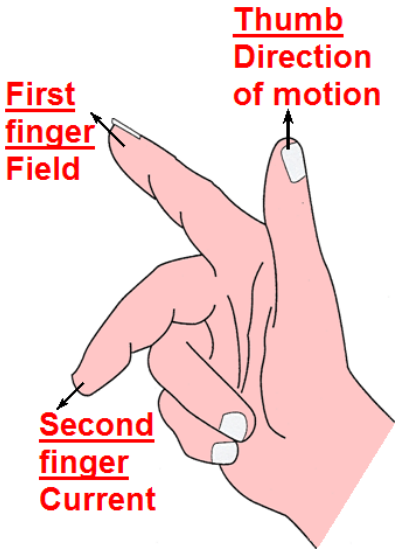
$$e = Blv$$
$$= 2 \times 0.15 \times 20$$
$$= 6 \text{ volts}$$

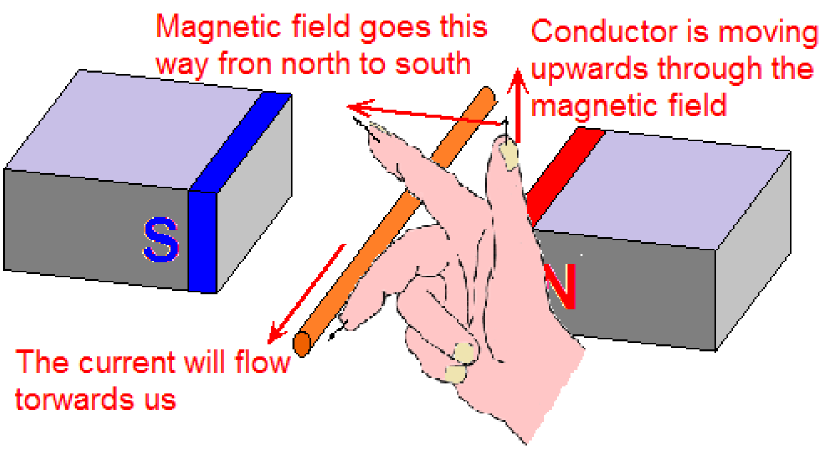
Example 2
A conductor of 0.5m in length is moved at 30 metres/second (m/s) perpendicularly through a magnetic field of flux density 3 teslas. Calculate the induced EMF.

$$e = Blv$$
$$= 3 \times 0.5 \times 30$$
$$= 45 \text{ volts}$$

The direction of this current can be found by using:

Fleming’s right hand generator rule





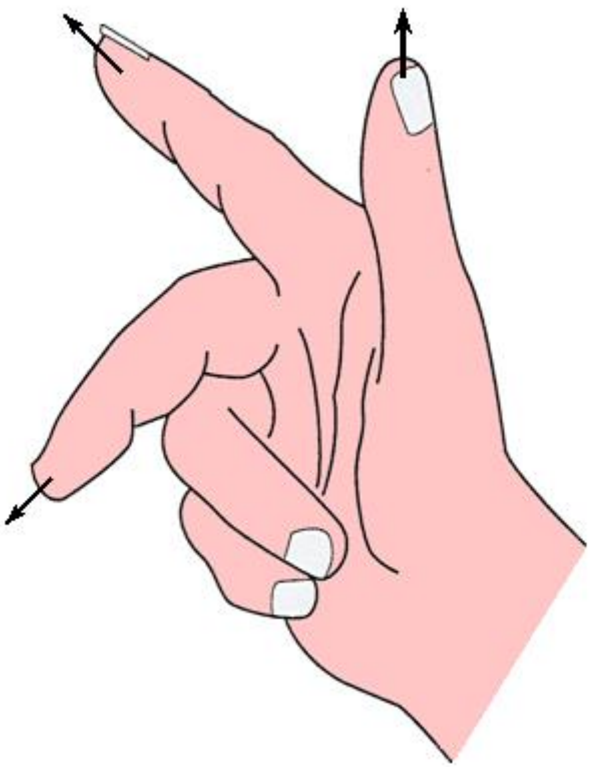
202: Principles of electrical science

Worksheet 10: Generation of an EMF

1. **Calculate the induced EMF in a cable with an effective length of 0.25m, moving at a velocity of 5m/s through a magnetic field with a flux density of 1.6 teslas.**

2. **The EMF in a conductor of effective length 0.25m moving at right angles through a magnetic field at a velocity of 5m/s is 1.375 volts. Calculate the magnetic flux density.**

3. **In the diagram below, label the meaning of the thumb, first finger and second finger to represent Fleming's right hand generator rule.**



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Handout 11: Force on current-carrying conductor

Learning outcome

The learner will:

5. understand the fundamental principles which underpin the relationship between magnetism and electricity.

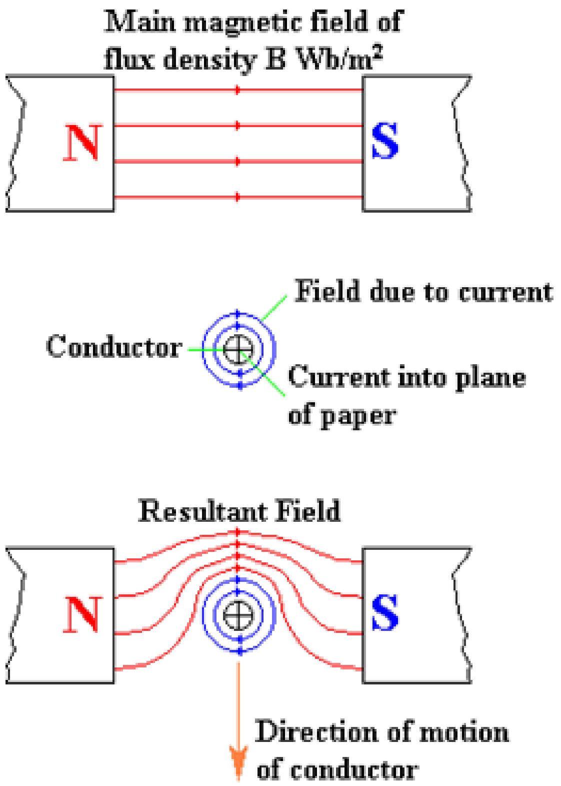
Assessment criteria

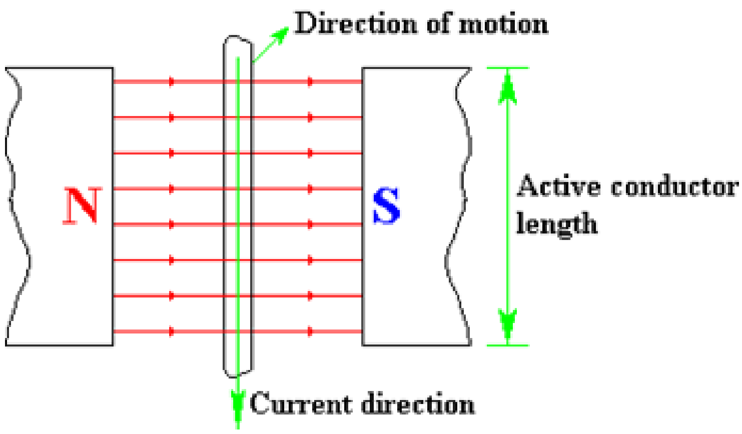
The learner can:

5.3 describe the magnetic effects of electrical currents in terms of:
- a production of a magnetic field
- b force on a current-carrying conductor in a magnetic field
- c electromagnetism
- d electromotive force.

Force on current-carrying conductor

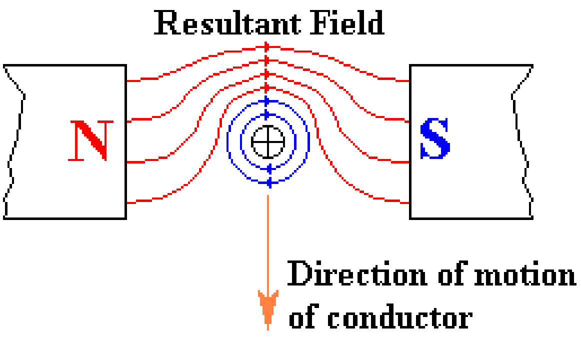
When a conductor is situated in a magnetic field, at right angles to it, and a current is then passed through the conductor, the latter will experience a mechanical force, causing it to move due to the interaction of the two magnetic fields.

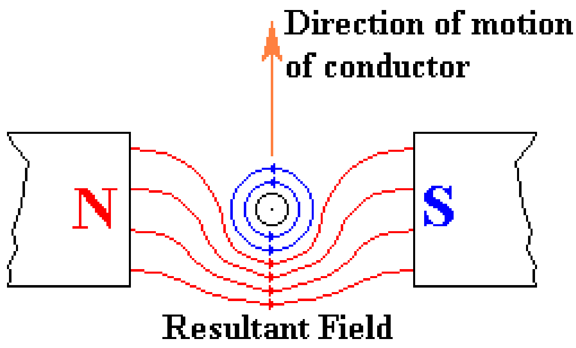




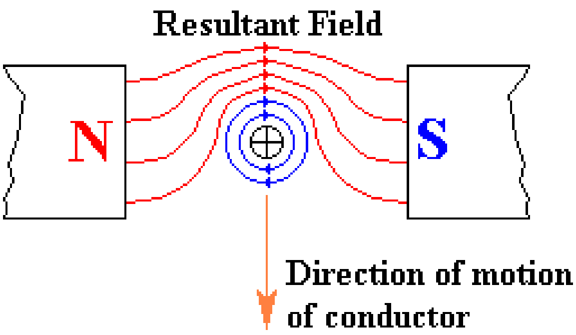
If the direction of the main magnetic field or the current in the conductor were reversed then the force would be in the opposite direction, as shown.

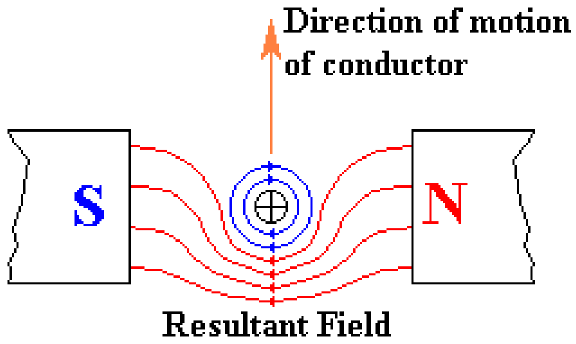
Changing direction of current





Changing direction of flux





The magnitude of the force on a current flowing at right angles to a magnetic field is proportional to:

- the flux density of the magnetic field
- the current flowing in the conductor
- the length of the conductor in the magnetic field.

The strength of the mechanical force is given by the formula:

$$F = B.I.L$$

where:

	F	=	Mechanical force exerted on the conductor measured in Newtons (N)
	B	=	Flux density of main magnetic field measured in Wb/m^2 – teslas (T)
	I	=	Current flowing in conductor measured in amperes (I)
	L	=	Length of conductor in the magnetic field measured in metres (m)

This principle of motion is how a motor works, ie the conversion of electrical energy into mechanical motion.

Example 1
A conductor of 20cm in length is situated perpendicularly in a magnetic field of flux density 5T and has a current of 10A flowing through it. Calculate the force on the conductor.

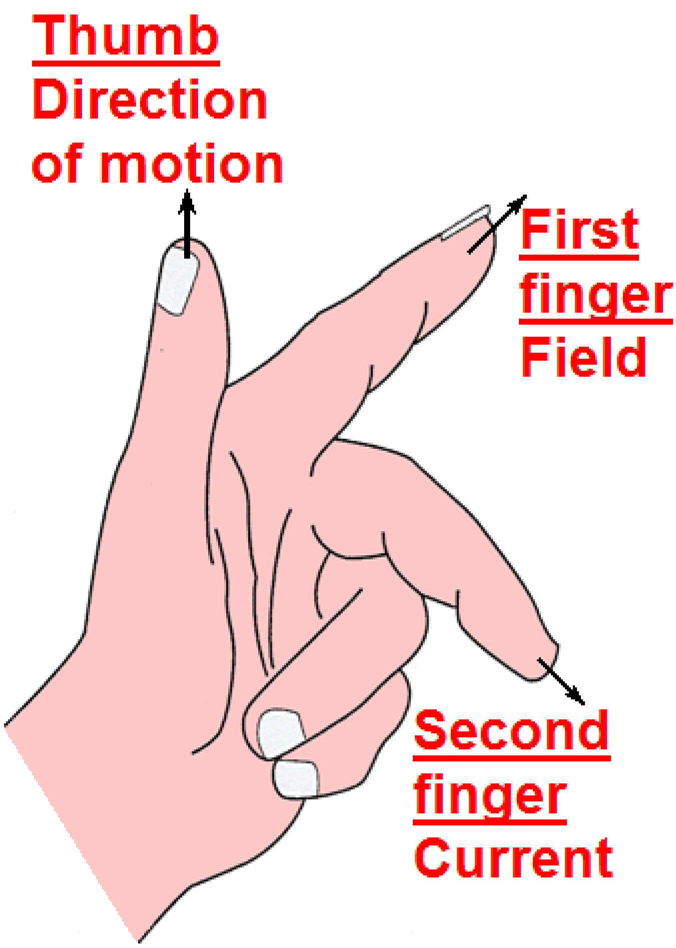
$$F = B.I.L$$
$$= 5 \times 10 \times 0.2$$
$$= 10 \text{ Newtons}$$

Example 2
A conductor of 0.5m in length is situated perpendicularly in a magnetic field of flux density of 10T and has a current of 15A flowing through it. Calculate the force on the conductor.

$$F = B.I.L$$
$$= 10 \times 15 \times 0.5$$
$$= 75 \text{ Newtons}$$

The direction of this force can be found by using:

Fleming's left-hand motor rule



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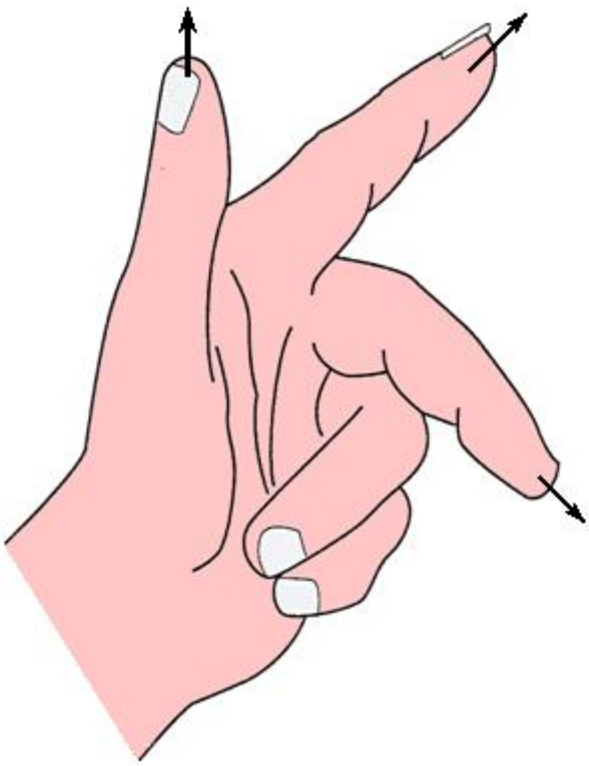
Worksheet 11: Force on current-carrying conductor

1. A straight conductor 10m in length and carrying a current of 10A is situated in and at right angles to a uniform magnetic field of flux density 0.2 Wb/m^2. Determine the force exerted upon the conductor.

2. A conductor 0.25m in length situated in and at right angles to a magnetic field experiences a force of 5N when the current flowing through it is 50A. Determine the flux density of the magnetic field.

3. In the diagram below label the meaning of the thumb, first finger and second finger to represent Fleming's left hand motor rule.



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Handout 12: AC generation

Learning outcome

The learner will:

5. understand the fundamental principles which underpin the relationship between magnetism and electricity.

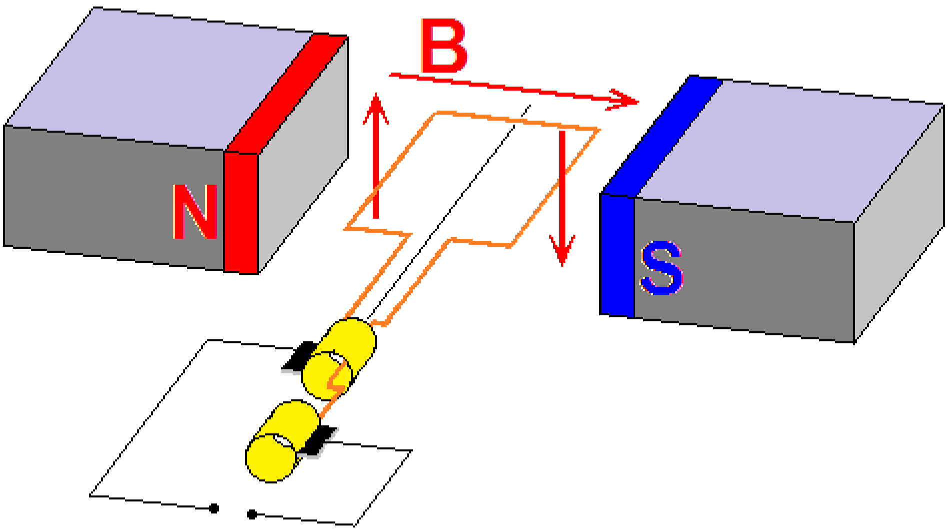
Assessment criteria

The learner can:

5.4 describe the basic principles of generating an AC supply in terms of:
- a a single-loop generator
- b sine-wave
- c frequency
- d EMF
- e magnetic flux.

AC generation

When a conductor cuts through a magnetic field, at right angles to the magnetic flux, an EMF (electromotive force) is induced in the conductor.



The diagram shows a single loop coil which rotates between the poles of a magnet. Slip-rings and carbon brushes are used to make contact with the coil. The former consist of a brass or copper shell connected to each side of the coil.

As the loop rotates, its sides cut through the magnetic flux set up by the poles and so an EMF is induced in the loop.

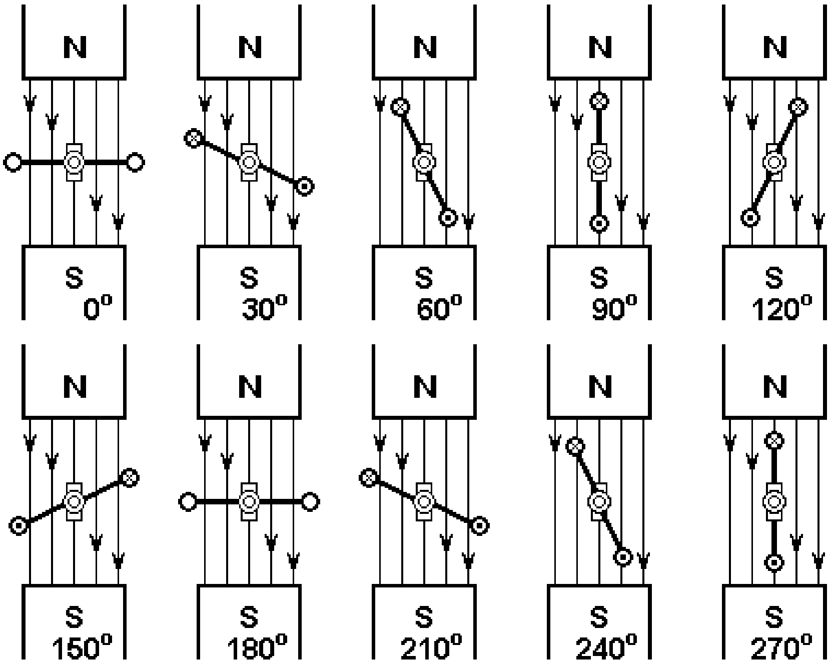
We have already seen that when a conductor moves across a magnetic field, it cuts the flux and an EMF is generated in it.

When the conductor moves along or parallel to the magnetic field, no flux is cut and therefore no EMF is induced.

If the conductor moves at right angles to the field, flux is cut at the maximum rate and a maximum EMF is induced.

If the conductor cuts the field at an angle, the induced EMF will depend on the angle between the line taken by the conductor and the magnetic flux, which means that the induced EMF will be somewhere between 0 and maximum value.

Consider the single loop rotated between poles, as in the diagram below; the EMF generated will be as shown.



The single loop with slip-rings is a form of AC alternator.

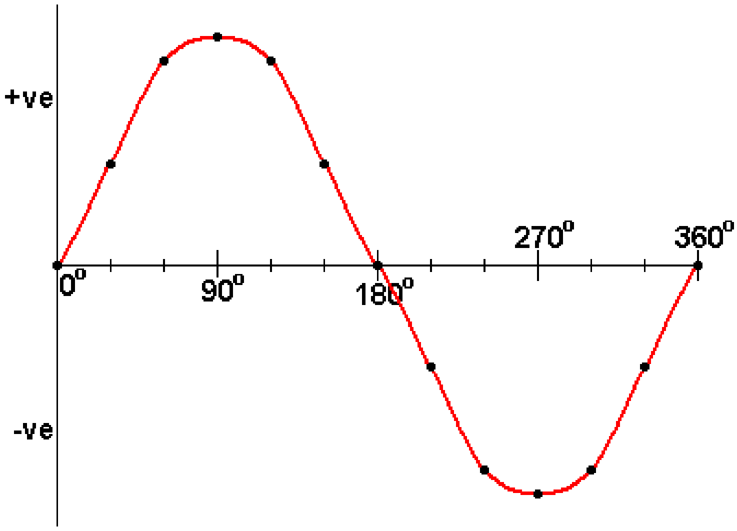
The simple alternator generates one cycle of its waveform for every complete revolution that it makes.

If more pairs of poles are added, the alternator will produce one cycle for each pair of poles during one revolution.

The frequency (symbol f) of an alternator is the number of cycles it produces every second.

Frequency is measured in hertz (Hz).

The waveform produced is known as a sine wave.



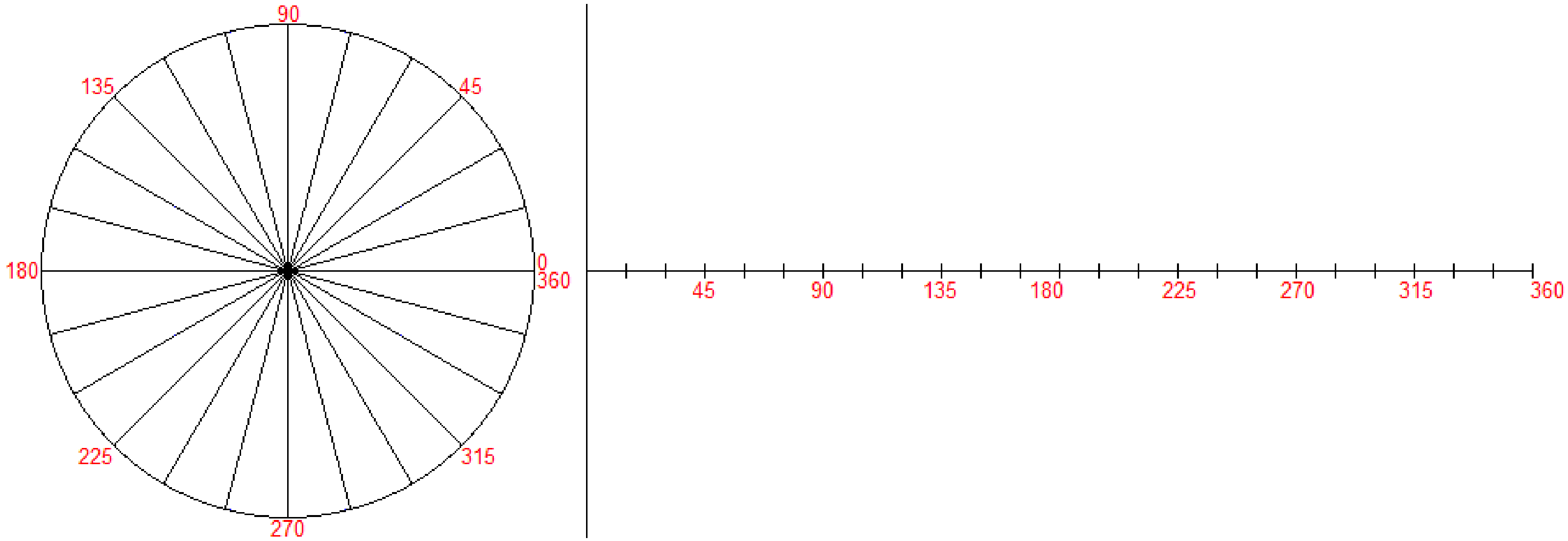
A machine having P pairs of poles and running at N rev/sec generates a frequency of f Hertz. Therefore:

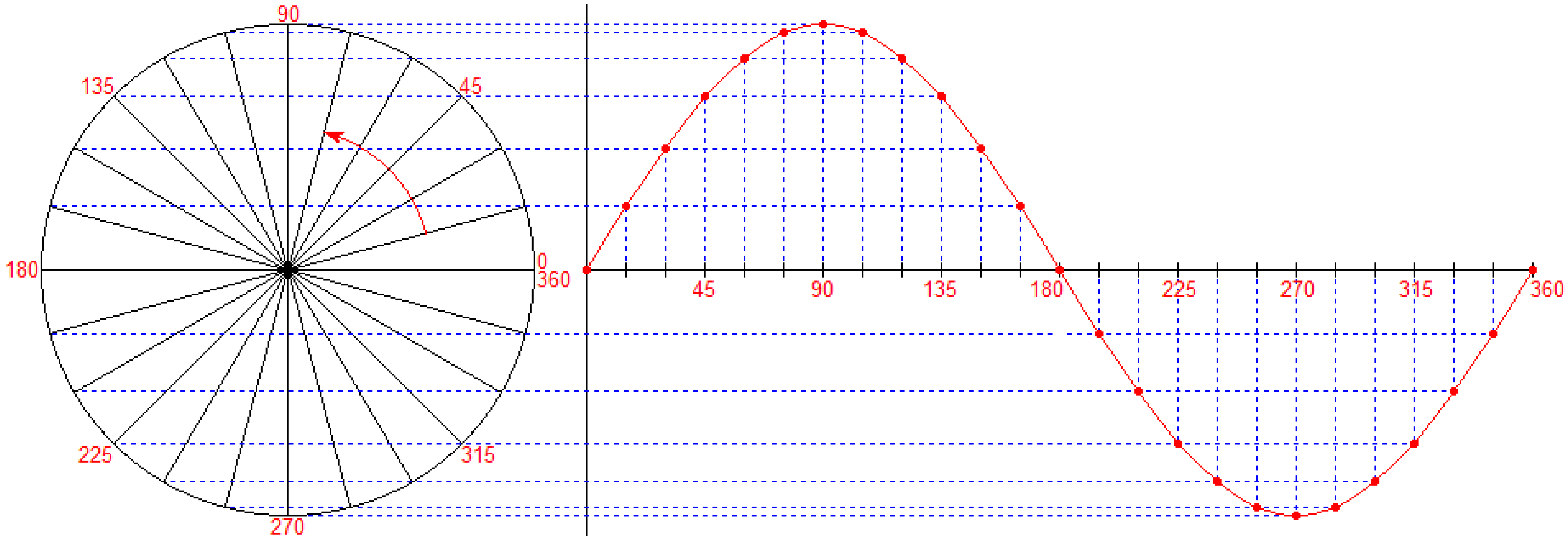
$$f = N.P$$

where:

f	=	Frequency (Hz)
N	=	Speed in revolutions per second
P	=	Number of pairs of poles (a north and south are one pair)

Plotting a sine wave to represent an AC waveform





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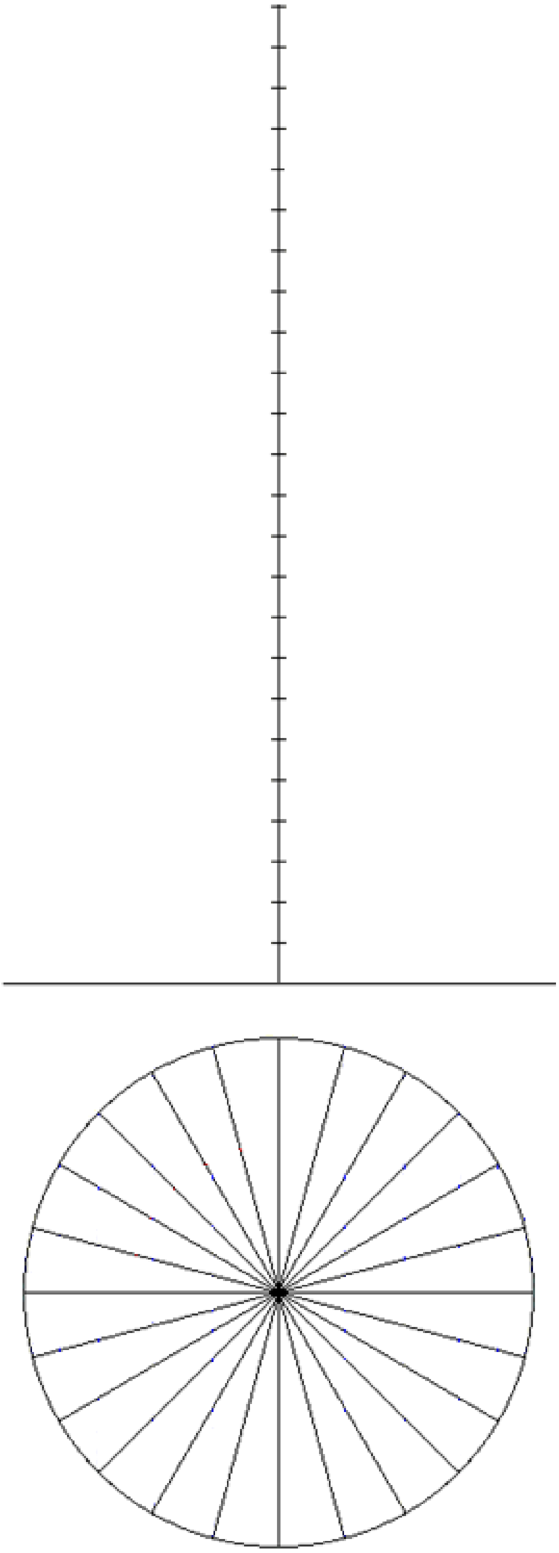
Worksheet 12: AC generation

Produce a sine wave.



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Handout 13: Sine wave quantities

Learning outcome

The learner will:

5. understand the fundamental principles which underpin the relationship between magnetism and electricity.

Assessment criteria

The learner can:

5.5 identify the **characteristics of sine-waves**.

Range

Characteristics of sine-waves: root mean square (RMS) value, average value, peak to peak value, periodic time, frequency, amplitude

Sine wave quantities

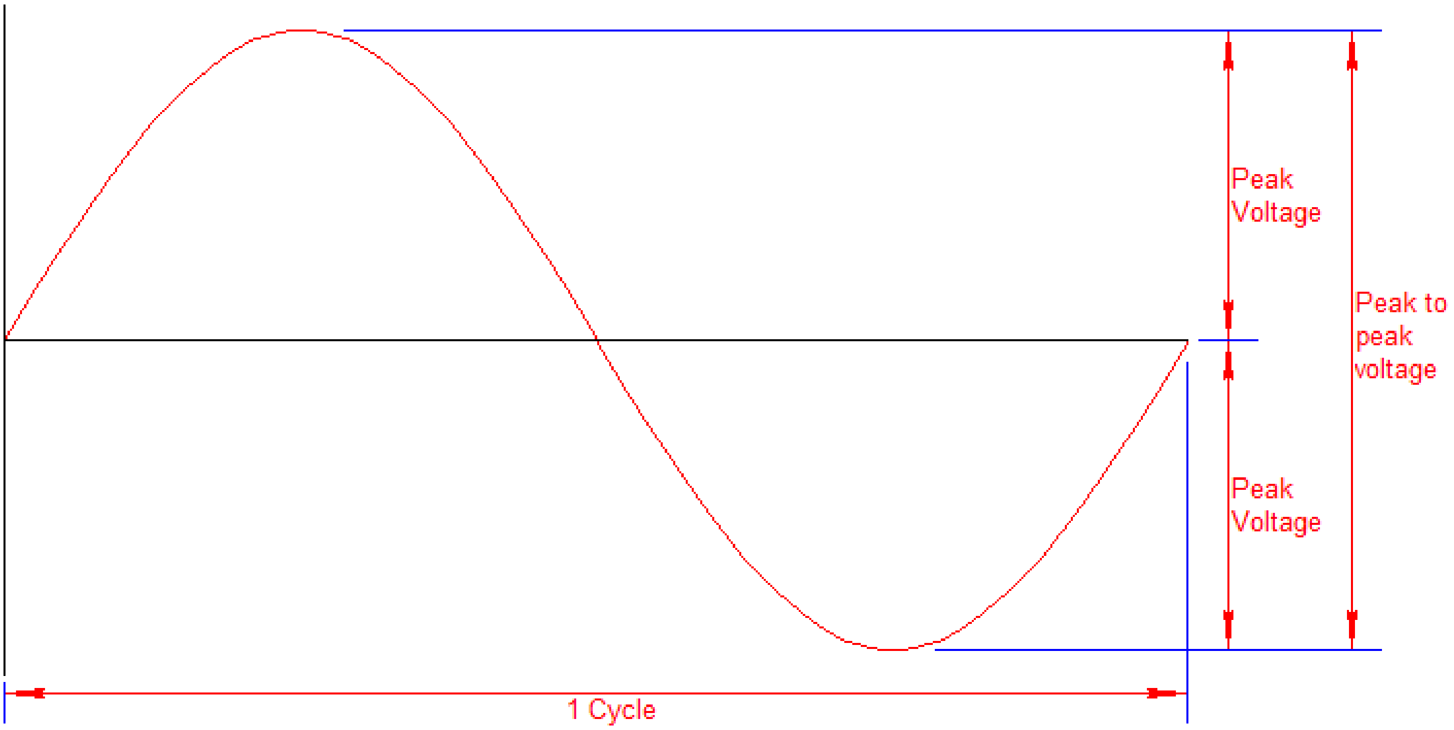
What is alternating current?

Alternating current (AC) is the flow of electrons; this rises to a maximum value in one direction and then falls back to zero, before repeating the process in the opposite direction.

The electrons within the conductor do not just flow in one direction. They move backwards and forwards.

The journey taken from start to finish is one cycle; the number of cycles that occur every second is said to be the frequency.

When we look at a sine wave, there are several values that can be measured from the alternating waveform. These are shown on the following diagrams.



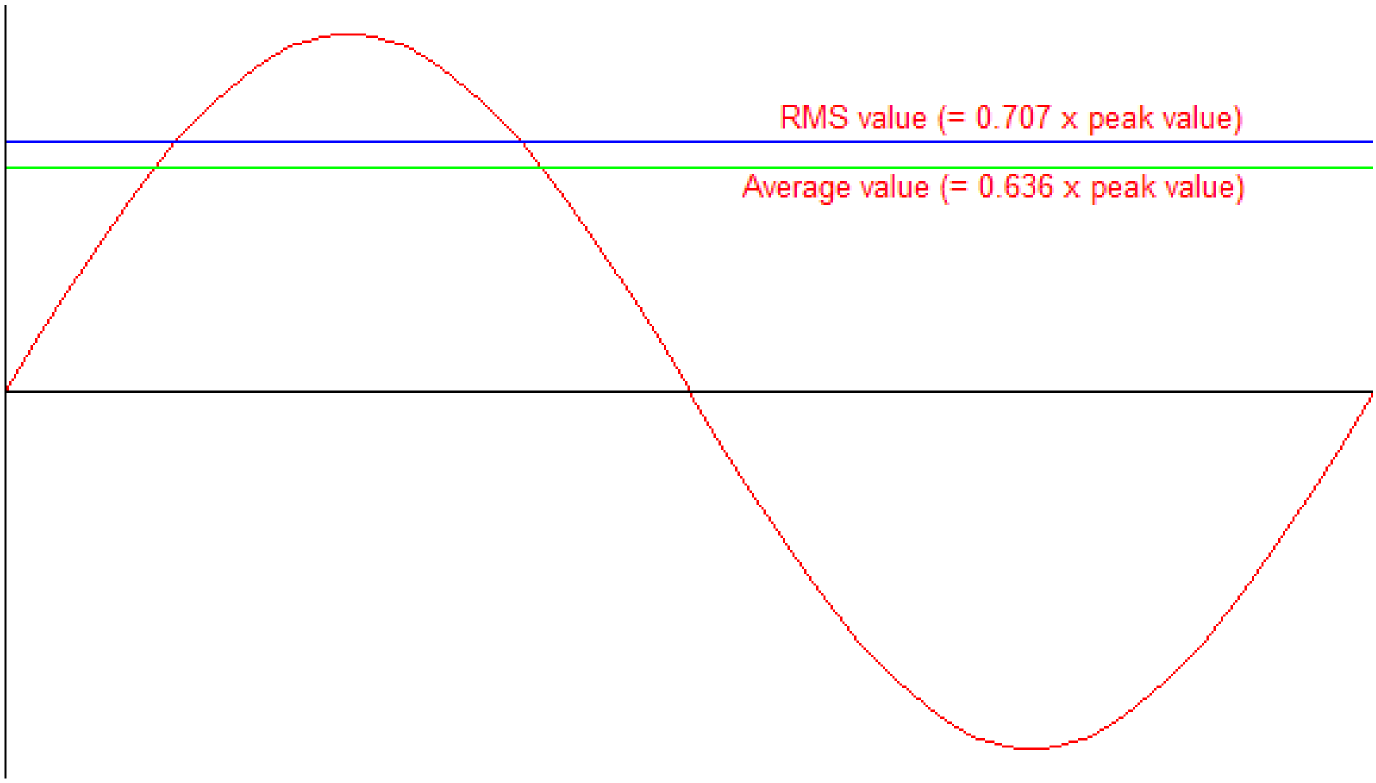
- Amplitude is the maximum voltage reached by the signal. It is measured in volts (V).
- Peak voltage is another name for amplitude.
- Peak to peak voltage is twice the peak voltage (amplitude).
- Frequency is the number of cycles per second. It is measured in hertz (Hz).

$$\text{Frequency} = \frac{1}{\text{Time period}}$$

Periodic time is the time taken for the signal to complete one cycle. It is measured in seconds (s).

$$\text{Time period} = \frac{1}{\text{Frequency}}$$

The instantaneous value of an alternating voltage or current is the value of voltage or current at one particular instant. The value may be zero if the particular instant is the time in the cycle at which the polarity of the voltage is changing. It may also be the same as the peak value, if the selected instant is the time in the cycle at which the voltage or current stops increasing and starts decreasing. There are actually an infinite number of instantaneous values between zero and the peak value.



The average value of an alternating current or voltage is the average of all the instantaneous values during one alternation. Since the voltage increases from zero to peak value and decreases back to zero during one alternation, the average value must be some value between those two limits. You could determine the average value by adding together a series of instantaneous values of the alternation (between 0° and 180°) and then dividing the sum by the number of instantaneous values used. The computation would show that one alternation of a sine wave has an average value equal to 0.636 times the peak value. The formula for average voltage is:

$$V_{avg} = 0.636 \times V_{peak}$$

Where V_{avg} is the average voltage of one alternation, and V_{peak} is the maximum or peak voltage.

Similarly, the formula for average current is:

$$I_{avg} = 0.636 \times I_{peak}$$

Where I_{avg} is the average current in one alternation, and I_{peak} is the maximum or peak current.

Do not confuse the above definition of an average value with that of the average value of a complete cycle. Since the voltage is positive during one alternation and negative during the other alternation, the average value of the voltage values occurring during the complete cycle is zero.

The effective value of an alternating current or voltage is the value of alternating current or voltage that produces the same amount of heat in a resistive component that would be produced in the same component by a direct current or voltage of the same value. The effective value of a sine wave is equal to 0.707 times the peak value. The effective value is also called the root mean square or RMS value. The formula for RMS voltage is:

$$V_{rms} = 0.707 \times V_{peak}$$

Where V_{rms} is the RMS voltage of one alternation, and V_{peak} is the maximum or peak voltage. Similarly, the formula for RMS current is:

$$I_{rms} = 0.707 \times I_{peak}$$

Where I_{rms} is the average current in one alternation, and I_{peak} is the maximum or peak current.

Also:

$$V_{peak} = 1.414 \times V_{rms}$$

and

$$I_{peak} = 1.414 \times I_{rms}$$

The RMS value is the effective value of a varying voltage or current. It is the equivalent steady DC (constant) value which gives the same effect.

For example, a lamp connected to a 6V RMS AC supply will light with the same brightness when connected to a steady 6V DC supply.

However, the lamp will be dimmer if connected to a 6V peak AC supply because the RMS value of this is only 4.2V (it is equivalent to a steady 4.2V DC).

$$\begin{aligned} V_{rms} &= 0.707 \times V_{peak} \\ &= 0.707 \times 6 \\ &= 4.2V \end{aligned}$$

Let's look at the voltage we use on a daily basis.

What does '230V AC' really mean? Is it the RMS or peak voltage?

If the peak value is meant then it should be clearly stated, otherwise assume it is the RMS value.

In everyday use, AC voltages (and currents) are always given as RMS values because this allows a sensible comparison to be made with steady DC voltages (and currents), such as from a battery.

For example, a '6V AC supply' means 6V RMS'; the peak voltage is 8.6V.

The UK mains supply is 230V AC; this means 230V RMS so the peak voltage of the mains is about 325V!

$$V_{peak} = 1.414 \times V_{rms}$$

$$= 1.414 \times 230$$

$$= 325\text{V}$$

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Worksheet 13: Sine wave quantities

1. A sine wave has a peak voltage of 100V; calculate the RMS value.

2. A sine wave has a peak voltage of 100V; calculate the average value.

3. A sine wave has a peak voltage of 565.7V; calculate the RMS value.

4. A sine wave has a peak voltage of 565.7V; calculate the average value.

5. A sine wave has a peak voltage of 90V; calculate the RMS value.

6. A sine wave has a peak voltage of 90V; calculate the average value.

7. A sine wave has an RMS voltage of 40V; calculate the peak value.

8. A sine wave has an RMS voltage of 200V; calculate the peak value.

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Handout 14: Basic mechanics – mass and weight

Learning outcome
The learner will:
3. understand basic mechanics and the relationship between force, work, energy and power.

Assessment criteria
The learner can:
3.1 specify what is meant by mass and weight.

Basic mechanics – mass and weight

Some may think incorrectly that when we talk about 'mechanics' we are talking about working on cars and lorries. Traditionally, and for the benefit of this lesson, mechanics is an area of science concerned with the behaviour of physical bodies when subjected to forces or displacements, and the subsequent effects of the bodies on their environment. It can be defined as a branch of science which deals with the motion of and forces on objects.

In electrical installation, we install equipment that moves other items by imparting a force on them, for example, an electric motor powering a machine. When selecting an electric motor, we need to select the correct size, that is, power rating. Too powerful and it is wasteful; not enough power and the equipment driven may not work as expected.

We need to understand how to calculate these forces and how they relate to the selection of the most appropriate pieces of equipment.

Mass versus weight

Many people confuse mass with weight and frequently interchange each term but they are two distinct and different entities and we must be able to differentiate between them.

What is mass?

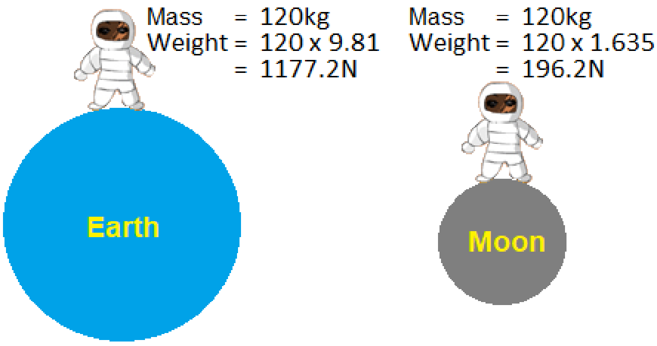
This is a measure of how much matter is in an object. This doesn't change regardless of where the object is – on Earth, the Moon, Jupiter or floating around in space – the object's mass will always be the same.

Points to remember about mass:

- Mass is indestructible. Wherever you are the mass will never change.
- Mass can never be zero, or it would not exist.
- Mass is not related to gravity, centrifugal force, etc, and these forces have no effect upon it.
- The SI unit of mass is the kilogram (kg).

What is weight?

Unfortunately, the mass of an object is often referred to as its weight, though these are in fact different concepts and quantities. In scientific contexts, mass refers to the amount of 'matter' in an object, whereas weight refers to the force exerted on an object by gravity. In other words, an object with a mass of 1.0 kilogram will weigh 9.81 newtons on the surface of the Earth (its mass multiplied by the gravitational field strength), since the newton is a unit of force, while the kilogram is a unit of mass.



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Worksheet 14: Basic mechanics – mass and weight

1. **Calculate the weight of a body of 50kg when subjected to the Earth's gravity of 9.81m/s^2.**

2. **Calculate the weight of a body of 50kg when subjected to the Moon's gravity of 1.622m/s^2.**

3. **Calculate the mass of a body having a weight of 735.75N when subjected to the Earth's gravity of 9.81m/s^2.**

4. **Calculate the mass of a body having a weight of 300N when subjected to the Moon's gravity of 1.622m/s^2.**

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Handout 15: Basic mechanics

Learning outcome
The learner will:
3. understand basic mechanics and the relationship between force, work, energy and power.

Assessment criteria
The learner can:
3.3 describe the main principles of the following and their interrelationships:
- a force
- b work
- c energy (kinetic and potential)
- d power
- e efficiency

3.4 calculate values of mechanical energy, power and efficiency.

Basic mechanics

Mass

Mass can be defined as the amount of matter in an object. The SI unit of mass is the kilogram (kg).

Acceleration

When an aircraft takes off, it starts from rest and increases its velocity until it can fly. This change in velocity is called acceleration. Acceleration is the change in velocity with time.

$$\text{Acceleration} = \frac{\text{final velocity (v)} - \text{initial velocity(u)}}{\text{Time}} \ (\text{m/s}^2)$$

where:

$$\text{Velocity} = \text{metres}$$
$$\text{Time} = \text{seconds}$$

The SI unit for acceleration is the metre per second per second, or m/s^2.

Example 1
If a car accelerates from a velocity of 3m/s to 15m/s in four seconds, calculate its average acceleration.

$$\text{Average velocity} = \frac{v + u}{t}\,\text{m/s}$$
$$= \frac{15 + 3}{4}\,\text{m/s}$$
$$= \frac{12}{4}$$
$$= 3\ \text{m/s}^2$$

Thus, the average acceleration is three metres per second, every second.

Force

The SI unit of force is the Newton (N).

A mass of 1 kilogram experiences a force of 9.81 Newtons as a result of gravity. In other words, it would require a force of 9.81 Newtons to raise a mass of 1kg against the pull of gravity on Earth.

To calculate the force on a body due to gravity (on Earth), multiply its mass by 9.81.

Example 2
A bundle of conduit has a mass of 800kg. What force will be required to lift it?

$$\begin{aligned}\text{Force required} &= \text{Mass} \times \text{Acceleration due to gravity} \\ &= 800 \times 9.81 \\ &= 7{,}848 \text{ Newtons}\end{aligned}$$

A force can be described as a 'push' or a 'pull'.

When a force acts on a body, it may:

a accelerate the body
b decelerate the body
c deform the body, ie change its shape
d be exactly resisted by other forces (equilibrium).

Work done

If a force is applied to a body and movement takes place then it is said that work has been done.

For example, when a weight is lifted, work is done.

Work is measured in terms of the distance moved by the body and the force that caused its movement. When the movement is in the same direction as the force, the work done is equal to the distance moved, multiplied by the force exerted.

$$\text{Work done} = \text{Force} \times \text{Distance (Nm)}$$

Force is measured in Newtons.

Work done is measured in Newton metres (Nm).

Example 3

What work must be done to lift a 200kg bundle of conduit from the floor on to a rack 2m high?

$$\begin{aligned}\text{Work done} &= \text{Force} \times \text{Distance} \\ &= 200 \times 9.81 \times 2 \\ &= 3{,}924 \text{ Nm}\end{aligned}$$

Energy

Energy is the capacity for doing work. It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms.

The unit of energy is the Newton metre, or Joule.

$$\begin{aligned} \text{Work or work done} &= \text{Energy} \\ &= \text{Force} \times \text{Distance} \\ \text{Energy} &= \text{Joules} \end{aligned}$$

Power

Power is defined as the rate of doing work.

The unit of Power is the watt. Since the watt is a small unit, the kilowatt (kW) is often used.

$$\begin{aligned} 1\text{kW} &= 1{,}000 \text{ watts} \\ 1 \text{ hour} &= 60 \times 60 \text{ seconds} \\ &= 3{,}600 \text{ seconds} \\ 1\text{kWh} &= 1{,}000 \times 3{,}600 \\ &= 3{,}600{,}000 \text{ joules} \\ \text{Average power} &= \frac{\text{amount of work done}}{\text{time taken to do it}} \end{aligned}$$

Efficiency

The efficiency of a system can be defined as the ratio of output power to input power. It is usually expressed as a percentage.

$$\text{Efficiency} = \frac{\text{Output energy or power}}{\text{Input energy or power}} \times 100\%$$

The difference between input power and output power is the wasted energy or losses. Therefore:

$$\text{Output} = \text{Input} - \text{Losses}$$

or

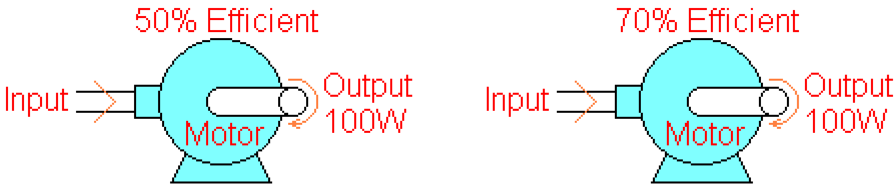
$$\text{Input} = \text{Output} + \text{Losses}$$

Example 4
A motor produces 100 watts output power and is:

a 50% efficient

b 70% efficient.

Calculate its input power in each case.



$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}} \times 100$$

$$\text{Input power} = \frac{\text{Output power}}{\text{Efficiency}} \times 100$$

a
$$\text{Input power} = \frac{100}{50} \times 100$$
$$= 200 \text{ watts}$$

b
$$\text{Input power} = \frac{100}{70} \times 100$$
$$= 142.86 \text{ watts}$$

Example 5
An electric motor drives a pump that lifts 1,000 litres of water each minute to a tank 20 metres above ground level. Calculate the power that the motor must provide if the pump is only:

a 50% efficient

b 80% efficient.

NB: One litre of water weighs 1kg (1kg = 9.81N)

$$\text{Work} = \text{Force} \times \text{Distance}$$
$$\text{Force} = \text{Mass in kg} \times 9.81$$
$$= 1{,}000 \times 9.81 \times 20$$
$$= 196{,}200 \text{ Nm/minute or Joules}$$
$$\text{Joules} = \text{Watts} \times \text{seconds}$$
$$\text{Watts} = \frac{\text{Joules}}{\text{seconds}}$$

$$\text{Power (Watts)} = \frac{196{,}200}{60}$$ (because time taken is 1 minute)

$$= 3{,}270 \text{ watts (output power)}$$

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}} \times 100$$

$$\text{Input power} = \frac{\text{Output power}}{\text{Efficiency}} \times 100$$

a

$$\text{Input power} = \frac{3{,}270}{50} \times 100$$

$$= 6{,}540 \text{ watts}$$

b

$$\text{Input power} = \frac{3{,}270}{80} \times 100$$

$$= 4{,}087.5 \text{ watts}$$

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Worksheet 15: Basic mechanics

1. **If a mass of 500kg is lifted through a height of 2m, calculate the amount of work done.**

2. **A mass of 300kg is raised through a vertical height of 8m. Calculate the amount of work done.**

3. **Calculate the work done when a force of 750N moves an object through a horizontal distance of 15m.**

4. **Calculate the work done when a force of 350N moves an object through a horizontal distance of 3.5m.**

5. **If the amount of work done by a force of 100N is 800Nm, calculate the distance the object has moved.**

6. **Calculate the distance covered by a trolley of 51kg when the amount of work done is 1,020Nm.**

7. **Calculate the opposition force of a transformer that moves 40m when the work done is 14,000Nm.**

8. **Calculate the weight of a transformer that moves 25m when the work done is 23,298.75Nm.**

9. **An object is moved across a distance of 20m in 5 seconds by a force of 50N. Calculate the power used.**

10. Calculate the power required to move a weight of 300N through a vertical distance of 5m in 2 seconds.

11. A mass of 40 litres of water is lifted through a height of 10m in 5 seconds. Calculate the power that has been used.

12. Calculate the power required to raise 2.5m^3 of water from a well 12.5m deep, in 30 seconds. NB: 1m^3 of water = 1,000kg.

13. A hoist raises a load of three tonnes through 8m in 15 seconds. Determine the power developed by the hoist. NB: 1 Tonne = 1,000kg.

14. An electric motor drives a pump that raises 1,000 litres of water each minute, to a tank 20m above ground level. Calculate the power that the motor must provide if the pump is only:

a) 50% efficient:

b) 80% efficient:

15. A pump raises 0.15m^3 of water per minute from a well 7.5m deep. Calculate the power required to drive the pump if it is only 75% efficient.

16. An electric motor drives a pump that raises 0.15m^3 of water per minute through a vertical height of 35m. Calculate:

a) the power required:

b) the power required to drive the pump if it has an efficiency of 72%:

c) the line current if the supply voltage to the motor is 220 volts DC:

17. A pump, which raises 0.12m^3 of water per minute from a well 8.5m deep, is driven by a 250V DC motor. Assuming that the efficiency of the pump is 72% and that of the motor is 78%, calculate the current drawn from the supply by the motor.

202: Principles of electrical science

Handout 16: Levers

Learning outcome

The learner will:

3. understand basic mechanics and the relationship between force, work, energy and power.

Assessment criteria

The learner can:

3.2 explain the principles of basic mechanics as they apply to **levers**, gears and pulleys.

Range

Levers: Class I, Class II, Class III

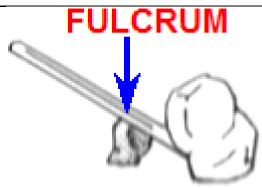
Levers

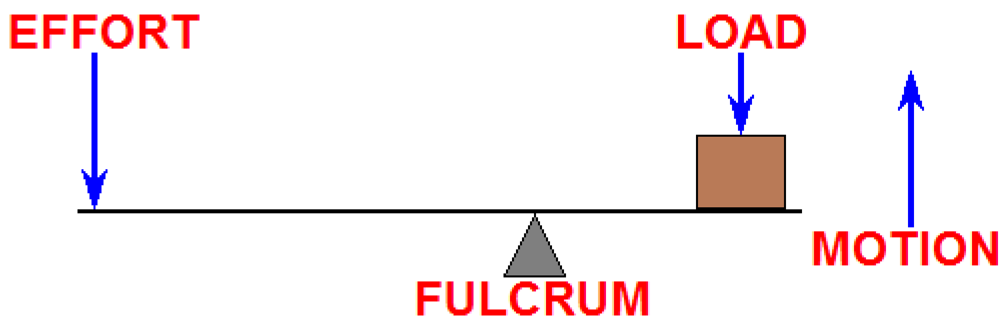
A lever is a machine consisting of a beam, or rigid rod, pivoted at a fixed hinge, or fulcrum. A lever amplifies an input force to provide a greater output force, which is said to provide leverage.

Classes of lever

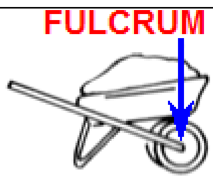
Levers are classified by the relative positions of the fulcrum and the input and output forces. It is common to call the input force the effort and the output force the load. This allows the identification of three classes of levers (or order) by the relative locations of the fulcrum, the load and the effort.

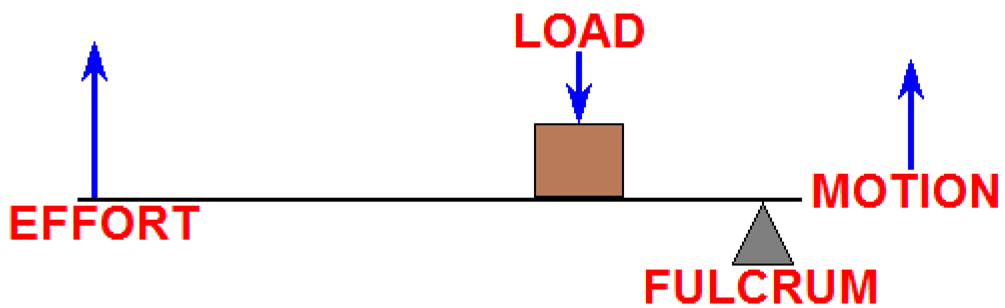
Class 1: Fulcrum in the middle – the effort is applied on one side of the fulcrum and the resistance on the other side; for example, a crowbar or a pair of scissors.



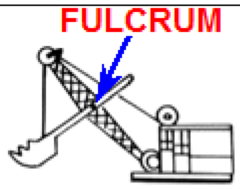


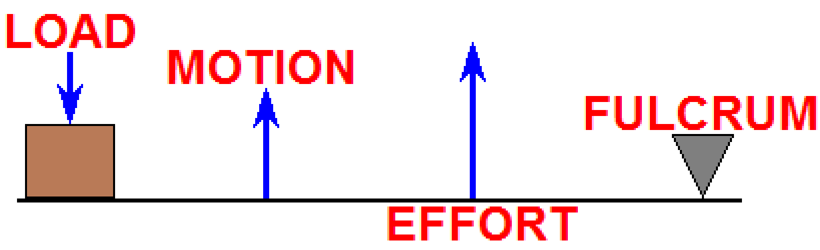
Class 2: Resistance in the middle – the effort is applied on one side of the resistance and the fulcrum is located on the other side; for example, a wheelbarrow, a nutcracker or a bottle opener.





Class 3: Effort in the middle – the resistance is applied on one side of the effort and the fulcrum is located on the other side; for example, a pair of tweezers or the human mandible.



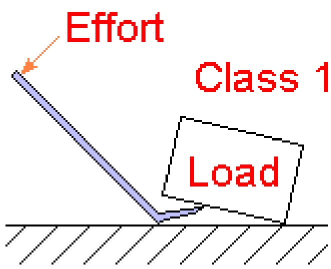


Lever calculations

The effort to be applied to a lever will depend on the weight of the load, how far from the fulcrum the load is and how far from the fulcrum the effort is applied. This can be summarised as follows:

$$\text{Effort} = \frac{\text{Load} \times \text{Load to fulcrum distance}}{\text{Effort to fulcrum distance}}$$

Example 1
A crowbar is used to lift a packing case. The load exerted by the packing case is 1,200N. Determine the effort needed to lift the packing case if the load is 10cm from the pivot and the effort is 1.0m from the pivot.



$$\begin{aligned}\text{Effort} &= \frac{\text{Load} \times \text{Load to fulcrum distance}}{\text{Effort to fulcrum distance}}\\ &= \frac{1{,}200 \times 0.1}{1}\\ &= 120\text{N}\end{aligned}$$

Example 2
A horizontal bar 1.75m in length is pivoted at a point 0.75m from one end and a downward force of 150N is applied at right angles to this end of the bar. Calculate the force that must be applied to the other end of the bar to maintain it in a horizontal position. Ignore the weight of the bar.

$$\begin{aligned}\text{Effort} &= \frac{\text{Load} \times \text{Load to fulcrum distance}}{\text{Effort to fulcrum distance}}\\ &= \frac{150 \times 0.75}{1}\\ &= 112.5\text{N}\end{aligned}$$

Gears

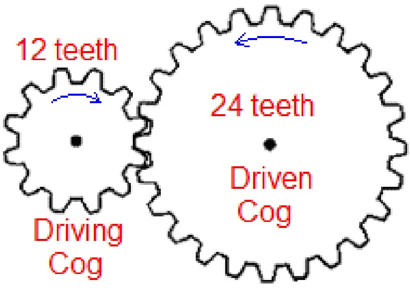
Gears are used for transmitting power from one part of a machine to another; for example, an electric motor in a factory transferring power, via the gear train, to piece of equipment being driven.

You can have any number of gears connected together and they can be different shapes and sizes. Each time you pass power from one gear wheel to another, you can do one of three things:

- increase/decrease speed
- increase/decrease force
- change direction.

The amount by which a pair of gears increases or decreases speed or power depends on the ratio between the two gears. This can be found simply by counting the number of teeth on each.

In the diagram to the right, the left-hand cog has 12 teeth and the right-hand cog has 24 teeth.



If the 12-teeth cog is coupled to the motor it is referred to as the driving cog; the 24-teeth cog is connected to the load and is referred to as the driven cog.

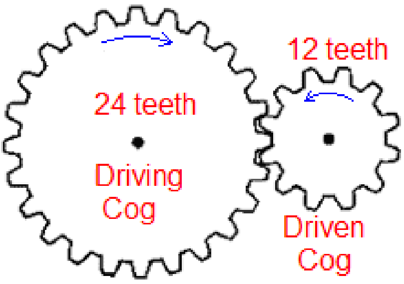
The ratio of this simple gear train is:

$$12:24 = 1:2$$

Very simply, if the driving cog is smaller than the driven cog then there will be a reduction in speed of the driven cog according to the gear ratio. In the example above, the 12-teeth driving cog would have to rotate twice for every single rotation of the driven cog, so speed would be reduced by a half. However, there would be twice as much power available at the driven cog, despite going slower.

Also, note that if the driving cog rotates clockwise the driven cog will rotate anticlockwise. If the direction of rotation is crucial, an extra cog (called an idler cog), is placed between the driving and driven cogs to restore the direction of rotation.

In this example, the larger 24-teeth cog is now the driving cog and the smaller 12-teeth cog is now the driven cog.



The ratio of this simple gear train is:

$$24:12 = 2:1$$

If the driving cog is larger than the driven cog there will be an increase in speed of the driven cog according to the gear ratio but it will deliver half as much power in this case.

If only a drive direction change is required, then two cogs with the same number of teeth could be used. These would have a ratio of 1:1 so there would be no change in speed or power available.

Pulleys

A pulley is simply a collection of one or more wheels over which you loop a rope to make it easier to lift things. Pulleys help us to multiply forces and are examples of what scientists call 'simple machines'. If you want to lift a very heavy weight there's only so much force your muscles can supply, even if you are very strong. But use a simple machine, such as a pulley, and you can effectively multiply the force your body produces.

The more wheels you have, and the more times you loop the rope around them, the more you can lift. The only drawback with using pulleys is that, whilst you can lift heavier loads, you have to pull the rope further (as can be seen on the following page).

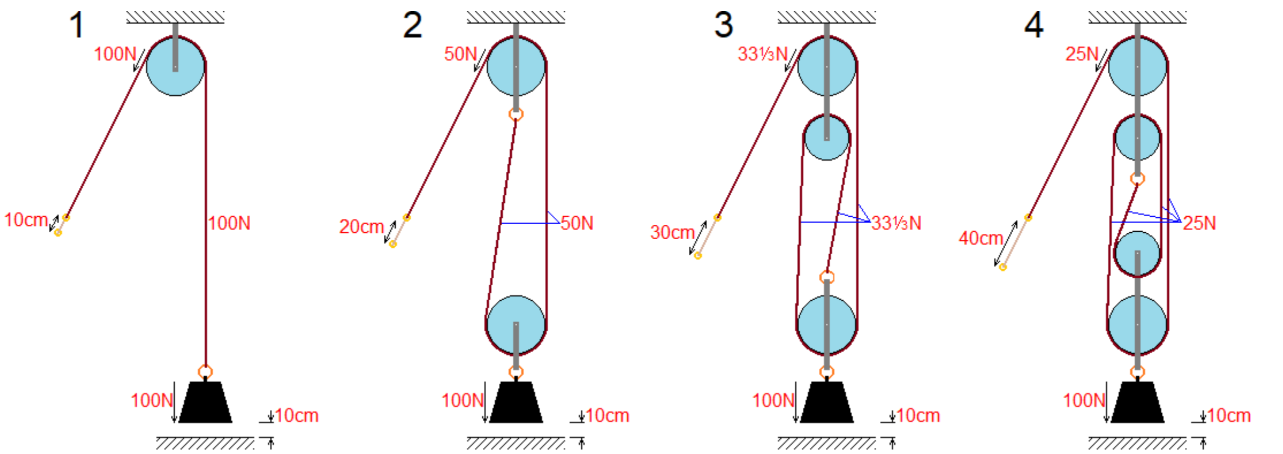


Diagram 1: There is only one pulley to lift a load with a weight of 100N through a distance of 10cm. To achieve this, the rope must be pulled with a force of 100N through a distance of 10cm; therefore, the mechanical advantage = 1.

Diagram 2: There are two pulleys to lift a load with a weight of 100N through a distance of 10cm. To achieve this, the rope must be pulled with a force of 50N through a distance of 20cm; therefore, the mechanical advantage = 2.

Diagram 3: There are three pulleys to lift a load with a weight of 100N through a distance of 10cm. To achieve this, the rope must be pulled with a force of 33 1/3N through a distance of 30cm; therefore, the mechanical advantage = 3.

Diagram 4: There are four pulleys to lift a load with a weight of 100N through a distance of 10cm. To achieve this, the rope must be pulled with a force of 25N through a distance of 40cm; therefore, the mechanical advantage = 4.

It can be seen that increasing the number of pulleys will mean less force needs to be applied to lift the same distance, but the force needs to be applied over a greater distance.

202: Principles of electrical science

Worksheet 16: Levers

1. **A piece of steel wire is to be cut by a pair of wire cutters. The wire is gripped 5mm from the fulcrum of the wire cutters, whilst the pressure is applied to the handles 80mm from the fulcrum. Calculate the force that must be applied to the handles in order to cut the wire if it requires a direct cutting force of 160N.**

2. **A lever is arranged so that a load of 1,000N is to be lifted at a distance of 200mm from the fulcrum. Calculate the force that must be applied 2m from the fulcrum to balance the load.**

3. **A crowbar is used to lift a packing case. The load is 200mm from the fulcrum and an effort of 50N is applied at the other end of the crowbar, 1.25m from the fulcrum. Determine the load in Newtons.**

4. **A load of 500N is situated on the end of a crowbar 150mm from the fulcrum. An effort of 37.5N is applied to the other end of the crowbar. Determine the length of the crowbar.**

202: Principles of electrical science

Handout 17: Electronic components

Learning outcome

The learner will:

6. understand the types, applications and limitations of electronic components in electrical systems and equipment.

Assessment criteria

The learner can:

6.2 state the basic operating principles of **electronic components and devices**.

Range

Electronic components and devices: capacitors, resistors, rectifiers, diodes, Zener, LED, photo, thermistors, DIAC, TRIAC, transistors, thyristors, invertors.

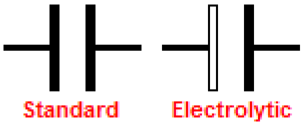
Electronic components

Capacitors

A capacitor is a passive two-terminal electrical component used to store energy in an electric field. The forms of practical capacitors vary widely, but all contain at least two electrical conductors separated by a dielectric (insulator); for example, one common construction consists of metal foils separated by a thin layer of insulating film. Capacitors are widely used as parts of electrical circuits in many common electrical devices.

When there is a potential difference (voltage) across the conductors, a static electric field develops across the dielectric, causing positive charge to collect on one plate and negative charge on the other plate. Energy is stored in the electrostatic field.

Capacitors are widely used in electronic circuits for blocking direct current while allowing alternating current to pass; in filter networks, for smoothing the output of power supplies; in the resonant circuits that tune radios to particular frequencies and in electric power systems for power factor correction.

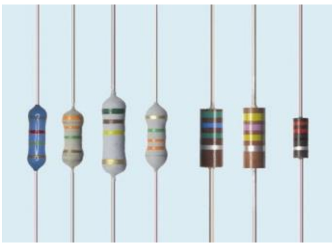


Various types of capacitors are available, usually referred to by their dielectric material, including:

- paper
- plastic
- glass
- mica
- ceramic
- aluminium (electrolytic)
- tantalum (electrolytic).

Apart from their capacitance in farads, capacitors are also graded according to their operating voltage which should not be exceeded in use, otherwise the dielectric will break down causing permanent damage.

Resistors



A resistor is a passive two-terminal electronic component that implements electrical resistance as a circuit element.

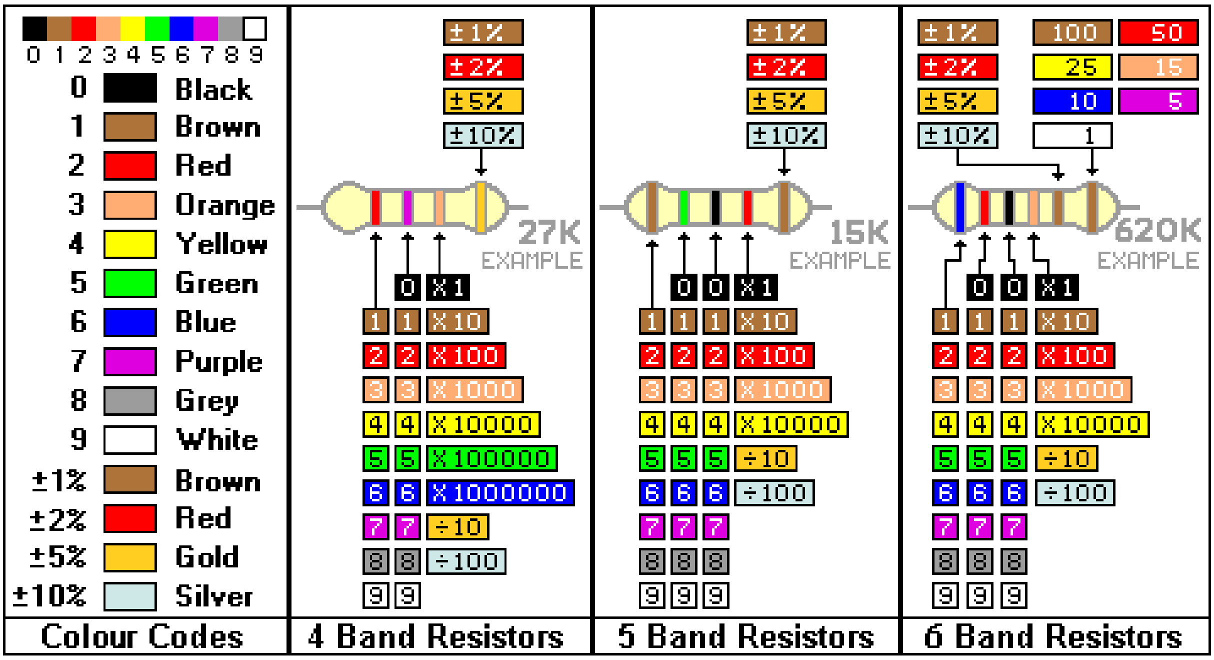
Practical resistors can be made of various compounds and films, as well as resistance wire (wire made of a high-resistivity alloy, such as nickel-chrome). Resistors are also implemented within integrated circuits, particularly analogue devices, and can also be integrated into hybrid and printed circuits.

Various types of resistors are available, usually referred to by their composition, including:

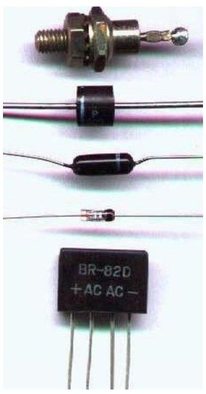
- carbon composition
- carbon pile
- carbon film
- thick film
- wire-wound resistors
- variable resistors
- potentiometers.

Apart from their resistance in ohms, resistors are also graded according to their power rating in watts and their tolerance expressed as a percentage.

To identify smaller resistors coloured bands are used; the following is the resistor colour code chart.



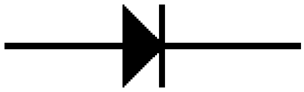
Diodes



In electronics, a diode is a two-terminal electronic component with an asymmetric transfer characteristic, with low (ideally zero) resistance to current flow in one direction and high (ideally infinite) resistance in the other. A semiconductor diode, the most common type today, is a crystalline piece of semiconductor material with a p–n junction connected to two electrical terminals.

The most common function of a diode is to allow an electric current to pass in one direction (called the diode's forward direction), while blocking current in the opposite direction (the reverse direction). This unidirectional behaviour is called rectification, and is used to convert alternating current to direct current, including extraction of modulation from radio signals in radio receivers.

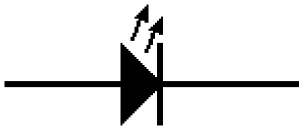
In the diagram (right), when the positive is applied to the left-hand end, current will flow (see the direction of the arrow). If the positive is applied to the right-hand end, current will not flow (current hits the solid bar).



Diode

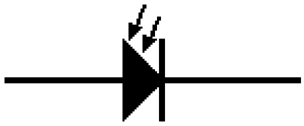
A light-emitting diode (LED) is a semiconductor light source. LEDs are used as indicator lamps in many devices and are increasingly used for other lighting, including area lighting.

Appearing as practical electronic components in 1962, early LEDs emitted low-intensity red light, but modern versions are available across the visible, ultraviolet, and infrared wavelengths, with very high brightness.



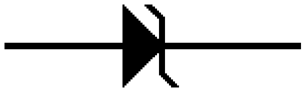
Light-emitting diode

A photodiode is a semiconductor device that consumes light energy to generate electric current. It is also sometimes referred as a photo-detector, photo-sensor, or light detector. Photodiode is very sensitive to light, so when light or photons falls on the photodiode it easily converts light into electric current.



Photodiode

Zener diodes are a special type of semiconductor diode. Unlike standard diodes that only allow current to flow in one direction, a Zener diode will allow current to flow in the opposite direction, but only when exposed to enough voltage. It has many applications, including simple reference voltages, clamping signals to specific voltage ranges, and easing the load on a voltage regulator.



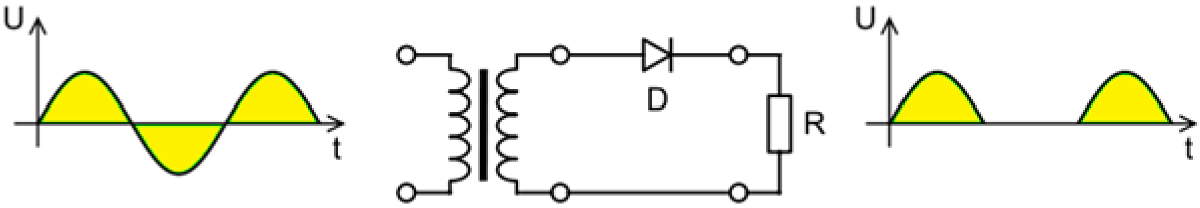
Zener diode

Rectifiers

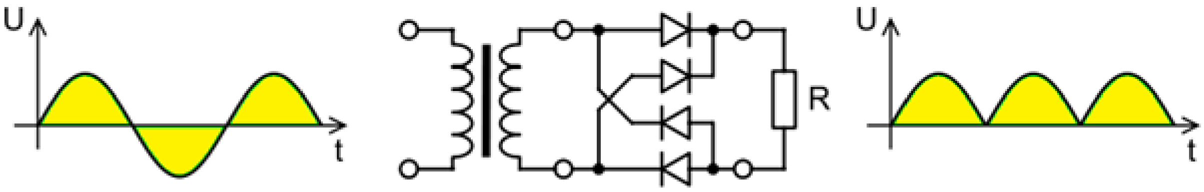
A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification.

Most rectifiers contain one or more diodes to produce unidirectional current flow that, by definition, is direct current. However, the DC produced will not be 'smooth', as derived from a battery, but will be 'pulsating', as shown in the following diagrams.

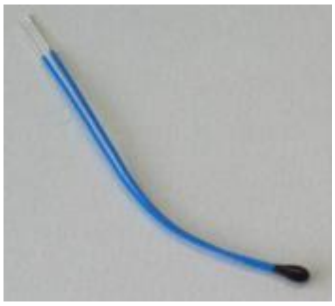
In half-wave rectification of a single-phase supply, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, this means the voltage is lower. Half-wave rectification requires a single diode in a single-phase supply, or three in a three-phase supply.



A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to pulsating DC and yields a higher average output voltage. Four diodes, in a bridge configuration, and any AC source are needed.



Thermistors



A thermistor is a type of resistor whose resistance varies significantly with temperature, more so than in standard resistors. The word is a combination of thermal and resistor. Thermistors are widely used as inrush current limiters, temperature sensors, self-resetting overcurrent protectors, and self-regulating heating elements.

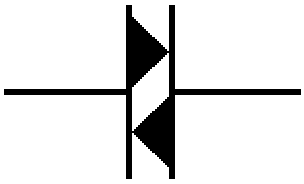
The material used in a thermistor is generally a ceramic or polymer. Thermistors typically achieve a higher precision within a limited temperature range, typically −90°C to 130°C.

There are two types of thermistor available:

- positive temperature coefficient (PTC)
- negative temperature coefficient (NTC).

With PTC devices, the resistance increases as the temperature increases; with NTC devices, the resistance decreases as the temperature increases.

DIAC



The DIAC, or DIode for Alternating Current, is a diode that conducts current only after its break-over voltage, V_{BO}, has been reached momentarily.

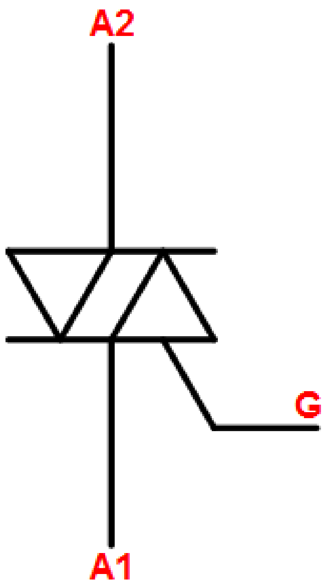
When this occurs, the diode enters the region of negative dynamic resistance, leading to a decrease in the voltage drop across the diode and, usually, a sharp increase in current through the diode.

The diode remains ‘in conduction’ until the current through it drops below a value characteristic for the device, called the holding current, I_H. Below this value, the diode switches back to its high-resistance (non-conducting) state. This behaviour is bidirectional, meaning typically the same for both directions of current. Most DIACs have a break-over voltage of around 30V.

DIACs have no gate electrode, unlike some other thyristors that they are commonly used to trigger, such as TRIACs.

DIACs are commonly found in dimmer switches, where they are used to ‘fire’ the TRIAC which is the device that actually controls the light output of the light source.

TRIAC



TRIAC, or TRIode for Alternating Current, is an electronic component that can conduct current in either direction when it is triggered (turned on).

TRIACs belong to the thyristor family and are closely related to silicon-controlled rectifiers (SCRs). However, unlike SCRs, which are unidirectional devices (ie can conduct current only in one direction), TRIACs are bidirectional and so current can flow through them in either direction. Another difference from SCRs is that TRIACs can be triggered by either a positive or a negative current applied to its gate electrode, whereas SCRs can be triggered only by currents going into the gate.

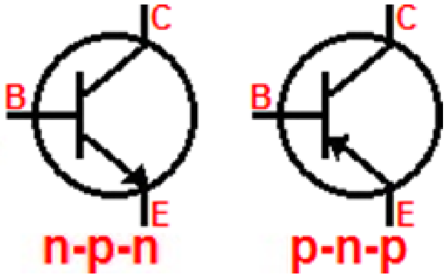
Once triggered, the device continues to conduct until the current drops below a certain threshold, called the holding current.

The bidirectionality makes TRIACs very convenient switches for AC circuits, also allowing them to control very large power flows with milliampere-scale gate currents. In addition, applying a trigger pulse at a controlled phase angle in an AC cycle allows one to control the percentage of current that flows through the TRIAC to the load; this is commonly used, for example, in controlling the speed of low-power induction motors, in dimming lamps and in controlling AC heating resistors.

Transistors

A transistor is a semiconductor device used to amplify and switch electronic signals and electrical power. It is composed of semiconductor material with at least three terminals for connection to an external circuit. A voltage or current applied to one pair of the transistor's terminals changes the current through another pair of terminals.

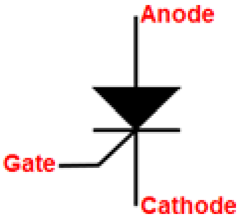
Because the controlled (output) power can be higher than the controlling (input) power, a transistor can amplify a signal. Today, some transistors are packaged individually, but many more are found embedded in integrated circuits.



Transistor as a switch: Transistors are commonly used as electronic switches, both for high-power applications (such as switched-mode power supplies) and for low-power applications (such as logic gates).

Transistor as an amplifier: The common-emitter amplifier is designed so that a small change in voltage (V_{in}) changes the small current through the base of the transistor; the transistor's current amplification combined with the properties of the circuit mean that small swings in V_{in} produce large changes in V_{out}.

Thyristor



A thyristor is a solid-state semiconductor device which conducts when its gate receives a current trigger and continues to conduct while it is forward biased (that is, while the voltage across the device is not reversed).

Some sources define silicon-controlled rectifiers and thyristors as the same device. Other sources define thyristors as a larger set of devices.

Because thyristors can control a relatively large amount of power and voltage with a small device, they find wide application in control of electric power, ranging from light dimmers and electric motor speed control, to high-voltage direct current power transmission.

Originally, thyristors relied only on current reversal to turn them off, making them difficult to apply for direct current; newer device types can be turned on and off through the control gate signal.

A thyristor is not a proportional control like a transistor and is only ever fully on or fully off.

Thyristors have three states:

- reverse blocking mode – voltage is applied in the direction that would be blocked by a standard diode
- forward blocking mode – voltage is applied in the direction that would cause a standard diode to conduct, but the thyristor has not yet been triggered into conduction
- forward conducting mode – the thyristor has been triggered into conduction and will remain conducting until the forward current drops below a threshold value known as the holding current.

Invertors

A power inverter, or inverter, is an electrical power converter that changes direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching and control circuits.

Solid-state inverters have no moving parts and are used in a wide range of applications, and from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC microgeneration sources such as solar panels or batteries.

The inverter performs the opposite function of a rectifier. The electrical inverter is a high-power electronic oscillator. It is so-named because early mechanical AC-to-DC converters were made to work in reverse, and thus were ‘inverted’ to convert DC to AC

202: Principles of electrical science

Worksheet 17: Electronic components

Using your notes answer the following questions.

1. **A resistor with four-band identification has green-blue-orange-silver bands. What is the value of this resistor?**

2. **What is a thermistor?**

3. **What is the unit used for capacitors?**

4. **In simple terms, what does a diode do?**

5. **Draw the symbol for a DIAC.**

6. **In simple terms, what does a thyristor do?**

7. Draw the symbol for a TRIAC.

8. Draw a half wave rectifier circuit, including the input and output waveforms.

9. Draw the symbols for an n-p-n and a p-n-p transistor.

202: Principles of electrical science

Handout 18: Electronic systems

Learning outcome

The learner will:

6. understand the types, applications and limitations of electronic components in electrical systems and equipment.

Assessment criteria

The learner can:

6.1 describe the function and application of electronic components that are used in **electrical systems**.

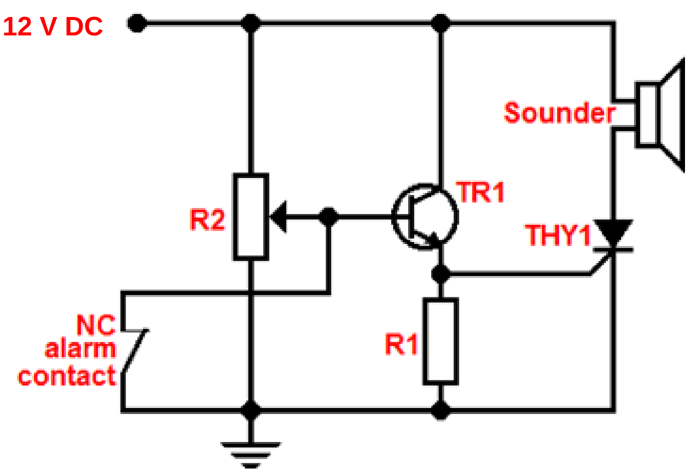
Range

Electrical systems: security alarms, telephones, dimmer switches, heating/boiler controls, motor control, wireless control systems.

Electrical systems

Security alarm system

The diagram (right) shows a circuit diagram for a very simple alarm system to indicate the use of electronic components in everyday electrical equipment.



The normally closed alarm contact maintains the transistor base at ground potential, turning the transistor hard off. R1 and R2 set the biasing for the transistor.

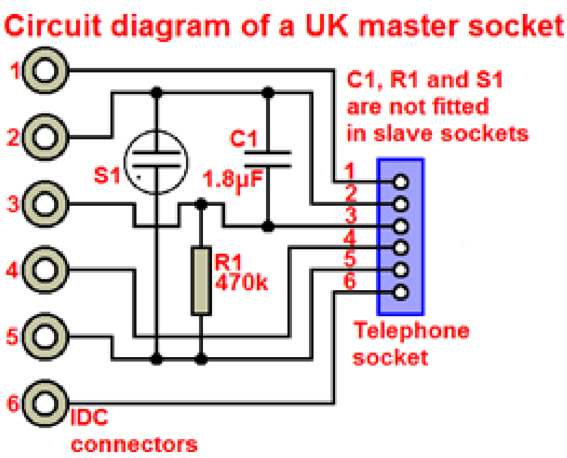
When the alarm contact is opened, the base rises to a potential higher than the emitter so the transistor turns fully on.

This causes a rise in potential to the gate of the thyristor THY1 which then turns on and the sounder will operate.

The thyristor will remain switched on even if the alarm contact is closed; the only way to turn off the thyristor and hence the sounder is to turn off the supply.

Telephone systems

Every plug and socket telephone (PST) system must have one master socket, but can have any number of slave/secondary sockets (subject to cable lengths and whether the wiring goes out of the premises).



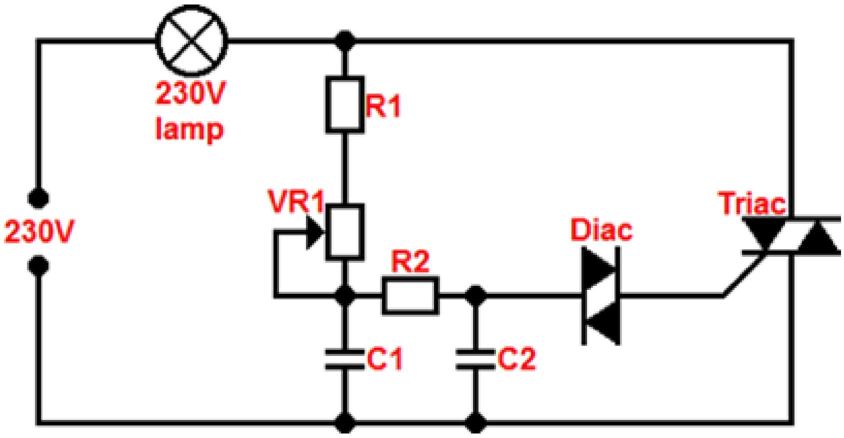
The master line jack unit (LJU) contains a capacitor, a resistor and a surge protector.

PBX (private branch exchange) master sockets used internally have the surge protector and resistor missing.

The capacitor is part of the ringing circuit, the resistor is for line testing purposes, and the surge protector is for arresting high-voltage discharges (not lightning!).

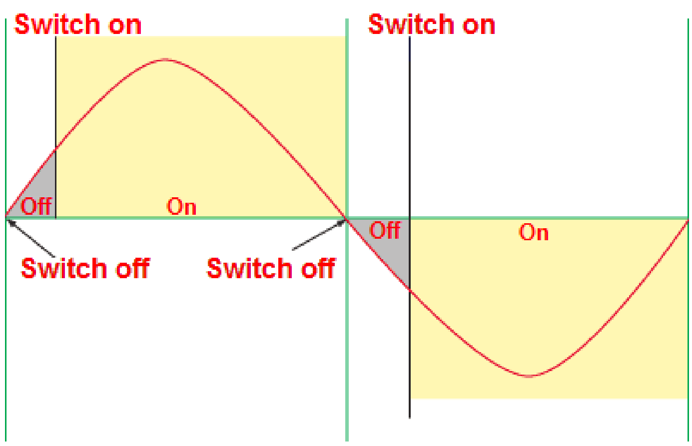
Secondary sockets, on the other hand, have no electrical components.

Light dimming



The circuit diagram, right, is an example of a dimmer switch, where a TRIAC has been utilised for controlling the intensity of light.

When AC mains is fed to this circuit, as per the setting of the pot, C2 charges fully after a particular delay, providing the necessary firing voltage to the DIAC.



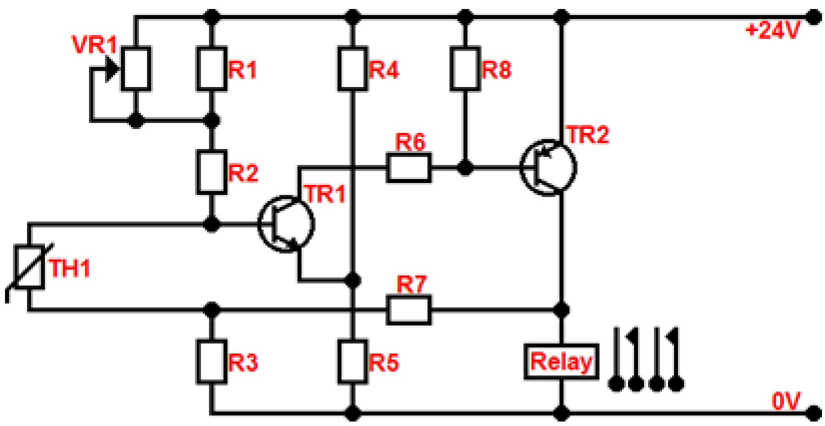
The DIAC conducts and triggers the TRIAC into conduction. However, this also discharges the capacitor whose charge reduces below the DIAC's firing voltage.

Due to this the DIAC stops conducting and so does the TRIAC.

This happens for each cycle of the mains AC sine wave signal, which cuts it into discrete sections, resulting in well-tailored lower voltage output.

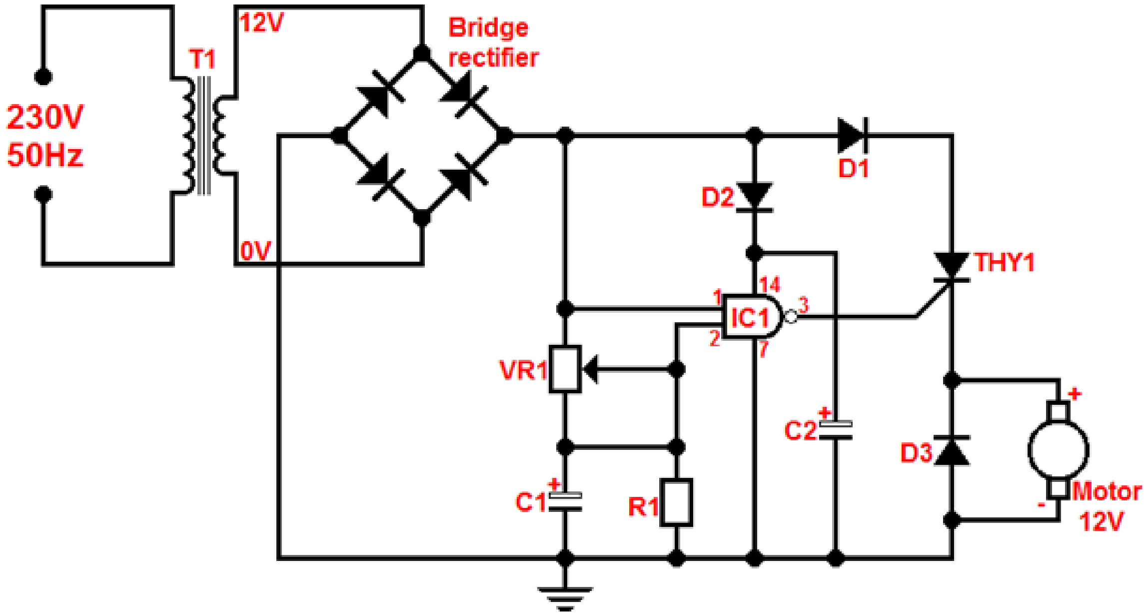
The setting of the pot sets the charge and the discharge timing of C2 which, in turn, decides for how long the TRIAC remains in a conducting mode for the AC sine signals.

Heating/boiler controls



When the temperature is lower than the preset temperature, transistor TR2 conducts and the relay activates the relay terminals to operate the heater.

Motor control



This is a speed controller circuit of a 12 volt DC motor. The speed of rotation can be adjusted from 5–60rpm.

The circuit works as follows. The supply is fed through a transformer to reduce the voltage to 20 volts AC. The bridge (full-wave) rectifier then converts this AC to DC. IC1 is a gate-type integrated circuit. It accepts the voltage from the bridge rectifier on pin 1. There is no filter to smooth the current.

The VR1, C1 and R1 is a phase shift or time delay to slow down or speed up the operation of IC1. The voltage from pin 3 triggers the gate of THY1 which starts conducting power to the motor, causing it to rotate. Speed control of the motor is achieved by adjusting VR1. The power supply input pin 14 of IC1 is filtered to smooth the current, by D2 and C2. D1 prevents noise from the motor and D3 provides reverse-voltage protection of the motor. D3 provides protection against reverse voltages produced by motor winding back – emf feeding back into control electronics and causing damage to them.

Wireless control systems

With advances in electronics, and particularly with most premises now having Wi-Fi, wireless control of accessories is now within the range of most households. This will have the following benefits:

- allows portable and remote control of accessories
- control and adjustment of lights (on/off) or create lighting scenes
- control shutters, blinds, gates, latches and garage doors
- manual or automatic control
- monitor window or door opening
- simulate occupancy when you are away from home.

Installation is greatly simplified because:

- No additional cables or wall cutting is needed. Receivers can be installed behind light fittings or into suitable installation boxes.
- Flexible positioning makes wireless control ideal for installation within existing or newly constructed buildings. With wireless control, you can move switches freely and re-locate when required.

- Transmitters are powered by battery and so do not require any wiring or additional power supply.

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Worksheet 18: Electronic systems

Using your notes, answer the following questions.

1. What is the purpose of the thyristor in the alarm circuit?

2. What is the purpose of the capacitor in the telephone socket?

3. What is the purpose of the bridge rectifier in the motor control circuit?

4. In the thermostat, what is the purpose of the thermistor?

5. In the dimmer switch, what is the purpose of the DIAC?

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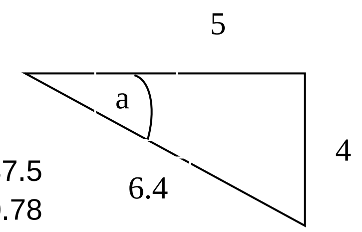
Sample questions version A

There are 40 multiple choice questions. Answer them all, selecting the correct answer out of the four provided.

1) Which is the correct formula to find I from the formula $P = I^2R$? (L 1.1)
   a) $I = \sqrt{\frac{P}{R}}$
   b) $I = \sqrt{\frac{R}{P}}$
   c) $I^2 = \frac{P^2}{R^2}$
   d) $I^2 = \frac{R^2}{P^2}$

2) Calculate the cosine of the following angle (a) in the figure below. (L 1.1)



   a) 37.5
   b) 0.78
   c) 0.63
   d) 0.8

3) The SI unit for Impedance is? (L2.2)
   a) Watts
   b) Henrys
   c) Hertz
   d) Ohm's

4) The electrical quantities symbol for Inductive Reactance is? (L2.2)
   a) W
   b) X_L
   c) Y
   d) Z

5) Kelvin is the measurement of? (L2.1)
   a) Length
   b) Area
   c) Mass
   d) Temperature

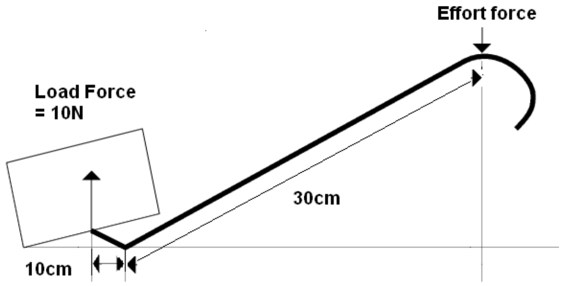
6) Which instrument would be used to measure Power? (L2.3)
   a) Ohm meter
   b) Volt meter
   c) Watt meter
   d) Amp meter

7) The SI unit for Energy is the? (L2.2)
   a) Watts
   b) Joule
   c) Ohm
   d) Farad

8) A 25 kilogram bag of cement falls to the ground from a height of 5 meters. How much force will the bag hit the ground with? (L3.4)
   a) 245.25N
   b) 5J
   c) 125N
   d) 196.2J

9) A wheel barrow is an example of a: (L3.2)
   a) Class 1 lever
   b) Class 2 lever
   c) Class 3 lever
   d) Class 4 lever

10) Calculate the effort required to lift a 10 Newton load with a crowbar in the figure below. (L3.4)

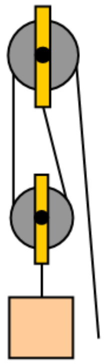


   a) 33 Newton's
   b) 0.3 Newton's
   c) 3.3 Newton's
   d) 6 Newton's

11) One set of gears are connected together. The smaller cog has 12 teeth and the larger cog has 20 teeth. The smaller cog rotates 40 times per second. How many times per second will the larger cog rotate? (L3.4)

a) 24 times per second
b) 67 times per second
c) 58 times per second
d) 87 times per second

12) Two pulleys are used to lift a load of 19000 Newton's, 4 metres above a surface. How much effort would be required to lift the load? (L3.4)



a) 4750 Newton's
b) 9500 Newton's
c) 76000 Newton's
d) 38000 Newton's

13) An electric motor has an input of 4kW and an output of 3.3KW. The efficiency of the motor is? (L3.4)

a) 90%
b) 100%
c) 82.5%
d) 121%

14) What is the correct formula for calculating work done? (L3.3)

a) $\text{Work done} = \frac{\text{force}}{\text{distance}}$
b) Work done = mass x acceleration x time taken
c) $\text{Work done} = \frac{\text{distance}}{\text{force}}$
d) Work done = force x distance

15) Which of the following statements is true? (L4.1)

a) Electrons are positively charged and Protons are negatively charged.
b) Electrons are negatively charged and Protons are positively charged.
c) Neutrons are negatively charged and Protons are positively charged.
d) Electrons are negatively charged and Neutrons are positively charged.

16) Identify the material which could act as an insulator. (L4.2)
   a) Gold
   b) Tungsten
   c) Glass
   d) Aluminium

17) A 6mm^2 cooper conductor has a resistivity of 1.78x10^{-8} and is 87 meters long. What is the resistance of the conductor? (L4.3)
   a) 0.26 Ohms
   b) 2.6 Ohms
   c) 26µ Ohms
   d) 26m Ohms

18) Which of the following materials would have the lowest resistivity? (L4.3)
   a) Air
   b) Aluminium
   c) Iron
   d) Copper

19) Which of the following statements is correct? (L4.4)
   a) As the voltage and the current increases, the resistance will decrease.
   b) As voltage increases, the current will also increase if the resistance stays the same.
   c) Current will decrease if resistance decreases and voltage stays the same.
   d) Voltage will increase if resistance increases and the current increases.

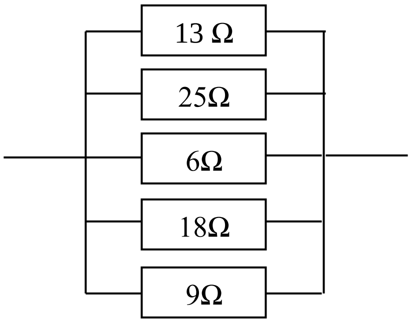
20) Which formula predicts the effect of Voltage, Current and Resistance? (L4.4)
   a) $V = IR$
   b) $V = \frac{I}{R}$
   c) $V = \frac{R}{I}$
   d) $V = I^2R$

21) As current flows in a series circuit, the current will: (L4.4)
   a) increase as it returns to the supply.
   b) decrease as it flows through each resistor of the circuit.
   c) stay the same throughout the circuit.
   d) not flow as the circuit is not connected in parallel.

22) Three resistors of equal value are placed in series and are connected to a 12 Volt supply, 1.3 Amps flows through the resistors. What are the values of each of the resistors? (L4.5)
   a) 2.3 Ohms
   b) 3 Ohms
   c) 2 Ohms
   d) 3.2 Ohms

23) Four resistors with values of 12 Ohms, 7.5 Ohms, 9 Ohms and 4.8 Ohms are wired in parallel and connected to a 110 Volt supply. How much current will flow through the 7.5 Ohm resistor? (L4.5)
a) 14.7 Amps
b) 9.2 Amps
c) 12.2 Amps
d) 23 Amps

24) What is the total resistance of the following resistors when wired in parallel: 13 Ohms, 25 Ohms, 6 Ohms, 18 Ohms and 9 Ohms? (L4.5)



a) 71 Ohms
b) 7.1 Ohms
c) 2.2 Ohms
d) 22 Ohms

25) A circuit has a total resistance of 12 Ohms and 6.44 Amps flows through it. How much power will the circuit dissipate? (L4.6)
a) 77 Watts
b) 1.86 Watts
c) 927 Watts
d) 498 Watts

26) An electric heater with a resistance of 16 Ohms is connected to a 220 Volt d.c. supply. What is the power dissipated by the heater? (L4.6)
a) 13.8 Watts
b) 0.073 Watts
c) 3 kilowatts
d) 3520 Watts

27) Calculate the volt drop of a circuit with a resistance of 1.2 Ohms with a current flow of 15 Amps. (L4.7)
a) 18 Volts
b) 12.5 Volt
c) 0.08 Volts
d) 6 Volts

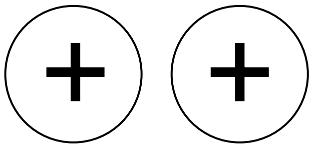
28) Which of the following effect would happen to a circuit if the current flow in the circuit was to increase? (L4.8)
a) The voltage of the circuit would increase
b) The resistance of the circuit would increase
c) The magnetic field would decrease
d) The power in the circuit would collapse

29) The effect that allows us to perform electroplating is: (L4.8)
   a) Magnetic
   b) Thermal
   c) Chemical
   d) Solar

30) The Tesla is the measurement for: (L5.2)
   a) Magnetic flux density
   b) Magnetic flux
   c) Induction
   d) Frequency

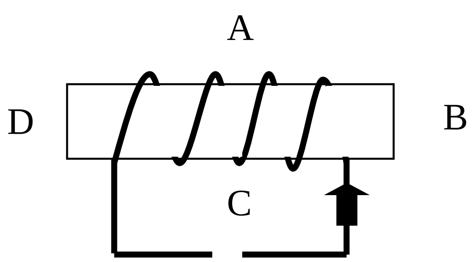
31) The correct formula to calculate Magnetic flux density is: (L5.2)
   a) $\beta = \frac{\varphi}{A}$
   b) $\beta = \frac{A}{\varphi}$
   c) $\beta = \varphi^2 A$
   d) $\varphi = \frac{\beta}{A}$

32) Two current carry conductors are placed side by side (see fig below). What will happen to the conductors? (L5.3)



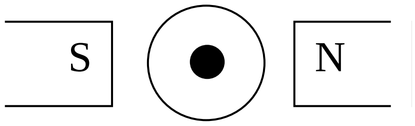
   a) They will rotate clockwise around each other
   b) The magnetic field of each conductor will cancel each other out
   c) They will repulse away from each other
   d) They will attract towards each other

33) Identify where the South Pole would be on this solenoid (see fig below). (L5.3)



   a) A
   b) B
   c) C
   d) D

34) A current carrying conductor is placed within a magnetic field. Which direction will the conductor (in the fig below) move? (L5.3)



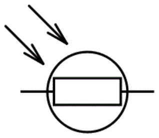
a) Left
b) Right
c) Down
d) Up

35) An alternator has a frequency of 60Hz. How long does it take to perform two full revolutions? (L5.4)
a) 330 milliseconds
b) 17 milliseconds
c) 60 milliseconds
d) 33 milliseconds

36) What is the generated emf when a 5000mm long conductor cuts a magnetic field of 0.5 Teslas at a velocity of 0.42 m/s? (L5.4)
a) 1 V
b) 1050 V
c) 105 V
d) 15 V

37) Which electronic device is designed to store an electrical charge? (L6.2)
a) Resistor
b) Diode
c) Capacitor
d) Diac

38) Which electronic device has the symbol (in the fig below)? (L6.2)



a) A thermistor
b) A Light admitting diode
c) A Thyristor
d) A light dependant resistor

39) What names are given to the two connections of a diode? (L6.2)
a) Anode and electrode
b) Cathode and electrode
c) Triac and Diac
d) Anode and Cathode

40) Which of the following electronic devices are suitable for detecting temperature change? (L6.1)

a) Variable resistor
b) Thermistors
c) Zener Diode
d) Triac

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Sample questions version B

There are 40 multiple choice questions. Answer them all, selecting the correct answer out of the four provided.

1) From a 50 metre cable drum, you have installed 13.6 metres of cable. What percentage of cable has been used? (L 1.1)
   a) 3.8%
   b) 72.8%
   c) 27.2%
   d) 65%

2) An insulation resistance tester is used to record the following values: 55MΩ, 72MΩ, 55MΩ, 18.5Ω, 10 MΩ and 89MΩ. What is the mean of these values? (L 1.1)
   a) 49.9MΩ
   b) 89MΩ
   c) 55MΩ
   d) 18.5MΩ

3) The SI unit for resistivity is? (L2.2)
   a) Ohm
   b) Ωm
   c) R
   d) Ω

4) Potential Difference is measured in? (L2.2)
   a) Amps
   b) Volts
   c) Newton's
   d) Joule's

5) In the SI system, time is measured in? (L2.1)
   a) Hours
   b) Minutes
   c) Seconds
   d) Kelvin's

6) Which instrument would be used to measure the resistance of a circuit? (L2.3)
   a) Ohm meter
   b) Conductance meter
   c) Continuity meter
   d) Amp meter

7) The SI unit for Capacitance is the? (L2.2)
   a) Volt
   b) Henry
   c) Hertz
   d) Farad

8) A load generates a force of 300 Newton's. Calculate the mass of the load. (L3.4)
   a) 3.6 kg
   b) 3060 kg
   c) 306 kg
   d) 30.6 kg

9) Lifting a load an electric motor uses 180,000 Joules of energy in 1 ½ minutes. (L3.4)
   What is the power rating of the motor?
   a) 500 W
   b) 1 kW
   c) 1.5 kW
   d) 2 kW

10) Crowbars are an example of what type of lever? (L3.2)
   a) Class 1
   b) Class 2
   c) Class 3
   d) Class 4

11) Force on a load is considered to be a combination of: (L3.3)
   a) mass and gravity
   b) time and acceleration
   c) weight and energy
   d) energy and work done

12) An electric motor has a 1.8 kW input and an efficiency of 88%. (L3.4)
What is the motor’s output?
a) 1.12 kW
b) 160 W
c) 1.6 kW
d) 160 kW

13) A four pulley system is required to lift a load force of 20000 Newton’s. (L3.4)
What is the effort force required to lift this load?
a) 5000 N
b) 800000 N
c) 5000 kg
d) 10000 N

14) A set of gears has a ratio of 16:1. The smaller cogwheel has 9 teeth. (L3.2)
How many teeth does the larger cogwheel have?
a) 14
b) 41
c) 82
d) 144

15) Current is described as: (L4.1)
a) the pressure to move the charge within a circuit.
b) the movement of electrons within a closed circuit.
c) the movement of protons within a conductor.
d) the standing force of the neutrons within an open circuit.

16) Porcelain is best described as? (L4.2)
a) A good conductor of electricity
b) A semi-conductor of electricity
c) An unstable conductor of electricity
d) A good insulator of electricity

17) A 2.5mm^2 copper conductor has a resistance of 1.5 Ohms. (L4.4)
If the conductor’s length is doubled what would the resulting resistance be?
a) 6 Ohms
b) 1.5 Ohms
c) 3 Ohms
d) 0.3 Ohms

18) A copper conductor has a resistance of 0.62 Ohms and is 36 meters long. What size is the conductor? Take the resistivity of copper to be 0.0172μΩm. (L4.3)

a) $1mm^2$
b) $1.5mm^2$
c) $2.5mm^2$
d) $4mm^2$

19) Two $4mm^2$ copper conductors are connected in parallel. Each conductor has a resistance of 0.5 Ohms. What is the combined resistance of the two conductors? (L4.4)

a) 0.5 Ohms
b) 0.25 Ohms
c) 1 Ohm
d) 0.75 Ohms

20) Four resistors each with an equal value of 6 Ohms are wired in parallel. What is the combined total resistance of the resistors? (L4.5)

a) 24 Ohms
b) 3 Ohms
c) 1.5 Ohms
d) 0.75 Ohms

21) A 5 Ohm resistor and a 7 Ohm resistor are wired in series and connected to a 25 volt supply. What is the power dissipated in the 7 Ohm resistor? (L4.5)

a) 52 Watts
b) 57 Watts
c) 89 Watts
d) 30 Watts

22) A copper conductor is forty meters long and has a c.s.a of $6mm^2$. If the conductor material was changed to aluminium the resulting resistance would be: (L4.3)

a) the same
b) lower
c) higher
d) unstable

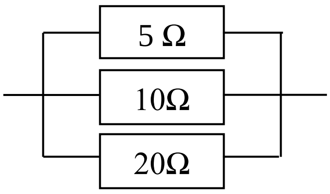
23) Which statement is correct with regards to what makes a good insulator? (L4.2)

a) The electrons are tightly bound to the nucleus.
b) The electrons are loosely bound to the nucleus.
c) The protons are tightly bound to the nucleus.
d) The protons are loosely bound to the nucleus.

24) Which of the following materials is a good conductor of electricity? (L4.2)
a) Air
b) Tungsten
c) Glass
d) Sand

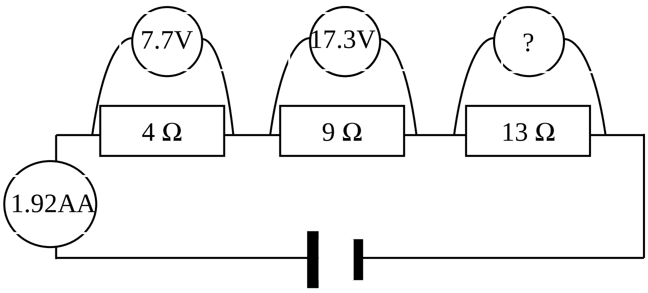
25) Which effect would make a Fuse blow? (L4.8)
a) Chemical
b) Magnetic
c) Thermal
d) Solar

26) What is the total combined resistance of the resistors show in the figure below? (L4.5)



a) 35 Ohms
b) 11.6 Ohms
c) 2.9 Ohms
d) 4.5 Ohms

27) What is the missing voltage value in the figure below? (L4.5)



a) 25 Volts
b) 12.5 Volt
c) 50 Volts
d) 27.5 Volts

28) A 16 Amp motor is connected to a cable with a very high resistance. (L4.7)
Which of the following issues would occur?
a) The motor will pull more current than it is designed to pull and damage itself.
b) Too much voltage will appear at the motor terminals damaging the motor.
c) There will be not enough voltage to operate the motor.
d) The motor would run in reverse.

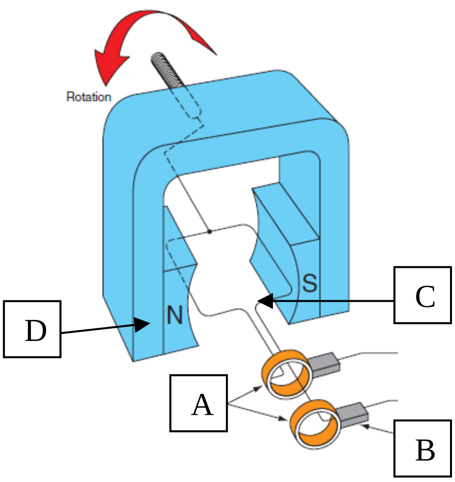
29) An aluminium conductor has a resistance of 0.88 Ohm's and a c.s.a of 1.5mm^2. (L4.3)
How long is the conductor if it's resistivity is 2.84x10^{-8} Ωm?
a) 46.5 m
b) 23 m
c) 34.5 m
d) 62 m

30) Magnetic Flux Density is defined by: (L5.2)
a) the measurement of quantity of magnetic flux.
b) the amount of flux in a given area.
c) the strength of a magnetic.
d) the magnets north and south poles.

31) A electric motor has a magnetic flux density of 30 Tesla's which covers an area of 250mm^2. What is the motor's magnetic flux value? (L5.2)
a) 75 Wb
b) 750 Wb
c) 7.5mWb
d) 7.5µWb

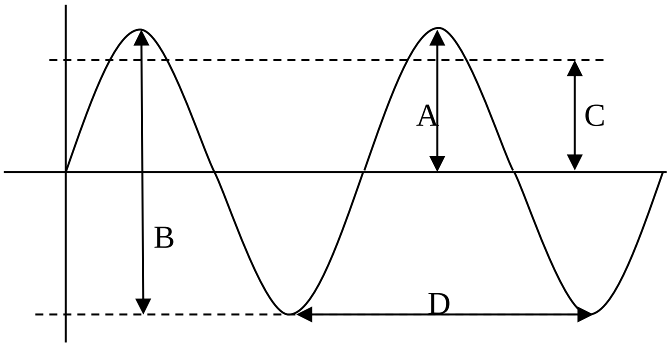
32) To induce an EMF into a conductor, what must you do? (L5.3)
a) Wrap the conductor around a magnet
b) Place and hold still a closed conductor within a magnetic field
c) Attach a magnet onto a conductor
d) Pass a closed conductor through a magnetic field

33) Identify the slip rings in the figure below. (L5.4)



a) A
b) B
c) C
d) D

34) Identify the figure below the Period? (L5.5)

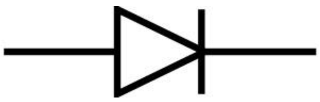


a) A
b) B
c) C
d) D

35) The formula to calculate the induced EMF within a conductor is: (L5.4)
a) E=VIL
b) E=BIL
c) E=vBl
d) E=WbIL

36) How long would a conductor need to be to produce 12 Volts when passed through a 0.9 Tesla magnet at 4m/s? (L5.4)
a) 33 m
b) 3.3 m
c) 33 cm
d) 33 mm

37) Identify the device in the figure below? (L6.2)

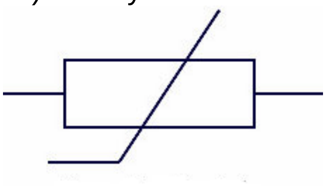


a) Triac
b) Diac
c) Resistor
d) Diode

38) In which of the following equipment would you expect to find a light dependant resistor? (L6.2)

a) Smoke Detector
b) Rectifier
c) Solar sensor
d) Dimmer switch

39) Identify the device in the figure below? (L6.2)



a) Triac
b) Thermistor
c) Resistor
d) Inverter

40) Which device is used to change alternating current into direct current? (L6.2)

a) Inverter
b) Pacifier
c) Converter
d) Rectifier