TTE Training Ltd.

Phase 1
Electrical Course Notes

E-CN-001

http://www.tteltd.co.uk

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Introduction to Electricity

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Section 1 - Regulations

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Whilst at work, all employees, and their employers, have to conform to safety regulations so that individuals are not put in danger. For example, the petro-chemical industry has strict regulations governing the production of flammable, toxic, noxious and corrosive substances such as petrol, trichloroethylene, ammonia and hydrochloric acid. These are just a few of the substances that we, as employees, may have to work with during our normal working day.

Whilst the **Health & Safety at Work Act (1974)** embraces all of the common safety aspects of working within industry, there are many manufacturing industries that require additional regulations to ensure safety at work. These regulations are legally binding in civil law and failure to comply may result in court proceedings being taken, especially if individuals sustain injuries as a result of bad practise. The main regulations that apply to the electrical industry are described in brief detail below.

Electricity at Work Regulations (1989)

The purpose of the Regulations requires precautions to be taken against the risk of death or personal injury from electricity in work activities. They apply to all industries and services, and include the manufacturing, supply, and installation of electrical equipment, electrical systems, and the competence of those required to manage labour and work near electricity. These Regulations are so strict that, if used to prosecute an individual in a court of Law, they state that it is for the defendant to prove they were not responsible for the offence occurring.

I.E.E. Wiring Regulations (BS 7671)

Compiled by the Institute of Electrical Engineers, these Regulations set a minimum standard to which all electrical installations should be constructed. Failure to comply will automatically prevent the issuing of an Installation Certificate of Worthiness and possibly the isolation or removal of the electrical supply by the supply authority.

Electrical Supply Regulations

These are the rules which govern the supply of electricity. They cover the methods employed to distribute the electrical supply around the country and also the associated equipment required to control and monitor the distribution. They also include the supply authorities obligation to provide an electrical supply which does not exceed certain limits (presently, domestic consumers receive 230Vac +/- 6% at 50Hz.)

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Selection, Installation and Maintenance of Electrical Apparatus for Use in Potentially Explosive Atmospheres (BS EN 60079: IEC 60079).

Whilst the I.E.T. Wiring Regulations cover the majority of electrical installations, areas such as petro-chemical plants and, more commonly, petrol stations, need their own regulations due to the potentially hazardous nature of the substances that are present. The processes utilised to produce products from fossil-fuels, as well as their end-use, have the potential to produce a flammable environment hence only specially designed and approved electrical equipment can be installed in the areas where these processes and materials may be present.

Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)

The DSEAR requires employers to eliminate or control the risks where a potentially explosive atmosphere may occur. Employers must classify areas where hazardous and/or explosive atmospheres may occur into zones. The classification given to a particular zone, and its size and location, depends on the likelihood of an explosive atmosphere occurring and its persistence if it does. Schedule 2 of DSEAR contains descriptions of the various classifications of zones for gases, vapour, and for dusts.

Areas classified into zones must be protected from sources of ignition. Equipment and protective systems intended to be used in zoned areas should be selected to meet the requirements of the Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996. Equipment already in use before July 2003 can continue to be used indefinitely provided a risk assessment shows it is safe to do so.

Some industry sectors and work activities are exempted because there is other legislation that fulfils the requirements. These exemptions are listed in regulation 3 of DSEAR.

Company Engineering Codes, Guidance and Procedures

Each company has its own process and engineering procedures and instructions and whilst they will embrace the national (legal) codes, they may contain Guidance and Procedures that appear unique due to a particular process, material or circumstances found in that company. They are frequently drafted by qualified Engineers and give detailed information on how to install, test and commission electrical equipment <u>before</u> it is put into service.

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Section 2 - What Is Electricity?

Many people tend to shy away from electricity because they do not understand it. All they know is that you cannot see or smell it and that it is a potential killer if you touch it. Only by understanding exactly what it is will people then learn to respect it and take the precautions necessary to avoid accidents.

In simple terms, electricity is a form of energy produced by the flow or accumulation of electrons.

Every material is made up of one or more elements; an element being a substance composed entirely of atoms of the same kind. Each atom consists of a core, or nucleus, around which electrons move in orbits at distances that are great compared to the size of the nucleus. The nucleus consists of *protons*, which carry a positive charge, and *neutrons*, which carry no charge. The orbiting *electrons* carry a negative charge. Each atom carries the same amount of electrons as protons and, therefore, under normal conditions, is said to be neutral i.e. the total negative charge on its electrons is equal to the total positive charge on its protons.

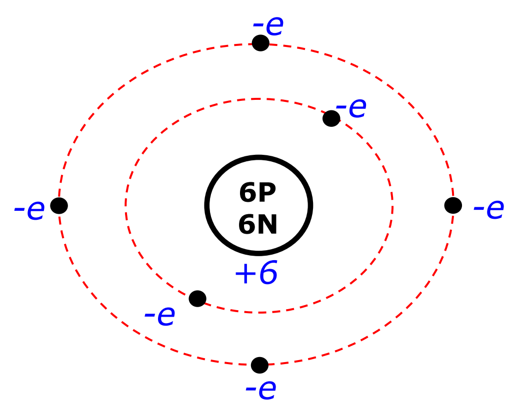

Fig. 2.1

The diagram above (Fig. 2.1), illustrates the arrangement of a **carbon** atom. The nucleus consists of six protons and six neutrons and therefore carries a positive charge of *+6e,* and is surrounded by six orbiting electrons, each carrying a negative charge of *-e.* The atom is, therefore, said to be balanced or neutral since it has an equal number of protons (positive charge) and electrons (negative charge).

The chemical behaviour of the different elements which constitute matter depends upon the number of orbiting electrons. This number varied between 1 (Hydrogen) to 93 (Uranium) until recent advances in nuclear physics identified elements with up to 103 electrons in man-made matter (plutonium has 94 electrons). The orbiting electrons form themselves into rings or 'shells', the innermost of which cannot contain more than 2 electrons. The remaining electrons orbit in further rings consisting of no more than 8 electrons per ring. When a ring is full, such as with helium (2 electrons) or neon (10 electrons), the orbiting electrons are tightly bound together and are difficult to displace hence insulating themselves from other atoms.

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The further away an electron is from the nucleus, the smaller is the force of attraction between that electron and the positive charge on the nucleus. It is, therefore, easier to detach such an electron from the atom. Such electrons are known as *free* or *conduction* electrons.

When atoms are packed tightly together, such as in metal, each outer electron experiences a small force of attraction towards neighbouring nuclei with the result that it is no longer bound to any individual atom. An atom which has lost, or gained, an electron is referred to as an ***ion*** thus, for an atom which has lost one or more electrons, its positive charge will be greater and is therefore termed a ***positive ion***.

An electrical supply is any device which has a surplus of electrons at its negative terminal (-) and a deficit of electrons at its positive terminal (+). So, when the supply is connected to a conductor, such as metal, the supply device attempts to become balanced, or neutral, and the positive terminal will steal an electron from the nearest atom in the conductor. This atom, in turn, attempts to become neutral and steals an electron from its neighbour and so on until the last atom steals an electron from the negative terminal of the supply. This exchange of electrons is known as **current flow** and flows from negative to positive.

Conductors

In metallic conductors, such as copper and aluminium, the atoms are arranged in a regular array called a crystal lattice. The electrons in the outer orbits of each metal atom are only loosely bound to the nucleus and are not closely associated with any particular atom hence they are easily released and free to move through the crystal lattice. Once an electron has left its orbit around a particular atom it becomes a ***free electron***. The remaining atom is left with an excess positive charge and is called a ***positive-ion***.

At normal temperatures, the ions possess energy and vibrate. Collisions between vibrating ions and free electrons cause the electrons to move in a random manner. Over a long period of time, the net motion of these free electrons is zero. If an electric field is applied to the conductor, the free electrons will acquire additional energy and will tend to move in the direction dictated by the field. This motion of charge carriers constitutes an electric current.

Insulators

In an insulator the electrons are very tightly bound to their respective atoms hence they are unlikely to move under the influence of an applied electric field. Insulating materials, such as rubber or porcelain, cannot therefore conduct any appreciable electric current under normal conditions.

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Section 3 - Electrical Terms & Units

Within electrical engineering you will come across some common terms such as Resistance, Potential Difference, Electro-motive Force, Power, and Alternating and Direct Current, to name but-a-few.

Resistance

Resistance, denoted ***R***, is a measure of the extent to which a material opposes the movement of electrons among its atoms hence the more easily the atoms give up and/or accept electrons, the lower the resistance. The unit of measurement is Ohms, (symbol ***Ω*** (omega)), named after **Georg Ohm** (1789-1854), the definition of which is, "*the resistance between two points of a conductor when 1 Volt, applied between these points, produces a current of 1 Ampere …*". Alternatively, it may be defined as, "*the resistance of a circuit in which a current of 1 Ampere generates heat at the rate of 1 Watt*".

Current

A measure of the rate-of-charge in a conductor passing a given point in a given time, Denoted ***I***** and measured in Amperes (abbreviated as"***A***") in honour of **André-Marie Ampere** (1775-1836). The unit may be defined in the following manner:

- One ampere is a coulomb of charge moving past a point in one second.
- It takes 628 x 10^{16} electrons to flow past a point each second for a current of one ampere to result.

Alternating Current (AC): a current whose magnitude alternates between positive and negative.

Direct Current (DC): a current that does not alternate but remains constantly positive or constantly negative.

***** The symbol *I* originates from the French phrase *intensité de courant*, or in English, *current intensity*.

Potential difference

Frequently abbreviated to *p.d.*, it is defined as, "t*he measure of the difference of potential (electrical energy) between two points of a conducting wire carrying a current of 1 Ampere when the power dissipated between these points is 1 Watt*". The unit of measurement is the Volt, frequently abbreviated as "***V***", in honour of **Alessandro Volta** (1745-1827), the inventor of the first battery cell.

The relationship between Power, (*P*), Current, (*I*) and Voltage (*V*) can be shown as:

P (Watts) = *V* (volts) x *I* (Amperes)

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Electromotive Force

An electromotive force is that which tends to produce an electric current in a circuit when the circuit is connected to a source of electrical energy, e.g. a battery, generator, solar cell, thermo-junctions between two dissimilar materials ; and is a measure of the energy supplied to each charge as it passes through the source. Abbreviated as ***e.m.f.***, it is symbolised by the letter ***E*** and is expressed and measured in Volts, (abbreviated as "***V***").

Quantity of Electricity

Measured in Coulombs, and symbolised by the letter "***Q***", it is defined as, "*the quantity of electricity passing a given point in a circuit when a current of 1 Ampere is maintained for 1 second*", hence:

$$Q \text{ (coulombs)} = I \text{ (amperes)} \times t \text{ (seconds)}$$

Power

Measured in Watts (after **James Watt**, 1736-1819), the power used in an electrical system is determined by the amount of work done in a given amount of time. Given that work and energy are measured in joules, and time in seconds:

the power used (expressed as Watts or Joules/sec.) = work done (J) ÷ time (s).

For the purpose of electrical supply, the Joule is too small a unit given that energy consumption is measured over longer periods of time. By using a larger power rating, i.e. the kilowatt (kW), and a longer time frame, i.e. an hour (h), a larger unit of energy is formed, the kilowatt-hour (kWh).

Inductance

Any circuit, in which a change of current is accompanied by a change of flux, and therefore an induced e.m.f., is said to be inductive or possess inductance. Circuits which have no components in the form of a coil may, for practical purposes, be regarded as non-inductive.

When a current flows through a wire a circular magnetic field is created around it. If the wire is coiled into a solenoid, the fields around the wire sum up, the result of which is a magnetic field similar to that of a bar magnet on the outside and a uniform magnetic field on the inside. Any attempt to increase current will expand the field which, by its nature, will increase the induced emf in each turn, (whose direction is opposite to that of the field), and oppose the increase in current flow.

Symbolised by the letter "***L***", the measurement unit for inductance is termed the Henry, abbreviated as "***H***", after **Joseph Henry** (1797-1878). Inductance may be described in the following manner; "*a circuit has an inductance of 1 Henry (or 1H) if an e.m.f. of 1 Volt is induced in the circuit when the current varies uniformly at the rate of 1 Ampere per second*".

Impedance

The **impedance** is the general term for the describing the ratio of voltage to current with regards to their relativel amplitudes and their phase angles. When the circuit is connected to a direct current (DC) source, there is no distinction between impedance and resistance; hence the latter can be thought of as impedance with a zero phase angle. Denoted as "***Z***", and expressed in ohms (**Ω**), it is also an expression of the opposition that an electronic component, circuit, or system offers to the current and is a combination of both resistance and reactance.

Reactance

Reactance, denoted "***X***", and expressed in Ohms, (***Ω***), it is an expression of the extent to which an electronic component, circuit, or system stores and releases energy as the current and voltage fluctuate with each cycle, (it is only relative to alternating current hence it is dependent upon frequency of supply).When AC passes through a component that contains reactance, energy might be stored and released in the form of a magnetic field, in which case the reactance is inductive (denoted X_L), or the energy might be stored and released in the form of an electric charge, in which case the reactance is capacitive (denoted X_C).

Capacitance

Capacitance, denoted ***C*** and measured in Farads (***F***), is derived from the ability of a component or system to hold an electric charge. As a component, a capacitor may be described as two metal plates separated by a non-conducting material. When connected to a circuit, electrons build up on the negative plate whilst an electric field propagates and repels electrons on the opposite plate making it positively charged. Due to the build up of electrons on the negative plate, incoming electrons are also repelled so the total current eventually decays to zero. The capacitance is defined as the charge stored/displaced across a capacitor divided by the potential difference across it and can also be calculated by the size of the plates and the dielectric properties of the insulator.

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Section 4 – Basic Electrical Principles

Magnetism

Originally produced from magnesia stone ore, the modern magnet is made of steel and is more commonly known for its unique property when utilised as a compass, i.e. when held in a horizontal plane, one end will seek and point towards the North Pole whilst the other is attracted to the opposite (South) Pole – these are called the North (N) and South (S) poles of the magnet respectively.

The magnetic field around each pole is shown in the diagram (Fig. 4.1). It must be realised that the lines of magnetic flux, as they are referred to, are imaginary however, they can be represented by placing a piece of card over a magnet and sprinkling iron filings over the card area. By gently tapping the card, the filings align themselves to the magnetic field around the magnet providing an image of the lines of magnetic flux.

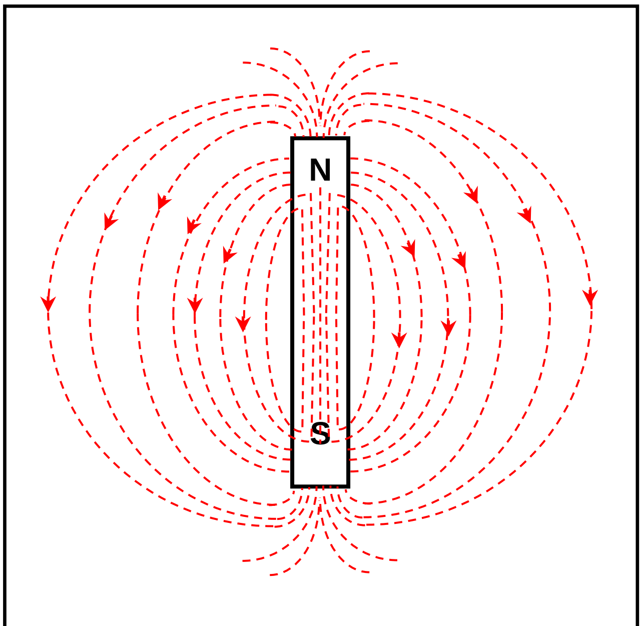

Fig. 4.1

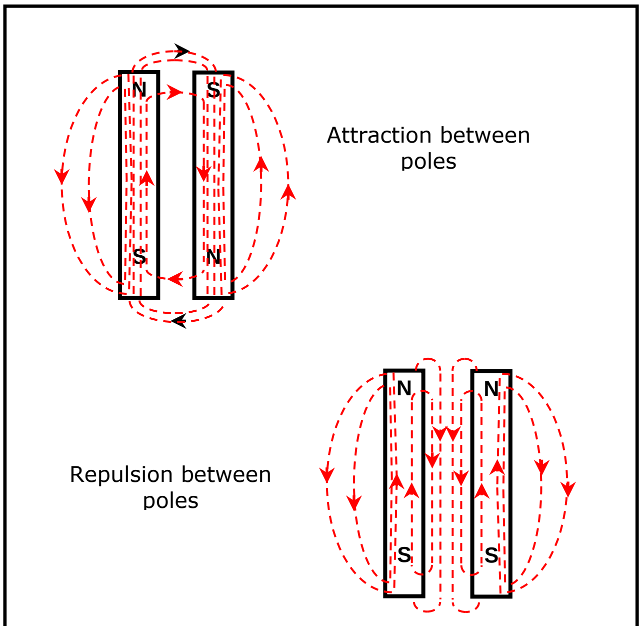

Fig. 4.2

Whilst there is no physical evidence of their existence, they do provide an explanation for the various magnetic effects hence they are assumed to have the following properties:

- the direction of a line of magnetic flux in a non-magnetic medium, such as air, is that of a north-seeking pole of a compass needle
- each line of magnetic flux forms a closed loop
- lines of magnetic flux never intersect
- lines of magnetic flux can be compared to stretched elastic cords, always trying to reduce their size

lines of magnetic flux which are parallel and in the same direction repel each other whereas lines in opposition attract each other, (Fig. 4.2)

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Electromagnetic Fields

In 1820, **Oersted** discovered that when electric current flows in a conductor, a magnetic field is produced around it. This can be confirmed by placing a compass next to a current-carrying conductor and watching the deflection of the needle, the direction of which will depend upon the direction of the current.

The diagram below (Fig. 4.3) provides a representation of the magnetic field produced by the current flow. The direction of the fields is governed by the direction of the current (demonstrated by the arrow) hence, when viewed with the current flowing away, the field direction around the conductor is clockwise.

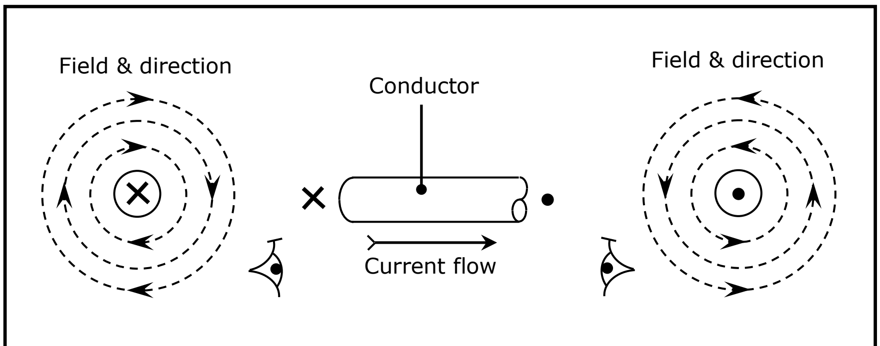

Fig. 4.3

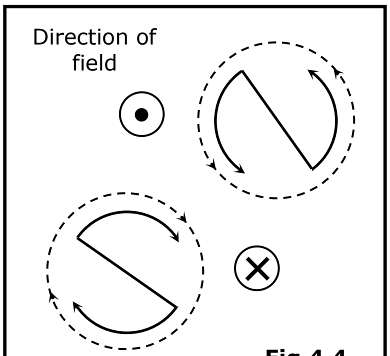

Fig.4.4

If the conductor is arranged in a coil, (Fig. 4.5), the field around each turn combines to form a composite field which is similar to that produced by a bar magnet, having both North and South poles.

Field direction produced by the current in a coil may be deduced by remembering the diagrams in Fig. 4.4. The outer (dotted) circle represents the coil winding, the arrow on which shows the direction of current flow and, hence, the orientation of the field. Alternatively, using the **right-hand**, point the thumb in the direction of the current and the natural curl of the fingers indicate the direction of the field, (right-hand grip rule).

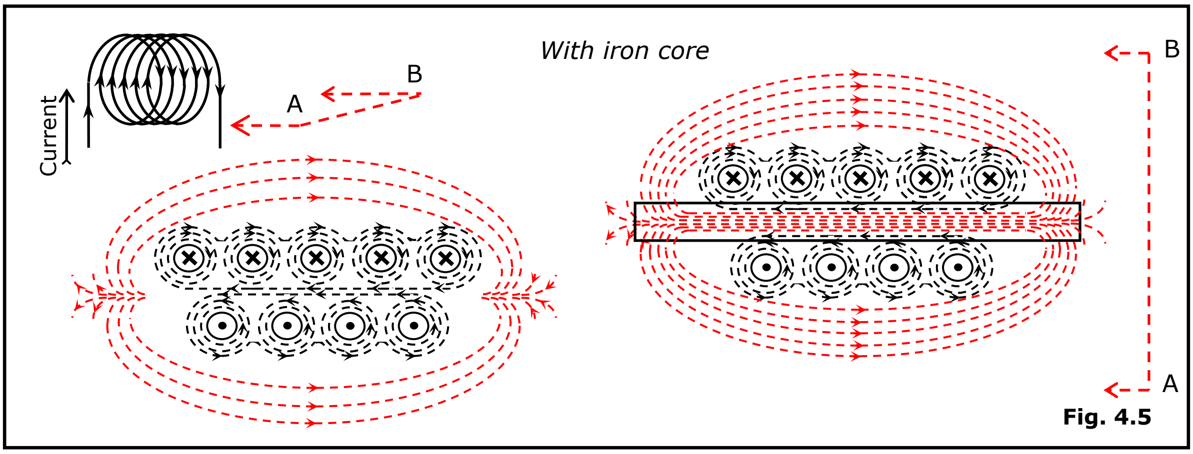

Fig. 4.5

Whilst the field in and around the coil is much stronger than that around a single conductor, it can be further intensified by placing a steel bar into the coil, as is demonstrated above.

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This can also be demonstrated with the use of a magnet & iron-ring, as shown in the diagram below (Fig. 4.9). When the field lines of the bar-magnet approach the iron ring (Fig. 4.6(a)), a current is induced in the ring which subsequently creates an electromagnetic force around it, the directions of which are shown. When the bar-magnet is moved in the opposite direction, (Fig. 4.6(b)), the current flow in the ring and, consequently, the direction of the associated magnetic field, is reversed.

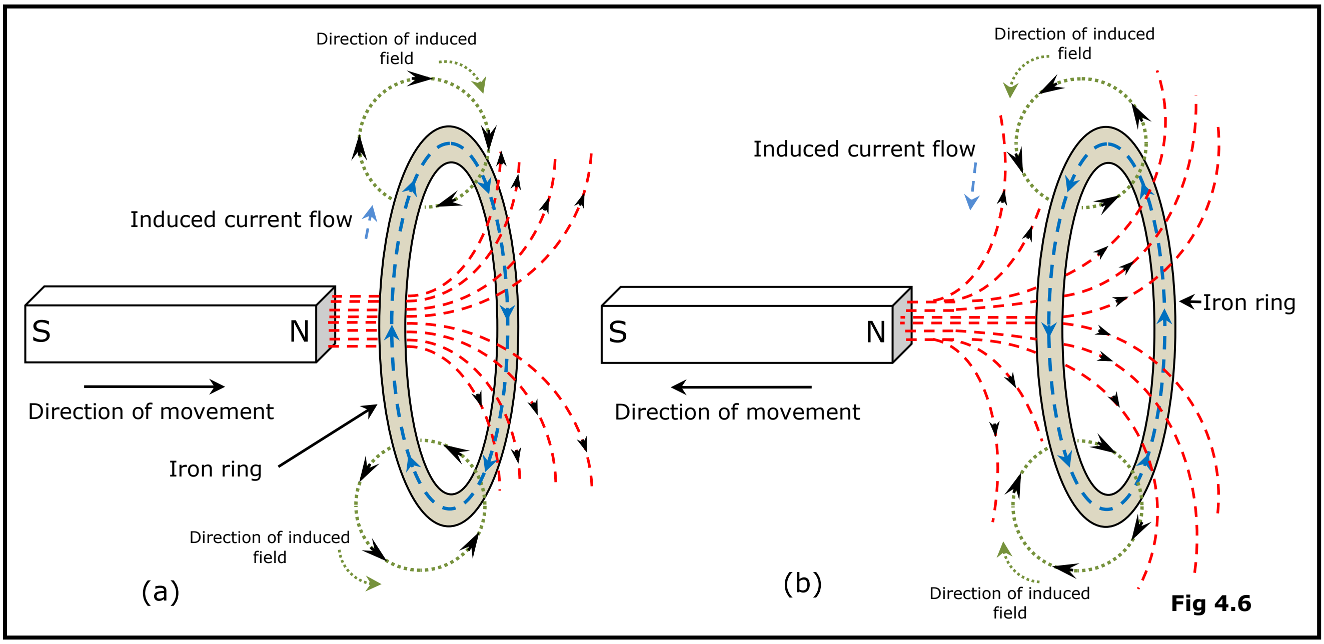

Fig 4.6

Note that the direction of the induced magnetic field within the ring is oriented so that it opposes the change in magnetic field resulting from movement of the bar-magnet.

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Electromagnetic Induction

In 1831, **Michael Faraday** discovered that electric current may be obtained with the aid of magnetic flux. In the diagram below (Fig. 4.7) a coil is wound around a steel core and connected to a galvanometer (G). When a permanent magnet is moved towards the coil the galvanometer deflects in one direction, and when the magnet is withdrawn the deflection is in the opposite direction.

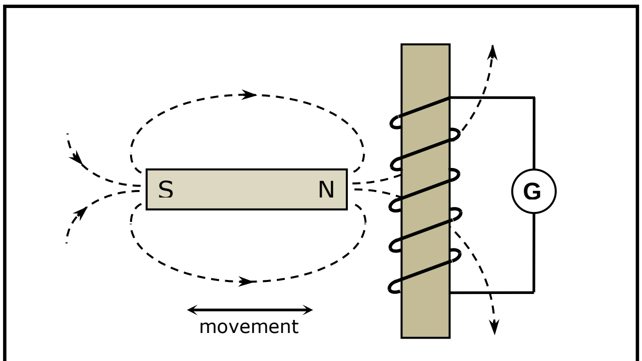

Fig.4.7

Bending the conductor into a loop concentrates the magnetic field inside the loop while weakening it outside. By bending the conductor into multiple closely-spaced loops to form a coil or "solenoid", the effect is enhanced and acts like as an **electromagnet**, generating a strong, well-controlled magnetic field whose strength and polarity is determined by the current flowing through it.

If the coil is wound around a section of iron bar and connected to a battery, (Fig.4.8), the iron would be magnetised and behave like a permanent magnet. The coil is said to "induce" current into the bar, hence it is referred to as an ***inductor***.

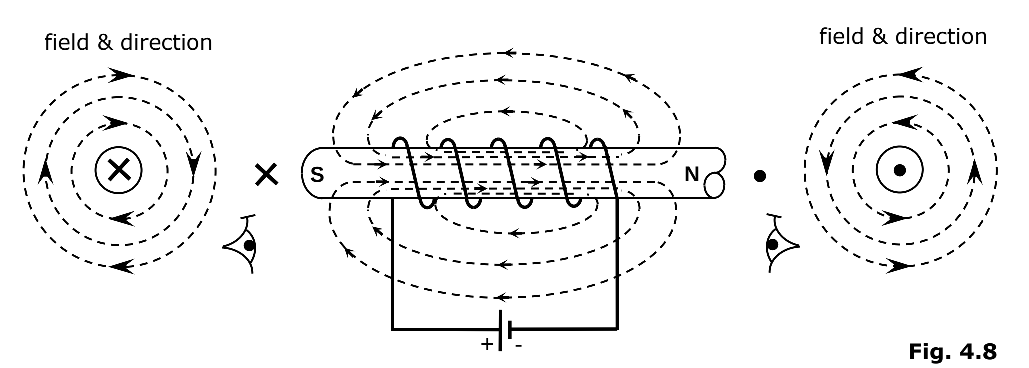

Fig. 4.8

The capacity of an inductor is controlled by a variety of factors:

- the number of coils - more coils means more inductance
- the radius of the coil – the smaller the radius the stronger the field
- the material that the coils are wrapped around (the core) : note – using iron as the core gives it much more inductance than air or any non-magnetic material would

(cont'd overleaf)

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- The cross-sectional area of the coil - more area means more inductance.
- The length of the coil - a short coil means narrower (or overlapping) coils, which means more inductance.
- The shape of the core – the toroidal (doughnut-shaped – see Fig. 4.9) cores provide more inductance, for a given core material and number of turns than solenoid (rod-shaped – see Fig. 4.8) cores.

In the diagram below (Fig. 4.9) two coils are wound around the same steel core (B), with one coil (A) connected to a D.C. supply and the other (C) connected to a galvanometer. At the instant switch (S) is closed, current will flow in coil A and the galvanometer (G) will show a deflection. When the switch is opened, the galvanometer will show an opposite deflection. This indicates that current flowing in coil A, and the changing magnetic field it produces, induces a current to momentarily flow in coil C.

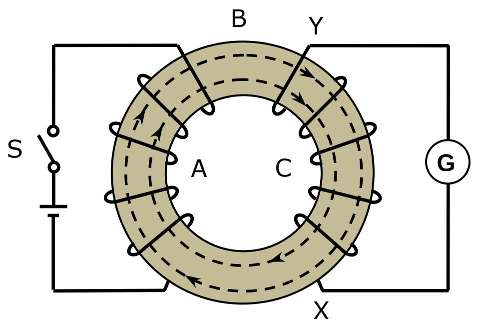

Fig.4.9

Faraday's Law, as it is referred, states that "*the magnitude of the induced electromagnetic force (e.m.f.) is proportional to the rate at which the magnetic flux passed through the coil is varied*".

Alternatively, this may also be described as : "*when a conductor cuts, or is cut by, a magnetic flux, an e.m.f. is generated in the conductor and the magnitude of the generated e.m.f. is proportional to the rate at which the conductor cuts, or is cut by, the magnetic flux*".

In 1834, **Heindrich Lenz** discovered a directional relationship between induced magnetic fields, voltage, and current when a conductor is passed within the lines of force of a magnetic field. In order to determine the direction of the induced e.m.f., **Lenz's Law**, as it is now referred, states, "*An induced electromotive force generates a current that induces a counter magnetic field that opposes the magnetic field generating the current.*", or alternatively, "*the direction of an induced e.m.f. is always such that it tends to set up a current opposing the motion or the change of flux responsible for inducing that e.m.f.*".

Using **Fig. 4.9** as an example, when switch S is closed, the direction of the magnetic flux in the steel core is clockwise (as shown). The induced current in coil C must, therefore, produce a flux that opposes the growth of flux in the core, i.e. in an anti-clockwise direction.

For this to occur, the current in coil C must be passing from X to Y hence this must also be the direction of the induced e.m.f.

The effect of induced fields may be observed by dropping a strong magnet through a vertical copper pipe. As it descends, currents bound inside the atoms of the magnet create counter-rotating currents in the copper which visibly reduces its speed.

Induced current can also be observed in the circuit below, (Fig. 4.10) using an inductor and lamp connected in parallel to a battery supply via a switch.

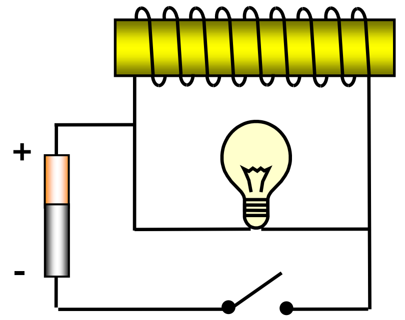

Fig. 4.10

The coil resistance is less than that of the lamp hence, when S is closed, the expectation would be for most of the current to flow through the coil, leaving the lamp to glow very dimly. In reality, when S is closed, the lamp glows brightly and then gets dimmer. When the switch is opened, the lamp glows brightly and then quickly extinguishes.

The reason for the lamps behavior is the inductor. When current first starts flowing in the coil, the coil wants to build up a magnetic field. While the field is building, the coil restrains the flow of current. Once the field is built, current can flow normally through the wire. When the switch is opened, the magnetic field induces current into the coil until the field collapses, keeping the lamp illuminated for a short period of time.

Using the water analogy, the action of the inductor may be compared to the relationship between a water-wheel and the water channel in which its paddles sit. When the water starts to flow, the paddles will initially restrict the water until the wheel achieves the same speed as the flow. If the upstream flow is interrupted the wheel will continue to rotate until its speed reduces to that of the water.

By resisting the change in the flow of electrons when the switch is opened, the inductor can be said to be doing the same thing with the flow of electrons in the wire.

Effect of a magnetic field on a moving charge

Whereas **Oersted** had shown that an electric current moving in a wire gives rise to an artificial magnetic field, Faraday showed the opposite, that is, if a wire moves in a magnetic field an artificial charge, or voltage, will be created in that wire. This is the basis of electrical power generation, i.e. the movement of a conductor, or a number of conductors, through a magnetic field.

Moving charges, such as electrons, produce magnetic fields. When the electrons flow in the same direction (for example, as an electric current in a conductor), they generate a cylindrical magnetic field, the direction of which can be determined by the "right-hand grip rule". The field lines form concentric circles around the conductor however, it should be noted that the strength of the field decreases with distance from the source.

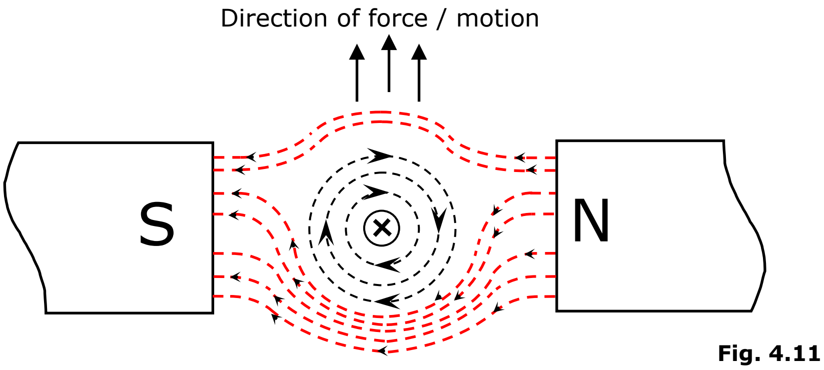

Fig. 4.11

Faraday introduced a useful analogy for visualising this, in the form of imaginary magnetic lines of force - those in the conductor form concentric circles round the conductor, and those in the externally applied magnetic field try to run in parallel lines above and below the conductor, (Fig. 4.11). If those above the conductor are in the opposite direction to that running round the conductor, they will be deflected so that they pass underneath the conductor (because magnetic lines of force cannot cross or run contrary to each other). Consequently, there will be a large number of magnetic field lines bunched together below the conductor, and a much smaller number above it. Since the magnetic field lines of force are no longer straight lines, but curved to run under the conductor, they are under tension (like stretched elastic bands), with energy stored up in the magnetic field. There is therefore a force that is being applied to the only moveable object in the system (the conductor) to move it upwards and out of the externally applied magnetic field.

If an external magnetic field is horizontally applied to the conductor, so that it crosses the flow of electrons, the two magnetic fields will interact resulting in a force that causes the motion of the conductor, (see Fig. 4.11, 4.12 and 4.13).

In order to ascertain the direction of the force (and the resulting motion), **Fleming** (1849-1945) devised a pair of visual mnemonics to demonstrate current flow and motion in a generator and the motion in an electric motor. These are commonly referred to as **Fleming's right-hand rule** (for generators) and **Fleming's left-hand rule** (for motors), (Fig. 4.13).

In order to ascertain the direction of the resulting force in a generator, **Flemings Right Hand Rule** applies (Fig. 4.12). If the right hand is held with the thumb, forefinger and centre finger extended mutually at right angles as shown in the figure, then, with the magnetic field in the direction (North to South) pointed by the forefinger and the motion of the conductor in the direction indicated by the thumb, the centre finger will point in the direction in which the e.m.f (i.e. voltage) is induced in that conductor (and in which current will flow when connected to a load).

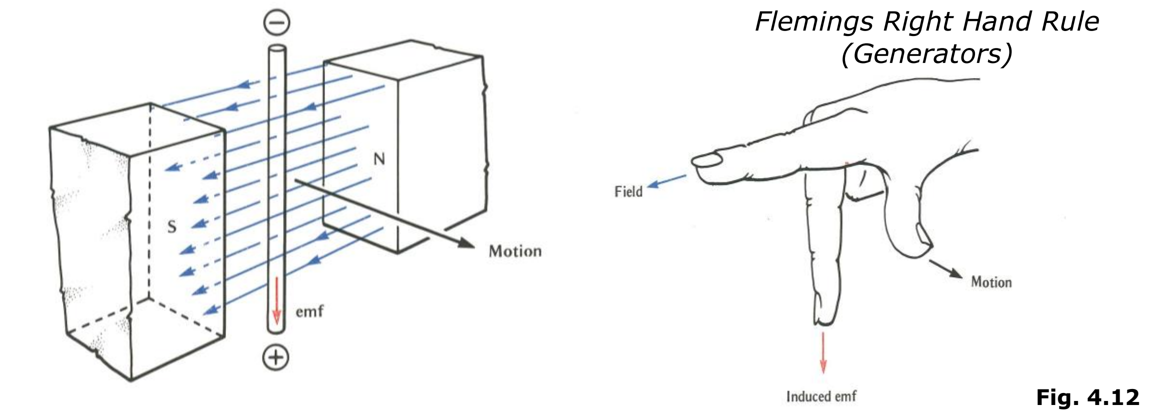

Fig. 4.12

The magnitude of the voltage induced in the moving conductor entirely depends on the strength of the magnetic field and the speed of movement.

Fig.'s 4.12 and 4.13 are similar in that they shows a conductor in a magnetic field, however in the later, a current flows from an external source and through the conductor.

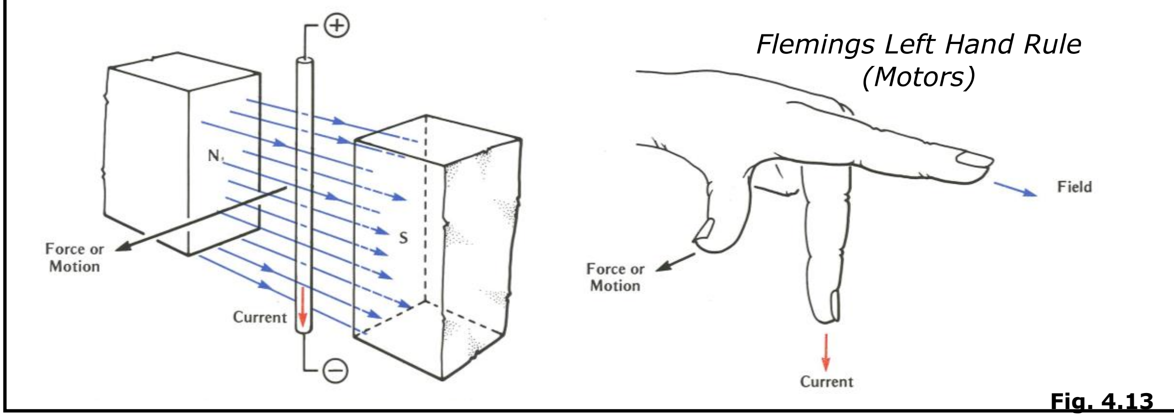

Fig. 4.13

The reaction between the current and the magnetic field through which it is passing causes a mechanical sideways force on the conductor. If the conductor is free to move, it will move sideways in the direction of the force. This is the basis of operation of all electric motors.

In order to ascertain the direction of the resulting force in a motor, **Flemings Left Hand Rule** applies (Fig. 4.13). If the left hand is held with the thumb, forefinger and centre finger extended mutually at right angles, then, with the magnetic field in the direction (North to South) pointed by the forefinger and the direction of current in the direction indicated by the centre finger, the thumb will point in the direction of the mechanical force on the conductor (or of its motion if it is free to move).

The magnitude of the force on the conductor entirely depends on the strength of the magnetic field and the strength of the current in the conductor.

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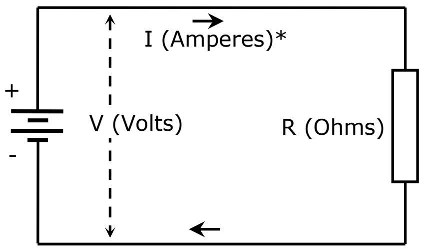
Ohm's Law

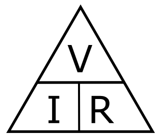
In 1827, **Georg Ohm** proposed a relationship between Resistance (R), Current (I) and Voltage (V). Now referred to as **Ohm's Law**, it states that, **"***the current through a conductor between two points is directly proportional to the potential difference across the two points and inversely proportional to the resistance between them*". This relationship is represented by the equation:

V (Volts) = I (Amperes) x R (Ohms)



(* Conventional current flow)

Alternatively, it can also be represented by Ohm's triangle:



A **hydraulic analogy** is frequently used to describe **Ohm's Law**. Water pressure, measured in Pascal's (or PSI), is the analog of voltage because establishing a water pressure difference between two points along a (horizontal) pipe causes water to flow. Water flow rate, as in litres per second, is the analog of current, as in Coulombs per second or Amperes. Finally, flow restrictors, such as an aperture placed in a pipe between points where the water pressure is measured, is the analog of resistance, measured in ohms.

The analogy follows that the rate of water flow through an aperture restrictor is proportional to the difference in water pressure across the restrictor. Similarly, the rate of flow of electrical charge, that is, the electric current, through an electrical resistor is proportional to the difference in voltage measured across the resistor.

In a simple **DC or AC circuit**, Power (P) = Current (I) x Voltage (V) however, in larger AC systems, this does not represent the actual work done because there is no allowance for the external effects that can increase the overall power used, e.g. the heat generated by the supply cable resistance etc. Using a combination of Ohms Law and the Power / Volts / Current relationship, these losses can be calculated using the formulae:

$$P = V.I \quad \text{and} \quad V = I.R$$

$$P = (I.R).I \quad \text{therefore} \quad P = I^2.R$$

In more complex **AC circuits**, the current and voltage are likely to be out-of-phase due to a combination of **resistance, capacitance,** and **inductance** which further "impedes" the flow of current. This effect, referred to as **impedance**, is further complicated any variation in the frequency. **Impedance** is measured in ohms and is characterised by the letter "**Z**".

All of these terms are discussed further in these notes.

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The Power Circle

The formulae for simple calculations can be remembered using the diagram below (Fig.4.20).

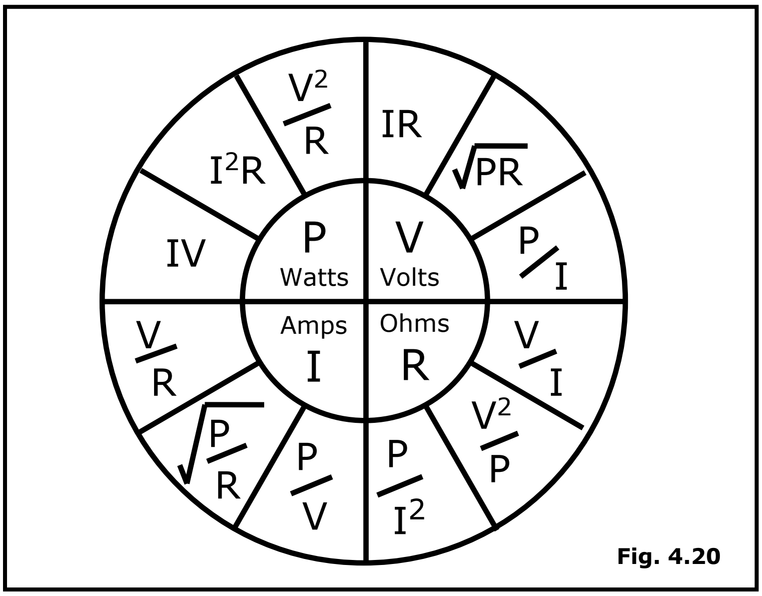

Fig. 4.20

Kirchoff's Laws

An analysis of current and voltage in electrical circuits, or networks, was described by **Gustav Kirchhoff** in 1845 and summarised into two "laws":

- **Kirchhoff's Law of Current** – "*at any junction in an electrical circuit, the sum of currents flowing into that junction is equal to the sum of currents flowing out of that junction. The algebraic sum of these currents must, therefore, be zero*".
- **Kirchhoff's Law of Voltage** – "*the directed sum of the electrical potential differences (voltage) around any closed circuit is zero*".

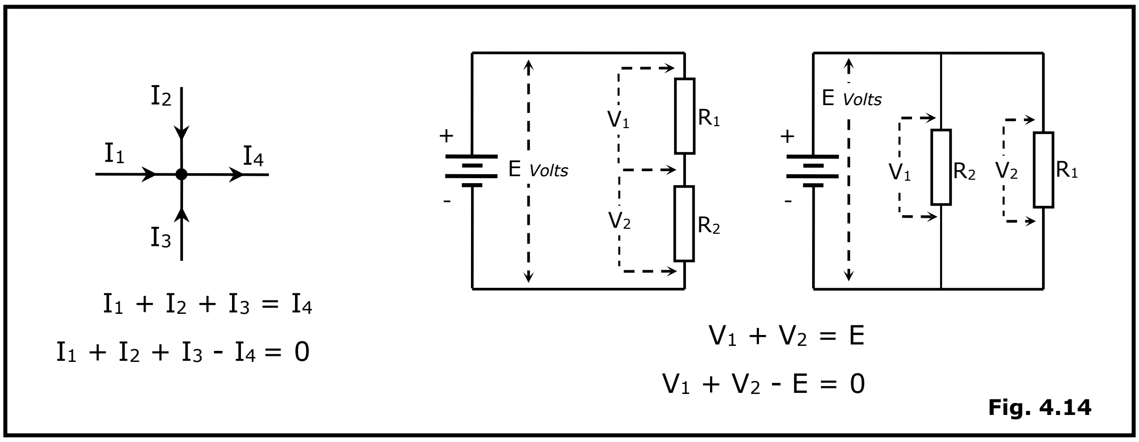

Fig. 4.14

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Resistors

A resistor is a linear passive* two-terminal electrical component that provides electrical resistance to a circuit hence controlling the current flow. Two of the most common type of resistor are shown in Fig. 4.15 (below).

The wire-wound resistor consists of high-resistivity wire wound on a ceramic former and welded to end-connections. This is then covered with a vitreous enamel that has good insulating properties, is moisture-resistant, and provides chemical and mechanical protection.

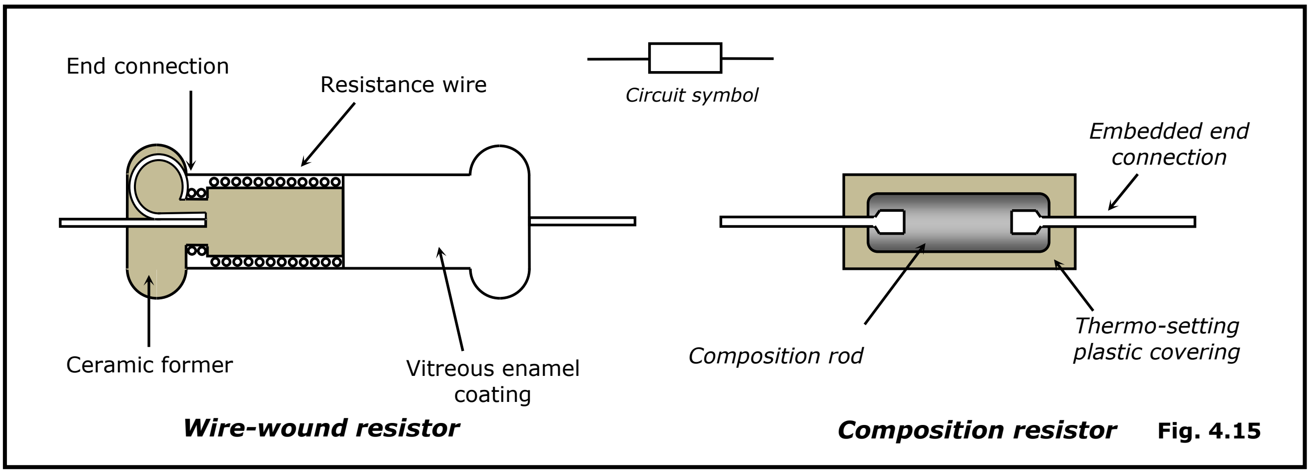

Fig. 4.15

* *Their resistance will be assumed to be constant when the temperature is constant*

The composition resistor consists of a resistive element made from carbon black, a resin binding agent, and a filling. The element is then covered with a plastic material that has similar properties to that used to cover the wire-wound resistor.

Identification of the value of a resistor is achieved by the coloured rings painted around it. These are linked to a colour code system as shown below.

4-band Resistor		***Code***	
Band 1	1st Number	*Digit*	*Colour*
Band 2	2nd Number	0	Black
Band 3	Multiplier	1	Brown
Band 4	Tolerance	2	Red
		3	Orange
		4	Yellow
5-band Resistor *(Bands 1 & 2 as 4-Band)*		5	Green
Band 3	3rd Number	6	Blue
Bands 4 & 5	As Bands 3 & 4 above	7	Violet
		8	Grey
		9	White
6-band Resistor *(Bands 1-3 as 5-Band)*		*Tolerance*	
		2%	Red
Band 6	Temp. coefficient	5%	Gold
		10%	Silver

Prefix	***Name***	***Multiplier***
T	Tera	X 10^{12}
G	Giga	X 10^{9}
M	Mega	X 10^{6}
K	Kilo	X 10^{3}
m	milli	X 10^{-3}
U / µ	micro	X 10^{-6}
N	nano	X 10^{-9}
p	pico	X 10^{-12}

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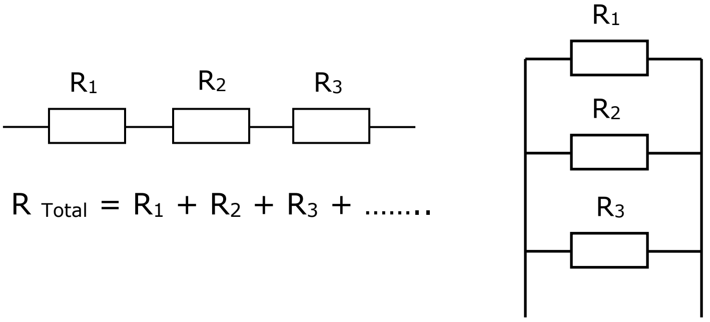
In an electrical circuit, resistors may be connected in series or parallel. For mathematical reasons it may necessary to calculate their total values hence the following applies, (Fig. 4.16).



$$R_{Total} = R_1 + R_2 + R_3 + \ldots\ldots.$$

$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots.$$

For 2 resistors in parallel only:

$$R_{Total} = \frac{R_1 \times R_2}{R_1 + R_2}$$

Series resistors ***Parallel resistors*** **Fig. 4.16**

It is not practical to manufacture resistors to every possible value hence "*preferred values*" are used. These values are such that, when the spread of tolerance limits is considered, the entire range of resistance can be achieved by combinations of series and parallel connections.

Capacitors

In Fig. 4.17 (below), two plates are connected to a source of potential separated by an insulating medium (air). The plate connected to the positive terminal will lose electrons as they are attracted to the source, resulting in an increased positive charge. The plate connected to the negative terminal will gain electrons as they are repelled from the source resulting in an increased negative charge. As the charge on the plates increases the current flow decays until the potential difference between them is equivalent to that across the source, at which point the current flow will be zero. When the source is removed the charge is released in an attempt to maintain the potential difference across it however it eventually decays to zero.

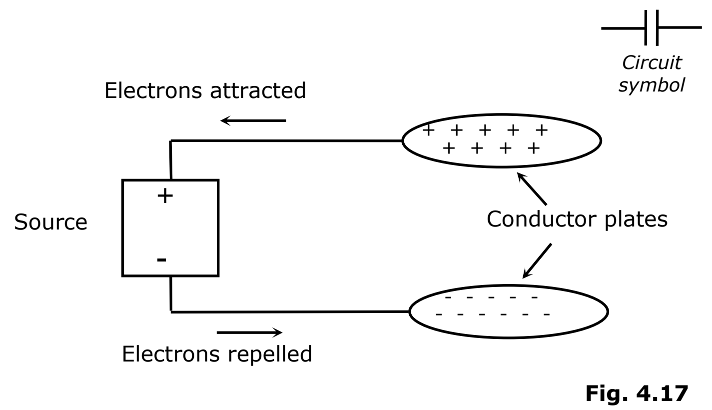


Fig. 4.17

The construction of a capacitor consists of two plates separated by an insulator, or **dielectric**, the purpose of which is to increase the level of capacitance.

Capacitors are assembled by rolling, folding or pressing, the materials depending on the property of the dielectric and the intended duty, (Fig. 4.18, *overleaf*). There are numerous types available for different applications and are usually referred to by the type of dielectric employed. These include metallised film, polyester film, polystyrene, mica, ceramic, and tantalum.

In Fig. 4.18 (*below*) the level of the capacitance is determined by the surface area (*S*) of the opposing electrode plates, the distance (*d*) between the electrodes, and the relative dielectric constant (ε^r) of the dielectric (insulator) between the electrodes.

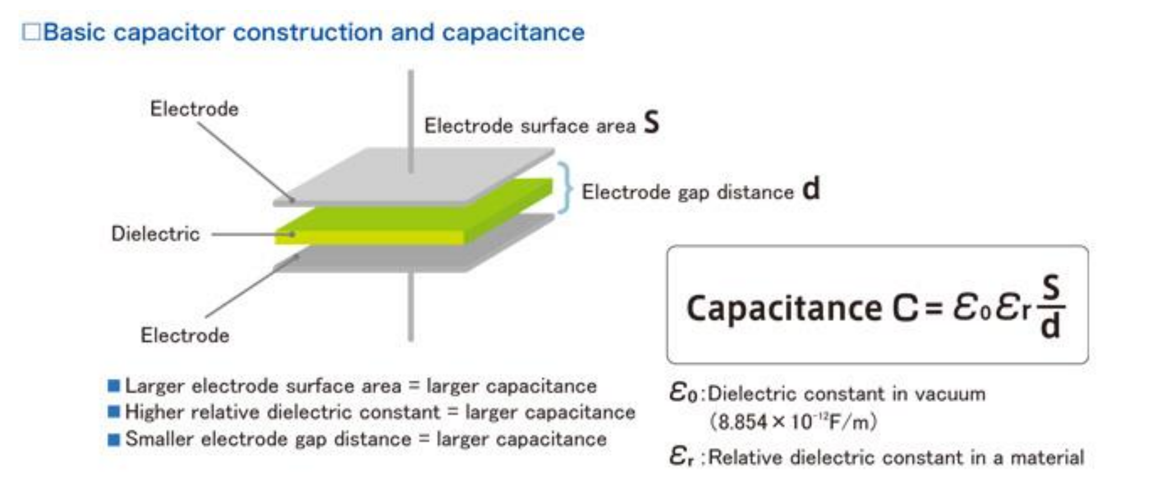


Fig. 4.18

In Fig. 4.19 (below) two plates with area *(A)* are separated by distance *(d)* with a dielectric material. When a charge of ±*Q* is applied across the plates an electric field *(E)* is generated in the region between them. The dielectric material becomes polarised and the resulting field opposes the field of charge on the plates, reducing the total internal field, and increasing the capacitance.

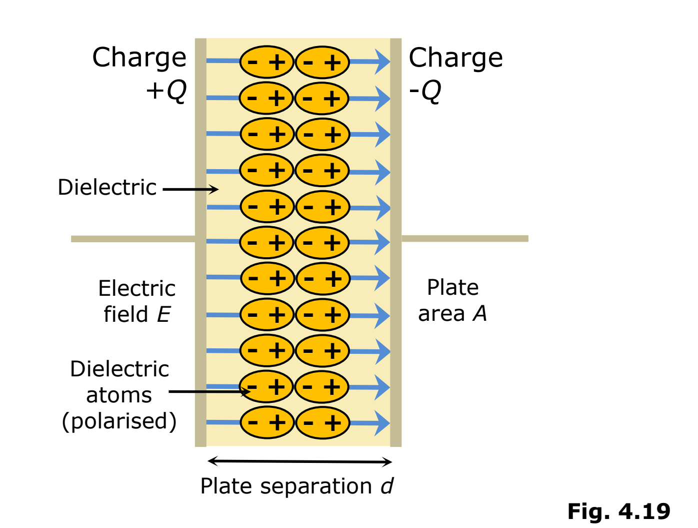


Fig. 4.19

The dielectric constant is the ratio of electric flux to charge, or **permittivity**, of the substance, to the permittivity of free space. It is an expression of the extent to which a material concentrates electric flux, and is the electrical equivalent of **relative magnetic permeability**.

As the dielectric constant increases, the electric flux density increases, (if other factors remain unchanged). This enables objects of a given size, such as sets of metal plates, to hold their electric charge for longer periods of time, and/or to hold large quantities of charge. Materials with high dielectric constants are useful in the manufacture of high-value capacitors.

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To obtain the correct values capacitors may be connected in series or parallel hence, it may necessary to calculate their total values as shown, (Fig. 4.20).

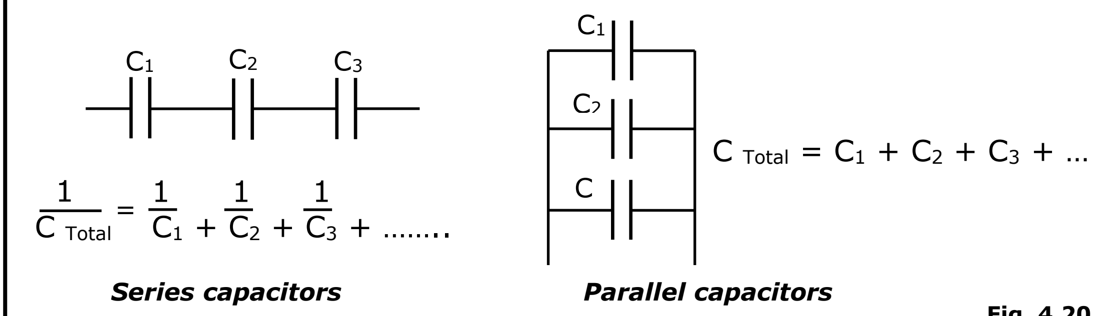

Fig. 4.20

Within a circuit, the level of charge (Q) a capacitor accumulates is determined by the current (I)* and time (t) hence : ***Charge (Q) = Current (I) x Time (t) or Q = I.t***

* the current decays over the time hence an average value must be taken.

The charge on a capacitor is directly proportional to the voltage across it hence:

$$Q \propto V \text{ or } Q = k.V$$

Where k is the constant of proportionality, otherwise termed as the capacitance (C) hence:

$$\boldsymbol{Q = C.V}$$

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Resistivity

Not to be confused with the resistance of a component, "*the value of resistivity is that resistance of a unit cube of a material measured between opposite faces*": the measurement unit is ohms/metre (***Ω/m***) and is symbolised by the Greek letter **ρ** (rho). The "*material*" is usually a conductor, the resistivity value (resistance per metre) of which may be found in tables which are used to calculate the overall resistance of a cable and/or load. Consideration must also be given to the effects of temperature on the material resistance (the resistance of pure metals increases as the temperature increases, whereas it has the opposite effect with carbon and insulating materials).

In a hydraulic analogy, increasing the cross-sectional area of a pipe reduces its resistance to flow, and increasing the length increases resistance to flow (and pressure drop for a given flow).

There are four elements to consider when determining the resistivity of a conductor; the type of material, it's cross-sectional area, it's length, and, when applicable, it's temperature coefficient. The relationship between three of these elements is:

$$R = \rho.\frac{\ell}{A}$$

Where:

R is the total resistivity of the material (ohms, Ω)

ρ is the material resistivity of a uniform specimen of the material (ohms/metre, Ω/m)

ℓ is the length of the piece of material (metres, m)

A is the cross-sectional area of the material (square metres, m^2)

In summary, the resistance of a material will increase with the length, but decreases with greater cross-sectional area. This resistance is measured in ohms. The Length over Cross-sectional Area has units of 1/distance. To conclude with ohms, resistivity must be in the units of "ohms × distance" (SI ohm-metre, US ohm-inch).

- A conductor such as a metal has high conductivity and a low resistivity.
- An insulator like glass has low conductivity and a high resistivity.

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Inductance

Faraday's Law of Electromagnetic Induction states that, if a conductor moves in a magnetic field, an e.m.f (or voltage) is induced in it. This is equally true if the magnetic field moves past a stationary conductor because the movement implies change. Faraday's Law, therefore, must also apply to any conductor around which the field changes, i.e. grows or decreases.

In Fig. 4.21(a), (below), a source of potential is connected to a coil, through which a current flows, hence there is a magnetic field concentrated along its axis, (circuit is represented diagrammatically in 4.21(b)). If the current started to **change, e.g.** increase, the magnetic field through all the turns of the coil would also be increasing. This is, therefore, a changing field which, by Faraday's Law, induces in each turn an e.m.f (or voltage), the direction of which would be to oppose the change, i.e. to try to prevent the current in this case increasing. The result is shown in Fig. 4.21(c), and explained as follows.

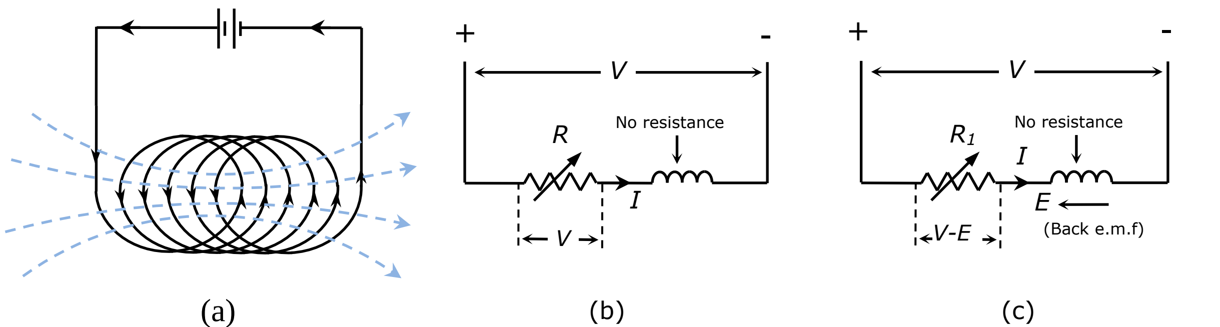

Fig. 4.21

In Fig. 4.21(b), a voltage *V* is applied through a variable resistance *R* to the coil. For any given setting of *R* the current *I* through the coil (assumed to have no resistance of its own) is given by Ohm's Law hence:

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

In Fig. 4.21(c), *R* is adjusted (decreased) to value R_1 in order to increase the value of *I* in the coil. The increased current gives rise to a stronger field (increase in magnetic flux) and an increase in the induced voltage *E* in the coil in a direction opposed to *V*. This induced voltage *E* is called the '**back-e.m.f**' of the coil, consequently the net voltage appearing across R_1 is no longer *V* but is now (*V-E*), hence, by Ohm's Law :

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

Although *R* has been reduced to R_1, *I* is not proportionately higher because *E* reduces the effective voltage hence Ohm's Law does not appear to apply in this case.

The value of back-e.m.f, *E, is* dependent upon the rate-of-change of current vs. time through the coil and on the physical construction of the coil, including the number of turns. Mathematically this is represented as:

$$E = -L\frac{di}{dt}$$

Where:

- $\frac{di}{dt}$ is the rate of change of current (positive if increasing) and time
- ***L*** is the value of inductance in the coil.

Note: If an iron core is present, the inductance L increases considerably, (the minus sign indicates that its direction opposes the increasing current, so that E is then negative).

A coil carrying electric current, especially one with an iron core, becomes magnetised, and as an electromagnet, it is a store of energy. The energy stored in a coil of inductance *L* (Henrys) and carrying a current *I* (Amperes) is :

$$\frac{1}{2} L I^2 \text{ (joules)}$$

All circuits possess inductance however, if it, or the circuit current, is high, problems occur when the current is interrupted, e.g. operating a switch. When the current is suddenly reduced, the inductance will induce a large voltage in opposition to this change, the result of which may be a damaging arc across the switch contacts as they open. The switching, therefore, is never instantaneous, taking a few milli or micro seconds for the energy to be released.

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Section 5 - Generation & Distribution

Simple Generation of an e.m.f

An e.m.f. (voltage) can be generated in a coil if either the coil or the field is rotated in relation to the other at a constant speed. The simplified diagram below, (Fig. 5.1), shows how this may be achieved as the coil *ab* rotates through the field between the magnet poles (N and S).

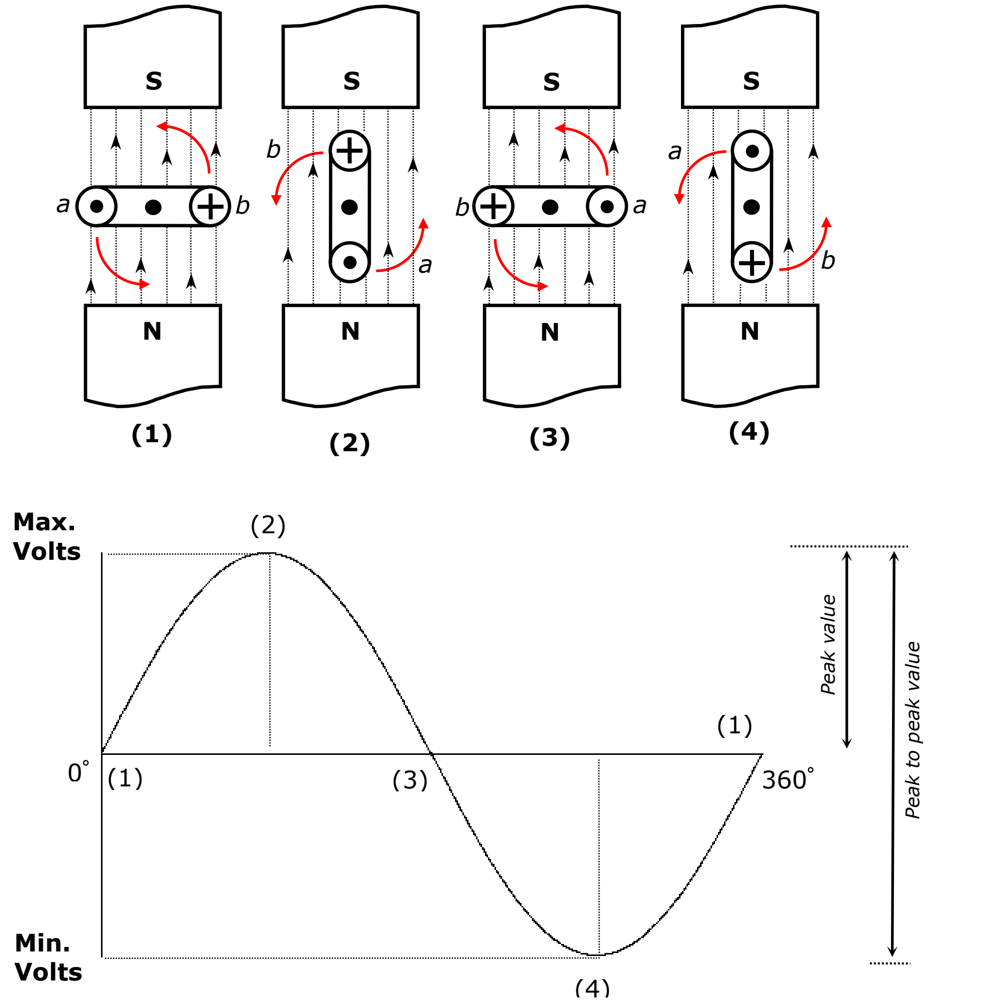

Fig. 5.1

The dotted lines and associated arrows represent the lines and direction of magnetic flux. As the coil *ab* rotates, the generated voltage can be represented as a sine wave as shown (Fig. 3.1). Subsequent revolutions of the coil merely produce a repetition of the voltage wave and each repetition, recurring at regular intervals, is termed a *cycle*. The number of cycles that occur in one second is termed the ***frequency***, the measurement unit of which is the ***Hertz***. The time required to complete one cycle of a waveform is the ***period***, which is also referred to as the ***wavelength***. The period (t) of a sine wave is inversely proportional to the frequency, i.e. the higher the frequency (f), the shorter the period and vice versa. This may be represented as :

$$t = \frac{1}{f} \quad \text{and} \quad f = \frac{1}{t}$$

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The **peak value** of the waveform is the maximum value reached during one half-cycle of the sine wave. The **peak-to-peak value** is the maximum value reached during the positive half-cycle to the maximum value reached during the negative half-cycle of the sine wave. The peak-to-peak value is twice that of the peak value, (see Fig. 3.1).

The **instantaneous value** of a sine wave is the value of voltage or current at one particular instant of time. There are an infinite number of instantaneous values between zero and the peak value.

The **average value** of a sine wave is the average of all the instantaneous values during one half-cycle. The average value is equal to 0.636 of the peak value. The formulas for average voltage and average current are:

$$E_{avg} = 0.636 \times E_{max} \quad \text{and} \quad I_{avg} = 0.636 \times I_{max}$$

Remember, the average value (E_{avg} or I_{avg}) is for one half-cycle only. The average value of a complete sine wave is zero.

The **effective value** 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 and is also referred to as the **root mean square** or **rms value**.

Since an alternating current having a maximum value of 1 ampere does not maintain a constant value, it will not produce as much heat in the resistance as will a direct current of 1 ampere. The diagram below, (Fig. 3.4), compares the heating effect of 1 ampere of dc to the heating effect of 1 ampere of ac.

The **rms value** of a current or voltage may be determined by taking equally spaced instantaneous values of the sine wave and extracting the square root of the average of the sum of these values hence the term "*Root-Mean-Square*".

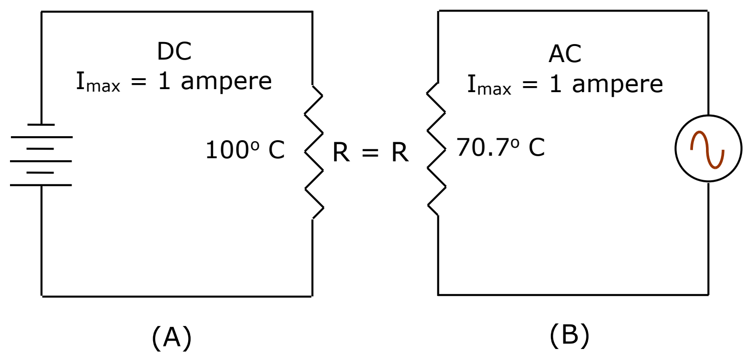

Fig. 5.2

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Examine views (A) and (B) of Fig. 3:4 and notice that the heat (70.7°C) produced by 1 ampere of alternating current (that is, an ac with a maximum value of 1 ampere) is only 70.7% of the heat

(100°C) produced by 1 ampere of direct current. Mathematically;

$$\frac{\text{The heating effect of 1 max a.c. ampere}}{\text{The heating effect of 1 max d.c. ampere}} = \frac{70.7^{o}C}{100^{o}C} = 0.707$$

For a sine wave, the RMS value is, therefore, approximately 0.707 of its peak value. The formulas for effective and maximum values of voltage and current are, therefore:

$$E_{eff} = 0.707 \times E_{max}$$

$$E_{max} = 1.414 \times E_{eff}$$

$$I_{eff} = 0.707 \times I_{max}$$

$$I_{max} = 1.414 \times I_{eff}$$

Note : AC values must be consistent, i.e. when calculating an effective value, all other values in the equation must be effective values. Similarly, when calculating an average value, all other values must be average values.

Single Phase Generation

On the previous pages it was seen that a coil rotating in a magnetic field produces an alternating voltage. To produce very high voltages in this way would require a large number of turns on the coil and it would also be necessary to have considerable insulation on the coil windings. In order to overcome this, and many other difficulties, it is more practical to rotate the magnetic field inside one or more stationary coils.

In order to achieve this, a coil is wound around the steel core of the rotor and is magnetised by an external d.c. supply via slip-rings, (a small d.c. generator is usually coupled to the rotor shaft to provide this supply and is commonly known as the exciter).

The diagram below (Fig.5.3) demonstrates how single-phase voltage may be generated, (the positions A-D relate to the position of the N pole of the electromagnet).

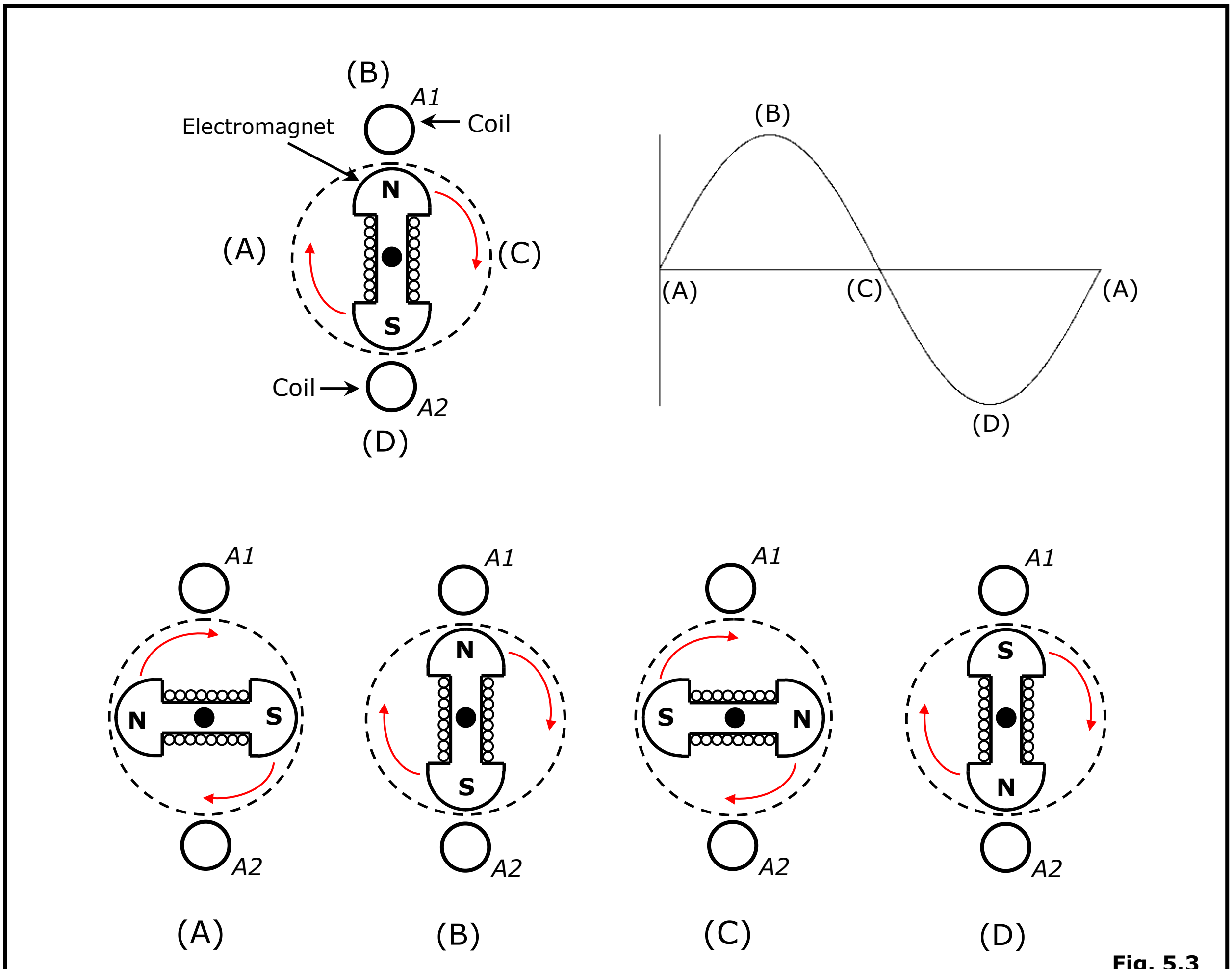

Fig. 5.3

Three Phase Generation

A three-phase electrical supply allows industry to be more cost-efficient, both in terms of the energy consumed and equipment maintenance. Without it, the consumer demand for power would result in much larger supply cables, increased costs (to the supplier and consumer) and less efficient and less reliable equipment.

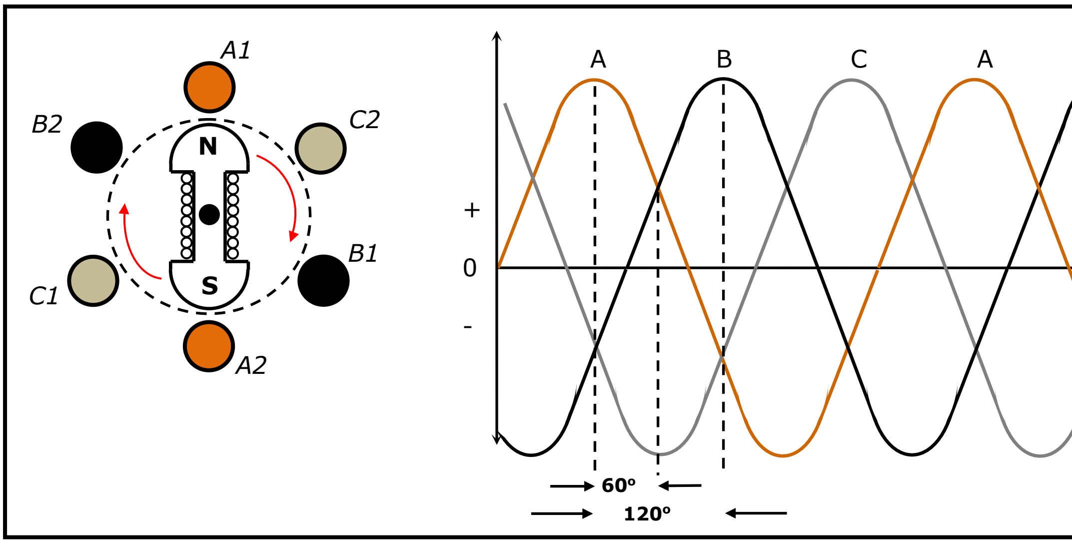

Fig. 5.4

In the generator shown in Fig. 5.4, two more coils, *B1-B2* and *C1-C2*, are added and spaced 120° apart from coil *A1-A2,* (the colours represent the Regulatory phase identification colours for the UK and Europe). As the magnet rotates voltage is generated in each coil the peaks of which are at 120° intervals as shown in the diagram.

Why three phases? Why not one, two, or four? In single-phase and dual-phase power, there are 100 moments per second when a sine wave is crossing zero volts and in 3-phase power this increases to 150 moments per second. Within the realms of the supply and manufacturing industries, increasing this to four phases would not significantly improve things and electrical systems would require the addition of a fourth wire, significantly increasing costs hence 3-phase is the most effective.

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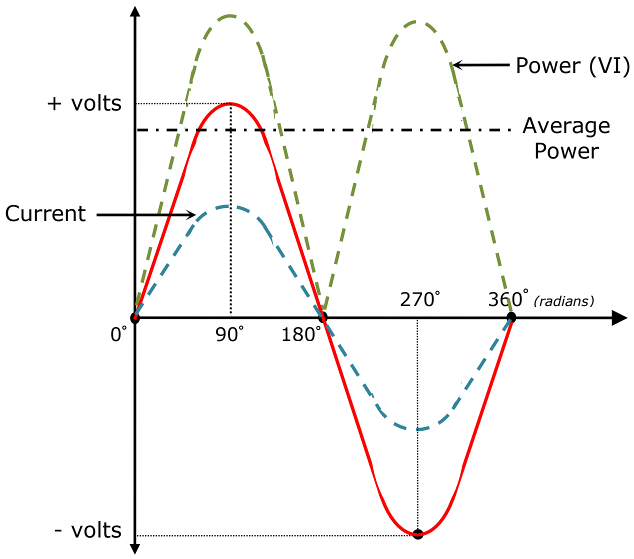
Effect of Load on Supply



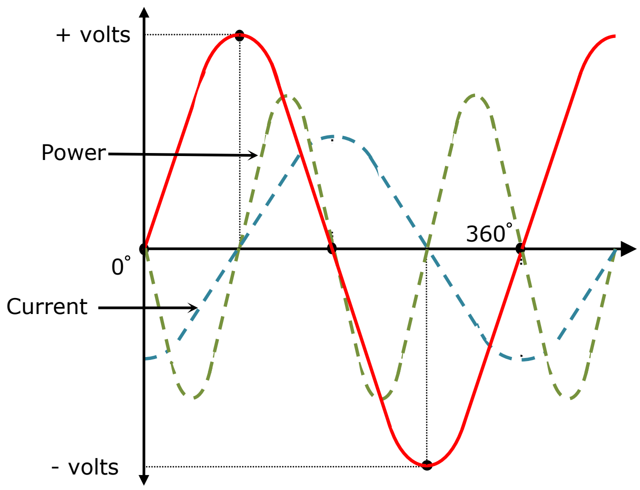
Resistive load
Current in-phase with voltage

When an alternating voltage (sine wave) is applied to a **resistor**, the resulting current is also an alternating sine wave. This follows Ohm's law which states that current is directly proportional to the applied voltage. Both are represented on a single axis in the diagram (left), which shows that the voltage and the resulting current are in phase with one another, i.e. the two waveforms achieve their maximum and minimum points at the same time and in the same direction.

The resulting power is the product of the voltage (V) and the current (I).

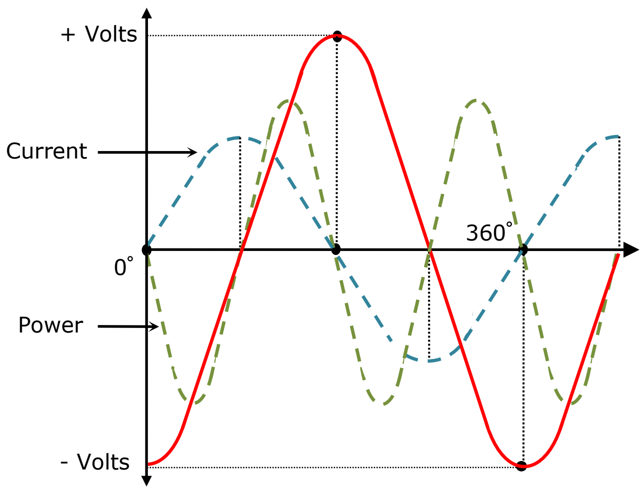
When a voltage is applied to an **inductor** it resists the change in current by producing a reverse electromotive force or e.m.f, or back e.m.f, which prevents current from flowing for the first ¼ cycle.

Despite the back e.m.f trying to limit it, the current continues to increase in an attempt to "catch up" to the voltage. As the voltage peaks and starts to decline, the magnetic field that was building as the voltage increased (and was opposing the current flow at the same time) will begin to collapse. The collapsing field produces an e.m.f that will attempt to maintain the current flow; hence the current will continue to increase while the voltage is decreasing. The current finally peaks a ¼ cycle (90°) "out-of-phase" with the voltage before starting its decline.



Inductive load
Currents lags voltage

The moment a voltage is applied to a **capacitor**, current flows and a charge (voltage) begins to build due to the movement of electrons away from the positive plate and the accumulating electrons on the negative plate. The moving electrons (current) begin to flow before the voltage is developed between the plates hence the current is said to lead the voltage, (*see diagram*).



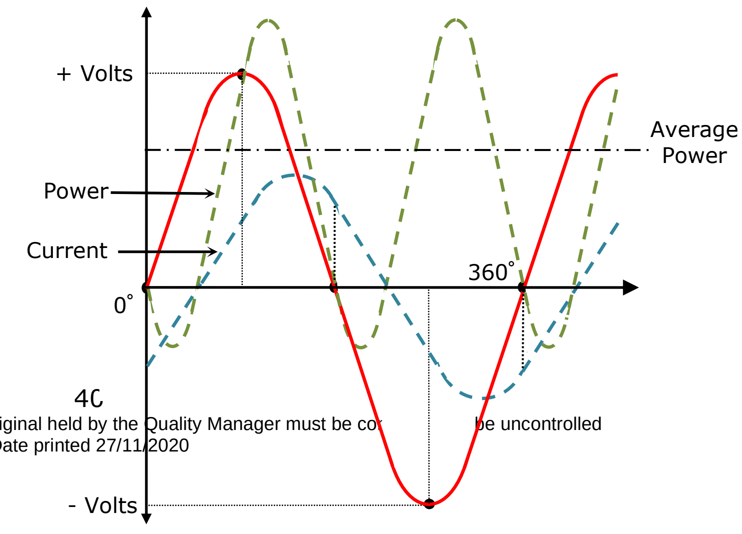
Capacitive load
Currents leads voltage

In a **capacitor**, the current flowing in it depends on the voltage difference across it. An alternating supply allows it to charge when the voltage is increasing above zero, and discharge when the voltage is reducing towards zero. Because a capacitor has almost no internal resistance, and most loads that it is connected to have only very small resistances in series with the capacitor, the charging and discharging currents largely depend on the rate at which the voltage is changing.

When the voltage is zero, the rate-of-change of voltage is very high (the sine-wave is at its steepest), so the current is also very high. At the peak of the voltage waveform, the rate-of-change of voltage is zero hence the current is also zero. Since the maximum positive current occurs when the voltage is passing through zero, moving into its positive cycle, and the maximum negative current happens when the voltage is passing through zero, moving into its negative cycle, the current peaks occur ¼ cycle (90º) before the voltage peaks hence the current "leads" the voltage.

The diagrams demonstrate that the average power over a complete cycle in inductive and capacitive loads is zero due to the phase angle between the voltage and the current.

In reality, the load is a combination of all three scenarios, i.e. resistance and inductive / capacitive reactance, the result is a reduced phase angle and a considerable improvement in the average power.



Resistive & Reactive load

It is accepted that the voltage is the reference quantity hence the following mnemonic may be used to indicate the phase relationship between the current and voltage

E L I - the Voltage (***E***) in **Inductive** circuits (***L***), leads the current (***I***)

I C E - the Current (***I***) in **Capacitive** circuits (***C***) leads the Voltage (***E***)

The product of the voltage and current is termed the **apparent power**. Denoted as "***S***" it is measured in Volt Amperes hence :

$$S = V.I$$

Because of the continuous fluctuation, the power in an ac circuit is taken to be the average value of the waveform. This is measured over a complete cycle and is referred to as the **active power**. Denoted as "***P***" and measured in **Watts**, (**W**), it is the product of the instantaneous values of voltage (***V***) and current (***I***), and the Cosine of the phase angle between them, referred to as Thetta (**θ**). In mathematical terms:

$$P = V.I.\cos\theta \quad \text{and} \quad P = S.\cos\theta$$

The cosine value of **θ** is between 1, (zero degree angle of difference), and 0, (90^o angle of difference). It follows therefore, that;

Active power, (*P*) ≤ *V.I*

The ratio of active power (*P*) to the apparent power (*S*) is termed the ***Power Factor**, i.e.*

$$\frac{\text{Active power } P \text{ (Watts)}}{\text{Apparent power } S \text{ (Volt Amperes)}} = \text{Power Factor } (\cos\theta)$$

$$\cos\theta = \frac{P}{S} = \frac{P}{VI}$$

Active Power (*P*) = Apparent Power (*S*) x Power Factor (Cos θ)

For a purely resistive circuit, the power factor, (Cos θ), is 1, i.e. the voltage and current have a zero degree angle of difference hence they are in **unity** - the cosine of 0 is 1.

For a purely inductive or purely capacitive circuit, the power factor, (Cos θ), is 0, i.e. the voltage and current have a 90^o angle of difference - the cosine of 90^o is 0.

Distribution

Power stations generate electricity at 25-33kV (depending upon the generator), and then step-up the voltage via transformers for transmission to the National Grid. Utilising both overhead and underground cables, electricity is supplied to the whole of the country at potentials ranging from 132 to 400kV, (using these extra-high voltages allows distribution via non-insulated overhead cables and are, subsequently, of a much smaller cross-sectional area).

Electricity companies then purchase the power from the network and sell it to the consumer after reducing the voltage to 11kV for industry and 400v for the domestic consumer. The supply to the ordinary household is either by an overhead insulated feed-cable or by an armoured or sheathed cable at 230v (single phase and neutral). The diagram below (Fig. 5.5) shows a typical Grid supply system from the generating plant to the consumer.

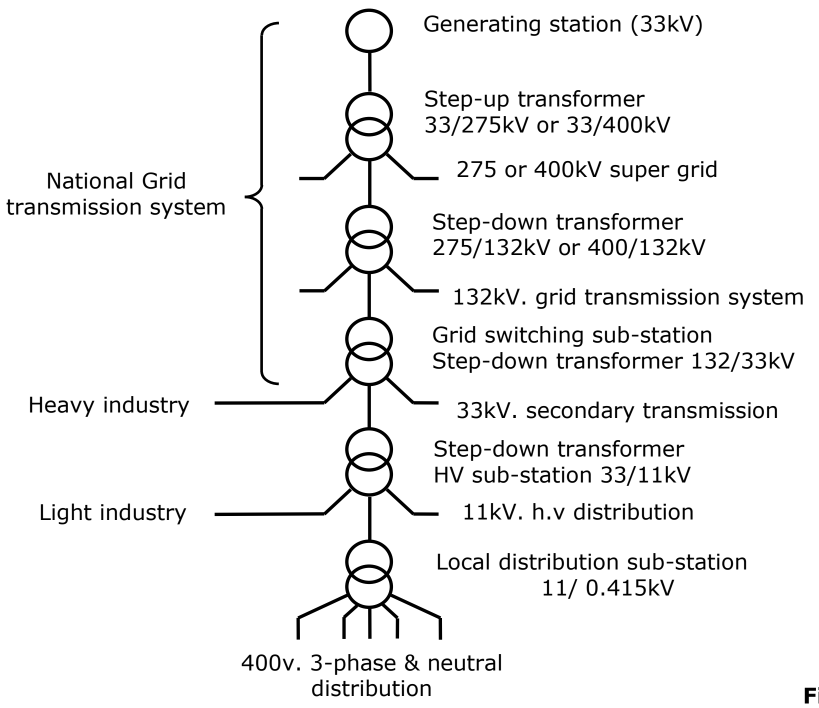


Fig. 5.5

The advantages of the Grid system are as follows:-

a) the whole country is linked to a common extra-high-voltage network
b) supply frequency and voltage is standardised
c) control of the system is centralised enabling generating plant to be more efficient
d) standby plant and spares are kept to a minimum
e) loss of supply due to breakdown is minimised
f) electricity can be supplied at no extra cost to isolated communities

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Section 6 - Electrical Safety

What Is Electric Shock?

Each movement of the human body, both conscious and unconscious, is produced by muscles reacting to minute electrical signals generated in the brain. These signals are distributed to the chosen muscles by the individual nerves, or "conductors", of the nervous system. If a large current, i.e. larger than that normally carried by the nervous system, is forced through the body, the muscles react in an uncontrolled manner. This experience is commonly called an electric shock. The muscle reaction is often so unnaturally strong that the victim may suffer the effect of being unable to counteract it. One such example is the effect of being unable to release a live conductor.

If the current is strong enough, it is likely to interrupt signals to and from the brain, and destroy or cause temporary paralysis of the cells which normally generate the body's controlling signals. The result of this destruction will almost certainly be fatal because the vital organs, notably the lungs and heart muscles, will cease to operate. Even temporary paralysis can prove fatal due to the brains temporary inability to transmit signals to the lungs which may result in death by asphyxiation (suffocation).

In the diagram below, (Fig. 6.1), a faulty earth terminal in the plug has resulted in the electrical appliance becoming "live".

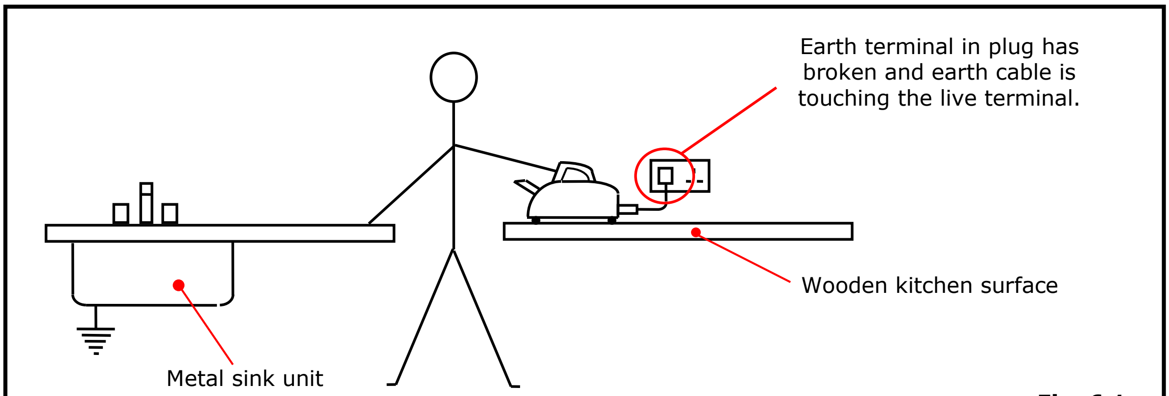

Fig. 6.1

Due to the broken earth cable touching the live conductor, the metal casing of the appliance has become "live". If an individual should inadvertently touch the appliance and an earthed metal surface, as in the diagram above, then the individual will receive an electric shock.

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Minimising the Risk

The risk of electric shock from an appliance can be reduced by taking the following steps :-

- use an appliance with an all insulated outer enclosure
- make sure that the appliance has a correctly rated fuse in the plug
- visually inspect all cables before use and periodically check all termination's
- install fault-sensitive circuit breakers at the consumer unit to limit the duration of the fault
- earth all exposed metal parts
- use appliances that operate from a reduced voltage, e.g. 50v. or 110v (55v. to earth) ; (Fig. 6.3)

Mains Voltage Supply via a Standard Transformer

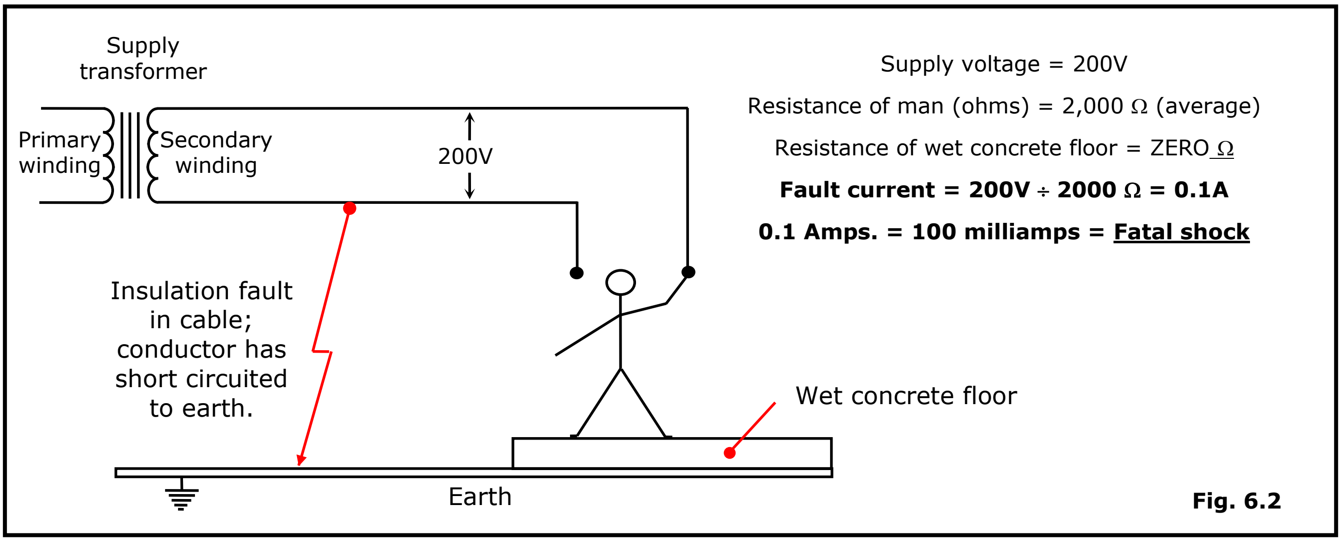

Fig. 6.2

Reduced Voltage Supply via a Centre Tapped Transformer

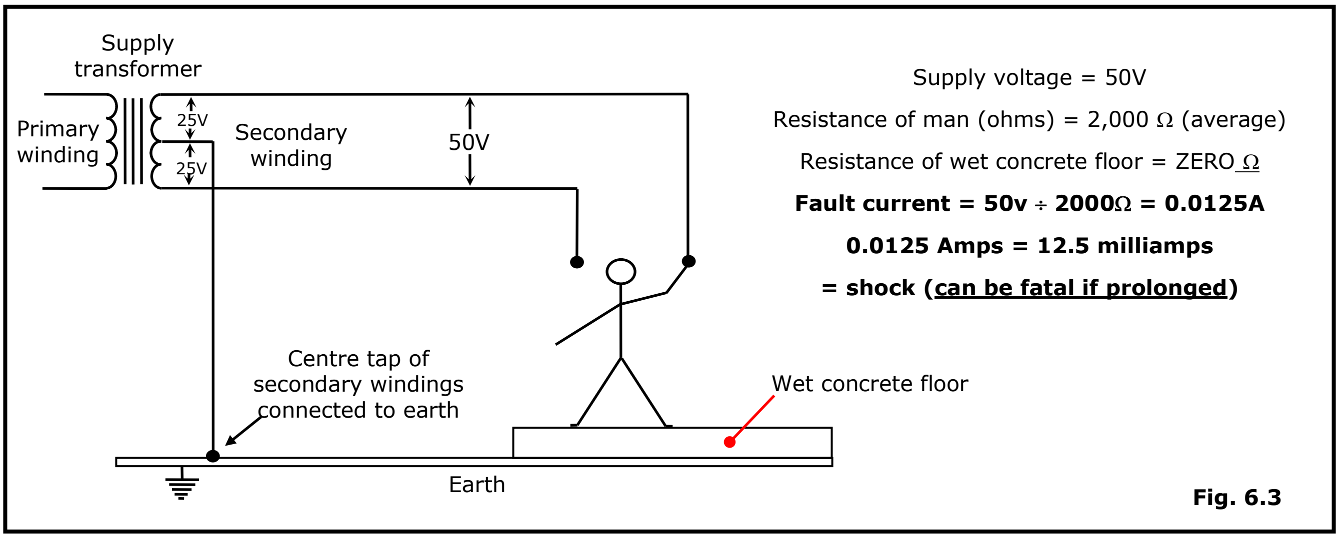

Fig. 6.3

Shock Path Resistance

The human body is composed largely of water and, therefore, has a very low resistance. The skin however, has a much higher resistance (provided it is not wet or damaged, e.g. burned), thus the majority of the resistance to the passage of current through the body is at the points of entry and exit through the skin. It should be noted that shock victim infrequently has bare feet and therefore, the resistance of footwear and floor coverings will, in many cases, increase the total resistance and limit the shock current to a lower level.

There are no reliable figures for shock current effects because they differ from person to person however, in general terms, a current over one milliampere (mA) will give a sensation of shock and a current approaching 100mA is likely to be fatal, particularly if it passes through the heart or the lungs.

Protection against electric shock

Basic Protection: Protection against electric shock under fault free conditions.

Note: For low voltage installations, systems and equipment, basic protection generally corresponds to protection against direct contact, that is "contact of persons or livestock with live parts".

Fault Protection: Protection against electric shock under single fault conditions.

Note: For low voltage installations, systems and equipment, fault protection generally corresponds to protection against indirect contact, mainly with regard to failure of basic insulation. Indirect contact is "contact of persons or livestock with exposed conductive parts which have become live under fault conditions".

In order to prevent indirect contact all exposed metal that is not normally live, e.g. central heating radiators, is connected, or **bonded**, to earth at the consumer unit via a separate earth cable. This is known as **equipotential bonding** and is further described in Section 7.

Effects of Electric Shock

The effect of a shock current flowing through the body from hand-held equipment is generally as shown in the table below.

Current (mA.)	Effect
0.9 - 1.2	Current just perceptible
1.2 - 1.6	Tickling sensation in the hands
1.6 - 2.2	Sensation that the hand has gone to sleep
2.2 - 2.8	Same sensation perceptible in the wrist
2.8 - 3.5	Slight stiffening of the hand
3.4 - 4.5	Considerable stiffening of the lower arm muscles
4.0 - 5.0	Feeling of cramp in the lower arm and slight trembling of the hands
5.0 - 9.0	Unpleasant cramping of the lower arm; limits of inability to “let-go” are reached
15 - 20	Release is impossible; cannot be tolerated for more than 15 minutes
20 - 40	Serious and very painful contraction of the muscles; breathing becomes increasingly difficult but resumes if current is interrupted
50 - 100	Ventricular fibrillation; a state of the heart leading directly to death
100 - 200	Serious burns and muscular contractions -the thoracic muscles constrict the heart thus inhibiting its action during shock (ventricular fibrillation is thereby prevented)

At very high voltages serious injury is often prevented because the victim experiences such a violent muscular contraction that they are thrown clear of the contact area. At lower voltages the muscle contractions is likely to be much less violent however the victim may not be able to release the contact area hence the duration of the shock could be fatal.

Burns

Electrical burns are frequently found at the points of entry and exit of the fault current. They may also be caused by contact, or near-contact, with an electrical arc or electromagnetic radiation.

Electric Shock Action

Before attempting to approach a casualty make sure that it is safe to do so by ensuring they are removed from the danger either by switching off the supply or by using an insulated item to physically force them away from the source.

- do not expose yourself to danger at any time
- do not touch any burns on the casualty’s body
- send for medical assistance immediately, even if it means leaving the casualty on their own for a short period of time
- if the casualty is not breathing and has no pulse, get some assistance immediately
- artificial ventilation and/or Cardiac Pulmonary Resuscitation should only be administered by <u>trained personnel only</u>

Portable Appliances

It has been established that 25% of all electrical accidents at work involve portable electrical appliances. A major contribution to these statistics is the fact that the portable appliances were directly connected to a 230v supply. Had the same appliances been operating from reduced voltage centre-tapped transformers it is possible that many of the accidents could have been avoided.

A further contribution to the statistics is the fact that the appliances were not fit for use. Prior to using ANY electrical equipment it must be visually inspected by the user and if a defect is suspected, or found, the equipment should be removed from service (e.g. placed in quarantine) and the fault reported to the person responsible and/or a competent electrical person. In order to meet the requirements of the Electricity at Work Regulations 1989 a portable equipment inspection and testing programme is necessary. This programme will consist of an inspection and testing schedule and will also include the results of all previous inspections and tests.

It should be noted that there is no specified test period. Factors that may influence the frequency of testing will include the age of equipment, frequency and type of use, and the type of environment it is used in.

Whilst in the workshop area safety is all important, therefore, prior to using any electrical equipment, it should be visually inspected for the following:-

- the "Tested" label has not exceeded the "Test By" date
- there is no damage to the flexible lead or associated plug
- there is no physical damage to the equipment that may interfere with its operation or expose any operational parts
- there are no signs of burning or overheating
- there are no signs of ingress of foreign materials such as liquids

If in doubt do not use the equipment until inspected by a competent electrical person.

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Section 7 – Earthing (Systems and Equipment)

The earth can be considered to be a vast conductor which is at reference, or zero, potential. People are usually in direct contact with this earth therefore any metal parts which are not bonded have the potential to become charged and a subsequent hazard if touched.

Connection to Earth

In a distribution system it is general practise to directly earth the star point of the secondary winding of the distribution transformer (see Fig. 7.1 below).

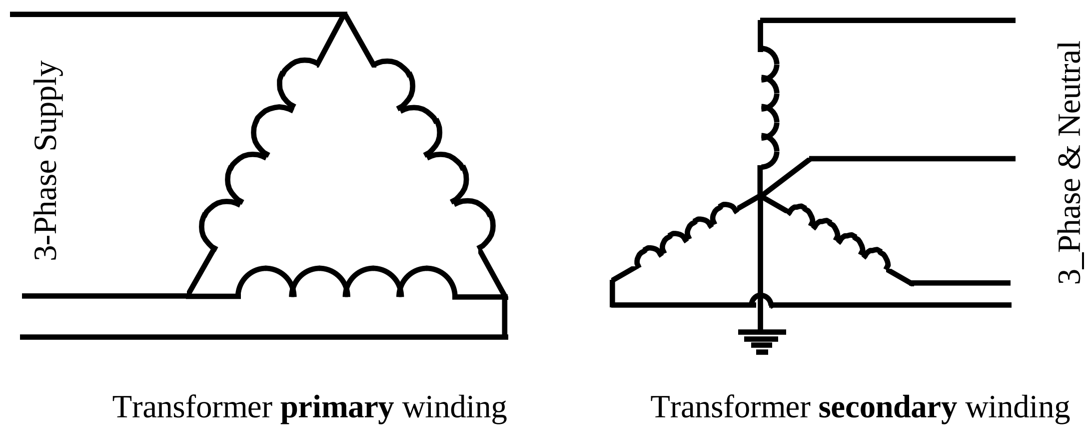

Fig. 7.1

An insulation failure on the secondary side of the transformer, or on its associated system, will result in the current returning to the star point. Due to the unreliability of the earth as a conductor, (seasonal ground conditions can affect the total resistance of the earth path), protective devices are installed to continuously monitor the system and will isolate the supply in the event of a fault condition.

In **high voltage systems** the purpose of earthing is to limit the fault current so that it can be interrupted safely by the switchgear via the circuit monitoring and protection systems.

The purpose of earthing in **low voltage systems** is to connect (bond) together all metal parts or objects, other than those intended to carry an electrical charge, to the earth so that dangerous potential differences cannot exist, either between different metal parts or between the metal parts and earth. This is known as **equipotential bonding** (Fig. 7.2 *overleaf*).

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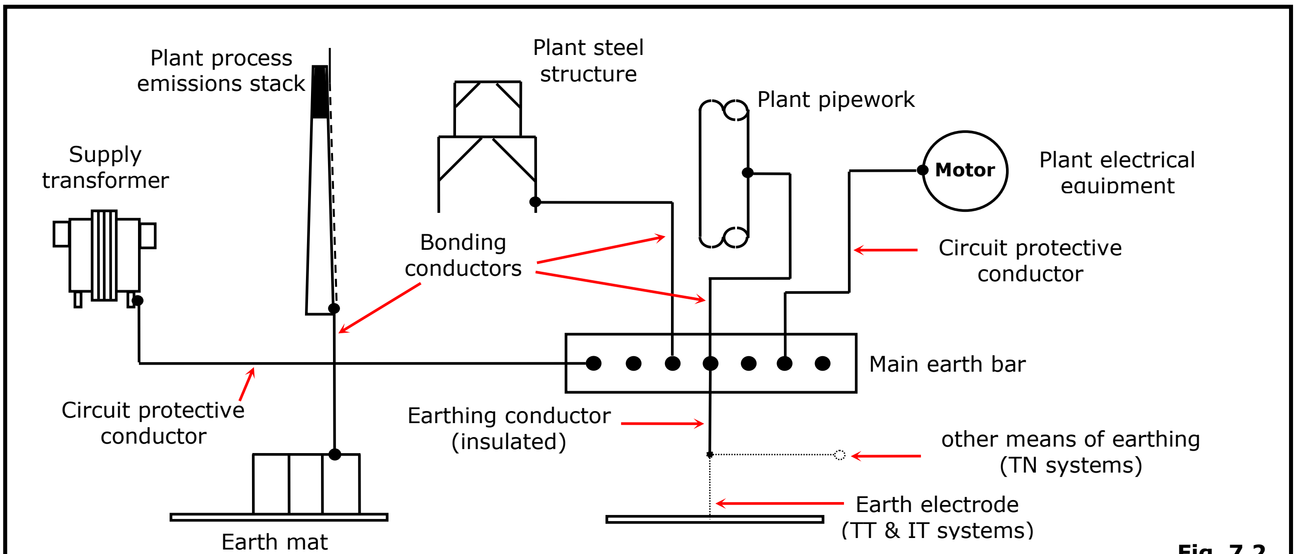

Fig. 7.2

It should be noted there are two distinct groups of metal parts. They are defined as :-

Exposed-conductive-part - a conductive part of the equipment which can be touched and which is not a live part but which may become live under fault conditions.

Extraneous-conductive-part - a conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation.

(BS7671, I.E.E. Regulations, 17th Edit.)

Earthing Systems

In any electrical system equipment earths are connected to an earth terminal by a continuous metallic path known as the **protective conductor.** This path usually consists of a separate earth conductor however, the metal armouring in domestic supply cables is frequently utilised as an earth and/or a neutral path providing that the cables have been correctly terminated in the associated joint.

During a supply cable fault to earth, the phase conductor and the earth return path act as a potential divider across the source voltage. Without efficient earthing potentials as high as 160v may occur on the exposed metalwork of the faulty equipment and any other metal parts that may be attached to it. These potentials can give a severe electrical shock to personnel if the affected parts are simultaneously accessible with other exposed metalwork which is at a lower potential (earthed). This is known as **"indirect contact".**

The risk of electrical shock from indirect contact can be minimised if all accessible metal parts are at the same potential or within 50v. This principle is known as **equipotential bonding** and can be achieved by fitting earth straps, or bonding conductors, between all metal parts which may otherwise be insulated from each other (Fig. 7.2).

In a domestic installation the earthing system may depend upon the local earthing conditions. For example, if the ground conditions local to the installation are very dry or consist of bedrock an effective earth could not be obtained by the usual method of installing an earth electrode into the ground. In these conditions the earth and neutral functions may be combined in a single conductor.

In order to cater for these different conditions, there are five types of distribution systems, all of which are shown and described in the following diagrams *.

(Fig.'s 7.3 to 7.7, taken from BS7671, I.E.E. Regulations, 17th Edit)*

The initials used to identify these systems correspond to the following :

T – Terra (earth)

N – Neutral

C – Combined

S - Separate

TN-C **system (Fig. 7.3)**

- Neutral and protective functions combined with a single conductor throughout the system.
- All exposed-conductive-parts of an installation are connected to the PEN conductor.
- An example of the TN-C arrangement is earthed concentric wiring but where it is intended to use this special permission must be obtained from the appropriate authority.

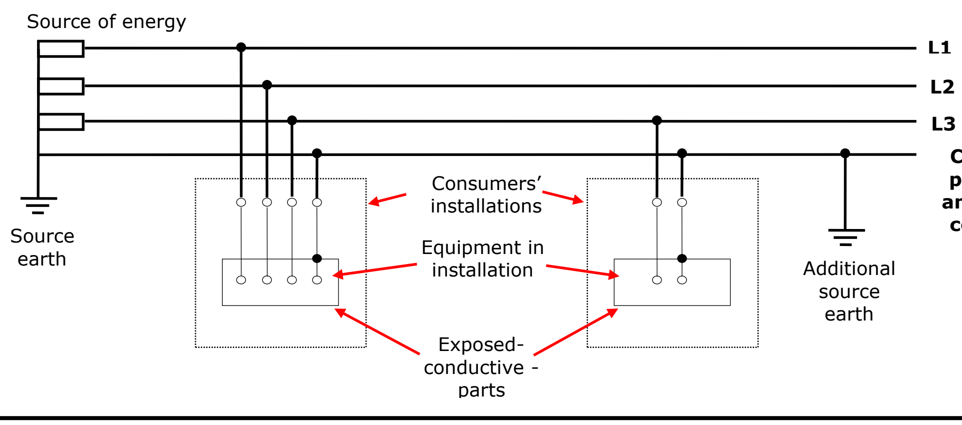

Fig. 7.3

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TN-S system (Fig. 7.4)

- Separate neutral and protective conductors throughout the system.
- The protective conductor (PE) is the metallic covering of the cable supplying the installation or a separate conductor.
- All exposed-conductive-parts of an installation are connected to this protective conductor via the main earthing terminal of the installation.

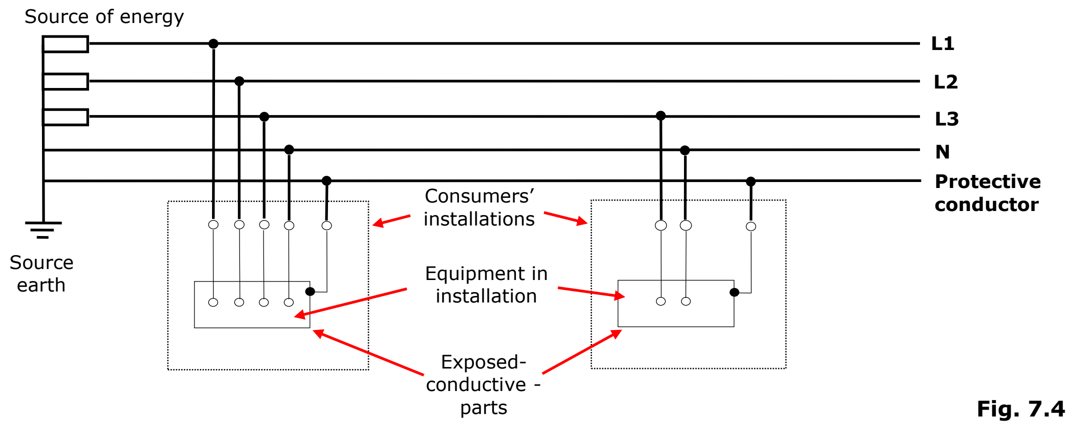

Fig. 7.4

TN-C-S system (Fig. 7.5)

- Neutral and protective functions combined in a single conductor in a part of the system.
- The usual form of a TN-C-S system is as shown above where **the supply is TN-C** and the arrangement in **the installation is TN-S**.
- This type of distribution is known as protective multiple earthing (PME) and the PEN conductor is referred to as the combined neutral and earth (CNE) conductor.
- The supply system PEN conductor is earthed at several points and an earth electrode may be necessary at, or near, a consumer's installation.
- All exposed-conductive -parts of an installation are connected to the PEN conductor via the main earthing terminal and the neutral terminal, these terminals being linked together.

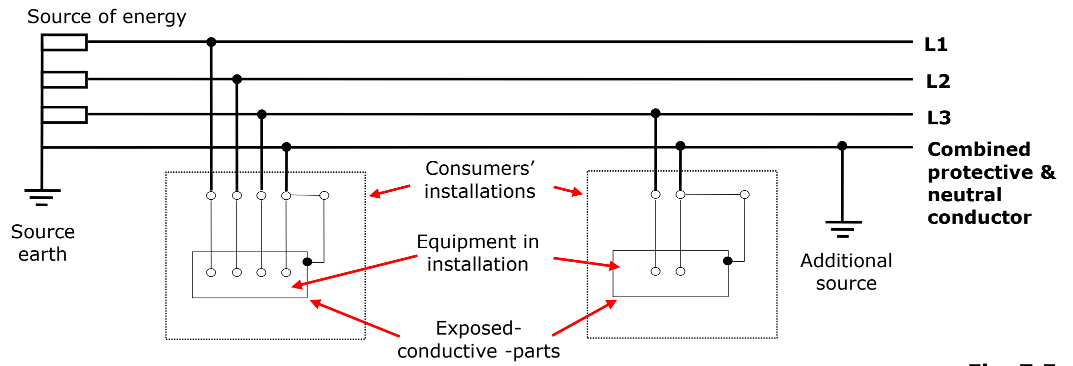

Fig. 7.5

TT system (Fig. 7.6)

- All exposed-conductive-parts of an installation are connected to an earth electrode which is electrically independent of the source earth.

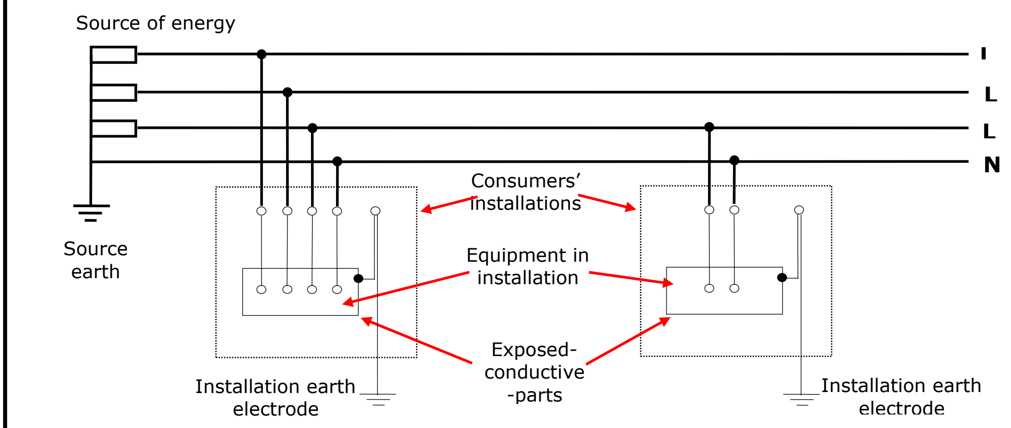

Fig. 7.6

IT system (Fig. 7.7)

- All exposed-conductive-parts of an installation are connected to an earth electrode.
- The source is either connected to Earth through a deliberately introduced earthing impedance or is isolated from earth.

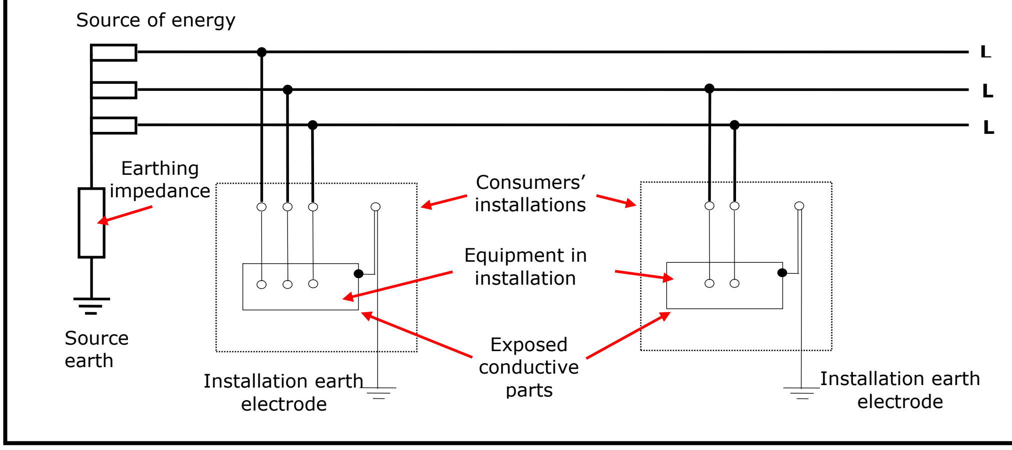

Fig. 7.7

It should be noted that Chapter 54 of the I.E.E. Regulations (17th Edition) give complete details of earthing and protective conductor arrangements.

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Section 8 - Protective Devices

Electrical distribution systems, equipment, and their associated controls must be protected against potential damage that may occur as a result of an abnormal condition (usually an electrical fault). The purpose of any protective device is :

- to remove the supply from that part of the system thereby maintaining the supplies to those parts that are "healthy"
- protect equipment against damage
- protect consumers and suppliers against damage
- limit the risk of fire
- protect personnel from conditions that may cause injury (such as arcing and explosion as a result of excessive current and temperature)

There are many types of protective devices all of which are primarily designed to protect the consumer in the event of a fault occurring. This section will concentrate on the following types of protection :

- High Rupture Capacity (HRC) Fuses
- Miniature Circuit Breakers (MCB's)
- Residual Current Devices (RCD's)

HRC Fuses

In the Regulations* a **fuse** is defined as "*a device which by the fusing of one or more of its specially designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a sufficient time*...."

The part of the fuse that operates in the event of a fault is known as the **fuse element**. This is defined as "*a part of the fuse designed to melt when the fuse operates ** ". It should be noted that the time taken for the element to melt will depend upon the value of the fault current.

HRC fuses are designed and constructed to break large fault currents rapidly without damage to the fuse enclosure or its surroundings hence its name **H**igh **R**upture **C**apacity. The fuse comprises of a ceramic body, two end-caps, the fuse element (there may be more than one) and quartz powder (see Fig. 8.1).

When the current exceeds the rated value of the fuse, the elements melt at multiple points along its their length. As they melt the elements will continue to conduct via an arc between the melted ends of the elements however, because of the intense heat and the surrounding quartz powder, fusion takes place resulting in rapid arc extinction. The two ends of the element are now encased by the fused quartz which acts as an excellent insulator thereby preventing any further arcing across the broken element.

* *I.E.E Regulations, 17th Edition.*

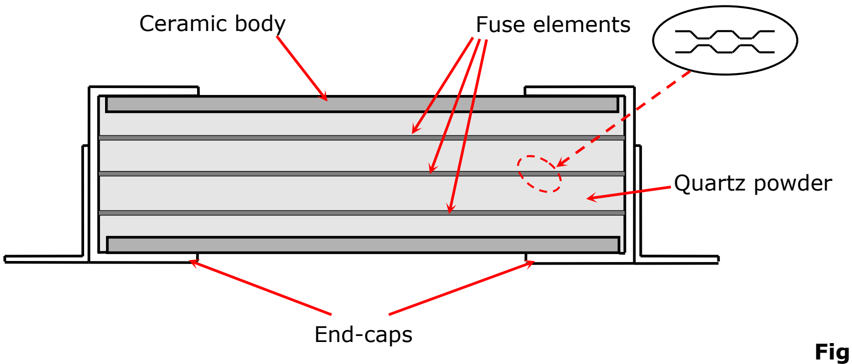

Fig. 8.1

Operating Characteristics

In order to protect the consumer and the circuit an HRC fuse must act rapidly. This is achieved by designing and constructing each fuse with prospective fault current "cut-off" value. This means that the short circuit current is interrupted before it can reach its full value in the first half cycle of short circuit (Fig. 8.2).

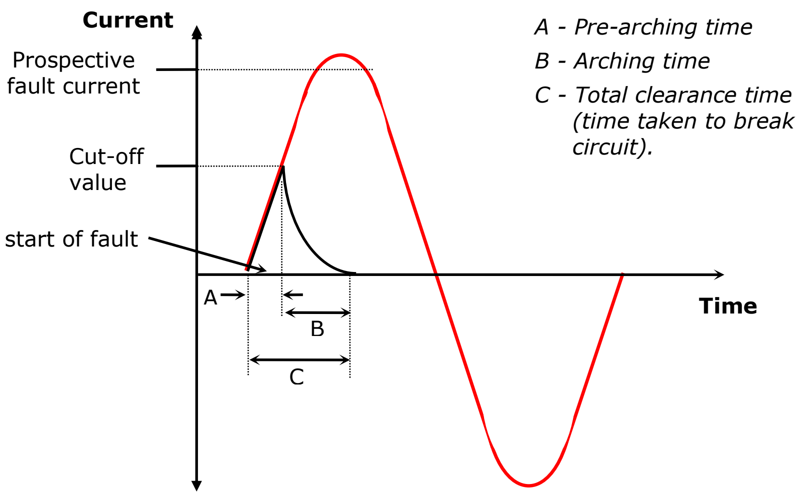

Fig. 8.2

The energy that is allowed through the circuit before the fuse disconnects can be calculated by the formulae ($I^2.t$).

Under short circuit conditions, a fuse must disconnect a circuit in sufficient time to ensure that the heat generated from the fault current does not damage the cable insulation. For this to be achieved the disconnection time "t" must not exceed the time/current characteristic total clearance time.

$$t = (k^2 \times S^2) \div I^2$$

Where: S = cross-sectional area of cable (mm's)

I = fault current (amps)

K = constant *(115 for insulated copper cable : Chapter 43, Table 43A, IEE Regs)*

In order to protect the user against electric shock, the I.E.E. Regulations require that, under fault conditions, any circuit protected by an **HRC fuse** should have an earth fault loop-impedance sufficiently low enough to ensure that the fuse will disconnect the circuit within **5 seconds**.
If the circuit is fed via a socket outlet then the disconnection time reduces to **0.4 seconds**.

Fuses have to be designed for different applications due to the varying types of load. Typically, steady load circuits would use a fuse that is rated equal to, or just above, the load rating. Alternatively when selecting a fuse rating for a fluctuating load circuit, e.g. a motor, you must take into account the load current fluctuations. Whilst the fluctuating current peaks are of comparatively short duration, the selected fuse should have a time/current characteristic that will accommodate them with interrupting the supply.

Safety

It is extremely important that correctly rated fuses are used in all applications. Whilst they cannot prevent faults, the potential consequences, particularly of using a higher rated fuse, may be fatal. In order to prevent fuse ratings being accidentally changed, any fuses that are removed for the purpose of electrical isolation should be taped together (if they are from a three-phase circuit), labelled, (listing the circuit details), and stored in a secure area. In conjunction, the source of isolation must also be labelled and state the rating of the removed fuses.

Discrimination

In any distribution system it is important to ensure that, in the presence of an electrical fault, the lower rated fuses should blow before the higher rated fuses. Each fuse rating would be selected according to the prospective load of the circuit that it is protecting. The diagram below, (Fig. 8.3), indicates how discrimination is achieved in a simple distribution system.

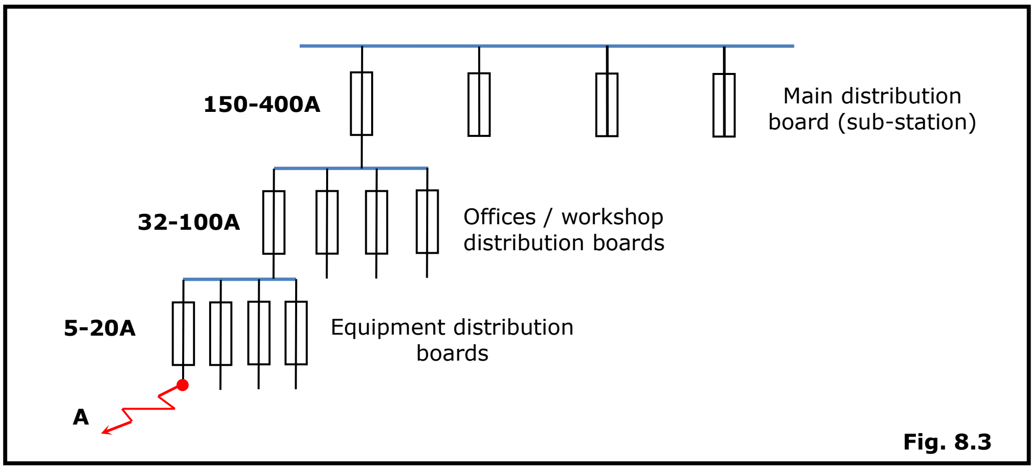

Fig. 8.3

In the event of a fault at point "**A**" the protection device immediately up-stream of the fault should operate and isolate the faulty circuit. It is desirable that only the upstream device should operate if it is able to clear the fault by itself, hence leaving the healthy circuits unaffected. This is known as **discrimination**.

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If the fault is greater than the breaking capacity of the upstream device then the next device in line should operate as well. This is known as **back-up protection**.

Reasons for using H.R.C. fuses

- They reduce danger to personnel, damage to equipment and the risks of fire.
- They reduce electromagnetic stresses which would, in the event of a fault, tend to distort and/or damage other current carrying parts of the equipment.
- They reduce thermal stresses to other current carrying parts of the equipment (heat is produced as a result of fault current).
- They reduce arc-splash damage.
- They retain all of their characteristics without the need for maintenance however long in service (laboratory tests on 34 (type "T") H.R.C. fuse links of various ratings after some 16 to 25 years of service showed no significant changes in any of their original characteristics).
- They contain no mechanisms or components that may wear, go out of adjustment or seize.
- Because of their low "cut-off" values and fast operating times of H.R.C. fuses, they are suitable for a variety of uses including back-up protection for circuit interrupting devices of inherent low rupturing capacity such as motor starters, contactors and circuit breakers.
- They operate without emission of smoke or flame.
- They ensure continuity of supply to healthy circuits when electrical faults occur.

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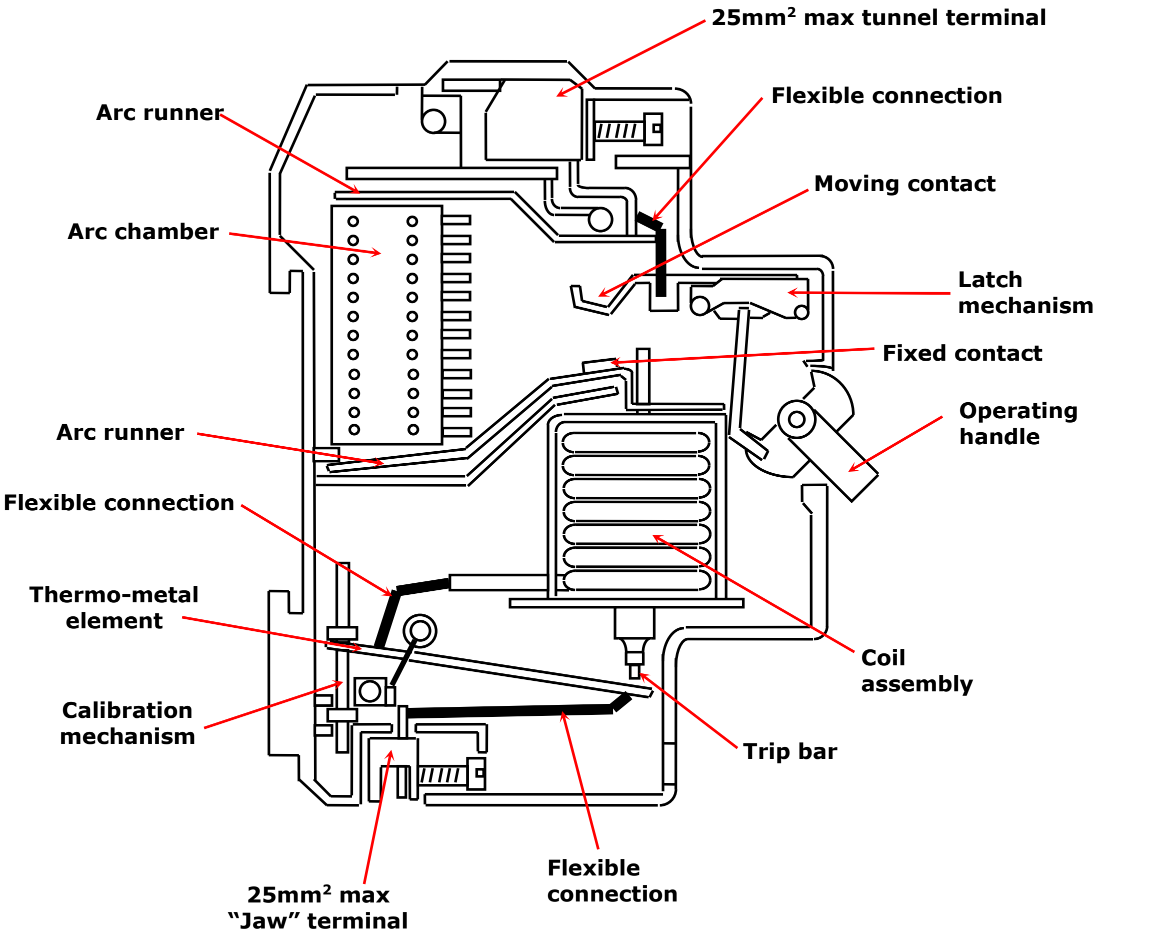
Miniature Circuit Breaker (MCB)

A miniature circuit breaker is a circuit protection device similar to a fuse, but re-settable. Most commonly available MCB's have two modes of operation:

Thermal overload protection - to protect cables and equipment from "long term" over current damage, i.e. generated heat.

Magnetic short circuit protection - to protect cables and equipment against very high fault currents caused by catastrophic component failure

All MCB's are rated by the normal current carrying capacity, operating voltage and by the maximum fault current and voltage that they can repeatedly break.



Crabtree MCB – "Polestar". Fig. 8.4

The Miniature Circuit Breaker has been designed to accommodate a variety of loads under different potential fault conditions however the correct type must be installed for a specific type of load, as described overleaf.

Small overload conditions

Light overload currents are detected by the use of thermo-metal which deflects at a rate in proportion to the size of the overload. The thermo-metal moves against a latching system which releases the contacts allowing them to open under spring pressure.

Large overload conditions

If the overload current reaches a predetermined level (which depends on the current rating and type classification of the MCB), then the current in the coil produces a magnetic field in the solenoid which is strong enough to pull in the armature and operate the latching mechanism to open the contacts.

Short circuit conditions

If the fault current is of a high enough level, not only does the solenoid trip the mechanism, it also forces the contacts apart very rapidly in a process known as "hammer trip". Under these conditions as the contacts separate an arc is drawn between them. The combination of magnetic fields in the MCB and the flow of the current in the arc acts to push the arc along the runners and into the arc chamber where it is quickly extinguished. The rapid opening of the contacts and extinction of the arc gives a total operating time that is typically 3.5 to 5 mS.

Selecting the right MCB

The essential distinction between Type *B*, *C* or *D* devices is based on their ability to handle surge currents without tripping. These are, typically, in-rush currents associated with fluorescent and other forms of discharge lighting, induction motors, battery charging equipment etc. BS 7671 specifically refers to Types *B* and *C,* and the choice will normally be between these two types.

- ***Type B*** devices are generally suitable for domestic applications. They may also be used in light commercial applications where switching surges are low or non-existent.
- ***Type C*** devices are the normal choice for commercial and industrial applications where fluorescent lighting, motors etc. are in use.
- ***Type D*** devices have more limited applications, normally in industrial use where high in-rush currents may be expected. Examples include large battery charging systems, winding motors, transformers, X-ray machines and some types of discharge lighting.

The classification of Types *B*, *C* or *D* is based on the fault current rating at which magnetic operation occurs to provide short time protection (typically less than 100ms) against short-circuits. It is important that equipment having high inrush currents should not cause the circuit-breaker to trip unnecessarily, and yet the device should trip in the event of a short-circuit current that could damage the circuit cables.

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The tripping characteristics, as illustrated in BS7671, show that:

- ***Type B*** devices are designed to trip at fault currents of 3-5 times rated current (I_n). For example a 10A device will trip at 30-50A.
- ***Type C*** devices are designed to trip at 5-10 times I_n (50-100A for a 10A device).
- ***Type D*** devices are designed to trip at 10-20 times I_n (100-200A for a 10A device).

Normal cable ratings relate to continuous service under specified installation conditions. Cables will, of course, carry higher currents for a short time without suffering permanent damage. Type *B* and *C* circuit breakers can generally be selected to achieve tripping times that will protect the circuit conductors against normal surge currents in accordance with BS 7671. This is more difficult to achieve with Type *D* devices, which may require lower earth loop impedance (Z_s) to achieve the operating times required by Regulation 413-02-08.

Sources of surge currents:

Surge currents in domestic installations are generally low, so that a Type *B* device is adequate. For example inrush currents associated with one or two fluorescent fittings, or the compressor motor in a refrigerator/freezer, are unlikely to cause unwanted tripping.

Fluorescent and other discharge lamps produce surge currents and while one or two fluorescent lamps are unlikely to cause a problem, the block switching of a number of fluorescent lamps in a shop, office or factory can produce substantial inrush currents. For this reason Type C devices are recommended for these applications.

The magnitude of the surge current will depend on the lamp rating, starting system and type of control gear used in the luminaires. Reputable MCB manufacturers produce tables listing the number of fittings of a particular make and type that can be used with their devices.

Overcoming unwanted tripping:

Sometimes failure of tungsten filament lamps can trip Type *B* circuit-breakers in domestic and retail environments. This is caused by high arcing currents occurring at the time of failure and is generally associated with inferior quality lamps. If possible the user should be encouraged to use better quality lamps. If the problem persists then one of the measures listed below should be considered.

A Type *C* device may be substituted for a Type *B* device where unwanted tripping persists, especially in commercial applications. Alternatively it may be possible to use a higher rated Type *B* MCB, say 10A rather than 6A. Whichever solution is adopted, the installation must be in accordance with BS 7671.

A change from Type *C* to Type *D* devices should only be taken after careful consideration of the installation conditions, in particular the operating times required by Regulation 413-02-08.

Residual Current Device (RCD)

The residual current device, or RCD, is principally designed to offer personal protection against accidental electrical shock (see Fig. 7:5 below). Most types work by monitoring the current normally flowing to and from a piece of equipment. Any difference (residual) resulting from a current path to earth, for example an individual touching the live conductor, is monitored and at a pre-determined level the device will remove the supply from the equipment.

Most modern types are double pole i.e. they switch both live and neutral connections. The device is rated by the amount of residual current required to trip, the time taken to trip and the nominal voltage and current the device will carry.

It should be noted that most RCD's do not protect against live to neutral faults hence back-up protection by fuse or MCB is required.

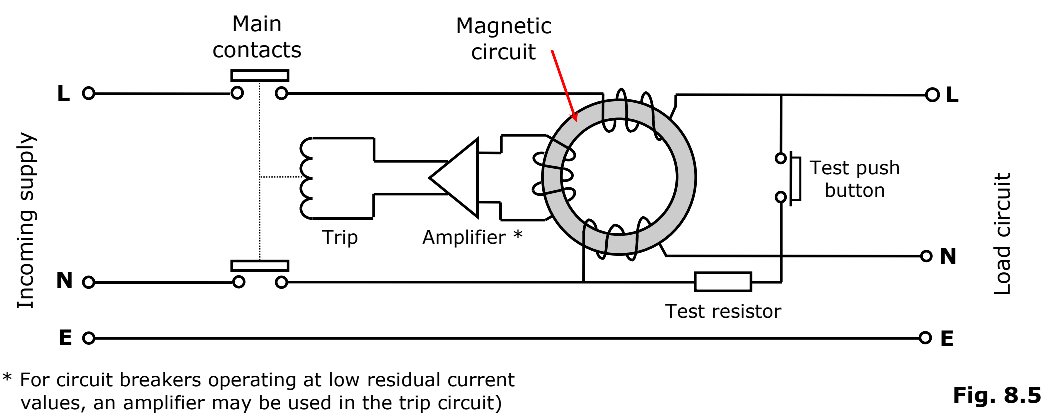

Fig. 8.5

Note 1 : All exposed metalwork must be earthed.

Note 2 : A test button is provided on all RCD's to enable the operation of the device to be checked.

Operation

The RCD operates on the current balance principle. Phase and neutral currents pass through identical coils wound in opposing directions on a magnetic circuit, so that each coil will provide equal but opposing numbers of ampere turns when there is no residual current, (the opposing ampere turns will cancel, and no magnetic flux will be set up in the magnetic circuit).

If a fault occurs, residual earth current passes to the circuit through the phase coil but returns through the earth path, thus avoiding the neutral coil, which will therefore carry less current. The result is an imbalance between the live and neutral coils and an alternating magnetic flux in the core. This flux induces an e.m.f into the trip circuit coil, which will cause the trip relay to operate when it exceeds a pre-determined level, opening the main contacts and interrupting the supply.

It should be noted that the RCD trip mechanism will operate at a residual current of between 50 and 100% of its rated tripping current.

Why use RCD's ?

The standard method of protection is to make sure that an earth fault results in a fault current high enough to operate the protective device quickly so that fatal shock is prevented. The are cases, however, where the impedance of the earth-fault loop, or the impedance of the fault itself, are too high to enable enough fault current to flow. In such a case, either:

- current will continue to flow to earth, perhaps generating enough heat to start a fire, or
- metalwork which is open to touch may be at a high potential relative to earth, resulting in severe shock danger.

Either or both of these possibilities can be removed by the installation of a residual current device (RCD). The increased use of RCD's has led to further development of devices that are combined with overload protection or designed for a specific purpose. These devices are frequently referred to by their initials, some of which are identified as follows :

RCCD	Residual Current operated circuit breaker
SRCD	socket outlet incorporating an RCD
PRCD	portable RCD, usually an RCD incorporated into a plug
RCBO	an RCCD which includes over-current protection
SRCBO	a socket outlet incorporating an RCBO

Applications

Residual current devices may be required for one of two main reasons :

(a) to ensure the compliance of an installation with BS 7671, IEE Wiring Regulations.

An RCD may be installed to meet the requirements of Regulation 413-02-15 where a high earth fault loop impedance disqualifies the use of over-current protection devices as a means of providing protection against indirect contact.

(b) to provide a higher level of protection than that given by direct earthing, against fire or shock risks caused by earth leakage currents.

Over-current protection devices cannot detect earth fault currents below their operating current. If they are the only means of earth fault protection it is possible for sufficient earth fault current to flow undetected to constitute a fire risk.

By using an RCD, the flow of the sustained earth fault current above the tripping current of an MCB is prevented hence the shock risk associated with these currents is also greatly reduced.

Residual current devices are completely selective in their operation. They are unaffected by parallel earth paths and are thus ideally suitable for the protection of the modern day installations. They are virtually tamperproof and provide a pre-determined level of protection. Even if earthing conditions substantially deteriorate they will continue to provide a higher level of protection than would have been given by direct earthing.

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Section 9 – Portable Appliance (Inspection and Testing)

Portable Appliance Testing (PAT)

Portable appliance testing will usually involve the following:

(a) Earth bond continuity tests

(b) Insulation resistance testing

(c) Functional checks

(1) Earth Bond Test (Class 1* equipment only)

Readings should show less than 0.1+R Ohms (where R is the resistance of the lead)

Tested at a current of 1.5 times the rating of the fuse and no greater than 25A for a period of between 5 and 20 seconds or with a short-circuit test current within the range 20mA to 200mA.

** see BS7671 IEE Regs. Section 2, "Definitions"*

(2) Insulation Resistance Test

The applied test voltage should be approximately 500 Vdc for :

Class 1 heating equipment < 3kW min. 0.3M Ohms

Class 1 All other equipment min. 1M Ohms

Class 2 Equipment min. 2M Ohms

Class 3 Equipment min. 250k Ohms

(3) Optional Tests

Flash Test: No flash-over or breakdown shall occur

Operation/Load test: Compare the reading with stated details on nameplate

Earth leakage test:

- Class 1 Handheld Appliances 0.75mA
- Other Class 1 Appliances 3.5mA
- Class 2 Appliances 0.25mA

Keeping Records

It has been seen that it is a defence under Regulation 29 of the Electricity at Work Regulations for a duty holder to ' prove that he took all reasonable steps and exercised all due diligence to avoid the commission of that offence'. It seems clear that the most effective method by which a duty holder would be able to prove this in court would be by producing records to show that he or she had acted within either the letter or the spirit of the law. Records are therefore essential for a proper and organised system of testing.

Record keeping should be seen as essential. Records provide evidence for the defence in the event of a prosecution and, more practically, such records enable the close monitoring of the electrical equipment. Records can highlight potential faults or adverse trends. Records are also essential for forming an accurate assessment of the necessary frequency of testing. For example,

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if over a number of consecutive test, few or no failures were recorded then he duty holder may consider reducing the frequency of tests, obviously the converse may also apply.

Replacement of appliance flexes

For flexes to be protected by the fuse in a BS1363 plug there is no limit to their length, providing their minimum cross-sectional areas are as below:

- 3A - 0.5mm^2
- 13A - 1.25mm^2

Other considerations *such as voltage drop may limit flex lengths. Smaller csa's than those given are acceptable if flex lengths are restricted. However, for replacement purposes the above simplified guidance is usually appropriate.*

The maximum lengths recommended for extension leads do not apply to appliance flexes or cord sets.

Ratings of Fuses

For the convenience of users, appliance manufacturers have now standardised on two plug fuse ratings- 3A & 13A and adopted appropriate flex sizes. For appliances up to 700W a 3A fuse is used, for those over 700W a 13A fuse is used.

The fuse within the plug is not fitted to protect the appliance, although in practice often it does. Portable and fixed appliances are generally designed to European standards for use throughout the European Union. The fuse contained within the plug serves to protect against faults in the flex and can allow the use of a reduced csa flexible cable. This is useful for appliances such as soldering irons, electric blankets etc. where the flexibility of a thin flexible cable is desirable.

Choosing Portable Appliance Testing Equipment

When you are sourcing a portable appliance tester, the first thing you may notice is the large range you have to choose from. For simplicity, PAT testing equipment can be categorised in one of three distinct categories.

Simple PASS or FAIL types

The PASS/FAIL or GO/NO-GO, type testers give a simple pass or fail test result allowing no interpretation of the test data. These testers generally only carry out insulation and earth continuity tests. Most PASS/FAIL PAT testers do not have a selectable Earth Continuity test current.

The **IEE Code of Practice** states that the earth continuity of an electrical appliance can be tested either:

a) With a current between 20-200mA while flexing the lead of the appliance or,

b) With a current not less than 1.5 times the rating current of the appliance, and no greater than 25 amps.

If the earth circuit on an appliance is susceptible to corrosion such as those found in a fridge, washing machine, kettle or dryer then you should test these appliances with the higher earth current to ensure any potential corroded earth wires are suitably stressed.

To test IT equipment the tester must be able to perform an earth bond test at the lower current of between 20 - 200mA. The disadvantage of this type of tester is that the high current types (usually 25A) are unsuitable for testing IT equipment and the low current types (usually 100mA) are unsuitable for testing general electrical appliances. A further disadvantage with all the PASS/FAIL type of testers is the earth bond pass limit is set, allowing no interpretation of the test result.

The **IEE Code of Practice** requires the earth bond resistance to be no greater than 0.1 Ohms + the resistance of the cable. A tester with a set Earth Continuity limit of 0.1 Ohms will wrongly fail equipment with long leads or low csa that may have a higher resistance. Some testers avoid this by setting the limit higher, usually 0.3 Ohms, but these do not comply with the IEE Code of Practice and may still wrongly fail equipment. PASS/FAIL testers have the advantage of being easy to use but have a limited practical use.

Using PAT Testing Labels

All portable appliance equipment that has been tested and inspected must be clearly identifiable. This usually achieved by labelling the equipment with a PAT Testing label.

The label or sticker must contain the following

- A unique identification code to enable equipment to be identified
- The status of the electrical equipment following the testing (PASS or FAIL)
- The date the appliance was tested together with the re-test period or the re-test date

This information provided on the label is designed so the equipment can be easily identifiable even if several similar items exist within the same premises and it also indicates to a non-technical user if the equipment is due for re-testing or should not be used.

Many modern PAT testers and PAT testing equipment can read bar-coded labels which is particularly convenient for the appliance identification code.

PAT labels or stickers can vary in design but should be durable and hard wearing enough to withstand the period of time between PAT testing without deterioration. The PAT label should be positioned in a prominent position where it is clearly visible.

Portable appliances that fail the PAT test must be put beyond use and clearly labelled with a visible sticker indicating that the appliance has failed.

Legal requirements for landlords

Any person who lets residential accommodation (such as houses, flats and bed-sits and even holiday homes, caravans and boats) as a business activity has a legal requirement to ensure the equipment supplied as part of the tenancy is safe.

The Electrical Equipment (Safety) Regulations 1994 requires that all mains supplied electrical equipment, (whether it be new or second-hand), supplied with the accommodation must be safe. Landlords therefore need to regularly maintain and check the electrical equipment they supply to ensure it is safe.

The supply of goods occurs at the time of the tenancy contract. It is, therefore, essential that property is checked prior to the tenancy to ensure that all goods supplied are in a safe condition. A record should be made of the goods supplied as part of the tenancy agreement and of checks made on those goods. The record should indicate who carried out the checks and when they did it.

It would be strongly advisable to have all electrical equipment checked before the start of each let and also to have the equipment checked at regular intervals thereafter. All test reports listing the equipment, the tests carried out and the results should be retained by the landlord.