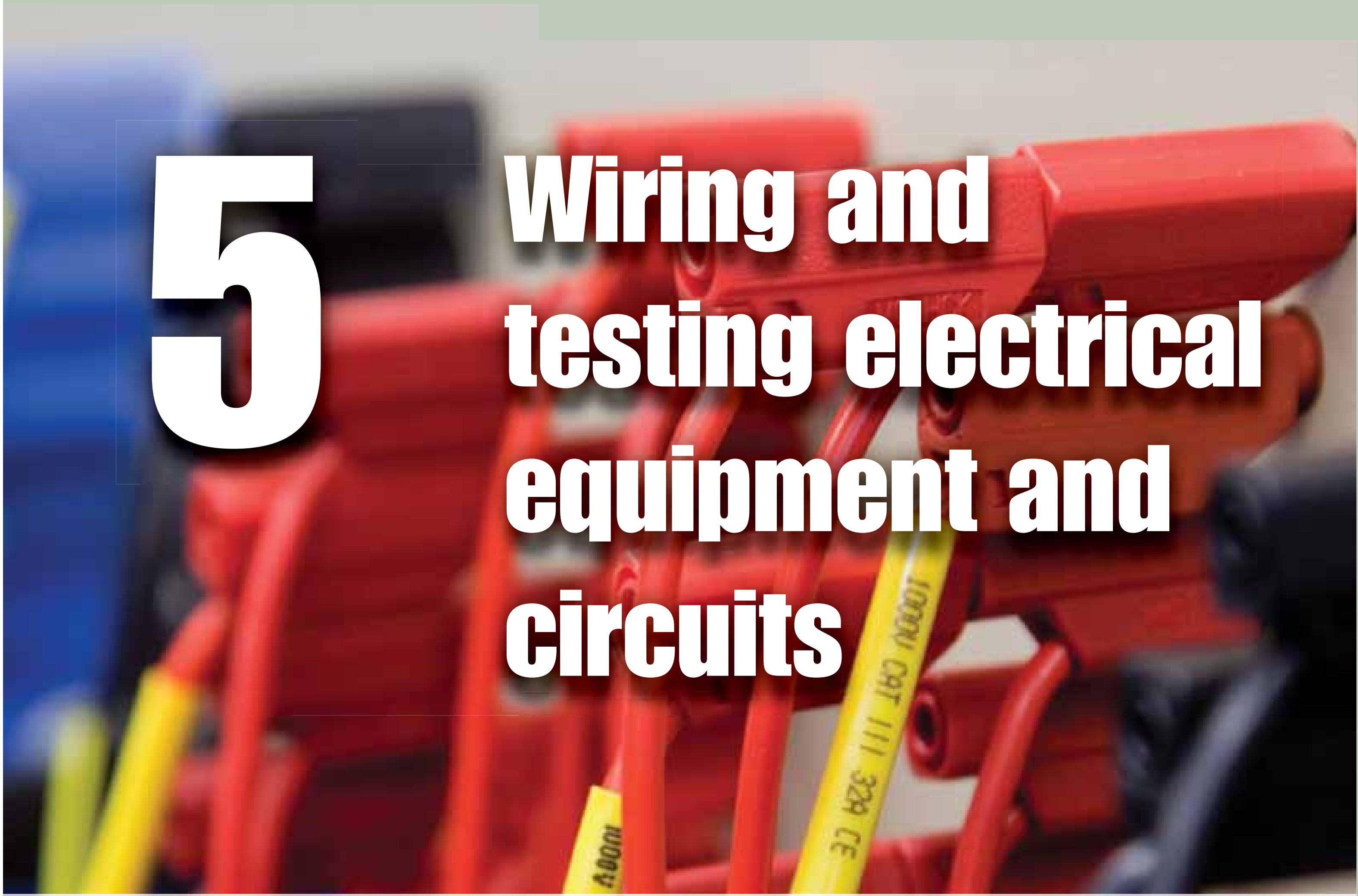
5 Wiring and testing electrical equipment and circuits



Electricity operates our cookers and washing machines, it lights our towns and motorways, office blocks and factories and it powers our computers and mobile phones. Electricity is an essential part of the systems that make cars, ships and aircraft work. But electricity is also dangerous and can cause fire and electric shock, which can be fatal. Because of this electrical wiring and equipment must be installed correctly, securely and safely.

This chapter introduces the components that make up, and protect, an electrical installation and the principles behind electrical circuits and equipment. It describes how an installation should be tested and faults found and rectified.

In this chapter you will learn about:

- what is a circuit
- cables
- electrical accessories
- electrical equipment
- fixing accessories and equipment
- connecting up
- types of circuit
- protecting the installation
- inspection and test

KITTING UP

Personal Protective Equipment (PPE)

Goggles *protect the eyes from flying objects when using power tools such as drills, saws and cutters.*

Gloves *are worn to protect ands from sharp edges and rough surfaces when lifting and carrying.*

Hi-viz waistcoat *makes sure you can be seen at all times. Compulsory on most construction sites*

Hard hat *protects the head from falling object. Compulsory on most construction sites.*

Ear defenders *are worn when using noisy equipment or in a noisy area.*

Dust masks *are worn when a task creates a lot of dust.*

Protective footwear *protects feet from injury from heavy objects. Compulsory on most construction sites.*

Keeping Safe

Health and safety are always the most important things to think about before starting any job. Electrical work carries its own particular risks. Electrical shock can be instantly fatal and faulty wiring and equipment can cause fires. Because of this, tools and equipment should be of a high standard and checked before use. Test instruments must be calibrated and proven against known supplies. Risk assessments must be drawn up and particularly hazardous work authorised using the Permit to Work system. First and foremost, however, the right personal protective equipment (PPE) needs to be selected for the work to be carried out.

Paperwork

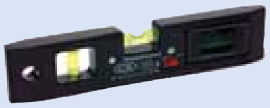
Every job involves some paperwork. Below is a table showing the main documents the electrician will need before starting work on an electrical installation.

Document	What it tells you
Layout drawing	Scale drawing showing a 'bird's eye' view of a room or building and the position of electrical accessories and equipment (all represented using the British Standard symbols found in the IET *On-Site Guide*)
Specification	Heights of electrical accessories, types of material to be used, fixing methods and any other detailed information needed to carry out the work
Circuit diagram	Shows how a circuit works but not exactly how it is wired or installed
Wiring diagram	Shows how a piece of equipment or a circuit is to be wired and connected. Will often show terminal numbers
Manufacturer's instructions	A handbook supplied with machines, boilers, control panels and other equipment
BS 7671	The electrical wiring regulations. All electrical work must conform to these regulations
On-Site Guide (published by IET)	A practical handbook from the IET which explains the BS 7671 regulations to the electrician

Toolkit

No job can be carried out without the correct tools. Shown below are the main items of equipment needed for the work in this chapter.

Philips and flat bladed screwdrivers of various sizes	Most modern fixing screws now have the x and star-shaped Phillips and Pozi-Drive slots which require a matching screwdriver. There are two sizes, small and large. Many terminal screw and older fixing screws have a single slot and require a matching screwdriver – there are many different screw and slot sizes requiring large and small screwdrivers 
Combination pliers	Made up of gripping jaws and a set of cutting blades, combination pliers enable you to carry out a number of jobs using only one tool 
Side cutters	Designed to cut cables, these can often be used in situations where it is difficult to use combination pliers, e.g. where only the tips of the cutting blades can gain access to the cable or wire 
Cable strippers	Cable strippers are much easier to use for stripping insulation and can be adjusted to fit various cable sizes 
Tape measure	Available in various lengths and useful for measuring a wide range of lengths 
Hammer	Available in various sizes and types, each of which can be used to drive different fixings into materials 
Crimping tool	Specialist tool for securing crimp lugs or terminations onto a cable conductor. Most have a set of various sized slots along the edges of their jaws so they can be used for most of standard crimped lug sizes 
Electric drill	Used for drilling holes in masonry, wood or metal, and as electric screwdrivers 

Screwdriver drill bit	A set of Phillips and flat-bladed screwdriver bits used with electric drills 
Masonry drill bit	Used for drilling holes in masonry 
Wood drill bit	Used for drilling holes in wood 
Small spirit level	Used to measure the level or plumb of a small object 
Large spirit level	Used to measure the level or plumb of a large object 
Chalk line	Used to create completely vertical lines 
Junior hacksaw	Smaller version of the hacksaw, used for cutting smaller items of metal and plastic 
Sharp knife with retractable blade [Stanley knife]	Used for a variety of jobs, from stripping cable sheathing to slicing through the tongues in wooden tongue-and-grooved floorboards. When not in use, the blade is hidden inside the handle 

Adjustable grips	Sometimes called pipe or slip grips, these can be easily adjusted to fit a workpiece by sliding one of the handles (and its jaw) up and down 
Adjustable spanner	Like adjustable grips, can be set to the size of a particular bolt or nut. In this case, the moveable jaw is set using a thumbscrew 
Specialist cable termination tools	Some equipment has non-standard terminals so specialist tools need to be used, e.g. for a telephone outlet with a grip-type terminal, a specialist tool is needed to push the conductor into the terminal jaws 
Voltage indicator	Shows whether voltage is present and can, in some cases, measure an actual amount 
Continuity tester	Confirms that a conductor or part of a circuit is unbroken and that current can flow from one end to the other <075071_ ph_097>
Insulation resistance tester	Confirms that the insulation on a cable is intact and that there are no short circuits between line and neutral and earth 

Equipment such as the continuity tester must be calibrated. This means that the instrument should be regularly re-set and checked against a known standard. A calibration record should be available as proof that an instrument has, in fact, been calibrated. The test instrument should also bear a calibration label.

Requirements for Electrical Installations: IET Wiring Regulations 17th Edition (BS 7671:2008)

It is vital to understand the importance of these regulations. BS 7671 (The IET Wiring Regulations) is the national standard to which all domestic and industrial wiring must conform. The 17th Edition Amendment No 1 contains extensive changes to align with European documents. Although it is a **non-statutory** document, all electrical installation work must comply with the guidelines it contains. Selection of suitable equipment, cable sizes, protection against shock and fire are among the subjects covered.

Key term

Non-statutory means that a document is not law but a code of practice. Failure to comply with this type of document can be used as evidence of negligence

Quick Tip

Only approved, good quality voltage indicators and electrical test equipment should be used. IET Guidance Note 3 details the best practice with regards to test instruments, for example the minimum amount of bare metal exposed at the tip of a test probe. Cheaper types of test instruments such as neon screwdrivers are not considered safe.

Keep It Safe

110V or battery powered power tools are the only type allowed on most construction sites.

QUICK CHECK

1. What power tool voltage is allowed on most construction sites?
2. What types of screwdriver will you need for basic electrical work?
3. Which document must an electrician's work conform to?

What is a circuit?

All electrical supplies are formed into circuits, some of which are simple paths along which current flows from positive to negative; others are more complex, made up of multiple routes and switching systems.

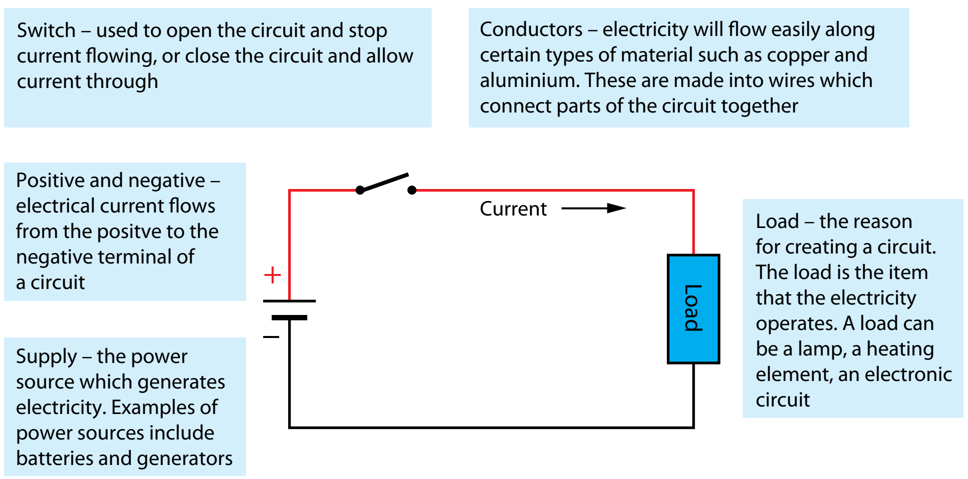


Figure 5.01 Labelled diagram of simple **d.c.** circuit

Key term

d.c. stands for direct current. This is the type of electricity produced by a battery and d.c. generator. Most mains installations, however, are fed by a.c., or alternating current

Property	Symbol	Measurement	Measurement symbol
Supply	V	volts	V
Potential difference	U	volts	V
Current	I	amps	A
Power	P	watts	W
Resistance	R	ohms	Ω

Table 5.01 Property and measurement

Did You Know

Ω is the Greek letter omega. Greek letters are widely used in science and engineering and are simply a way to represent a measurement or a property.

Did You Know

The multiplication sign is not shown in a formula because it could be mistaken for the letter X.

Simple circuit calculations

There are relationships between the properties which are expressed as a series of laws.

- **Ohms Law** – resistance in a circuit is equal to the voltage divided by the current R = U/I
- **Power Law** – power consumed by a circuit equals the voltage multiplied by the current: P = VR.

You will sometimes see power written as kW. This is kilowatts and means 1000 W. Kilo means 1000 (other examples are that one kilometre (km) = 1000 metres and one kilogram (kg) = 1000 grams).

Series and parallel

Circuits can be divided into two overall types: series and parallel.

Series circuits

In a series circuit, both loads must be connected and working because the current has to travel through each load, in turn, to reach the negative terminal. If one of the loads fails, the circuit will be broken.

Wherever you measure the current in a series circuit, it will be the same. However, the voltages measured at the loads will be different from the supply voltage. All these voltages will, however, add up to the supply voltage.

The disadvantages of the series circuit are:

- if one load fails, then all loads will lose their supply
- each load has to be designed to operate on a different voltage from the supply and, in turn, the voltage at one load will depend on the size of the other loads in the circuit.

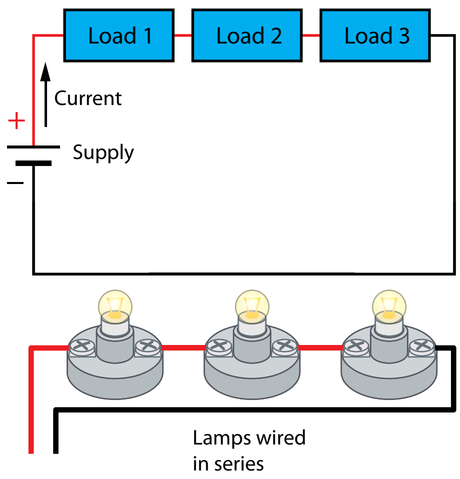


Figure 5.02 Simple circuit with three loads in series

Quick Tip

Voltmeters are connected in parallel, usually across the terminals of a load. Ammeters, for reading current, must be connected in series. To overcome the need for opening a circuit to allow ammeter connection, the clip-on ammeter has been developed. The jaws of the ammeter close round a cable and the current value is read from its display screen.

Parallel circuits

Most of the circuits used in domestic, commercial and industrial installations are parallel. In this case, if one or more of the loads fail, the other loads will continue to work. This is because each load forms its own individual circuit path between positive and negative.

The voltage will be the same at whichever point it is measured. The current will be different from the supply current at each load. The sum of the load currents will equal the supply current.

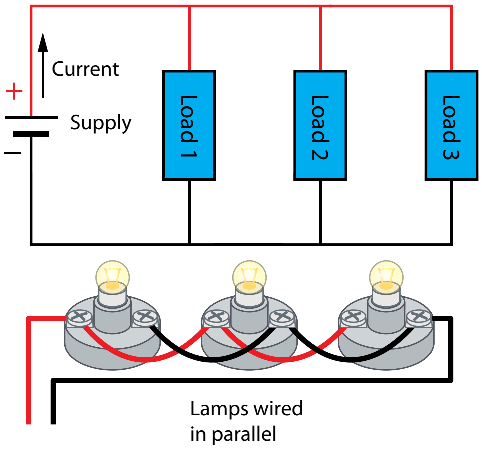


Figure 5.03 Simple circuit with three loads in parallel

QUICK CHECK

1. What are the two main disadvantages of a series circuit?
2. What is the resistance of a circuit if the supply is 230 V and the current is 30 A?
3. How much power is consumed by a load if it is supplied at 110 V and the current is 25 A?

Cables

Cables are the nervous system of all electrical installations, the method by which the electrical supply is carried. There are numerous types of cable, each designed for a particular job and environment. Cables used for domestic installations, for example, do not have to contend with the same harsh treatment and extremes of temperature as those used in heavy industrial premises. A cable is a collection of components, as can be seen from the diagram below.

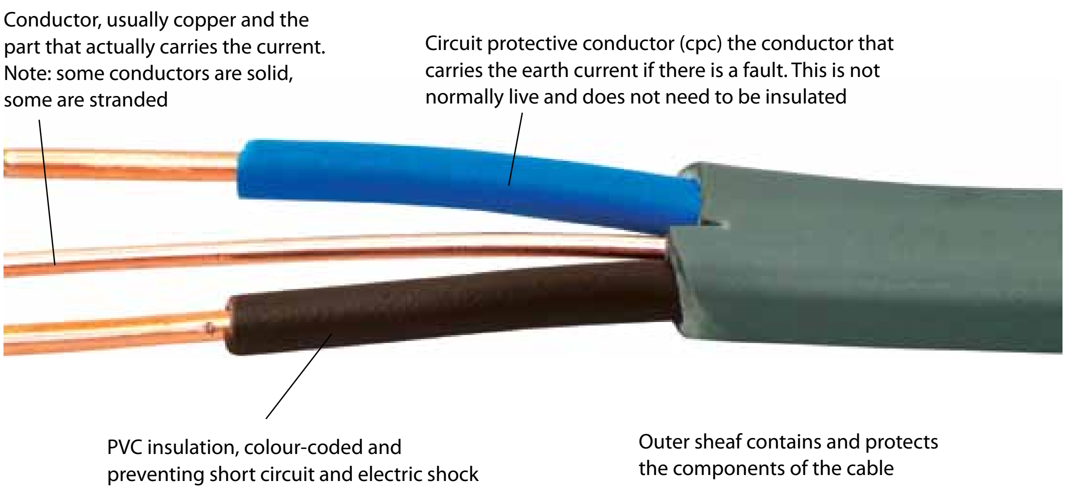


Figure 5.04 A twin-and-earth cable

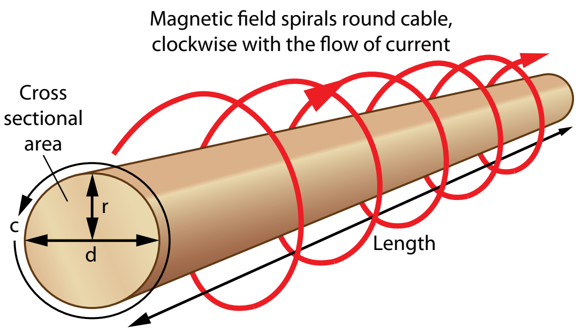


Figure 5.05 Conductor showing explanation of cross-sectional area

Cable size

The amount of current a cable can carry depends on the cross-sectional area of its conductor. The larger the cross-sectional area, the more current it can take. It is, therefore, important to select the correct size for the job.

All materials have resistance to electrical current. Some materials have a resistance so high it is virtually impossible for any current to pass through them. These are called insulators and include plastic, glass and wood. Other materials have a very low resistance and allow current to pass through them easily. These are called conductors. The amount of resistance in a material is called its resistivity (ρ) and is measured in ohms per metre or Ω/m. This means that:

- the longer the conductor, the greater its resistance
- the greater its cross-sectional area, the lower its resistance.

Cable size	Maximum current	Typical use
1.5 mm²	10 A	Lighting circuits
2.5 mm²	20 A	One or more 13 A sockets wired as a ring final circuit
4.0 mm²	25 A	Water heaters
6.0 mm²	30 A	Electric showers
10.0 mm²	45 A	Large cooker
16.0 mm²	60 A	Main supply to a house

Table 5.02 Common cable sizes and maximum current carrying capacity and a typical use

Key term

Volt drop occurs along the length of a conductor. The further from the supply you go, the more the voltage is reduced. The tables in Appendix 4 of BS 7671: 2008 show how many millivolts are dropped at each metre of a conductor, if 1 A is flowing. If 2 A were flowing then the figure would be doubled, 3 A and the figure would be trebled and so on. BS 7671 states the maximum allowable volt drop for lighting circuits is 6.5 V and for other circuits, 11.9 V.

This is a general rule. There are a number of factors that can reduce the amount of current a cable can carry. Among these are:

- ambient temperature – the temperature of the surrounding air
- presence of other conductors – cables produce heat when carrying current and when cables are bunched together their combined heat reduces current capacity
- confined space – if a cable is buried in a wall or run through conduit, its current-generated heat cannot escape
- the length of run – the longer the cable run the less current it can carry because, like water pressure in a pipe, the voltage is reduced the further you go from the power source (**volt drop**).

There is a set of tables in Appendix 4 of BS 7671:2008 that show the **volt drop/amp/metre** for various types of cables and installation methods. These tables are used to calculate the size of cable needed for a particular circuit.

Property	Symbol	Measurement	Symbol
Resistivity	ρ (rho, the Greek letter r)	ohms per metre	Ω/m

Table 5.03 Properties and measurements

Did You Know

The higher the temperature, the higher the resistance, the lower the temperature, the lower the resistance.

$R = \rho l/a$
R – resistance
ρ – resistivity
l – length of conductor
a – cross sectional area of conductor

Twin-and-earth

Twin-and-earth is the basic cable used for domestic installations and in any situation where there is minimal risk of damage. It is normally run through floors and ceilings and, when dropped to a switch or a socket, is cut into the wall and plastered over. This cut is called a chase. The back boxes for accessories such as sockets and switches are also set into the wall so that when the wall has been finished the cable is invisible and only the front plate of the accessory can be seen.

Cables in vertical chases are usually run through a thin oval conduit (see Chapter 6) or covered by a light capping. This protects the cable while the wall is being plastered. If a cable is chased horizontally across a wall, it must be run inside steel conduit (see Chapter 6). The reason for this is that it is generally assumed that cables run vertically down the wall to fittings such as sockets and switches. Someone erecting a shelf or cupboard, for example, might deem it safe to drill and fix to the wall between two switches or sockets. Steel conduit will offer some protection against cable damage if this happens.

When twin-and-earth cable is run under floors and in an attic space, it should be passed through the wooden joists. The joists can be either drilled or notched to allow the cable passage. There are a number of requirements for these holes and notches.

- Maximum hole diameter = 0.25 of joist depth.
- Holes should be centred at between 0.25 and 0.4 of the joist span.
- Holes in the same joists must be at least three x hole diameter apart.
- Maximum notch depth = 0.125 of joist depth.
- Notches must be located between 0.1 and 0.25 of joist span.

Care must be taken not to trap or damage cables when fixing or re-fixing floor boards.

If it is necessary to run a twin-and-earth cable on the surface, then it should be clipped.

When clipping a twin-and-earth cable it is important to run the cable in a straight line.

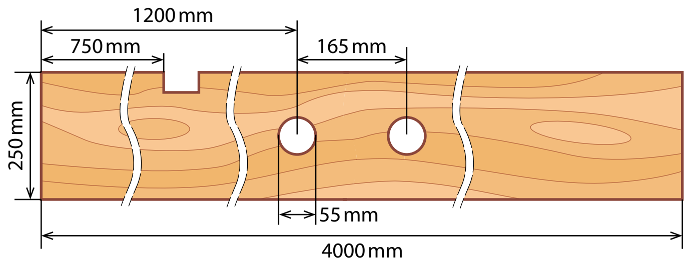


Figure 5.06 A wooden ceiling joist showing measurements

Clipping twin-and-earth cable

Checklist			
PPE	**Tools and equipment**	**Consumables**	**Source information**
• Goggles • Protective footwear • Hi-viz jacket	• Tape measure • Chalk or laser line • Spirit level • Hammer	• Twin-and-earth cable • Cable clips	• BS7671:2008 • IET On-Site Guide • Layout drawing

1

Mark a straight line to clip to.

2

Straighten the cable.

3

Clip at either end of run (in this image one clip is shown in place the other is being hammered in).

4

Fill in with clips at regular intervals.

Stripping twin-and-earth

We have already seen that the earth or circuit protective conductor (cpc), in a twin-and-earth is not insulated. The cpc can, therefore, be used for stripping twin-and-earth.

1. Use side cutters to bite into the end of the cable.
2. Peel open the outer sheath so that the cpc can be gripped using pliers.
3. Pull the cpc back using the pliers so that it cuts through the outer sheath.

4. Once the required length is reached, peel away the sheath and cut neatly.
5. Strip the insulation from the conductors using a cable stripping tool. Do not strip away too much insulation. 10 mm is about right for most terminations.

Single cables

Single, or non-sheathed, cables have only one layer of insulation and no outer sheath. They must be run inside conduit or trunking (see Chapter 6). BS 7671:2008 Regulation 521.10.1 makes this clear. Singles are often used in industrial installations because metal conduit and trunking provides the extra **mechanical protection** for the electrical installation.

Installing single cables

Conduit runs can be long, and often include a number of angles and bends – so installing single cable into conduit is a two-person job. One person will usually have to pull the cables at one end of the conduit run while the other person feeds them in at the other.

The standard method for wiring conduit is to push a draw wire or draw tape into one end of the run. This tape or wire is usually made of steel or nylon. While flexible enough to work its way round the various bends and angles, it is strong enough not to buckle as it is pushed into the pipe.

Once the draw wire or tape reaches the far end and is pulled out, the cables need to be connected or 'made off'.

Hands On

Prepare a loom of six 2.5 mm² single cables ready to be drawn into conduit. A secure method is as follows.

1. Strip one cable back about 200 mm. We will call this cable A.
2. Strip the other cables back to 10 mm.
3. Wrap the bared conductor, the first of these other cables, neatly round the bared conductor of cable A.
4. Wrap the bared conductor of the next conductor tightly round the bared conductor of cable A. Start this at the point where the previous conductor winding finished.
5. Repeat for the remaining three cables.
6. The remaining length of bared conductor from cable A should be attached to the draw wire and wound tightly back on itself.
7. The advantages of this method are:
   - the joint is very secure and will not give way while being pulled into a conduit.
   - the cables are layered rather than bunched into a cumbersome clump on the end of the draw wire.

It is important to pull all the required cables through a conduit run at the same time. Trying to install more cables into a pipe that already contains one or more circuits is both difficult and can also damage the existing cables.

Quick Tip

For a socket or switch, the exposed cores of a twin-and-earth should be 1.5 times the width of the box. Too short and it will be difficult to connect, too long and it will be difficult to fix the face plate to the back box without damaging the cables.

Key term

Mechanical protection – protection against physical damage

Figure 5.07 Jointing cables ready to be drawn into a conduit

Figure 5.08 Single cables on drums being drawn into conduit

Conduit runs will include a number of inspection boxes. It is at these points that the cables should be pulled out then fed into the next section. The cables should be laid carefully into the box and not twisted around each other.

Keep It Safe

Extension lead safety:

- Always use a three-core extension lead that includes a cpc.
- Always fully uncoil an extension lead when in use.
- Do not plug one extension lead into another.

Magnetic effect

When current flows, a magnetic field is set up and spirals along the outside of the conductor, clockwise with the current (see Figure 5.05). Because of this, a conduit or trunking run should not be filled with cables that all carry current in the same direction. The combined magnetic fields of such a set of cables will cause heat and vibration. This effect must be countered by including cables with opposing current flows. This also applies to entries into metal distribution boards and other enclosures.

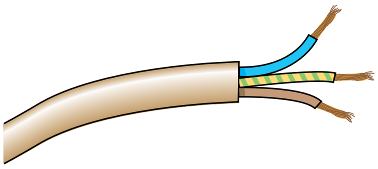


Figure 5.09 Example of flexible cable, stripped showing cores and conductors

Flexible cable

Flexible cable is often called 'flex' or 'a lead'. It is used to connect a piece of electrical equipment to the supply, for example a kettle or a television. BS 7671 Regulation 521.9.3 states that flexible cable should not normally be used for fixed wiring except for certain types of installation, such as caravans.

Flex is usually connected to the main supply either by a plug and socket or directly into a connection unit, often called a spur outlet.

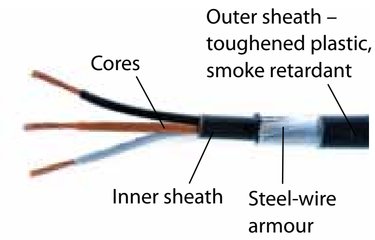


Figure 5.10 Steel wire armoured cable

Armoured cable

Because it has a layer of steel wires wound around its inner sheath, armoured cable can withstand a lot of physical punishment. As a result, this type of cable can be used for industrial installations and as an underground supply cable. Another use for armoured cable is as a sub-main feed from a main supply position in a large building to distribution boards feeding separate areas of the building, for example the floors of an office block. The cable's armouring can also serve as the cpc and as such must be securely connected to the earth of both its supply and load.

Key terms

High voltage – there are three main grades of voltage:

- **Extra Low Voltage** – 0V to 50V
- **Low Voltage** – 50V to 1000V (the 400V and 230V mains voltages in most installations are considered to be low voltage)
- **High Voltage** – 1000v and upwards

Types of armoured cable

- **XLPE/SWA** – armoured cables that utilise a grade of insulation designed to limit the amount of smoke and poisonous fumes emitted in case of fire. XPLE cables are used in locations where the general public is present e.g. airports and railway stations.
- **Paper insulated** – a type of **high voltage** armoured cable. It consists of a single conductor (usually aluminium) insulated by chemical-impregnated paper. Some high voltage cables have a combined earth and neutral layer wound around the inner core.
- **Galvanised steel wire braided** – an armoured signal cable that has both mechanical protection and an aluminium screen (see page XX for information about screened cables).
- **Trailing cables** – used in rough conditions as a flexible cable to feed machinery. An example of this would be a quarry or a large construction site.

Terminating steel-wire armoured cable

Checklist			
PPE	**Tools and equipment**	**Consumables**	**Source information**
• Protective footwear • Hi-viz jacket	• Tape measure • Knife – retractable blade type • Junior hacksaw • Adjustable spanner and grips	• Steel-wire armoured cable • Cable termination gland kit • Cable shroud	• BS7671:2008

1

Strip the outer sheath.

2

Saw halfway through the armouring wires.

3

Bend the wires back and forth until they snap off.

4

Strip outer sheath another few mm, then push the shroud and female gland onto the cable (this can be added before stripping the cable).

5

Push the male gland onto the cable. The dome section is seated under the armour wires.

6

Secure the female gland onto male thread, clamping the armour wire securely.

Hands On

Using the illustrations above as a guide, fit a termination set to the end of a steel wire armoured cable.

Fixing steel wire armoured cables

Steel wire armour can be run on cable tray (see Chapter 6) using either cable-ties or cleats, depending on the size of the cable. If fixing directly to a wall, use a chalk line or laser level in the same way as with the twin and earth to make sure your cable is straight and neat.

BS 7671:2008 states that armoured cables can also be run underground, providing that the following precautions are taken:

- The trench must be deep enough to avoid the cable being damaged by any 'reasonable' ground disturbance.
- The cable must be marked by covers or marking tape.

Routes of underground cable should also be marked out on plans and drawings to avoid damage caused by future ground work, such as pipe laying.

Fire resistant cable

When there is a fire, emergency lighting and alarms need to keep working for as long as possible – both to alert people to the danger and to allow them to find their way to the nearest exit. The cables supplying these systems must be able to withstand extreme heat and continue to carry current long after the rest of the installation has broken down.

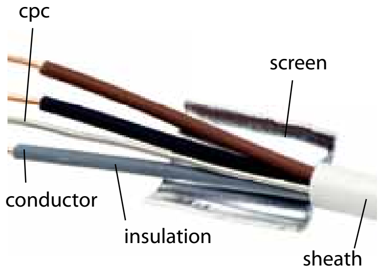


Figure 5.11 FP Gold 200 cable

FP Gold

FP Gold is the main type of fire resistant cable currently in use and is very simple to install and connect.

FP consists of a fire-resistant, low smoke-emitting outer sheath extruded over a layer of aluminium tape. The tape acts as both a moisture barrier and screening. The conductors are insulated with a fire-resistant material called Insudite. Although FP can be run into a fitting in the same way as twin-and-earth, sealed glands are available. These must be used if the environment is damp or if the cable is installed outdoors.

The main disadvantage of FP is that it can be easily damaged during installation. Bends must not be tight and care must be taken when preparing the cable for connection. To remove the outer sheath, use a sharp knife and score round the outer sheath then carefully flex the cable to free the cores.

Mineral insulated cable

Mineral insulated cable was the first type of fireproof cable in general use. It consists of copper sheath filled with tightly packed magnesium oxide powder which acts as the insulation around the cable's bare conductors. The copper sheath can also be used as the cable's cpc.

In older installations, mineral insulated cable is used for more general wiring such as sub-main supplies and even electric motor connections. If it is used for motor feeds the cable must be formed into a loop before termination into the motor. This loop acts like a spring and absorbs the vibration from the motor itself. Vibration could cause the cable gland to loosen which would both allow moisture ingress and impair the earth continuity of the cable connection (see page XX for information about earth continuity).

Mineral insulated cable is remarkable because the powder insulation will hold the bare cores apart at exactly the same distance even if the cable is damaged. In fact it is possible to beat it almost flat and for it to still work.

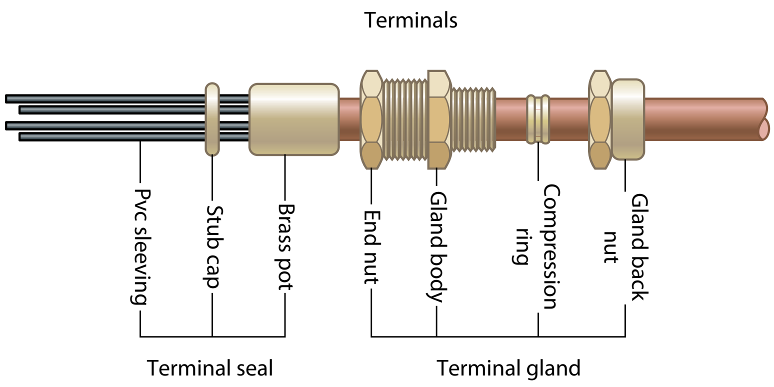


Figure 5.12 Mineral insulated cable and its gland

The main disadvantage of mineral insulated cable is that the magnesium oxide insulation is highly absorbent and, if the cable end is left exposed for any length of time, it will absorb moisture from the air and cause a low resistance between the conductors. Because of this, a moisture-proof sealing gland has to be applied to the cable when terminating.

Key terms

Twisted pair – a type of wiring in which two conductors (the forward and return conductors of a single circuit) are twisted together for the purposes of cancelling out electromagnetic interference

Dielectric – an insulating layer that is affected by the presence of an electric current. The current will cause positive and negative charges to shift into the two sides of the material. Dielectrics are used in capacitors (see page??)

Category 5

Category 5 and the newer 5e are examples of **twisted pair** cables. They are designed to carry signals for video and telephone and are used as the cabling for computer networks such as ethernet. Because it is not screened, Category 5 cable must be installed separately from mains cables because the signals it carries can be distorted by the mains cable's magnetic field. The maximum length of run for a Category 5 cable is 100 metres. However, longer runs are possible if equipment, such as a repeater, is used to boost the signal.

Telephone cables

Telephone cables are also twisted pair cables and connect the telephone to the network. They are pvc-sheathed with copper conductors and are identified as two-pair, three pair, etc.

Coaxial

Television aerial cables are coaxial cables. These cables have a single copper conductor which carries the signal. This conductor is contained in layer of insulation called a **dielectric**, designed to allow an electrical charge to pass between this conductor and an outer layer of woven conductor called a screen. The purpose of the screen is to stop the signal leaking from the cable.

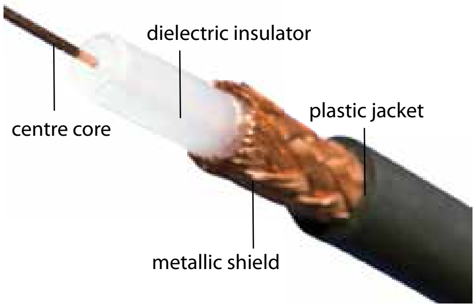


Figure 5.13 Coaxial cable

Fibre optic

Fibre optic cables carry data in the form of light pulses that are reflected back and forth along the inside of the conductor wall. Care must be taken when installing fibreoptic cables because they are delicate and cannot be bent sharply. You should also never look into the cables themselves. The cores themselves are sharp and the light pulses they carry are bright enough to cause eye-damage.

QUICK CHECK

1. What is a cpc?
2. What are the two functions of the armouring on steel wire armoured cable?
3. What is the main precaution to be taken when terminating mineral insulated cable?

Electrical accessories

Once installed, cables are usually connected to electrical accessories such as 13 A sockets, light switches and isolating switches. These accessories provide connection and control points for electrical equipment.

Plug

Items of electrical equipment of 13 A and less are usually connected to the supply using a 13 A plug. Modern plugs tend to be sealed and pre-fitted to equipment. The only removable part is the fuse, which provides close electrical protection for the flex (see page XX).

If a plug needs to be fitted to a flexible cable, it should be wired according to Figure 5.14.

Figure 5.14 13 A plug showing connections

The pins on a 13 A plug are partly insulated. This prevents conducting metal from being exposed to touch as the pins make contact with the live part of the socket.

Larger loads of 16 A and over, as well as 110V and extra low voltage equipment can be connected to the supply using round-pinned, industrial plugs. These are colour coded as follows.

- **Extra low voltage** – violet
- 110 V – yellow
- 230 V – blue (two types of commando plugs of 16 A max and 32 A max)
- 400 V three-phase – red

Industrial plugs are also available for loads with similar current ratings and voltages.

Figure 5.15 13 A socket and plug

Socket outlet

The 13 A socket outlet is the main connection point in most installations. Equipment is connected to the supply by means of a plug which fits into the three slots on the face of the socket. The slots are protected by shutters which are opened when the plug's earth pin is pushed into place.

There are a number of industrial sockets available. These have round outlet holes and are usually protected by a flap when not in use. The flaps have a hooking device which latches onto the plug once it is inserted and locks it in place.

Double-pole switch/outlet – the 'spur outlet'

Another type of connection outlet is the **double-pole** switch, often called a 'spur outlet'. This is a fixed connection which means that once the flex is connected to the outlet it cannot be pulled out without being disconnected.

There are various types of 'spur outlets', for example:

- double-pole isolator
- fused switch
- double-pole switch with flex outlet
- fused switch with flex outlet.

Keep It Safe

Earth conductors should never, ever be switched.

Hands On

Connect up two cables to a spur outlet. Mark one cable up as the feed and the other as the load. Check the terminals and note which line and neutral terminals are for the feed conductors and which are for the load. Some spur outlets are marked 'Feed' and 'Load', others 'In' and 'Out'. It is important to connect the correct conductors to the correct terminals.

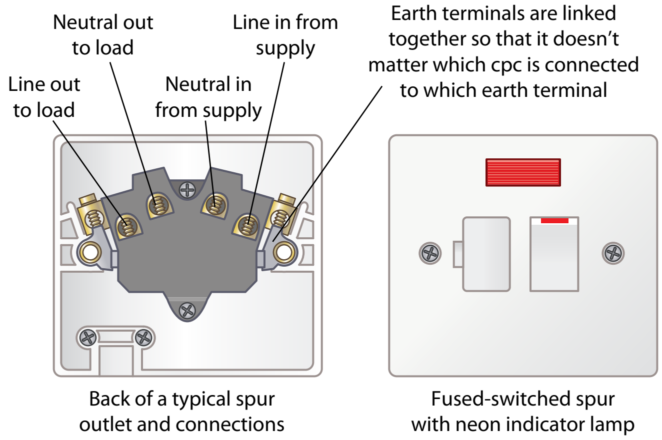


Figure 5.16 A spur outlet

Junction box

Junction boxes are a means of making a connection at a point in a circuit between the supply and an accessory. BS 7671:2008 states that while junction boxes are normally hidden out of sight under a floor or in a roof space, they still need to be accessible. Junction boxes are available at different current ratings, the higher the rated current the larger and more robust the junction box and its terminals. Examples are 5 A, 20 A and 30 A. There are also three, four and six terminal versions.

Figure 5.17 A junction box

Light switches

There are many styles of light switch. Most of these are available as one-way, two-way and intermediate versions. Switch plates can contain more than one switch. So, if there are two separate lights in a room, each to be switched separately, a two-**gang** switch will be used. If there are three lights then a three-gang switch is needed.

Grid switches are versatile assemblies designed to allow an electrician to create the type of switch needed for a particular job. Fixed to a standard box, various components can be assembled to create a one, two, three (or more) gang switch. Double-pole switches, fuse holders and neon indicator lights can also be fitted.

Pull cord switches are generally used in bathrooms where there are strict regulations about which types of accessories and electrical equipment can be installed. The rules apply because of the damp atmosphere and presence of water in bathrooms.

Key terms

Double-pole switch – a switch that opens both line and neutral. This ensures that electrical equipment is completely cut off from the supply

Gang – when used in connection with a switch, the word 'gang' means the number of actual switches in a single switch faceplate

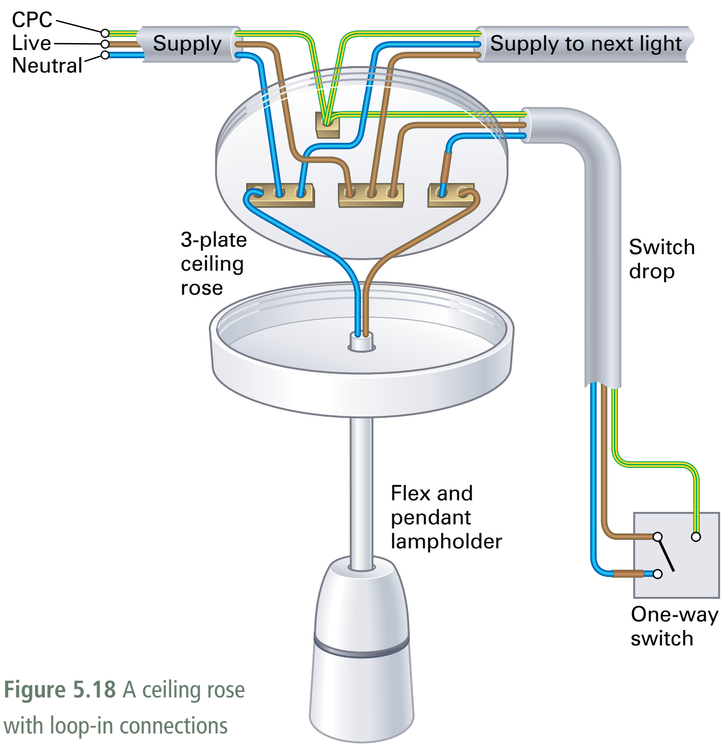


Figure 5.18 A ceiling rose with loop-in connections

Light fittings

The basic light fitting consists of a lampholder, flex and a ceiling rose which is fixed to the ceiling and provides the main connection point. This arrangement is usually called a pendant fitting. The battenholder is an alternative version in which the lampholder is fitted directly to the ceiling rose. These are normally used in bathrooms or where there is a low ceiling and a flex would cause the lampholder to become an obstruction.

Most ceiling roses are fitted with line, neutral and earth terminals plus an extra set called the loop-in terminal. This is used as a connection point for the lighting circuit's line feed when the circuit is wired in twin-and-earth cable (see page XX).

Ceiling roses and lampholders also feature cord-grips. The cores of the flex must be long enough to pass under these grips, which take the weight of the lampholder, lamp and whatever shade might be fitted to the pendant.

Connectors

There are times when cable conductors need to be connected together. The approved method for doing this is to use connectors (sometimes called 'chocolate' or 'choccy' blocks). These are available in strips and are, like junction boxes, sized to suit various current ratings. Connectors should never be used outside an enclosure such as a plastic connection box (sometimes known as an adaptable box), because the metal terminal screws are exposed to touch and could cause electric shock.

Crimped ferrules can also be used for joining conductors. Again, these should be secured inside an enclosure.

QUICK CHECK

- What are the voltage colour-schemes for plugs and sockets?
- When would a battenholder be used?
- What is a 'loop-in' terminal?

Electrical equipment

There are four main types of electrical equipment:

- electromagnetic
- heating
- control
- electronic (see Chapter 11).

Generator

Magnetic fields are formed into lines which run between the magnetic poles. These lines are called magnetic flux and have a north-to-south orientation. If a conductor is passed across these lines, a voltage is **induced** into the conductor.

Voltage strength affected by:	Polarity affected by:
Density of flux Denser flux = higher voltage	Direction of magnetic flux
Speed at which the conductor is moved Faster movement = higher voltage	Direction conductor is moved through the magnetic field
Cross-sectional area of conductor Larger conductor = higher voltage	
Length of conductor Longer conductor = higher voltage	

Table 5.04 Voltage strength and polarity

Key terms

Induced – the process of electromagnetic induction, this is the effect caused by passing a conductor across lines of magnetic flux

Polarity – in a circuit is the direction which the current flows. This is governed by the position of the positive and negative terminals because current flows from positive to negative

The practical application of this principle is to form the conductor into a series of loops, or windings, then rotate it within the magnetic field. This machine is called a generator. The resulting electricity is picked up by carbon brushes and, from there, connected to the load.

There are two types of supply: direct current (d.c.) and alternating current (a.c.). With a d.c. supply, the **polarity** remains fixed (batteries also produce d.c.).

The mains supply to all normal electrical installations is a.c.; in this case the current constantly changes direction. In the UK this swapover occurs 50 times per second and is called the supply frequency. One of the advantages of a.c. is that it is easily transformed (see page 172).

The windings in a d.c. generator are connected to a segmented cylinder called a commutator. As it turns through its circle, each carbon brush picks up the half of the winding that is rotating in a particular direction through the magnetic field. That way each brush remains either positive or negative.

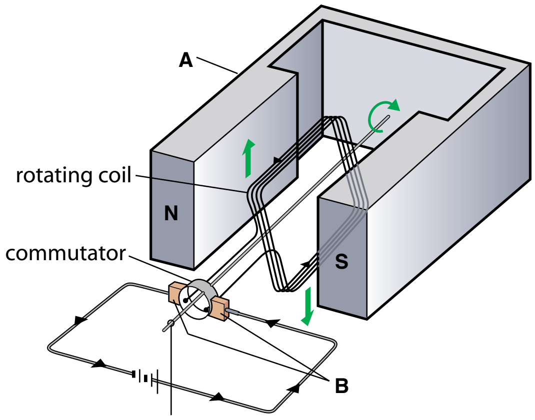


Figure 5.19 A d.c. generator

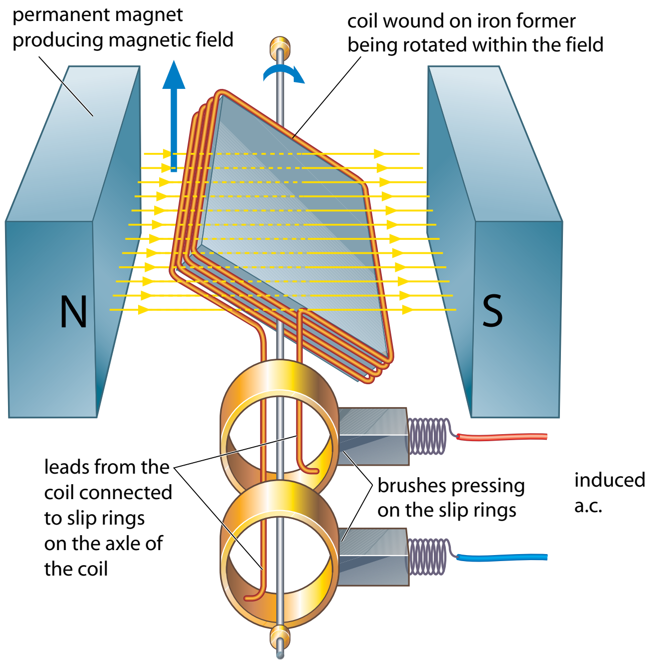


Figure 5.20 An a.c. generator

For a.c. generation, each end of the windings is connected to a separate slip ring. Each ring is, in turn, permanently connected to a carbon brush which picks up its induced voltage as it completes its rotation and cuts the flux first one way then the other, changing the polarity of the brush as it goes.

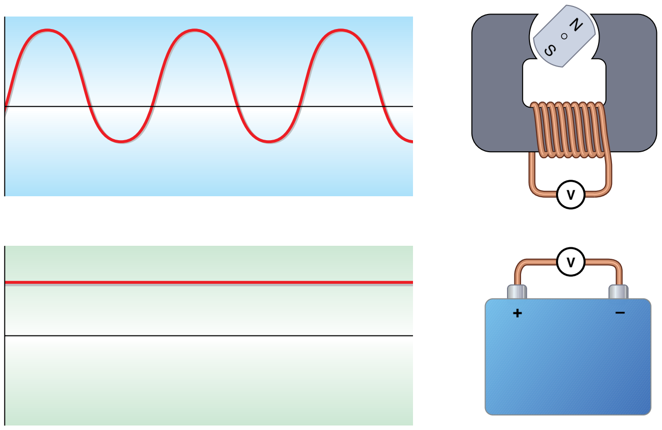


Figure 5.21 The difference between d.c. output and a.c. sine wave

The property	The symbol	Its measurement	Measurement symbol
Magnetic flux	Φ (phi the Greek letter F)	webers (pronounced vay-bers)	Wb
Magnetic flux density	B	teslas	T
Inductance	L	henrys	H
Frequency	F	hertz	Hz

Table 5.05 Properties and measurements

National power generation

The giant generators that provide the high voltage power for national distribution are located in power stations and driven by steam. The steam is produced using:

- coal
- oil
- gas
- nuclear power
- wind power is also used more and more and wind turbines are becoming a common sight.

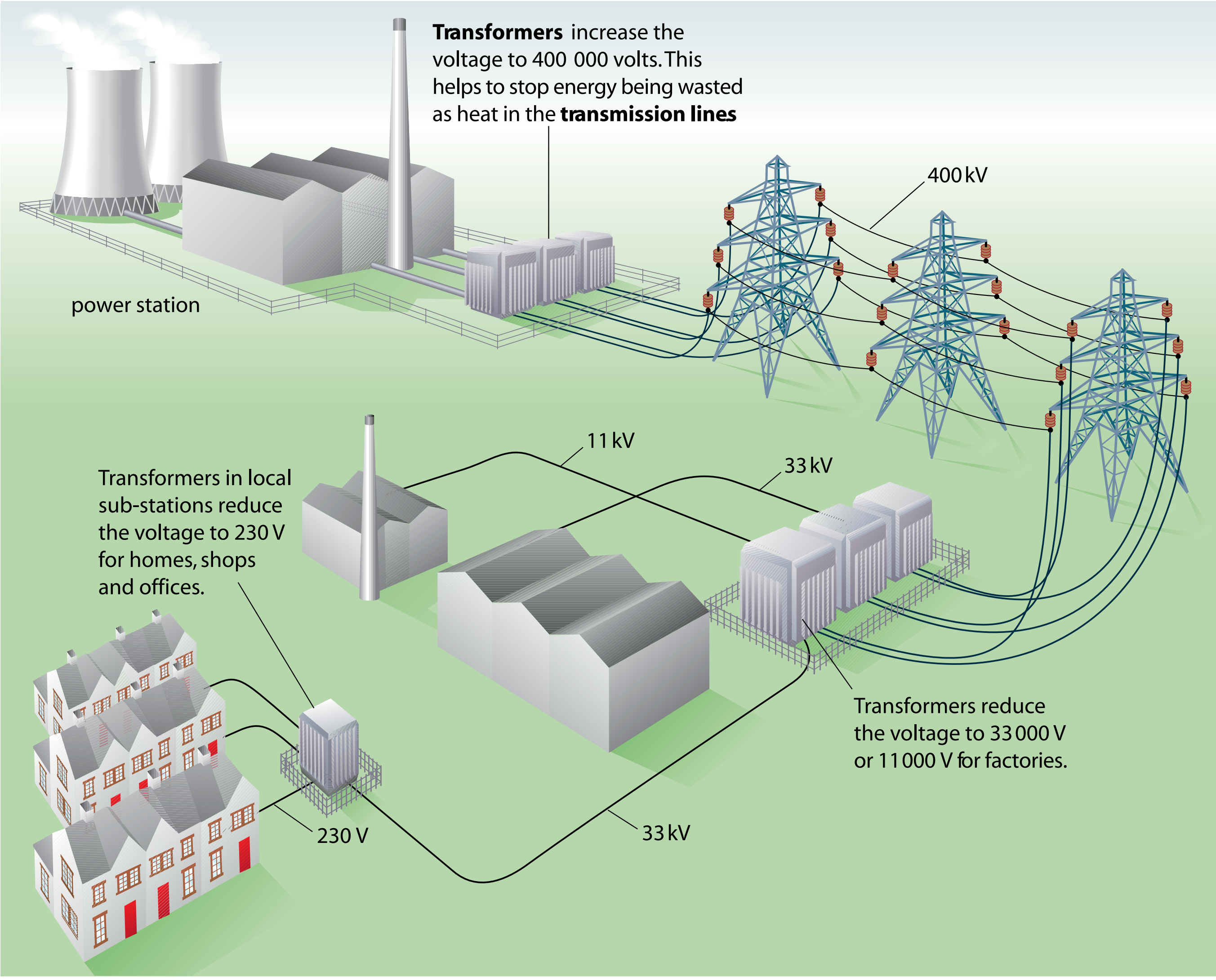


Figure 5.22 The national grid

Poly-phase supplies

Electricity generated by power stations is produced as a poly-phase supply. This means that there is more than one line conductor connected to the generator and that power is induced into each of these lines in turn.

In the UK a poly-phase system consists of three lines. They are colour-coded:

- L1 – brown
- L2 – black
- L3 – grey.

The voltage between any of the lines, for example L1 and L2, is called phase voltage or U_{ph}

The voltage measured between any of the line conductors and neutral and earth is called line voltage or U_L

$$U_L = U_{ph} \times 1.7$$

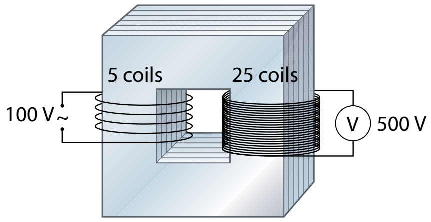
$$U_{ph} = \frac{U_L}{1.7}$$

For a mains supply $U_L = 230\,V$ and $U_{ph} = 400\,V$

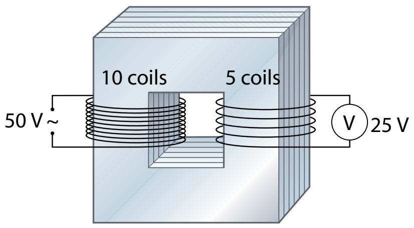
The reason electricity is generated as poly-phase is that it spreads the load over the phases. Because of this the conductors each carry less current and can be smaller. Also, some types of electric motor, such as the induction motor, are operated by the relationship between the phases.

Transformer

Transformers are designed to either decrease (step-down) or increase (step-up) voltage. The national power distribution system is divided into its various sections by a series of transformers which step up the power station voltage of 25,000 V (25k V) to 400 kV. Then step it down again by stages until it reaches the local distribution transformer and is reduced to 400/230 V.



A step-up transformer has more turns in the secondary coil than in the primary coil. The potential difference across the secondary coil is greater than that across the primary coil.



A step-down transformer has fewer turns in the secondary coil than in the primary coil. The potential difference across the secondary coil is less than that across the primary coil.

Figure 5.23 A transformer showing step-up and step-down versions

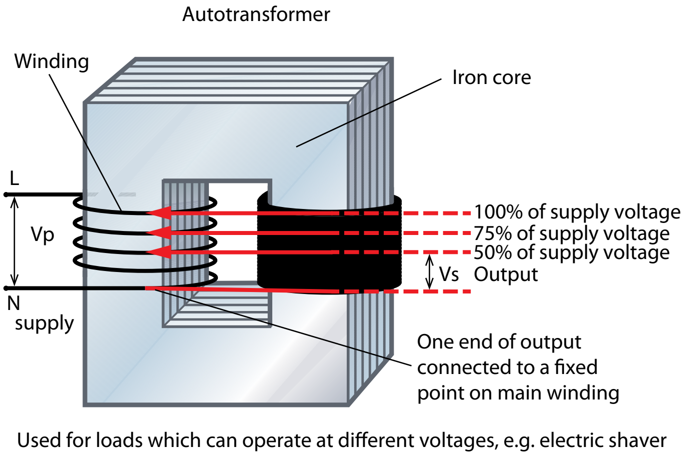
How a transformer works

The transformer's heart is an iron core, which is made up of layers or laminations. Wound round the core are two sets of insulated conductors. One set of these windings is connected to an a.c. supply source. This is the primary winding. The other windings are connected to the load. This is the secondary winding.

1. When the supply is switched on, the core becomes magnetised.
2. Because the supply is a.c., the magnetic poles constantly swap over and the strength of the magnetic field changes.
3. The secondary winding is now a conductor in a changing magnetic field.
4. As a result, voltage is induced into the secondary winding.

The amount of output voltage depends on the number of turns in the winding.

Types of transformer



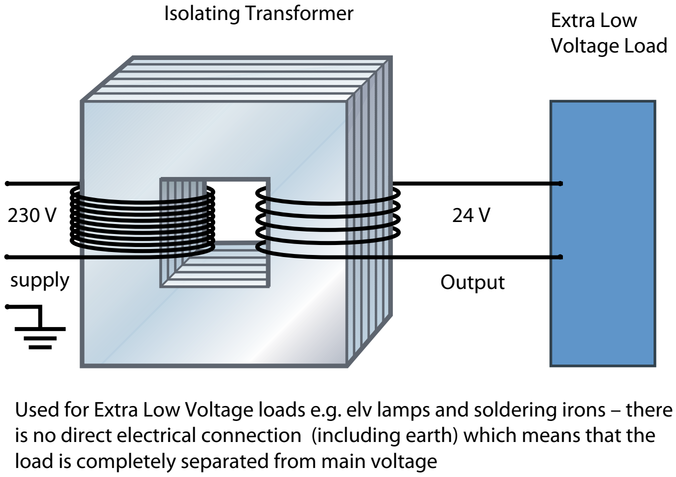


Figure 5.24 An auto-transformer and an isolating transformer

Electric motors

Figure 5.05 on page 158 shows how a magnetic field corkscrews in a clockwise direction along the outside of a conductor when it is carrying current. If this live conductor is placed in a magnetic field it will bend the lines of flux and force will be exerted on the conductor at the point where the two magnetic fields are orientated in the same direction.

Quick Tip

A simple d.c. motor can also be converted into a generator by switching off its supply then rotating it mechanically.

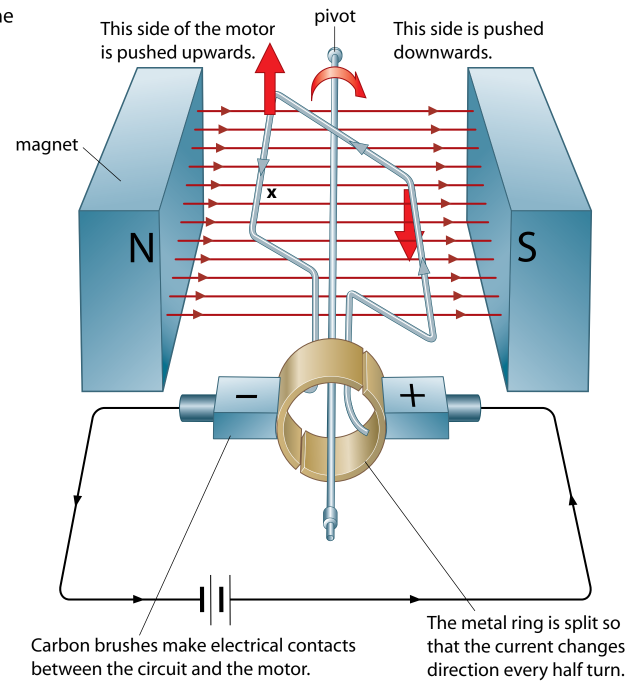


Figure 5.25 A simple d.c. electric motor

This force can be calculated.

$F = BIl$
F is force exerted on the conductor in newtons,
B is magnetic flux density (see page XX) of the magnetic field.
I is the current in amps that is flowing in the conductor
l is the length of the conductor in metres

If the conductor is formed into a set of windings, the same as those in a generator, it will become a rotating machine, an electric motor.

Property	Symbol	Measured in	Symbol
Force	F	newtons	N

Table 5.05 Properties and measurements

Quick Tip

- A generator converts mechanical energy into electrical energy.
- An electric motor converts electrical energy into mechanical energy.

Discharge lighting

Fluorescent light (or luminaires) are started using electromagnetic effect. For the lamp to operate, current has to be discharged from the elements at one end of the lamp to the element at the other end. Once this has occurred, the **inert gas** in the tube will glow and give light.

Key term

Inert gases – non-flammable types such as helium and argon

There are two main components in the fluorescent fitting that create this discharge.

Starter

A small capsule plugged into the fitting. The starter is filled with inert helium gas. It also contains a bi-metal switch. Because a bi-metallic strip is made up of two different metals which expand and contract at varying rates, heating and cooling will cause it to bend. This bending action can be used to make and break a switch.

Choke

The choke consists of a laminated iron core like that of a transformer. An insulated conductor (a winding) is wound round the iron core.

How the fluorescent fitting starts

1. The light switch is operated and current flows into the fitting circuit.
2. The starter is open so current cannot pass though, however, as the helium gas heats up. The bi-metal switch bends and makes the circuit.
3. Current flows into the tube through the choke.
4. As soon as the contact is made in the starter, the helium gas cools down and the switch opens.
5. The supply is cut off to the choke and lamp.
6. The current drops to zero almost instantly, but the magnetic field takes longer.

7. As the magnetic field collapses it induces a voltage into the choke, which causes the tube to attempt to strike.
8. This cycle is repeated until the tube strikes and current can flow through the tube bypassing the starter.

This is a typical starting process for fluorescent luminaires. There are others, such as the use of an auto-transformer (see page XX).

Hands On

Remove the cover from a fluorescent luminaire. Identify the main components, trace the wiring and draw out the circuit. Match the drawing and components to the description above.

QUICK CHECK

1. Which set of transformer windings are connected to the supply?
2. Which type of electrical supply has a constantly changing polarity?
3. How much forced will be exerted on a 0.3 m long conductor, carrying 12 A when it is placed in a magnetic field of 0.2T density?

Heating

Many items of domestic electrical equipment work on heating element principles. An element is a coiled, uninsulated conductor of high resistance. The high resistance produces heat and, depending on the type of material used, light. The incandescent lamp, which includes standard light ‘bulbs’ (rapidly being replaced by low energy lamps), consists of a sealed glass bulb containing an element and filled with inert – non-flammable – gas. Once the element heats up it glows brightly enough to provide illumination.

Types of heating include:

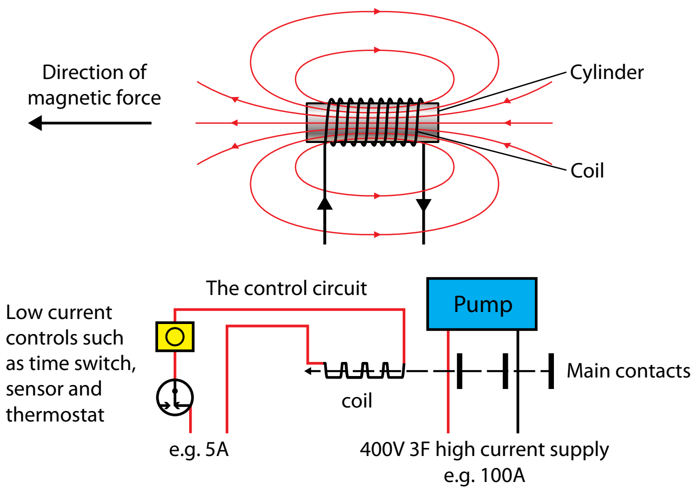
- electric fires
- fan heaters
- hot water elements
- kettle elements
- under-floor heating
- oil-filled radiators
- cooker hotplates, and oven and grill elements.

Electrical controls

Electrical control is the method by which electrical loads are switched on and off automatically. Increasingly electronic circuitry is being used for this type for control but the basic electrical systems are still installed and are in use.

Electromagnetic switching

When a coil of copper is wound into a coil then energised, a uniform magnetic flux will be set up both around and inside the coil. If an iron rod is placed in the coil, it will be drawn inside by the magnetic field. If the rod is spring-loaded so that it returns out of the coil once the supply is switched off, it can then be used as an automatic switch. This device is called a solenoid.



Control circuits often use one supply to switch another e.g. a low current supply to switch a high current load. An example of this is a heavy duty pump operated by a time switch and thermostat.

Figure 5.26 The principle of the solenoid coil and simple control circuit

The solenoid principle is the basis of electrical control circuits. Smaller switching devices of this type are called relays, larger, higher current versions are called contactors. Control circuits often use one supply to switch another, which means that a low current supply can be used to supply a coil, which in turn operates the switching for a high current load. Low current devices such as sensors and time switches can be connected into the coil circuit.

Thermostat

Thermostats are an automatic switch used to regulate temperature, whether the heat output from an oven or the low temperature of a refrigerator. The main components of a thermostat are a bi-metallic strip and heating coil. Because a **bi-metallic strip** is made up of two different metals which expand and contract at varying rates, heating and cooling will cause it to bend. This bending action can be used to make and break a switch.

The rod-type expands and contracts lineally and is used for water heater control. Oven thermostats use the expansion and contraction of liquid to operate. The liquid is contained in a tube inserted into the oven heating area.

Three-setting switch

As well as using a thermostat to control temperature, many grill elements in cookers use a three-position switch.

The elements themselves are arranged into banks and the switch connects the elements in three different configurations:

- series – low heat
- series and parallel – medium heat
- parallel – high heat.

Time switch

The standard time switch consists of a rotating dial powered by the electrical supply. Operating times can be set on the clock dial. Some older types of time switch are fitted with clockwork motors that are wound up by the rotation of the dial during normal working conditions then supply enough energy to operate the time switch dial if the power fails. Increasingly, electronic timers are being used – particularly on controllers for systems such as heating.

Passive infrared sensors (PIR)

PIR is widely used to operate external security lighting for both commercial and domestic premises. The sensor emits infrared light which is invisible to the human eye. If a person crosses the beam of light, the beam will be broken and a switch triggered. PIRs can also be used for intruder alarms.

Fixing accessories and equipment

Most electrical equipment is fixed to walls and ceilings. The following fixing methods should be employed for most situations. It is vital that all electrical equipment is fixed securely and that it is also level. This includes cables. So, always use a spirit level, whether you are fixing a large distribution board or a single plastic light switch.

Masonry walls (block, plaster, brick)

Wall plugs and woodscrews should be used. Wall plugs are usually made of plastic and are designed to open up and grip the sides of the fixing hole when a screw is turned into them.

Plasterboard wall and ceilings

Cavity fixing should be used on plasterboard surfaces. There are a number of cavity fixings, including the umbrella bolt which is forced shut when pushed into the fixing hole. The spring-loaded anchors snap open when it exits into the cavity. There are also wall plug type fixings equipped with teeth-like protrusions designed to grip the sides of the fixing hole.

One method of fixing a heavy light fitting to a plasterboard ceiling is to install a wooden 'noggin' between two joists. The light can then be fixed to the noggin.

Large equipment

A metal version of the wall plug fitted with a bolt rather than a woodscrew is used for larger equipment. One type of heavy fixing is the raw bolt. Once the plug is driven home into the fixing hole, a wedge is hammered into it. The wedge opens the plug's jaws, which grip the sides of the fixing hole.

Cable fixings

Most cables have associated fixings available, for example cable clips for twin-and-earth and p-clips for fire proof cables. Cable clips are nailed into the surface. The nails supplied with the clips are usually masonry type nails which can be driven into brick and plaster.

Cable ties are used for securing cables to cable tray (see Chapter 8). These are available in carious sizes and, for the most part, can only be used once. One side of the cable tie is serrated. The teeth face one way and lock against the slot in the cable tie's head. Once pulled home, it is impossible to release. There are, however, re-usable cable ties available, although they are expensive.

See Chapter 8 for more detail on fixing methods.

Hands On

Study the workshop and a classroom in your college or training centre. What types of surfaces are present? How would you fix various items of electrical equipment to those surfaces? Write a method statement for each, including tools and material required, and a step-by-step fixing guide.

Positioning electrical equipment

Electrical equipment must be fitted in the correct positions. The electrician will be supplied with a scale layout drawing for most jobs. This gives the exact position for the switches, sockets and other accessories and equipment. There are times when this is crucial, for example, in a kitchen where a wrongly-sited socket or switch could be covered by a cupboard.

The *Electrician's Guide to the 17th Edition of the IEE Wiring Regulations BS 7671:2008 and Part P of the Building Regulations* (2nd edition) gives details of heights and positioning of electrical equipment in a domestic installation. For example:

- 13A, telephone and television aerial sockets – 450 mm from the finished floor level
- switches, doorbell pushes etc – 1200 mm from the finished floor level
- in a kitchen, 13A sockets should be a minimum of 300 mm from a sink.

Connecting up

All accessories and equipment need to be connected. There are a number of methods for doing this. It is important, however, to remember the following when terminating cables into accessories and equipment.

- The conductor must be inside the terminal with no bare metal exposed.
- If a single, small conductor is to be connected into a terminal, bend the conductor double for a tight fit.
- Never cut any of the strands from a stranded cable to make the conductor fit the terminal.
- Be careful not to clamp the terminal screw onto the insulation.
- Make sure connections are tight because loose connections cause hot spots.
- The outer sheath of a cable must be taken into the enclosure of an accessory or connection box of any kind.

Basic terminal

This type of terminal is a small cylinder set into the back of an accessory. It is usually made of brass. A screw set into the side of the cylinder secures the conducer in place. In some types, a clamping plate is fitted to the bottom of the terminal screw; in others, the screw itself compresses the conductor.

Post terminal

Some electrical equipment has a terminal which consists of a short threaded post onto which a set of nuts and washers are fitted. When connecting to a post-type terminal, the conductor should be either formed into a hook or a circle. When bending the conductor, make sure the bend follows the tightening direction of the locking nut (usually clockwise). A better connection can be made using a crimped lug.

Figure 5.27 Crimp-lug and crimping tool

Soldered termination

The connections in many electronic circuits are made by soldering, which is similar to welding but on a much smaller scale. Soldering requires a soldering iron and a material called flux. The flux is melted onto the termination using the tip of the soldering iron. When it cools and dries (which is almost instantly), it secures the conductor to the termination point. Care must be taken when soldering because:

- the soldering iron is extremely hot
- the fumes from the flux are harmful to health, which means that good ventilation is required.

Electronic components or electrostatic devices (ESD) must not be exposed to static electricity. To counter this, the technician must wear a wrist band connected to the installation earth. For more detailed information on soldering, electronic components and static hazards, see Chapter 11.

Identification of cores

BS 7671:2008 states that all conductors must be clearly identified. For many cables this has already been achieved by using colour-coded cores.

For single-phase	For three-phase
Brown – line	• Brown – Line 1
Blue – neutral	• Black – Line 2
Green and yellow – Earth	• Grey – Line 3

Table 5.06 Colour-coded cores

The cpc in a twin-and-earth cable is un-insulated. This means that when the cable is connected the cpc must be covered using green and yellow striped sleeving. When using twin-and-earth to wire lighting circuits (see page XX) the blue conductor between the switch and the light is often used as a switch line and not a neutral. In this case a small piece of brown tape or sleeving must be used to identify this fact. The same applies when using three-core and earth for two-way lighting circuits (see page XX). In this case, the black and grey cores must be identified as line conductors.

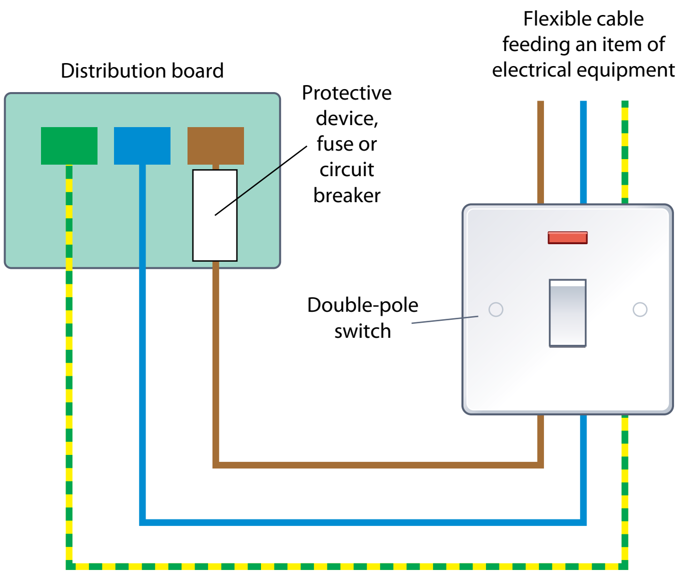


Figure 5.28 A radial circuit

Types of circuit

There are five main types of circuit the electrician is likely to install. These are:

- radial
- lighting
- ring final
- alarm
- control (see page XX).

Radial circuit

A radial circuit is a basic circuit used to feed a single piece of electrical equipment such as a cooker, shower or water heater. Radial circuits consist of a line feed, neutral return and a cpc, connected to the load via a double-pole isolator placed in an accessible position adjacent to the load.

Ring final circuit

13A sockets are usually wired as a ring final circuit. There is no limit to the number of sockets that can be connected into a ring final circuit provided the circuit covers an area of less than 100 m². In a ring final circuit, the line, neutral and cpc are run from the distribution board, connected to each socket in turn then brought back into the distribution board. This means that there are two lines, two neutrals and two cpcs as the supply end of the ring.

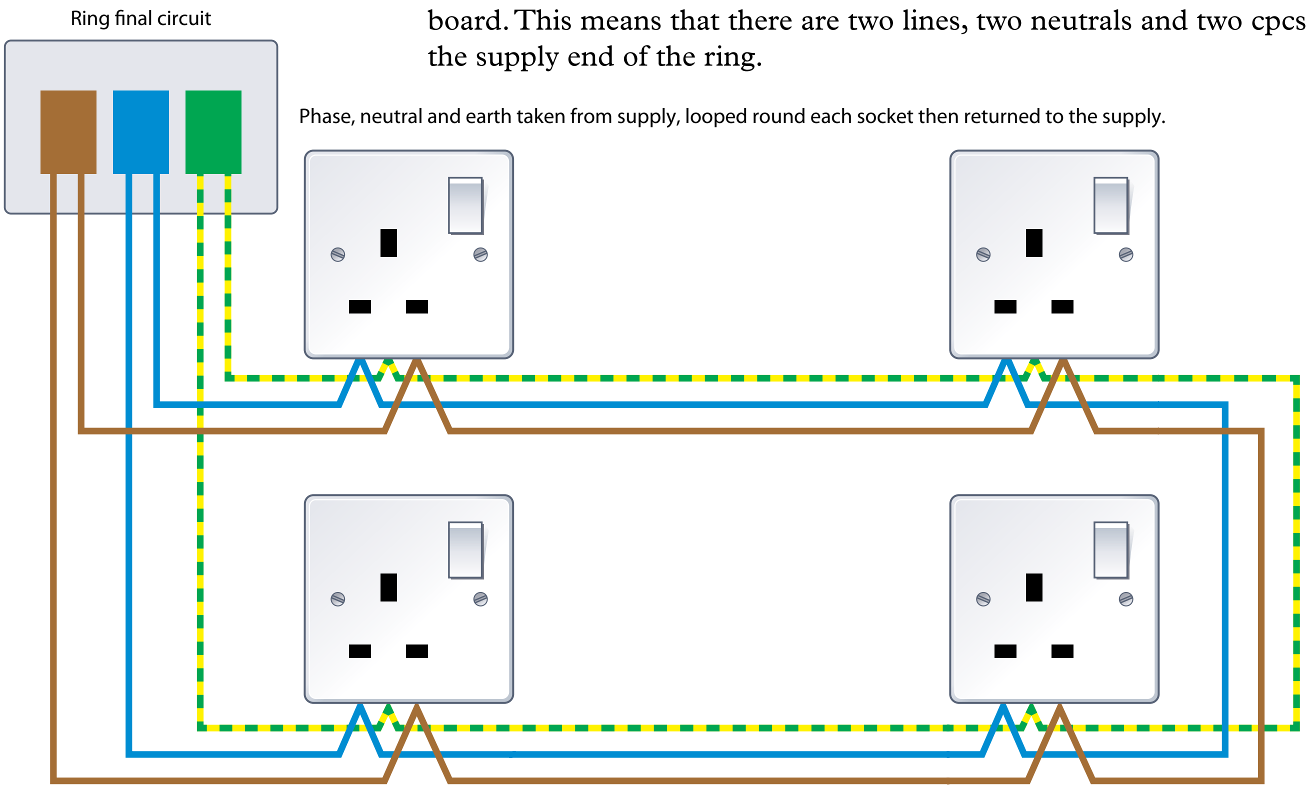


Figure 5.29 A ring final circuit

Ring final circuits are normally wired in 2.5 mm² cable and backed up by either a 32 A circuit breaker or a 30 A fuse. BS 7671:2008 also states that ring final circuits should incorporate shock protection in the form of a residual current device (RCD) (see page XX).

It is possible to connect a radial sub-circuit into a ring final circuit. This is called a spur. Spurs are used when extra outlets are required and it is not possible to open up the ring itself. The spur should be connected into ring final circuit either by connecting into an existing socket outlet or by installing a 30 A junction box in one of the ring final circuit cables. The BS 7671:2008 guidelines for spurs are:

- the number of spurs in a ring final circuit should not exceed the number of sockets in the ring
- the spur should feed one fixed load or two 13 A socket outlets (either two single sockets or one double).

If a large number of spurs are needed then it is good practice to wire an extra ring final circuit rather than use large numbers of spurs off an existing ring.

One-way lighting circuits

Loop-in method

The loop-in method is used when wiring a lighting circuit in twin-and-earth cable. It can be seen from the diagram that the blue conductor running from the switch to the light is used as a 'switch line'. A small piece of brown tape or sleeving identifies this is a line conductor and not the neutral. Lighting is usually wired using 1.5 mm² and backed up with a 6 A circuit breaker or 5 A fuse.

Two-way lighting circuit

Two-way switching is used to control lighting on a stair way, a corridor or in a room with two entrances and exits. Each switch will either turn the light on or off. A two-way switch acts as a **change-over switch** and does not have a straightforward on-off position. This means that if the power is off it is impossible to tell if a two-way switching is in the on or off position.

More switches can be added into this system, if for example a room has three or more entrances and exits. These are called intermediate switches and work by changing the current's route through the strappers.

Key term

Change-over switch – a functional switch that alters the current flow through a circuit rather than simply switching it on and off, like the points on a railway track

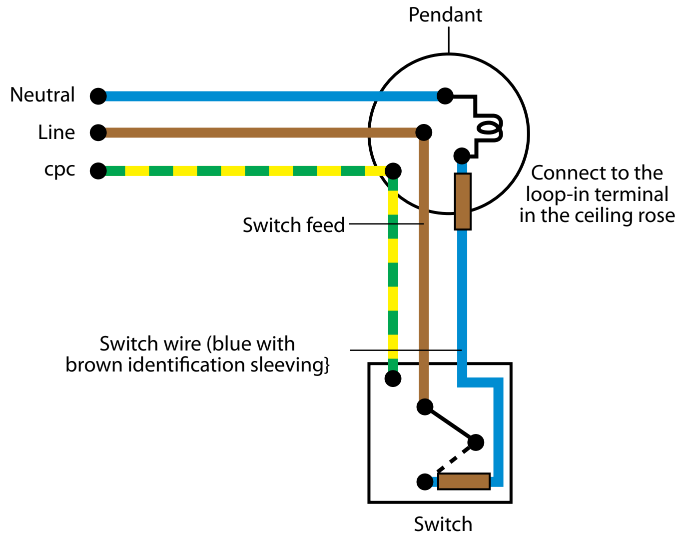


Figure 5.30 A one-way light loop-in method

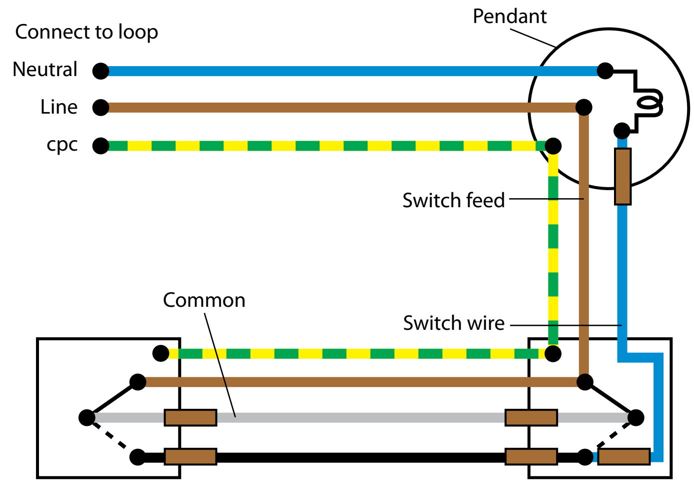


Figure 5.31 A two-way lighting circuit (loop-in method)

Did You Know

There are two types of switch.

- **Functional** – which operates as part of a circuit's normal operation. This includes light switches and automatic controls such as thermostats and sensors. Functional switches are operated on-load (with load still on) and switch the line conductors only.
- **Isolator** – a switch used only for cutting power to equipment so that repairs or maintenance can be carried out. Switches both line and neutral conductors off-load (load switched off).

Lighting circuits using singles

The previous diagrams showed how to wire lighting circuits using twin and earth. If conduit or trunking is used, however (see Chapter 8), the actual wiring method for the circuit will be different. The diagrams below illustrate the main wiring layout for lighting circuits using singles. An intermediate switch has been added into the two-way circuit.

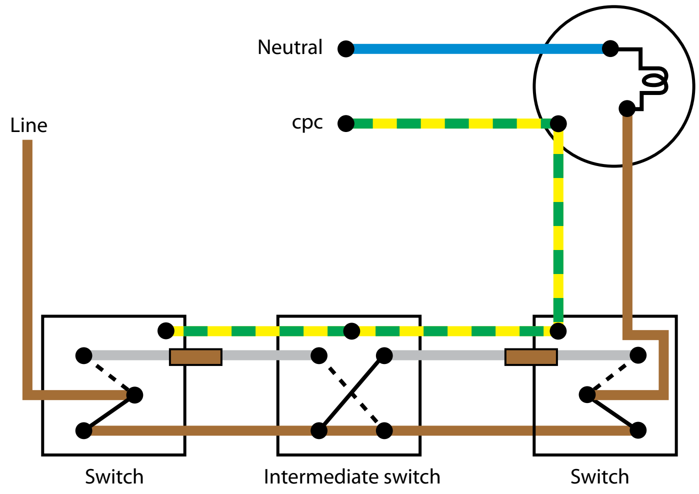


Figure 5.32 A one-way and two-way plus intermediate lighting circuit using singles

Alarm circuits

Alarm circuits are used to control and operate emergency systems such as fire, gas and intruder alarms. They usually have a main control panel and are activated by sensors such as smoke detectors, heat detectors and the break-glass switches you find in schools and other public buildings.

Maintained emergency lighting

This is lighting supplied by both the normal electrical system and the emergency back-up system.

Non-maintained emergency lighting

This is emergency lighting that only operates when the mains supply fails.

Vehicle electrical systems

Cars, aircraft and other forms of transport all have electrical circuits within their engine and control systems. These circuits provide:

- the current which starts the vehicle
- the current for components such as spark plugs which keep the engine running
- lights
- audio equipment
- gauges and displays
- automatic locks
- alarm systems.

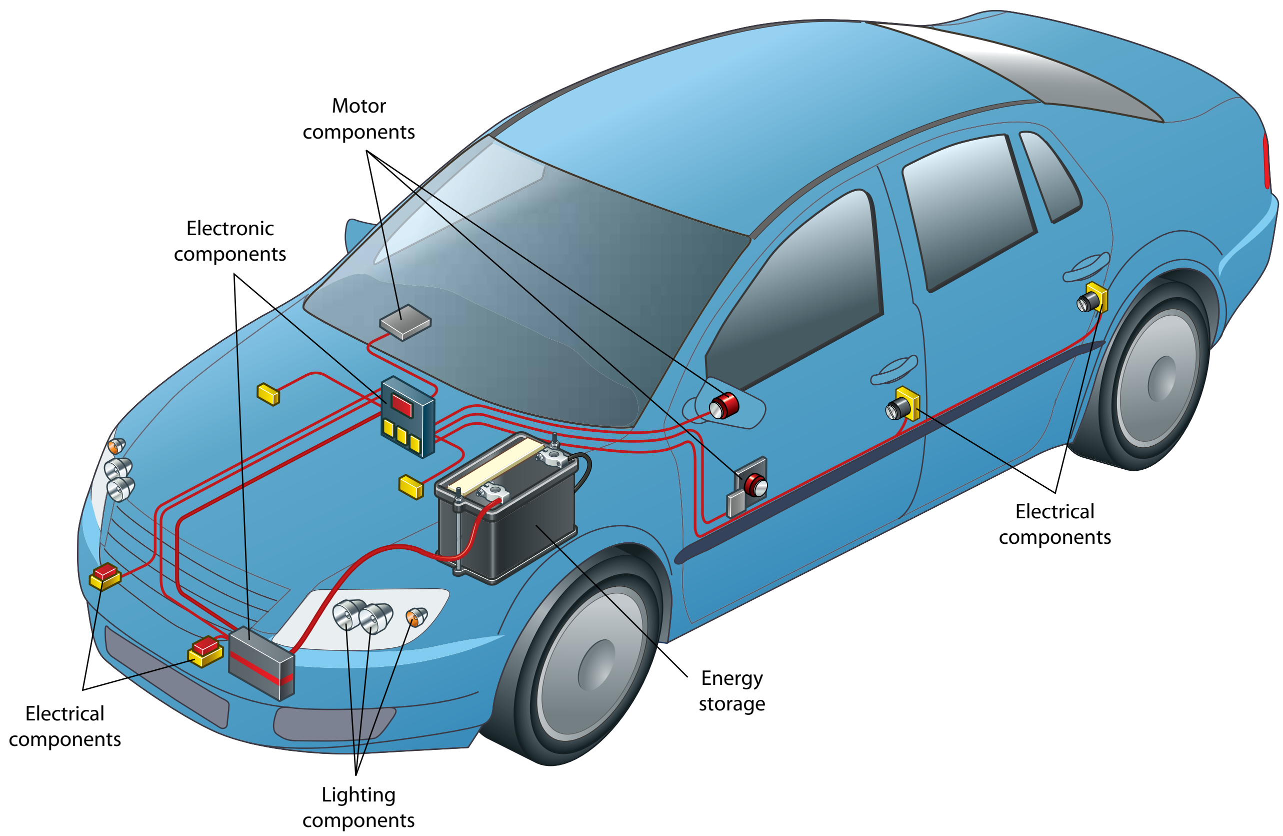


Figure 5.33 A basic car circuit

Motor vehicles have a battery, which is a d.c. power source. Cars also have an a.c. generator or alternator which provides an a.c. supply to its starting system as well as charging the battery while the engine is running. In a car, the negative is connected to the metal body of the car itself.

Protecting the installation

Electrical protection is a term used to describe the methods by which electrical installations and their users are protected from fire and shock. There are two main types of electrical protection:

- overcurrent
- shock.

Prospective fault current

When an electrical fault occurs, a large fault current will flow from the source of supply to the fault itself. This is called the Prospective fault current (Pfc) and it is this current that will operate the protective device. There are two types of prospective fault current.

- Prospective short circuit current – the maximum current that will flow to the point of a short circuit
- Prospective earth fault current – the amount of current that will flow to the point of a line to earth fault.

Overcurrent

When too much current flows this is called overcurrent. This can be caused by:

- **a short circuit** – when line and neutral accidently make direct contact
- **overcurrent** – the load is too big for its supply cable.

Installations and individual circuits are protected from overcurrent by fuses and circuit breakers:

- **fuse** – a conductor contained inside a cartridge or holder designed to melt and break when its rated current is exceeded
- **circuit breaker** – an automatic switch designed to open when its rated current is exceeded.

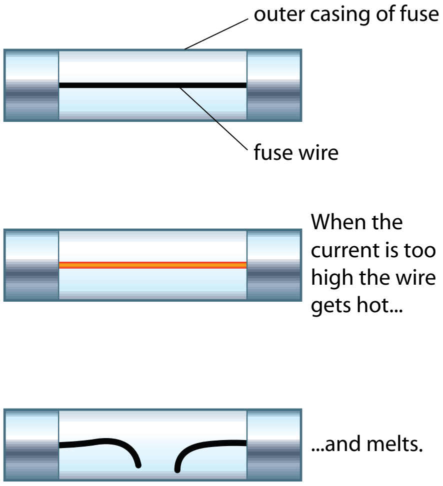


Figure 5.34 How a fuse breaks under fault

No protective device operates instantaneously and will take more than its rated value before operating. For most devices this is 1.4 times their rating. BS 7671:2008 states that all protective devices must be able to withstand the full Pfc. Faults cause large amounts of energy to be released in the protective device, and it must be able to contain the energy.

Some overcurrent devices, such as HRC fuses, are designed to take extra current for several seconds and are used in circuits where the load draws a very high current on start-up before settling down to its normal value. An example of this is the electric motor which draws a high starting current, especially if it is connected to a mechanical load.

Discrimination

BS 7671:2008 explains that the protective device closest to the fault should operate when a fault occurs. For example, if the fault is with a kettle, plugged into a 13 A socket, then the fuse in the kettle's plug should blow and not the main 100 A fuse protecting the whole installation. The diagram below shows a typical layout of fuses and circuit breakers supplying a load.

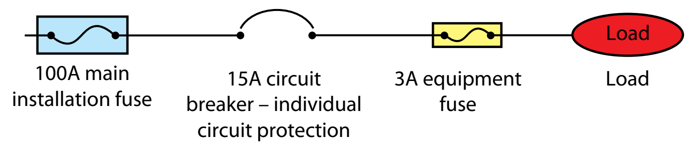


Figure 5.35 Discrimination

Hands On

Under the supervision of a tutor, open the front cover to a working distribution board. You will see the circuit breakers. Check the circuit breaker sizes against the circuits they protect. What size cables would you expect to see feeding each of those circuits?

Distribution board

All the circuits in an installation begin at a distribution board. The board is supplied via a meter which records how much power is used per hour. The line conductor of each circuit is connected to an individual circuit breaker. The circuit breaker has a current rating suitable for the circuit. The neutral and cpc are connected to their appropriate connection bars.

Shock

Electric shock can occur if the outside surface of a piece of equipment such as a cooker or washing machine accidently becomes **live** (known as an earth fault). To prevent anyone touching the faulty equipment, the frame or main enclosure of the equipment should be connected to the earth. A residual current device, or RCD, is connected into the circuit. This is designed to cut the supply if an earth fault does occur. BS 7671:2008 the RCD to operate in less than 30 milliseconds (0.03 seconds)

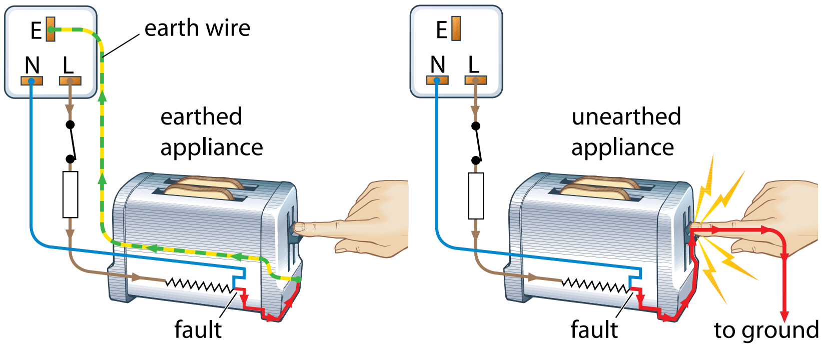


Figure 5.36 Faulty toaster

Earthing systems

All installations are supplied from a sub-station transformer. This is a **three-phase** machine wired in a configuration called star. The centre or star point is connected to earth via an earth electrode. An earth electrode is a stake driven into the ground. The neutral from the installation is also connected to the star point. There are three main methods for connecting the installation earth to the sub-station earth.

TT – Terra-Terra: The installation earth is connected to the main body of the earth via an earth electrode driven into the ground adjacent to the building. This is not a direct connection to the supply transformer star point but it brings the earth to the same electrical potential and the transformer earth. This system tends to be used in rural areas.

Figure 5.37 RCBO

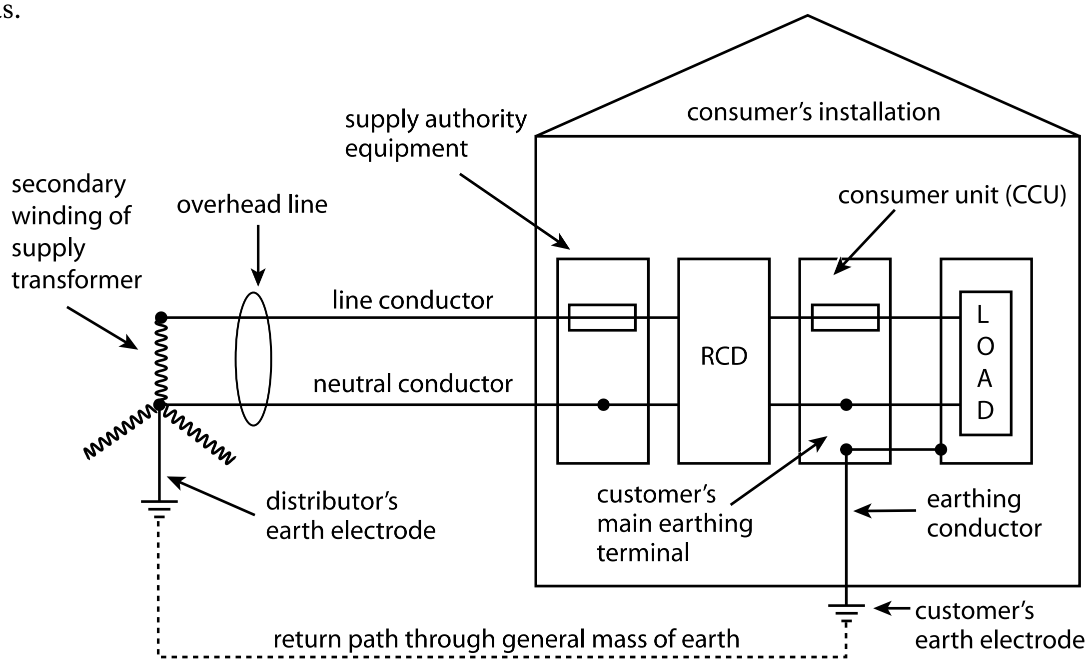


Figure 5.38 A TT system

TNS – Terra Neutral Separate: In this case a separate conductor connects the installation earth to the supply transformer star point. This conductor is typically the armouring of the supply cable.

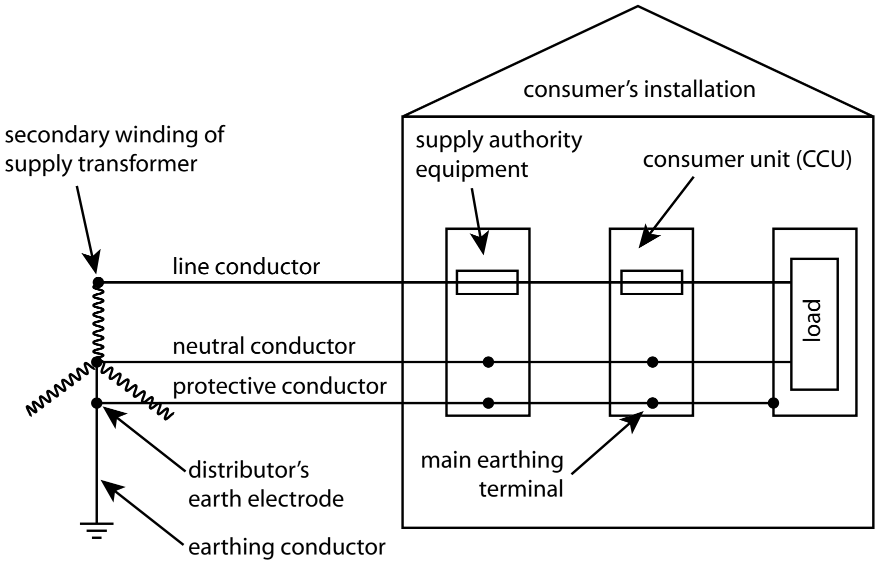


Figure 5.39 A TN-S system

TNC-S – Terra Neutral Combined-Separate: By connecting the installation earth to the neutral on the supply side, any earth fault becomes a short circuit between line and neutral. This increases the fault current which will, in turn, operate the protective device more quickly.

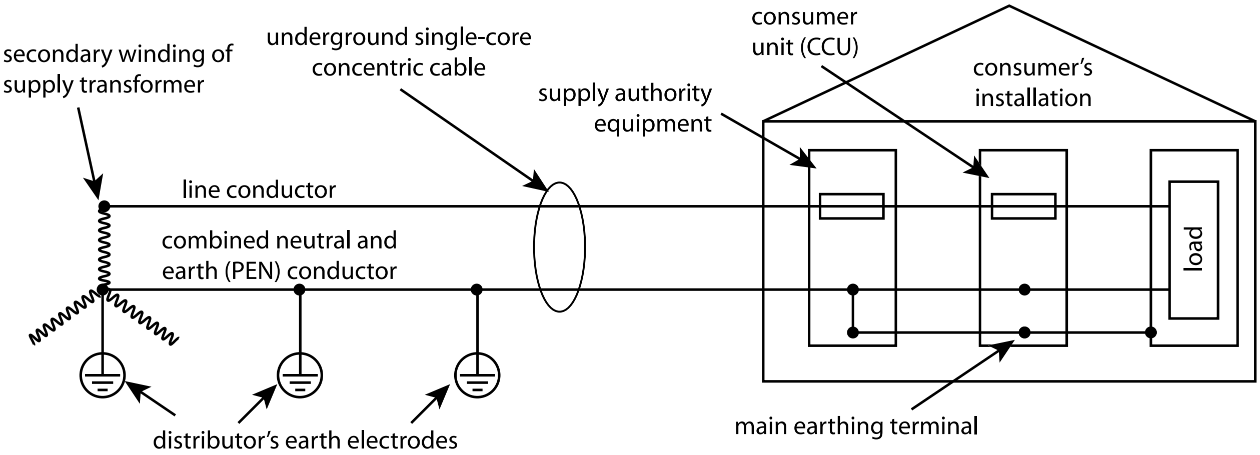


Figure 5.40 A TN-C-S system

Hands On

Under the supervision of your tutor, locate the main entry point of the supply to your college or training centre building. Study the layout and try to establish which earthing system has been used.

Equipotential bonding

All metalwork in an installation should be connected to the building's earth system. This includes metal trunking, water pipes and gas pipes. Below are the names for various parts of the earthing system.

- Exposed conductive part – metalwork that encloses a live part such as a connection terminal or cables and is part of the electrical installation or equipment.
- Extraneous conductive part – metal work such as water and gas pipes that could become live in the event of a fault.
- Protective conductor – the cable that connects metalwork to the installation's main earthing point.
- Main earthing terminal – the connection point joining the installation's protective conductors to the supply earth.

Key terms

Equipotential –everything being at the same electrical potential; in simple terms, everything is connected together

Polarity – the direction in which the current flows. When polarity is correct, the line and neutral conductors are connected to the correct terminals

QUICK CHECK

1. What two types of fault will cause overcurrent?
2. Which protective device should operate in the event of a fault?
3. Where is a TT system mostly used?

Inspection and testing

Once an electrical installation is finished it must be tested to ensure that it is safe to use and functions correctly. This is called inspection and testing. There are seven main tests that have to be carried out.

- **Visual inspection** – an inspection of the installation and its wiring and components to ensure correct installation methods have been used and that there is no sign of damage.
- **Continuity of protective conductor** – a test to confirm that the installation's protective conductors are not broken and provide a low resistance path to earth in the event of a fault.
- **Polarity** – not usually carried out as a specific test but proved during other tests.
- **Continuity of ring final circuit** – a series of tests to confirm that the correct wiring and connection of ring final circuits.
- **Insulation resistance** – test to ensure there are no short circuits or faults to earth.
- **Earth fault loop impedance** – carried out when the circuit is live, this test measures the fault path from the point of an earth fault, to the supply transformer then back to the fault.
- **Functionality** – the final check that everything is functioning safely and correctly.

Approved and calibrated instruments must be used and their serial number recorded on the test sheet. Great care must be taken when carrying the last two tests as these are performed on live circuits.

Quick Tip

To check you will need to unlock the RCD – keep the key to this padlock with you at all times.

Safe isolation

Before any testing takes place the supply must be switched off and secured. These are the basic steps to be taken when shutting down a supply.

1. Identify circuit to be switched off and isolate, normally by removing or operating the protective device.
2. If the protective device is a fuse, remove and place in a secure place. If the protective device is a circuit breaker, fit a lock to prevent it from being switched back on before the work is complete. Erect warning notices and barriers.
3. Test voltage indicator on a known supply or a proving unit.
4. Re-test isolated circuit.
5. Retest voltage indicator on proving unit, to be sure not damaged in test of circuit.
6. If it is dead, work can begin.

The inspection and test and fault finding procedures are described in detail in Chapter 10 Maintaining electrical equipment and systems.

INDUSTRY FOCUS

Tom is an apprentice and works for a medium-sized electrical installations company in Hertfordshire.

What sort of work does your company undertake?

We carry out a lot of different types of electrical work, everything from domestic installations to alarms and even some photovoltaic arrays. Those are what people call solar cells, panels that convert light to electricity. Most of our work is domestic though; rewiring houses, adding in extra circuits and putting the electrical services and wiring in new houses.

What do you do as an apprentice?

At first I helped the electricians pull in cables. I also did a lot of hammer and chisel work, cutting chases in walls for the twin-and-earth to be run in, cutting out the holes for switch and socket boxes. After a while I was given wiring to pull in myself The electrician would explain what the circuit was for and where the sockets or switches were going to be, mark them on the wall for me, then I would be left to install the cables myself. After doing that for a few months I was allowed to actually connect up the accessories and fittings. You have to learn fast and take on responsibility as soon as you can. We normally work in pairs so you have to pull your weight.

I attend college as well, of course. That’s where I learn the theory that backs up what I do on site.

Do you enjoy the job?

Most of the time! I like working with my hands and with my brain so electrical work gives me the best of both worlds. Yes, I have to pull cables in and actually do physical work but some of the circuits and installations are really complicated and you have to plan out exactly how you’re going to do them. You have to understand circuit and wiring diagrams. I enjoy alarm circuits because they are more complicated and you have to think about what you are doing all the time.

Most of the time we work inside but there are jobs outside. Digging cable trenches and laying supply cables, for example, and fitting outside lights and sockets as well.

What would you like to do in the future?

The thing about the electrical industry is that you can specialise. We fit alarms but there are companies that are alarm specialists. There are test and inspection specialists and even stage lighting companies. I think I would like to do something like that. But before you can you have to get your basic electrical qualifications and skills.

CHECK YOUR KNOWLEDGE

1 The electromotive force at the supply end of a circuit is measured in:

a Ohms
b Amps
c Watts
d Volts

2 Resistance is:

a the flow of electricity round a circuit
b a property of a material that opposes current flow
c a property in a material that lowers temperature
d the effect of a magnetic field on a conductor

3 A parallel circuit has three identical loads. The supply current is 30A, what is the current at the second load?

a 10A
b 3A
c 0.1A
d 30A

4 A set of lamps are wired in parallel. One of the lamps fails. What will happen to the other lamps when the power is switched on?

a They will all work.
b Only those on the supply side of the faulty lamp will work.
c The lamps will work but will be dim.
d None of the lamps will work.

5 A series circuit has five loads. The fourth load is 2.76kW and the current is 12A. The voltage across that load is…

a 400V
b 230V
c 550V
d 110V

6 Which of these cable types can be used for fire alarm circuits?

a Twin-and-earth
b Flex
c Fibre optic
d FP Gold

7 How many 13A sockets can be connected into a ring final circuit that covers an area of less than 100m?

a 100
b 20
c No limit
d Depends on local building regulations

8 A voltage is **induced** into a conductor when it is:

a passed across lines of magnetic flux
b moved along the lines of magnetic flux
c attached to a magnet
d rubbed with a magnet

9 A machine that creates electricity is a:

a Element
b Solenoid
c Transformer
d Generator

10 An earth system that relies on an earth electrode to connect the installation to the earth is:

a TT
b TNS
c TNC-S
d TLC