

chapter 6

Basic electrical circuitry and applications

Unit 2 Outcome 3

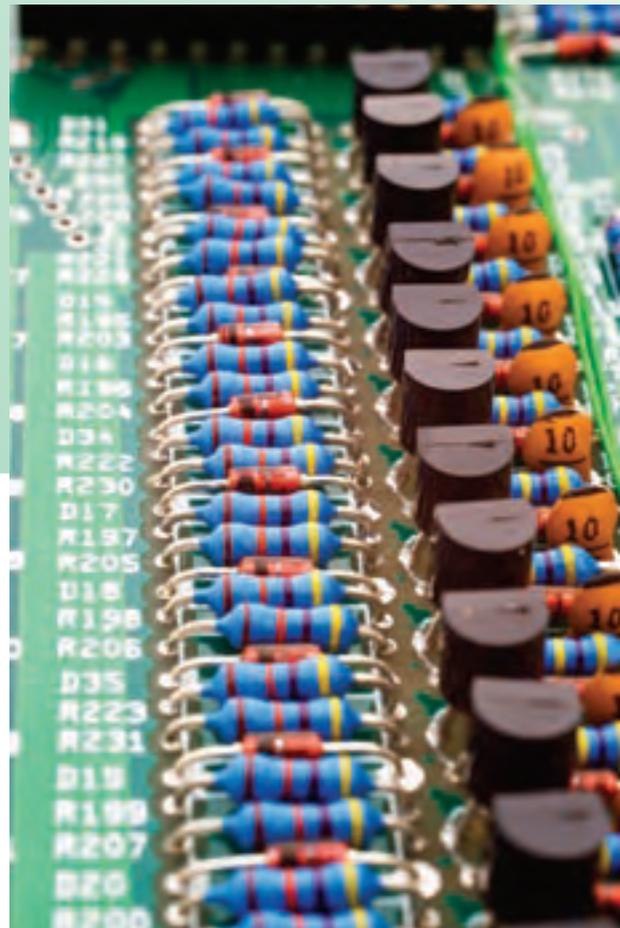
The primary role of an electrician is the installation of electrical circuits and applications. In order to install any type of application, however, it is vital that from the start of your career you are able to put together basic circuitry. This requires knowledge of all parts of the electrical circuit, from the source of supply to the load.

This chapter will cover the various wiring systems, enclosures and equipment you will need to become familiar with in order to carry out your work as an electrician.

We have looked at a number of the terms covered in this chapter earlier in this book. Earthing and bonding, conduction and shock protection all have important roles to play in understanding basic circuitry, and it is these factors you will have to remember when assembling any piece of electrical equipment.

On completion of this chapter the candidate will be able to:

- **state the component parts of an electrical circuit**
- **determine appropriate wiring systems**
- **state the component elements of electrical cables**
- **differentiate between earthing and bonding**
- **list possible conductive parts of structures**
- **state the purpose and function of earth protection**
- **list basic principles or shock protection, circuit overload and short-circuit protection.**



The component parts of an electrical circuit

On completion of this topic area the candidate will be able to state the component parts of an electric circuit.

BS 7671 defines a circuit as ‘an assembly of electrical equipment supplied from the same origin and protected against overcurrent by the same protective devices’. So what does make up the circuit?

Source of supply

Often a circuit is thought of as being the load and the conductors supplying the load. However in reality they are only part of the circuit. In order for current to flow two conditions have to be met.

1. There has to be a potential difference applied across the circuit (voltage).
2. There has to be a complete circuit (circle) for current to flow around.

The source of supply can be a.c. or d.c. If a d.c. supply is required, then this is derived from a battery. For an a.c. supply, either an a.c. generator or a d.c. generator with electrical components to rectify the supply, can be used.

An a.c. supply can be obtained directly from the mains. Single phase 230 V or three phase 400 V are those generally available in the UK.

The size and type of voltage required for the supply is determined by the load equipment to be used. All electrical equipment will have a plate attached to it indicating its safe working voltage.

Circuit conductors (cable)

The circuit conductors are those parts of the circuit which the current passes through. These are the cables. Cables have two components to them. One is the conductor itself. This is usually made of copper. The other part is insulation, usually made from PVC, which forms a sheath around the conductor. The insulation is required to:

- prevent the conductors touching together; this could short the circuit and preventing it from working
- prevent users of the circuit from coming into contact with the conductors and receiving an electric shock.

The type of insulation required is determined by the voltage which is to be applied to the cable.

Cables come as either single or multicore cables. Both have an overall sheath to keep all the associated cables together and to provide a minimal degree of mechanical protection. Appendix 4 of BS 7671 gives details on the sizes and types of cables available to us. We will be looking in more detail at types of cable later in this chapter.

Remember

If a d.c. supply requires a higher voltage, a series of batteries can be used rather than just one

Remember

A transformer can be used for an alternative voltage

Did you know?

The voltage will change depending on the intended use for the cable. A bell circuit which is to be supplied at 6 V will require considerably less insulation than a cable used to supply a heater at 230 V

The size of conductor used in a circuit is important and needs to be calculated accurately. We need to be sure that the conductor is large enough to carry the current produced by the load and to be sure that the load receives sufficient voltage for it to work safely.

Circuit protection

Every circuit requires protection if, in the event of a fault, damage is to be avoided. The inclusion into the circuit of a suitably rated fuse or protective device, such as a miniature circuit breaker (MCB) will protect both the load, and the cables supplying the load, from the heat damage associated with large fault currents.

Protective devices are used to provide a circuit with overload protection, short-circuit protection and shock protection. We will be looking at these in greater detail later in this chapter.

The protective device, or fuse, is deliberately designed to be a 'weak link' in a circuit. When current increases to a level where damage can be sustained, the fuse operates and automatically interrupts the supply to the circuit. As the fuse is a part of the circuit, once it is 'broken' it also breaks the flow within the circuit, ending the supply.

Circuits supplied at voltages below 50 V may be required to have circuit protection for functional reasons. Circuits supplied at 50 V and above are required to have circuit protection that complies with the requirements of BS 7671. For example, low voltage circuits (above 50 volts, but not exceeding 1000 volts) supplying socket outlets must automatically disconnect in the event of an earth fault within 0.4 seconds.

Protective device types include:

- Rewirable fuses to BS 3036
- Cartridge fuses to BS 1361
- Cartridge fuses to BS 88
- MCBs to BS EN 60898
- RCBOs to BS EN 61009.

Circuit control

It is vital that any circuit, no matter its level of complexity, can be controlled. This could be either:

- a simple switch, allowing us to turn the circuit on or off
- a time switch, which activates the circuit at certain times
- a float switch, which controls the water levels in a pump.

The last example is known as functional switching.

Isolation is the ability to remove the supply from all the live conductors, such as at the mains switch, to a complete installation. Emergency switching is another area of control that is required for some circuits. This allows us to press one button and turn off the main supply to a series of equipment, in the event of danger.



Remember

BS 7671 Appendix 4 has tables indicating the current carrying capacity and volt drop for given sizes and types of cable



Did you know?

Circuits supplying fixed equipment, such as lighting, are only required to disconnect within 5 seconds



Did you know?

RCBO stands for residual current device (RCD) with overland protection, combining the capabilities of RCD and MCB

Load

The load refers to the item that requires the supply in order to function. For example, this might mean the lights in a circuit, a heater, a motor to drive a pump or any item of equipment (or combinations of these) that require an electrical supply in order for them to work.

Electrical loads are rated in watts or kilowatts (W and kW). The size of the load is generally stamped on the equipment or marked on a nameplate. This can contain the:

- rating in watts
- frequency of the supply
- supply voltage
- full load current.

If this information is not available on a nameplate, then it would be necessary to refer to the manufacturer's literature to establish the requirements of the load.

Determine appropriate wiring systems, enclosures and equipment

On completion of this topic area the candidate will be able to determine appropriate wiring systems, enclosures and equipment.

The role of BS 7671

Chapter 13 Part 1 of BS 7671 requires that all electrical installations shall be designed to provide for the protection of persons, livestock and property and the proper functioning of the electrical installation for the intended use.

In order to do this BS 7671 requires us to determine the characteristics of the available supply. This can be done by calculation, measurement, enquiry or inspection of existing supplies. The characteristics that need to be determined are:

- the nature of the current – either a.c. or d.c.
- the number of conductors
- voltage
- frequency
- maximum current allowed
- prospective short-circuit current
- earth loop impedance
- nature and size of the load
- number and type of circuits required
- the location and any special conditions that may apply. This should take into account the nature of the location and structure that will support the wiring system and the accessibility of the wiring to people and livestock.

Insulation colours

To identify cables the insulation is coloured in accordance with BS 7671, Table 51.

Table 51 Identification of conductors	
Function	Colour
Protective conductors	Green and yellow
Functional earthing conductor	Cream
a.c. power circuit⁽¹⁾	
Phase of single-phase circuit	Brown
Neutral of single- or three-phase circuit	Blue
Phase 1 of three-phase a.c. circuit	Brown
Phase 2 of three-phase a.c. circuit	Black
Phase 3 of three-phase a.c. circuit	Grey
Two-wire unearthed d.c. power circuit	
Positive of two-wire circuit	Brown
Negative of two-wire circuit	Grey
Two-wire earthed d.c. power circuit	
Positive (of negative earthed) circuit	Brown
Negative (of negative earthed) circuit	Blue
Positive (of positive earthed) circuit	Blue
Negative (of positive earthed) circuit	Grey
Three-wire d.c. power circuit	
Outer positive of two-wire circuit derived from three-wire system	Brown
Outer negative of two-wire circuit derived from three-wire system	Grey
Positive of three-wire circuit	Brown
Mid-wire of three-wire circuit ⁽²⁾	Blue
Negative of three-wire circuit	Grey
Control circuits, ELV and other applications	
Phase conductor	Brown, black, red, orange, yellow, violet, grey, white, pink or turquoise
Neutral or mid-wire ⁽³⁾	Blue

NOTES

(1) Power circuits include lighting circuits.

(2) Only the middle wire of three-wire circuits may be earthed.

(3) An earthed PELV conductor is blue.

Table 6.01 To identify cable insulation in accordance with BS 7671

You will come across conductors with these colours of insulation for many years to come, but only in existing installations. From 1 April 2004, the colours of conductor insulation for new installations changed.

Safety tip

Great care must be taken when installing and connecting cables, especially where old and new cable colours are present in the same building

Conductor	Old colour
Phase	Red
Neutral	Black
Protective conductor	Green and yellow
Phase one	Red
Phase two	Yellow
Phase three	Blue
Neutral	Black
Protective conductor	Green and yellow

Table 6.02 Old conductor insulation colours

Single- or three-phase power supplies

In the UK the size of supply brought into most households is 100 amps single phase, 50 Hertz. Should the assumed current demand of an installation exceed 100 amps, then a three-phase supply is required. However the selection of a three-phase supply can also simply be down to the load, i.e. a requirement to install three-phase machines, motors, pumps etc.

Appendix 1 of the *On Site Guide* gives details of the requirements for calculating demand and diversity for installations. You will deal with single- and three-phase supplies in greater detail in chapter 11.

Switching of lighting circuits

There are numerous switching arrangements that make up a lighting circuit. This section will look at the most common ones. It would not be practical to look at all the possible combinations, as there are simply far too many.

Cabling	Switching arrangements
Wiring in conduit and/or trunking Wiring using multicore/composite cables.	Two-way switching Intermediate switching One-way switching

Table 6.03 Switching arrangements

Did you know?

Reference numbers in brackets here are used by manufacturers to define cable types

Wiring in conduit and trunking

Wiring in this type of installation is carried out using PVC single-core insulated cables (Ref. 6491 X). This code number is a manufacturer's code used to denote different types of cable. The phase (live) conductor is taken directly to the first switch and looped from switch to switch for all the remaining lights connected to

that particular circuit. The neutral conductor is taken directly to the lighting outlet (luminaires) and looped between all the remaining luminaires on that circuit. The switch wire is run between the switch and the luminaire it controls.

Wiring using multicore/composite cables

This type of cable is normally a sheathed multicore twin and earth or three cores and earth (two-way and intermediate circuits only) (Ref. 6242Y and 6243Y respectively). A 'loop in' or 'joint box' method may be employed with this type of installation. In many instances a loop-in system is specified as there are no joint boxes installed and all terminations are readily accessible at the switches and ceiling roses.

With a joint box system normally only one cable is run to each wiring outlet. Where such joint boxes are installed beneath floors they should be accessible by leaving a screwed trap in the floorboard directly above the joint box. All conductors should be correctly colour identified.

On a composite cable installation, where the conductors other than brown are used as a phase conductor, they should be fitted with a brown sleeve at their terminations.

All conductors must be contained within a non-combustible enclosure at wiring outlets (i.e. the sheathing of the cable must be taken into the wiring accessory). Throughout the lighting installation a circuit protective conductor (cpc) must be installed and terminated at a suitable earthing terminal in the accessory/box.

Where an earthing terminal may not be fitted in a PVC switch pattress, the cpc may be terminated in a connector. Where the sheathing is removed from a composite cable the cpc must be fitted with an insulating sleeve (green and yellow); this provides equivalent insulation to that provided by the insulation of a single-core non-sheathed cable of appropriate size complying with BS 6004 or BS 7211.

One-way switching

The most basic circuit possible is the one-way switch controlling one light, as shown in Figure 6.01. In this system, one terminal of the one-way switch receives the switch feed; the switch wire leaves from the other terminal and goes directly to the luminaire (a). Once operated, the switch contact is held in place mechanically and therefore the electricity is continually flowing through to the light (b).

In other words, we supply the switch feed terminal, point (A).

Operate the switch and it comes out at the switch wire terminal, point (B).

Figures 6.02 to 6.04 show the full circuit when wired using single-core cables, which would be run in either conduit or trunking.

Using the old cable colours again, Figure 6.02 now shows a second light point fed from the same switch wire. This means that the second light is now wired in parallel



Remember

Red sleeving changes to brown sleeving



Remember

Cables supplying switches of any circuit and the cables feeding away from the switch to the light are identified. The cable from the distribution board to the switch is called the switch feed, and the cable from the switch to the light is called the switch wire



Find out

Find out what is pattress

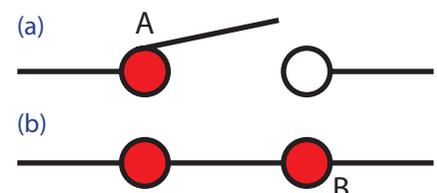


Figure 6.01 One-way switching

with the first light.

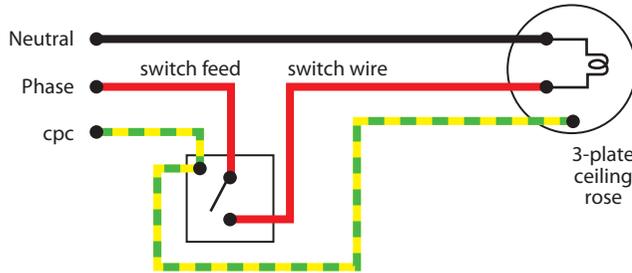


Figure 6.02 One-way switching for wiring with single-core cables (old cable colours)

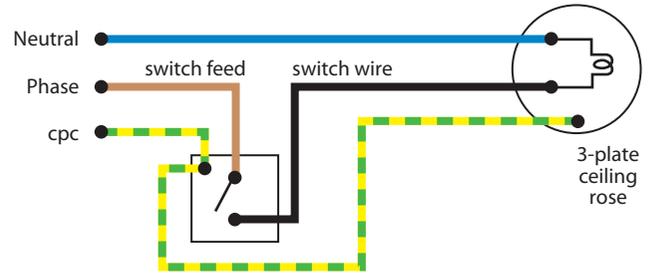


Figure 6.03 One-way switching for wiring with single-core cables (new cable colours)

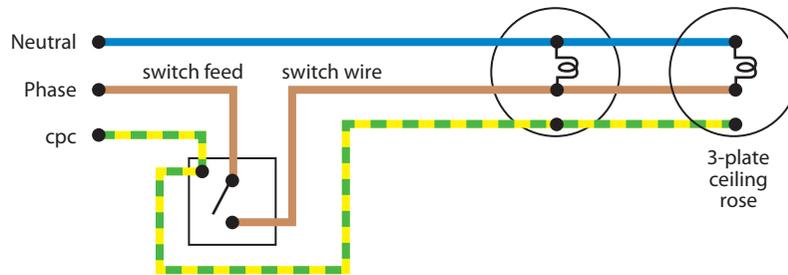
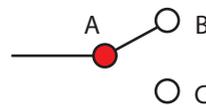


Figure 6.04 Extra lighting fed from the same switch, wired in parallel (new cable colours)

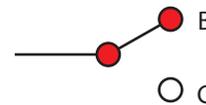
Two-way switching

Sometimes we need to switch a light on, or off, from more than one location, e.g. at opposite ends of a long corridor. When this is required, a different switching arrangement must be used, the most common being the two-way switch circuit. In this type of circuit, the switch feed is feeding one two-way switch, and the switch wire goes from the other two-way switch to the luminaire(s). Two wires known as ‘strappers’ then link the two switches together. In other words:

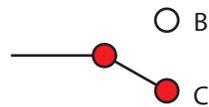
we supply the switch feed terminal, point (A).



However, depending on the switch contact position, the electricity can come out on either terminal B or terminal C. In the following diagram it is shown energising terminal B.

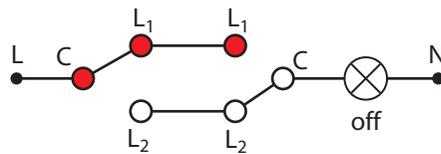


If we now operated the switch, the contact would move across to energise terminal C. Please note that actual switch terminals are not marked in this way.



Switching of lighting circuits

By connecting together the two two-way switches we now have the ability at each switch to either energise the switch wire going to the light or to de-energise it (this is why this system is ideal for controlling lighting on corridors or staircases). In the first diagram below, the luminaire is off.



However, operate the second switch and we energise the common terminal (C) and the luminaire will now come on.

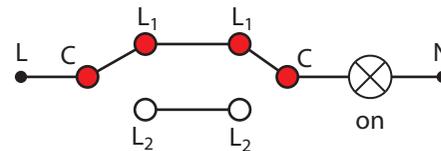
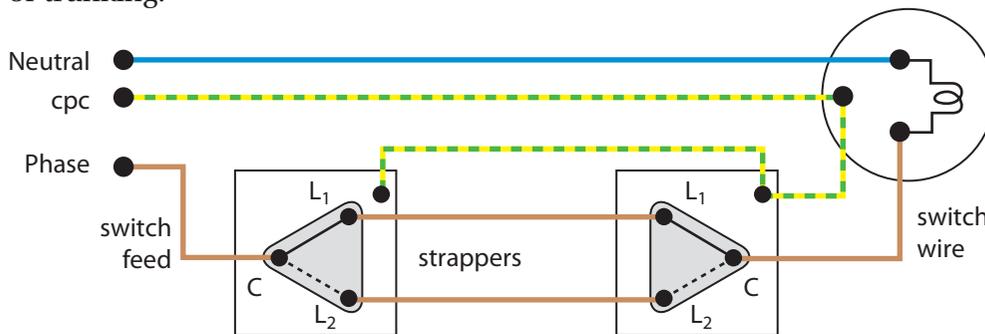
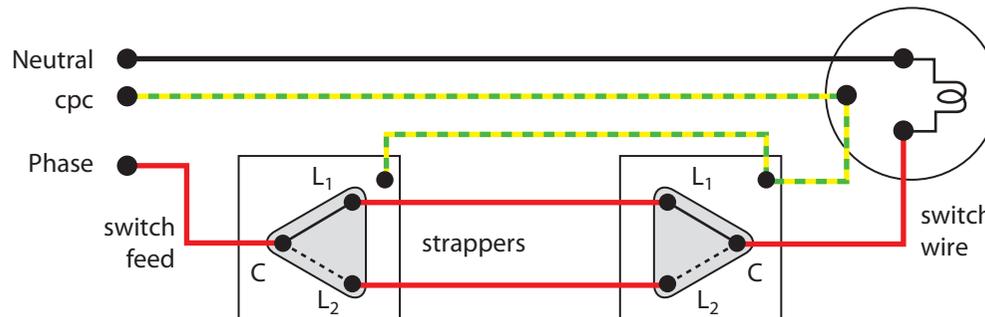


Figure 6.05 shows the full circuit when wired using single-core cable in conduit or trunking.



(a) New cable colours



(b) Old cable colours

Figure 6.05 Full circuit wired with single-core cable. Old and new colours

We can also use two-way switches for other purposes. Figure 6.06 shows one two-way switch to control two indicator lamps. This sort of system is frequently used as an entry system outside offices or dark rooms, where the two lamps can be marked, for example as 'available' and 'busy'.

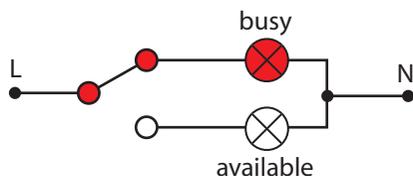


Figure 6.06 Two-way switch controlling two lamps

Intermediate switching

If more than two switch locations are required, e.g. in a long corridor with other corridors coming off it, then intermediate switches must be used. The intermediate switches are wired in the 'strappers' between the two-way switches.

The action of the intermediate switch is to cross-connect the 'strapping' wires. This gives us the ability to route a supply to any terminal depending upon the switch contact positions.

When we operate the switch into position two, the switch contacts cross over (Figure 6.07).

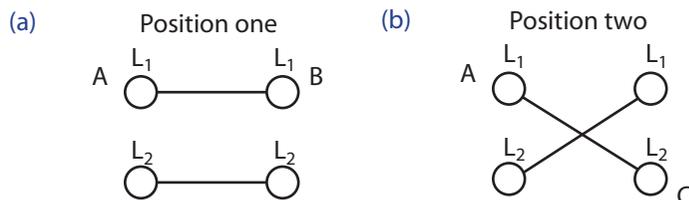


Figure 6.07

This means that a signal sent into terminal A can always be directed on to either terminal B or terminal C as required.

Ignoring terminal markings, Figure 6.08 shows an arrangement where the switch wire is de-energised and therefore the luminaire is off.

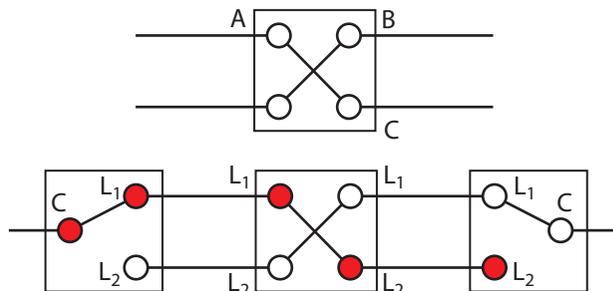


Figure 6.08

However, by operating the intermediate switch, we can route the switch feed along another section of the 'strappers' and energise the switch wire terminal, and therefore the luminaire will come on, as shown in Figure 6.09.

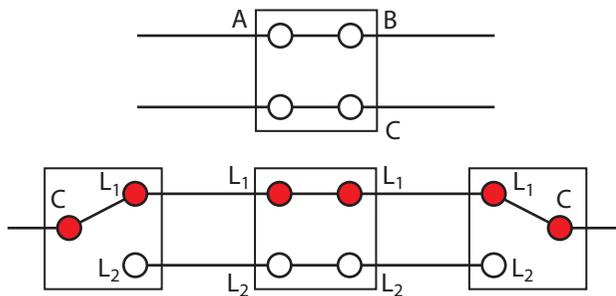


Figure 6.09

To use the example of a long hotel main corridor with other minor corridors coming off it, if we have an intermediate switch at each junction with the main corridor, anyone joining or leaving the main corridor now has the ability to switch luminaires on or off.

Figure 6.10 shows the full circuit in the new colours, when wired using single-core cable in conduit or trunking.

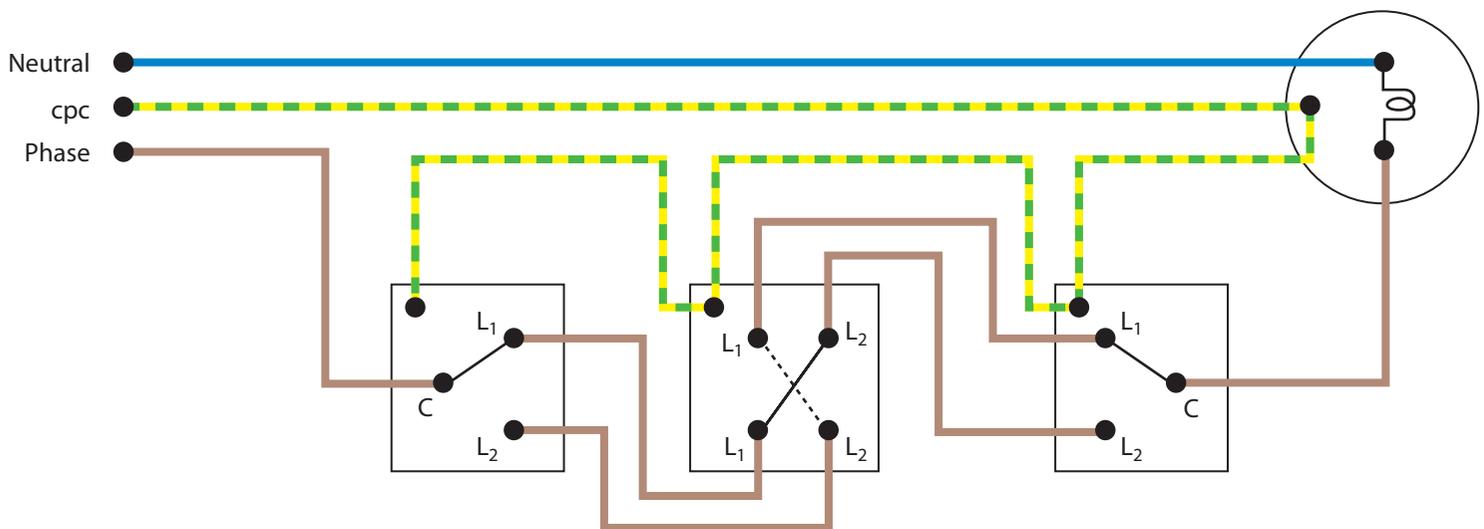


Figure 6.10 New cable colours

Note: in this diagram the light will be off.

Wiring with multicore cables

Multicore cables (commonly referred to as twin and earth) are basically a three-core cable consisting of a phase, neutral and earth conductor. Both the phase and neutral conductors consist of copper conductors insulated with coloured insulation (see Figure 6.11 and 6.12), the earth being a non-insulated bare copper conductor sandwiched in between the phase and neutral. In the old colours, the correct use of this cable type would be to use two red conductors (switch feed and switch wire)



Remember

Any number of intermediate switches may be used between two-way switches and they are all wired into the 'strappers'. In other words, an intermediate switch has two positions

from switch locations up to luminaires. However, for ease, it was common practice for many to use a cable containing red and black conductors.

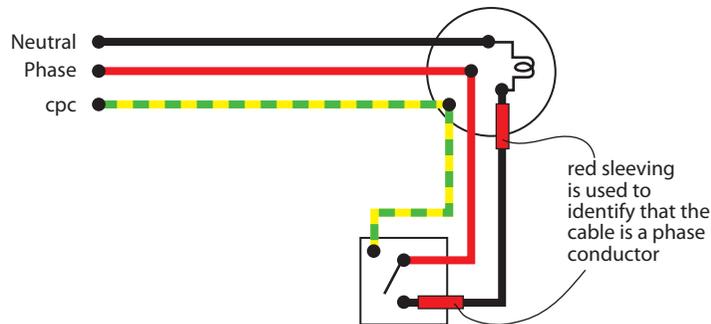


Figure 6.11 Old cable colours

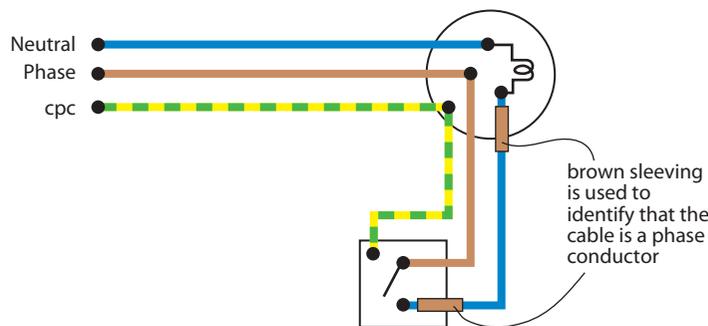


Figure 6.12 New cable colours

This means that the black conductor should be sleeved at both ends to indicate that it is a 'live' conductor. (Please be aware that many did not sleeve the conductors and therefore a luminaire connected across two black conductors is actually connected to a switch wire and a neutral.)

The outer white or grey covering is the sheath, and its main purpose is to prevent light mechanical damage of the insulation of the conductors.

This cable is often used for wiring domestic and commercial lighting circuits, and you would normally use 1.5mm² cable. Using this type of cable instead of singles is slightly more complicated because you are restricted as to where you plan your runs, i.e. in the old colours the cable will always consist of a red, black and earth conductor.

Two-way switching and conversion circuit

This method of switching using multicore cables requires the use of four-core cable. This is a cable that has three coloured and insulated conductors and a bare earth conductor. The three coloured conductors are in the old colours, coloured red, yellow, and blue. This type of cable is normally only stocked in 1.5mm and used in a lighting circuit where its application is for switching that requires more than one switch position, i.e. two-way and intermediate switching.

It is also used for converting an existing one-way switching arrangement into a two-way switching arrangement. The first step in this process is to replace the existing one-way switch with a two-way switch. This would then be connected as shown in Figure 6.13.

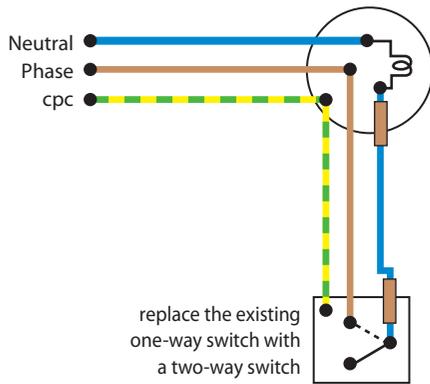


Figure 6.13 Conversion of one-way lighting into two-way switching

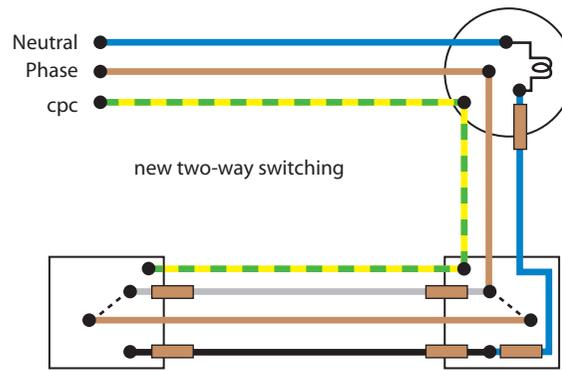


Figure 6.14 Conversion of one-way lighting into two-way switching

The next step is to install the multicore cable between this location and the new two-way switch location and complete the circuit connections as in Figure 6.14.

Note: In Figure 6.14 the light will be off.

Intermediate switching

Figure 6.15 illustrates an intermediate lighting circuit using multicore cables.

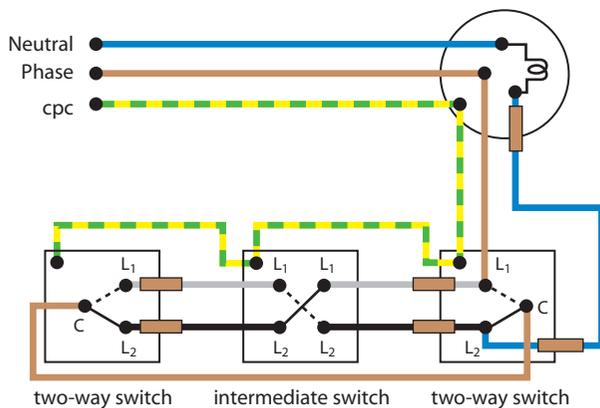


Figure 6.15 Intermediate switching

Note: In Figure 6.15 the light will be on.

Wiring using a junction/joint box

This method of wiring is considered somewhat old-fashioned, as it has now been superseded by the loop-in method. However, that is not to say that you will not come across this method in the millions of households in the country that have a junction box method installed. Care should be taken when wiring junction boxes, and the following precautions should be observed:

- the protective outer sheath should be taken inside the junction box entries to a minimum of 10mm
- where terminations are made into a connector, only sufficient insulation should be removed to make the termination

- sufficient slack should be left inside the joint box to prevent excess tension on conductors
- cables should be inserted so that they are not crossing; they should be neat and fitted so that the lid fits without causing damage
- correct size joint boxes should be used
- joint boxes should be secured to a platform fitted between the floor and ceiling joists.

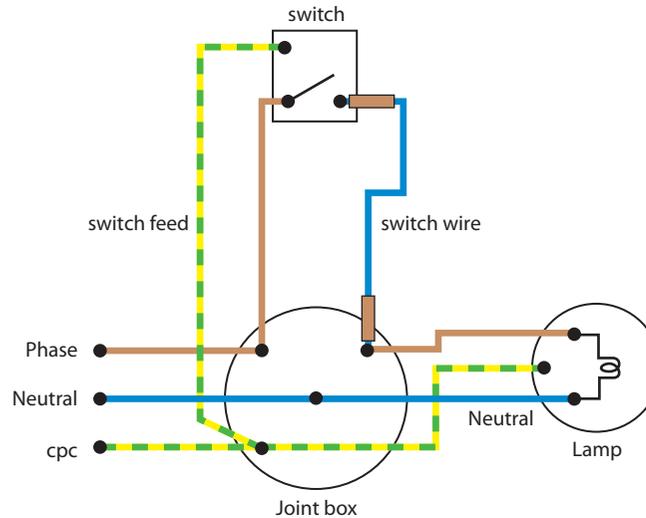


Figure 6.16 One-way switch using a joint box

Figure 6.16 illustrates the control of one light via a one-way switch using this method.

Rings, radials and spurs

Before the early 1950s different types and sizes of socket outlet and plug were in use in domestic premises, which was very annoying and inconvenient! In 1947, 5 A and 15 A socket outlets were deemed obsolete, and agreement was reached on a standard 13 A socket outlet with a fused plug, to BS 1363. In this section we will be looking at the standard power-circuit arrangements found in domestic premises. In particular the following will be investigated:

- ring circuits
- permanently connected equipment
- non-fused spurs
- fused spurs
- radial circuits.

Ring circuits

In this system the phase, neutral and circuit protective conductors are connected to their respective terminals at the consumer unit, looped into each socket outlet in turn and then returned to their respective terminals in the consumer unit, thus forming a ring. Each socket outlet has two connections back to the mains supply.

The requirements for a standard domestic ring circuit are as shown in the bullet points below. An unlimited number of socket outlets may be installed provided the following points are taken into account.

- Each socket outlet of twin or multiple sockets is to be regarded as one socket outlet.
- The floor area served by a single 30 A or 32 A ring final circuit must not exceed 100m² in domestic installations.
- Consideration must be given to the loading of the ring main, especially in kitchens and utility rooms, which may require separate circuit(s).
- When more than one ring circuit is installed in the same premises, the socket outlets installed should be reasonably shared among the ring circuits so that the assessed load is balanced.
- Immersion heaters, storage vessels in excess of 15 litres capacity or permanently connected heating appliances forming part of a comprehensive space-heating installation, are supplied by their own separate circuit.

A typical domestic ring circuit is shown in Figure 6.17.

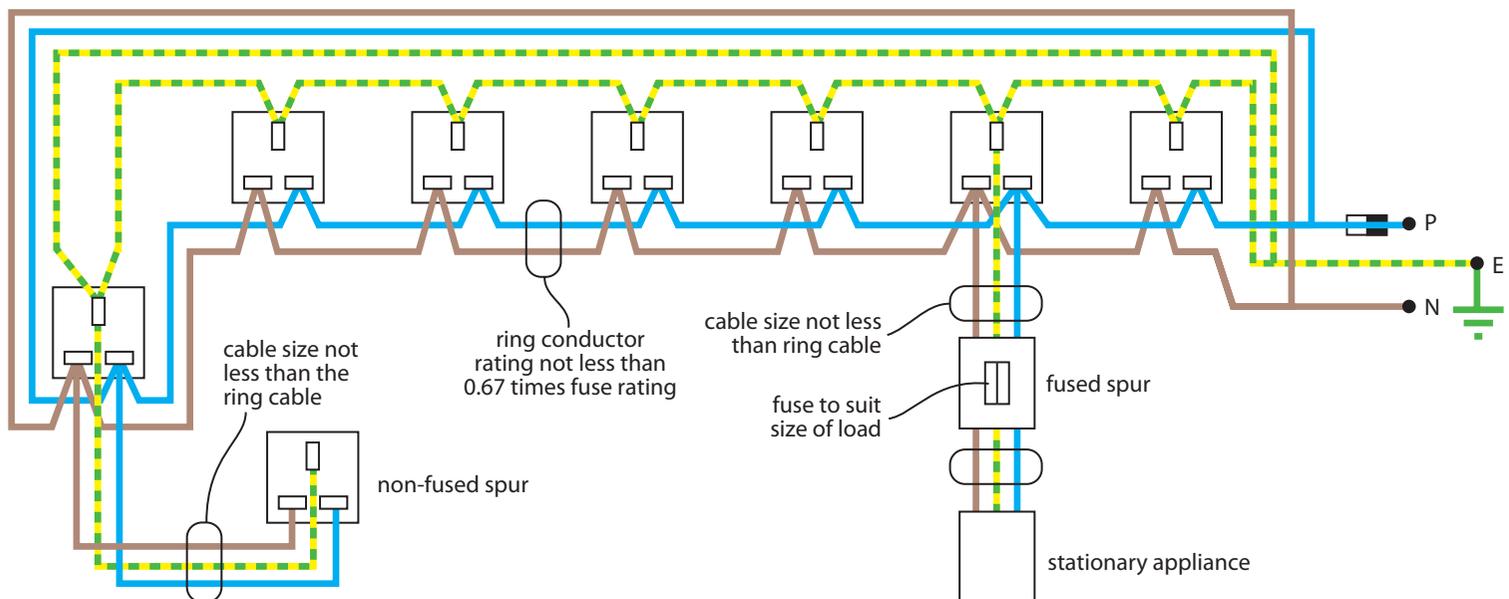


Figure 6.17 Domestic ring circuit with spurs

Permanently connected equipment

Permanently connected equipment should be locally protected by a fuse which does not exceed 13 A and be controlled by a switch complying with BS 7671 chapter 46, or be protected by a circuit breaker not exceeding 16 A rating.

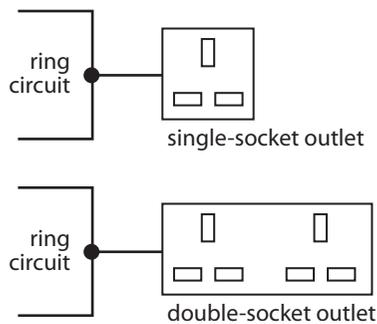


Figure 6.18 Non-fused spurs

Non-fused spurs

Spurs may be installed on a ring circuit. These may be fused, but it is more common to install **non-fused spurs** connected to a circuit at the terminals of socket outlets, at junction boxes, or at the origin of the circuit in the distribution board. A non-fused spur may supply only one single or one twin-socket outlet or one item of permanently connected equipment. The total number of non-fused spurs should not exceed the total number of socket outlets and items of fixed equipment connected directly to the ring circuit. The size of conductor for a non-fused spur must be the same as the size of conductor used on the ring circuit.

Fused spurs

A **fused spur** is connected to a circuit through a fused connection unit. The fuse incorporated should be related to the current carrying capacity of the cable used for the spur but should not exceed 13 A. When sockets are wired from a fused spur the minimum size of the conductor is 1.5mm² for rubber- or PVC-insulated cables with copper conductors and 1mm² for mineral-insulated cables with copper conductors. The total number of fused spurs is unlimited.

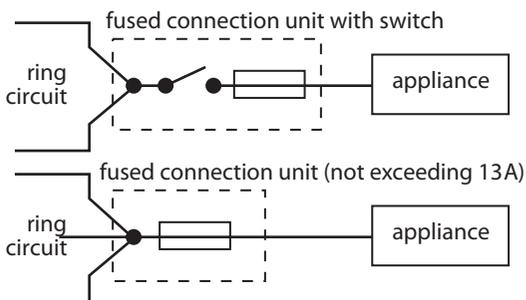


Figure 6.19 Fused spurs

Radial circuits

In a radial circuit the conductors do not form a loop but finish at the last outlet. As with the ring circuit, the number of outlets in any circuit is unlimited in a floor area up to the maximum allowed. In each case this will be determined by the estimated load and shock protection constraints.

A2 Radial circuit

The current rating of the cables is determined by the rating of the overcurrent protection device, i.e. 30 A or 32 A cartridge fuse or MCB. This means that copper-conductor PVC cables of not less than 4mm², or copper-conductor mineral-insulated cables of not less than 2.5mm², may be used, and the floor area served may not exceed 75m². See Figure 6.20 and Table 6.04.

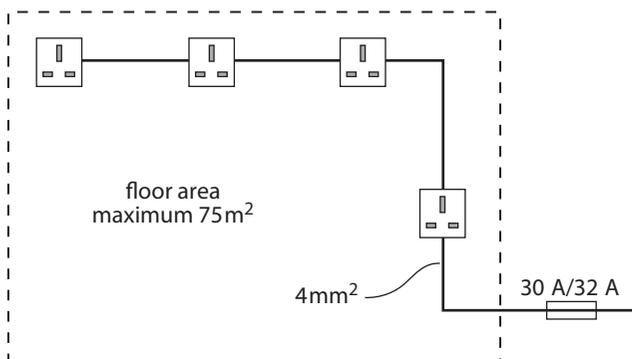


Figure 6.20 A2 radial circuit

Remember



The cable sizes shown are nominal, and if derating factors apply e.g. grouping or ambient temperature, these sizes may need to be increased. In practice this would mean that a 30 A or 32 A circuit breaker or fuse would be used as an overcurrent protection device and the circuit cable would be selected accordingly as required by Regulation 433-02-04

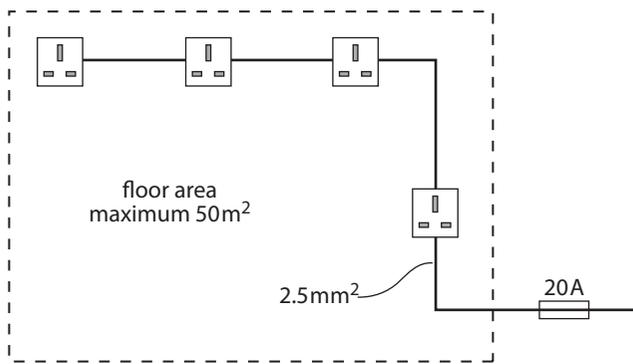


Figure 6.21 A3 radial circuit

A3 Radial circuit

In domestic premises this circuit is wired in 2.5mm² copper cable and protected by a 20A device. The floor area is limited to 50m²; in this area any number of socket outlets may be installed. See Figure 6.21 and Table 6.04.

Type of circuit	Overcurrent protection device		Type of protective device		Maximum floor area served	
	1	2 Rating A	3 Rating A	4 (PVC) mm ²		5 (MICC) mm ²
A1 Ring		30 or 32	Any	2.5	1.5	100
A2 Radial		30 or 32	Cartridge fuse or circuit breaker	4	2.5	75
A3 Radial		20	Any	2.5	1.5	50

Table 6.04 Overcurrent protection

Component elements of electrical cables

On completion of this topic area the candidate will be able to state the component elements of electrical cables.

Selecting a cable for an electrical installation is very important; consideration must be given to the following criteria in order to ensure the correct type of cable is chosen:

- conductor material
- conductor size
- insulation
- environmental conditions.

Conductor material

Copper and aluminium

The choice generally is between copper and aluminium. Copper has better conductivity for a given cross-sectional area and is preferable, but its cost has risen over the years. Aluminium conductors are now sometimes preferred for the medium and larger range of cables. All cables smaller than 16mm² cross-sectional area (csa) must have copper conductors.

Conductor	Advantages	Disadvantages
Copper	<ul style="list-style-type: none"> • Easier to joint and terminate • Smaller cross-sectional area for given current rating 	<ul style="list-style-type: none"> • More costly • Heavier
Aluminium	<ul style="list-style-type: none"> • Cheaper • Lighter • Not recommended for use in hazardous areas 	<ul style="list-style-type: none"> • Bulkier for given current rating

Table 6.05 Copper and aluminium conductors compared

Other conductor materials

- **Cadmium copper:** has a greater tensile strength for use with overhead lines.
- **Steel reinforced aluminium:** for very long spans on overhead lines.
- **Silver:** used where extremely good conductivity is required. However, it is extremely expensive.
- **Copperclad (copper-sheathed aluminium):** cables that have some of the advantages of both copper and aluminium but are difficult to terminate.

Whatever the choice of conductor material the conductors themselves will usually be either stranded or solid. Solid conductors are easier, and therefore cheaper, to manufacture but the installation of these cables is made more difficult by the fact that they are not very pliable. Stranded conductors are made up of individual strands that are brought together in set numbers. These provide a certain number of strands such as 3, 7, 19, 37 etc. and, with the exception of the 3-strand conductor, all have a central strand surrounded by the other strands within the conductor.

Conductor size

There are many factors that affect the choice of size of conductor.

- **Load and future development**
The current the cable is expected to carry can be found from the load, taking into account its possible future development, i.e. change in use of premises, extensions or additions.
- **Ambient temperature**
The hotter the surrounding area, the less current the cable is permitted to carry.
- **Grouping**
If a cable is run with other cables then its current carrying capacity must be reduced.
- **Type of protection**
Special factors must be used when BS 3036 (semi-enclosed) fuses are employed.

Did you know?



Solid conductors are not as common as stranded; their use has been restricted to either very small or very large conductor sizes

- **Whether placed in thermal insulation**

If cables are placed in thermal insulation, de-rating factors must be applied.

- **Voltage drop**

The length of circuit, the current it carries and the cross-sectional area of the conductor will affect the voltage drop. Regulation 525-01-02 states that the maximum voltage drop must not exceed 4 per cent of the nominal voltage of supply.

Insulation and sheathing

To insulate the conductors of a cable from each other and to insulate the conductors from any surrounding metalwork, materials with extremely good insulating properties must be used. This material around the cable is called the sheath. Cables can be installed in a variety of different situations, and you must take care that the type of insulation and sheath on the chosen cable is suitable for that particular situation.

Insulation types

Listed below are some of the working properties of the more common types of cable insulation:

- PVC
- synthetic rubbers
- silicon rubber
- magnesium oxide
- phenol-formaldehyde.

PVC

This is a good insulator: it is tough, flexible and cheap. It is easy to work with and easy to install. However, thermoplastic polymers such as PVC do not stand up to extremes of heat and cold, and BS 7671 recommends that ordinary PVC cables should not constantly be used in temperatures above 60°C or below 0°C. Care should be taken when burning off this type of insulation (to salvage the copper) because the fumes produced are toxic.

Synthetic rubbers

These insulators, such as Vulcanised Butyl Rubber, will withstand high temperatures much better than PVC and are therefore used for the connection of such things as immersion heaters, storage heaters and boiler-house equipment.

Silicon rubber

FP 200 cable using silicon rubber insulation and with an extruded aluminium over-sheath foil is becoming more popular for wiring such things as fire-alarm systems. This is due largely to the fact that silicon rubber retains its insulation properties after being heated up or burned and is somewhat cheaper than mineral-insulated metal-sheathed cables.

Magnesium oxide

This is the white powdered substance used as an insulator in mineral-insulated cables. This form of insulation is hygroscopic (absorbs moisture) and therefore must be protected from damp with special seals. Mineral-insulated cables are able to withstand very high temperatures and, being metal sheathed, are able to withstand a high degree of mechanical damage.

Phenol-formaldehyde

This is a thermosetting polymer used in the production of such things as socket outlets, plug tops, switches and consumer units. It is able to withstand temperatures in excess of 100°C.

Environmental conditions

Many factors affect cable selection. Some will be decided by factors previously mentioned and some by the following:

- risk of excessive ambient temperature
- effect of any surrounding moisture
- risk of electrolytic action
- proximity to corrosive substances
- risk of damage by animals
- effect of exposure to direct sunlight
- risk of mechanical stress
- risk of mechanical damage.

Find out



Appendix 4 of BS 7671 gives tables of different types of cable, and shows that the current rating changes in accordance with the conditions under which the cable is installed. Take a look at this and make a copy for your own reference

Ambient temperature

Current-carrying cables produce heat, and the rate at which the heat can be dissipated depends upon the temperature surrounding the cable. If the cable is in a cold situation, then the temperature difference is greater and there can be substantial heat loss. If the cable is in a hot situation, then the temperature difference of the cable and its surrounding environment will be small, and little, if any, of the heat will be dissipated.

Problem areas are boiler-houses and plant rooms, thermally insulated walls and roof spaces. PVC cables that have been stored in areas where the temperature has dropped to 0°C should be warmed slowly before being installed. However, if cables have been left out in the open and the temperature has been below 0°C (say, a heavy frost has attacked the cables), then you must report this situation to the person in charge of the installation. These low temperatures can damage PVC cables.

Moisture

Water and electricity do not mix, and care should be taken at all times to avoid the movement of moisture into any part of an electrical installation by using watertight enclosures where appropriate. Any cable with an outer PVC sheath will resist the penetration of moisture and will not be affected by rot. However, suitable watertight glands should be used for termination of these cables.

Electrolytic action

Two different metals together in the presence of moisture can be affected by electrolytic action, resulting in the deterioration of the metal. Care should be taken to prevent this. An example is where brass glands are used with galvanised steel boxes in the presence of moisture. Metal-sheathed cables can suffer when run across galvanised sheet-steel structures, and if aluminium cables are to be terminated on to copper bus bars then the bars should be tinned.

Corrosive substances

The metal sheaths, armour, glands and fixings of cables can also suffer from corrosion when exposed to certain substances. Examples include:

- magnesium chloride used in the construction of floors
- plaster undercoats containing corrosive salts
- unpainted walls of lime or cement
- oak and other types of acidic wood.

Metalwork should be plated or given a protective covering. In any environment where a corrosive atmosphere exists special materials may be required.

Damage by animals

Cables installed in situations where rodents are prevalent should be given additional protection or installed in conduit or trunking, as these animals will gnaw cables and leave them in a dangerous condition. Installations in farm buildings should receive similar consideration and should, if possible, be placed well out of reach of animals to prevent the effects of rubbing, gnawing and urine.

Direct sunlight

Cables sheathed in PVC should not be installed in positions where they are exposed to direct sunlight because this causes them to harden and crack: the ultraviolet rays leach out the plasticiser in the PVC, making it hard and brittle.



Did you know?

Many house fires are attributed to rodent damage to cabling

Earthing and bonding

On completion of this topic area the candidate will be able to differentiate between the terms earthing and bonding and give examples on the usage of each.

Remember



An earth fault is an unintentional connection between phase and earth

Earthing

BS 7671 defines **earthing** as a connection of any exposed conductive parts of an installation to its main earthing terminal. This is done to ensure that all the metalwork associated with the electrical installation is effectively connected to the general mass of the Earth.

This means that, in the event of an earth fault, the voltage developed to earth is restricted to 230 V. This is the case even on a 400 V three-phase supply, where automatic disconnection of the supply can be achieved.

Bonding

BS 7671 fails to define bonding, but does define a bonding conductor. This is a protective conductor providing equipotential bonding. This in turn is defined as an electrical connection maintaining various exposed conductive parts and extraneous conductive parts at substantially the same potential.

In order for current to flow, two conditions have to be met.

1. There has to be a circuit for current to pass along.
2. There has to be a potential difference (voltage).

By joining together all the metal work within the installation, it is now no longer possible for a difference of potential to exist between the various items of metalwork. Therefore there is no difference of potential, meaning no current flow. This prevents anyone, who comes into contact with a live piece of metal work, receiving an electric shock when they touch another piece of metal.

Earthed equipotential bonding and automatic disconnection of the supply, sometimes referred to as **EEBADS**, is the main method of shock protection against indirect contact. This involves both **earthing** and **bonding**.

First, all the metal work within the installation is bonded together. This places all the metalwork at the same potential and prevents a difference of potential from existing between any of the items of metalwork. Having done this, the metalwork is then connected with the **general mass of earth**, via the **main earth terminal** and the **earthing conductor**. Now in the event of a fault to earth, automatic disconnection of the supply can be achieved.

Exposed and extraneous conductive parts

On completion of this topic area the candidate will be able to list exposed conductive parts and extraneous conductive parts of metallic structures and services.

Exposed conductive parts

These are the metallic parts of an electrical system, which can be touched and which are not normally live. However these can become live under fault conditions.

Examples of exposed conductive parts are:

- metal casings of appliances such as heaters
- kettles
- ovens
- wiring containment systems such as metal conduit, cable tray and trunking.

Extraneous conductive parts

These are metallic parts within a building, which do not form part of the electrical system, but can also become live under fault conditions. Examples are:

- water and gas pipes
- air conditioning
- boilers
- air ducting systems
- structural steel work of the building.

Earth protection

On completion of this topic area the candidate will be able to state the purpose of earthing and the function of earth protection.

Purpose of earthing

By connecting to earth all metalwork not intended to carry current, a path is provided for leakage current which can be detected and interrupted by fuses, circuit breakers and residual current devices. Figure 6.22 illustrates the earth return path from the consumer's earth to the supply earth.

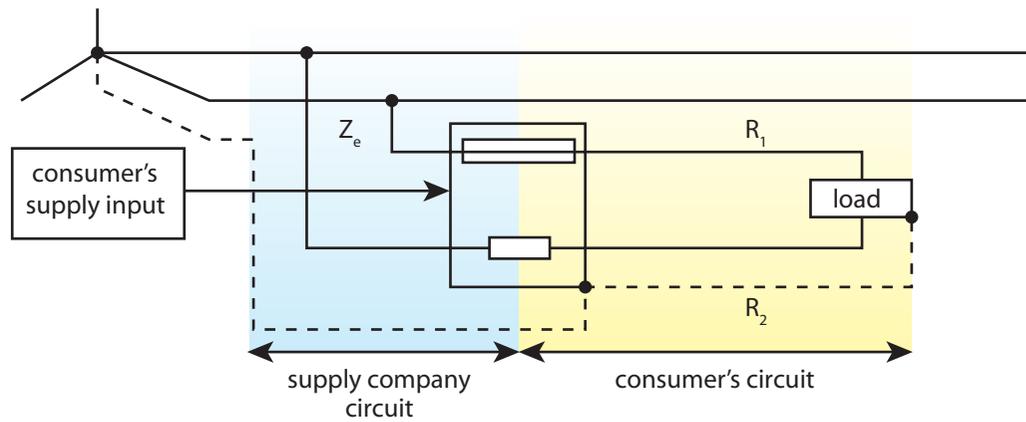


Figure 6.22 The earth-fault loop path

The connection at the consumer's earth can be by means of either an earth electrode at the building where the earth is required or may be in the form of a cable which runs back to the generator or transformer and is then connected to an earth point.

Because the transformer or generator at the point of supply always has an earth point, a circuit is formed when earth-fault currents are flowing. If these fault currents are large enough they will operate the protective device, thereby isolating the circuit. The star point of the secondary winding in a three-phase four-wire distribution transformer is connected to the earth to maintain the neutral at earth potential.

Results of an unearthed appliance

A person touching the appliance shown, which is live due to a fault, completes the earth circuit and receives an electric shock.

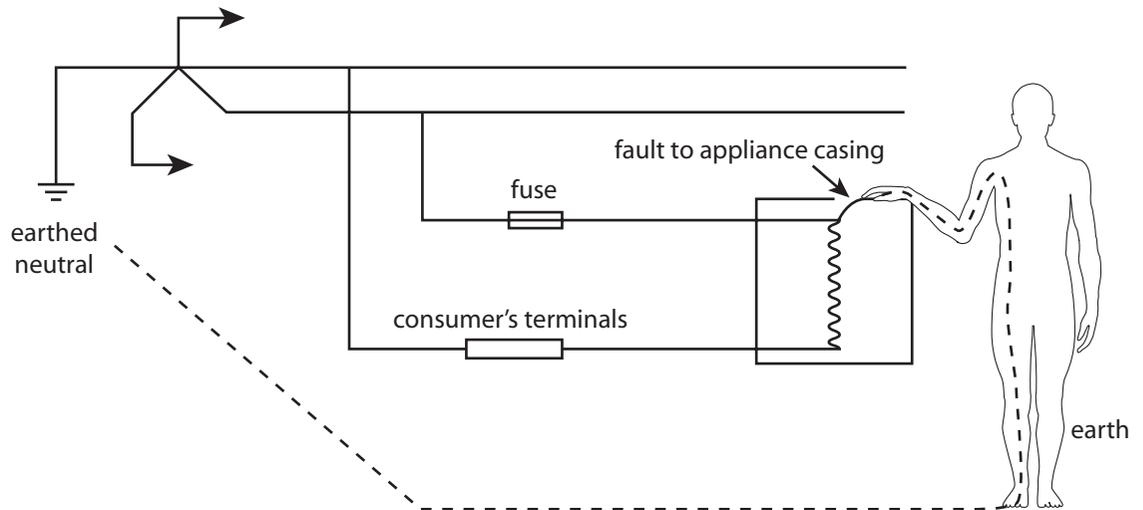


Figure 6.23 Electric shock

Results of a bad earth

A bad earth circuit – i.e. one with too large a resistance – can sometimes have more disastrous effects than having no earth at all. This is shown in the illustration, where the earth-fault circuit has a high resistance mainly due to a bad contact at point A.

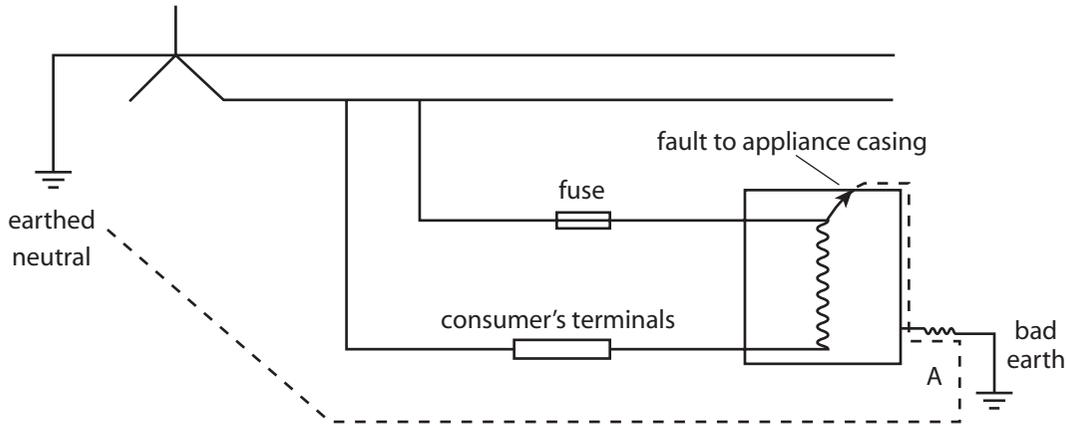


Figure 6.24 Bad earth path

The severity of shock will depend mainly upon the surroundings, the condition of the person receiving the shock and the type of supply. When the current starts to flow, the high resistance connection will heat up and this could be a fire hazard. Also, because the current flowing may not be high enough to blow the fuse or trip the circuit breaker, the appliance casing remains live.

Results of a good earth path

A good earth path, that is a low resistance one, will allow a high current to flow. This will cause the protective device to operate quickly, thereby isolating the circuit and giving protection against electric shock.

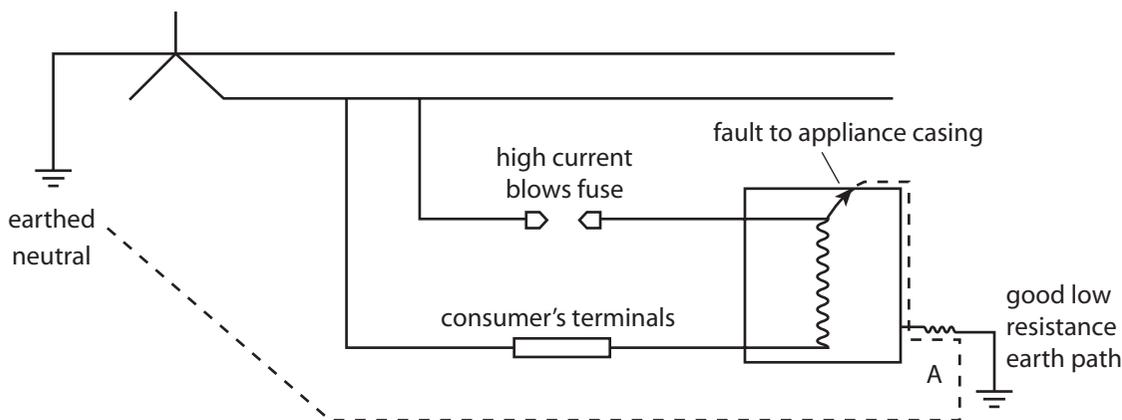
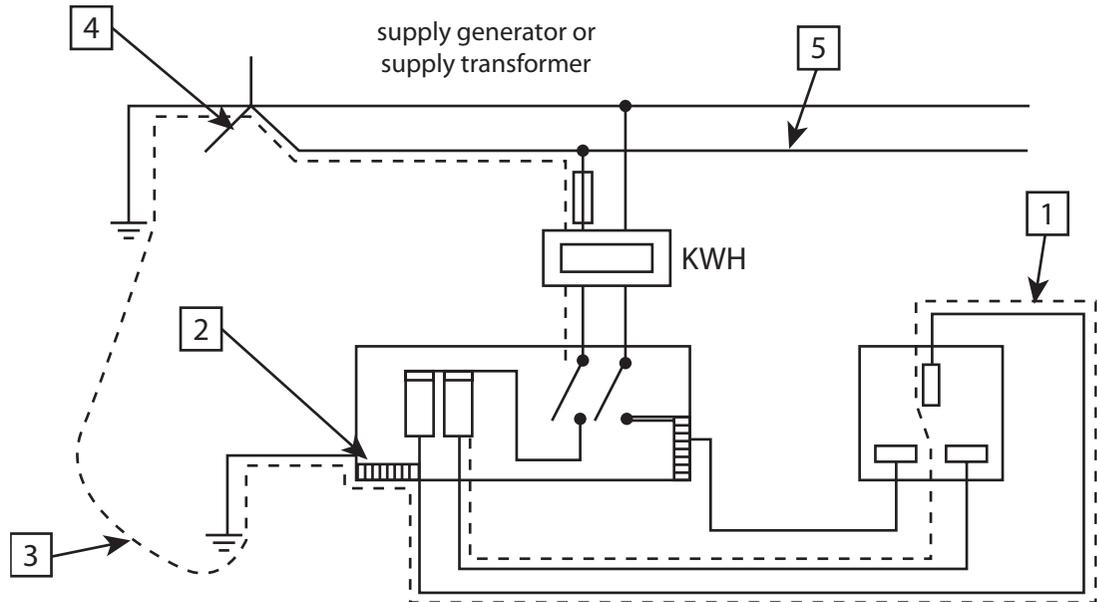


Figure 6.25 Good earth path

Earth-fault loop impedance

The path made or followed by the earth fault current is called the earth-fault loop or phase-earth loop. It is termed **impedance** because part of the circuit is the transformer or generator winding, which is inductive. This inductance, along with the resistance of the cables to and from the fault, makes up the impedance.



- 1 The circuit protective conductor (cpc) within the installation.
- 2 The consumer's earthing terminal and earthing conductor.
- 3 The earth return path, which can be either by means of an electrode or via the cable armouring.
- 4 The path through the earthed neutral point of the transformer and the transformer winding (or generator winding).
- 5 The phase conductor.

Figure 6.26 Earth-fault loop impedance

Electrical protection

On completion of this topic area and the candidate will be able to list basic principles of shock protection, circuit overload and short-circuit protection

Shock protection

BS 7671 classifies electric shock into two categories – shock resulting from either:

- **direct contact** with the electrical supply

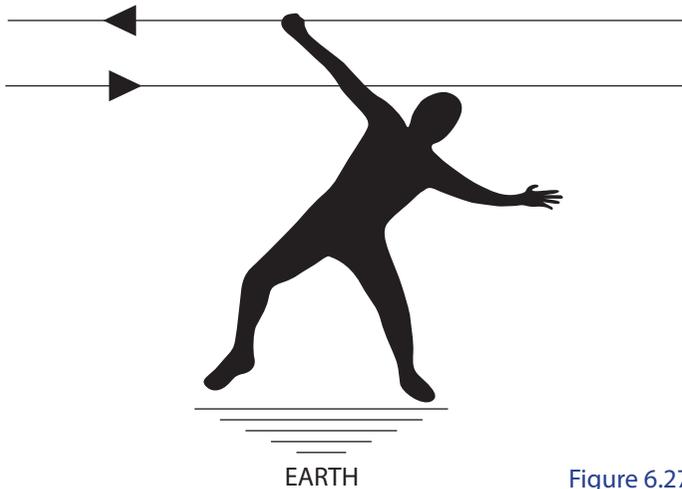


Figure 6.27 Direct contact

- **indirect contact** with the supply via exposed conductive parts or metalwork that have become live due to a fault.

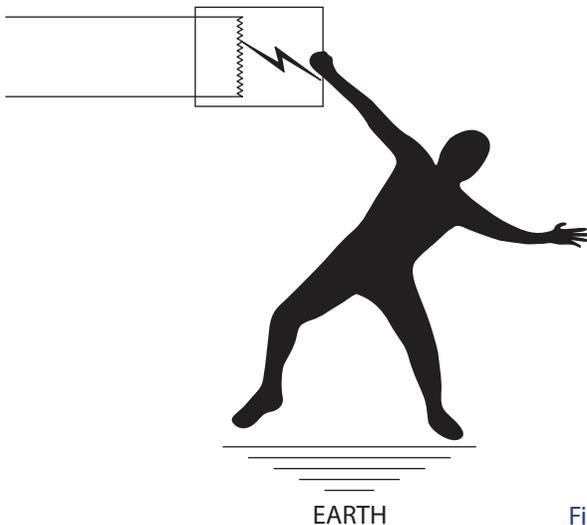


Figure 6.28 Indirect contact

BS 7671 requires protective measures to be taken against:

- **both** direct and indirect contact
- or protection against direct contact
- or protection against indirect contact

Protection against both direct and indirect contact

Research has shown that the human body can withstand indefinitely, without sustaining damage, 50 volts or less. Logically then, if the voltage of an installation is reduced to 50 V or less, then it will not matter if anyone comes into contact either directly or indirectly with the supply, as they will not be hurt.

Remember



The more chance there is of danger, the greater the precautions you will need to take

For this system to be effective the supply must be run through a safety isolating transformer. This device has no connection to earth, so the installation must meet the requirements of BS 7671 for a SELV (separate extra low voltage) supply.

This method of protection is used when there is an increased risk of an electric shock due to body resistance being reduced, such as in damp and wet conditions.

Protection against direct contact

Measures to be taken to prevent electric shock by direct contact include (Regulation 412):

- (i) protection by insulating live parts
- (ii) protection by barriers or enclosures
- (iii) protection by obstacles, so preventing access
- (iv) protection by placing out of reach
- (v) IP codes/ratings are applied to electrical equipment to create an industry standard. These are covered below.

RCDs (residual contact devices) may be used as a supplementary means of shock prevention from direct contact, but only in addition to the measures listed in (i) to (v) above. We will look further at RCDs in chapter 12, pages 307–308.

Barriers or enclosures

All live electrical components should be within enclosures. In some cases they will also be protected by barriers, preventing easy access from the public.

In order to make sure that these requirements are followed correctly, an index of protection codes is applied to electrical equipment enclosures to create an industry standard. The first number in the code relates to the protection against direct contact in terms of the degree of accessibility, e.g. IP2X means that there is no contact with a probe of more than 12mm in diameter and less than 80mm long (approximately the length of a human finger). IPXXB is as above but for probes up to a maximum of 80mm. IP4X is used for protection against wires of 1 mm in diameter.

The horizontal top surface of the barrier or enclosure, which is readily accessible, should be protected to IP4X.

Protection against indirect contact

In this situation, conductive parts, such as metalwork, have become live due to fault conditions. The potential voltage on this metalwork rises above that of earth and electric shock results when a person touches the metalwork.

Measures taken to prevent electric shock by indirect contact include (Section 413 in BS 7671) the following.

- (i) Earthed equipotential bonding and the automatic disconnection of the supply (EEBAD).

- (ii) Use of class II equipment and/or equivalent insulation. Class II usually relates to portable equipment or factory-built equipment. Equipment to this class must not have enclosing metalwork earthed. Furthermore for a class II installation, close supervision is required to ensure the installation or its equipment is not changed from class II. The symbol on the equipment that indicates that it is class II or double insulated is a square within a square.
- (iii) Non-conducting location, i.e. physical separation from exposed conductive parts, no earth connection.
- (iv) Earth free local equipotential bonding. Every part is bonded and therefore 'no voltage difference – no shock'.
- (v) Electrical separation. A transformer fed secondary is not connected to earth or an isolated generator supply is used.

Methods (iii) to (v) have a limited application, as close supervision is required. The design must be specified by a qualified electrical engineer. The basic limitation of these methods is the need to maintain their design condition. There should be no incorrect modifications, additions or deterioration.

Overcurrent protection

Protection devices

In a healthy electrical system, insulation between phase conductors and neutral conductors or between live conductors and earth is sound, with current flowing from the supply, through the load and returning via the neutral to its source.

Overcurrent protection is provided by means of a circuit breaker or fuse. These devices are designed to operate within specified limits, disconnecting the supply automatically in the event of an overload or fault current (short circuits or earth faults). Earth-fault protection is also provided by means of a circuit breaker or fuse, which operates under earth-fault conditions. If a high value current flows, these will safely disconnect the supply but may not be relied upon to detect and disconnect the supply in the event of low values of earth leakage current.

Residual current devices (RCDs) are designed to detect and automatically disconnect the supply in the event of earth-faults. Earth-faults can exist, for example, when a live conductor touches an equipment case or if you cut through a cable when cutting the grass. They are potentially dangerous and must be eliminated in order to prevent hazards resulting from electric shock or abnormal temperature rises and fires in the electrical installation.

Overcurrent protection device applies to fuses and miniature circuit breakers (MCBs). In this section we will be looking at the various means by which these devices provide protection to cables and circuits from damage caused by too much current flowing. The appropriate device must operate within 0.4 or 5.0 seconds.

Definition

Overload – an overcurrent occurring in a circuit which is electrically sound

Overload and short circuit protection

All circuit conductors must be sized correctly and must be of the correct current-carrying capacity for the load that they have to carry. All circuits on an installation must be protected against **overcurrent**. This is a current exceeding the rated value or current-carrying capacity of the cable conductor. Overcurrent conditions arise from either overloads or short circuits.

Overload current occurs in a circuit which is electrically sound, i.e. a circuit now carrying more current than it was designed to carry due to faulty equipment or too many pieces of equipment connected to the circuit. Overload is only a temporary fault condition and is easily corrected. Examples of how overload occurs include:

- several 13 A plugs connected to an adaptor and then plugged into one 13 amp socket outlet
- a stalled motor.

Such conditions cause the cable temperature to rise, resulting in an increased fire risk.

Fault current is the level of current flowing at a level up to and including the prospective short circuit current (the prospective short circuit current being the maximum current that the supply transformer is capable of delivering).

The prospective short circuit current must also be taken into account when selecting the type of overcurrent device to be installed.

This fault occurs at a point between live conductors of negligible impedance or between a live conductor and an exposed conductive part. It is more serious than an overload current and will usually not be as easily corrected.

Examples of faults are: a wiring fault (live connected to neutral or earth by mistake); a nail or screw being driven through an energised cable, making contact with the live conductors and either neutral or earth conductors.

A fuse is the weak link in a circuit which will melt when too much current flows, thus protecting the circuit conductors from damage.

Calculation of the cable size therefore automatically involves the correct selection of protective devices.

Remember

The priority of the protective device is to protect the circuit conductors, not the appliance or the user

Activity

Have a look at the consumer unit in your own home and see how many circuits there are and how many outlets are supplied by each circuit. Do you think the way your house's circuits have been divided up is reasonable? If not, why not?



FAQ



Q What's the difference between an mcb and an RCD?

A An mcb is an overcurrent protective device. Like a fuse, it is designed to disconnect the circuit if the current flowing is excessive. An RCD measures the current flowing in the phase and neutral conductors, and will trip out if the difference between them (the residual current) exceeds the rated value.

Q Why do I have to put coloured sleeving on switch wires and 'strappers'?

A Many accidents have occurred as a result of 'mistaken identity' of conductors, so marking them is essential. It is even more important since the 2004–2006 colour coding changes. It is possible to have a blue conductor that could be an old phase conductor or a new neutral. Similarly, black conductors could be old neutrals or new phases. Extreme caution is necessary!

Q Can I spur off the immersion heater circuit to supply the central heating system?

A No. Immersion heaters supplying vessels containing more than 15 litres of water must be permanently connected to their own separate circuit.

Q Why is a spur off a ring circuit called a 'non-fused spur'?

A Because a spur connected in this way breaks one of the 'golden rules' of circuit design, i.e. the fuse size (30/32 A) should always be smaller than the conductor current carrying capacity (27 A for 2.5mm², clipped direct), which it isn't! Therefore it is called unfused because the circuit fuse is too big to protect the spur cable.

Q What protects a non-fused spur cable from overload, then?

A Well, in a sense the spur cable is protected by the maximum load that can be connected to it. This 2 x 13 A socket outlets or 26 A, drawn through a 27 A cable. Now you see why 'spurs off spurs' are not allowed as, with two twin socket outlets, you could have 4 x 13 A – in other words 52 A flowing through a 27 A cable!

Q Why do properties have more than one ring circuit even though the floor area is less than 100m²?

A Remember that the unlimited number of socket outlets per A1 ring circuit rule is always subject to loading. With the number of appliances increasing all the time, it would be very easy to overload a single ring circuit. Also the Regulations tell us to divide the circuits up to 'minimise inconvenience in the event of a fault' so it is not a good idea to have all outlets on one circuit. This is especially true of lighting circuits where loss of one circuit should not result in the loss of lighting on that floor of a building.

Knowledge check



1. List five types of circuit protection device and their BS numbers. Which of these are overcurrent protective devices and which are residual current devices?
2. Draw circuit and wiring diagrams for the following circuits.
 - One-way lighting circuit.
 - Two-way lighting circuit.
 - Two-way and intermediate lighting circuit.
3. How many socket outlets can be installed in a standard (A1) domestic ring circuit?
4. What is the maximum floor area standard domestic A2 and A3 radial circuits can serve?
5. What is the maximum floor area that a domestic ring circuit can serve when protected by a 30/32 A protective device?
6. What is the total number of fused spurs that could be fitted to a standard domestic ring circuit? What would be the limitation of this arrangement?
7. Define the terms exposed conductive parts and extraneous conductive parts.
8. Draw a labelled diagram showing the earth-fault loop path.
9. What is the minimum degree of protection allowed for protection by barriers or enclosures?
10. Explain the difference between an 'overload current' and a 'short circuit current'.