5

ELECTROTECHNOLOGY

In this chapter you will learn about the concepts and principles related to electrical and electronic systems, electronic components, basic circuit theory and how to build circuits. You will also examine a range of design concepts for electrotechnology design and production tasks and some useful construction details for electronic projects.

Unlike mechanical systems that have been used for thousands of years, **electricity** and systems that use electricity are much more recent. Alessandro Volta invented the first battery in 1800 and by the middle of the 19th century, generators could produce an electric **current**. One of the first useful electrical systems in 1838 was the Morse code method of communication. By the early 20th century there were systems that converted the electric current into light, heat and mechanical energy. Later scientists and engineers discovered ways of controlling the movement of electrons in a circuit, and the field of electronic engineering was created. Recently engineers have combined light and electronics to develop optoelectronic systems such as DVD players. At the beginning of the 21st century we see and use many electrical and electronic systems every day. When you switch on the light in a room you are using a very large electrical system. The GPS, blood-pressure monitor and iPhone are examples of electronic systems. Other common systems include railways and tramways, room heaters, television transmitters and receivers, digital cameras, hair dryers and computers.

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Electrotechnology systems

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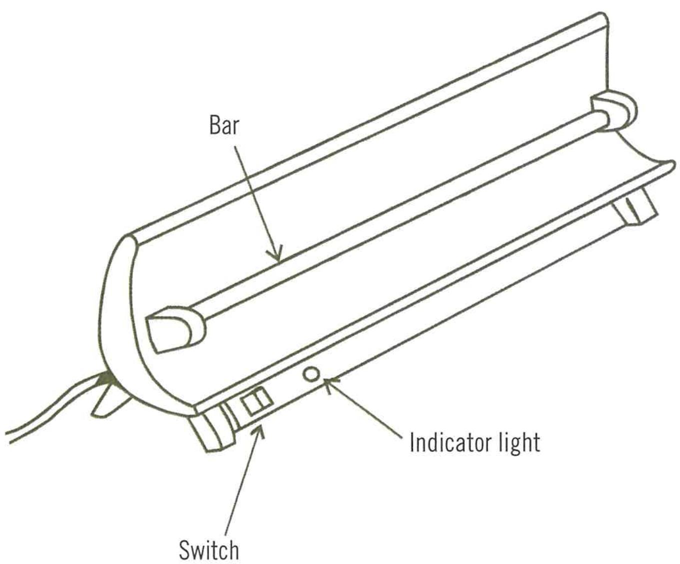
Electrotechnology systems

Electrical, electronic and microelectronic systems make up what we call electrotechnology systems. They all need electricity to operate, with the main differences being the size, amount of electricity required and the components used.

An electrical system: a heater

Heaters, motors and generators can all be classified as electrical systems. They use or produce relatively high electric currents. A basic example would be a bar heater with an indicator lamp. The mains socket, power lead and switch can be considered as being out of the system and are therefore not included in the process box. The system is made up of two main components: the heater element and the indicator lamp.



Basic bar heater

An electrical system uses relatively large currents and at times high voltages.

Open and closed loop systems

The words 'open' and 'closed' are used to describe the way the output is achieved in a system. The heater in the example of the electrical system would be an open loop system because there is no feedback. The heater will continue to provide heat and heat the air until it is switched off manually.

If we add a temperature sensor we can control the system by feedback. The system then becomes a closed loop system. The sensor senses the output (heat) and adjusts the input to provide just the amount of heat required. A simple bimetallic switch reacts to heat by bending when it gets hot. This sensor will switch the heater off if it gets too hot and switch it back on again as the air cools to a set temperature. A complex sensor will use electronic components such as thermistors, transistors and integrated circuits to give better control. Better control here would mean more precise temperature control and also less time delay in reacting to

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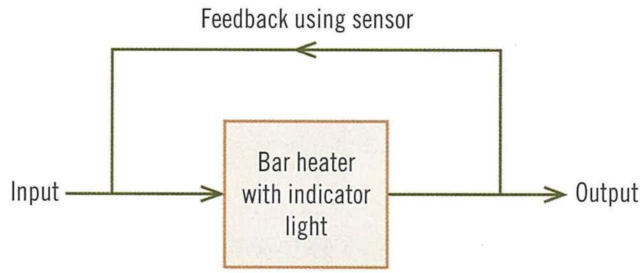
temperature changes. This delay is called lag and can be found in all closed loop systems. A good feedback electronic control unit will have very small lag.

The output of the system is not monitored and the input is not affected by the output in an open loop system.

The output of a closed loop system is monitored in some way and controls the input. You should clearly define both input and output before deciding whether a system is an open or closed loop. A garden solar light is not a closed loop system and yet needs no human intervention.

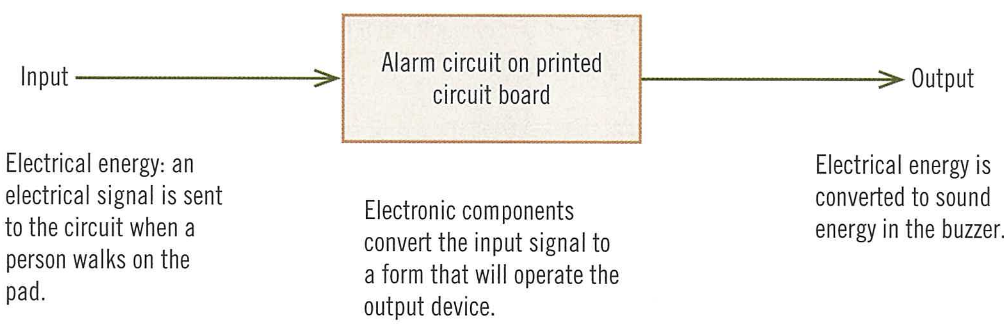
Block diagram: heater



An electronic system: alarm circuit

Electronic components such as resistors, transistors, capacitors, diodes, thermistors and integrated circuits are used to control the flow of electrons in the circuits of electronic systems. The electric current in these systems is relatively small. A simple alarm is a good example of an electronic system. A sensor, such as a pressure pad, is connected to the input of the electronic circuit. A buzzer produces a beeping sound when a person walks on the pad.

Block diagram (IPO): alarm circuit



Electronic and microelectronic systems use small currents and low voltages.

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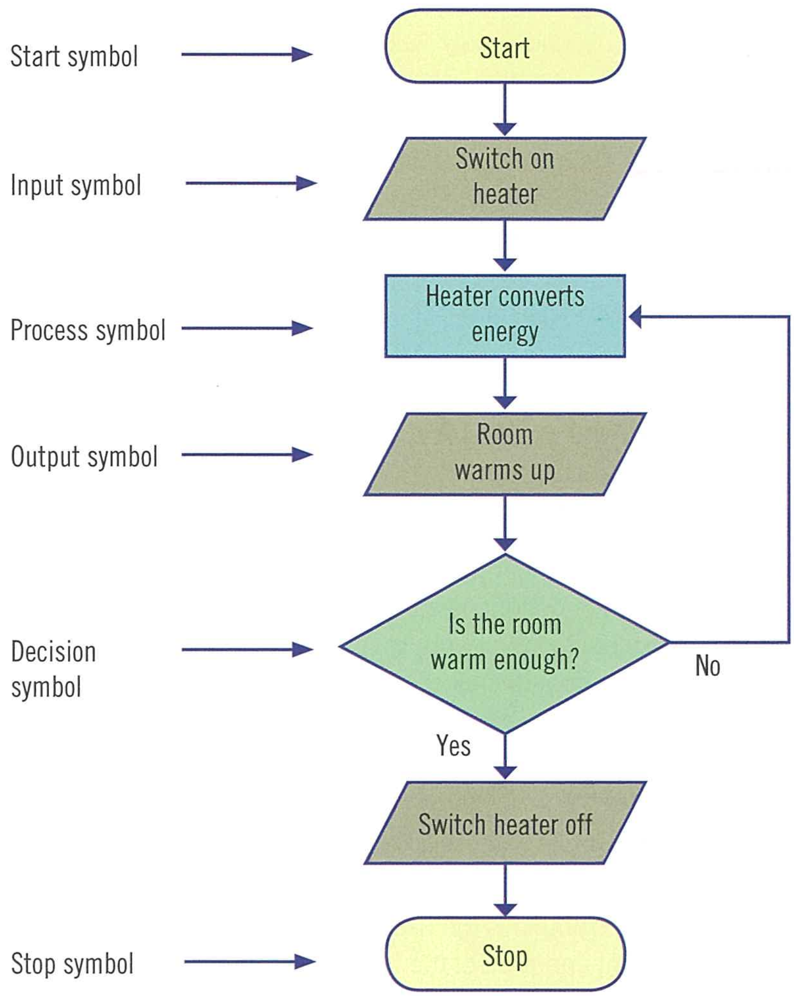
Flow charts

Flow charts and block diagrams can be used to explain the operation of a system. The chart below shows the operation of a basic bar heater used to heat a room. Note the symbols used.



Block diagram of a closed loop system

LEARNING ACTIVITY 5.1

1 Use block diagrams to describe the input, process and output of the following.

- **a** Hair dryer
- **b** Alarm system for car
- **c** Electric fish-tank pump
- **d** Garden solar light

2 Explain the difference between open loop and closed loop electronic systems, giving an example of each.

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3 a A modern electric kettle is an example of an electrical system. Sketch a diagram of such a kettle.

   b Explain its operation in terms of input, process and output.

   c Explain whether the system is open or closed loop.

4 A battery-operated alarm clock radio is an example of an electronic system. Terms such as 'radio waves', 'light energy', 'sound energy', 'electrical energy' and 'electronic components' would be used to describe its operation. Draw a block diagram and explain the operation of the system as it wakes you up in the morning.

5 When you load a washing machine and switch it on, it fills with water to a certain level. The machine then turns off the inlet tap and goes through its washing cycle. At the end of the cycle, dirty water is pumped out and fresh water is taken in for a rinsing cycle. The rinse water is eventually pumped out and the machine spins the load and stops, completing the whole process. Draw a flow chart to explain the operation of a washing machine from start to stop.

Components and their uses

There are a large number of electronic components. A basic circuit for a flashing light can be made up of only three different types of components, whereas a more complex circuit for an infra-red receiver would contain many more components. Details about components can be found in the catalogues of major suppliers of electronic equipment and on their websites. Information such as uses, operating temperature, power rating and tolerance can be obtained. This section will outline such information about the following basic components: resistors, capacitors, inductors and semiconductors.

Resistors

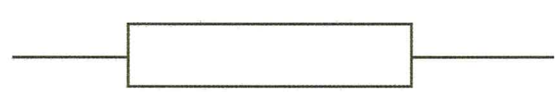
Resistors have three main purposes:

1 They limit the electric current in circuits. The greater the resistance, the smaller the current is going to be. A common example is the use of a resistor next to a light-emitting diode (LED) to reduce the current and protect the LED from damage.

2 They control the current in a circuit. A variable resistor can be used to control the current in, say, a motor to increase or decrease its speed.

3 They divide voltage. For instance, 9 volts can be divided into 8 volts and 1 volt by using two selected resistors or a variable resistor. This is how the volume control in an amplifier works.

A narrow rectangle or a zigzag line is used to represent a resistor. The rectangle symbol is most widely used nowadays.



Resistor symbols

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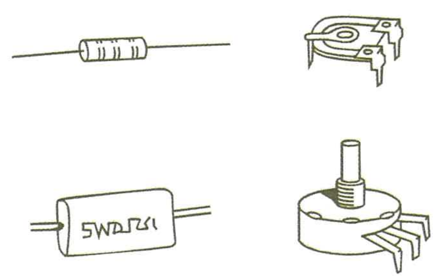
Types of resistors

There are many types of resistors and each has its advantages and disadvantages. The five main types are:

1. **carbon-composition resistors**, which contain graphite, ceramic and resin, are cheap, but can be affected by heat and be unreliable
2. **carbon-film resistors**, which use carbon deposited onto a ceramic core, are more accurate than carbon-composition resistors, and are normally pale yellow with four colour bands
3. **metal-film resistors**, which have metal coated onto a ceramic core, are more accurate than either type mentioned above, and are normally blue with five colour bands
4. **wire-wound resistors**, which use windings of nickel–chromium wire round a central core, are accurate and can handle large currents
5. **foil resistors**, which have a thin foil of nickel–chromium that is bonded to a ceramic base, are very accurate and are not greatly affected by heat.



Fixed resistors   Variable resistors

Resistor types

Resistor values: the ohm

A resistor has an electrical property called resistance. Resistance values are given in ohms (or Ω, the Greek letter 'omega'). These range from a fraction of an ohm to millions of ohms. Not every single value is available commercially. Only 'preferred' values are made and sold because in the values of the resistors most basic circuits are not critical. Also, resistors can be placed in series or in parallel to obtain other values.

There are many ways resistance values can be written.The following table gives some examples of resistor notation used in circuit diagrams.

Resistor value (Ω)	Notation
12	12R, 12 Ω
500	500R, 500 Ω
1000	1K (K = kilo/thousand)
1200	1K2
12200	12K2
560000	560K
1200000	1M2 (M = mega/million)

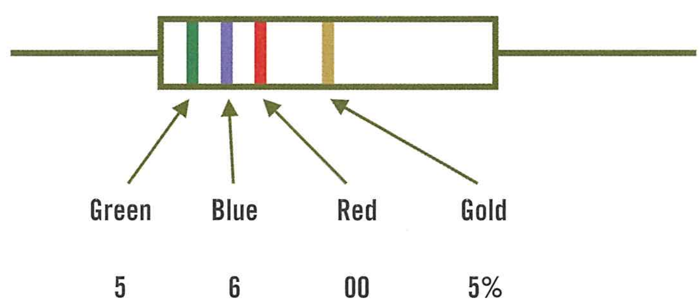
Colour code

The colour of the band and its position make up a code. Most resistors will have four colour bands, but some will have five. Each colour is given a number, as shown in the table below.

Colour	Number	Multiply by
Silver		0.01
Gold		0.1
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1000
Yellow	4	10000
Green	5	100000
Blue	6	1000000
Violet (purple)	7	
Grey	8	
White	9	

For instance, red is given the number 2, green the number 5 and blue the number 6. If the first three colours (for a four-colour band resistor) are green, blue and red, the resistor will have a value of 5600 ohms.

1. The first band colour is green, which gives us the first number (5).
2. The second band colour is blue, which gives us the second number (6).
3. The third band colour is red, which gives us number 2, but we do not write down 2; instead we write 00 (two zeros). The third colour gives us the number of zeros we need.
4. So the number indicated by the colour bands is 5600. This is the same as 5.6K or 5K6. A common mistake is to write down 562.



The colour code for a 5.6K or 5K6 resistor

Tolerance

The band gap is wider between the last two bands; in this case, the third and the fourth bands. We use this to read the colours in the right order. The fourth or last band gives us a percentage (for example, 2%) rather than a number. A gold band, which is the most common, is 5%. This is called the tolerance of the resistor.

A 5600 ohm resistor rarely turns out to be exactly this value. If a tolerance value of 5% is quoted for this resistor, its true value can be anywhere between 5320 ohms and 5880 ohms.

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Tolerance is the estimated range the resistor value falls within ±5% of the quoted value. This is explained below:

1 5% of 5600 is 280.

2 5600 minus 280 is 5320 ohms, the minimum value acceptable.

3 5600 plus 280 is 5880 ohms, the maximum value acceptable.

Testing resistors

The resistance value in ohms of a resistor can be measured with an analogue or digital multimeter. This should be done before the resistor is in a circuit. If you have to do this when the resistor is in a circuit, you should switch the power off so as not to damage the multimeter. You should also consider the fact that other components will affect the reading.

Analogue meter

1 Set the dial to the ohms position. Choose a scale just above the resistance value. For example, '× 10' means that the reading will have to be multiplied by 10.

2 If you are not sure, choose the biggest scale, such as '× 1000'.

3 Touch the tips of the test leads together and adjust the control (this is a knob on some meters). The reading should be zero ohms. This is called zero-adjust. Your eye should be straight above the pointer to avoid error. If the pointer does not move, the fuse inside the meter needs to be replaced.

4 Connect the test leads to the terminals of the resistor. If the pointer does not move, change to a lower scale until the pointer is in a position where the scale is easy to read. Recheck the zero-adjust if you have had to change the scale. You should not forget the scale multiplier (such as '× 10') when noting the value.

Digital meter

1 Set the dial to the ohms position; select the largest value if you are not sure. Check the zero reading by touching the test leads. There is no adjusting knob, but if the reading is not zero, the meter could be faulty or the battery needs to be replaced.

2 Measure the resistance by touching the terminals of the resistor with the test leads. If the display shows 20, you need to check the dial position to decide whether or not it is just 20 ohms, 20K or 20M.

3 The dial position specifies the maximum resistance measurable in that particular position. Most meters will display the number 1 if the resistor value is higher.

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A digital multimeter

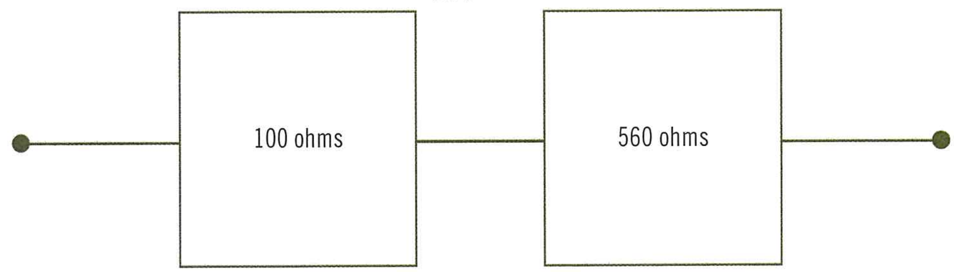
Resistors in series

Two or more resistors can be placed in series to obtain a higher value resistor. The term 'series' means that the same electric current goes through each resistor.

A 100 ohm resistor in series with a 560 ohm resistor gives a total of 660 ohms. We add the values to find the total resistance:

$$R_{(total)} = R_1 + R_2 \ldots$$

Two resistors in series



Take care if the two resistors use different notation, such as 100 ohms and 10K. The total will be 10 100 ohms, not 110 ohms.

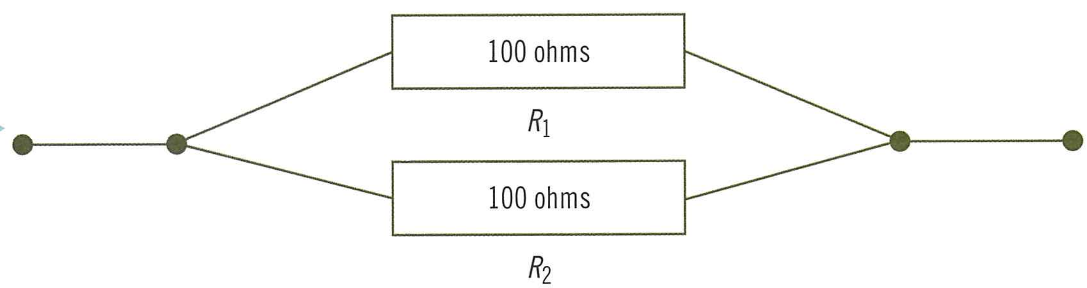
Resistors in parallel

When resistors are connected in parallel, the total resistance decreases. Parallel connection means that the ends of the resistors are connected together.

Two 100 ohm resistors in parallel will give a total of exactly half the resistance – 50 ohms. If the resistors are not the same, this equation can be used:

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

Two resistors in parallel



LEARNING ACTIVITY 5.2

1 Name five types of resistors.

2 A 2700 ohm resistor can be written in two other ways. What are they?

3 List the colours of the following four-band resistors of 5% tolerance.

- **a** 1K
- **b** 68K
- **c** 2.2M
- **d** 10R

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4 Calculate the minimum and maximum values acceptable for a 680 ohm resistor with a tolerance of 5%.

5 Write down the values for each of the resistors with the first three colours shown.

  a Orange white red

  b Brown red orange

  c Green blue yellow

  d Brown green black

6 Draw and calculate the total resistance of the following resistors.

  a Two 680 ohm resistors in parallel

  b Two 560 ohm resistors in series

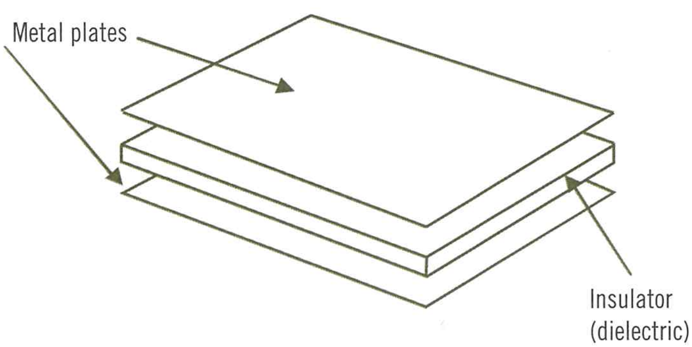
Capacitors

A capacitor is an electronic component that stores electric charge, namely electrons. It has two terminals connected to two thin metal plates, with an insulator (called a dielectric) in between. The capacitor has an electrical property called **capacitance**.

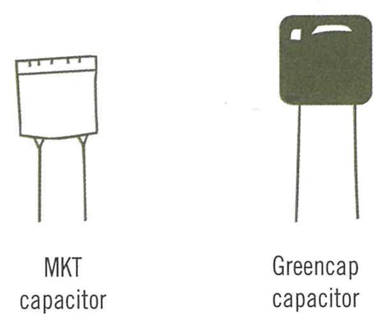
The structure, symbols and types of capacitors are shown in the diagrams and photographs that follow.

Capacitors: structure, symbols and types

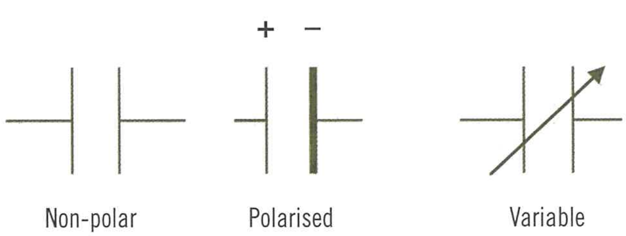
Structure of a capacitor



Types of capacitors



Capacitor symbols



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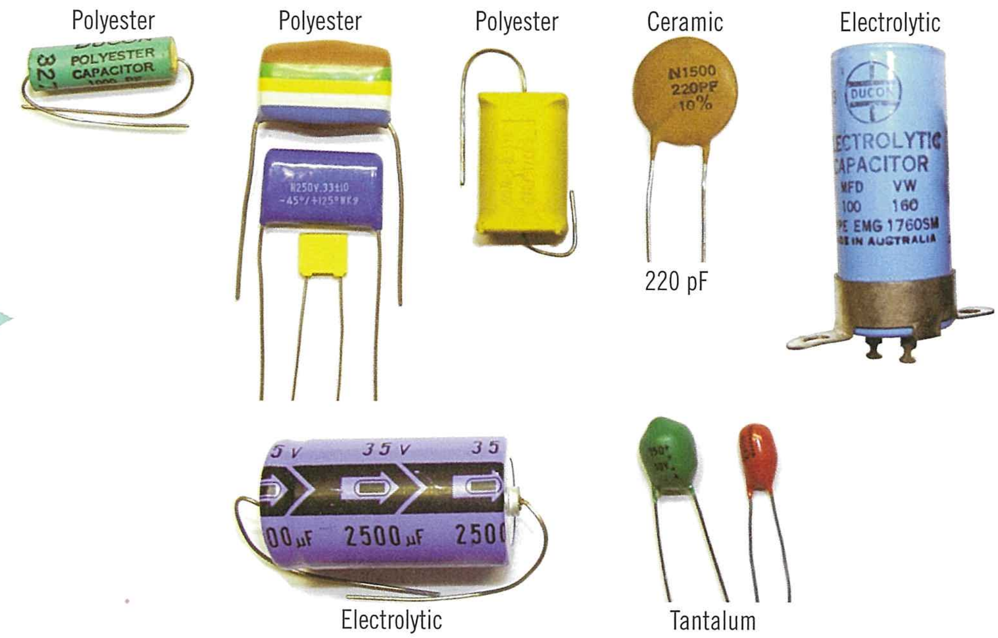
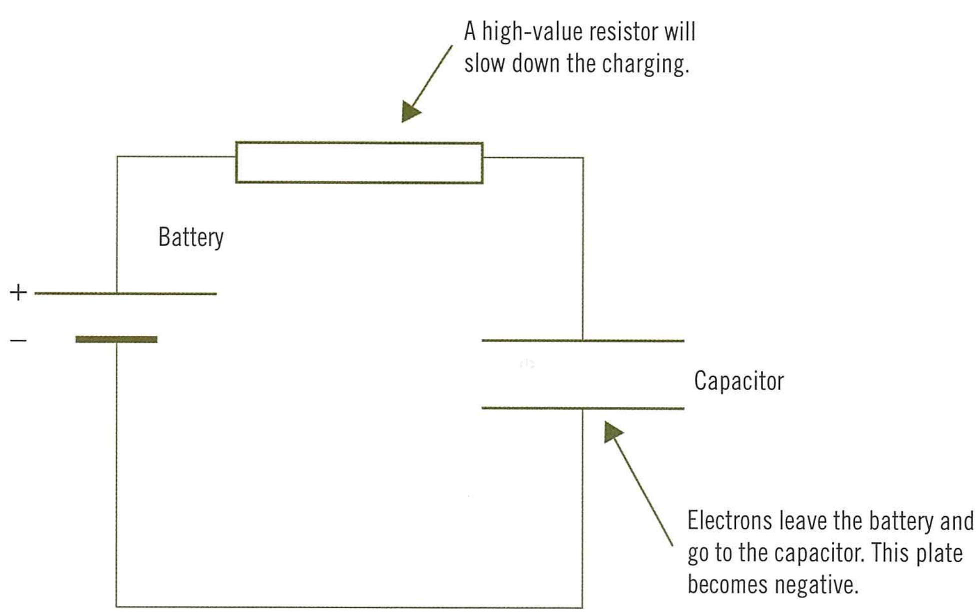


The many varieties of capacitors

Charging and discharging capacitors

The plates of the capacitor are neutral until they are connected to a source of electricity, such as a battery. The battery will remove electrons from one plate and add electrons to the other so that they become positive and negative respectively. This happens very quickly if there is no resistance in the circuit. There is a quick flow of electrons (a sudden current) until the plates are fully charged. Once this happens, the electrons stop flowing and the current stops. If the capacitor is now disconnected from the battery, the charge will remain on the plates, but with time it will leak away and the capacitor will be discharged. A quicker discharge can be achieved by simply making the terminals touch each other.

Very large capacitors should be handled with care when fully charged as they can give an electric shock if discharged through the human body.



Charging a capacitor

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Capacitor values: the farad

A capacitor connected to a battery of *V* volts will store a charge of *Q* coulombs. The ratio *Q/V* is called the capacitance *C* of the capacitor (just like the ratio *V/I* = resistance).

The letter *C* is used for capacitance. Capacitance is measured in farads (F); for example, *C* = 0.001 farad, or 0.001 F.

A large-value capacitor will store more charge than a small-value one if they are connected to the same battery. As capacitor values are generally very small, other units with prefixes such as 'milli–', 'micro–', and 'pico–' are more convenient.

1 millifarad = 1 mF = 0.001 F (1 farad divided by 1000)
1 mF is 1/1000 F, just like 1 mm is 1/1000 m or 0.001 m
1 microfarad = 1 μF (pronounced 'mu F' and sometimes written as simply uF)
1 μF = 1 farad divided by 1 million
1 nanofarad = 1 nF = 1 farad divided by 1000 million
1 picofarad = 1 pF = 1 farad divided by 1 000 000 million

Types of capacitors and their uses

Capacitors are generally named after the insulating material used between the plates or the special use they have. The three most common are ceramic, polyester and electrolytic capacitors. There are fixed capacitors and variable capacitors.

- **Ceramic capacitors** are mainly disc-shaped, and values range from 1 pF (picofarad) to 100 000 pF. The plates consist of a deposit of silver on a thin sheet of mica or ceramic. These capacitors are non-polar, which means they have no positive and negative terminals and can be connected either way in a circuit. They should, however, be placed so that any writing on the body is easy to read.
- **Polyester capacitors** are also known as greencap capacitors. They are non-polar and values range from 0.001 μF (microfarads) to 4.7 μF. Ceramic and polyester capacitors are used as bypass and coupling capacitors. This has to do with allowing AC electricity through while blocking direct current (DC) electricity. Speaker systems use them to channel high-frequency signals to the tweeter.
- **Electrolytic capacitors** are typically used where large values for capacitance are required. The most common is the aluminium electrolytic capacitor. The negative plate is in the shape of a can and the positive plate is a roll of aluminium foil inside the can. The space between the plates is filled with a semi-liquid material called an electrolyte. Aluminium oxide deposited on the foil forms the insulator required. Electrolytic capacitors are polarised (that is, they have positive and negative terminals), and care should be taken when placing them in circuits. If connected the wrong way, they may explode due to the chemical reactions inside. Electrolytic capacitors are used in power supplies and timing circuits.
- Other types of **fixed capacitors** are polycarbonate, MKT, polypropylene, polystyrene and tantalum.
- **Variable capacitors** are capacitors that can be adjusted to give different values from around 2 pF to 500 pF. Rotary or compression types are also made. In the rotary type the amount of overlap between the plates determines the capacitance value. In the compression type (also called a trimmer capacitor), the spacing between the plates is changed. Air or mica is used as the insulator between the plates. Variable capacitors are used in tuning circuits, as you would find in a radio.
- **Supercapacitors** are similar in size to electrolytic capacitors, though they have a much larger capacity and energy density.

Supercapacitors are better than traditional capacitors as they not only cope with higher surges, but also react faster. Supercapacitors use a carbon surface to store electric charge. The surface area is much greater than in traditional capacitors that use metal surfaces. Supercapacitors can be charged and recharged much faster and they do not deteriorate over time, so they last longer. You can find more information on supercapacitors in Chapter 2, page 46.

Capacitor data

The numbers and letters found on a capacitor give information about the capacitor. The amount of information depends both on how much can be printed on the body and on the manufacturer, who will provide more in the catalogue. Three important quantities are usually found: the capacitance value, the voltage rating and the tolerance.

Polarised capacitors have indicators to show which leg is positive and which is negative. The shorter leg will be negative, or the arrow sign will point to the negative leg. The capacitor value is printed on most electrolytic capacitors, such as 100 μF. Ceramic and polyester capacitors use a coding system.

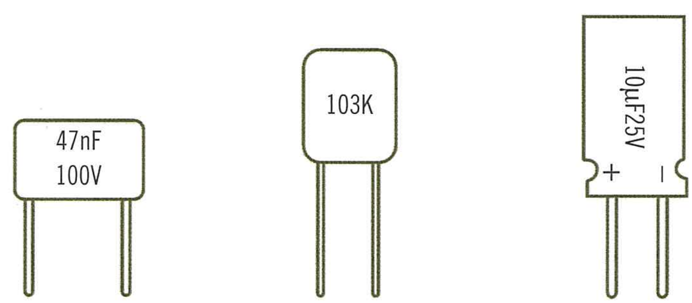
Coding system

1 If there is a decimal point in the code (such as 0.01) the value is in microfarads; for example, 0.01 μF.

2 If there are three numbers and a letter (such as 472 J), the value is in picofarads. The code is 472, giving a value of 4700 pF. The first two numbers are written down (47), and the last number is the number of zeros that should be added. In this case we should add two zeros. The letter J indicates a tolerance of 5%.

3 If there are only two numbers (such as 33), the value is just in picofarads, such as 33 pF.

Capacitor markings



Tolerance

Capacitors, like resistors, have tolerance percentages.

The tolerance letters and values used are F = 1%, J = 5%, K = 10%, L = 15% and M = 20%.

Voltage rating

The voltage rating is printed on most capacitors. If a capacitor has a rating of 50 volts, it can be used up to this voltage, but never beyond that value. If it is used beyond the value, the capacitor will overheat and be permanently damaged.

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Capacitors in series

Similar to resistors, capacitors can be connected (two or more) in series. The total capacitance will be reduced. This is the opposite effect to that obtained when resistors are connected in series. For example, two 100 μF capacitors in series will be equivalent to just 50 μF (which is half the value). If the capacitors are polarised, the positive end of one should be connected to the negative end of the other.

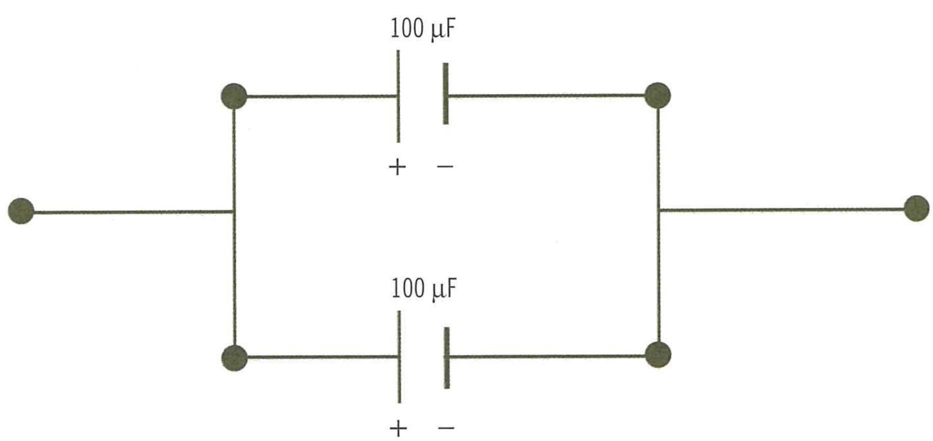
$$C_{\text{series}} = \left(\frac{C_1 \times C_2}{C_1 + C_2}\right)$$

Two capacitors in series

Capacitors in parallel

When capacitors are connected in parallel the total capacitance will increase. The total capacitance will be equal to the sum of the two (or more) capacitances. For instance, two 100 μF capacitors in parallel will be equivalent to a 200 μF one. The two positive ends of the capacitors must be joined up, as shown in the diagram below.

$$C_{\text{parallel}} = C_1 + C_2$$



Two capacitors in parallel

Inductors

An inductor is a coil of wire with either an air core (the space inside the coil) or a core made of a magnetic material, such as iron. Air-cored inductors are used in radio tuning circuits, and iron-cored inductors can be found in power supplies and fluorescent lamps. Electromagnets, relays, solenoids, ignition coils, electric motors and transformers all contain coils and can be thought of as inductors.

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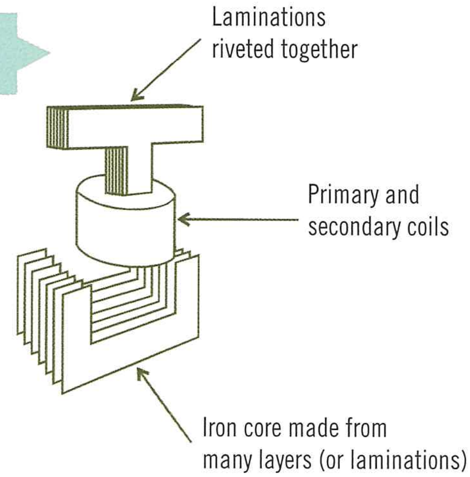
A transformer



The main property of inductors in basic electronic circuits is their ability to generate electricity. This can be put to good use in an ignition coil, but can be harmful to circuit components if protective devices are not used. A good example is the inclusion of a diode across a relay coil. When a relay is switched on or off, a high voltage is produced for a fraction of a second. This voltage can harm the transistor used to switch the relay. If a diode is connected across the relay coil, it will stop that high voltage reaching the transistor.

An electric motor actually produces electricity as the coil spins, but that electricity effectively reduces the current in the coil and stops it overheating. If, for some reason, the motor coil stops spinning while the motor is still connected to the power source, the current in the circuit remains high and the coil overheats and can burn out. You should always switch off the power if a motor is jammed and cannot spin.

LEARNING ACTIVITY 5.3

1 a Draw a diagram showing the structure of a capacitor.
  b Explain how you would charge and then discharge the capacitor.
2 Capacitance can be indicated in millifarads. Name three other possible units.
3 Name four types of capacitors.
4 What advantages do supercapacitors offer?
5 Explain why you should take care when using electrolytic capacitors.
6 Write down the value and tolerance of the capacitors with the following markings.
  a 392J
  b 474K
  c 105J
7 Draw and calculate the total capacitance of the following electrolytic capacitors.
  a Two 470 μF capacitors in parallel
  b Two 1000 μF capacitors in series
8 Explain what makes up an inductor and give four examples of inductors.
9 Explain why a diode is needed across a relay coil in a circuit.
10 Explain why power should be cut off if a motor is jammed and does not spin.

Semiconductors

In a conductive material such as copper, electrons can move almost freely within the material. These are called ‘free’ electrons. In an insulator such as plastic, electrons are bound to the atoms and are not free to move, except at very high voltages. A semiconductor is somewhere between a conductor and an insulator. Two commonly used semiconductors are silicon and germanium; both are used to make components such as diodes and transistors.

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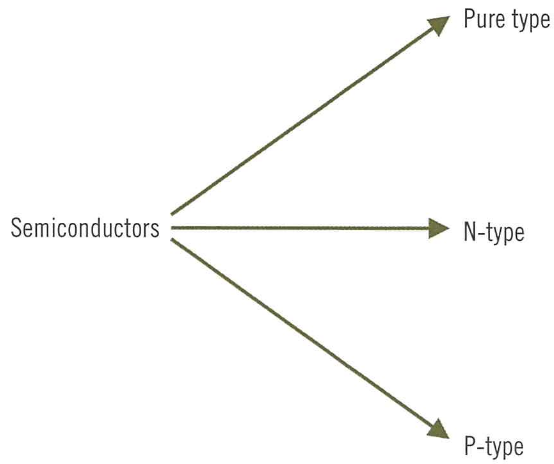
A material can be a conductor, an insulator or a semiconductor.



Types of semiconductors

Types of semiconductors and their uses

Semiconductors are classified as pure, N-type or P-type.

- A pure semiconductor is one to which no foreign atoms are added. They are poor conductors at low temperatures, but will conduct at higher temperatures as electrons break free and move. A pure semiconductor makes a good temperature sensor.
- In an N-type semiconductor, atoms of one selected element such as phosphorus are added to a bit of pure semiconductor. This is called 'doping' and results in extra electrons being available to produce electric currents. The current is cause by the flow of negative (hence, N) charges.
- In a P-type semiconductor, another element such as boron is used in the doping process. This results in an opposite effect. Instead of providing extra electrons, the boron atoms create what are called 'holes' ready to accept electrons. When an electron moves to fill a hole, it creates a hole in the space it has left behind. Another electron may move in to fill the new hole. The hole has 'moved'. As a hole can be considered as positive (electron missing), the current in this case is caused by the flow of something positive (hence, P).

Semiconductor devices

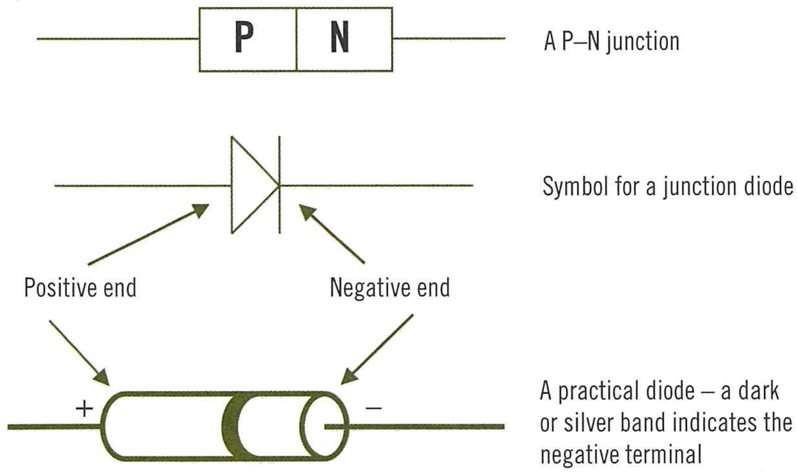
Diodes

There are four main types of **diodes**: junction diodes, zener diodes, light-emitting diodes and photodiodes.

Junction diodes

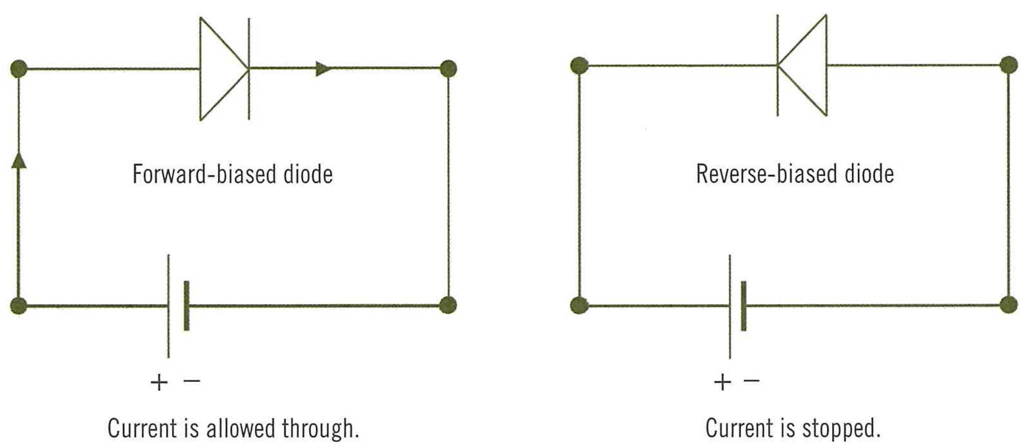
When a P-type and an N-type semiconductor are joined together we have a P–N junction (see illustration on page 134). This is how junction diodes are made. A junction diode has a positive (also called the anode) and a negative terminal (or cathode).

A junction diode

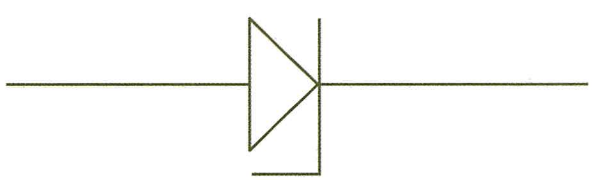


The diode acts as a one-way valve in a circuit by allowing current to flow in one direction only. When this happens, the diode is said to be forward-biased. When the diode is connected so that it stops the flow of electricity, it is said to be reverse-biased. This works only up to a certain voltage. The arrow in the symbol tells us in which direction the diode will allow current to pass.

Forward- and reverse-biased diodes



Symbol for a zener diode



Zener diodes

The zener diode is similar to the usual junction diode except that it is always used in the reverse-bias mode. Even in this mode a diode will eventually conduct once voltage across it reaches a certain value. This voltage remains fixed regardless of any changes that may take place in the circuit. The supply voltage may increase for some reason, but the voltage across the zener diode will not. This makes the zener diode very useful in voltage regulation, giving a fixed reference voltage over a range of input voltages.

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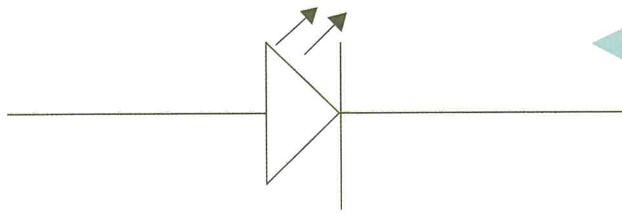
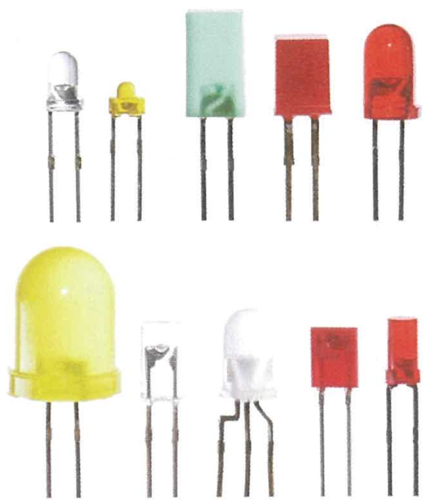
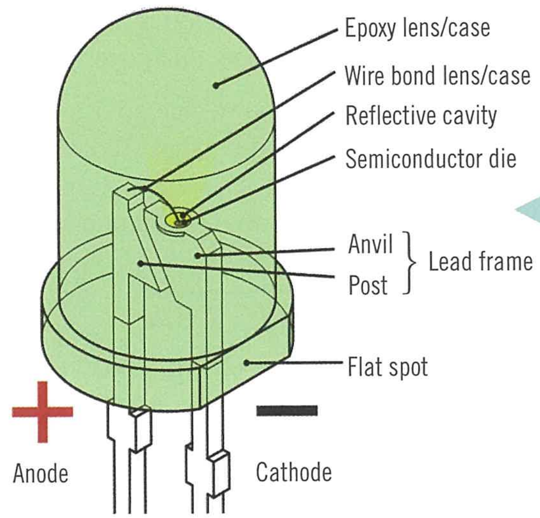
Light-emitting diodes

The light-emitting diode (LED) is simply a junction diode that emits visible light when it conducts in the forward-bias mode. LEDs are available in different sizes and colours and are used mainly as indicators, but they can also be found inside components called optocouplers. Infra-red-emitting diodes are used in remote control systems.



Symbol for light-emitting diode

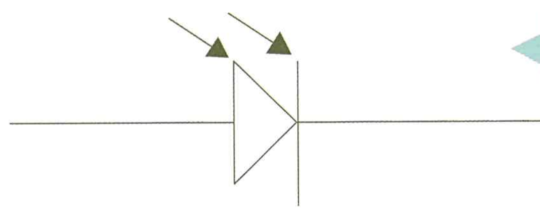




Light-emitting diodes

Photodiodes

The operation of a photodiode depends on the amount of light (mainly infra-red) falling on the P–N junction. The more intense the light, the greater the current will be. Photodiodes make good light sensors. These diodes are used in the reverse-bias mode.



Symbol for a photodiode

Care when using diodes

As with all electronic components special care is needed when selecting and using diodes, especially LEDs. Identify the positive (also called anode) and the negative terminals and insert the diode the right way in the circuit. Manufactures quote the maximum reverse voltage that the diode can handle. This is important with LEDs, as this voltage can be quite low. If an LED is connected the wrong way to a 9 volt battery it will be damaged as the maximum reverse voltage allowed is only about 3 volts for most LEDs.

Manufacturers also quote the maximum current that can pass through a diode. Using a resistor next to it can protect a diode. An LED will operate well with a current of about 20 mA. It will overheat with larger currents. A resistor of about 1 kV next to the LED will protect it in most basic circuits.

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Testing diodes

A diode can be tested using a multimeter. This is best done when the component is not in a circuit and with an analogue meter, although a digital one can also be used.

1 Set up the multimeter to measure resistance (in the low ohms range, such as × 1). Place the leads across the terminals of the diode and note the reading.
2 It will be either high (the needle will not move) or low (about 600 ohms, depending on the diode).
3 Reverse the leads and note the new reading. It should be the opposite of that obtained previously. If both readings are the same, the diode is faulty.
4 Other components may affect the readings if the diode is in a circuit, but the power should be switched off if this method is attempted. Power should always be off when measuring resistance; otherwise the multimeter would be damaged.
5 With the power on, the voltage across a diode can be measured to check for correct operation. This should be about 0.6 volt for most diodes when they are conducting (forward-biased). If it is known that the diode should be conducting and a much higher or lower voltage is obtained, the component is faulty.

LEARNING ACTIVITY 5.4

1 Explain the difference between a conductor and a semiconductor. Give two examples of each.
2 There are three classifications for semiconductors. What are they?
3 Explain the main difference between a P-type and an N-type semiconductor.
4 List the four main types of diodes.
5 What is the basic function of a junction diode?
6 What do the letters 'LED' stand for?
7 What is the maximum reverse voltage for an LED?
8 What test instrument can we use to test a diode?

Transistors

Transistors are still the most common and important devices in basic electronics. Many types of transistors are available, but there are two main classes: junction transistors and field effect transistors.

Junction transistors

There are two kinds of junction transistors: NPN and PNP, where N stands for negative and P for positive. In the NPN transistor a very thin slice of P-type semiconductor is sandwiched between two thicker slices of N-type semiconductor. The layers are called the **emitter** (E), **base** (B) and **collector** (E), and each is connected to a terminal or pin so that the transistor has three legs or terminals.

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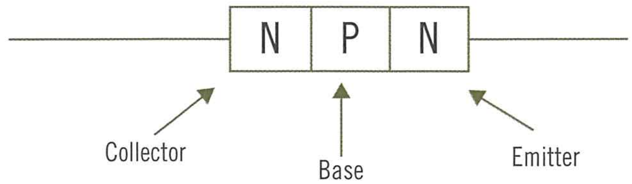
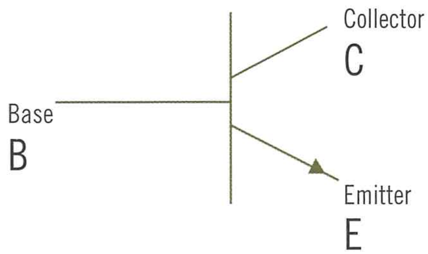
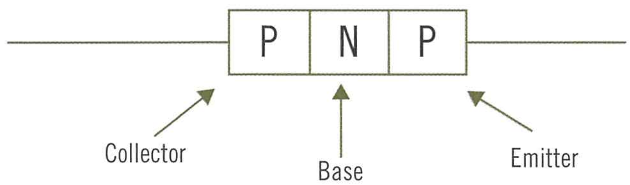


An NPN transistor

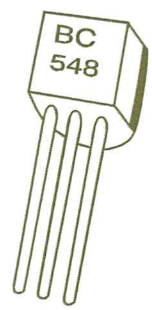
Symbol for an NPN transistor



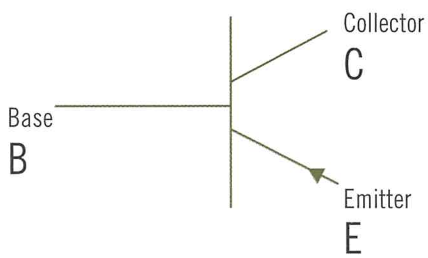
The arrow shows that current goes from the base (+) to the emitter (–).



A PNP transistor



Symbol for a PNP transistor

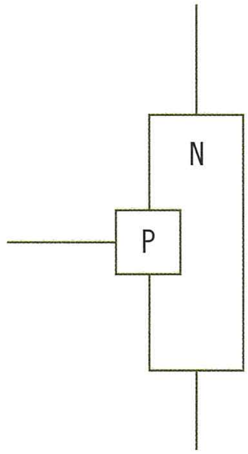


The arrow points in, indicating that current passes from the emitter (+) to the base (–).

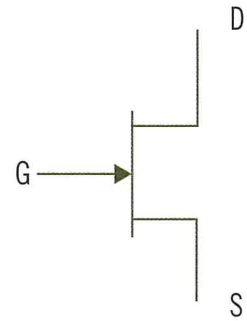
Field effect transistors

Field effect transistors (FETs) look the same as junction transistors – they both have three terminals (B, C and E) – but their construction and mode of operation are different. There are two types of FETs: N-channel and P-channel and the terminals or pins are labelled source S, gate G and drain D (see illustration on page 138). A FET can be a junction FET (JFET) or an insulated gate FET (IGFET). A popular variation of the latter is the MOSFET, where MOS stands for metal oxide semiconductor. MOSFETs are used extensively in integrated circuits and amplifiers. They are better converters of energy than junction transistors. Another advantage of FET transistors is that they are less affected by heat. A disadvantage, however, is that they are very sensitive to electrostatic discharge (ESD).

A field effect transistor



An N-channel FET



Symbol for N-channel FET

The following precautions will prevent damage to components (especially integrated circuits) made up of MOSFETs:

1 Do not touch the leads if possible.
2 Do not remove the component from its packaging until it is ready for use.
3 Wear an antistatic strap, which may be earthed using the earth pin on a DC power supply. This prevents the build-up of static electricity on the person. Do not connect the strap directly to the mains socket earth pin.
4 Use an earth-tipped soldering iron.

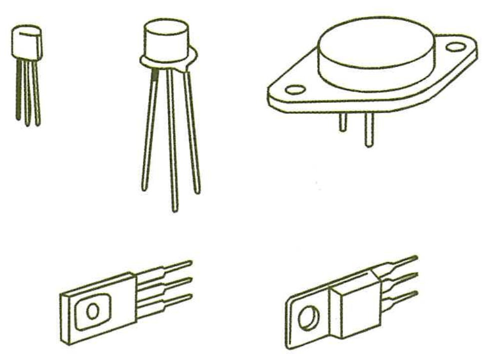
Transistor identification

Transistors are identified by a number of codes. In one common code, the first letter printed gives the semiconductor material used: A for germanium and B for silicon. The second letter indicates the most suitable use. For example, a transistor coded C is for audio-frequency use. Printed numbers often relate to voltage and power ratings for the transistor:

- A BC 548 transistor is a silicon audio-frequency one, with a voltage of up to 30 volts allowed and a power rating of 0.5 watt.
- A BC 546 transistor is similar except that the maximum voltage allowed is 60 volts. In a circuit with a 9 volt supply, either transistor can be used.

Transistors come in a variety of shapes and sizes or packages. Each package has its own pin configuration and this information is essential as it tells us where the base, emitter and collector are located.

Some transistor packages



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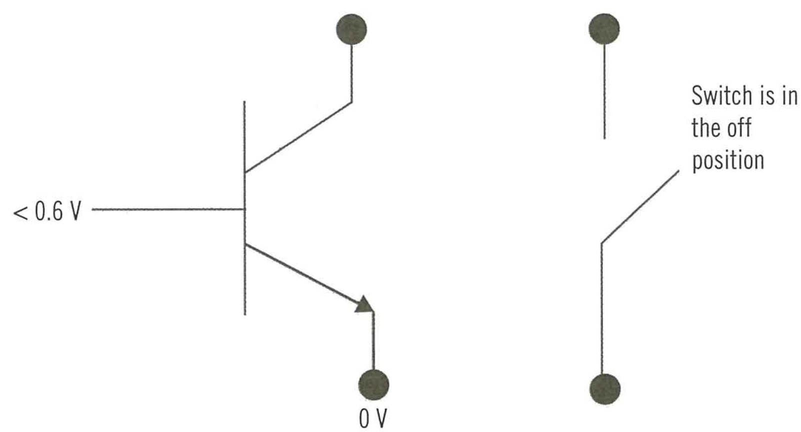
The junction transistor as a switch

A transistor can be used as an electronic switch. A finger or a lever (or some other kind of action) activates a mechanical switch; a transistor switch is activated by voltage. If the voltage (between the base and the emitter) is below about 0.6 volt, the transistor acts as an 'off' switch. There is no connection between the emitter and the collector. When this voltage is increased to above about 1 volt, the transistor conducts and the emitter and collector act as an 'on' switch. The switch is not perfect as there is a small voltage loss (0.1 volt) across it. A perfect switch is a short circuit with no voltage loss.

Measuring the voltage across the base and the emitter is a good way of testing whether a transistor is fully on or off. A reading of less than 0.6 volt indicates the transistor is off and one of more than 1.0 volt indicates the transistor is on. These values depend on the type of transistor, but they should not vary much.

Measuring the voltage between the collector and the emitter is also another way of checking the transistor. A low value (0.1 volt) means that the transistor is fully on, and a high value (a few volts) means that the transistor is off.



The transistor as a switch

The junction transistor as an amplifier

The output current from, say, a microphone is very low and not strong enough to operate a loudspeaker. It needs to be made bigger (amplified) before entering the speaker coils. This is done by a number of transistors in an **amplifier**. A transistor can be set to **amplify** current.

The voltage values set at the three terminals of a transistor are critical for correct performance. If they are too low the transistor will be off, and might as well not be there as no amplification takes place. If they are set too high, many things can happen, such as overheating and distortion. The trick is to set the transistor so that it is neither on nor off, but partly on. The voltage between the base and the emitter should not be allowed to fall below 0.6 volt or rise above a certain value. This is achieved mainly by using resistors, capacitors and regulators. The transistor acts as an amplifier over a limited voltage range. A small change in the base current (the input) is amplified to a larger change at the collector current (the output).

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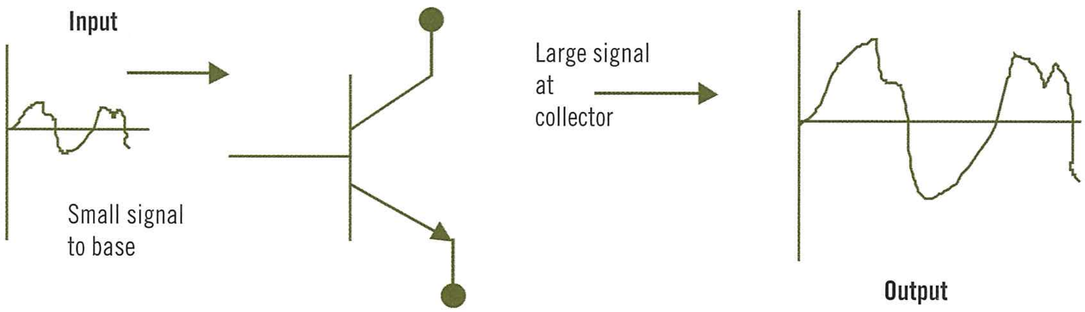
The signal being amplified is in analogue form. Voltage values can assume any value including positive and negative ones.

The transistor as an amplifier of analogue signals



Integrated circuits

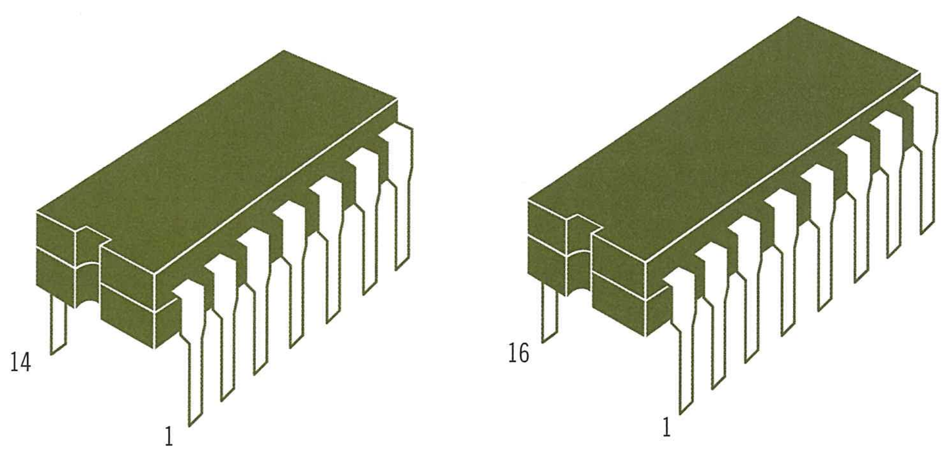
An **integrated circuit** (IC) is a complete circuit that is manufactured as a single package. It contains a number of transistors and at times resistors, diodes and capacitors, all made on a single chip or wafer of silicon semiconductor. There are two different types of integrated circuits:

1 Transistor-transistor-logic (TTL) integrated circuits require a supply voltage of 5 volts.

2 Complementary metal oxide semiconductor (CMOS) integrated circuits require between 1 and 3 volts. These chips are easily damaged by static electricity and must be handled carefully.

There are also two main groups of ICs: linear ICs and digital ICs.

Integrated circuits (14-pin and 16-pin)



Linear ICs

Linear ICs include amplifier-type circuits and deal mainly with analogue signals. These are electrical signals that change over a range of values. The signal from a microphone is analogue, as it can range from zero volts when there is no sound to pick up to a few millivolts for a loud sound. The LM 384, a 5 watt audio amplifier IC, is a good example of a linear IC.

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Digital ICs

Digital ICs contain switching-type circuits and handle digital signals. These signals have only two values: high (H) or low (L). In voltage terms, H would be somewhere near the supply voltage (a few volts) and L would be zero volts. Another way of indicating H is to write the number 1 and L is then 0. Calculators, CD players and computers are designed to deal with digital signals. An analogue signal can be converted into a digital signal and vice versa using converters. Integrated circuits come in different packages, like transistors. The dual in-line (DIL) types have 8, 14 or 16 terminals or pins, and the orientation of the pins should be well understood before they are used.

Programmable integrated circuits

A **programmable integrated circuit** (PIC) is basically a digital IC with input, process and output. The process part is programmable. A computer program is used to decide what happens to the input signals as they enter the chip. The output of the IC will depend on the instructions programmed in. This could be a simple two states on/off or high/low output, and a LED will flash on and off if it is connected to this type of output. The timing and sequencing of the on/off sequences can be changed by reprogramming. Electric motors and other output devices can be programmed to turn on and off at predetermined times and sequences. PICs are good control devices to use in robot construction and in similar projects.

The number of inputs and outputs vary according to the type of PIC used.

PICAXE and STAMP chips are examples of programmable ICs.

LEARNING ACTIVITY 5.5

1 What are the two main classes of transistors?

2 Name the two types of junction transistors. What do the letters stand for?

3 Draw the symbol for a PNP transistor. Label the terminals or pins.

4 Which of the following forms the middle layer in a transistor: the base, the collector or the emitter?

5 What are the types of field effect transistors and what are the pins called?

6 Draw the symbol for an N-channel FET.

7 What are the advantages of FET and MOSFETs over junction transistors?

8 What is the disadvantage of FET and MOSFETs over junction transistors?

9 Give an example of a code used in labelling a transistor.

10 State two uses for transistors.

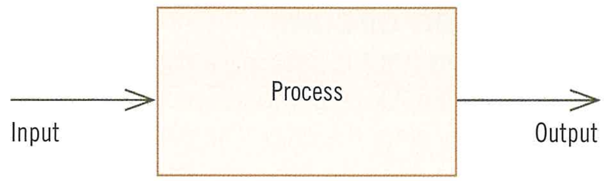
11 What are the two types or families of integrated circuits?

12 Why should CMOS ICs be handled with care?

13 Which type of IC deals mainly with analogue signals?

Transducers, sensors and switches

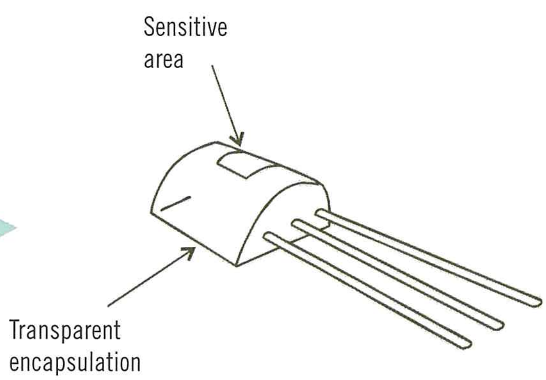
Transducers are devices that convert one form of energy into another. Microphones, loudspeakers, motors and generators are good examples of transducers. They are often used as input and output devices in electronic and electrical systems, as shown in the table below. A transducer itself has an input, a process and an output.



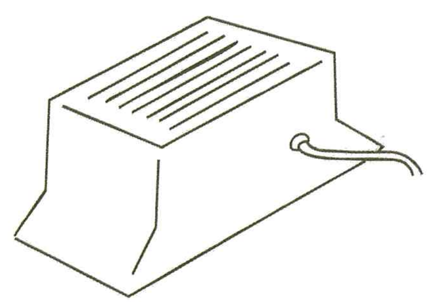
The input, process and output of some transducers

Transducer type	Input	Process	Output
Electric motor	Electrical energy	Force on a conductor	Motion energy
Electric generator	Motion energy	Electromagnetic induction current is produced if a wire moves through a magnetic field.	Electrical energy
Solar cell	Solar (light) energy	Photovoltaic effect in semiconductors	Electrical energy
Loudspeaker	Electrical energy	Force on a conductor. A coil with a current through it rotates if it is placed in a magnetic field.	Sound energy
Microphone	Sound energy	Electromagnetic induction. Electric current is produce if a wire cuts a magnetic field.	Electrical energy

Examples of transducers



Phototransistor



Buzzer

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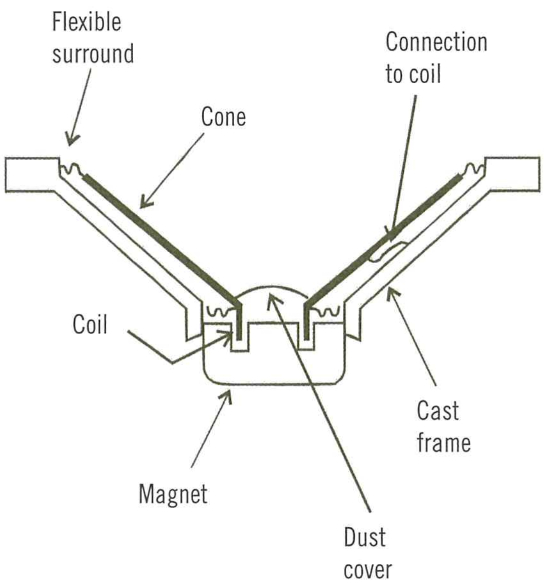
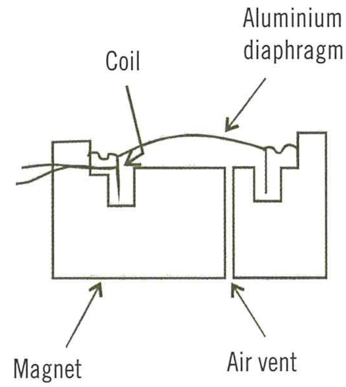


Loudspeaker



Microphone

Motors

Electric motors convert electrical energy into mechanical kinetic energy, together with some unwanted (inefficient) heat and sound energies. They can operate on DC or AC electricity depending on the design. DC motors are most commonly used in kits and project work; they can be continuous or stepping:

- In a **continuous motor** the shaft will rotate as long as the power is connected.
- In a **stepping motor** the shaft will rotate a few degrees and then stop. Power needs to be pulsed to the motor, which will repeat the rotate-and-stop cycle. Special electronic circuitry is needed to provide the power pulses.

Servo motors are continuous motors, but have a feedback loop. This helps in the accurate positioning of the shaft. These motors also need some electronic circuitry for proper operation.

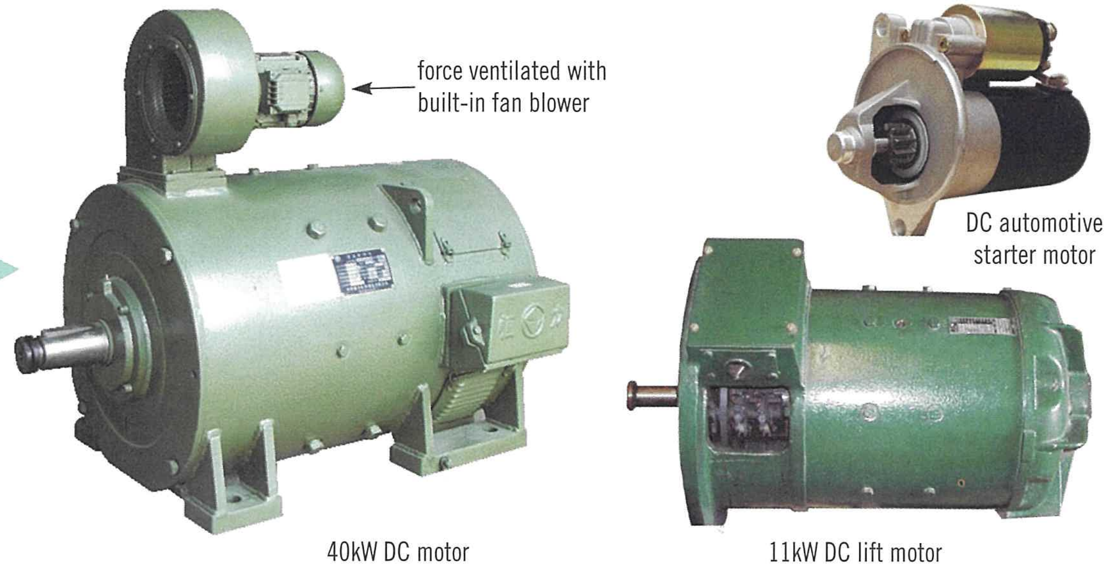
Electric motor operation is based on electromagnetism. A current-carrying conductor generates a magnetic field; when this is placed in an external magnetic field, it will experience a force proportional to the current in the conductor, and to the strength of the external magnetic field.

Opposite (north and south) polarities attract, while like polarities (north and north, south and south) repel.

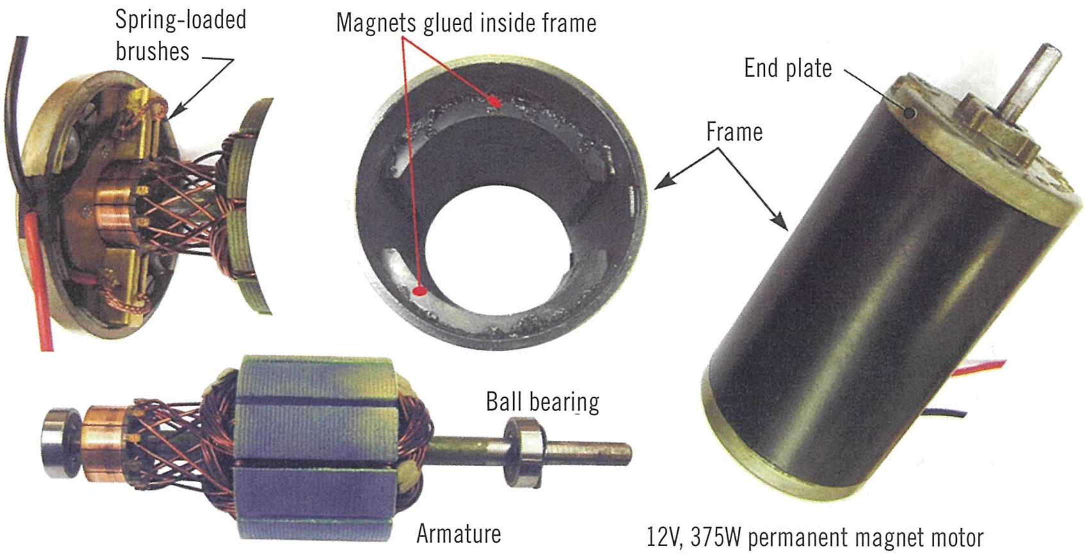
The internal configuration of a DC motor is designed to harness the magnetic interaction between a current-carrying conductor and an external magnetic field to generate rotational motion.

Motors are rated by their operating voltage and torque or turning force. Small DC motors are generally rated somewhere between 1.5 and 9 volts. They spin fairly fast at a few thousand revolutions per minute (rpm) and have low torque. A gear train can be used to reduce speed and at the same time increase torque.

Examples of DC motors, both industrial and automotive



12 V 375 W permanent magnet motor



Generators

An electric generator is a device that converts (input) mechanical energy into (output) electrical energy. A generator forces electric charge (carried by electrons) to flow through an external electrical circuit. Typical sources of mechanical input energy may be petrol or diesel motors (portable) for small to medium scale use, or steam turbines (plant) as used in large scale electricity generation. The reverse conversion of electrical energy into mechanical energy is done by an electric motor. Generators and motors have a number of similar features and functions.

Sensors

Sensors convert quantities such as temperature, light, pressure, force, motion, displacement and flow into electrical signals. Something in the sensor, at times a physical property such as resistance, changes as conditions change. For example:

- The resistance of a light-dependent resistor (LDR) changes as light intensity changes.
- The resistance of a thermistor changes as its temperature changes.

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Types of sensors

What is sensed	Sensor type
Light	LDR Phototransistor Photodiode
Heat	Thermistor Thermocouple Silicon semiconductor
Motion	Optoelectronic Hall effect
Pressure	Switch Strain gauge
Sound	Microphone Ultrasound receiver

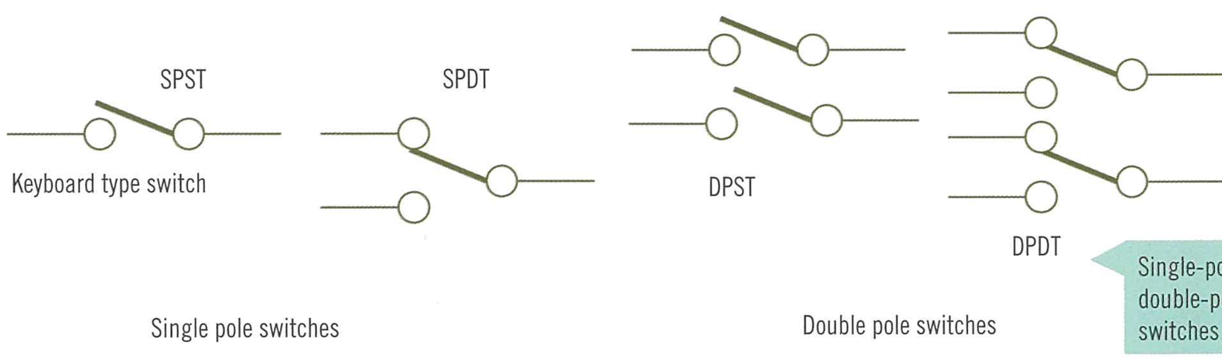
Switches

In a switch, metal contacts are made to touch each other to allow electricity to pass through, or they are separated to stop the flow. A switch has a current and a voltage rating. A 1.5 amps, 250 volts switch will work well up to these values, but will overheat if these values are exceeded.

Poles and throws

A switch is named after the number of poles and **throws** it provides.

1 A single-pole (SP) switch will be able to make or break one circuit only.
2 A double-pole (DP) switch will control two circuits.
3 The throws are the number of positions to which each pole can be switched. There are single-throw (ST), double-throw (DT) and even triple-throw (TT) switches.

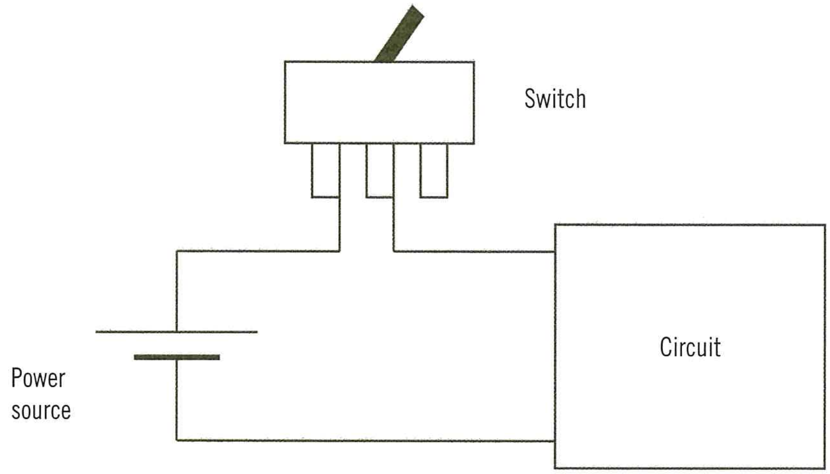


Single-pole and double-pole switches

Using switches

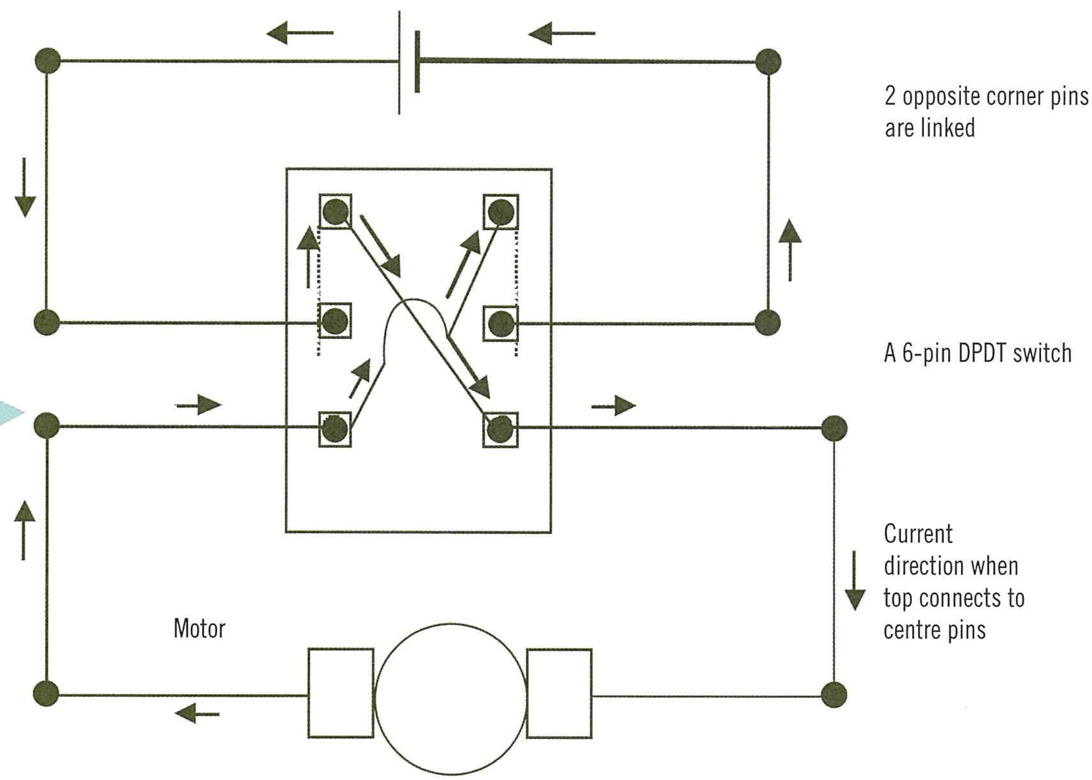
Single-pole switches are most commonly used for switching power on and off in a single circuit. The double-throw type will have three terminals and only two of them are used: the centre one and either one of the other two.

Using a single-pole switch



The double-pole double-throw (DPDT) switch can be used to switch two circuits. In this case one row or pole is used for one circuit and the other for the second one. Another popular use of this type of switch is to reverse the direction of the current in a motor and make it spin the other way.

Using a double-pole switch



Arrows indicate the direction of the current.

Manual switches

Push-button, toggle, slide, rotary and keyboard type switches are the most widely used types of manual switches. Push-button switches can be of the NO (normally open) type, or the NC (normally closed) type.

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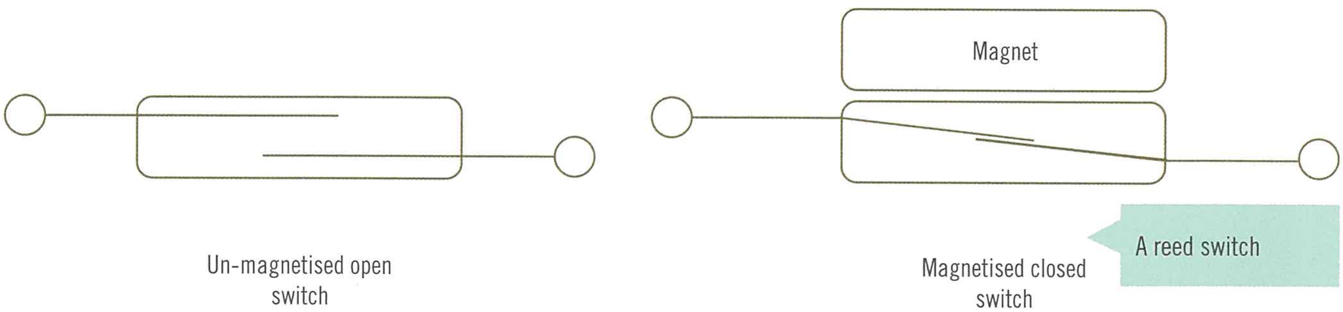
A push-button switch

Reed switches

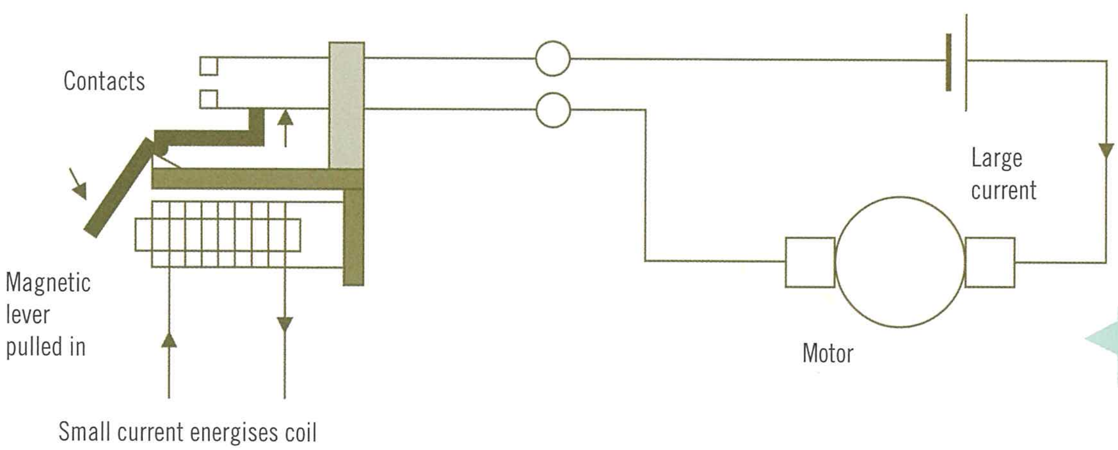
Reed switches are operated using permanent magnets or electromagnets. The metal contacts of reed switches are made of two strips of magnetic material such as nickel–iron sealed in a glass tube. A magnet or a coil activates the switch.



A reed switch

Relay switches

A relay is a switch that is activated when an electric current passes through a coil inside it. The switch can then turn on one or more circuits. A relay is used when a small output current from, say, an electronic circuit is not big enough to operate a device that needs a large current. That small current is used to energise the relay, which in turn switches on a separate circuit containing the device. Relays are used in cars to switch on many electrical components such as headlights, fans and windscreen wipers.



A relay switch

LEARNING ACTIVITY 5.6

1 What are transducers? Give four examples.
2 Name three types of motors.
3 Which type of motor incorporates a feedback loop?
4 Explain why a gear train is needed in some motor applications.
5 Give three examples of sensors, and state the physical or other property that changes in each case.

6 What do the letters stand for in the switches listed below?

   a SPDT

   b DPDT

   c DPTT

7 What are the two main uses of a DPDT switch?

8 What do the letters NO and NC stand for when describing switches?

9 Explain how a reed switch works.

Electrical power sources

Electrotechnology systems need the right power source to operate efficiently. Batteries, solar cells and mains electricity are the most common sources of electric power. The requirements of the system in terms of shape, size, voltage and current dictate the kind of power source that is suitable.

Batteries

An electromotive force (EMF) is the force that is required to move the electrons in the circuit from the negative terminal to the positive one. If this direction does not change the power is from a DC source. The word 'voltage' is commonly used instead of EMF, simply because EMF is measured in volts.

The most popular DC power source is the battery, and batteries or cells can be grouped into two types: primary and secondary cells:

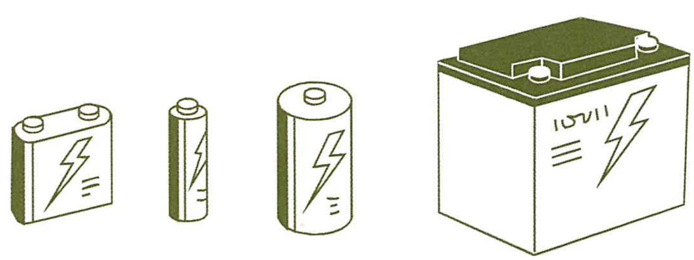
1 A primary cell cannot be recharged.

2 A secondary cell can be recharged.

A cell is the most basic battery. A battery is in fact a collection of cells connected together. The car battery, for example, is made up of six very efficient 2 volt secondary cells connected in series (positive to negative) to give 12 volts.

Six 2 volt cells connected in series produces 12 volts.

Cells in series – a battery



Connecting cells (or batteries) in series will increase the voltage available, but the maximum current that can be drawn from the power source will not increase. In fact, the maximum current that can be supplied will be the same as that supplied by only one cell. This is why you cannot start a car with a lot of torch batteries connected to give 12 volts. The voltage will be high enough, but there will not be enough current to turn the starter motor as a

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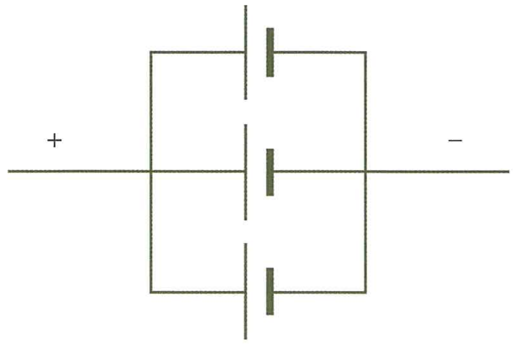
torch cell is not a very efficient source of current. The motor may need 40 amps, but a torch battery gives out less than 1 amp.



Three 2 volt cells in parallel still produce 2 volts, but three times the current can be drawn from the combination.

Batteries in parallel

If current rather than voltage is needed, the batteries or cells are connected in parallel rather than in series, but this time the current available is increased, although the voltage stays the same. This combination is often used with solar cells.

Wet and dry cells

There are three main parts to a cell: the two terminals made of metal and the chemical between them – the electrolyte. If the electrolyte is a liquid, the cell is called a wet cell. A car battery is a good example. The electrolyte in a torch battery is in the form of a paste and this type of cell is called a dry cell. Batteries are often named after the materials used for making them, such as carbon–zinc, lead–acid, nickel–cadmium and lithium.

Properties of some batteries

Name	Voltage (V)	Wet or dry	Primary or Secondary	Notes
Carbon–zinc	1.5	Dry	Primary	General use; lowest price
Lead–acid	2.2	Wet	Secondary	High current: 6 to 12 V
Lithium	3.3	Dry	Primary	Small and light; used in heart pacemakers and computers
Mercury cell	1.35	Dry	Primary	Miniature button type used in cameras and hearing aids
Nickel–cadmium	1.25	Dry	Secondary	Constant voltage; used in power tools

Charging batteries

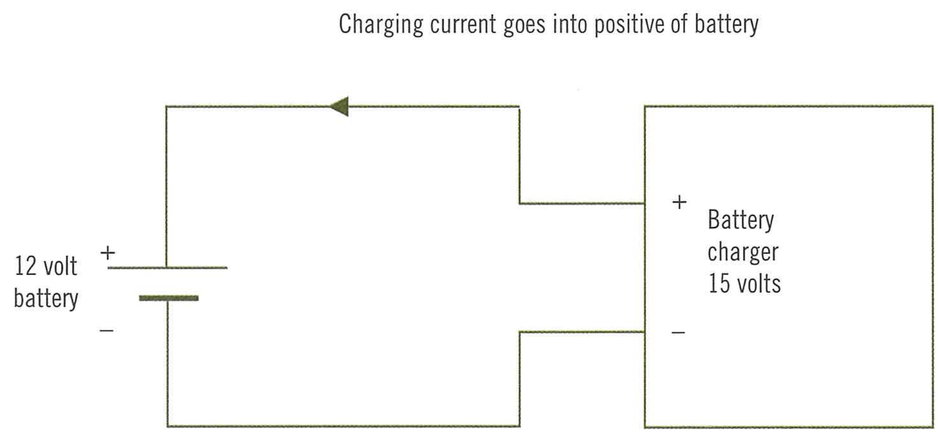
An electric current normally comes out of the positive side of a battery. If the battery needs recharging, an electric current needs to be passed in the opposite direction, into the positive terminal. Not all batteries can be recharged as the chemical process inside some cannot be reversed.

A battery charger that has a slightly higher voltage than the battery is used. The positive of the charger is connected to the positive of the battery. Nickel–cadmium and other rechargeable batteries can be recharged by inserting them in a mains-powered recharger. The charging current is controlled so as not to overheat the battery. If the cell will not fully charge, it should be discharged until its voltage is about half the rated value before being recharged.

1 Fast charging a NiCad battery shortens its life. It can also cause it to explode as it overheats.

2 A car battery should never be recharged using another battery as this can lead to an explosion.

Charging a battery



Battery capacity

Apart from the voltage of a battery, another important quantity is its energy rating. Energy rating or battery capacity is quoted in amp × hours or simply amp-hours. A 40 amp-hour (Ah) battery can provide a current of 1 amp over 40 hours. The same battery will supply 2 amps for 20 hours. We get the number 40 when we multiply the amps by the hours:

$$\text{Amp-hours} = \text{amps} \times \text{hours}$$

Other power sources

Other types of power sources are nuclear cells, fuel cells and solar cells. Some of these cells are discussed elsewhere in this book.

1 The **nuclear cell** converts nuclear energy into electrical energy. Nuclear cells are used in spacecrafts and satellites.

2 A **fuel cell** uses hydrogen and oxygen gas. Electricity is produced as the two gases combine to form water. Such cells are still being developed and are not commonly available.

3 The **solar cell** converts light energy into electrical energy. A large surface area is required to produce useful output power, but small cells can be used in calculators and similar devices.

LEARNING ACTIVITY 5.7

1 What does EMF stand for?

2 What are the two types of cells and what is the main difference between them? Give an example of each type.

3 Explain what changes and what stays the same when batteries are connected in series.

4 Explain what changes and what stays the same when batteries are connected in parallel.

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5 Explain the difference between a wet and a dry cell. Give an example of each.

6 What can we say about the electric current when a battery is being recharged?

7 A 40amp-hour battery is connected to a 2amp electric motor. For how long will the battery last?

8 Apart from the common battery, name three sources of electric power.

9 What are the gases used in fuel cells?

Understanding circuits

There are many quantities associated with electricity – current, voltage, resistance, charge, power, capacitance and inductance, to name a few. The next section explains the meaning of the four that are most widely used in circuit calculations and how we can work out their values in simple circuits.

Summary of voltage, current, charge and resistance symbols and units

Quantity	Symbol for quantity	Measurement unit	Symbol for unit
EMF	*E*	Volt	V
Voltage	*V*	Volt	V
Current	*I*	Ampere	A
Charge	*Q*	Coulomb	C
Resistance	*R*	Ohm	Ω

Source: Table 1.2, Peter Phillips, *Electrical Principles,* 2nd Edition, Cengage Learning, 2012, p. 12.

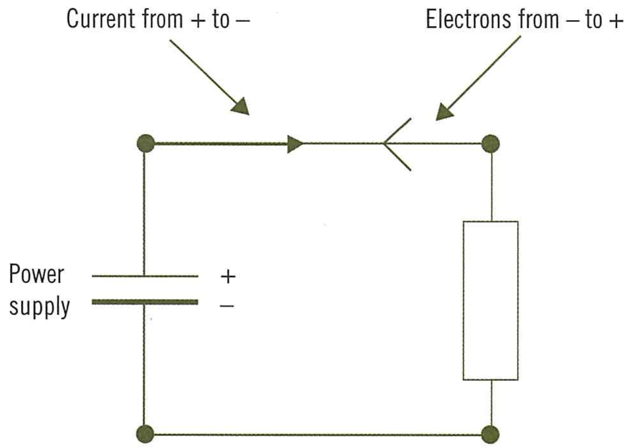
Current, *I*

Electric current is a measure of the flow of electric charge. If there is a lot of charge and it is flowing very fast, the current will be high. Electrons carry the charge and these move round the circuit, leaving the battery at the negative end. They then go through the components and devices to finally return to the battery at the positive end. Electrons flow from negative to positive. The direction of the current is the opposite (see the illustration on page 152).

Current is measured in amperes (also called amps or A). The Italicised letter *I* denotes current in equations.

Current is always shown by an arrow going from positive to negative. Electric current was discovered first and it was given that direction. Many years later it was found that small atomic particles called electrons made up electric current. It was decided to leave things as they were. Current goes in one direction and electrons go the other way.

Movement of electrons and current direction in a circuit

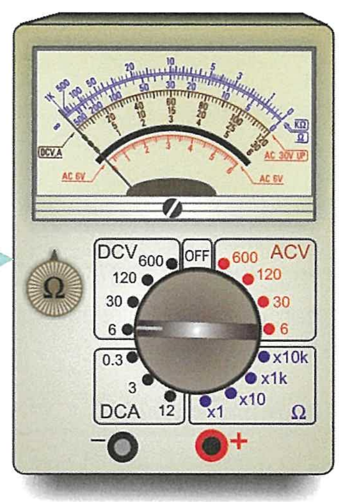


Voltage, *V*

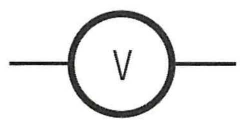
Voltage is a measure of how much energy is being converted by a given number of electrons as they move round the circuit. In a resistor this energy is converted from electrical energy into heat energy. A large voltage will mean that a lot of energy is being converted. In a car battery the energy conversion is from chemical energy to electrical energy.

Voltage is measured in volts or V. The italicised letter *V* denotes voltage in equations.

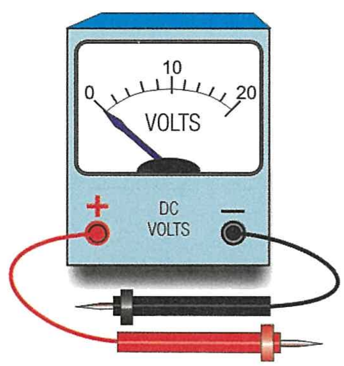
Multimeters



Analogue multimeter set to read voltage



Voltmeter symbol



Simplified voltmeter drawing

Digital multimeter set to read voltage

Resistance, *R*

Resistance is a measure of how the flow of electrons is being resisted. A large-value resistor will reduce the flow and hence the electric current. A connecting wire or speaker cable needs to have a very low resistance to allow the electrons to flow easily and not waste their energy. We want all that energy to go to a component or a speaker. A low-resistance wire will be short, thick and made of a good conductor. When circuit calculations are made we assume that all connecting wires have zero resistance.

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Resistance is measured in ohms (Ω). The italicised letter *R* denotes resistance in equations.

Power, *P*

Power is a measure of not only the amount of energy converted, but also of how fast it is being converted. Power is the rate of conversion of energy.

Power is measured in watts (W). The italicised letter *P* denotes power in equations.

Basic circuit theory

A circuit is made up of a power source, such as a 9 volt battery, connected to electrical and electronic components and devices. The name we give to the circuit depends on the way in which the components are connected. Apart from the very simple circuit in which the battery is connected to a single component, there are two basic circuit types: series circuits and parallel circuits.

An understanding of circuit theory will enable you to use technological principles to work out the power *P* in watts, current *I* in amps, resistance *R* in ohms, and voltage *V* in volts, in a circuit, and where relevant compare with specifications as published by manufacturers. You will also understand the tests that need to be done if a circuit is not working and be able to modify circuits so that you can improve them. You may even be able to design your own circuits if you have a good knowledge of component behaviour.

A simple circuit

The simplest circuit is made up of the power source connected and a **load**. The load could be a resistor, a buzzer, a motor, a heater, and so on. In the diagram on page 154 the power source has a voltage of 9 volts. A resistor of 12 ohms (12 Ω) is connected to it. We can work out two other important electrical quantities for the circuit: the electric current *I* (the amps), and the power *P* (in watts).

Ohm's law

Ohm's law gives the relationship between the voltage *V*, the current *I* and the resistance *R*. If we know or can measure two of them we can work out the third one.

$$V = I \times R$$

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

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

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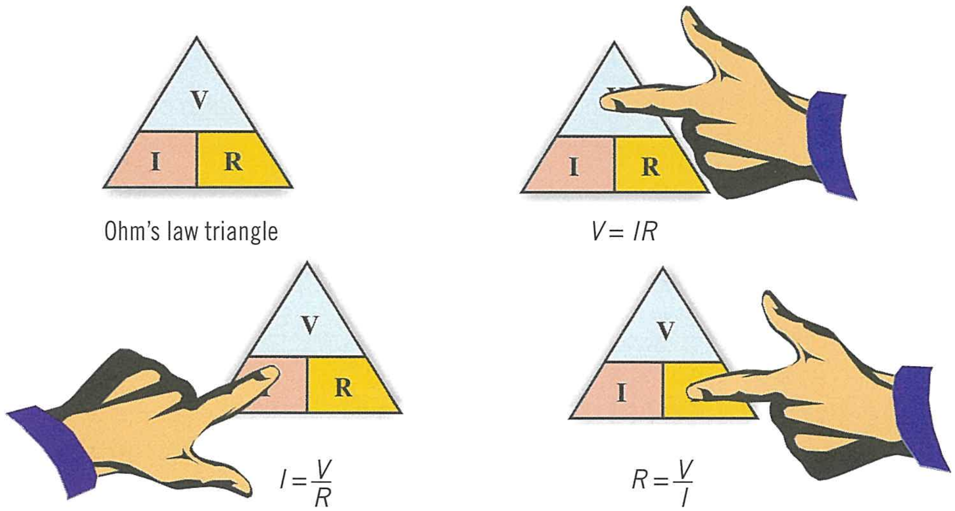
The diagram below shows visually Ohm's law at a glance – that is, using the Ohm's law triangle to derive equations for power, current, voltage and resistance.

Ohm's law at a glance – Ohm's law triangle



Ohm's law equations

1 Write the equation. $I = \frac{V}{R}$

2 Multiply both sides by *R*. $I \times R = \frac{V}{R} \times R$

3 Cancel out the *R*s on the right-hand side. $I \times R = \frac{V}{\cancel{R}} \times \cancel{R}$

$I \times R = V$

4 Rewrite the equation with *V* on the left-hand side (*V* is now the subject). $V = I \times R$

Ohm's law – power, current and resistance equations

1 Write the power equation. $P = V \times I$

2 Write Ohm's law for *V*. $V = I \times R = IR$

3 Replace *V* in equation 1 with *IR*. $P = IR \times I$

4 Multiply $I \times IR$ to give I^2R. $P = I^2R$

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Power, voltage and resistance equations

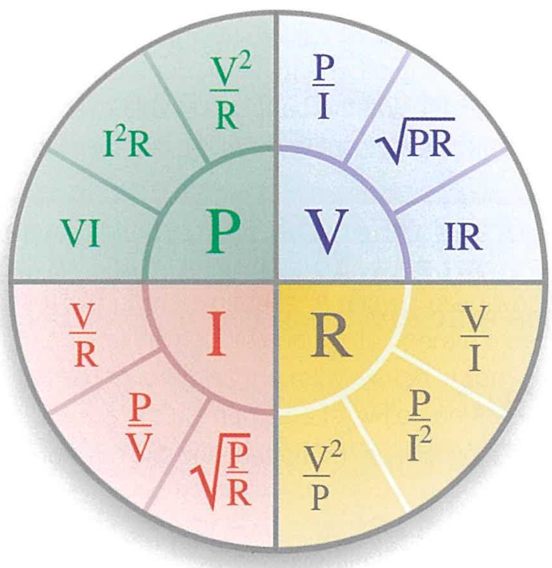
1. Write the power equation. $P = V \times I$

2. Write Ohm's law for *I*. $I = \dfrac{V}{R}$

3. Replace *I* in equation 1 with $\dfrac{V}{R}$. $P = V \times \dfrac{V}{R}$

4. Multiply $V \times \dfrac{V}{R}$ to give $\dfrac{V^2}{R}$. $P = \dfrac{V^2}{R}$

Summary of equations – the equation wheel (*V*, *I*, *R* and *P*)



Working out the current in amps

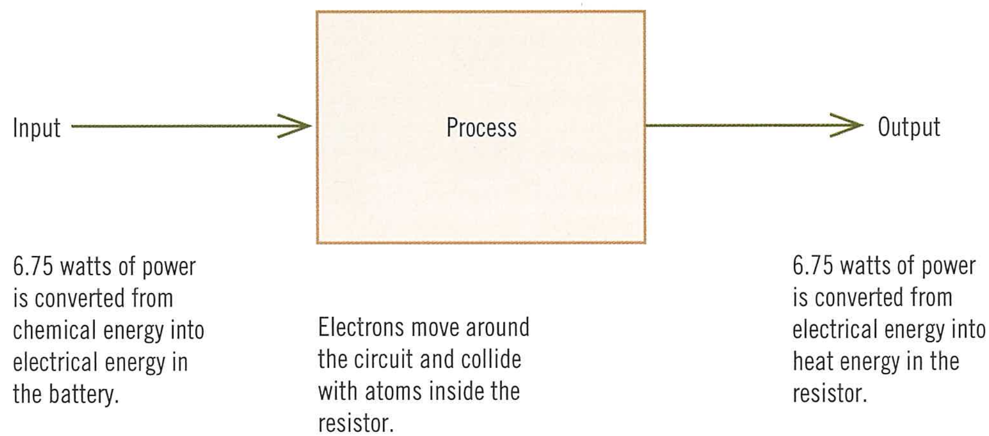
If $V = 9$ volts and $R = 12$ ohms we can use Ohm's law to work out the electric current in the circuit.

1. Ohm's law: $V = I \times R$.
2. This means the current $I = V \div R$.
3. $I = V \div R$, so *I* equals 9 volts divided by 12 ohms, which is 0.75 amp.
4. This can be converted into milliamps by multiplying by 1000. The current in the circuit is 750 milliamps or 750 mA.

Working out the power in watts

To work out electrical power we multiply the voltage by the current.

1. Power equation: $P = I \times V$.
2. $P = 0.75 \times 9 = 6.75$ watts (Note that we always use amps and not milliamps in equations.)
3. This means that 6.75 joules of energy are being converted every second from one form into another. In a resistor, electrical energy is converted into heat energy.



Energy changes in a simple circuit

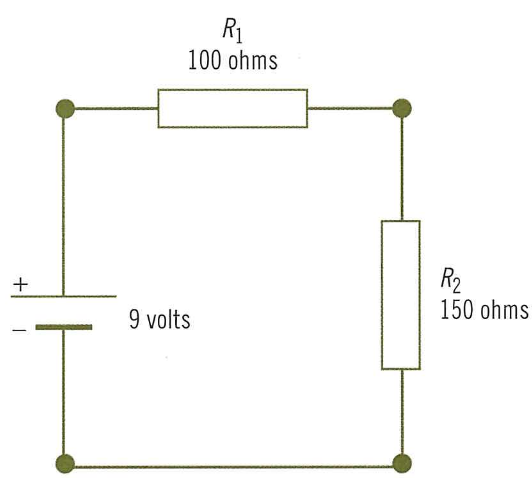
Lost volts and internal resistance

The calculations above assume one important thing: the battery is perfect and 100% efficient. All the chemical energy is converted into electrical energy. This is not the case for practical batteries. A good car battery is a good energy converter; however, some of the chemical energy available is converted into heat inside the battery and whatever remains is then given to the load. The battery gets hot and wastes energy. We say that the battery has internal resistance.

The voltage drops when the battery is powering a device. The voltage may drop from 12 volts to, say, 10 volts. The greater the drop, the less efficient the battery.

A series circuit

A series circuit is a single loop linking the battery and the resistors.



A series circuit

There are four basic rules or steps to use when working out electrical quantities in series circuits. They are given below.

Resistance

We start by finding the total resistance. Resistor values add up.

In this case we sum up the ohms of the two resistors to get what is called the total resistance of the circuit.

$$R_{total} = R_1 + R_2 = 100\,W + 150\,W = 250\,\text{ohms or } 250\,W$$

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Current

Current (amps) is the same throughout the circuit.

Once we know the total resistance, the current coming out of the battery can be calculated. The same current passes through both resistors.

$$I = V \div R = 9\,V \div 250\,W = 0.036\,\text{amp}$$

So 0.036 amp leaves the battery, goes through the first resistor, then through the second resistor and back to the battery. No current is lost; whatever leaves the battery comes back to it. Note that current, as shown by an arrow, goes from positive to negative.

Voltage

What about the voltage in a series circuit?

Voltage is added up: $V = V_1 + V_2$.

The current through the 100 ohm resistor is 0.036 amp. This allows us to use Ohm's law to calculate the voltage:

For the 100 Ω resistor: $V = I \times R = 100 \times 0.036 = 3.6\,V$
For the 150 Ω resistor: $V = I \times R = 150 \times 0.036 = 5.4\,V$

You will notice that the resistors share the 9 V provided by the battery.

$$3.6\,V + 5.4\,V = 9.0\,V$$

This is called the potential divider principle. The voltage is divided between resistors. (Potential is another word for voltage.)

Power

Power, just like voltage, adds up.

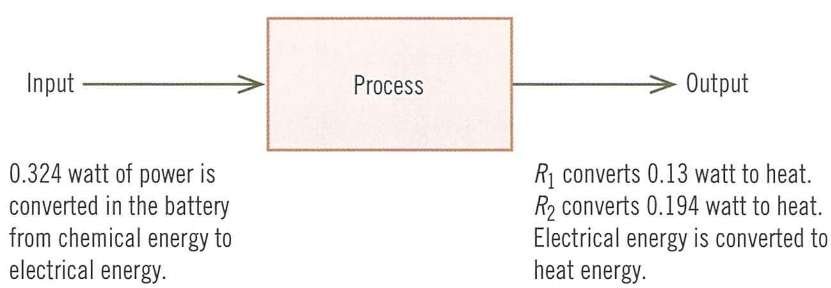
To work out the power we multiply voltage by current.

The battery is 9 volts and the current through it is 0.036 amp. The power will be 0.324 watt. This is the total power input. $P = V \times I = 9\,V \times 0.036\,\text{amp} = 0.324\,\text{watt}$.

The power output for the two resistors will be:

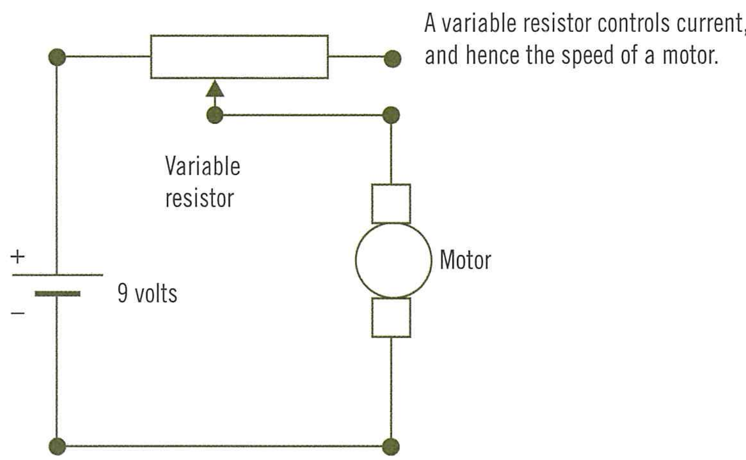
$$P\,(\text{for } R_1) = 3.6 \times 0.036 = 0.13\,\text{watt}$$
$$P\,(\text{for } R_2) = 5.4 \times 0.036 = 0.194\,\text{watt}$$

Notice that 0.13 + 0.194 = 0.324, so that the power provided by the battery is shared by the resistors, but the total power output is the same as the power input. This is because of the 'conservation of energy' principle.



Power distribution in a series circuit

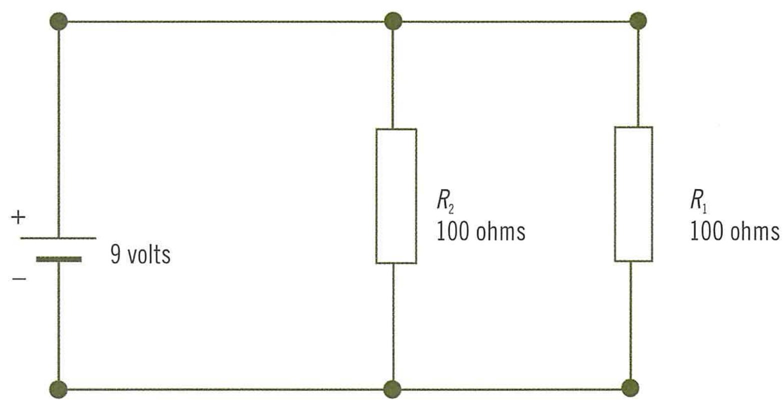
Practical use of a series circuit



A parallel circuit

Similar to a series circuit, there are four rules or steps to remember for a parallel circuit. Applying the rules enables us to work out resistance, voltage, current and power for each component.

A parallel circuit



Resistance

We start by finding the total resistance. The total resistance is given by using the following equation.

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

The total resistance is halved from 100 ohms to 50 ohms – this is the case whenever the two resistors are identical. This means that a single 50 ohm resistor could replace the two 100 ohm resistors.

Voltage

Voltage is the same across components in parallel:

$$V = V_1 = V_2 = 9\,V$$

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Current

We can now use Ohm's law to work out the current through each resistor:

Through R_1, $I_1 = V_1 \div R_1 = 9\,V \div 100\,ohms = 0.09\,amp$
Through R_2, $I_2 = V_2 \div R_2 = 9\,V \div 100\,ohms = 0.09\,amp$

The current, as expected, should be the same as the resistors are the same. If the resistors are not identical, the currents will not be, but they will still add up.

Current from the battery splits and is shared between the resistors, but must add up as it leaves and re-enters the battery. No current is lost in a circuit.

The total current I from the battery is therefore

$$\begin{aligned} I &= I_1 + I_2 \\ &= 0.09\,A + 0.09\,A \\ &= 0.18\,A \end{aligned}$$

Power

We can work out power as we now know the voltage and the current for each component.

The power output of the battery, the power output will be:

$$\begin{aligned} P &= V \times I \\ &= 9\,V \times 0.18\,A = 1.62\,W \end{aligned}$$

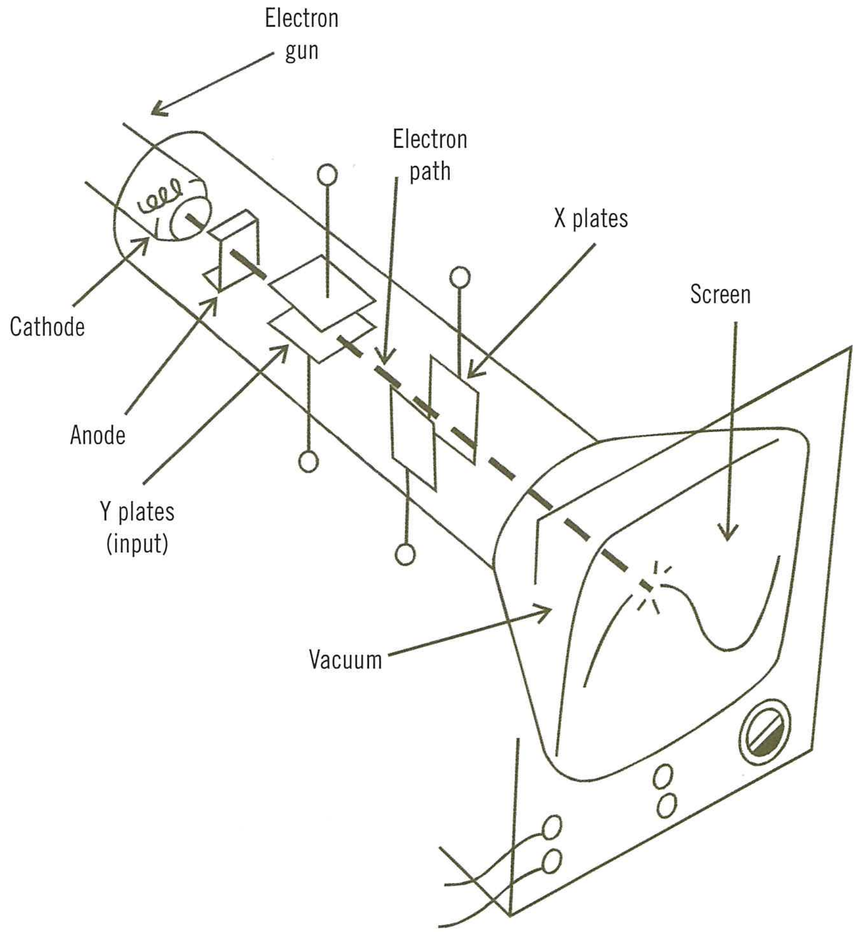
For R_1 the power $P_1 = V_1 \times I_1 = 9\,V \times 0.09\,A = 0.81\,W$.
For R_2 the power $P_2 = V_2 \times I_2 = 9\,V \times 0.09\,A = 0.81\,W$, the same as for R_1.
Note that $0.81 + 0.81 = 1.62$.

Here again the conservation of energy applies. The two resistors share the power output from the battery, but the total power remains constant. No power is lost.

Alternating current electricity

Dissimilar to DC electricity, where the polarities (positive and negative) do not change, the polarities of alternating current (AC) power sources change from positive to negative and then back again. This means that the electric current in an AC circuit is continuously changing direction. A DC motor will not work if connected to an AC power source as the coil tries to spin one way and then the other way. Loudspeakers, however, rely on AC to make the cones move in and out. How fast a loudspeaker cone moves in and out depends on the frequency of the power source.

AC voltages and current can be measured using multimeters and an instrument called a cathode ray oscilloscope (CRO). The CRO will also display the waveform (see the illustration on page 160). The voltage values of AC electricity are changing all the time. Which value can we use? The answer is to quote the maximum or peak value or the RMS (root mean square) value.



A CRO displaying an AC waveform

Peak value

The peak value of AC is the maximum value reached as the voltage rises and then falls.

RMS value

RMS stands for root mean square. A 12 volt RMS AC power source will provide the same power (in watts) as a 12 volt DC power source. A heater will produce the same amount of heat if connected to either power source. We can think of RMS as a DC equivalent. The RMS voltage of the AC power used in homes in Australia is 240 volts. The peak voltage is about 1.4 times higher.

The RMS value is about 70% of the maximum or peak value, and is some kind of average.

Frequency

Frequency is measured in hertz (Hz). The voltage goes through cycles as the changes are repeated. Mains electric power used in homes in Australia has a frequency of 50 hertz.

The frequency of AC is the number of cycles per second.

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Stepping up and stepping down AC voltages

One advantage of AC over DC is that it can be stepped up or down easily by using transformers. It can also be converted into DC by using diodes, capacitors and semiconductors (called regulators). The process of converting AC into DC is called rectification, and this is what happens in a laboratory power supply.

Rectification is the process of changing AC to DC.

Safety and electricity

Our body can conduct electricity. An electric current will pass through the body if we provide a path for it to do so. This will be the case if we touch a live mains power outlet while some part of our body is connected to earth. Electricity will flow through the body to earth. We can think of earth as a big object, or sink, always ready to accept electrons. Given half a chance, electrons will flow to earth.

The effect on the body will depend on the value of the electric current through it. Your heart will stop beating if the current is about 200 mA DC. Much smaller currents will cause pain and muscle contraction. Larger currents will result in severe burns.

The human body offers less resistance to AC electricity than to DC. This is because the body acts as a capacitor as well and capacitors allow AC current through, but will block DC currents. This is why exposure to even low values of AC can cause an electric shock.

Students are not permitted to work on electrical products or equipment that operate above 50 V AC or smoothed 120 V DC. Only people with an appropriate electrical licence are permitted to work on such products or equipment.

LEARNING ACTIVITY 5.8

1 List the four quantities we associate with electricity, give their symbols and state the unit of measurement for each of them.

2 If current is a measure of the flow of charge, what do each of the following measure?

a Voltage

b Resistance

c Power

3 A simple circuit is made up of a battery of V volts connected to a single resistor of R ohms. The current in the circuit is I amps and the power is P watts. Copy and complete the table below, working out the missing quantities in each row.

R (Ω)	V (V)	I (A)	P (W)
12		4	
	6	2	
	12		36

4 What have you assumed about the battery when working out the quantities in Question **3**?

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5 A 10ohm resistor and a 5ohm resistor are connected in series. A 30volt battery supplies an electric current *I* to the resistors.

a Draw the circuit diagram.

a Calculate the value of the current *I*.

6 Calculate the power supplied by the battery and the power used by each resistor in the circuit in Question **5** and show that power or energy is conserved.

7 Calculate the total resistance of the following resistor combinations.

a A 1K resistor in series with a 1.8K resistor

b A 200ohm resistor in series with 2.2K resistor

c Two 18ohm resistors in parallel

d A 6ohm resistor in parallel with a 3ohm resistor

8 A 6ohm resistor, a 3ohm resistor and a 12volt battery are all connected in parallel. Draw the circuit diagram and work out the following quantities.

a Total resistance

b Total current leaving the battery

c Current through the 6ohm resistor

d Current through the 3ohm resistor

e Power delivered by the battery

f Power used up by each resistor

9 Show that power is conserved in the circuit.

10 Explain the difference between AC and DC electricity.

11 What does RMS stand for? Explain the difference between peak and RMS values.

12 What can be used to step AC up or down?

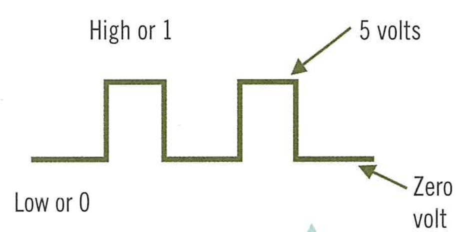
13 What is the maximum AC voltage a student can work with?

Digital circuits

Logic gates, flip-flops, PICs, encoders and decoders are examples of digital circuits.

1 The outputs of these circuits are in digital form, either on or off, or high (1) or low (0).

2 A 'high' will represent the supply voltage, such as 5volts, and a 'low' is zero volt.



A digital signal

3 The most common types of digital components are the transistor–transistor–logic (TTL) and the complementary metal oxide semiconductor (CMOS).

Logic gates and truth tables

There are many types of logic gates. Each gate has its own symbol and truth table. The truth table gives information about inputs and outputs. The most commonly used logic gates are described next.

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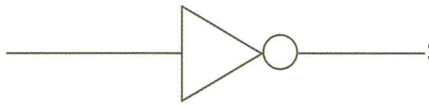
NOT or INVERT gate

A NOT gate is the simplest and has just one input and one output. It is also called an inverter because it inverts the input, changing it from a low or 0 to a high or 1.

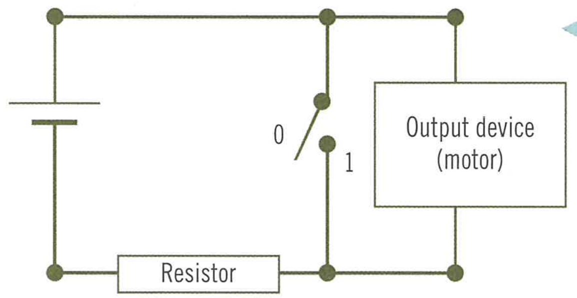


Symbol for a NOT gate

A NOT gate

Input A	Output Q
0	1
1	0

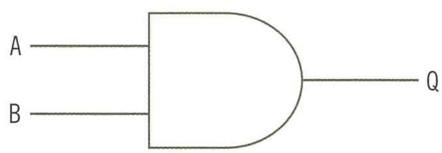
Truth table



The switch in the circuit acts as a NOT gate input. When it is OFF (0) the output device is ON (1) and vice versa.

The AND gate

The basic AND gate has two inputs and one output. More complex gates have several inputs. The output Q is high if both A and B inputs are high.

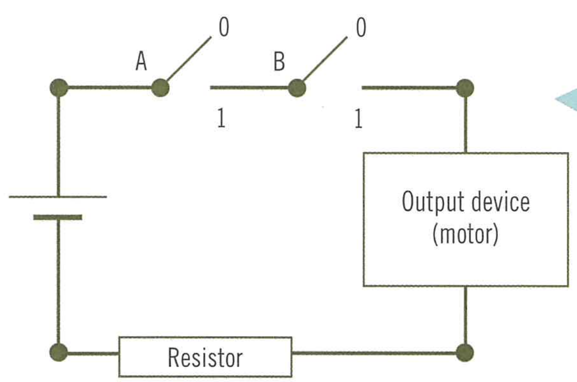


Symbol for an AND gate

An AND gate

Input A	Input B	Output Q
0	0	0
0	1	0
1	0	0
1	1	1

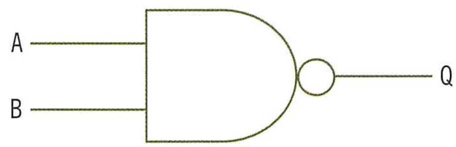
Truth table



Two switches in series with an output device act as the two inputs to an AND gate. Both switches must be ON (1) if the device is to be ON (1).

The NAND gate

The output of the NAND gate is the opposite of an AND gate. You just have to change (invert) the output of an AND gate to get the one for a NAND gate. The symbol is similar to the AND gate except for the small circle or bubble.

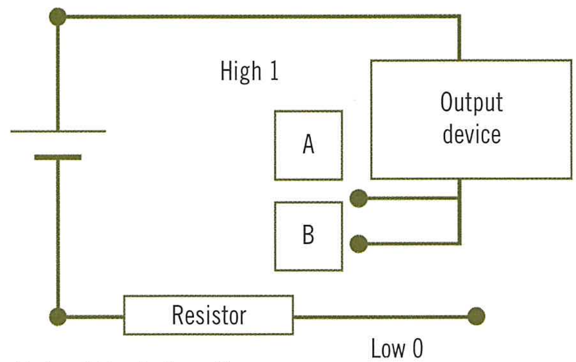


Symbol for a NAND gate

The NAND gate

Input A	Input B	Output Q
0	0	1
0	1	1
1	0	1
1	1	0

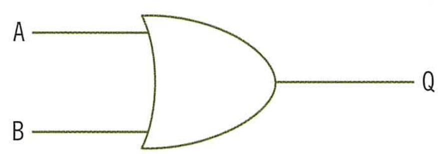
Truth table



If both points A and B in the circuit are connected to the high rail the device will not turn on. This simulates the last row of the truth table.

The OR gate

The output of the OR gate will be high only if either input A OR input B (or both) are high.

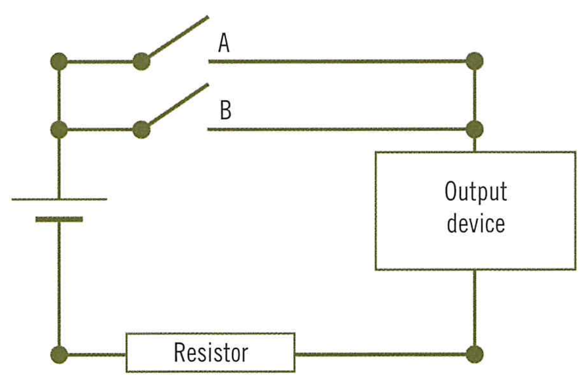


Symbol for an OR gate

The OR gate

Input A	Input B	Output Q
0	0	0
0	1	1
1	0	1
1	1	1

Truth table



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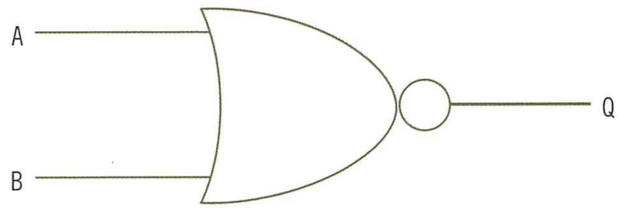
The NOR gate

A NOR gate output is the opposite that of an OR gate. The symbol is similar except for the circle or bubble.



Symbol for a NOR gate

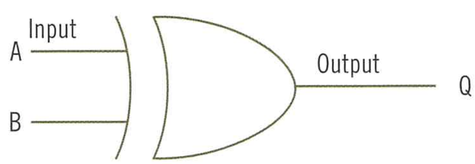
The NOR gate

Input A	Input B	Output Q
0	0	1
0	1	0
1	0	0
1	1	0

Truth table

The XOR gate (or exclusive OR gate)

The XOR gate is similar to the OR gate except for the bottom row, for which the output is low. This only gives an output when the inputs are different, hence the name exclusive OR (that is, input A or input B).



Symbol for an XOR gate

The XOR gate

Input A	Input B	Output Q
0	0	0
0	1	1
1	0	1
1	1	0

Truth table

Uses of logic gates

Logic gates have many uses because they can combine two (at times more) inputs to give a single output. This means that they control the output. A typical 14-pin DIL (dual in-line) IC chip will contain four identical logic gates. Each gate will have three pins: two for inputs and one for output; therefore, 12 pins in all for the gates. The remaining two pins are used for the power source. Not all the gates in the chip have to be used.

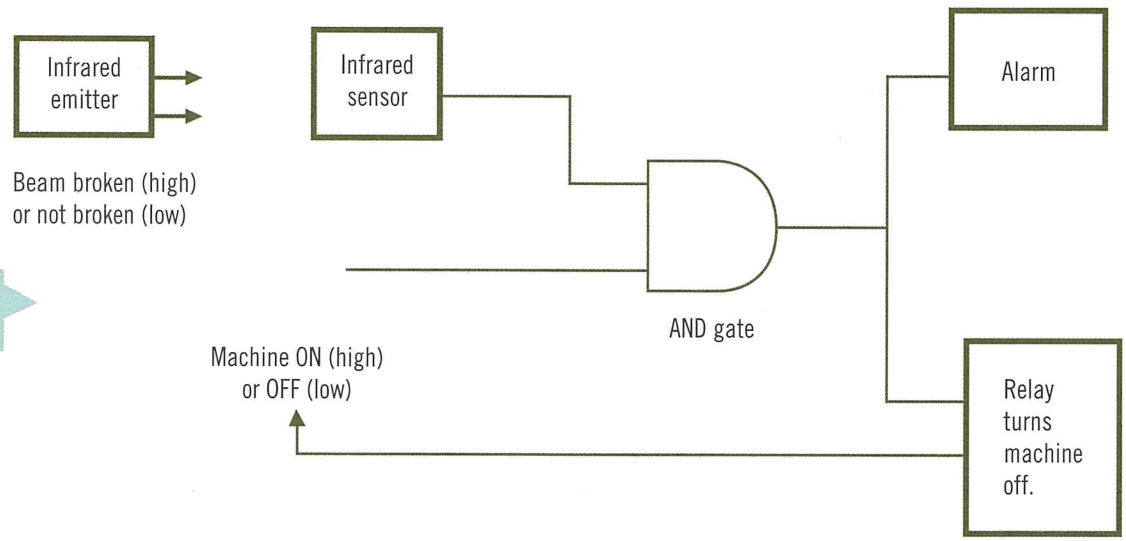
The AND gate as used to control a machine is explained below. A safety system is designed such that a machine is turned off if the operator's face or hand gets too close to a dangerous part of the machinery. An alarm is also sounded.

1 As the face breaks the beam, the output of the sensor goes high (1). This and the output of the machine (1) form the inputs of the AND gate.

2 If they are both high (1), the output of the gate will be high, turning on the alarm and the relay.

3 The relay can then turn the machine off.

Using an AND gate in an alarm circuit



LEARNING ACTIVITY 5.9

1 Give four examples of digital circuits.

2 Explain the difference between an analogue and a digital signal.

3 What do the letters TTL, CMOS and DIL stand for?

4 List five types of logic gates and draw the symbol for each one.

5 Draw the truth table for a NAND gate.

6 A buzzer (output) needs to sound (high) when a driver leaves the headlights on (input A is high) and turns off the ignition (input B is low). The buzzer should not sound for any other combination of headlight and ignition states. A student suggests that a logic gate circuit using a NAND or a NOR gate will perform the required function. Has the student solved the problem? If not, why not and can you solve the problem? The table below will help you reach a conclusion.

A: Headlight	B: Ignition	Q: Buzzer
Off	Off	
Off	On	
On	Off	
On	On	

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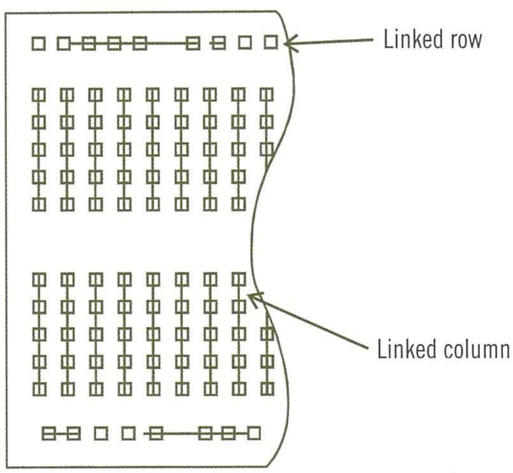
Designing and modelling systems

There are a number of methods available for building electronic circuits. Three of these will be discussed: breadboards, vero boards and printed circuit boards. Each has its advantages and disadvantages.

Breadboards

Breadboards (also called protoboards) do not involve any soldering. Components are inserted in holes in the board and are easily removed. This technique is very good for testing a circuit as different components can be tried in order to investigate their effects on the performance of the circuit.

The protoboards come in different sizes, but the spacing between the holes is the same. These holes are arranged in a special layout with a set number of holes connected by a copper strip running underneath. It is important to know which holes connect to which and which holes are not connected. Breadboards are good for testing circuits before permanent construction as there is no soldering involved.



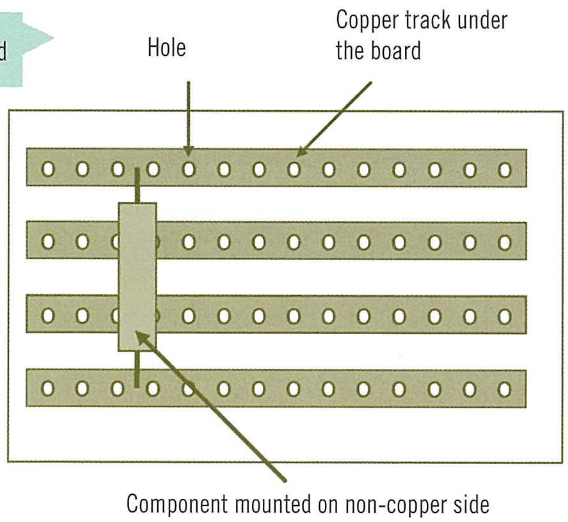
Part of a breadboard showing the copper strips

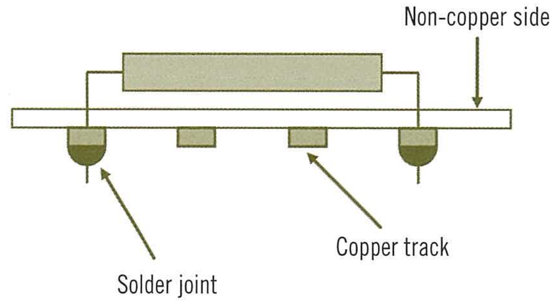
Vero (or strip) boards

Circuit boards are used to combine electronic components and connectors together to form a complete circuit. One type is the strip board. These boards are easy to use as no **etching** is involved. Rows of copper tracks are provided and the component leads are simply inserted in selected holes in the track and soldered into place. A track can be split in two by removing the copper around a hole.

- Vero or strip boards are good to use as no etching or milling is involved.
- This method is not suitable for mass production.
- The placement of components and the splitting of tracks need careful thought.

A Vero or strip board





Care when using strip boards

1 Use pliers to bend component leads.

2 Bend the leads along the tracks. This reduces the risk of shorting tracks. The leads can be left at a 45° angle or pinched all the way down.

3 When soldering wires such as battery clip terminals, **tin** the ends before inserting into the holes. 'Tinning' means coating the strands with a small amount of solder. This process keeps the strands together, making it easy to solder onto the copper tracks and prevent shorts.

4 Use pliers as **heat sinks** when soldering to stop the components from overheating.

5 Use a multimeter to check whether tracks are shorting and do this every time you solder a joint rather than at the end. The sharp corner of a small screwdriver can be used to remove any small amount of solder that has joined two tracks.

6 Examine the soldering joints with a magnifying glass.

7 A track can be split into two or more tracks by removing the copper around a hole with a small drill (about 4 mm) turned by hand. Make sure this has been done where necessary. Count how many such disconnections are needed and check before the power is switched on.

Printed circuit boards

A printed circuit board (PCB) is made up of a laminate (an insulating material) that is about 1 mm thick with a very thin layer of copper foil bonded to it. In a single-sided PCB the copper is on one side only. There are also double-sided PCBs, and even multilayered ones made up of as many as 30 layers of copper.

PCBs are ideal if many circuits have to be made. Many components can also be fitted within a small area and the finished product looks good.

Preparing PCBs

PCBs can be prepared in a number of ways. Hand drawing, heat transferring or photo-etching the tracks are the main methods used. Methods using computers and special software are now gaining popularity as they have many advantages. The four steps for producing a board ready for component assembly are:

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1 Clean the board with an abrasive cleaner. Wire wool can be used, though this tends to scratch the surface and may damage the copper. Dry the board. Avoid touching the copper to keep it grease-free.

2 Transfer the artwork – the tracks joining the components – to the board.

3 Remove the unwanted copper from the board by chemical etching or by using a milling machine for the computerised method.

4 Drill the holes for the components.

Drawing by hand

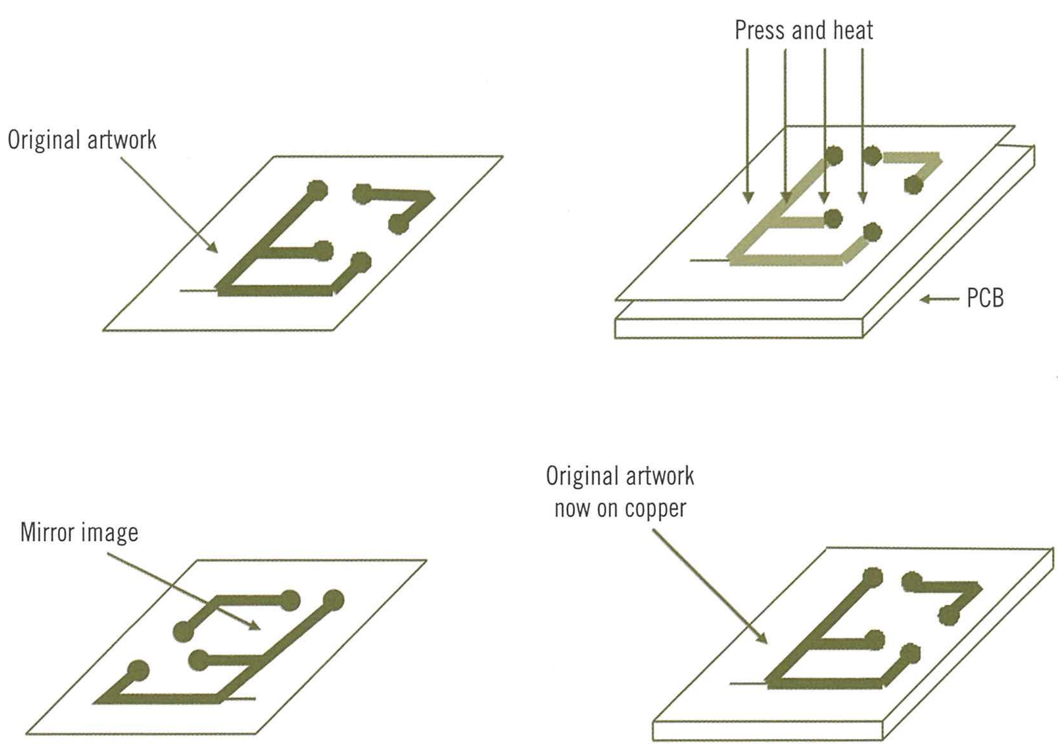
Tape the artwork to PCB with some carbon paper in between. Draw pattern with pen or pencil. This need not be very accurate. A copy of the artwork should appear on the copper. If there is no carbon paper, you could drill the holes after taping and draw the tracks with the etch-resist pen by linking the holes.

The advantage of this method is that it is cheap and does not need any expensive equipment.The disadvantage is that fine, thin tracks are difficult to draw and there is always a risk of the ink from the pen joining two tracks or pads (especially the pads needed for integrated circuits).

Heat transfer method

Heat is used to transfer the artwork from paper to the copper. The original artwork needs to be flipped to get a mirror image so that when it is pressed onto the copper and heated, we end up with the original. No etch-resist pen is needed. The process works best if the flipped image is on special paper called TTS paper. TTS stands for toner transfer system. Normal paper tends to burn easily, but TTS paper releases the ink more easily and does not burn readily.

There are many ways you can get a flipped image. You could use computer software to draw the artwork, flip the image and print it. Scanning instead of drawing the artwork is another possibility. Alternatively, some photocopiers will flip the image, or you can photocopy the image on clear acetate and flip it before photocopying it a second time.



The heat transfer method

The flipped artwork needs to be pressed onto the copper and heated so that the ink is transferred to the metal. This can be done using a household iron, but the best results are obtained if the artwork is taped to the PCB and fed through a special heater called a TTS heater. The PCB together with the paper is then soaked in water. When the paper is peeled off slowly the artwork will be seen on the copper.

Advantages of using the head transfer method are:

1 This method produces good results if done properly. It is quick; no wet ink or chemicals are involved.

2 Thin tracks and pads can be transferred without problems. The final appearance is also much better than when using the hand-drawing system.

3 The success of this operation is greatly affected by the kind of printer, photocopier, paper and heating system used.

Photo-etching

In the photo-etching process, no dark ink is used in the transfer of the artwork to the PCB. A chemical replaces the ink. There are two types of photo-etching: positive and negative. In the positive process the original artwork is used; in the negative one, the artwork needs to be reversed so that the dark parts become transparent and vice versa. The chemical solutions used for each are different.

The positive process is simpler. First the artwork pattern is photocopied on a clear acetate sheet as used in overhead projectors. This pattern has to be transferred to the PCB. A special chemical (called positive photo-resist) is sprayed onto the copper side of the PCB and allowed to dry in darkness. The artwork is then placed on the PCB and the lot exposed to ultraviolet light for a set time. The PCB is then soaked in a solution called a developer. After a while the artwork will appear on the copper. Ultraviolet exposure time and developer concentration are given on the containers housing the chemicals.

Advantages of using photo-etching are:

1 Photo-etching is used extensively in industry for mass production of circuit boards.

2 Very fine tracks can be reproduced.

3 The artwork on acetate paper can be used more than once.

Using computer software

There are a number of software packages available that will produce the artwork needed for electronic circuits. The artwork can be printed out and used as described above, or a special milling machine linked to the computer can mill out the tracks. The advantage of this computerised method is that no chemical etching is needed. The tracks can, however, be very close together and care should be taken when soldering to avoid shorting the tracks. Many circuits can be prepared on one large board, which is then cut up.

Advantages of using computer software are:

1 No chemical is used in the preparation of boards, making the whole process very safe.

2 The initial cost of setting up a computerised system with a milling machine needs to be taken into account.

Etching the PCB

Once the artwork has been transferred to the PCB, the unwanted copper has to be removed from the board. This is done by leaving the board in a solution that dissolves copper, a process called etching. Ferric chloride or ammonium persulfate is commonly used. These chemicals

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need to be treated with care, and skin and eye protection should be used. Etching is not needed if a milling machine is used.

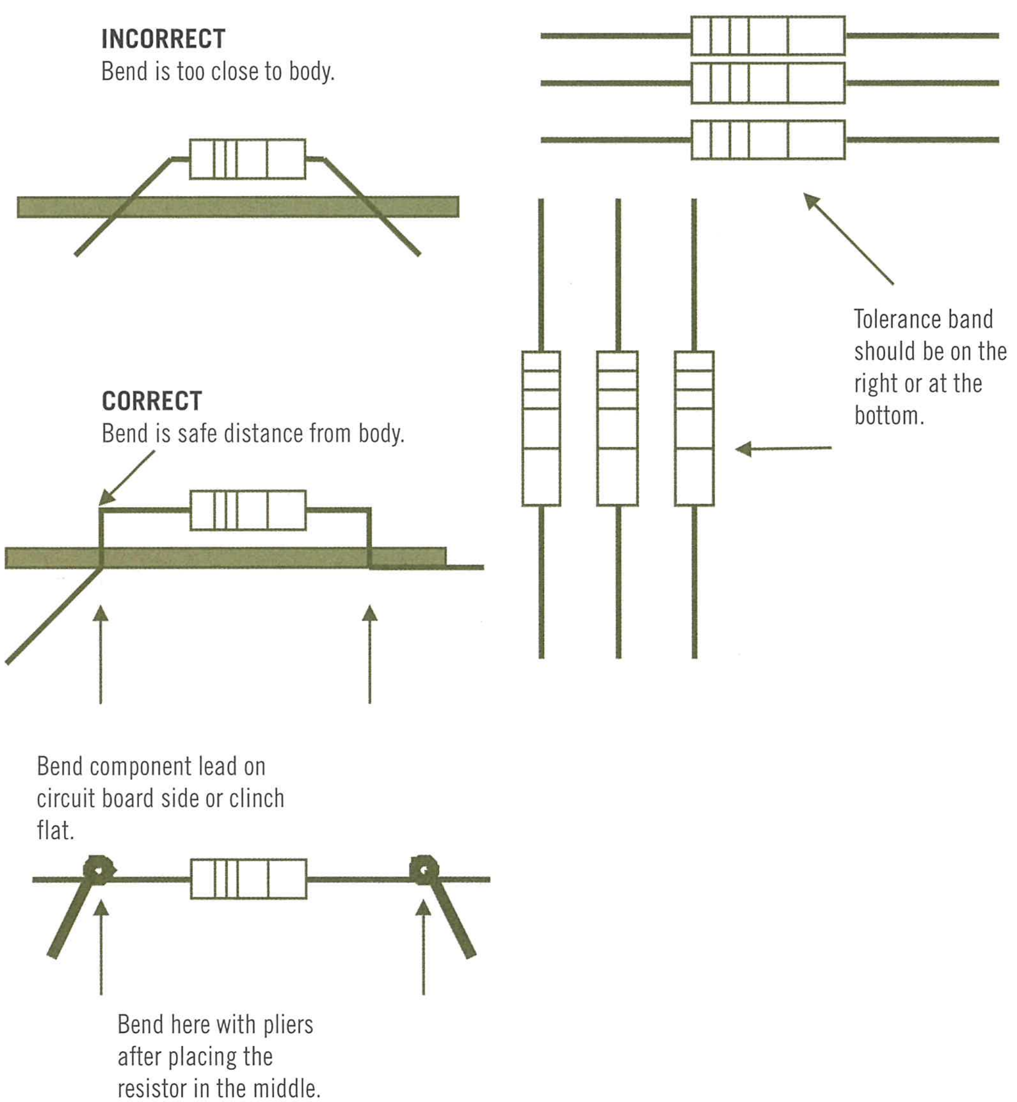
Corrosive chemicals are used in the etching process. The use and disposal of chemicals create safety issues.

Drilling the board

Holes through which the components leads go are drilled using a high-speed drill press fitted with a 0.8 mm or 1 mm drill bit. A few components may require a bigger bit. After drilling, the rim of the holes should be tidied up using a 2–3 mm drill bit twisted by hand. This is called de-burring.

Mounting components on boards

The correct placing of components on a board improves the appearance of the final product. This also helps if the circuit does not work and needs to be tested. If you have to bend the leads of a component, you should use pliers to produce a neat 90° bend.



Mounting a resistor on a board

Solder and soldering

Solder used in electronics is mainly a mixture of tin (60%) and lead (40%). Lead-free solder is also available. It melts at a higher temperature, but is safer to use. Solder conducts electricity well and melts easily compared with other metals. It is used to join component and terminal leads to copper on the circuit board. A soldering iron is used to melt the solder, which comes in the form of a thin wire.

Safety and care

1 When solder melts, a poisonous gas is released; you should avoid breathing these fumes. Solder in a space that is well ventilated. Do not eat or drink while soldering as the fumes will find an easy path to your lungs.

2 Wash your hands after handling solder wire as it contains lead, which is poisonous. Lead-free solder is available, but is more expensive.

3 The tip of the soldering iron is very hot at about 330ºC. Always place the iron in a holder after soldering.

4 Use safety glasses when soldering.

5 Never flick solder from the tip of the iron and do not play around with molten solder.

6 Do not touch the tip to find out if it is hot. You should try to melt some solder. If the solder melts, the iron is hot.

7 Wipe the tip of the iron on a wet sponge to clean it. If the tip (or bit) of the iron is clean, solder does not form into balls but flows freely. The bit should look clean and shiny.

8 Do not use hard abrasives or files to clean the tip.

9 Before putting the iron away, melt a bit of solder onto the tip. This protects the bit and keeps it shiny. Do not clean the tip.

Getting ready for soldering

1 Make sure the copper surface and lead to be joined are clean.

2 Heat the iron. Set the temperature to 330°C if you are using a temperature-controlled one. A higher temperature setting will reduce the life of the bit.

3 Clean the tip by wiping it gently and slowly on a damp sponge.

4 Test for cleanliness by melting some solder. If the solder forms into a ball, repeat the cleaning process until the solder flows well.

Soldering components

1 Place the tip of the iron firmly against the component lead and the copper base.

2 Place a tiny amount of solder at the very tip of the iron to form what is called a heat bridge. The component lead and the copper will heat up more quickly if you do this.

3 Place the end of the solder wire on the copper just where the component lead is. The solder should melt. If it does not, try again. Do not move the iron. When the solder stars melting, apply more around the joint. Do not move the iron.

4 When enough solder has been melted, remove the solder wire and, at the same time, lift the iron tip straight up. Clean the bit if it is dirty and place the iron in the holder.

5 Let the solder joint cool; do not blow on it.

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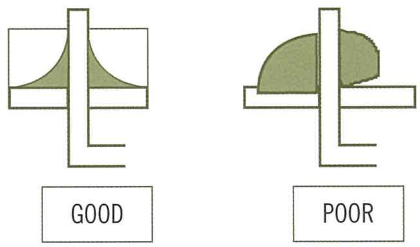
Inspecting a solder joint

1 The surface should be clean, smooth and shiny.

2 There should be enough solder around the joint. Too much solder will join up the copper tracks.

3 The joint should not be ball-shaped. Too much solder, a dirty copper surface, a dirty iron tip and inadequate heating will result in a badly soldered joint.



Solder joints

LEARNING ACTIVITY 5.10

1 What are the three methods of preparing PCBs?

2 Draw up a table that outlines the advantages and disadvantages of each method of preparing PCBs.

3 List the four steps required to prepare a PCB ready for the assembly of components.

4 What are the four methods of transferring artwork tracks to a PCB?

5 What is de-burring?

6 Solder is a mixture of which two metals?

7 Write down four safety precautions necessary when soldering.

8 Write down two procedures for keeping a soldering iron in good condition.

9 What is a heat bridge?

10 List the causes of a low-grade soldered joint.

Weblinks

www.technologystudent.com

www.engineersedge.com

www.howstuffworks.com

www.energyquest.com.au

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END-OF-CHAPTER ACTIVITIES

1 List the colours of the following four-band resistors of 5% tolerance.
   a 1.2K
   b 56K
   c 3.3M
   d 12R
2 A student is given two 120 ohm resistors of 5% tolerance. What are the colours of the resistor?
3 What is the total resistance if the two resistors of Question 2 are connected in series?
4 What is the total resistance if the two resistors of Question 2 are connected in parallel?
5 Write down the values for the resistors with the first three colours below.
   a Yellow white red
   b Brown green orange
6 Write down the value and tolerance of the capacitors with the following markings.
   a 102J
   b 472K
7 Calculate the total capacitance of the following electrolytic capacitors.
   a Two 33 μF capacitors in parallel
   b Two 100 μF capacitors in series
8 Which type of semiconductor makes a good temperature sensor and why?
9 Use words and diagrams to explain the difference between a forward-biased diode and a reverse-biased one.
10 Explain how you would identify the negative terminal of the following components.
   a An LED
   b A diode
   c A polarised capacitor
11 Draw the symbols for a PNP and an NPN transistor.
12 Explain the conditions for a transistor to act as:
   a an off switch
   b an on switch.
13 State the input and the output of a transistor that is used as an amplifier.
14 Draw the pin layout for a 14-pin integrated circuit. Indicate all the pin numbers.
15 Explain the input, output and process of the following transducers.
   a Loudspeaker
   b Electric motor
   c Microphone
16 What type of sensor would you select in the following situations?
   a An alarm sounds when a burglar opens a door
   b A buzzer sounds when an appliance tips over
   c A buzzer sounds when a car engine overheats
17 Using words and diagrams, explain how a relay switch works.
18 Outline one application of a relay switch.
19 Draw a circuit diagram to show how a DPDT switch can be used to reverse the rotation of a motor.

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20 Work out the voltage available if three 1.5 volt batteries are connected:

   a in series

   b in parallel.

21 What is the main advantage of connecting batteries in parallel?

22 A lithium ion battery used in a video camera has a 1.5 amp-hour capacity. How long can the camera operate before the battery goes completely flat?

23 Use Ohm's law to work out the current in a circuit in which a 12 ohm resistor is connected to a 24 volt battery.

24 Calculate the power supplied by the battery in Question **23**.

25 Calculate the total resistance and the current in a circuit in which two 5 ohm resistors are connected in series to a power supply of 10 volts.

   a What will be the voltage across each resistor?

   b Calculate the power delivered by the battery and that used by each resistor.

26 a What would be the total resistance and the current from the power supply if the resistors in Question **25** were connected in parallel to the same battery?

   b Calculate the power delivered by the battery and that used by each resistor.

27 Draw the symbol and the truth table for the following logic gates.

   a OR gate

   b AND gate

   c NOR gate

   d XOR gate

28 You have two push-button switches, A and B, and a red LED. Draw a system using a logic gate where the LED will light up if either A or B is pressed, but not both at the same time.

29 What will happen if a NOT gate is placed just before the LED in your answer to Question **28**?

30 List all the safety precautions and care needed when soldering components.

31 List the correct sequence required when soldering.