Electrons, insulators and conductors

In an insulator all electrons are bound firmly to their atoms; in a conductor some electrons can move freely from atom to atom. An insulator can be charged by rubbing because the charge produced cannot move from where the rubbing occurs, i.e. the electric charge is **static**. A conductor will become charged only if it is held with an insulating handle; otherwise electrons are transferred between the conductor and the ground via the person's body.

Good insulators include plastics such as polythene, cellulose acetate, Perspex and nylon. All metals and carbon are good conductors. In between are materials that are both poor conductors and (because they conduct to some extent) poor insulators. Examples are wood, paper, cotton, the human body and the Earth. Water conducts and if it were not present in materials like wood and on the surface of, for example, glass, these would be good insulators. Dry air insulates well.

Electrostatic induction

This effect may be shown by bringing a negatively charged polythene strip near to an insulated metal sphere X which is touching a similar sphere Y (Figure 35.5a). Electrons in the spheres are repelled to the far side of Y.

If X and Y are separated, with the charged strip still in position, X is left with a positive charge (deficient of electrons) and Y with a negative charge (excess of electrons) (Figure 35.5b). The signs of the charges can be tested by removing the charged strip (Figure 35.5c), and taking X up to the cap of a positively charged electroscope. Electrons will be drawn towards X, making the leaf more positive so that it rises. If Y is taken towards the cap of a *negatively* charged electroscope the leaf again rises; can you explain why, in terms of electron motion?

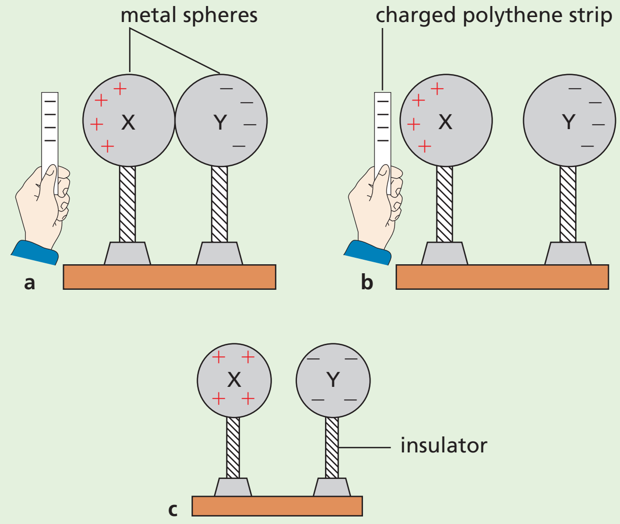


Figure 35.5 Electrostatic induction

Attraction between uncharged and charged objects

The attraction of an uncharged object by a charged object near it is due to electrostatic induction.

In Figure 35.6a a small piece of aluminium foil is attracted to a negatively charged polythene rod held just above it. The charge on the rod pushes free electrons to the bottom of the foil (aluminium is a conductor), leaving the top of the foil short of electrons, i.e. with a net positive charge, and the bottom negatively charged. The top of the foil is nearer the rod than the bottom. Hence the force of attraction between the negative charge on the rod and the positive charge on the top of the foil is greater than the force of repulsion between the negative charge on the rod and the negative charge on the bottom of the foil. The foil is pulled to the rod.

A small scrap of paper, although an insulator, is also attracted by a charged rod. There are no free electrons in the paper but the charged rod pulls the electrons of the atoms in the paper slightly closer (by electrostatic induction) and so distorts the atoms. In the case of a negatively charged polythene rod, the paper behaves as if it had a positively charged top and a negative charge at the bottom.

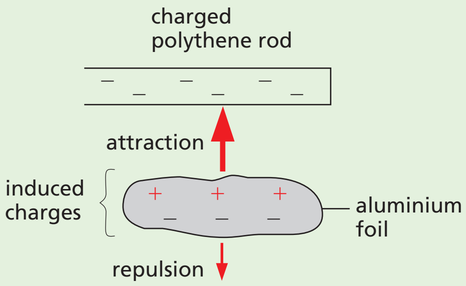


Figure 35.6a An uncharged object is attracted to a charged one.

Figure 35.6b A slow stream of water is bent by electrostatic attraction.

In Figure 35.6b a slow, uncharged stream of water is attracted by a charged polythene rod, due to the polar nature of water molecules (one end of a molecule is negatively charged while the other end is positively charged).

Dangers of static electricity

a) Lightning

A tall building is protected by a lightning conductor consisting of a thick copper strip fixed on the outside of the building connecting metal spikes at the top to a metal plate in the ground (Figure 35.7).

Thunderclouds carry charges; a negatively charged cloud passing overhead repels electrons from the spikes to the Earth. The points of the spikes are left with a large positive charge (charge concentrates on sharp points) which removes electrons from nearby air molecules, so charging them positively and causing them to be repelled from the spike. This effect, called **action at points**, results in an 'electric wind' of positive air molecules streaming upwards which can neutralise electrons discharging from the thundercloud in a lightning flash. If a flash occurs it is now less violent and the conductor gives it an easy path to ground.

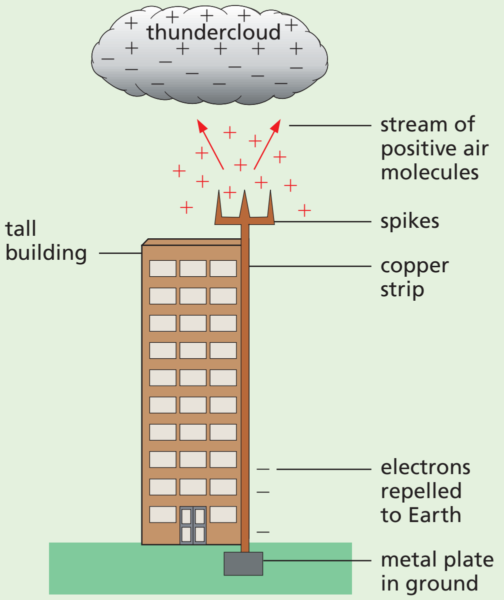


Figure 35.7 Lightning conductor

b) Refuelling

Sparks from static electricity can be dangerous when flammable vapour is present. For this reason, the tanks in an oil tanker may be cleaned in an atmosphere of nitrogen – otherwise oxygen in the air could promote a fire.

An aircraft in flight may become charged by 'rubbing' the air. Its tyres are made of conducting rubber which lets the charge pass harmlessly to ground on landing, otherwise an explosion could be 'sparked off' when the aircraft refuels. What precautions are taken at petrol pumps when a car is refuelled?

c) Operating theatres

Dust and germs are attracted by charged objects and so it is essential to ensure that equipment and medical personnel are well 'earthed' allowing electrons to flow to and from the ground, for example by conducting rubber.

d) Computers

Computers require similar 'anti-static' conditions as they are vulnerable to electrostatic damage.

Uses of static electricity

a) Flue-ash precipitation

An electrostatic precipitator removes the dust and ash that goes up the chimneys of coal-burning power stations. It consists of a charged fine wire mesh which gives a similar charge to the rising particles of ash. They are then attracted to plates with an opposite charge. These are tapped from time to time to remove the ash, which falls to the bottom of the chimney from where it is removed.

b) Photocopiers

These contain a charged drum and when the paper to be copied is laid on the glass plate, the light reflected from the white parts of the paper causes the charge to disappear from the corresponding parts of the drum opposite. The charge pattern remaining on the drum corresponds to the dark-coloured printing on the original. Special **toner** powder is then dusted over the drum and sticks to those parts which are still charged. When a sheet of paper passes over the drum, the particles of toner are attracted to it and fused into place by a short burst of heat.

c) Inkjet printers

In an inkjet printer tiny drops of ink are forced out of a fine nozzle, charged electrostatically and then passed between two oppositely charged plates; a negatively charged drop will be attracted towards the positive plate causing it to be deflected as shown in Figure 35.8. The amount of deflection and hence the position at which the ink strikes the page is determined by the charge on the drop and the p.d. between the plates; both of these are controlled by a computer. About 100 precisely located drops are needed to make up an individual letter but very fast printing speeds can be achieved.

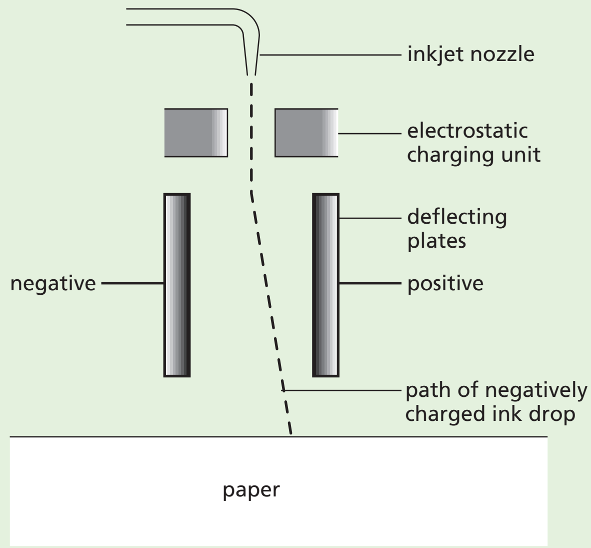


Figure 35.8 Inkjet printer

van de Graaff generator

This produces a continuous supply of charge on a large metal dome when a rubber belt is driven by an electric motor or by hand, as shown in Figure 35.9a.

a) Demonstrations

In Figure 35.9a sparks jump between the dome and the discharging sphere. Electrons flow round a complete path (circuit) from the dome. Can you trace it? In part Figure 35.9b why does the 'hair' stand on end? In Figure 35.9c the 'windmill' revolves due to the reaction that arises from the 'electric wind' caused by the action at points effect, explained on p. 153 for the lightning conductor.

In Figure 35.9d the 'body' on the insulating stool first gets charged by touching the dome and then lights a neon lamp.

The dome can be discharged harmlessly by bringing your elbow close to it.

b) Action

Initially a positive charge is produced on the motor-driven Perspex roller because it is rubbing the belt. This induces a negative charge on the 'comb' of metal points P (Figure 35.9a). The charges are sprayed off by 'action at points' on to the outside of the belt and carried upwards. A positive charge is then induced in the comb of metal points, Q, and negative charge is repelled to the dome.

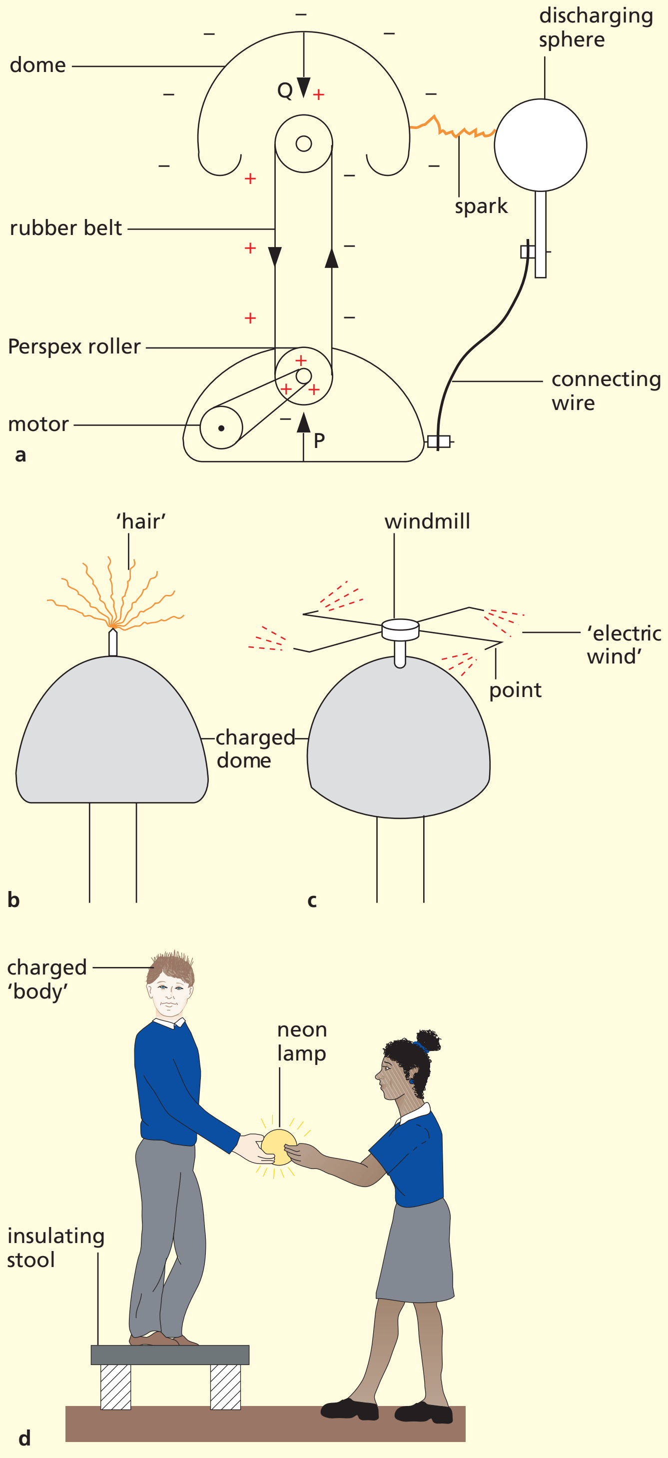


Figure 35.9

Electric fields

When an electric charge is placed near to another electric charge it experiences a force. The electric force does not require contact between the two charges so we call it an 'action-at-a-distance force' – it acts through space. The region of space where an electric charge experiences a force due to other charges is called an **electric field**. If the electric force felt by a charge is the same everywhere in a region, the field is uniform; a uniform electric field is produced between two oppositely charged parallel metal plates (Figure 35.10). It can be represented by evenly spaced parallel lines drawn perpendicular to the metal surfaces. The direction of the field, denoted by arrows, is the direction of the force on a small positive charge placed in the field (negative charges experience a force in the opposite direction to the field).

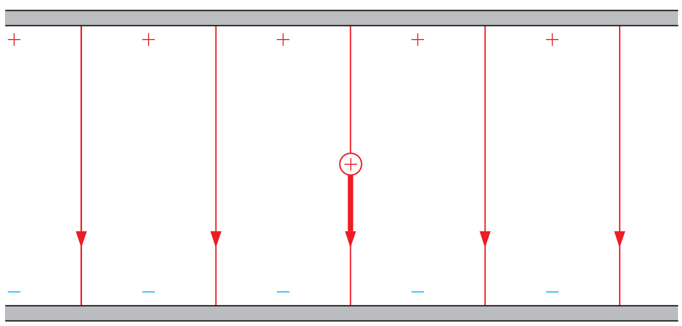


Figure 35.10 Uniform electric field

Moving charges are deflected by an electric field due to the electric force exerted on them; this occurs in the inkjet printer (Figure 35.8).

The electric field lines radiating from an isolated positively charged conducting sphere and a point charge are shown in Figures 35.11a, b; again the field lines emerge at right angles to the conducting surface.

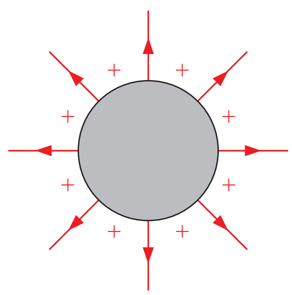


Figure 35.11a

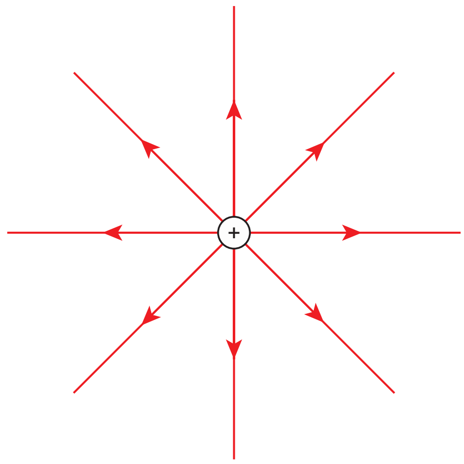


Figure 35.11b Radial electric field

Questions

1 Two identical conducting balls, suspended on nylon threads, come to rest with the threads making equal angles with the vertical, as shown in Figure 35.12.
Which of these statements is true?
This shows that:
A the balls are equally and oppositely charged
B the balls are oppositely charged but not necessarily equally charged
C one ball is charged and the other is uncharged
D the balls both carry the same type of charge
E one is charged and the other may or may not be charged.

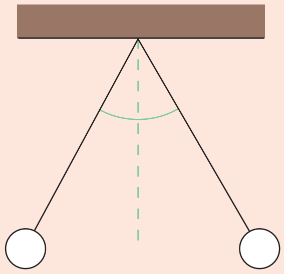


Figure 35.12

2 Explain in terms of electron movement what happens when a polythene rod becomes charged negatively by being rubbed with a cloth.

3 Which of statements A to E is true?
In the process of electrostatic induction
A a conductor is rubbed with an insulator
B a charge is produced by friction
C negative and positive charges are separated
D a positive charge induces a positive charge
E electrons are 'sprayed' into an object.

Checklist

After studying this chapter you should be able to

- describe how positive and negative charges are produced by rubbing,
- recall that like charges repel and unlike charges attract,
- explain the charging of objects in terms of the motion of negatively charged electrons,
- describe the gold-leaf electroscope, and explain how it can be used to compare electrical conductivities of different materials,
- explain the differences between insulators and conductors,
- describe how a conductor can be charged by induction,
- explain how a charged object can attract uncharged objects,
- give examples of the dangers and the uses of static electricity,
- explain what is meant by an electric field.

36 Electric current

- Effects of a current
- The ampere and the coulomb
- Circuit diagrams
- Series and parallel circuits
- Direct and alternating current
- Practical work: Measuring current

An **electric current** consists of moving electric charges. In Figure 36.1, when the van de Graaff machine is working, the table-tennis ball shuttles rapidly to and fro between the plates and the meter records a small current. As the ball touches each plate it becomes charged and is repelled to the other plate. In this way charge is carried across the gap. This also shows that 'static' charges, produced by friction, cause a deflection on a meter just as current electricity produced by a battery does.

In a metal, each atom has one or more loosely held electrons that are free to move. When a van de Graaff or a battery is connected across the ends of such a conductor, the free electrons drift slowly along it in the direction from the negative to the positive terminal of a battery. There is then a current of negative charge.

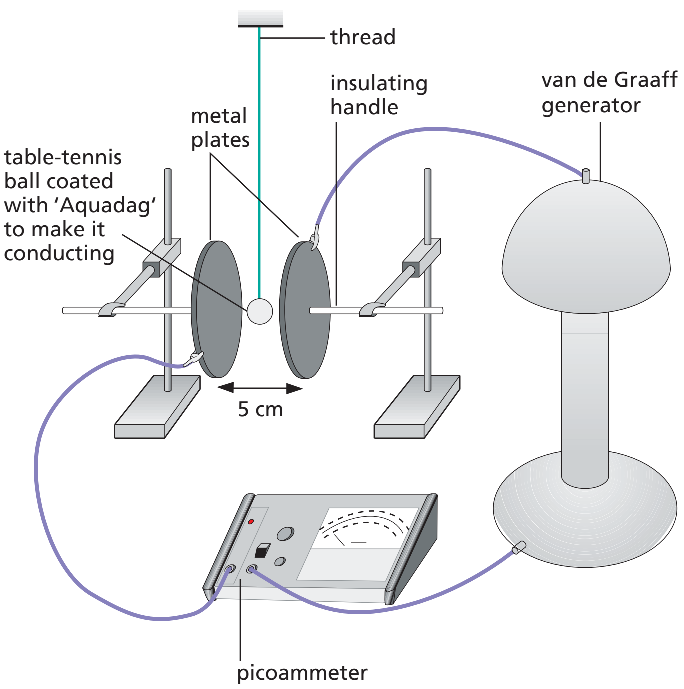


Figure 36.1 Demonstrating that an electric current consists of moving charges

Effects of a current

An electric current has three effects that reveal its existence and which can be shown with the circuit of Figure 36.2.

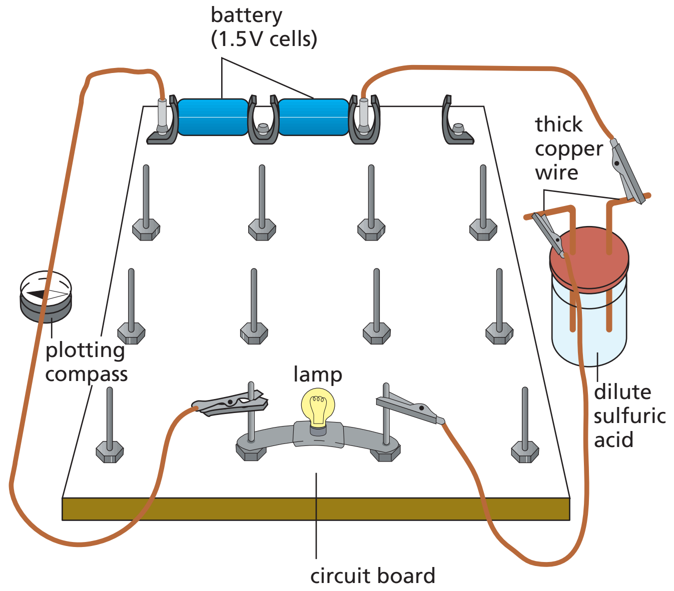


Figure 36.2 Investigating the effects of a current

a) Heating and lighting

The lamp lights because the small wire inside (the filament) is made white hot by the current.

b) Magnetic

The plotting compass is deflected when it is placed near the wire because a magnetic field is produced around any wire carrying a current.

c) Chemical

Bubbles of gas are given off at the wires in the acid because of the chemical action of the current.

The ampere and the coulomb

The unit of current is the **ampere** (A) which is defined using the magnetic effect. One milliampere (mA) is one-thousandth of an ampere. Current is measured by an **ammeter**.

The unit of charge, the **coulomb** (C), is defined in terms of the ampere.

One coulomb is the charge passing any point in a circuit when a steady current of 1 ampere flows for 1 second. That is, 1 C = 1 A s.

A charge of 3 C would pass each point in 1 s if the current were 3 A. In 2 s, 3 A × 2 s = 6 A s = 6 C would pass. In general, if a steady current I (amperes) flows for time t (seconds) the charge Q (coulombs) passing any point is given by

$$Q = I \times t$$

This is a useful expression connecting charge and current.

Circuit diagrams

Current must have a complete path (a circuit) of conductors if it is to flow. Wires of copper are used to connect batteries, lamps, etc. in a circuit since copper is a good electrical conductor. If the wires are covered with insulation, such as plastic, the ends are bared for connecting up.

The signs or symbols used for various parts of an electric circuit are shown in Figure 36.3.

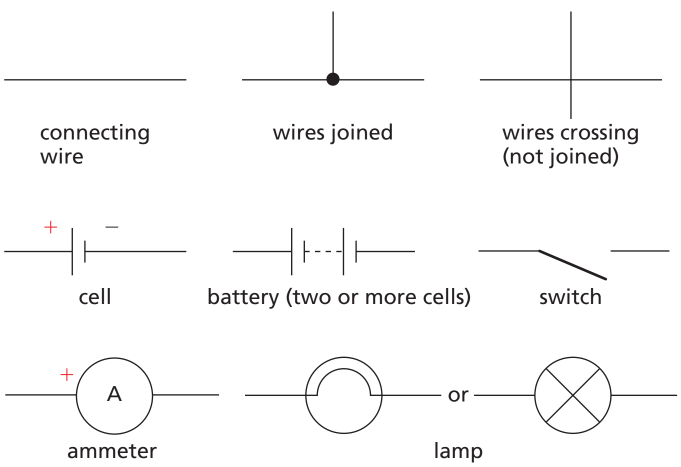


Figure 36.3 Circuit symbols

Before the electron was discovered scientists agreed to think of current as positive charges moving round a circuit in the direction from positive to negative of a battery. This agreement still stands. Arrows on circuit diagrams show the direction of what we call the **conventional current**, i.e. the direction in which **positive** charges would flow. Electrons flow in the opposite direction to the conventional current.

Practical work

Measuring current

(a) Connect the circuit of Figure 36.4a (on a circuit board if possible) ensuring that the + of the cell (the metal stud) goes to the + of the ammeter (marked red). Note the current.

(b) Connect the circuit of Figure 36.4b. The cells are **in series** (+ of one to – of the other), as are the lamps. Record the current. Measure the current at B, C and D by disconnecting the circuit at each point in turn and inserting the ammeter. What do you find?

(c) Connect the circuit of Figure 36.4c. The lamps are **in parallel**. Read the ammeter. Also measure the currents at P, Q and R. What is your conclusion?

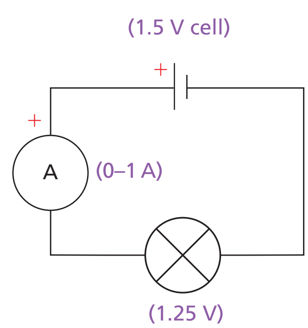


Figure 36.4a

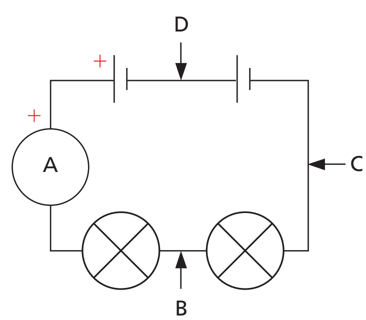


Figure 36.4b

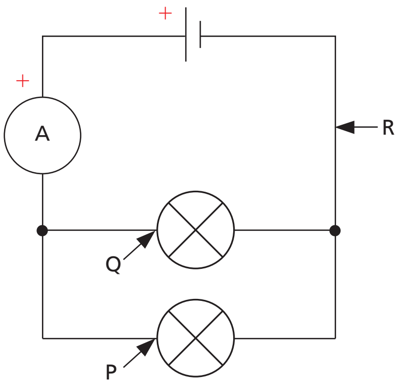


Figure 36.4c

Series and parallel circuits

a) Series

In a **series circuit**, such as the one shown in Figure 36.4b, the different parts follow one after the other and there is just one path for the current to follow. You should have found in the previous experiment that the reading on the ammeter (e.g. 0.2 A) when in the position shown in the diagram is also obtained at B, C and D. That is, current is not used up as it goes round the circuit.

The current is the same at all points in a series circuit.

b) Parallel

In a **parallel circuit**, as in Figure 36.4c, the lamps are side by side and there are alternative paths for the current. The current splits: some goes through one lamp and the rest through the other. The current from the source is larger than the current in each branch. For example, if the ammeter reading was 0.4 A in the position shown, then if the lamps are identical, the reading at P would be 0.2 A, and so would the reading at Q, giving a total of 0.4 A. Whether the current splits equally or not depends on the lamps (as we will see later); for example, it might divide so that 0.3 A goes one way and 0.1 A by the other branch.

The sum of the currents in the branches of a parallel circuit equals the current entering or leaving the parallel section.

Direct and alternating current

a) Difference

In a **direct current (d.c.)** the electrons flow in one direction only. Graphs for steady and varying d.c. are shown in Figure 36.5.

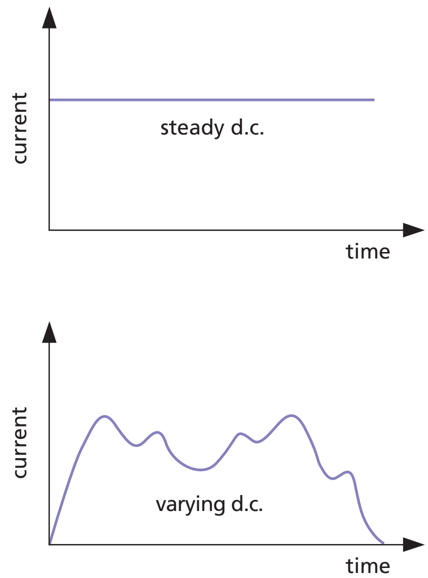


Figure 36.5 Direct current (d.c.)

In an **alternating current (a.c.)** the direction of flow reverses regularly, as shown in the graph in Figure 36.6. The circuit sign for a.c. is given in Figure 36.7.

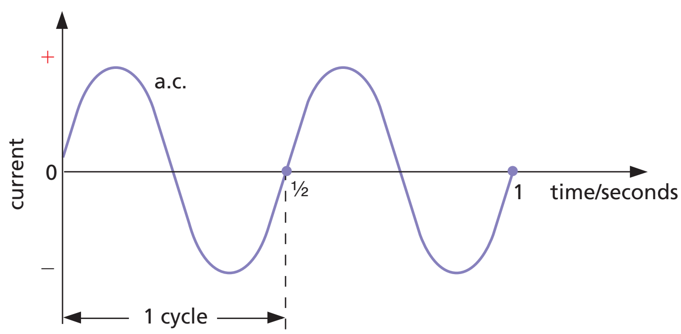


Figure 36.6 Alternating current (a.c.)

Figure 36.7 Symbol for alternating current

The pointer of an ammeter for measuring d.c. is deflected one way by the direct current. Alternating current makes the pointer move to and fro about the zero if the changes are slow enough; otherwise no deflection can be seen.

Batteries give d.c.; generators can produce either d.c. or a.c.

b) Frequency of a.c.

The number of complete alternations or cycles in 1 second is the **frequency** of the alternating current. The unit of frequency is the **hertz** (Hz). The frequency of the a.c. in Figure 36.6 is 2 Hz, which means there are two cycles per second, or one cycle lasts $1/2 = 0.5$ s. The mains supply in the UK is a.c. of frequency 50 Hz; each cycle lasts 1/50th of a second. This regularity was used in the tickertape timer (Chapter 2) and is relied upon in mains-operated clocks.

Questions

1 If the current in a floodlamp is 5 A, what charge passes in
 a 1 s,
 b 10 s,
 c 5 minutes?

2 What is the current in a circuit if the charge passing each point is
 a 10 C in 2 s,
 b 20 C in 40 s,
 c 240 C in 2 minutes?

3 Study the circuits in Figure 36.8. The switch S is open (there is a break in the circuit at this point). In which circuit would lamps Q and R light but not lamp P?

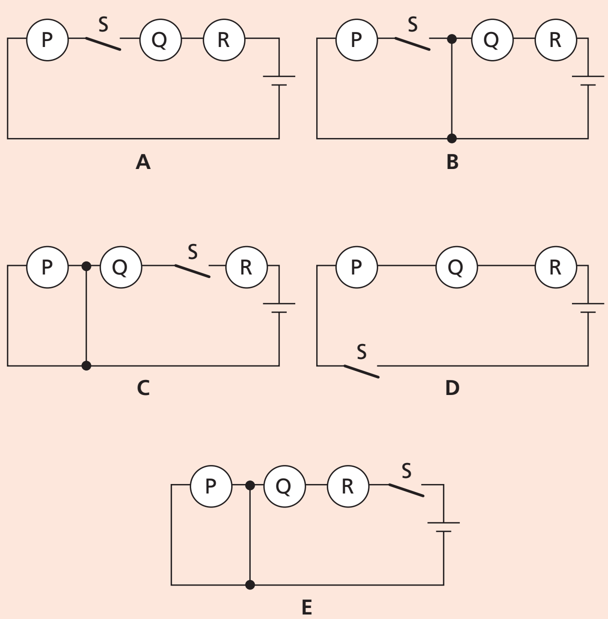


Figure 36.8

4 Using the circuit in Figure 36.9, which of the following statements is correct?
 A When S_1 and S_2 are closed, lamps A and B are lit.
 B With S_1 open and S_2 closed, A is lit and B is not lit.
 C With S_2 open and S_1 closed, A and B are lit.

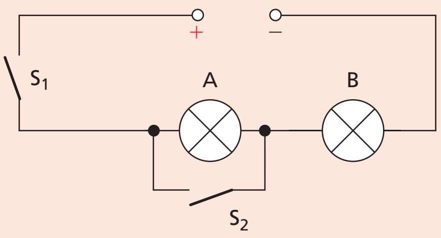


Figure 36.9

5 If the lamps are both the same in Figure 36.10 and if ammeter A_1 reads 0.50 A, what do ammeters A_2, A_3, A_4 and A_5 read?

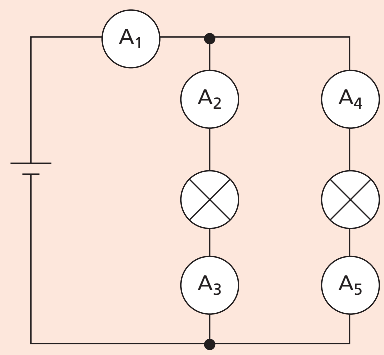


Figure 36.10

Checklist

After studying this chapter you should be able to

- describe a demonstration which shows that an electric current is a flow of charge,
- recall that an electric current in a metal is a flow of electrons from the negative to the positive terminal of the battery round a circuit,
- state the three effects of an electric current,
- state the unit of electric current and recall that current is measured by an ammeter,
- define the unit of charge in terms of the unit of current,
- recall the relation $Q = It$ and use it to solve problems,
- use circuit symbols for wires, cells, switches, ammeters and lamps,
- draw and connect simple series and parallel circuits, observing correct polarities for meters,
- recall that the current in a series circuit is the same everywhere in the circuit,
- state that for a parallel circuit, the current from the source is larger than the current in each branch,
- recall that the sum of the currents in the branches of a parallel circuit equals the current entering or leaving the parallel section,
- distinguish between electron flow and conventional current,
- distinguish between direct current and alternating current,
- recall that frequency of a.c. is the number of cycles per second.

37 Potential difference

- Energy transfers and p.d.
- Model of a circuit
- The volt
- Cells, batteries and e.m.f.
- Voltages round a circuit
- Practical work: Measuring voltage

A battery transforms chemical energy to electrical energy. Because of the chemical action going on inside it, it builds up a surplus of electrons at one of its terminals (the negative) and creates a shortage at the other (the positive). It is then able to maintain a **flow of electrons**, i.e. an **electric current**, in any circuit connected across its terminals for as long as the chemical action lasts.

The battery is said to have a **potential difference** (**p.d.** for short) at its terminals. Potential difference is measured in **volts** (V) and the term **voltage** is sometimes used instead of p.d. The p.d. of a car battery is 12 V and the domestic mains supply in the UK is 230 V.

Energy transfers and p.d.

In an electric circuit electrical energy is supplied from a source such as a battery and is transferred to other forms of energy by devices in the circuit. A lamp produces heat and light.

When each one of the circuits of Figure 37.1 is connected up, it will be found from the ammeter readings that the current is about the same (0.4 A) in each lamp. However, the mains lamp with a potential difference of 230 V applied to it gives much more light and heat than the car lamp with 12 V across it. In terms of energy, the mains lamp transfers a great deal more electrical energy in a second than the car lamp.

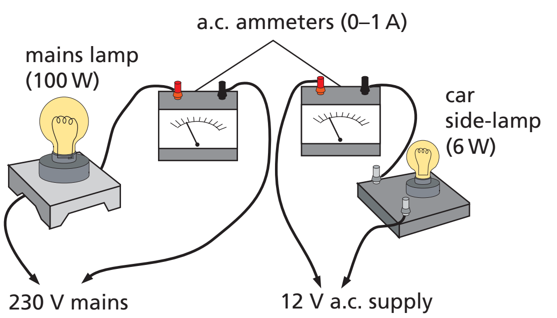


Figure 37.1 Investigating the effect of p.d. (potential difference) on energy transfer

Evidently the p.d. across a device affects the rate at which it transfers electrical energy. This gives us a way of defining the unit of potential difference: the volt.

Model of a circuit

It may help you to understand the definition of the volt, i.e. what a volt is, if you *imagine* that the current in a circuit is formed by 'drops' of electricity, each having a charge of 1 coulomb and carrying equal-sized 'bundles' of electrical energy. In Figure 37.2, Mr Coulomb represents one such 'drop'. As a 'drop' moves around the circuit it gives up all its energy which is changed to other forms of energy. Note that **electrical energy, not charge or current, is 'used up'**.

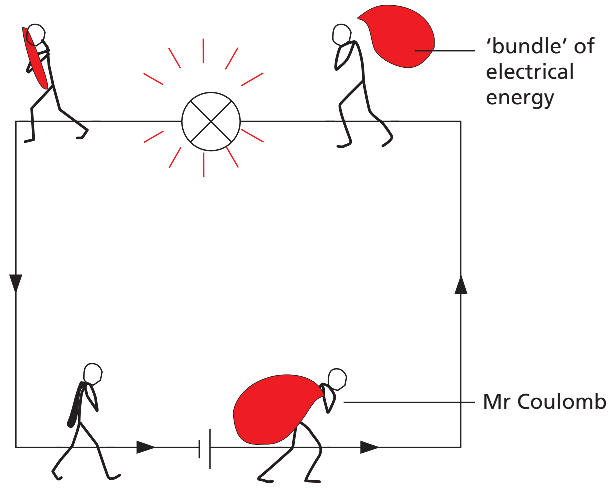


Figure 37.2 Model of a circuit

In our imaginary representation, Mr Coulomb travels round the circuit and unloads energy as he goes, most of it in the lamp. We think of him receiving a fresh 'bundle' every time he passes through the battery, which suggests he must be travelling very fast. In fact, as we found earlier (Chapter 36), the electrons drift along quite slowly. As soon as the circuit is complete, energy is delivered at once to the lamp, not by electrons directly from the battery but from electrons that were in the connecting wires. The model is helpful but is not an exact representation.

The volt

The demonstrations of Figure 37.1 show that the greater the voltage at the terminals of a supply, the larger is the 'bundle' of electrical energy given to each coulomb and the greater is the rate at which light and heat are produced in a lamp.

The p.d. between two points in a circuit is 1 volt if 1 joule of electrical energy is transferred to other forms of energy when 1 coulomb passes from one point to the other.

That is, 1 volt = 1 joule per coulomb (1 V = 1 J/C). If 2 J are given up by each coulomb, the p.d. is 2 V. If 6 J are transferred when 2 C pass, the p.d. is 6 J/2 C = 3 V.

In general if E (joules) is the energy transferred (i.e. the work done) when charge Q (coulombs) passes between two points, the p.d. V (volts) between the points is given by

$$V = E/Q \qquad \text{or} \qquad E = Q \times V$$

If Q is in the form of a steady current I (amperes) flowing for time t (seconds) then $Q = I \times t$ (Chapter 36) and

$$E = I \times t \times V$$

Cells, batteries and e.m.f.

A 'battery' (Figure 37.3) consists of two or more **electric cells**. Greater voltages are obtained when cells are joined in series, i.e. + of one to – of next. In Figure 37.4a the two 1.5 V cells give a voltage of 3 V at the terminals A, B. Every coulomb in a circuit connected to this battery will have 3 J of electrical energy.

The cells in Figure 37.4b are in opposition and the voltage at X, Y is zero.

If two 1.5 V cells are connected in parallel, as in Figure 37.4c, the voltage at terminals P, Q is still 1.5 V but the arrangement behaves like a larger cell and will last longer.

Figure 37.3 Compact batteries

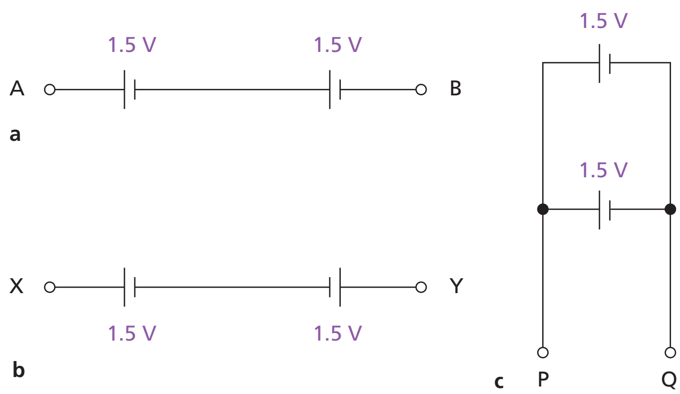


Figure 37.4

The p.d. at the terminals of a battery decreases slightly when current is drawn from it. This effect is due to the internal resistance of the battery which transfers electrical energy to heat as current flows through it. The greater the current drawn, the larger the 'lost' voltage. When no current is drawn from a battery it is said to be an 'open circuit' and its terminal p.d. is a maximum. This maximum voltage is termed the **electromotive force** (**e.m.f.**) of the battery. Like potential difference, e.m.f. is measured in volts and can be written as

e.m.f. = 'lost' volts + terminal p.d.

In energy terms, the e.m.f. is defined as the number of joules of chemical energy transferred to electrical energy and heat when one coulomb of charge passes through the battery (or cell).

In Figure 37.2 the size of the energy bundle Mr Coulomb is carrying when he leaves the cell would be smaller if the internal resistance were larger.

Practical work

Measuring voltage

A **voltmeter** is an instrument for measuring voltage or p.d. It looks like an ammeter but has a scale marked in volts. Whereas an ammeter is inserted **in series** in a circuit to measure the current, a voltmeter is connected across that part of the circuit where the voltage is required, i.e. **in parallel**. (We will see later that a voltmeter should have a high resistance and an ammeter a low resistance.)

To prevent damage the + terminal (marked red) must be connected to the point nearest the + of the battery.

(a) Connect the circuit of Figure 37.5a. The voltmeter gives the voltage across the lamp. Read it.

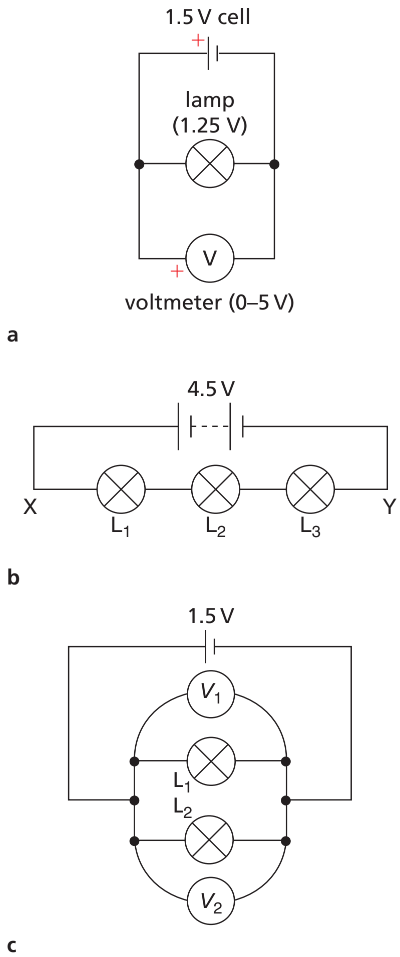


Figure 37.5

(b) Connect the circuit of Figure 37.5b. Measure:
- **(i)** the voltage V between X and Y,
- **(ii)** the voltage V_1 across lamp L_1,
- **(iii)** the voltage V_2 across lamp L_2,
- **(iv)** the voltage V_3 across lamp L_3.

How does the value of V compare with $V_1 + V_2 + V_3$?

(c) Connect the circuit of Figure 37.5c, so that two lamps L_1 and L_2 are in parallel across one 1.5 V cell. Measure the voltages, V_1 and V_2, across each lamp in turn. How do V_1 and V_2 compare?

Voltages round a circuit

a) Series

In the previous experiment you should have found in the circuit of Figure 37.5b that

$$V = V_1 + V_2 + V_3$$

For example, if $V_1 = 1.4\,V$, $V_2 = 1.5\,V$ and $V_3 = 1.6\,V$, then V will be $(1.4 + 1.5 + 1.6)\,V = 4.5\,V$.

The voltage at the terminals of a battery equals the sum of the voltages across the devices in the external circuit from one battery terminal to the other.

b) Parallel

In the circuit of Figure 37.5c

$$V_1 = V_2$$

The voltages across devices in parallel in a circuit are equal.

Questions

1 The p.d. across the lamp in Figure 37.6 is 12 V. How many joules of electrical energy are changed into light and heat when
  a a charge of 1 C passes through it,
  b a charge of 5 C passes through it,
  c a current of 2 A flows in it for 10 s?

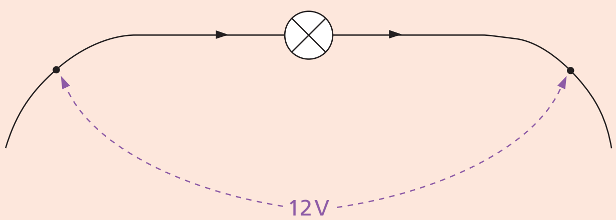


Figure 37.6

2 Three 2 V cells are connected in series and used as the supply for a circuit.
  a What is the p.d. at the terminals of the supply?
  b How many joules of electrical energy does 1 C gain on passing through
    (i) one cell, **(ii)** all three cells?

3 Each of the cells shown in Figure 37.7 has a p.d. of 1.5 V. Which of the arrangements would produce a battery with a p.d. of 6 V?

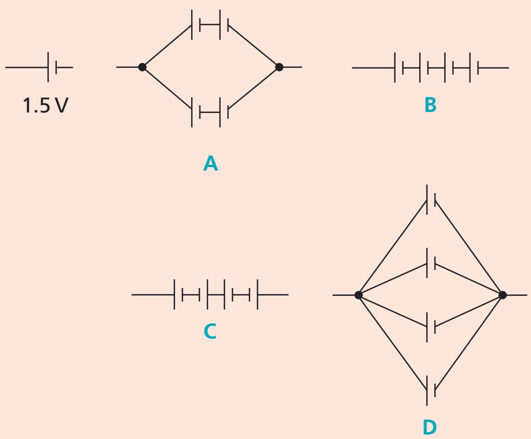
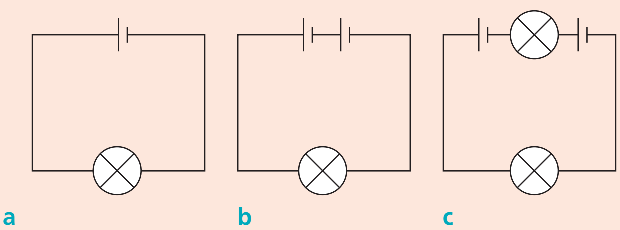


Figure 37.7

4 The lamps and the cells in all the circuits of Figure 37.8 are the same. If the lamp in **a** has its full, normal brightness, what can you say about the brightness of the lamps in **b**, **c**, **d**, **e** and **f**?



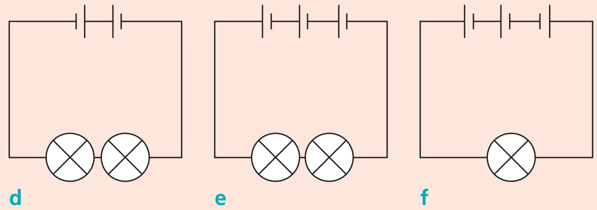


Figure 37.8

5 Three voltmeters V, V_1 and V_2 are connected as in Figure 37.9.
  a If V reads 18 V and V_1 reads 12 V, what does V_2 read?
  b If the ammeter A reads 0.5 A, how much electrical energy is changed to heat and light in lamp L_1 in one minute?
  c Copy Figure 37.9 and mark with a + the positive terminals of the ammeter and voltmeters for correct connection.

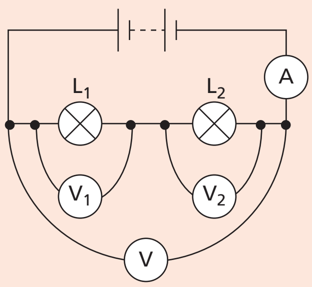


Figure 37.9

6 Three voltmeters are connected as in Figure 37.10.

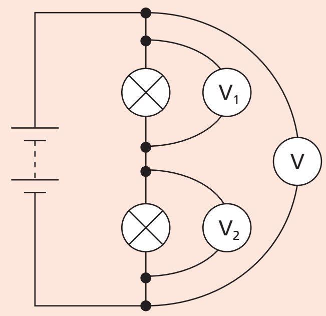


Figure 37.10

What are the voltmeter readings *x*, *y* and *z* in the table below (which were obtained with three different batteries)?

V/V	*V*$_1$/V	*V*$_2$/V
x	12	6
6	4	*y*
12	*z*	4

Checklist

After studying this chapter you should be able to

- describe simple experiments to show the transfer of electrical energy to other forms (e.g. in a lamp),
- recall the definition of the unit of p.d. and that p.d. (also called 'voltage') is measured by a voltmeter,
- demonstrate that the sum of the voltages across any number of components in series equals the voltage across all of those components,
- demonstrate that the voltages across any number of components in parallel are the same,
- work out the voltages of cells connected in series and parallel,
- explain the meaning of the term electromotive force (e.m.f.).

38 Resistance

- The ohm
- Resistors
- *I–V* graphs: Ohm's law
- Resistors in series
- Resistors in parallel
- Resistor colour code
- Resistivity
- Potential divider
- Practical work: Measuring resistance

Electrons move more easily through some conductors than others when a p.d. is applied. The opposition of a conductor to current is called its **resistance**. A good conductor has a low resistance and a poor conductor has a high resistance. The resistance of a wire of a certain material

(i) increases as its length increases,
(ii) increases as its cross-sectional area decreases,
(iii) depends on the material.

A long thin wire has more resistance than a short thick one of the same material. Silver is the best conductor, but copper, the next best, is cheaper and is used for connecting wires and for domestic electric cables.

The ohm

If the current in a conductor is I when the voltage across it is V, as shown in Figure 38.1a, its resistance R is defined by

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

This is a reasonable way to measure resistance since the smaller I is for a given V, the greater is R. If V is in volts and I in amperes, then R is in **ohms** (symbol Ω, the Greek letter omega). For example, if $I = 2\,\text{A}$ when $V = 12\,\text{V}$, then $R = 12\,\text{V}/2\,\text{A}$, that is, $R = 6\,\Omega$.

The ohm is the resistance of a conductor in which the current is 1 ampere when a voltage of 1 volt is applied across it.

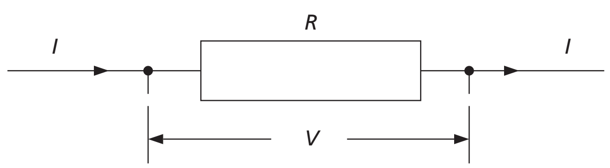


Figure 38.1a

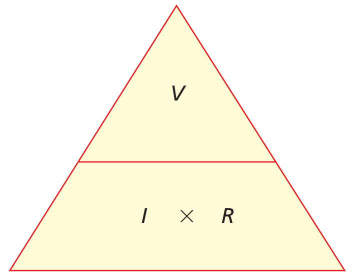


Figure 38.1b

Alternatively, if R and I are known, V can be found from

$$V = IR$$

Also, when V and R are known, I can be calculated from

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

The triangle in Figure 38.1b is an aid to remembering the three equations. It is used like the 'density triangle' in Chapter 5.

Resistors

Conductors intended to have resistance are called **resistors** (Figure 38.2a) and are made either from wires of special alloys or from carbon. Those used in radio and television sets have values from a few ohms up to millions of ohms (Figure 38.2b).

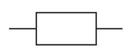


Figure 38.2a Circuit symbol for a resistor

Figure 38.2b Resistor

Figure 38.2c Variable resistor (potentiometer)

Variable resistors are used in electronics (and are then called **potentiometers**) as volume and other controls (Figure 38.2c). Variable resistors that take larger currents, like the one shown in Figure 38.3, are useful in laboratory experiments. These consist of a coil of constantan wire (an alloy of 60% copper, 40% nickel) wound on a tube with a sliding contact on a metal bar above the tube.

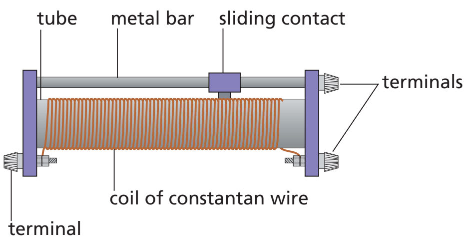


Figure 38.3 Large variable resistor

There are two ways of using such a variable resistor. It may be used as a **rheostat** for changing the current in a circuit; only one end connection and the sliding contact are then required. In Figure 38.4a moving the sliding contact to the left reduces the resistance and increases the current. This variable resistor can also act as a **potential divider** for changing the p.d. applied to a device; all three connections are then used. In Figure 38.4b any fraction from the total p.d. of the battery to zero can be 'tapped off' by moving the sliding contact down. Figure 38.5 shows the circuit diagram symbol for a variable resistor being used in rheostat mode.

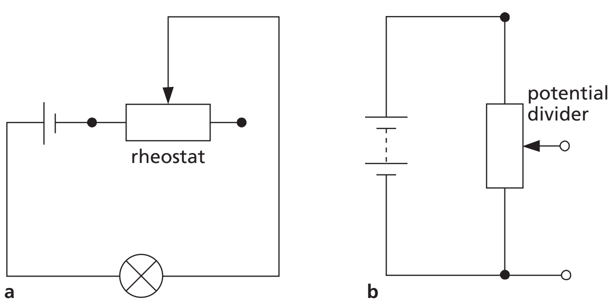


Figure 38.4 A variable resistor can be used as a rheostat or as a potential divider.

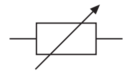


Figure 38.5 Circuit symbol for a variable resistor used as a rheostat

Practical work

Measuring resistance

The resistance R of a conductor can be found by measuring the current I in it when a p.d. V is applied across it and then using $R = V/I$. This is called the **ammeter–voltmeter** method.

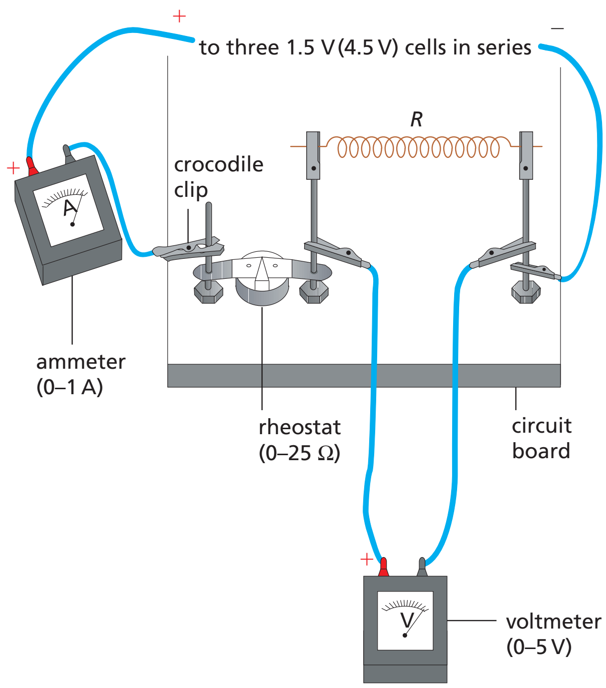


Figure 38.6

Set up the circuit of Figure 38.6 in which the unknown resistance R is 1 metre of SWG 34 constantan wire. Altering the rheostat changes both the p.d. V and the current I. Record in a table, with three columns, five values of I (e.g. 0.10, 0.15, 0.20, 0.25 and 0.3 A) and the corresponding values of V. Work out R for each pair of readings.

Repeat the experiment, but instead of the wire use **(i)** a lamp (e.g. 2.5 V, 0.3 A), **(ii)** a semiconductor diode (e.g. 1N4001) connected first one way then the other way round, **(iii)** a thermistor (e.g. TH 7). (Semiconductor diodes and thermistors are considered in Chapter 41 in more detail.)

I–V graphs: Ohm's law

The results of the previous experiment allow graphs of I against V to be plotted for different conductors.

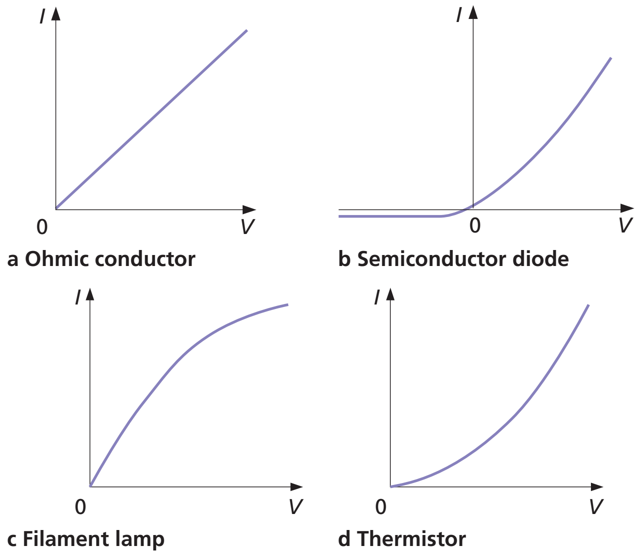


Figure 38.7 I–V graphs

a) Metallic conductors

Metals and some alloys give I–V graphs that are a straight line through the origin, as in Figure 38.7a, provided that their temperature is constant. I is directly proportional to V, i.e. $I \propto V$. Doubling V doubles I, etc. Such conductors obey **Ohm's law**, stated as follows.

> The current in a metallic conductor is directly proportional to the p.d. across its ends if the temperature and other conditions are constant.

They are called **ohmic** or **linear conductors** and since $I \propto V$, it follows that V/I = a constant (obtained from the slope of the I–V graph). The resistance of an ohmic conductor therefore does not change when the p.d. does.

b) Semiconductor diode

The typical I–V graph in Figure 38.7b shows that current passes when the p.d. is applied in one direction but is almost zero when it acts in the opposite direction. A diode has a small resistance when connected one way round but a very large resistance when the p.d. is reversed. It conducts in one direction only and is a **non-ohmic conductor**.

c) Filament lamp

A filament lamp is a non-ohmic conductor at high temperatures. For a filament lamp the I–V graph bends over as V and I increase (Figure 38.7c). That is, the resistance (V/I) increases as I increases and makes the filament hotter.

d) Variation of resistance with temperature

In general, an increase of temperature increases the resistance of metals, as for the filament lamp in Figure 38.7c, but it decreases the resistance of semiconductors. The resistance of semiconductor **thermistors** (see Chapter 41) decreases if their temperature rises, i.e. their I–V graph bends upwards, as in Figure 38.7d.

If a resistor and a thermistor are connected as a potential divider (Figure 38.8), the p.d. across the resistor increases as the temperature of the thermistor increases; the circuit can be used to monitor temperature, for example in a car radiator.

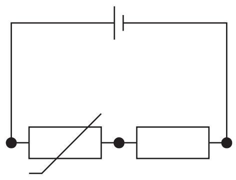


Figure 38.8 Potential divider circuit for monitoring temperature

e) Variation of resistance with light intensity

The resistance of some semiconducting materials decreases when the intensity of light falling on them increases. This property is made use of in **light-dependent resistors** (LDRs) (see Chapter 41). The I–V graph for an LDR is similar to that shown in Figure 38.7d for a thermistor. Both thermistors and LDRs are non-ohmic conductors.

Resistors in series

The resistors in Figure 38.9 are in series. The same current I flows through each and the total voltage V across all three is the sum of the separate voltages across them, i.e.

$$V = V_1 + V_2 + V_3$$

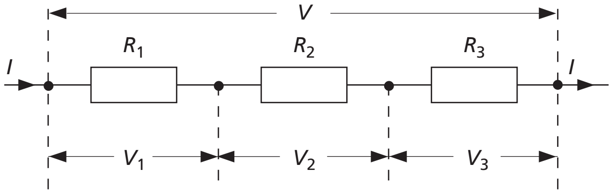


Figure 38.9 Resistors in series

But $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$. Also, if R is the combined resistance, $V = IR$, and so

$$IR = IR_1 + IR_2 + IR_3$$

Dividing both sides by I,

$$R = R_1 + R_2 + R_3$$

Resistors in parallel

The resistors in Figure 38.10 are in parallel. The **voltage V between the ends of each is the same** and the total current I equals the sum of the currents in the separate branches, i.e.

$$I = I_1 + I_2 + I_3$$

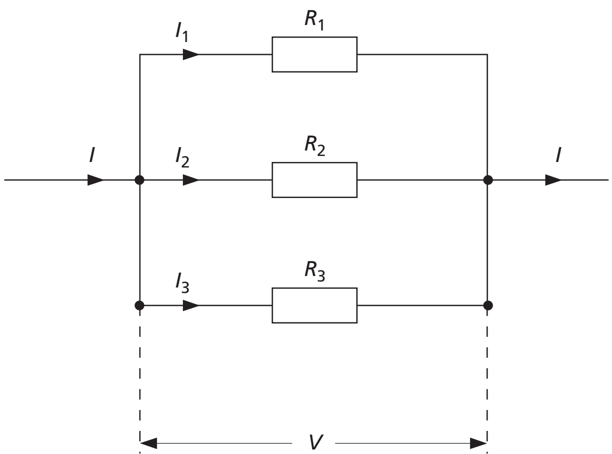


Figure 38.10 Resistors in parallel

But $I_1 = V/R_1$, $I_2 = V/R_2$ and $I_3 = V/R_3$. Also, if R is the combined resistance, $I = V/R$,

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Dividing both sides by V,

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

For the simpler case of *two* resistors in parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_2}{R_1R_2} + \frac{R_1}{R_1R_2}$$

$$\therefore \quad \frac{1}{R} = \frac{R_2 + R_1}{R_1R_2}$$

Inverting both sides,

$$R = \frac{R_1R_2}{R_1 + R_2} = \frac{\text{product of resistances}}{\text{sum of resistances}}$$

The combined resistance of two resistors in parallel is less than the value of either resistor alone. Check this is true in the following Worked example. Lamps are connected in parallel rather than in series in a lighting circuit. Can you suggest why? (See p.180 for the advantages.)

Worked example

A p.d. of 24 V from a battery is applied to the network of resistors in Figure 38.11a.

a What is the combined resistance of the 6 Ω and 12 Ω resistors in parallel?

b What is the current in the 8 Ω resistor?

c What is the voltage across the parallel network?

d What is the current in the 6 Ω resistor?

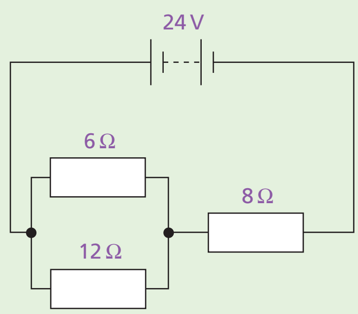


Figure 38.11a

a Let R_1 = resistance of 6 Ω and 12 Ω in parallel. Then

$$\frac{1}{R_1} = \frac{1}{6} + \frac{1}{12} = \frac{2}{12} + \frac{1}{12} = \frac{3}{12}$$

$$\therefore \quad R_1 = \frac{12}{3} = 4\ \Omega$$

b Let R = total resistance of circuit = 4 + 8, that is, $R = 12\ \Omega$. The equivalent circuit is shown in Figure 38.11b, and if I is the current in it then, since $V = 24\ \text{V}$

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

$\therefore$ current in 8 Ω resistor = 2 A

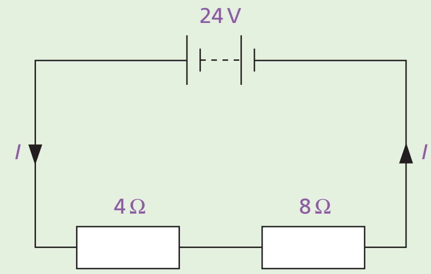


Figure 38.11b

c Let V_1 = voltage across parallel network in Figure 38.11a. Then

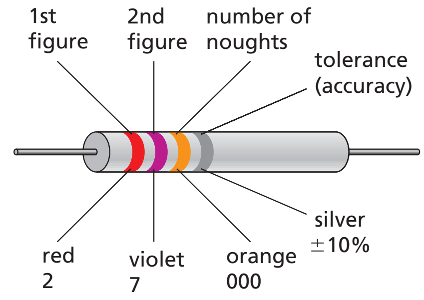
$$V_1 = I \times R_1 = 2\ \text{A} \times 4\ \Omega = 8\ \text{V}$$

d Let I_1 = current in 6 Ω resistor, then since $V_1 = 8\ \text{V}$

$$I_1 = \frac{V_1}{6\ \Omega} = \frac{8\ \text{V}}{6\ \Omega} = \frac{4}{3}\text{A}$$

Resistor colour code

Resistors have colour coded bands as shown in Figure 38.12. In the orientation shown the first two bands on the left give digits 2 and 7; the third band gives the number of noughts (3) and the fourth band gives the resistor's 'tolerance' (or accuracy, here ±10%). So the resistor has a value of 27 000 Ω (±10%).



resistor value = 27 000 Ω (±10%)
= 27 kΩ (±10%)

Figure	Colour
0	black
1	brown
2	red
3	orange
4	yellow
5	green
6	blue
7	violet
8	grey
9	white

Tolerance	
±5%	gold
±10%	silver
±20%	no band

Figure 38.12 Colour code for resistors

Resistivity

Experiments show that the resistance R of a wire of a given material is

(i) directly proportional to its length l, i.e. $R \propto l$,
(ii) inversely proportional to its cross-sectional area A, i.e. $R \propto 1/A$ (doubling A halves R).

Combining these two statements, we get

$$R \propto \frac{l}{A} \quad \text{or} \quad R = \frac{\rho l}{A}$$

where ρ is a constant, called the **resistivity** of the material. If we put $l = 1$ m and $A = 1\ \text{m}^2$, then $\rho = R$.

The resistivity of a material is numerically equal to the resistance of a 1 m length of the material with cross-sectional area 1 m².

The unit of ρ is the **ohm-metre** (Ω m), as can be seen by rearranging the equation to give $\rho = AR/l$ and inserting units for A, R and l. Knowing ρ for a material, the resistance of any sample of it can be calculated. The resistivities of metals increase at higher temperatures; for most other materials they decrease.

Worked example

Calculate the resistance of a copper wire 1.0 km long and 0.50 mm diameter if the resistivity of copper is $1.7 \times 10^{-8}\,\Omega\,\text{m}$.

Converting all units to metres, we get

$$\text{length } l = 1.0\,\text{km} = 1000\,\text{m} = 10^3\,\text{m}$$
$$\text{diameter } d = 0.50\,\text{mm} = 0.50 \times 10^{-3}\,\text{m}$$

If r is the radius of the wire, the cross-sectional area $A = \pi r^2 = \pi(d/2)^2 = (\pi/4)d^2$, so

$$A = \frac{\pi}{4}\left(0.50 \times 10^{-3}\right)^2\,\text{m}^2 \approx 0.20 \times 10^{-6}\,\text{m}^2$$

Then

$$R = \frac{\rho l}{A} = \frac{\left(1.7 \times 10^{-8}\,\Omega\,\text{m}\right) \times \left(10^3\,\text{m}\right)}{0.20 \times 10^{-6}\,\text{m}^2} = 85\,\Omega$$

Potential divider

In the circuit shown in Figure 38.13, two resistors R_1 and R_2 are in series with a supply of voltage V. The current in the circuit is

$$I = \frac{\text{supply voltage}}{\text{total resistance}} = \frac{V}{(R_1 + R_2)}$$

So the voltage across R_1 is

$$V_1 = I \times R_1 = \frac{V \times R_1}{(R_1 + R_2)} = V \times \frac{R_1}{(R_1 + R_2)}$$

and the voltage across R_2 is

$$V_2 = I \times R_2 = \frac{V \times R_2}{(R_1 + R_2)} = V \times \frac{R_2}{(R_1 + R_2)}$$

Also the ratio of the voltages across the two resistors is

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

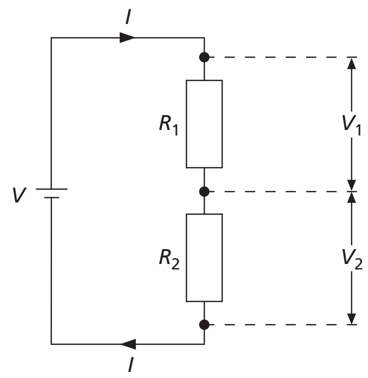


Figure 38.13 Potential divider circuit

Returning to Figure 38.8 (p. 169), can you now explain why the voltage across the resistor increases when the resistance of the thermistor decreases?

Questions

1 What is the resistance of a lamp when a voltage of 12 V across it causes a current of 4 A?

2 Calculate the p.d. across a 10 Ω resistor carrying a current of 2 A.

3 The p.d. across a 3 Ω resistor is 6 V. What is the current flowing (in ampere)?

A $\frac{1}{2}$ **B** 1 **C** 2 **D** 6 **E** 8

4 The resistors R_1, R_2, R_3 and R_4 in Figure 38.14 are all equal in value. What would you expect the voltmeters A, B and C to read, assuming that the connecting wires in the circuit have negligible resistance?

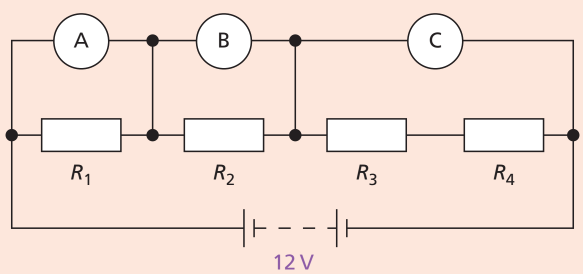


Figure 38.14

5 Calculate the effective resistance between A and B in Figure 38.15.

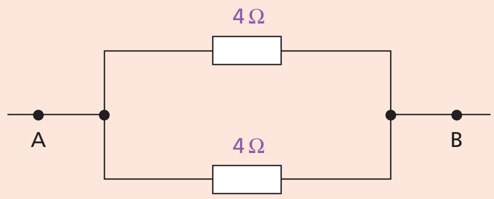


Figure 38.15

6 What is the effective resistance in Figure 38.16 between
  a A and B,
  b C and D?

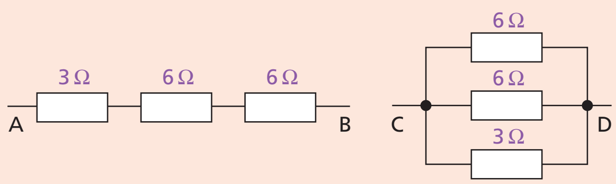


Figure 38.16

7 Figure 38.17 shows three resistors. Their combined resistance in ohms is
  A $1\frac{5}{7}$ **B** 14 **C** $1\frac{1}{5}$ **D** $7\frac{1}{2}$ **E** $6\frac{2}{3}$

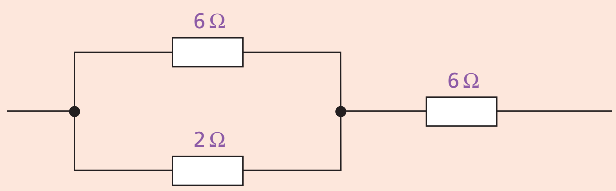


Figure 38.17

8 a The graph in Figure 38.18 illustrates how the p.d. across the ends of a conductor is related to the current in it.
    (i) What law may be deduced from the graph?
    (ii) What is the resistance of the conductor?
  b Draw diagrams to show how six 2 V lamps could be lit to normal brightness when using a
    (i) 2 V supply,
    (ii) 6 V supply,
    (iii) 12 V supply.

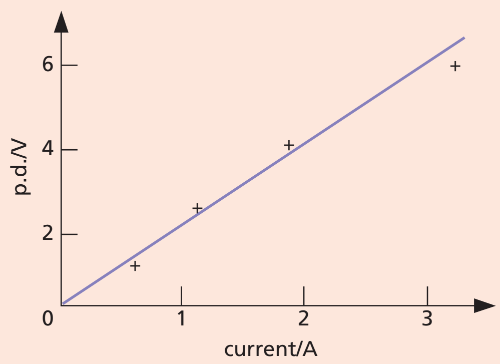


Figure 38.18

9 When a 4 Ω resistor is connected across the terminals of a 12 V battery, the number of coulombs passing through the resistor per second is
  A 0.3 **B** 3 **C** 4 **D** 12 **E** 48

Checklist

After studying this chapter you should be able to

- define resistance and state the factors on which it depends,
- recall the unit of resistance,
- solve simple problems using $R = V/I$,
- describe experiments using the ammeter–voltmeter method to measure resistance, and study the relationship between current and p.d. for (a) metallic conductors, (b) semiconductor diodes, (c) filament lamps, (d) thermistors, (e) LDRs,
- plot I–V graphs from the results of such experiments and draw appropriate conclusions from them,
- use the formulae for resistors in series,
- recall that the combined resistance of two resistors in parallel is less than that of either resistor alone,
- calculate the effective resistance of two resistors in parallel,
- relate the resistance of a wire to its length and diameter,
- calculate voltages in a potential divider circuit.

39 Capacitors

- Capacitance
- Types of capacitor
- Charging and discharging a capacitor
- Effect of capacitors in d.c. and a.c. circuits

A **capacitor** stores electric charge and is useful in many electronic circuits. In its simplest form it consists of two parallel metal plates separated by an insulator, called the **dielectric** (Figure 39.1a). Figure 39.1b shows the circuit symbol for a capacitor.

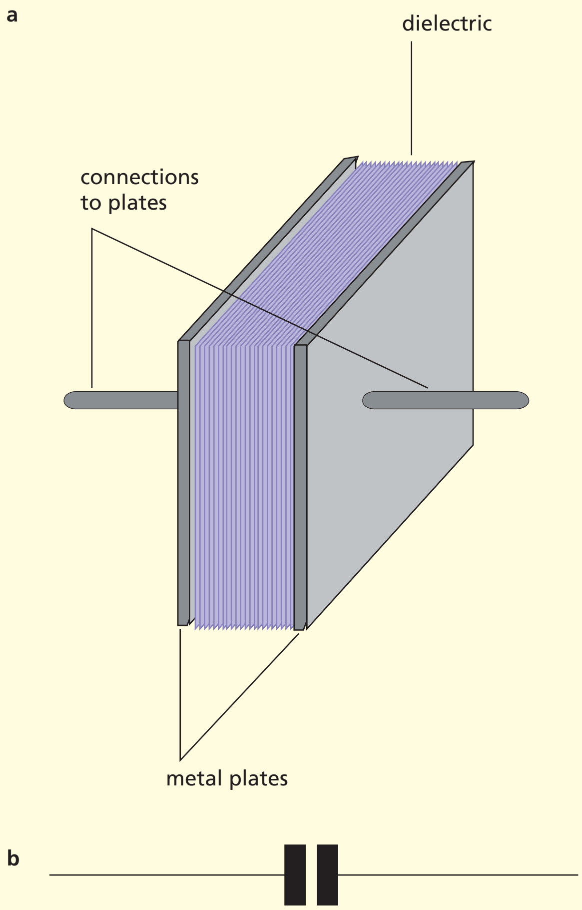


Figure 39.1a A parallel-plate capacitor; **b** symbol for a capacitor

Capacitance

The more charge a capacitor can store, the greater is its **capacitance** (C). The capacitance is large when the plates have a large area and are close together. It is measured in **farads** (F) but smaller units such as the microfarad (μF) are more convenient.

$$1\,\mu\text{F} = 1 \text{ millionth of a farad} = 10^{-6}\,\text{F}$$

Types of capacitor

Practical capacitors, with values ranging from about 0.01 μF to 100 000 μF, often consist of two long strips of metal foil separated by long strips of dielectric, rolled up like a 'Swiss roll', as in Figure 39.2. The arrangement allows plates of large area to be close together in a small volume. Plastics (e.g. polyesters) are commonly used as the dielectric, with films of metal being deposited on the plastic to act as the plates (Figure 39.3).

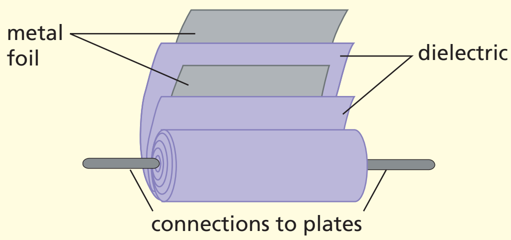


Figure 39.2 Construction of a practical capacitor

Figure 39.3 Polyester capacitor

The **electrolytic** type of capacitor shown in Figure 39.4a has a very thin layer of aluminium oxide as the dielectric between two strips of aluminium foil, giving large capacitances. It is polarised, i.e. it has positive and negative terminals (Figure 39.4b), and these *must* be connected to the + and – terminals, respectively, of the voltage supply.

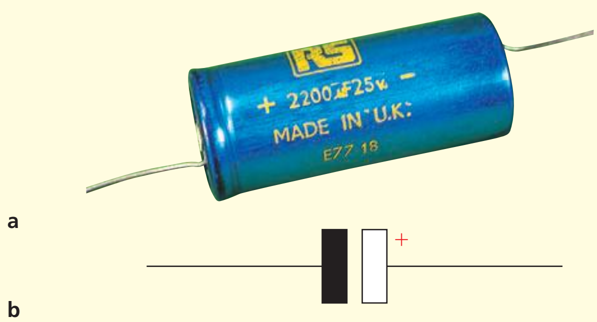


Figure 39.4a Electrolytic capacitor; **b** symbol showing polarity

Charging and discharging a capacitor

a) Charging

A capacitor can be charged by connecting a battery across it. In Figure 39.5a, the + terminal of the battery attracts electrons (since they have a negative charge) from plate X and the – terminal of the battery repels electrons to plate Y. A positive charge builds up on plate X (since it loses electrons) and an equal negative charge builds up on Y (since it gains electrons).

During the charging, there is a *brief* flow of electrons round the circuit from X to Y (but not through the dielectric). A momentary current would be detected by a sensitive ammeter. The voltage builds up between X and Y and opposes the battery voltage. Charging stops when these two voltages are equal; the electron flow, i.e. the charging current, is then zero. The variation of *current* with time (for both charging or discharging a capacitor) has a similar shape to the curve shown in Figure 39.7b.

During the charging process, electrical energy is transferred from the battery to the capacitor, which then stores the energy.

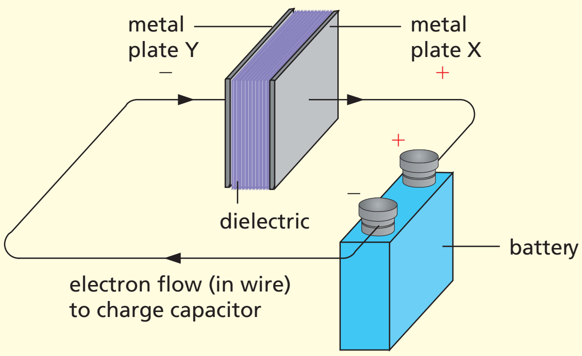


Figure 39.5a Charging a capacitor

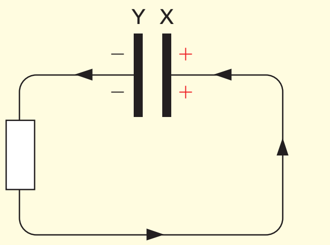


Figure 39.5b Discharging a capacitor

b) Discharging

When a conductor is connected across a charged capacitor, as in Figure 39.5b, there is a brief flow of electrons from the negatively charged plate to the positively charged one, i.e. from Y to X. The charge stored by the capacitor falls to zero, as does the voltage across it. The capacitor has transferred its stored energy to the conductor. The 'delay' time taken for a capacitor to fully charge or discharge through a resistor is made use of in many electronic circuits.

c) Demonstration

The circuit in Figure 39.6 has a two-way switch S. When S is in position 1 the capacitor *C* charges up, and discharges when S is in position 2. The larger the values of *R* and *C* the longer it takes for the capacitor to charge or discharge; with the values shown in Figure 39.6, the capacitor will take 2 to 3 minutes to fully charge or discharge. The direction of the deflection of the centre-zero milliammeter reverses for each process. The corresponding changes of capacitor charge (measured by the voltage across it) with time are shown by the graphs in Figures 39.7a and b. These can be plotted directly if the voltmeter is replaced by a datalogger and computer.

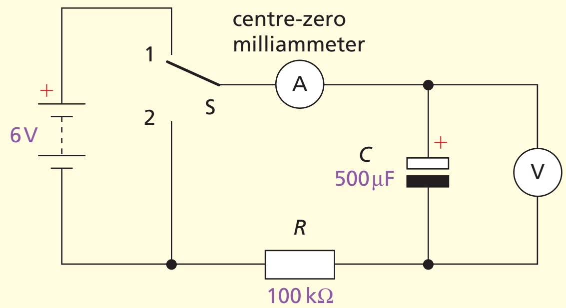


Figure 39.6 Demonstration circuit for charging and discharging a capacitor

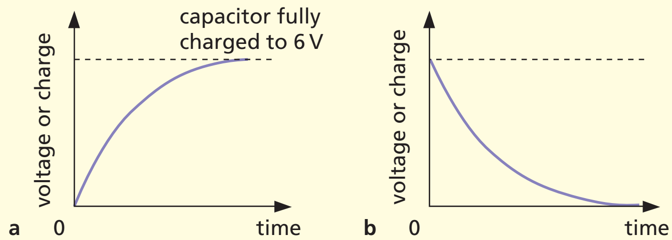


Figure 39.7 Graphs: **a** charging; **b** discharging

Effect of capacitors in d.c. and a.c. circuits

a) Direct current circuit

In Figure 39.8a the supply is d.c. but the lamp does not light, that is, a capacitor blocks direct current.

b) Alternating current circuit

In Figure 39.8b the supply is a.c. and the lamp lights, suggesting that a capacitor passes alternating current. In fact, no current actually passes *through* the capacitor since its plates are separated by an insulator. But as the a.c. reverses direction, the capacitor charges and discharges, causing electrons to flow to and fro rapidly in the wires joining the plates. Thus, effectively, a.c. flows round the circuit, lighting the lamp.

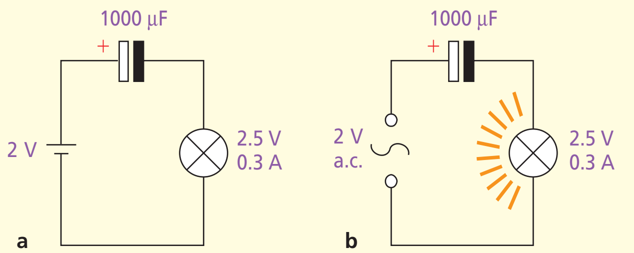


Figure 39.8 A capacitor blocks direct current and allows a flow of alternating current.

Questions

1 a Describe the basic construction of a capacitor.
b What does a capacitor do?
c State two ways of increasing the capacitance of a capacitor.
d Name a unit of capacitance.

2 a When a capacitor is being charged, is the value of the charging current maximum or zero
(i) at the start, or
(ii) at the end of charging?
b When a capacitor is discharging, is the value of the current in the circuit maximum or zero
(i) at the start, or
(ii) at the end of charging?

3 How does a capacitor behave in a circuit with
a a d.c. supply,
b an a.c. supply?

Checklist

After studying this chapter you should be able to

- state what a capacitor does,
- state the unit of capacitance,
- describe in terms of electron motion how a capacitor can be charged and discharged, and sketch graphs of the capacitor voltage with time for charging and discharging through a resistor,
- recall that a capacitor blocks d.c. but passes a.c. and explain why.

40 Electric power

- Power in electric circuits
- Electric lighting
- Electric heating
- Joulemeter
- House circuits
- Paying for electricity
- Dangers of electricity
- Practical work: Measuring electric power.

Power in electric circuits

In many circuits it is important to know the rate at which electrical energy is transferred into other forms of energy. Earlier (Chapter 13) we said that **energy transfers were measured by the work done** and power was defined by the equation

$$\text{power} = \frac{\text{work done}}{\text{time taken}} = \frac{\text{energy transfer}}{\text{time taken}}$$

In symbols

$$P = \frac{E}{t} \qquad (1)$$

where if E is in joules (J) and t in seconds (s) then P is in J/s or watts (W).

From the definition of p.d. (Chapter 37) we saw that if E is the electrical energy transferred when there is a steady current I (in amperes) for time t (in seconds) in a device (e.g. a lamp) with a p.d. V (in volts) across it, as in Figure 40.1, then

$$E = ItV \qquad (2)$$

Substituting for E in (1) we get

$$P = \frac{E}{t} = \frac{ItV}{t}$$

or

$$P = IV$$

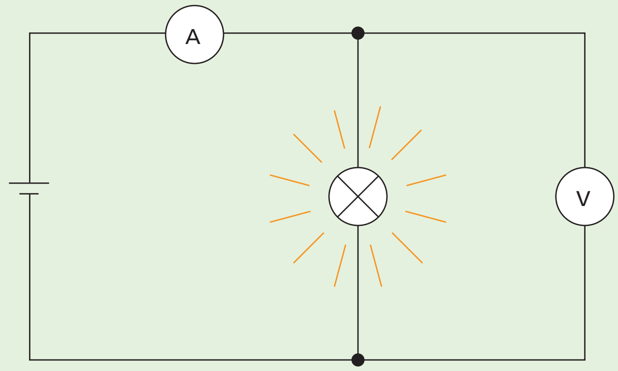


Figure 40.1

Therefore to calculate the power P of an electrical appliance we multiply the current I in it by the p.d. V across it. For example if a lamp on a 240 V supply has a current of 0.25 A in it, its power is 240 V × 0.25 A = 60 W. The lamp is transferring 60 J of electrical energy into heat and light each second. Larger units of power are the **kilowatt** (kW) and the **megawatt** (MW) where

$$1\,\text{kW} = 1000\,\text{W} \quad \text{and} \quad 1\,\text{MW} = 1\,000\,000\,\text{W}$$

In units

$$\text{watts} = \text{amperes} \times \text{volts} \qquad (3)$$

It follows from (3) that since

$$\text{volts} = \frac{\text{watts}}{\text{amperes}} \qquad (4)$$

the volt can be defined as a **watt per ampere** and p.d. calculated from (4).

If all the energy is transferred to heat in a resistor of resistance R, then $V = IR$ and the rate of production of heat is given by

$$P = V \times I = IR \times I = I^2R$$

That is, if the current is doubled, four times as much heat is produced per second. Also, $P = V^2/R$.

Practical work

Measuring electric power

a) Lamp

Connect the circuit of Figure 40.2. Note the ammeter and voltmeter readings and work out the electric power supplied to the lamp in watts.

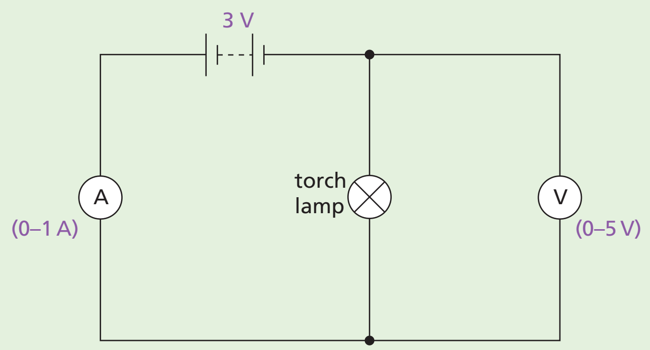


Figure 40.2

b) Motor

Replace the lamp in Figure 40.2 by a small electric motor. Attach a known mass m (in kg) to the axle of the motor with a length of thin string and find the time t (in s) required to raise the mass through a known height h (in m) at a steady speed. Then the power output P_o (in W) of the motor is given by

$$P_o = \frac{\text{work done in raising mass}}{\text{time taken}} = \frac{mgh}{t}$$

If the ammeter and voltmeter readings I and V are noted while the mass is being raised, the power input P_i (in W) can be found from

$$P_i = IV$$

The efficiency of the motor is given by

$$\text{efficiency} = \frac{P_o}{P_i} \times 100\%$$

Also investigate the effect of a greater mass on: (i) the speed, (ii) the power output and (iii) the efficiency of the motor at its rated p.d.

Electric lighting

a) Filament lamps

The **filament** is a small coil of tungsten wire (Figure 40.3) which becomes white hot when there is a current in it. The higher the temperature of the filament, the greater is the proportion of electrical energy transferred to light and for this reason it is made of tungsten, a metal with a high melting point (3400 °C).

Most lamps are gas-filled and contain nitrogen and argon, not air. This reduces evaporation of the tungsten which would otherwise condense on the bulb and blacken it. The coil is coiled compactly so that it is cooled less by convection currents in the gas.

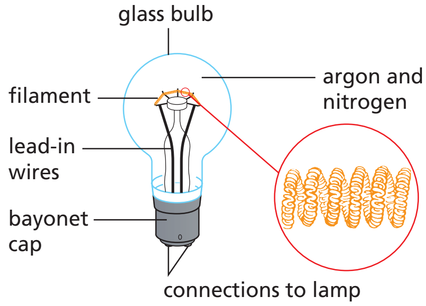


Figure 40.3 A filament lamp

b) Fluorescent strips

A filament lamp transfers only 10% of the electrical energy supplied to light; the other 90% becomes heat. Fluorescent strip lamps (Figure 40.4a) are five times as efficient and may last 3000 hours compared with the 1000-hour life of filament lamps. They cost more to install but running costs are less.

When a fluorescent strip lamp is switched on, the mercury vapour emits invisible ultraviolet radiation which makes the powder on the inside of the tube fluoresce (glow), i.e. visible light is emitted. Different powders give different colours.

c) Compact fluorescent lamps

These energy-saving fluorescent lamps (Figure 40.4b) are available to fit straight into normal light sockets, either bayonet or screw-in. They last up to eight times longer (typically 8000 hours) and use about five times less energy than filament lamps for the same light output. For example, a 20 W compact fluorescent is equivalent to a 100 W filament lamp.

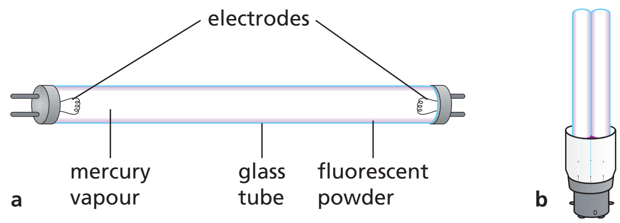


Figure 40.4 Fluorescent lamps

Electric heating

a) Heating elements

In domestic appliances such as electric fires, cookers, kettles and irons the ‘elements’ (Figure 40.5) are made from Nichrome wire. This is an alloy of nickel and chromium which does not oxidise (and so become brittle) when the current makes it red hot.

The elements in **radiant** electric fires are at red heat (about 900 °C) and the radiation they emit is directed into the room by polished reflectors. In **convector** types the element is below red heat (about 450 °C) and is designed to warm air which is drawn through the heater by natural or forced convection. In **storage** heaters the elements heat fire-clay bricks during the night using ‘off-peak’ electricity. On the following day these cool down, giving off the stored heat to warm the room.

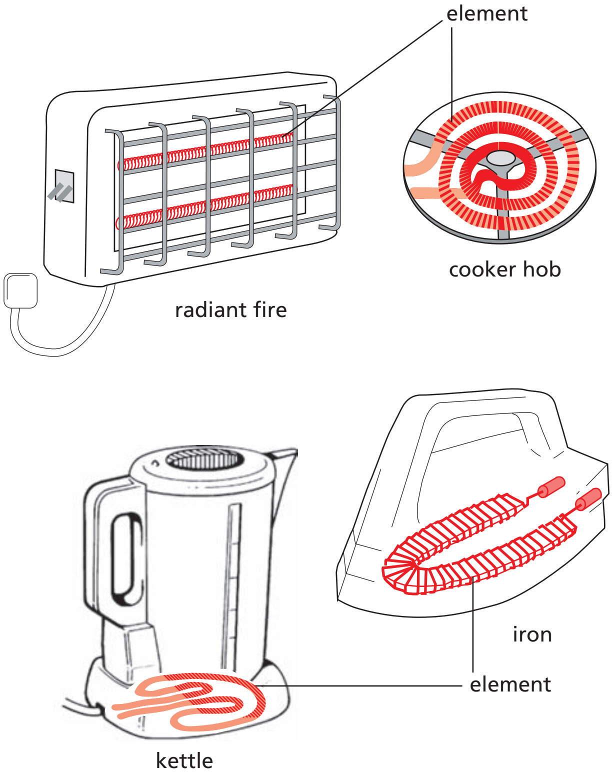


Figure 40.5 Heating elements

b) Three-heat switch

This is sometimes used to control heating appliances. It has three settings and uses two identical elements. On ‘high’, the elements are in parallel across the supply voltage (Figure 40.6a); on ‘medium’, there is only current in one (Figure 40.6b); on ‘low’, they are in series (Figure 40.6c).

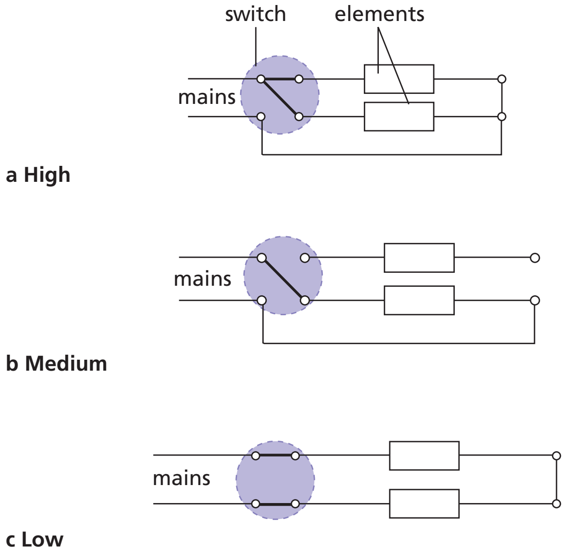


Figure 40.6 Three-heat switch

c) Fuses

A **fuse** protects a circuit. It is a short length of wire of material with a low melting point, often ‘tinned copper’, which melts and breaks the circuit when the current in it exceeds a certain value. Two reasons for excessive currents are ‘short circuits’ due to worn insulation on connecting wires and overloaded circuits. Without a fuse the wiring would become hot in these cases and could cause a fire. **A fuse should ensure that the current-carrying capacity of the wiring is not exceeded.** In general the thicker a cable is, the more current it can carry, but each size has a limit.

Two types of fuse are shown in Figure 40.7a. **Always switch off before replacing a fuse,** and always replace with one of the same value as recommended by the manufacturer of the appliance.

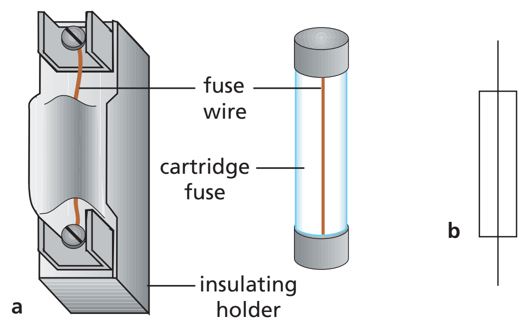


Figure 40.7a Two types of fuse; **b** the circuit symbol for a fuse

Joulemeter

Instead of using an ammeter and a voltmeter to measure the electrical energy transferred by an appliance, a **joulemeter** can be used to measure it directly in joules. The circuit connections are shown in Figure 40.8. A household electricity meter (Figure 40.12) is a joulemeter.

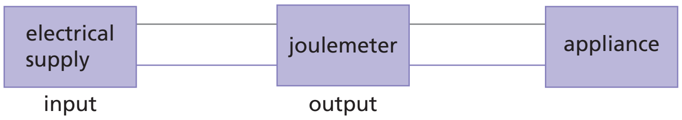


Figure 40.8 Connections to a joulemeter

House circuits

Electricity usually comes to our homes by an underground cable containing two wires, the **live** (L) and the **neutral** (N). The neutral is earthed at the local sub-station and so there is no p.d. between it and earth. The supply is a.c. (Chapter 36) and the live wire is alternately positive and negative. Study the typical house circuits shown in Figure 40.9.

a) Circuits in parallel

Every circuit is connected in parallel with the supply, i.e. across the live and neutral, and receives the full mains p.d. of 230 V (in the UK). The advantages of having appliances connected in parallel, rather than in series, can be seen by studying the lighting circuit in Figure 40.9.

(i) The p.d. across each lamp is fixed (at the mains p.d.), so the lamp shines with the same brightness irrespective of how many other lamps are switched on.

(ii) Each lamp can be turned on and off independently; if one lamp fails, the others can still be operated.

b) Switches and fuses

These are always in the live wire. If they were in the neutral, light switches and power sockets would be 'live' when switches were 'off' or fuses 'blown'. A fatal shock could then be obtained by, for example, touching the element of an electric fire when it was switched off.

c) Staircase circuit

The light is controlled from two places by the two two-way switches.

d) Ring main circuit

The live and neutral wires each run in two complete rings round the house and the power sockets, each rated at 13 A, are tapped off from them. Thinner wires can be used since the current to each socket flows by two paths, i.e. from both directions in the ring. The ring has a 30 A fuse and if it has, say, ten sockets, then all can be used so long as the total current does not exceed 30 A, otherwise the wires overheat. A house may have several ring circuits, each serving a different area.

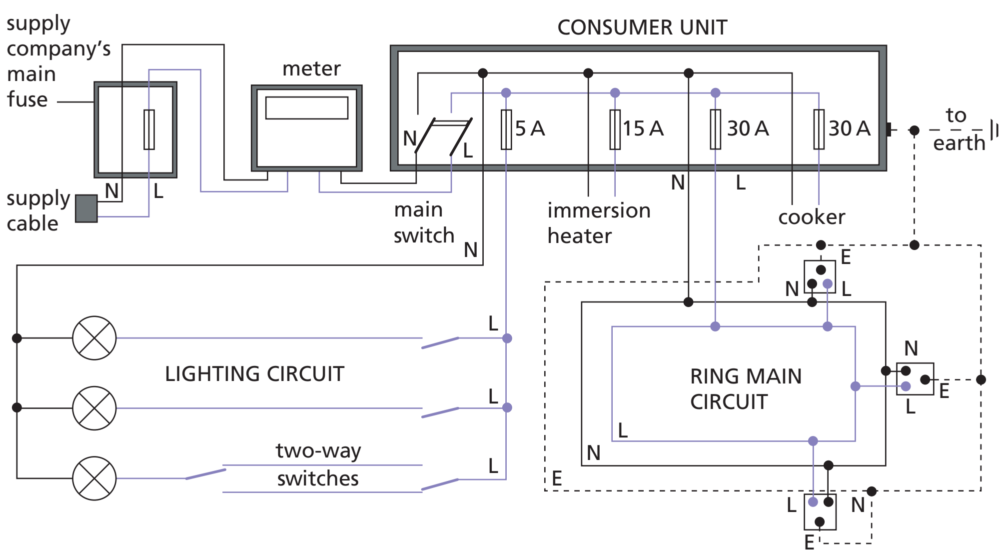


Figure 40.9 Electric circuits in a house

e) Fused plug

Only one type of plug is used in a UK ring main circuit. It is wired as in Figure 40.10a. Note the colours of the wire coverings: L – brown, N – blue, E – green and yellow. It has its own cartridge fuse, 3 A (red) for appliances with powers up to 720 W, or 13 A (brown) for those between 720 W and 3 kW.

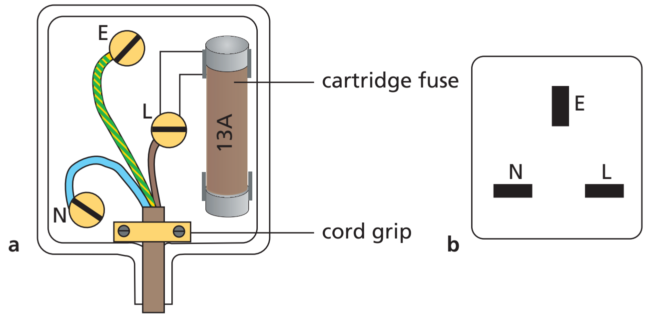


Figure 40.10 a Wiring of a plug; **b** socket

Typical power ratings for various appliances are shown in Table 40.1, p. 182. Calculation of a current in a device allows the correct size of fuse to be chosen.

In some countries the fuse is placed in the appliance rather than in the plug.

f) Safety in electrical circuits

Earthing

A ring main has a third wire which goes to the top sockets on all power points (Figure 40.9) and is earthed by being connected either to a **metal** water pipe entering the house or to an earth connection on the supply cable. This third wire is a safety precaution to prevent electric shock should an appliance develop a fault.

The earth pin on a three-pin plug is connected to the metal case of the appliance which is thus joined to earth by a path of almost zero resistance. If then, for example, the element of an electric fire breaks or sags and touches the case, a large current flows to earth and 'blows' the fuse. Otherwise the case would become 'live' and anyone touching it would receive a shock which might be fatal, especially if they were 'earthed' by, say, standing in a damp environment, such as on a wet concrete floor.

Circuit breakers

Figure 40.11 Circuit breakers

Circuit breakers (Figure 40.11) are now used instead of fuses in consumer units. They contain an electromagnet (Chapter 45) which, when the current exceeds the rated value of the circuit breaker, becomes strong enough to separate a pair of contacts and breaks the circuit. They operate much faster than fuses and have the advantage that they can be reset by pressing a button.

The **residual current circuit breaker** (RCCB), also called a **residual current device** (RCD), is an adapted circuit breaker which is used when the resistance of the earth path between the consumer and the substation is not small enough for a fault-current to blow the fuse or trip the circuit breaker. It works by detecting any difference between the currents in the live and neutral wires; when these become unequal due to an earth fault (i.e. some of the current returns to the substation via the case of the appliance and earth) it breaks the circuit before there is any danger. They have high sensitivity and a quick response.

An RCD should be plugged into a socket supplying power to a portable appliance such as an electric lawnmower or hedge trimmer. In these cases the risk of electrocution is greater because the user is generally making a good earth connection through the feet.

Double insulation

Appliances such as vacuum cleaners, hairdryers and food mixers are usually **double insulated**.

Connection to the supply is by a two-core insulated cable, with no earth wire, and the appliance is enclosed in an insulating plastic case. Any metal attachments that the user might touch are fitted into this case so that they do not make a direct connection with the internal electrical parts, such as a motor. There is then no risk of a shock should a fault develop.

Paying for electricity

Electricity supply companies charge for the **electrical energy** they supply. A joule is a very small amount of energy and a larger unit, the **kilowatt-hour** (kWh), is used.

> A kilowatt-hour is the electrical energy used by a 1 kW appliance in 1 hour.

$$1\,\text{kWh} = 1000\,\text{J/s} \times 3600\,\text{s}$$
$$= 3\,600\,000\,\text{J} = 3.6\,\text{MJ}$$

A 3 kW electric fire working for 2 hours uses 6 kWh of electrical energy – usually called 6 'units'. Electricity meters, which are joulemeters, are marked in kWh: the latest have digital readouts like the one in Figure 40.12. At present a 'unit' costs about 8p in the UK.

Typical powers of some appliances are given in Table 40.1.

Table 40.1 Power of some appliances

DVD player	20 W	iron	1 kW
laptop computer	50 W	fire	1, 2, 3 kW
light bulbs	60, 100 W	kettle	2 kW
television	100 W	immersion heater	3 kW
fridge	150 W	cooker	6.4 kW

Note that the current required by a 6.4 kW cooker is given by

$$I = \frac{P}{V} = \frac{6400\ \text{W}}{230\ \text{V}} = 28\,\text{A}$$

This is too large a current to draw from the ring main and so a separate circuit must be used.

Figure 40.12 Electricity meter with digital display

Dangers of electricity

a) Electric shock

Electric shock occurs if current flows from an electric circuit through a person's body to earth. This can happen if there is **damaged insulation** or **faulty wiring**. The typical resistance of dry skin is about 10 000 Ω, so if a person touches a wire carrying electricity at 240 V, an estimate of the current flowing through them to earth would be $I = V/R = 240/10\,000 = 0.024\,\text{A} = 24\,\text{mA}$. For wet skin, the resistance is lowered to about 1000 Ω (since water is a good conductor of electricity) so the current would increase to around 240 mA.

It is the **size of the current** (not the voltage) and the **length of time** for which it acts which determine the strength of an electric shock. The path the current takes influences the effect of the shock; some parts of the body are more vulnerable than others. A current of 100 mA through the heart is likely to be fatal.

Damp conditions increase the severity of an electric shock because water lowers the resistance of the path to earth; wearing shoes with insulating rubber soles or standing on a dry insulating floor increases the resistance between a person and earth and will reduce the severity of an electric shock.

To avoid the risk of getting an electric shock:

- Switch off the electrical supply to an appliance before starting repairs.
- Use plugs that have an earth pin and a cord grip; a rubber or plastic case is preferred.
- Do not allow appliances or cables to come into contact with water. For example holding a hairdryer with wet hands in a bathroom can be dangerous. Keep electrical appliances well away from baths and swimming pools!
- Do not have long cables trailing across a room, under a carpet that is walked over regularly or in other situations where the insulation can become damaged. Take particular care when using electrical cutting devices (such as hedge cutters) not to cut the supply cable.

In case of an electric shock, take the following action:

1 **Switch off the supply** if the shocked person is still touching the equipment.
2 **Send for qualified medical assistance.**
3 **If breathing or heartbeat has stopped, commence CPR** (cardiopulmonary resuscitation) by applying chest compressions at the rate of about 100 a minute until there are signs of chest movement or medical assistance arrives.

b) Fire risks

If flammable material is placed too close to a hot appliance such as an electric heater, it may catch fire. Similarly if the electrical wiring in the walls of a house becomes overheated, a fire may start. Wires become hot when they carry electrical currents – the larger the current carried, the hotter a particular wire will become, since the rate of production of heat equals I^2R (see p. 177).

To reduce the risk of fire through **overheated cables**, the maximum current in a circuit should be limited by taking these precautions:

- Use plugs that have the correct fuse.
- Do not attach too many appliances to a circuit.
- Don't overload circuits by using too many adapters.
- Appliances such as heaters use large amounts of power (and hence current), so do not connect them to a lighting circuit designed for low current use. (Thick wires have a lower resistance than thin wires so are used in circuits expected to carry high currents.)

Damaged insulation or faulty wiring which leads to a large current flowing to earth through flammable material can also start a fire.

The factors leading to fire or electric shock can be summarised as follows:

damaged insulation	→ electric shock and fire risk
overheated cables	→ fire risk
damp conditions	→ increased severity of electric shocks

Questions

1 How much electrical energy in joules does a 100 watt lamp transfer in
  a 1 second,
  b 5 seconds,
  c 1 minute?

2 **a** What is the power of a lamp rated at 12 V 2 A?
  b How many joules of electrical energy are transferred per second by a 6 V 0.5 A lamp?

3 The largest number of 100 W lamps connected in parallel which can safely be run from a 230 V supply with a 5 A fuse is
  A 2 **B** 5 **C** 11 **D** 12 **E** 0

4 What is the maximum power in kilowatts of the appliance(s) that can be connected safely to a 13 A 230 V mains socket?

5 The circuits of Figures 40.13a and b show 'short circuits' between the live (L) and neutral (N) wires. In both, the fuse has blown but whereas circuit a is now safe, b is still dangerous even though the lamp is out which suggests the circuit is safe. Explain.

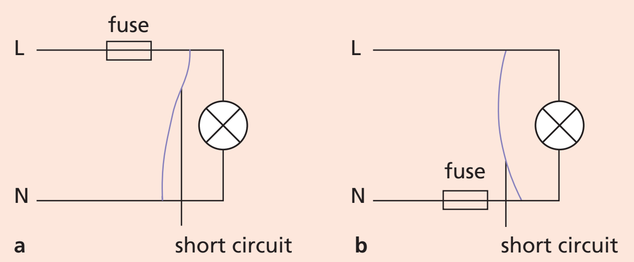


Figure 40.13

6 What steps should be taken before replacing a blown fuse in a plug?

7 What size fuse (3 A or 13 A) should be used in a plug connected to
  a a 150 W television,
  b a 900 W iron,
  c a 2 kW kettle,
  if the supply is 230 V?

8 What is the cost of heating a tank of water with a 3000 W immersion heater for 80 minutes if electricity costs 10p per kWh?

9 a Below is a list of wattages of various appliances. State which is most likely to be the correct one for each of the appliances named.

60 W 250 W 850 W 2 kW 3.5 kW

(i) kettle
(ii) table lamp
(iii) iron

b What will be the current in a 920 W appliance if the supply voltage is 230 V?

Checklist

After studying this chapter you should be able to

- recall the relations $E = ItV$ and $P = IV$ and use them to solve simple problems on energy transfers,
- describe experiments to measure electric power,
- describe electric lamps, heating elements and fuses,
- recall that a joulemeter measures electrical energy,
- describe with the aid of diagrams a house wiring system and explain the functions and positions of switches, fuses, circuit breakers and earth,
- state the advantages of connecting lamps in parallel in a lighting circuit,
- wire a mains plug and recall the international insulation colour code,
- perform calculations of the cost of electrical energy in joules and kilowatt-hours,
- recall the hazards of damaged insulation, damp conditions and overheating of cables and the associated risks.

41 Electronic systems

- Electronic systems
- Input transducers
- Output transducers
- Semiconductor diode
- Transistor
- Transistor as a switch
- Practical work: Transistor switching circuits: light-operated, temperature-operated.

The use of electronics in our homes, factories, offices, schools, banks, shops and hospitals is growing all the time. The development of semiconductor devices such as transistors and integrated circuits ('chips') has given us, among other things, automatic banking machines, laptop computers, programmable control devices, robots, computer games, digital cameras (Figure 41.1a) and heart pacemakers (Figure 41.1b).

Figure 41.1a Digital camera

Figure 41.1b Heart pacemaker

Electronic systems

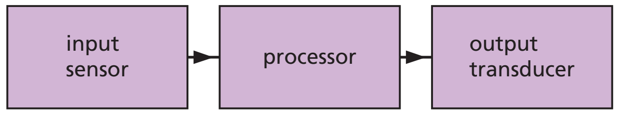


Figure 41.2 Electronic system

Any electronic system can be considered to consist of the three parts shown in the block diagram of Figure 41.2, i.e.

(i) an **input sensor** or **input transducer**,
(ii) a **processor** and
(iii) an **output transducer**.

A 'transducer' is a device for converting a non-electrical input into an electrical signal or vice versa.

The **input sensor** detects changes in the environment and converts them from their present form of energy into electrical energy. Input sensors or transducers include LDRs (light-dependent resistors), thermistors, microphones and switches that respond, for instance, to pressure changes.

The **processor** decides on what action to take on the electrical signal it receives from the input sensor. It may involve an operation such as counting, amplifying, timing or storing.

The **output transducer** converts the electrical energy supplied by the processor into another form. Output transducers include lamps, LEDs (light-emitting diodes), loudspeakers, motors, heaters, relays and cathode ray tubes.

In a radio, the input sensor is the aerial that sends an electrical signal to processors in the radio. These processors, among other things, amplify the signal so that it can enable the output transducer, in this case a loudspeaker, to produce sound.

Input transducers

a) Light-dependent resistor (LDR)

The action of an LDR depends on the fact that the resistance of the semiconductor cadmium sulfide decreases as the intensity of the light falling on it increases.

An LDR and a circuit showing its action are shown in Figures 41.3a and b. Note the circuit symbol for an LDR, sometimes seen without a circle. When light from a lamp falls on the 'window' of the LDR, its resistance decreases and the increased current lights the lamp.

LDRs are used in photographic exposure meters and in series with a resistor to provide an input signal for a transistor (Figure 41.16, p. 190) or other switching circuit.

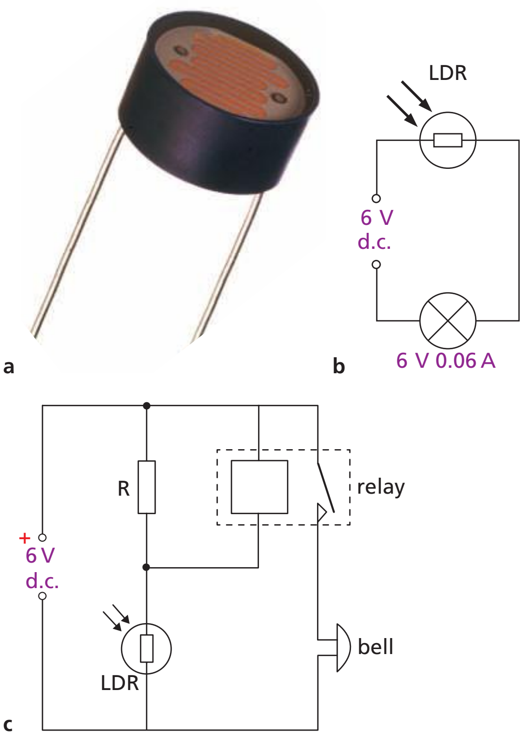


Figure 41.3 a LDR; **b** LDR demonstration circuit; **c** light-operated intruder alarm

Figure 41.3c shows how an LDR can be used to switch a 'relay' (Chapter 45.) The LDR forms part of a potential divider across the 6 V supply. When light falls on the LDR, the resistance of the LDR, and hence the voltage across it, decreases. There is a corresponding increase in the voltage across resistor R and the relay; when the voltage across the relay coil reaches a high enough p.d. (its operating p.d.) it acts as a switch and the normally open contacts close, allowing current to flow to the bell, which rings. If the light is removed, the p.d. across resistor R and the relay drops below the operating p.d. of the relay so that the relay contacts open again; power to the bell is cut and it stops ringing.

b) Thermistor

A thermistor contains semiconducting metallic oxides whose resistance decreases markedly when the temperature rises. The temperature may rise either because the thermistor is directly heated or because a current is in it.

Figure 41.4a shows one type of thermistor. Figure 41.4b shows the symbol for a thermistor in a circuit to demonstrate how the thermistor works. When the thermistor is heated with a match, the lamp lights.

A thermistor in series with a meter marked in °C can measure temperatures (Chapter 38). Used in series with a resistor it can provide an input signal to a transistor (Figure 41.18, p. 191) or other switching circuit.

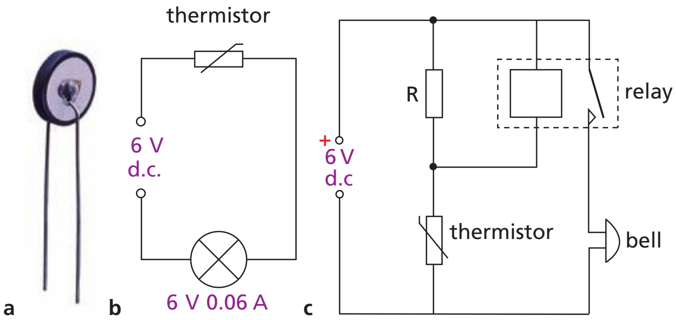


Figure 41.4 a Thermistor; **b** thermistor demonstration circuit; **c** high-temperature alarm

Figure 41.4c shows how a thermistor can be used to switch a relay. The thermistor forms part of a potential divider across the d.c. source. When the temperature rises, the resistance of the thermistor falls, and so does the p.d. across it. The voltage across resistor R and the relay increases. When the voltage across the relay reaches its operating p.d. the normally open contacts close, so that the circuit to the bell is completed and it rings. If a variable resistor is used in the circuit, the temperature at which the alarm sounds can be varied.

Output transducers

a) Relays

A switching circuit cannot supply much power to an appliance so a relay is often included; this allows the small current provided by the switching circuit to control the larger current needed to operate a buzzer as in a temperature-operated switch (Figure 41.18, p. 191) or other device. Relays controlled by a switching circuit can also be used to switch on the mains supply for electrical appliances in the home. In Figure 41.5 if the output of the switching circuit is 'high' (5 V), a small current flows to the relay which closes the mains switch; the relay also isolates the low voltage circuit from the high voltage mains supply.

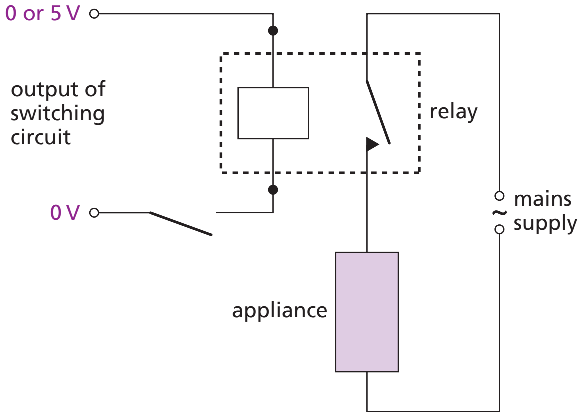


Figure 41.5 Use of a relay to switch mains supply

b) Light-emitting diode (LED)

An LED, shown in Figure 41.6a, is a diode made from the semiconductor gallium arsenide phosphide. When forward biased (with the cathode C connected to the negative terminal of the voltage supply, as shown in Figure 41.6b), the current in it makes it emit red, yellow or green light. No light is emitted on reverse bias (when the anode A is connected to the negative terminal of the voltage supply). If the reverse bias voltage exceeds 5 V, it may cause damage.

In use an LED must have a suitable resistor R in series with it (e.g. 300 Ω on a 5 V supply) to limit the current (typically 10 mA). Figure 41.6b shows the symbol for an LED (again the use of the circle is optional) in a demonstration circuit.

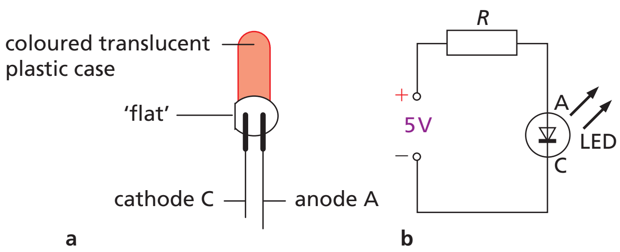


Figure 41.6 LED and demonstration circuit

LEDs are used as indicator lamps on computers, radios and other electronic equipment. Many clocks, calculators, video recorders and measuring instruments have seven-segment red or green numerical displays (Figure 41.7a). Each segment is an LED and, depending on which have a voltage across them, the display lights up the numbers 0 to 9, as in Figure 41.7b.

LEDs are small, reliable and have a long life; their operating speed is high and their current requirements are very low.

Diode lasers operate in a similar way to LEDs but emit coherent laser light; they are used in optical fibre communications as transmitters.

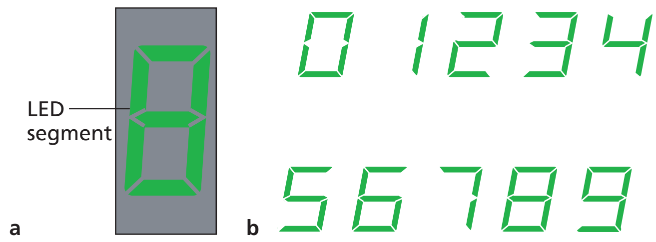


Figure 41.7 LED numerical display

Semiconductor diode

A diode is a device that lets current pass in one direction only. One is shown in Figure 41.8 with its symbol. (You will also come across the symbol without its outer circle.) The wire nearest the band is the **cathode** and the one at the other end is the **anode**.

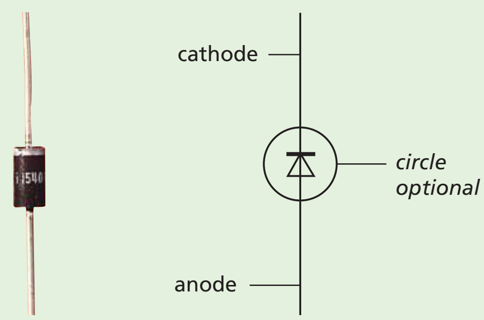


Figure 41.8 A diode and its symbol

The typical *I–V* graph is shown in Figure 38.7b (p. 169). The diode conducts when the anode goes to the + terminal of the voltage supply and the cathode to the – terminal (Figure 41.9a). It is then **forward-biased**; its resistance is small and conventional current passes in the direction of the arrow on its symbol. If the connections are the other way round, it does not conduct; its resistance is large and it is **reverse-biased** (Figure 41.9b).

The lamp in the circuit shows when the diode is conducting, as the lamp lights up. It also acts as a resistor to limit the current when the diode is forward-biased. Otherwise the diode might overheat and be damaged.

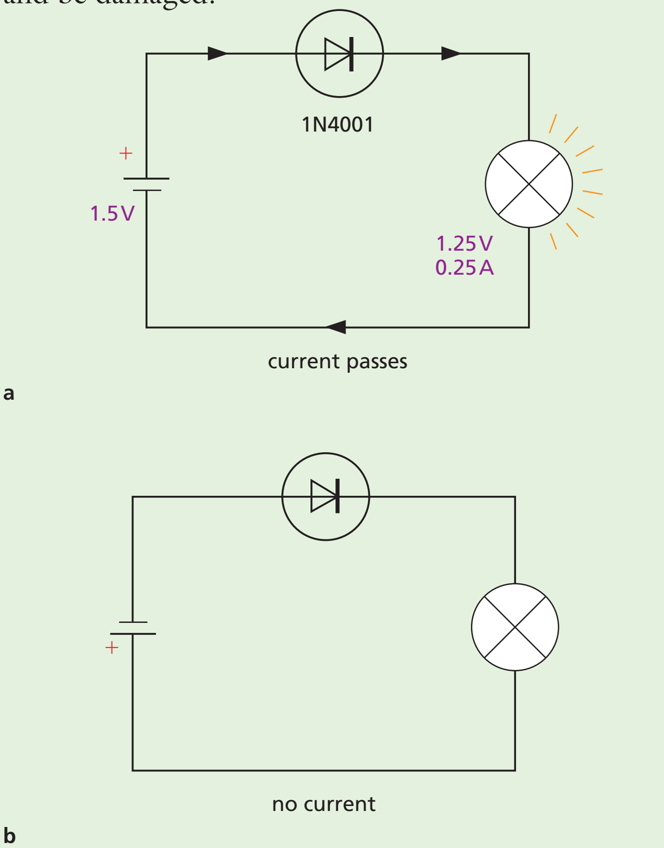


Figure 41.9 Demonstrating the action of a diode

A diode is a **non-ohmic** conductor. It is useful as a **rectifier** for changing alternating current (a.c.) to direct current (d.c.). Figure 41.10 shows the rectified output voltage obtained from a diode when it is connected to an a.c. supply.

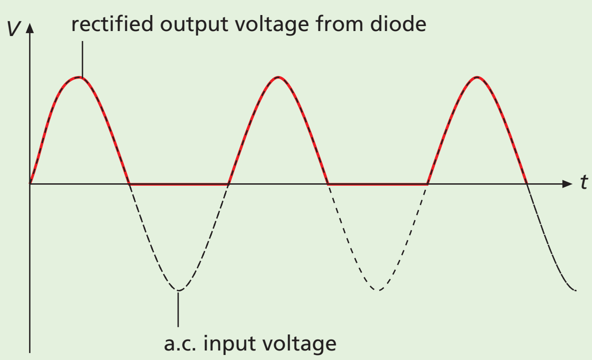


Figure 41.10 Rectification by a diode

Transistor

Transistors are the small semiconductor devices which have revolutionised electronics. They are made both as separate components in their cases, like those in Figure 41.11a, and also as parts of **integrated circuits** (ICs) in which millions may be 'etched' on a 'chip' of silicon (Figure 41.11b).

Transistors have three connections called the **base** (B), the **collector** (C) and the **emitter** (E). In the transistor symbol shown in Figure 41.12, the arrow indicates the direction in which conventional current flows in it when C and B are connected to a battery + terminal, and E to a battery – terminal. Again, the outer circle of the symbol is not always included.

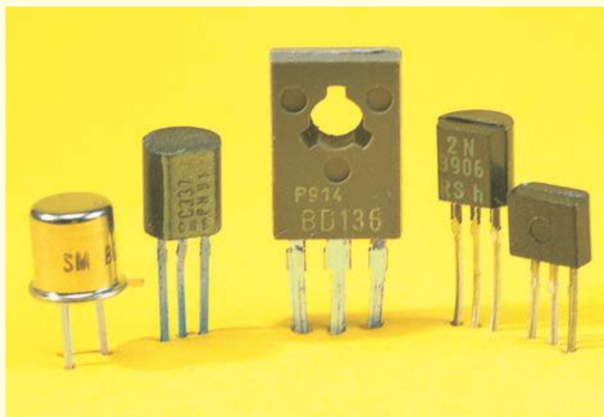


Figure 41.11a Transistor components

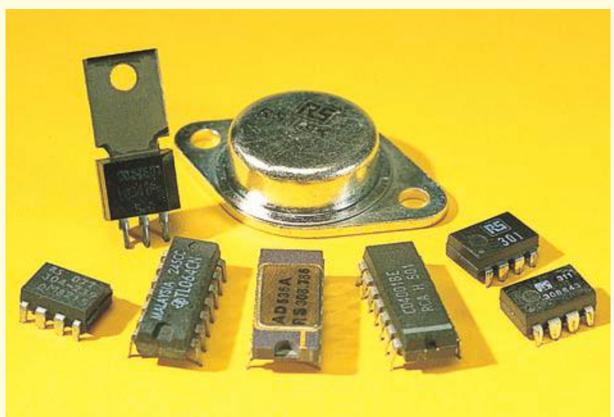


Figure 41.11b Integrated circuits which may each contain millions of transistors

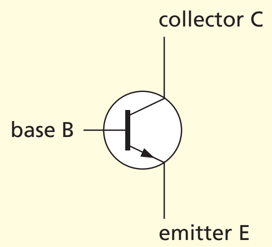


Figure 41.12 Symbol for a transistor

There are two current paths through a transistor. One is the **base–emitter path** and the other is the **collector–emitter** (via base) **path**. The transistor's usefulness arises from the fact that it can link circuits connected to each path so that the current in one controls that in the other, just like a relay.

Its action can be shown using the circuit of Figure 41.13. When **S is open**, the base current I_B is zero and neither L_1 nor L_2 lights up, showing that the collector current I_C is also zero even though the battery is correctly connected across the C–E path.

When **S is closed**, B is connected through R to the battery + terminal and L_2 lights up but not L_1. This shows there is now collector current (which is in L_2) and that it is much greater than the base current (which is in L_1 but is too small to light it).

Therefore, **in a transistor the base current I_B switches on and controls the much greater collector current I_C.**

Resistor R has to be in the circuit to limit the base current which would otherwise create so large a collector current as to destroy the transistor by overheating.

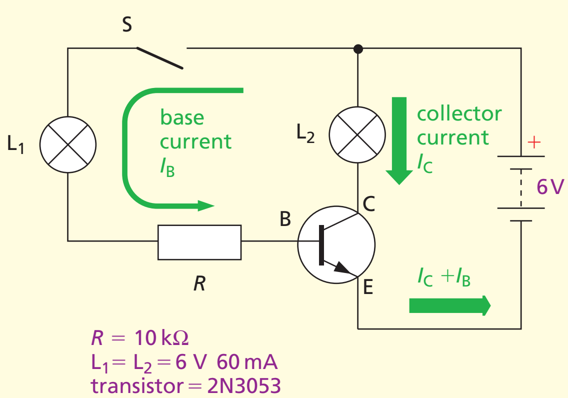


Figure 41.13 Demonstration circuit

Transistor as a switch

a) Advantages

Transistors have many advantages over other electrically operated switches such as relays. They are small, cheap, reliable, have no moving parts, their life is almost indefinite (in well-designed circuits) and they can switch on and off millions of times a second.

b) 'On' and 'off' states

A transistor is considered to be 'off' when the collector current is zero or very small. It is 'on' when the collector current is much larger. The resistance of the collector–emitter path is large when the transistor is 'off' (as it is for an ordinary mechanical switch) and small (ideally it should be zero) when it is 'on'.

To switch a transistor 'on' requires the base voltage (and therefore the base current) to exceed a certain minimum value (about +0.6 V base voltage).

c) Basic switching circuits

Two are shown in Figures 41.14a, b. The 'on' state is shown by the lamp in the collector circuit becoming fully lit.

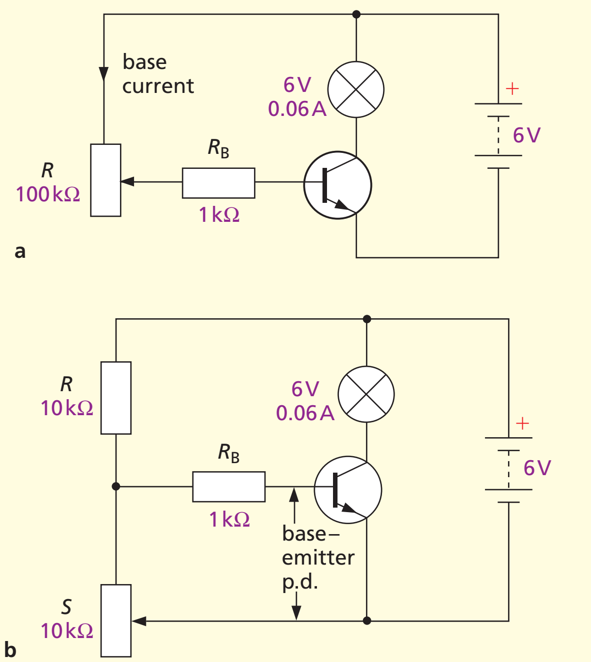


Figure 41.14 Transistor switching circuits

Rheostat control is used in the circuit in Figure 41.14a. 'Switch-on' occurs by reducing R until the base current is large enough to make the collector current light the lamp. (The base resistor R_B is *essential* in case R is made zero and results in +6 V from the battery being applied directly to the base. This would produce very large base and collector currents and destroy the transistor by overheating.)

Potential divider control is used in the circuit in Figure 41.14b. Here 'switch-on' is obtained by adjusting the variable resistance S until the p.d. across S (which is the base–emitter p.d. and depends on the value of S compared with that of R) exceeds +0.6 V or so.

Note In a potential divider the p.d.s across the resistors are in the ratio of their resistances (see Chapter 38). For example, in the circuit shown in Figure 41.14b, the p.d. across R and S in series is 6 V. If $R = 10\,\text{k}\Omega$ and S is set to $5\,\text{k}\Omega$, then the p.d. across R, that is V_R, is 4 V and the p.d. across S, that is V_S, is 2 V. So $V_R/V_S = 4\,\text{V}/2\,\text{V} = 2/1$.

In general

$$\frac{V_R}{V_S} = \frac{R}{S} \quad \text{and} \quad V_S = (V_R + V_S) \times \frac{S}{(R+S)}$$

Also see question 2 on p. 191.

Practical work

Transistor switching circuits

The components can be mounted on a circuit board, for example an 'S-DeC' as in Figure 41.15a. The diagrams in Figure 41.15b show how to lengthen transistor leads and also how to make connections (without soldering) to parts that have 'tags', for example, variable resistors.

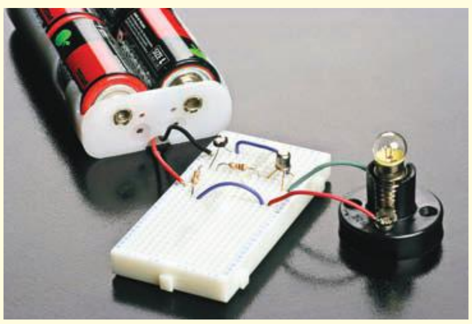


Figure 41.15a Partly built transistor switching circuit

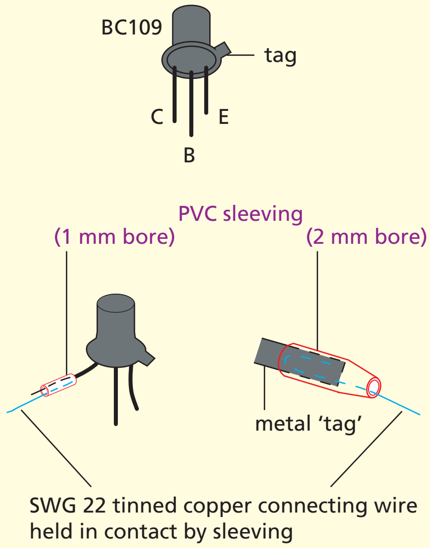


Figure 41.15b Lengthening transistor leads and making connections to tags

In many control circuits, devices such as LDRs and thermistors are used in potential divider arrangements to detect small changes of light intensity and temperature, respectively. These changes then enable a transistor to act as a simple processor by controlling the current to an output transducer, such as a lamp or a buzzer.

a) Light-operated switch

In the circuit of Figure 41.16 the LDR is part of a potential divider. The lamp comes on when the LDR is shielded: more of the battery p.d. acts across the increased resistance of the LDR (i.e. more than 0.6 V) and less across R. In the dark, the base–emitter p.d. increases as does the base current and so also the collector current.

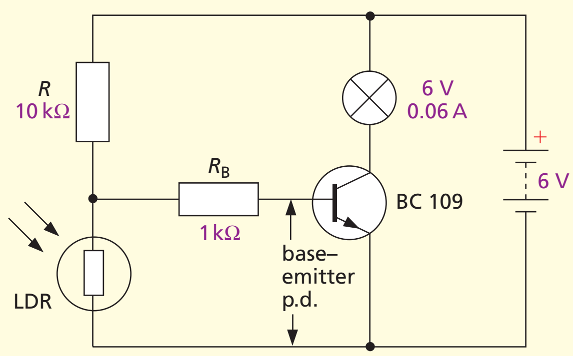


Figure 41.16 Light-operated switch

If the LDR and R are interchanged the lamp goes off in the dark and the circuit could act as a light-operated intruder alarm.

If a variable resistor is used for R, the light level at which switching occurs can be changed.

b) Temperature-operated switch

In the low-temperature-operated switch of Figure 41.17, a thermistor and resistor form a potential divider across the

6 V supply. When the temperature of the thermistor falls, its resistance increases and so does the p.d. across it, i.e. the base-emitter p.d. rises. When it reaches 0.6 V, the transistor switches on and the collector current becomes large enough to operate the lamp. The circuit could act as a frost-warning device.

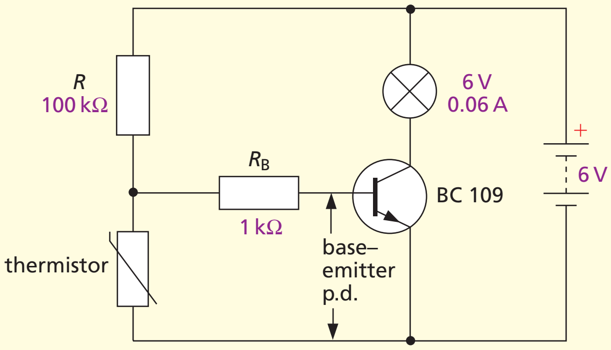


Figure 41.17 Low-temperature-operated switch

If the thermistor and resistor are interchanged, the circuit can be used as a high-temperature alarm (Figure 41.18).

When the temperature of the thermistor rises, its resistance decreases and a larger share of the 6 V supply acts across R, i.e. the base–emitter p.d. increases. When it exceeds 0.6 V or so the transistor switches on and collector current (too small to ring the buzzer directly) goes through the relay coil. The relay contacts close, enabling the buzzer to obtain, directly from the 6 V supply, the larger current it needs.

The diode D protects the transistor from damage: when the collector current falls to zero at switch off this induces a large p.d. in the relay coil (see Chapter 43). The diode is forward-biased by the induced p.d. (which tries to maintain the current in the relay coil) and, because of its low forward resistance (e.g. 1 Ω), offers an easy path for the current produced. To the 6 V supply the diode is reverse-biased and its high resistance does not short-circuit the relay coil when the transistor is on.

If R is variable the temperature at which switching occurs can be changed.

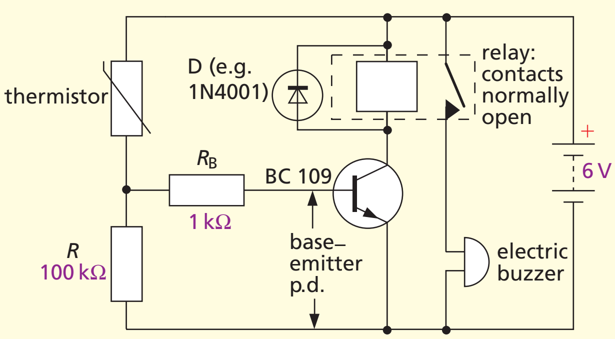


Figure 41.18 High-temperature-operated switch

Questions

1 Figure 41.19a shows a lamp, a semiconductor diode and a cell connected in series. The lamp lights when the diode is connected in this direction. Say what happens to each of the lamps in b, c and d. Give reasons for your answers.

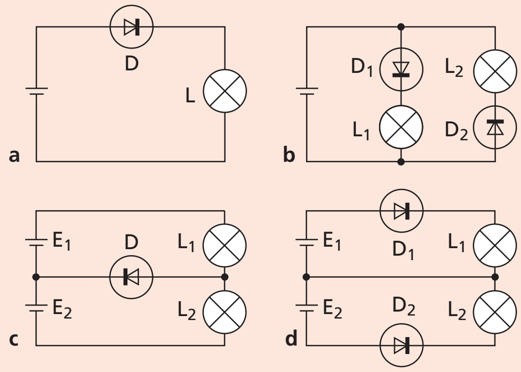


Figure 41.19

2 What are the readings V_1 and V_2 on the high-resistance voltmeters in the potential divider circuit of Figure 41.20 if

a $R_1 = R_2 = 10\,\text{k}\Omega$,

b $R_1 = 10\,\text{k}\Omega$, $R_2 = 50\,\text{k}\Omega$,

c $R_1 = 20\,\text{k}\Omega$, $R_2 = 10\,\text{k}\Omega$?

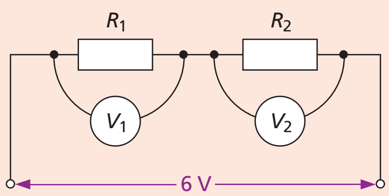


Figure 41.20

3 A simple moisture-warning circuit is shown in Figure 41.21, in which the moisture detector consists of two closely spaced copper rods.

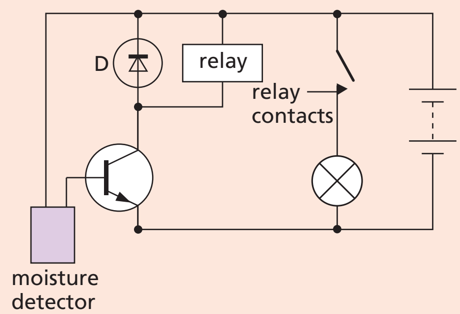


Figure 41.21

▶▶

a Describe how the circuit works when the detector gets wet.
b Warning lamps are often placed in the collector circuit of a transistor. Why is a relay used here?
c What is the function of D?

Checklist

After studying this chapter you should be able to

- recall the functions of the input sensor, processor and output transducer in an electronic system and give some examples,
- describe the action of an LDR and a thermistor and show an understanding of their use as input transducers,
- understand the use of a relay in a switching circuit,
- explain what is meant by a diode being forward biased and reverse biased and recall that a diode can produce rectified a.c.

42 Digital electronics

- Analogue and digital electronics
- Logic gates
- Logic gate control systems
- Problems to solve
- Electronics and society

Analogue and digital electronics

There are two main types of electronic circuits, devices or systems – analogue and digital.

In **analogue circuits**, voltages (and currents) can have any value within a certain range over which they can be varied smoothly and continuously, as shown in Figure 42.1a. They include amplifier-type circuits.

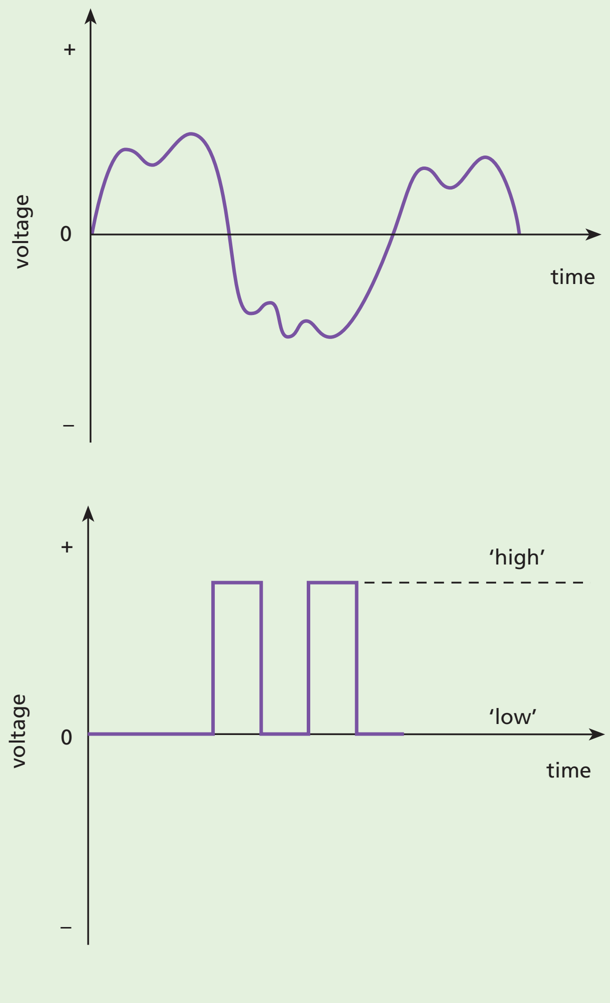


Figure 42.1

In **digital circuits**, voltages have only one of two values, either 'high' (e.g. 5 V) or 'low' (e.g. near 0 V), as shown in Figure 42.1b. They include switching-type circuits such as those we have considered in Chapter 41.

A **variable resistor** is an analogue device which, in a circuit with a lamp, allows the lamp to have a wide range of light levels. A **switch** is a digital device which allows a lamp to be either 'on' or 'off'.

Analogue meters display their readings by the deflection of a pointer over a continuous scale (see Figure 47.4a, p. 220). **Digital meters** display their readings as digits, i.e. numbers, which change by one digit at a time (see Figure 47.4b, p. 220).

Logic gates

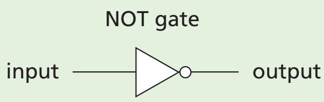
Logic gates are switching circuits used in computers and other electronic systems. They 'open' and give a 'high' output voltage, i.e. a signal (e.g. 5 V), depending on the combination of voltages at their inputs, of which there is usually more than one.

There are five basic types, all made from transistors in integrated circuit form. The behaviour of each is described by a **truth table** showing what the output is for all possible inputs. 'High' (e.g. 5 V) and 'low' (e.g. near 0 V) outputs and inputs are represented by 1 and 0, respectively, and are referred to as **logic levels** 1 and 0.

a) NOT gate or inverter

This is the simplest gate, with one input and one output. It produces a 'high' output if the input is 'low', i.e. the output is then NOT high, and vice versa. Whatever the input, the gate inverts it. The symbol and truth table are given in Figure 42.2.

▶▶



Input	Output
0	1
1	0

Figure 42.2 NOT gate symbol and truth table

b) OR, NOR, AND, NAND gates

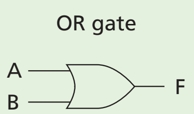
All these have two or more inputs and one output. The truth tables and symbols for 2-input gates are shown in Figure 42.3. Try to remember the following.

OR: output is 1 if input A **OR** input B **OR** both are 1

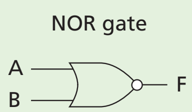
NOR: output is 1 if neither input A **NOR** input B is 1

AND: output is 1 if input A **AND** input B are 1

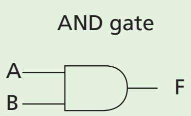
NAND: output is 1 if input A **AND** input B are **NOT** both 1



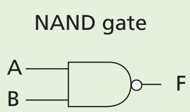
A	B	F
0	0	0
0	1	1
1	0	1
1	1	1



A	B	F
0	0	1
0	1	0
1	0	0
1	1	0



A	B	F
0	0	0
0	1	0
1	0	0
1	1	1



A	B	F
0	0	1
0	1	1
1	0	1
1	1	0

Figure 42.3 Symbols and truth tables for 2-input gates

Note from the truth tables that the outputs of the NOR and NAND gates are the inverted outputs of the OR and AND gates, respectively. They have a small circle at the output end of their symbols to show this inversion.

c) Testing logic gates

The truth tables for the various gates can be conveniently checked by having the logic gate integrated circuit (IC) mounted on a small board with sockets for the power supply, inputs A and B and output F (Figure 42.4). A 'high' input (i.e. logic level 1) is obtained by connecting the input socket to the positive of the power supply, e.g. +5 V and a 'low' input (i.e. logic level 0) by connecting to 0 V.

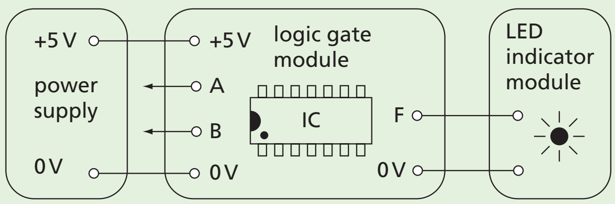


Figure 42.4 Modules for testing logic gates

The output can be detected using an indicator module containing an LED that lights up for a 1 and stays off for a 0.

Logic gate control systems

Logic gates can be used as processors in electronic control systems. Many of these can be demonstrated by connecting together commercial modules like those in Figure 42.8b

a) Security system

A simple system that might be used by a jeweller to protect an expensive clock is shown in the block diagram for Figure 42.5. The clock sits on a push switch which sends a 1 to the NOT gate, unless the clock is lifted when a 0 is sent. In that case the output from the NOT gate is a 1 which rings the bell.

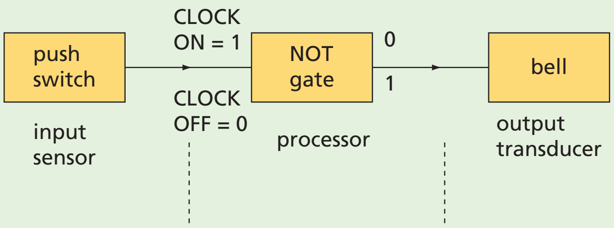


Figure 42.5 Simple alarm system

b) Safety system for a machine operator

A safety system could prevent a machine (e.g. an electric motor) from being switched on before another switch had been operated, for example, by a protective safety guard being in the correct position. In Figure 42.6, when switches A *and* B are on, they supply a 1 to each input of the AND gate which can then start the motor.

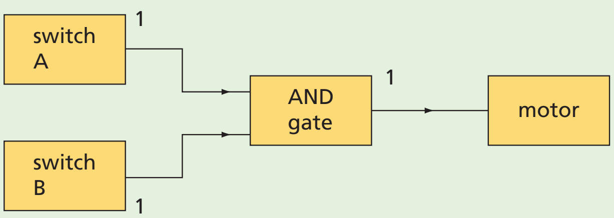


Figure 42.6 Safety system for controlling a motor

c) Heater control system

The heater control has to switch on the heating system when it is

(i) **cold**, i.e. the temperature is below a certain value and the output from the temperature sensor is 0, and

(ii) **daylight**, i.e. the light sensor output is 1.

With these outputs from the sensors applied to the processor in Figure 42.7, the AND gate has two 1 inputs. The output from the AND gate is then 1 and will turn on the heater control. Any other combination of sensor outputs produces a 0 output from the AND gate, as you can check.

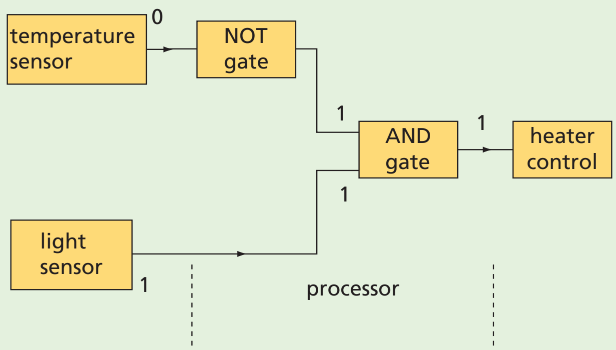


Figure 42.7 Heater control system

d) Street lights

A system is required that allows the street lights either to be turned on manually by a switch at any time, or automatically by a light sensor when it is dark. The arrangement in Figure 42.8a achieves this since the OR gate gives a 1 output when either or both of its inputs are 1.

The system can be demonstrated using the module shown in Figure 42.8b.

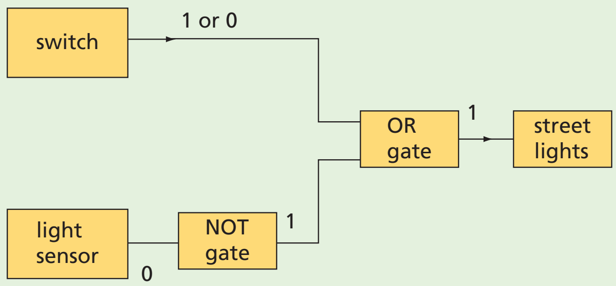


Figure 42.8a Control system with manual override

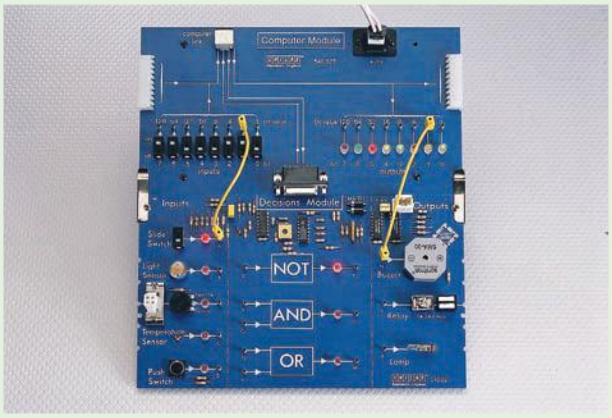


Figure 42.8b Module for demonstrating street lights

▶▶

Problems to solve

Design and draw block diagrams for logic control systems to indicate how the following jobs could be done. If possible build them using modules.

1 Allow a doorbell to work only during the **day**.

2 Give warning when the temperature of a domestic hot water system is too **high** or when a switch is pressed to **test** the alarm.

3 Switch on a bathroom heater when it is **cold** and **light**.

4 Sound an alarm when it is **cold** or a switch is **pressed**.

5 Give warning if the temperature of a room **falls** during the **day** and also allow a **test** switch to check the alarm works.

6 Give warning of **frosty** conditions at **night** to a gardener who is sometimes very tired after a hard day and may want to switch off the alarm.

Electronics and society

Electronics is having an ever-increasing impact on all our lives. Work and leisure are changing as a result of the social, economic and environmental influences of new technology.

a) Reasons for the impact

Why is electronics having such a great impact? Some of the reasons are listed below.

(i) **Mass production** of large quantities of semiconductor devices (e.g. ICs) allows them to be made very cheaply.

(ii) **Miniaturisation** of components means that even complex systems can be compact.

(iii) **Reliability** of electronic components is a feature of well-designed circuits. There are no moving parts to wear out and systems can be robust.

(iv) **Energy consumption** and use of natural resources is often much less than for their non-electronic counterparts. For example, the transistor uses less power than a relay.

(v) **Speed of operation** can be millions of times greater than for other alternatives (e.g. mechanical devices).

(vi) **Transducers** of many different types are available for transferring information in and out of an electronic system.

To sum up, electronic systems tend to be cheaper, smaller, more reliable, less wasteful, much faster and can respond to a wider range of signals than other systems.

b) Some areas of impact

At home devices such as washing machines, burglar alarms, telephones, cookers and sewing machines contain electronic components. Central heating systems and garage doors may have automatic electronic control. For home entertainment, DVD players, interactive digital televisions or computers with internet connections and electronic games are finding their way into more and more homes.

Medical services have benefited greatly in recent years from the use of electronic instruments and appliances. Electrocardiograph (ECG) recorders for monitoring the heart, ultrasonic scanners for checks during pregnancy, gamma ray scanners for detecting tumours, hearing aids, heart pacemakers, artificial kidneys, limbs and hands with electronic control (Figure 42.9), and 'keyhole' surgery are some examples.

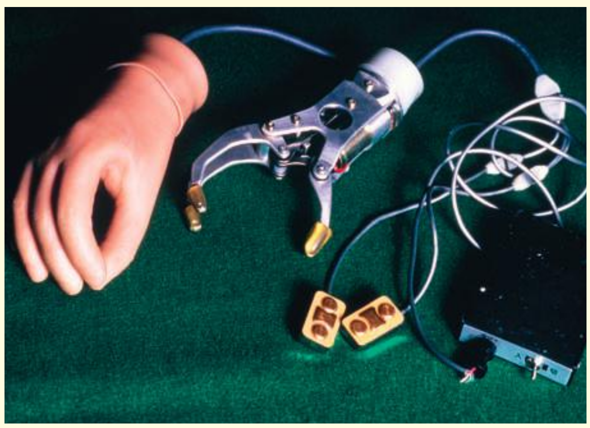


Figure 42.9 Electronically controlled artificial hands

In industry microprocessor-controlled equipment is taking over. Robots are widely used for car assembly work, and to do dull, routine, dirty jobs such as welding and paint spraying. In many cases production lines and even whole factories, such as sugar refineries and oil refineries, are almost entirely automated. Computer-aided design (CAD) of products is increasing (Figure 42.10), even in the clothing industry. Three-dimensional printers programmed by CAD files can now produce solid objects in a variety of materials for use as prototypes or components in industries ranging from aerospace to entertainment.

In offices, banks and shops computers are used for word processing, data control and communications via **email**: text, numbers and pictures are transmitted by electronic means, often by high-speed digital links. Cash dispensers and other automated services at banks are a great convenience for their customers. Bar codes (like the one on the back cover of this book) on packaged products are used by shops for stock control in conjunction with a bar code reader (which uses a laser) and a data recorder connected to a computer. A similar system is operated by libraries to record the issue and return of books. Libraries provide electronic databases and internet facilities for research.

Figure 42.10 Computer-aided design of clothing

Communications have been transformed. Satellites enable events on one side of the world to be seen and heard on the other side, as they happen. Digital telephone and communication links, smart phones, tablets, social media and cloud computing are the order of the day.

Leisure activities have been affected by electronic developments. For some people, leisure means participating in or attending sporting activities and here the electronic scoreboard is likely to be in evidence. For the golf enthusiast, electronic machines claim to analyse 'swings' and reduce handicaps. For others, leisure means listening to music, whose production, recording and listening facilities have been transformed by the digital revolution. Electronically synthesised music has become the norm for popular recordings. The lighting and sound effects in stage shows are programmed by computer. For the cinemagoer, special effects in film production have been vastly improved by computer-generated animated images (Figure 42.11). The availability of home computers and games consoles in recent years has enabled a huge market in computer games and home-learning resources to develop.

Figure 42.11 Computer animation brings the tiger into the scene

c) Consequences of the impact

Most of the social and economic consequences of electronics are beneficial but a few cause problems.

An **improved quality of life** has resulted from the greater convenience and reliability of electronic systems, with increased life expectancy and leisure time, and fewer dull, repetitive jobs.

Better communication has made the world a smaller place. The speed with which news can be reported to our homes by radio, television and the internet enables the public to be better informed.

Databases have been developed. These are memories which can store huge amounts of information for rapid transmission from one place to another. For example, the police can obtain in seconds, by radio, details of a car they are following. Databases raise questions, however, about invasion of privacy and security.

Employment is affected by the demand for new equipment – new industry and jobs are created to make and maintain it – but when electronic systems replace mechanical ones, redundancy and/or retraining needs arise. Conditions of employment and long-term job prospects can also be affected for many people, especially certain manual and clerical workers. One industrial robot may replace four factory workers.

The public attitude to the electronics revolution is not always positive. Modern electronics is a 'hidden' technology with parts that are enclosed in a tiny package (or 'black box') and do not move. It is also a 'throwaway' technology in which the whole lot is discarded and replaced – by an expert – if a part fails, and rapid advances in design technology cause equipment to quickly become obsolete. For these reasons it may be regarded as mysterious and unfriendly – people feel they do not understand what makes it tick.

d) The future

The only certain prediction about the future is that new technologies will be developed and these, like present ones, will continue to have a considerable influence on our lives.

Today the development of 'intelligent' computers is being pursued with great vigour, and voice recognition techniques are already in use. Optical systems, which are more efficient than electronic ones, are being increasingly developed for data transmission, storage and processing of information.

Questions

1 The combined truth tables for four logic gates **A**, **B**, **C**, **D** are given below. State what kind of gate each one is.

Inputs		Outputs			
		A	B	C	D
0	0	0	0	1	1
0	1	0	1	1	0
1	0	0	1	1	0
1	1	1	1	0	0

2 What do the symbols **A** to **E** represent in Figure 42.12?

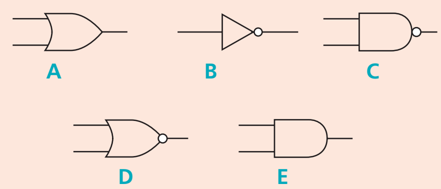


Figure 42.12

3 Design and draw the block diagrams for logic control systems to:
- **a** wake you at the crack of dawn and which you can also switch off,
- **b** protect the contents of a drawer which you can still open without setting off the alarm.

Checklist

After studying this chapter you should be able to

- explain and use the terms analogue and digital,
- state that logic gates are switching circuits containing transistors and other components,
- describe the action of NOT, OR, NOR, AND and NAND logic gates and recall their truth tables,
- design and draw block diagrams of logic control systems for given requirements.

43 Generators

- Electromagnetic induction
- Faraday's law
- Lenz's law
- Simple a.c. generator (alternator)
- Simple d.c. generator (dynamo)
- Practical generators
- Applications of electromagnetic induction

The effect of producing electricity from magnetism was discovered in 1831 by Faraday and is called **electromagnetic induction**. It led to the construction of generators for producing electrical energy in power stations.

Electromagnetic induction

Two ways of investigating the effect follow.

a) Straight wire and U-shaped magnet

First the wire is held at rest between the poles of the magnet. It is then moved in each of the six directions shown in Figure 43.1 and the meter observed. Only *when it is moving upwards* (direction 1) or *downwards* (direction 2) is there a deflection on the meter, indicating an induced current in the wire. The deflection is in opposite directions in these two cases and only lasts while the wire is in motion.

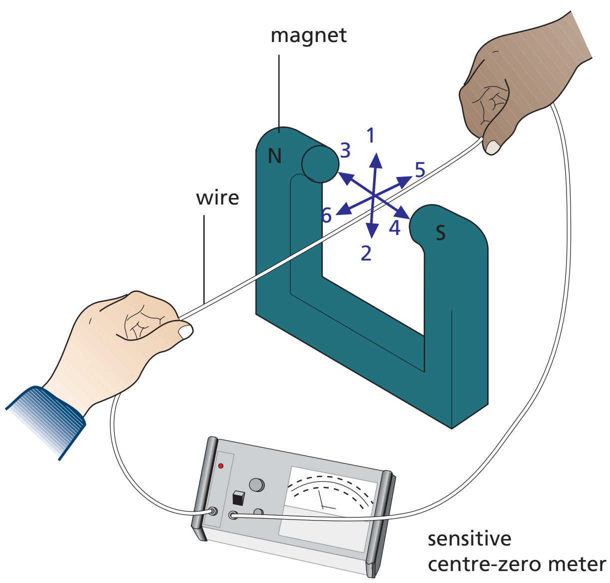


Figure 43.1 A current is induced in the wire when it is moved up or down between the magnet poles.

b) Bar magnet and coil

The magnet is pushed into the coil, one pole first (Figure 43.2), then held still inside it. It is then withdrawn. The meter shows that current is induced in the coil in one direction as the magnet is *moved in* and in the opposite direction as it is *moved out*. There is no deflection when the magnet is at rest. The results are the same if the coil is moved instead of the magnet, i.e. only *relative motion* is needed.

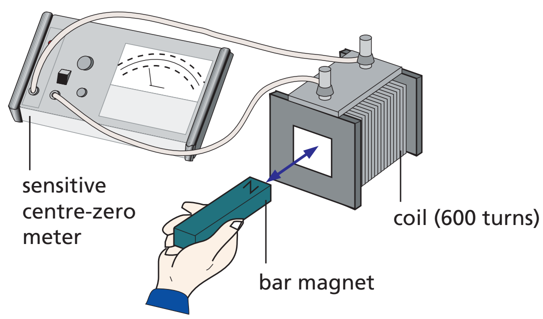


Figure 43.2 A current is induced in the coil when the magnet is moved in or out.

Faraday's law

To 'explain' electromagnetic induction Faraday suggested that a voltage is induced in a conductor whenever it 'cuts' magnetic field lines, i.e. moves *across* them, but not when it moves along them or is at rest. If the conductor forms part of a complete circuit, an induced current is also produced.

Faraday found, and it can be shown with apparatus like that in Figure 43.2, that the induced p.d. or voltage increases with increases of

(i) the **speed of motion** of the magnet or coil,
(ii) the **number of turns** on the coil,
(iii) the **strength of the magnet**.

These facts led him to state a law:

> The size of the induced p.d. is directly proportional to the rate at which the conductor cuts magnetic field lines.

Lenz's law

The direction of the induced current can be found by a law stated by the Russian scientist, Lenz.

> The direction of the induced current is such as to oppose the change causing it.

In Figure 43.3a the magnet approaches the coil, north pole first. According to Lenz's law the induced current should flow in a direction that makes the coil behave like a magnet with its top a north pole. The downward motion of the magnet will then be opposed since like poles repel.

When the magnet is withdrawn, the top of the coil should become a south pole (Figure 43.3b) and attract the north pole of the magnet, so hindering its removal. The induced current is thus in the opposite direction to that when the magnet approaches.

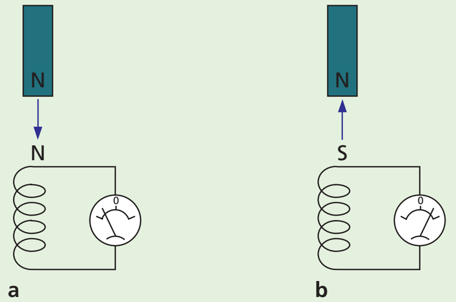


Figure 43.3 The induced current opposes the motion of the magnet.

Lenz's law is an example of the principle of conservation of energy. If the currents caused opposite poles from those that they do make, electrical energy would be created from nothing. As it is, mechanical energy is provided, by whoever moves the magnet, to overcome the forces that arise.

For a straight wire moving at right angles to a magnetic field a more useful form of Lenz's law is **Fleming's right-hand rule** (the 'dynamo rule') (Figure 43.4).

> Hold the thumb and first two fingers of the right hand at right angles to each other with the **F**irst finger pointing in the direction of the **F**ield and the thu**M**b in the direction of **M**otion of the wire, then the se**C**ond finger points in the direction of the induced **C**urrent.

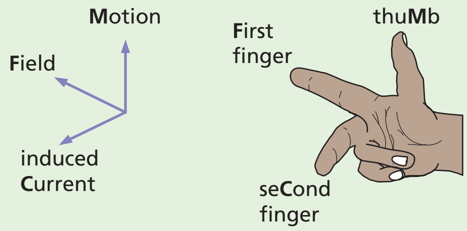


Figure 43.4 Fleming's right-hand (dynamo) rule

Simple a.c. generator (alternator)

The simplest alternating current (a.c.) generator consists of a rectangular coil between the poles of a C-shaped magnet (Figure 43.5a). The ends of the coil are joined to two **slip rings** on the axle and against which **carbon brushes** press.

When the coil is rotated it cuts the field lines and a voltage is induced in it. Figure 43.5b shows how the voltage varies over one complete rotation.

As the coil moves through the vertical position with **ab** uppermost, **ab** and **cd** are moving along the lines (**bc** and **da** do so always) and no cutting occurs. The induced voltage is zero.

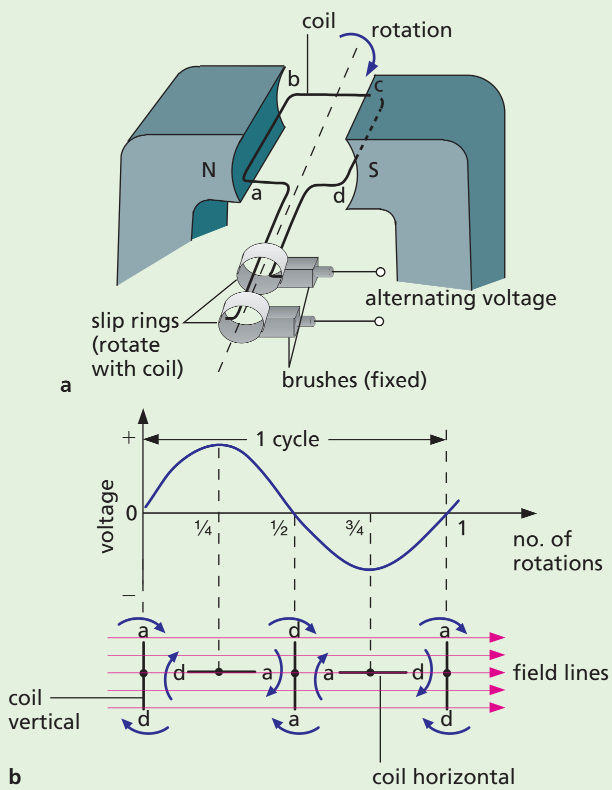


Figure 43.5 A simple a.c. generator and its output

During the first quarter rotation the p.d. increases to a maximum when the coil is horizontal. Sides **ab** and **dc** are then cutting the lines at the greatest rate.

In the second quarter rotation the p.d. decreases again and is zero when the coil is vertical with **dc** uppermost. After this, the direction of the p.d. reverses because, during the next half rotation, the motion of **ab** is directed upwards and **dc** downwards.

An alternating voltage is generated which acts first in one direction and then the other; it causes alternating current (a.c.) to flow in a circuit connected to the brushes. The **frequency** of an a.c. is the number of complete cycles it makes each second and is measured in **hertz** (Hz), i.e. 1 cycle per second = 1 Hz. If the coil rotates twice per second, the a.c. has frequency 2 Hz. The mains supply is a.c. of frequency 50 Hz.

Simple d.c. generator (dynamo)

An a.c. generator becomes a direct current (d.c.) one if the slip rings are replaced by a **commutator** (like that in a d.c. motor, see p. 216), as shown in Figure 43.6a.

The brushes are arranged so that as the coil goes through the vertical, changeover of contact occurs from one half of the split ring of the commutator to the other. But it is when the coil goes through the vertical position that the voltage induced in the coil reverses, so one brush is always positive and the other negative.

The voltage at the brushes is shown in Figure 43.6b; although varying in value, it never changes direction and would produce a direct current (d.c.) in an external circuit.

In construction the simple d.c. dynamo is the same as the simple d.c. motor and one can be used as the other. When an electric motor is working it also acts as a dynamo and creates a voltage which opposes the applied voltage. The current in the coil is therefore much less once the motor is running.

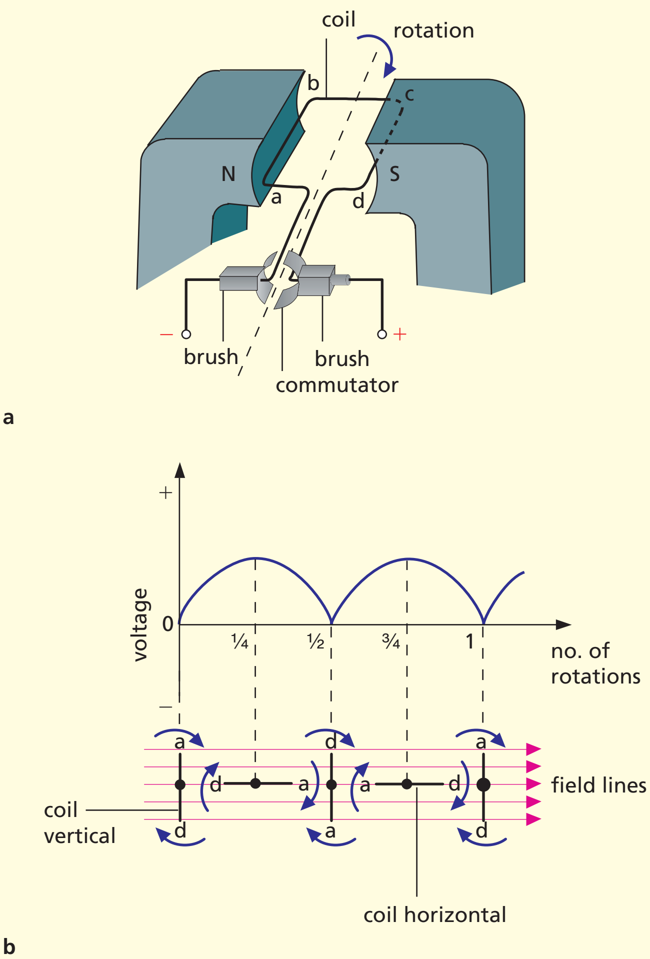


Figure 43.6 A simple d.c. generator and its output

Practical generators

In actual generators several coils are wound in evenly spaced slots in a soft iron cylinder and electromagnets usually replace permanent magnets.

a) Power stations

In power station alternators the electromagnets rotate (the rotor, Figure 43.7a) while the coils and their iron core are at rest (the stator, Figure 43.7b). The large p.d.s and currents (e.g. 25 kV at several thousand amps) induced in the stator are led away through stationary cables, otherwise they would quickly destroy the slip rings by sparking. Instead the relatively small d.c. required by the rotor is fed via the slip rings from a small dynamo (the exciter) which is driven by the same turbine as the rotor.

▶▶

a Rotor (electromagnets)

b Stator (induction coils)

Figure 43.7 The rotor and stator of a power station alternator

In a thermal power station (Chapter 15), the turbine is rotated by high-pressure steam obtained by heating water in a coal- or oil-fired boiler or in a nuclear reactor (or by hot gas in a gas-fired power station). A block diagram of a thermal power station is shown in Figure 43.8. The energy transfer diagram was given in Figure 15.7, p. 63.

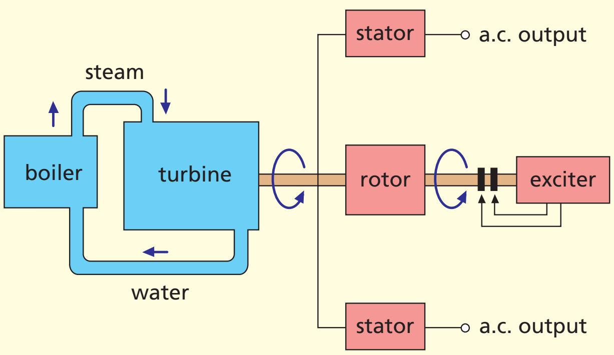


Figure 43.8 Block diagram of a thermal power station

b) Cars

Most cars are now fitted with alternators because they give a greater output than dynamos at low engine speeds.

c) Bicycles

The rotor of a bicycle generator is a permanent magnet and the voltage is induced in the coil, which is at rest (Figure 43.9).

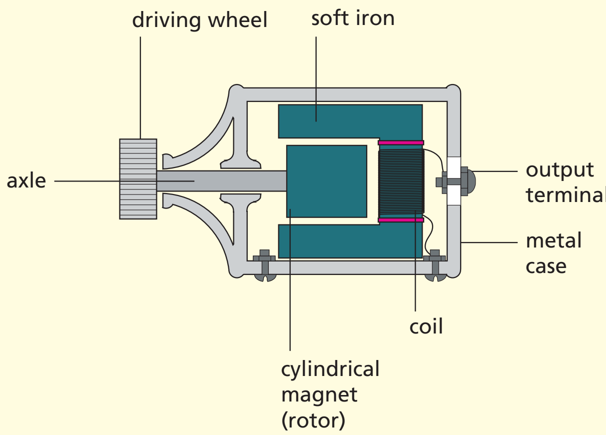


Figure 43.9 Bicycle generator

Applications of electromagnetic induction

a) Moving-coil microphone

The moving-coil loudspeaker shown in Figure 46.7 (p. 218) can be operated in reverse mode as a microphone. When sound is incident on the paper cone it vibrates, causing the attached coil to move in and out between the poles of the magnet. A varying electric current, representative of the sound, is then induced in the coil by electromagnetic induction.

b) Magnetic recording

Magnetic tapes or disks are used to record information in sound systems and computers. In the recording head shown in Figure 43.10, the tape becomes magnetised when it passes over the gap in the pole piece of the electromagnet and retains a magnetic record of the electrical signal applied to the coil from a microphone or computer. In playback mode, the varying magnetisation on the moving tape or disk induces a corresponding electrical signal in the coil as a result of electromagnetic induction.

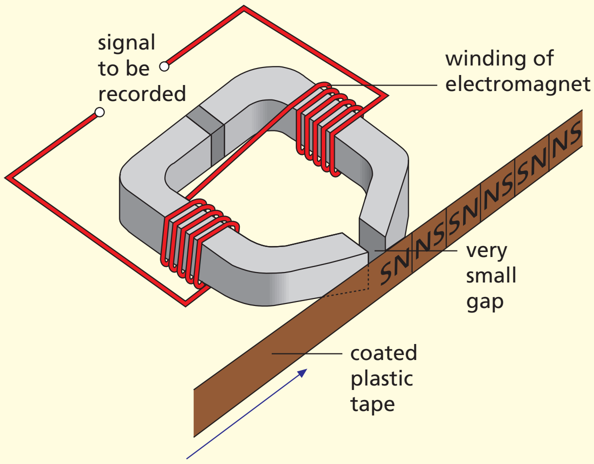


Figure 43.10 Magnetic recording or playback head

Checklist

After studying this chapter you should be able to

- describe experiments to show electromagnetic induction,
- recall Faraday's explanation of electromagnetic induction,
- predict the direction of the induced current using Lenz's law or Fleming's right-hand rule,
- draw a diagram of a simple a.c. generator and sketch a graph of its output.

Questions

1 A simple generator is shown in Figure 43.11.

a What are A and B called and what is their purpose?

b What changes can be made to increase the p.d. generated?

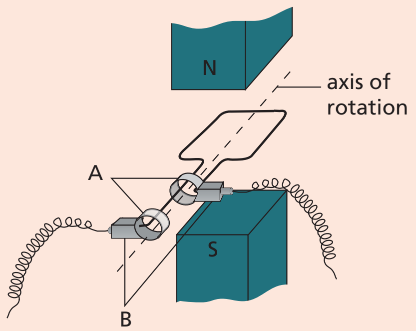


Figure 43.11

2 Describe the deflections observed on the sensitive, centre-zero galvanometer G (Figure 43.12) when the copper rod XY is connected to its terminals and is made to vibrate up and down (as shown by the arrows), between the poles of a U-shaped magnet, at right angles to the magnetic field. Explain what is happening.

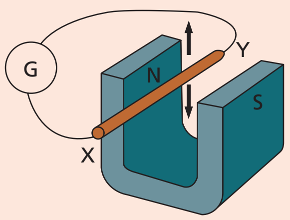


Figure 43.12

44 Transformers

- Mutual induction
- Transformer equation
- Energy losses in a transformer
- Transmission of electrical power
- Applications of eddy currents
- Practical work: Mutual induction with a.c.

Mutual induction

When the current in a coil is switched on or off or changed, a voltage is induced in a neighbouring coil. The effect, called **mutual induction**, is an example of electromagnetic induction and can be shown with the arrangement of Figure 44.1. Coil A is the **primary** and coil B the **secondary**.

Switching on the current in the primary sets up a magnetic field and as its field lines 'grow' outwards from the primary they 'cut' the secondary. A p.d. is induced in the secondary until the current in the primary reaches its steady value. When the current is switched off in the primary, the magnetic field dies away and we can imagine the field lines cutting the secondary as they collapse, again inducing a p.d. in it. Changing the primary current by *quickly* altering the rheostat has the same effect.

The induced p.d. is increased by having a soft iron rod in the coils or, better still, by using coils wound on a complete iron ring. More field lines then cut the secondary due to the magnetisation of the iron.

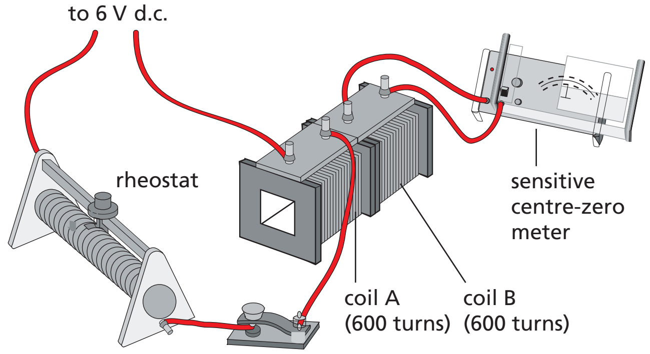


Figure 44.1 A changing current in a primary coil (A) induces a current in a secondary coil (B).

Practical work

Mutual induction with a.c.

An alternating current is changing all the time and if it flows in a primary coil, an alternating voltage and current are induced in a secondary coil.

Connect the circuit of Figure 44.2. The 1 V high current power unit supplies a.c. to the primary and the lamp detects the secondary current.

Find the effect on the brightness of the lamp of

(i) pulling the C-cores apart slightly,
(ii) increasing the secondary turns to 15,
(iii) decreasing the secondary turns to 5.

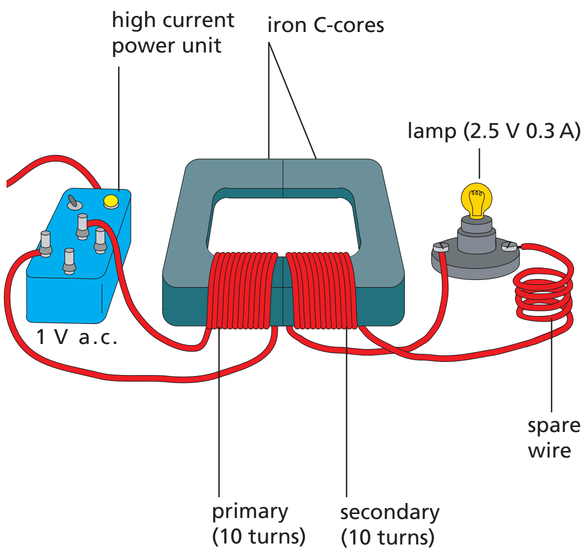


Figure 44.2

Transformer equation

A **transformer** transforms (changes) an *alternating* voltage from one value to another of greater or smaller value. It has a primary coil and a secondary coil wound on a complete soft iron core, either one on top of the other (Figure 44.3a) or on separate limbs of the core (Figure 44.3b).

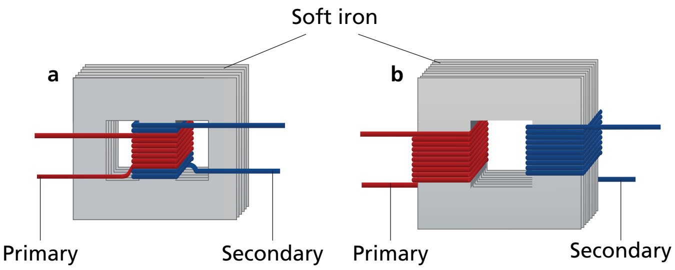


Figure 44.3 Primary and secondary coils of a transformer

An alternating voltage applied to the primary induces an alternating voltage in the secondary. The value of the secondary voltage can be shown, for a transformer in which all the field lines cut the secondary, to be given by

$$\frac{\text{secondary voltage}}{\text{primary voltage}} = \frac{\text{secondary turns}}{\text{primary turns}}$$

In symbols

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

A **step-up transformer** has more turns on the secondary than the primary and V_s is greater than V_p (Figure 44.4a). For example, if the secondary has twice as many turns as the primary, V_s is about twice V_p. In a **step-down transformer** there are fewer turns on the secondary than the primary and V_s is less than V_p (Figure 44.4b).

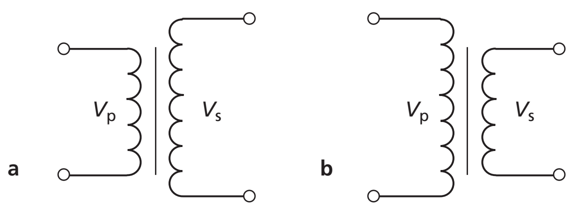


Figure 44.4 Symbols for a transformer: **a** step-up ($V_s > V_p$); **b** step-down ($V_p > V_s$)

Energy losses in a transformer

If the p.d. is stepped up in a transformer, the current is stepped down in proportion. This must be so if we assume that all the electrical energy given to the primary appears in the secondary, i.e. that energy is conserved and the transformer is 100% efficient or 'ideal' (many approach this efficiency). Then

power in primary = power in secondary

$$V_p \times I_p = V_s \times I_s$$

where I_p and I_s are the primary and secondary currents, respectively.

$$\therefore \quad \frac{I_s}{I_p} = \frac{V_p}{V_s}$$

So, for the ideal transformer, if the p.d. is doubled the current is halved. In practice, it is more than halved, because of small energy losses in the transformer arising from the following three causes.

a) Resistance of windings

The windings of copper wire have some resistance and heat is produced by the current in them. Large transformers like those in Figure 44.5 have to be oil-cooled to prevent overheating.

Figure 44.5 Step-up transformers at a power station

b) Eddy currents

The iron core is in the changing magnetic field of the primary and currents, called **eddy currents**, are induced in it which cause heating. These are reduced by using a **laminated** core made of sheets, insulated from one another to have a high resistance.

c) Leakage of field lines

All the field lines produced by the primary may not cut the secondary, especially if the core has an air gap or is badly designed.

Worked example

A transformer steps down the mains supply from 230 V to 10 V to operate an answering machine.

a What is the turns ratio of the transformer windings?
b How many turns are on the primary if the secondary has 100 turns?
c What is the current in the primary if the transformer is 100% efficient and the current in the answering machine is 2 A?

a Primary voltage, $V_p = 230\,\text{V}$
Secondary voltage, $V_s = 10\,\text{V}$

$$\text{Turns ratio} = \frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{10\text{ V}}{230\text{ V}} = \frac{1}{23}$$

b Secondary turns, $N_s = 100$
From **a**,

$$\frac{N_s}{N_p} = \frac{1}{23}$$

$$\therefore \quad N_p = 23 \times N_s = 23 \times 100$$
$$= 2300 \text{ turns}$$

c Efficiency = 100%

$\therefore$ power in primary = power in secondary

$$V_p \times I_p = V_s \times I_s$$

$$\therefore \quad I_p = \frac{V_s \times I_s}{V_p} = \frac{10\,\text{V} \times 2\,\text{A}}{230\,\text{V}} = \frac{2}{23}\,\text{A} = 0.09\,\text{A}$$

Note In this ideal transformer the current is stepped up in the same ratio as the voltage is stepped down.

Transmission of electrical power

a) Grid system

The **National Grid** is a network of cables throughout Britain, mostly supported on pylons, that connects over 100 power stations to consumers. In the largest modern stations, electricity is generated at 25 000 V (25 kilovolts = 25 kV) and stepped up at once in a transformer to 275 or 400 kV to be sent over long distances on the Supergrid. Later, the p.d. is reduced by substation transformers for distribution to local users (Figure 44.6).

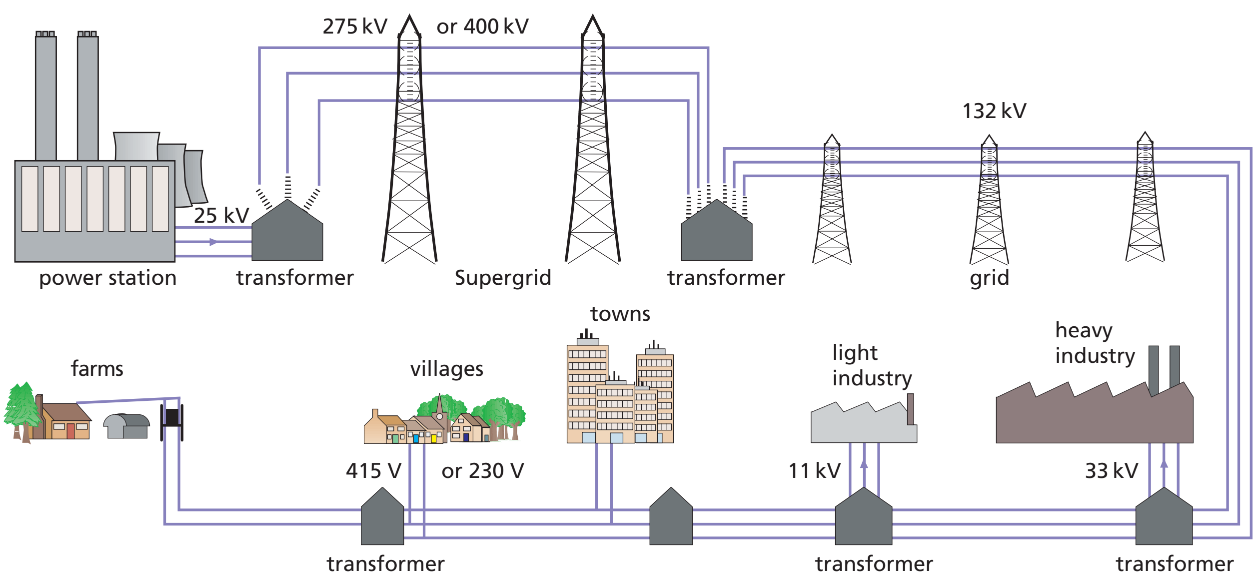


Figure 44.6 The National Grid transmission system in Britain

At the National Control Centre, engineers direct the flow and re-route it when breakdown occurs. This makes the supply more reliable and cuts costs by enabling smaller, less efficient stations to be shut down at off-peak periods.

b) Use of high alternating p.d.s

The efficiency with which transformers step alternating p.d.s up and down accounts for the use of a.c. rather than d.c. in power transmission. High voltages are used in the transmission of electric power to reduce the amount of energy 'lost' as heat.

Power cables have resistance, and so electrical energy is transferred to heat during the transmission of electricity from the power station to the user. The power 'lost' as heat in cables of resistance R is I^2R, so I should be kept low to reduce energy loss. Since power = IV, if 400 000 W of electrical power has to be sent through cables, it might be done, for example, either as 1 A at 400 000 V or as 1000 A at 400 V. Less energy will be transferred to heat if the power is transmitted at the lower current and higher voltage, i.e. 1 A at 400 000 V. High p.d.s require good insulation but are readily produced by a.c. generators.

Applications of eddy currents

Eddy currents are the currents induced in a piece of metal when it cuts magnetic field lines. They can be quite large due to the low resistance of the metal. They have their uses as well as their disadvantages.

a) Car speedometer

The action depends on the eddy currents induced in a thick aluminium disc (Figure 44.7), when a permanent magnet, near it but *not touching it*, is rotated by a cable driven from the gearbox of the car. The eddy currents in the disc make it rotate in an attempt to reduce the relative motion between it and the magnet (see Chapter 43). The extent to which the disc can turn, however, is controlled by a spring. The faster the magnet rotates the more the disc turns before it is stopped by the spring. A pointer fixed to the disc moves over a scale marked in mph (or km/h) and gives the speed of the car.

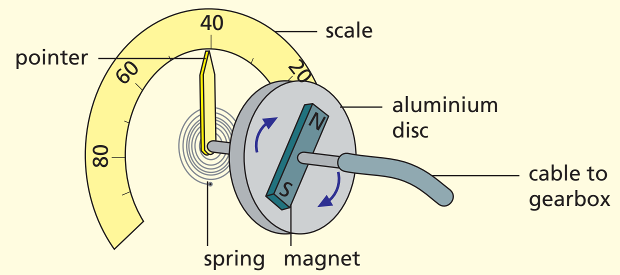


Figure 44.7 Car speedometer

b) Metal detector

The metal detector shown in Figure 44.8 consists of a large primary coil (A), through which an a.c. current is passed, and a smaller secondary coil (B). When the detector is swept over a buried metal object (such as a nail, coin or pipe) the fluctuating magnetic field lines associated with the alternating current in coil A 'cut' the hidden metal and induce eddy currents in it. The changing magnetic field lines associated with these eddy currents cut the secondary coil B in turn and induce a current which can be used to operate an alarm. The coils are set at right angles to each other so that their magnetic fields do not interact.

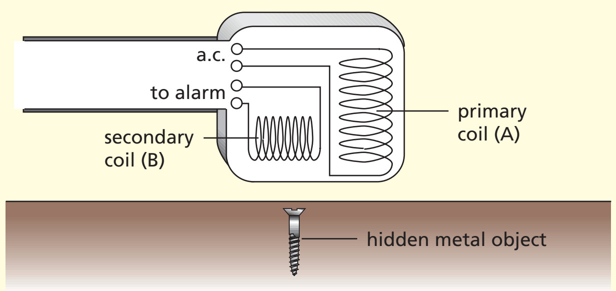


Figure 44.8 Metal detector

Questions

1 Two coils of wire, A and B, are placed near one another (Figure 44.9). Coil A is connected to a switch and battery. Coil B is connected to a centre-reading moving-coil galvanometer, G.

a If the switch connected to coil A were closed for a few seconds and then opened, the galvanometer connected to coil B would be affected. Explain and describe, step by step, what would actually happen.

b What changes would you expect if a bundle of soft iron wires was placed through the centre of the coils? Give a reason for your answer.

▶▶

c What would happen if more turns of wire were wound on the coil B?

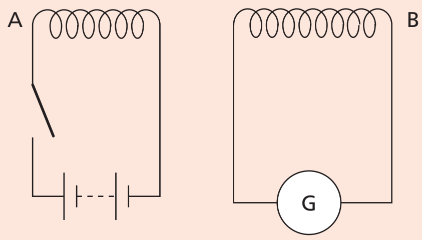


Figure 44.9

2 The main function of a step-down transformer is to
A decrease current
B decrease voltage
C change a.c. to d.c.
D change d.c. to a.c.
E decrease the resistance of a circuit.

3 a Calculate the number of turns on the secondary of a step-down transformer which would enable a 12 V lamp to be used with a 230 V a.c. mains power, if there are 460 turns on the primary.
b What current will flow in the secondary when the primary current is 0.10 A? Assume there are no energy losses.

4 A transformer has 1000 turns on the primary coil. The voltage applied to the primary coil is 230 V a.c. How many turns are on the secondary coil if the output voltage is 46 V a.c.?
A 20 **B** 200 **C** 2000 **D** 4000 **E** 8000

Checklist

After studying this chapter you should be able to

- explain the principle of the transformer,
- recall the transformer equation $V_s/V_p = N_s/N_p$ and use it to solve problems,
- recall that for an ideal transformer $V_p \times I_p = V_s \times I_s$ and use the relation to solve problems,
- recall the causes of energy losses in practical transformers,
- explain why high voltage a.c. is used for transmitting electrical power.

45 Electromagnets

- Oersted's discovery
- Field due to a straight wire
- Field due to a circular coil
- Field due to a solenoid
- Magnetisation and demagnetisation
- Electromagnets
- Electric bell
- Relay, reed switch and circuit breaker
- Telephone
- Practical work: Simple electromagnet

Oersted's discovery

In 1819 Oersted accidentally discovered the magnetic effect of an electric current. His experiment can be repeated by holding a wire over and parallel to a compass needle that is pointing N and S (Figure 45.1). The needle moves when the current is switched on. Reversing the current causes the needle to move in the opposite direction.

Evidently around a wire carrying a current there is a magnetic field. As with the field due to a permanent magnet, we represent the field due to a current by **field lines** or **lines of force**. Arrows on the lines show the direction of the field, i.e. the direction in which a N pole points.

Different field patterns are given by differently shaped conductors.

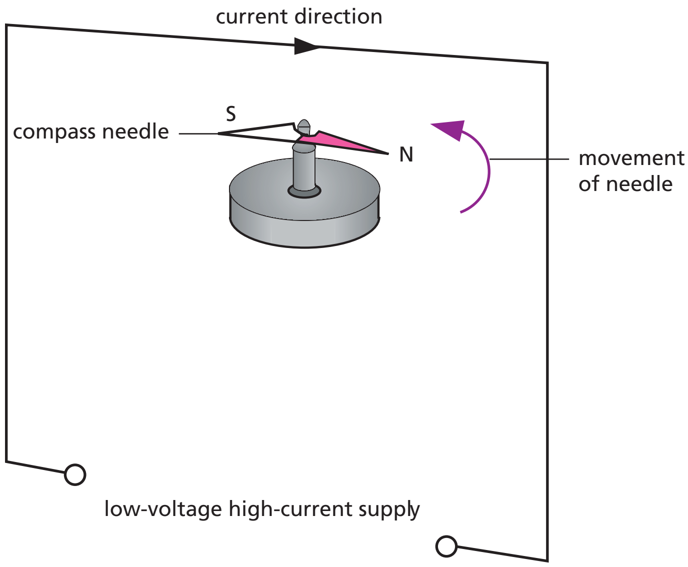


Figure 45.1 An electric current produces a magnetic effect.

Field due to a straight wire

If a straight vertical wire passes through the centre of a piece of card held horizontally and there is a current in the wire (Figure 45.2), iron filings sprinkled on the card settle in concentric circles when the card is gently tapped.

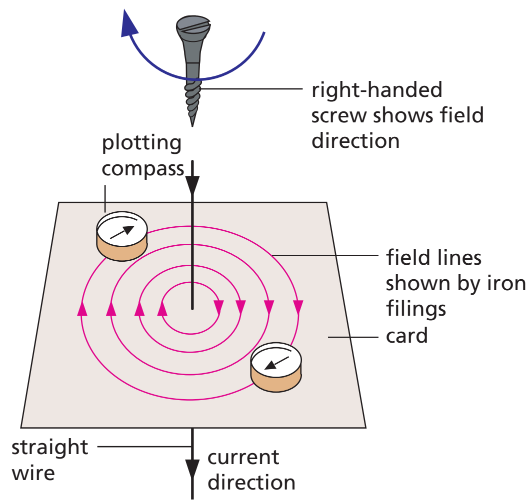


Figure 45.2 Field due to a straight wire

Plotting compasses placed on the card settle along the field lines and show the direction of the field at different points. When the current direction is reversed, the compasses point in the opposite direction showing that the direction of the field reverses when the current reverses.

If the current direction is known, the direction of the field can be predicted by the **right-hand screw rule**:

> If a right-handed screw moves forwards in the direction of the current (conventional), the direction of rotation of the screw gives the direction of the field.

Field due to a circular coil

The field pattern is shown in Figure 45.3. At the centre of the coil the field lines are straight and at right angles to the plane of the coil. The right-hand screw rule again gives the direction of the field at any point.

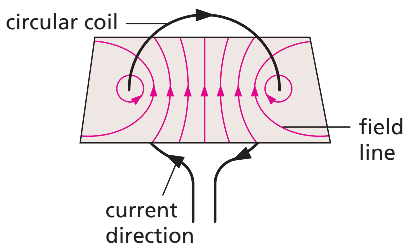


Figure 45.3 Field due to a circular coil

Field due to a solenoid

A **solenoid** is a long cylindrical coil. It produces a field similar to that of a bar magnet; in Figure 45.4a, end A behaves like a N pole and end B like a S pole. The polarity can be found as before by applying the right-hand screw rule to a short length of one turn of the solenoid. Alternatively the **right-hand grip rule** can be used. This states that if the fingers of the right hand grip the solenoid in the direction of the current (conventional), the thumb points to the N pole (Figure 45.4b). Figure 45.4c shows how to link the end-on view of the current direction in the solenoid to the polarity.

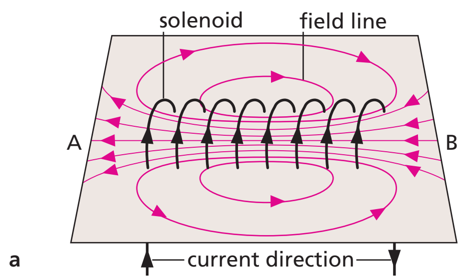


Figure 45.4a Field due to a solenoid

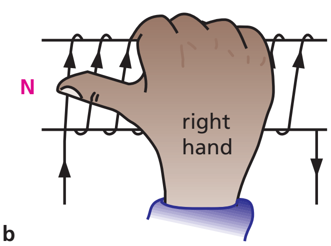


Figure 45.4b The right right-hand grip rule

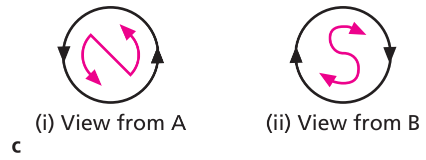


Figure 45.4c End-on views

Inside the solenoid in Figure 45.4a, the field lines are closer together than they are outside the solenoid. This indicates that the magnetic field is stronger inside a solenoid than outside it.

The field inside a solenoid can be made very strong if it has a large number of turns or a large current. Permanent magnets can be made by allowing molten ferromagnetic metal to solidify in such fields.

Magnetisation and demagnetisation

A ferromagnetic material can be magnetised by placing it inside a solenoid and gradually increasing the current. This increases the magnetic field strength in the solenoid (the density of the field lines increases), and the material becomes magnetised. Reversing the direction of current flow reverses the direction of the magnetic field and reverses the polarity of the magnetisation. A magnet can be demagnetised by placing it inside a solenoid through which the current is repeatedly reversed and reduced.

Practical work

Simple electromagnet

An **electromagnet** is a coil of wire wound on a soft iron core. A 5 cm iron nail and 3 m of PVC-covered copper wire (SWG 26) are needed.

(a) Leave about 25 cm at one end of the wire (for connecting to the circuit) and then wind about 50 cm as a single layer on the nail. **Keep the turns close together and always wind in the same direction.** Connect the circuit of Figure 45.5, setting the rheostat at its maximum resistance.
Find the number of paper clips the electromagnet can support when the current is varied between 0.2 A and 2.0 A. Record the results in a table. How does the 'strength' of the electromagnet depend on the current?

(b) Add another two layers of wire to the nail, winding in the *same direction* as the first layer. Repeat the experiment. What can you say about the 'strength' of an electromagnet and the number of turns of wire?

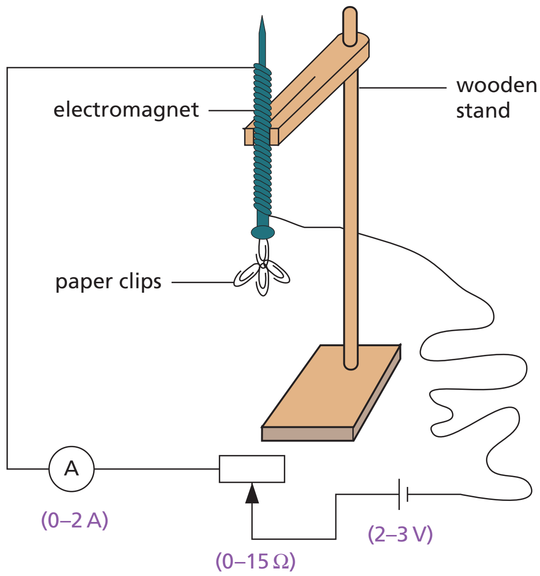


Figure 45.5

(c) Place the electromagnet on the bench and under a sheet of paper. Sprinkle iron filings on the paper, tap it gently and observe the field pattern. How does it compare with that given by a bar magnet?

(d) Use the right-hand screw (or grip) rule to predict which end of the electromagnet is a N pole. Check with a plotting compass.

Electromagnets

The magnetism of an electromagnet is *temporary* and can be switched on and off, unlike that of a permanent magnet. It has a core of soft iron which is magnetised only when there is current in the surrounding coil.

The strength of an electromagnet increases if

(i) the **current** in the coil increases,
(ii) the **number of turns** on the coil increases,
(iii) the poles are moved **closer together**.

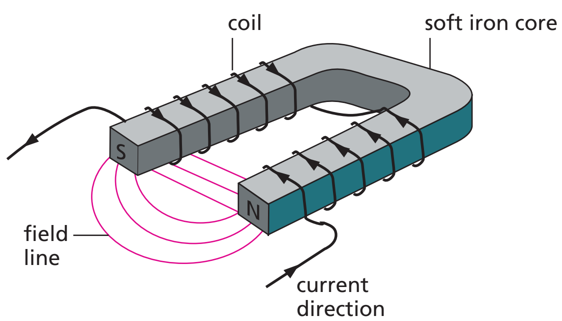


Figure 45.6 C-core or horseshoe electromagnet

In C-core (or horseshoe) electromagnets condition **(iii)** is achieved (Figure 45.6). Note that the coil on each limb of the core is wound in *opposite* directions.

As well as being used in cranes to lift iron objects, scrap iron, etc. (Figure 45.7), electromagnets are an essential part of many electrical devices.

Figure 45.7 Electromagnet being used to lift scrap metal

Electric bell

When the circuit in Figure 45.8 is completed, by someone pressing the bell push, current flows in the coils of the electromagnet which becomes magnetised and attracts the soft iron bar (the armature).

The hammer hits the gong but the circuit is now broken at the point C of the contact screw.

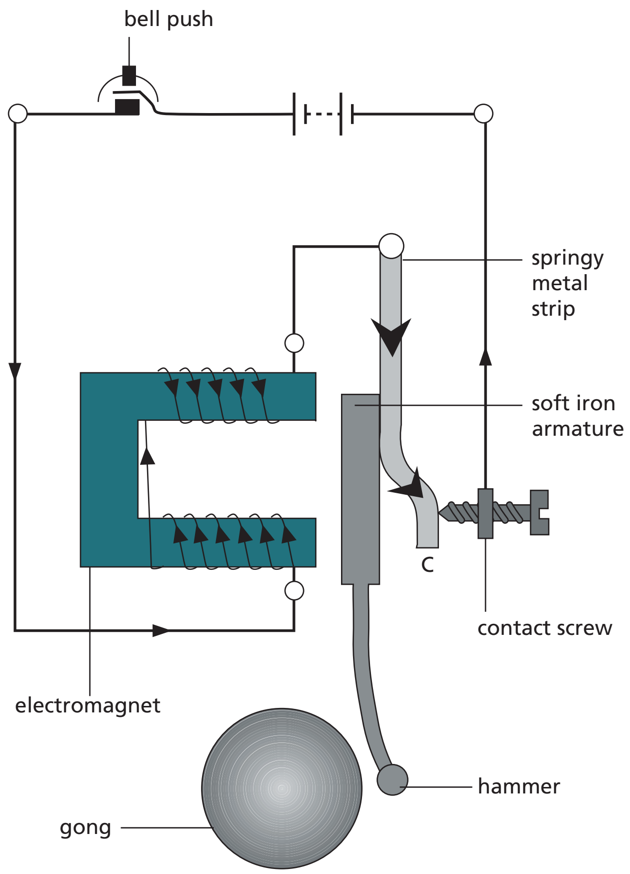


Figure 45.8 Electric bell

The electromagnet loses its magnetism (becomes demagnetised) and no longer attracts the armature. The springy metal strip is then able to pull the armature back, remaking contact at C and so completing the circuit again. This cycle is repeated so long as the bell push is depressed, and continuous ringing occurs.

Relay, reed switch and circuit breaker

a) Relay

A **relay** is a switch based on the principle of an electromagnet. It is useful if we want one circuit to control another, especially if the current and power are larger in the second circuit (see question 3, p. 214). Figure 45.9 shows a typical relay. When a current is in the coil from the circuit connected to AB, the soft iron core is magnetised and attracts the L-shaped iron armature. This rocks on its pivot and closes the contacts at C in the circuit connected to DE. The relay is then 'energised' or 'on'.

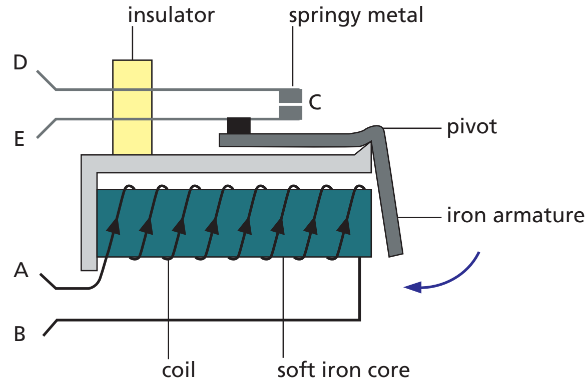


Figure 45.9 Relay

The current needed to operate a relay is called the **pull-on** current and the **drop-off** current is the smaller current in the coil when the relay just stops working. If the coil resistance, R, of a relay is $185\,\Omega$ and its operating p.d. V is $12\,\text{V}$, then the pull-on current $I = V/R = 12/185 = 0.065\,\text{A} = 65\,\text{mA}$. The symbols for relays with normally open and normally closed contacts are given in Figure 45.10.

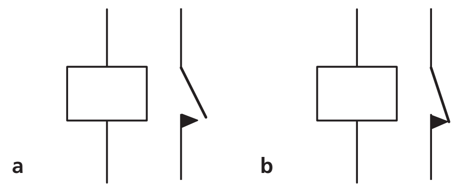
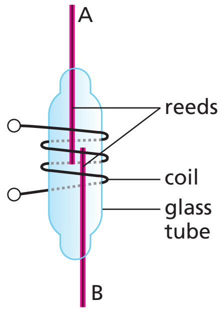


Figure 45.10 Symbols for a relay: **a** open; **b** closed

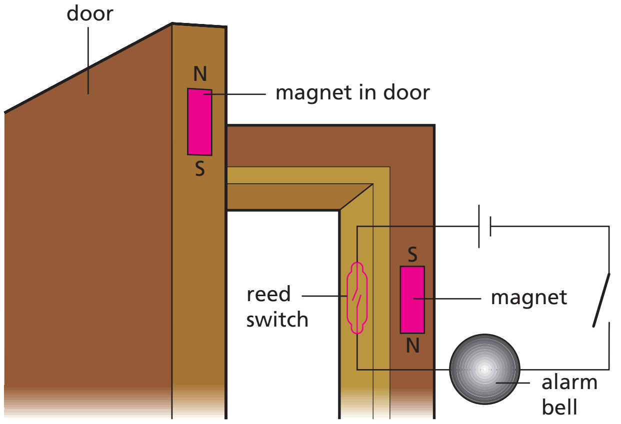
Some examples of the use of relays in circuits appear in Chapter 41.

b) Reed switch

One such switch is shown in Figure 45.11a. When current flows in the coil, the magnetic field produced magnetises the strips (called **reeds**) of magnetic material. The ends become opposite poles and one reed is attracted to the other, so completing the circuit connected to AB. The reeds separate when the current in the coil is switched off. This type of reed switch is sometimes called a **reed relay**.



a Reed switch



b Burglar alarm activated by a reed switch

Figure 45.11

Reed switches are also operated by permanent magnets. Figure 45.11b shows the use of a normally open reed switch as a burglar alarm. How does it work?

c) Circuit breaker

A **circuit breaker** (p. 181) acts in a similar way to a normally closed relay; when the current in the electromagnet exceeds a critical value, the contact points are separated and the circuit is broken. In the design shown in Figure 40.11, when the iron bolt is attracted far enough towards the electromagnet, the plunger is released and the push switch opens, breaking contact to the rest of the circuit.

Telephone

A telephone contains a microphone at the speaking end and a receiver at the listening end.

a) Carbon microphone

When someone speaks into a carbon microphone (Figure 45.12), sound waves cause the diaphragm to move backwards and forwards. This varies the pressure on the carbon granules between the movable carbon dome which is attached to the diaphragm and the fixed carbon cup at the back. When the pressure increases, the granules are squeezed closer together and their electrical resistance decreases. A decrease of pressure has the opposite effect. The current passing through the microphone varies in a similar way to the sound wave variations.

b) Receiver

The coils are wound in opposite directions on the two S poles of a magnet (Figure 45.13). If the current goes round one in a clockwise direction, it goes round the other anticlockwise, so making one S pole stronger and the other weaker. This causes the iron armature to rock on its pivot towards the stronger S pole. When the current reverses, the armature rocks the other way due to the S pole which was the stronger before becoming the weaker. These armature movements are passed on to the diaphragm, making it vibrate and produce sound of the same frequency as the alternating current in the coil (received from the microphone).

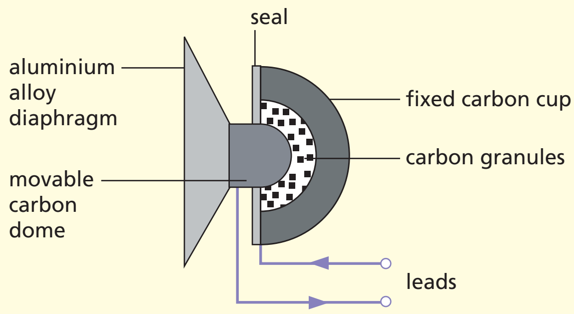


Figure 45.12 Carbon microphone

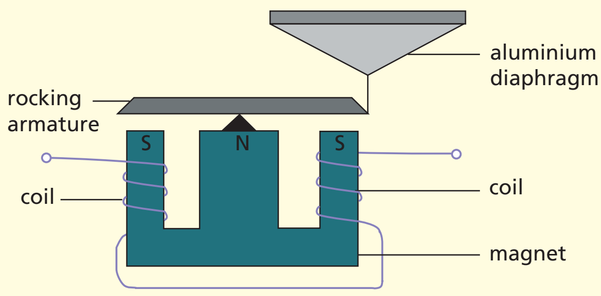


Figure 45.13 Telephone receiver

Questions

1 The vertical wire in Figure 45.14 is at right angles to the card. In what direction will a plotting compass at A point when
  a there is no current in the wire,
  b the current direction is upwards?

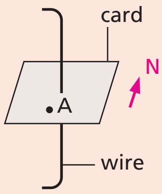


Figure 45.14

2 Figure 45.15 shows a solenoid wound on a core of soft iron. Will the end A be a N pole or S pole when the current is in the direction shown?

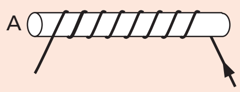


Figure 45.15

3 Part of the electrical system of a car is shown in Figure 45.16.
  a Why are connections made to the car body?
  b There are *two* circuits in parallel with the battery. What are they?
  c Why is wire A thicker than wire B?
  d Why is a relay used?

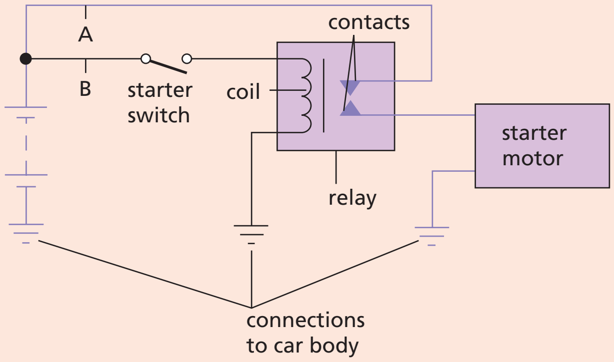


Figure 45.16

Checklist

After studying this chapter you should be able to

- describe and draw sketches of the magnetic fields round current-carrying, straight and circular conductors and solenoids,
- recall the right-hand screw and right-hand grip rules for relating current direction and magnetic field direction,
- describe the effect on the magnetic field of changing the magnitude and direction of the current in a solenoid,
- identify regions of different magnetic field strength around a solenoid,
- make a simple electromagnet,
- describe uses of electromagnets,
- explain the action of an electric bell, a relay, a reed switch and a circuit breaker.

46 Electric motors

- The motor effect
- Fleming's left-hand rule
- Simple d.c. electric motor
- Practical motors
- Moving-coil loudspeaker
- Practical work: A model motor

Electric motors form the heart of a whole host of electrical devices ranging from domestic appliances such as vacuum cleaners and washing machines to electric trains and lifts. In a car the windscreen wipers are usually driven by one and the engine is started by another.

The motor effect

A wire carrying a current in a magnetic field experiences a force. If the wire can move, it does so.

a) Demonstration

In Figure 46.1 the flexible wire is loosely supported in the strong magnetic field of a C-shaped magnet (permanent or electromagnet). When the switch is closed, current flows in the wire which jumps upwards as shown. If either the direction of the current or the direction of the field is reversed, the wire moves downwards. **The force increases if the strength of the field increases and if the current increases.**

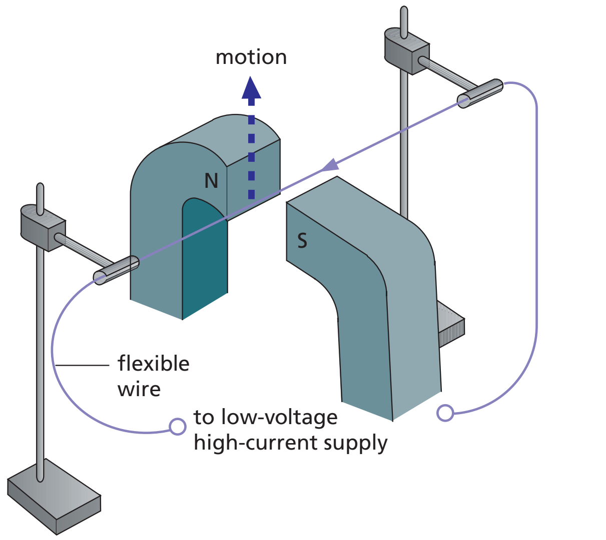


Figure 46.1 A wire carrying a current in a magnetic field experiences a force.

b) Explanation

Figure 46.2a is a side view of the magnetic field lines due to the wire and the magnet. Those due to the wire are circles and we will assume their direction is as shown. The dotted lines represent the field lines of the magnet and their direction is towards the right.

The resultant field obtained by combining both fields is shown in Figure 46.2b. There are more lines below than above the wire since both fields act in the same direction below but they are in opposition above. If we *suppose* the lines are like stretched elastic, those below will try to straighten out and in so doing will exert an upward force on the wire.

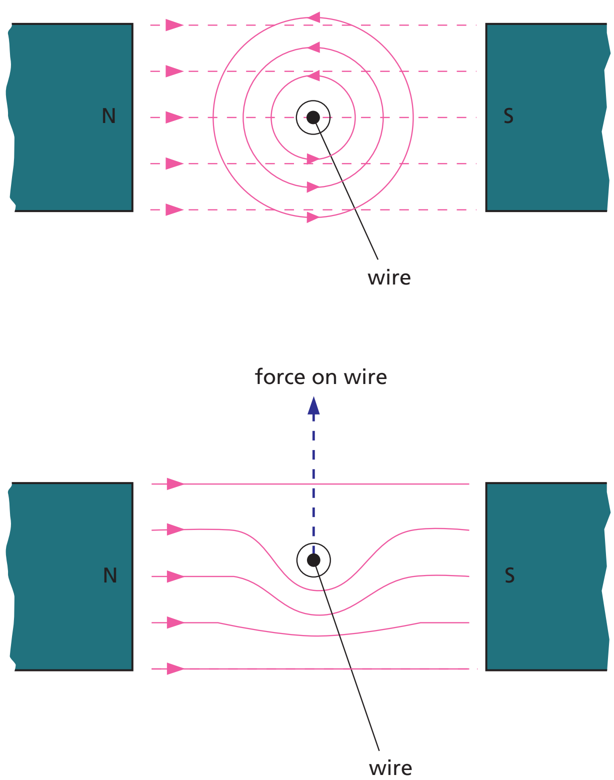


Figure 46.2

Fleming's left-hand rule

The direction of the force or thrust on the wire can be found by this rule which is also called the **motor rule** (Figure 46.3).

> Hold the thumb and first two fingers of the left hand at right angles to each other with the **F**irst finger pointing in the direction of the **F**ield and the se**C**ond finger in the direction of the **C**urrent, then the **Th**umb points in the direction of the **Th**rust.

If the wire is not at right angles to the field, the force is smaller and is zero if the wire is parallel to the field.

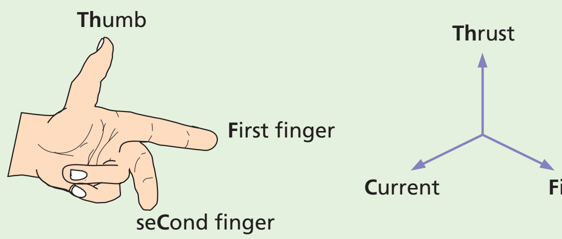


Figure 46.3 Fleming's left-hand (motor) rule

Simple d.c. electric motor

A simple motor to work from direct current (d.c.) consists of a rectangular coil of wire mounted on an axle which can rotate between the poles of a C-shaped magnet (Figure 46.4). Each end of the coil is connected to half of a split ring of copper, called a **commutator**, which rotates with the coil. Two carbon blocks, the **brushes**, are pressed lightly against the commutator by springs. The brushes are connected to an electrical supply.

If Fleming's left-hand rule is applied to the coil in the position shown, we find that side **ab** experiences an upward force and side **cd** a downward force. (No forces act on **ad** and **bc** since they are parallel to the field.) These two forces form a **couple** which rotates the coil in a clockwise direction until it is vertical.

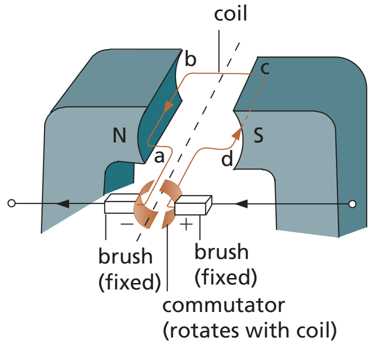


Figure 46.4 Simple d.c. motor

The brushes are then in line with the gaps in the commutator and the current stops. However, because of its inertia, the coil overshoots the vertical and the commutator halves change contact from one brush to the other. This reverses the current through the coil and so also the directions of the forces on its sides. Side **ab** is on the right now, acted on by a downward force, while **cd** is on the left with an upward force. The coil thus carries on rotating clockwise.

The more turns there are on the coil, or the larger the current through it, the greater is the couple on the coil and the faster it turns. The coil will also turn faster if the strength of the magnetic field is increased.

Practical motors

Practical motors have:

(a) **a coil of many turns wound on a soft iron cylinder or core** which rotates with the coil. This makes it more powerful. The coil and core together are called the **armature**.

(b) **several coils** each in a slot in the core and each having a pair of commutator segments. This gives increased power and smoother running. The motor of an electric drill is shown in Figure 46.5.

(c) **an electromagnet** (usually) to produce the field in which the armature rotates.

Most electric motors used in industry are **induction motors**. They work off a.c. (alternating current) on a different principle from the d.c. motor.

Figure 46.5 Motor inside an electric drill

Practical work

A model motor

The motor shown in Figure 46.6 is made from a kit.

1 Wrap Sellotape round one end of the metal tube which passes through the wooden block.
2 Cut two rings off a piece of narrow rubber tubing; slip them on to the Sellotaped end of the metal tube.
3 Remove the insulation from one end of a 1.5-metre length of SWG 26 PVC-covered copper wire and fix it under both rubber rings so that it is held tight against the Sellotape. This forms one end of the coil.
4 Wind 10 turns of the wire in the slot in the wooden block and finish off the second end of the coil by removing the PVC and fixing this too under the rings but on the opposite side of the tube from the first end. The bare ends act as the **commutator**.
5 Push the axle through the metal tube of the wooden base so that the block spins freely.
6 Arrange two 0.5-metre lengths of wire to act as **brushes** and leads to the supply, as shown. Adjust the brushes so that they are vertical and each touches one bare end of the coil when the plane of the coil is horizontal. **The motor will not work if this is not so**.
7 Slide the base into the magnet with *opposite poles facing*. Connect to a 3 V battery (or other low-voltage d.c. supply) and a slight push of the coil should set it spinning at high speed.

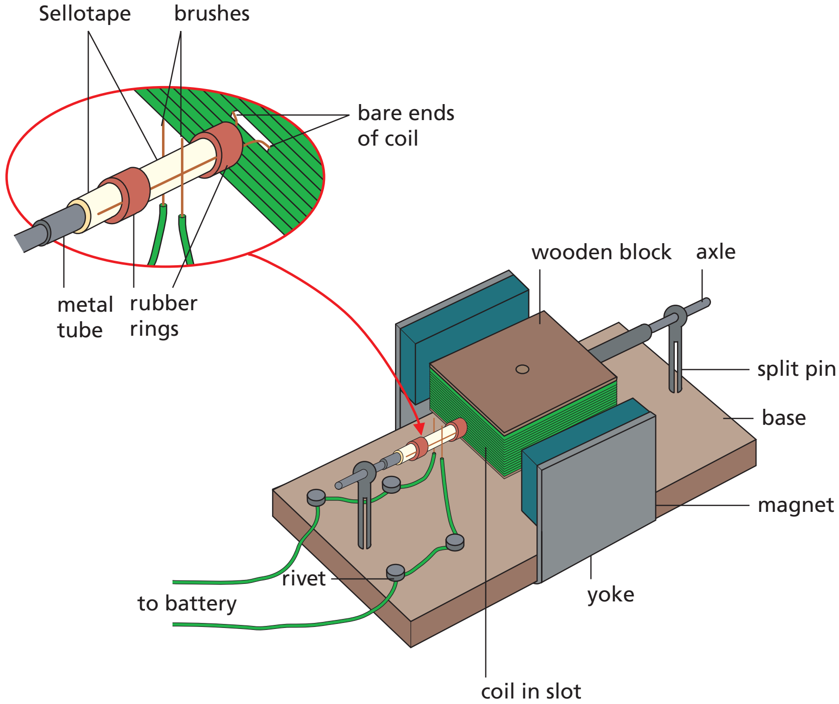


Figure 46.6 A model motor

Moving-coil loudspeaker

Varying currents from a radio, disc player, etc. pass through a short cylindrical coil whose turns are at right angles to the magnetic field of a magnet with a central pole and a surrounding ring pole (Figure 46.7a).

A force acts on the coil which, according to Fleming's left-hand rule, makes it move in and out. A paper cone attached to the coil moves with it and sets up sound waves in the surrounding air (Figure 46.7b.

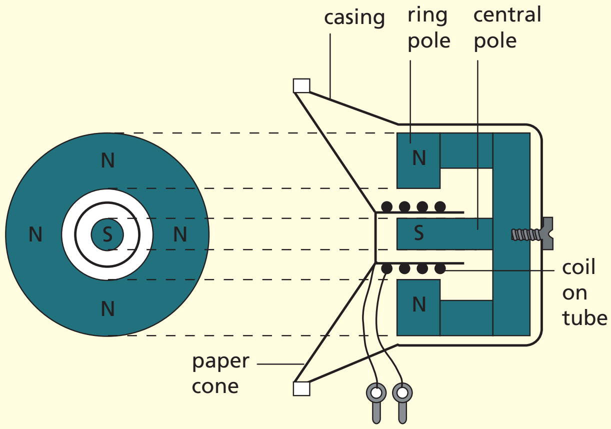


Figure 46.7 Moving-coil loudspeaker

Questions

1 The current direction in a wire running between the N and S poles of a magnet lying horizontally is shown in Figure 46.8. The force on the wire due to the magnet is directed
   - **A** from N to S
   - **B** from S to N
   - **C** opposite to the current direction
   - **D** in the direction of the current
   - **E** vertically upwards.

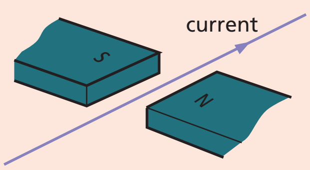


Figure 46.8

2 In the simple electric motor of Figure 46.9, the coil rotates anticlockwise as seen by the eye from the position X when current flows in the coil. Is the current flowing clockwise or anticlockwise around the coil when viewed from above?

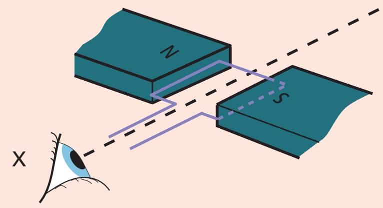


Figure 46.9

3 An electric motor is a device which transfers
   - **A** mechanical energy to electrical energy
   - **B** heat energy to electrical energy
   - **C** electrical energy to heat only
   - **D** heat to mechanical energy
   - **E** electrical energy to mechanical energy and heat.

4 **a** Draw a labelled diagram of the essential components of a simple motor. Explain how continuous rotation is produced and show how the direction of rotation is related to the direction of the current.
   b State what would happen to the direction of rotation of the motor you have described if
   - **(i)** the current was reversed,
   - **(ii)** the magnetic field was reversed,
   - **(iii)** both current and field were reversed simultaneously.

Checklist

After studying this chapter you should be able to

- describe a demonstration to show that a force acts on a current-carrying conductor in a magnetic field, and recall that it increases with the strength of the field and the size of the current,
- draw the resultant field pattern for a current-carrying conductor which is at right angles to a uniform magnetic field,
- explain why a rectangular current-carrying coil experiences a couple in a uniform magnetic field,
- draw a diagram of a simple d.c. electric motor and explain how it works,
- describe a practical d.c. motor.

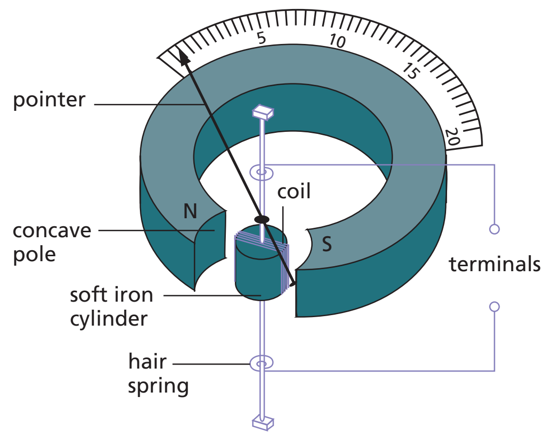
47 Electric meters

- Moving-coil galvanometer
- Ammeters and shunts
- Voltmeters and multipliers
- Multimeters
- Reading a voltmeter

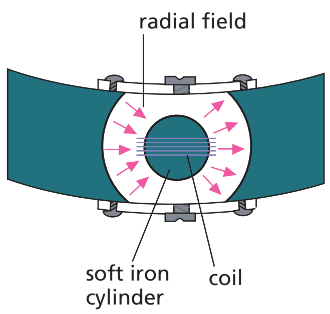
Moving-coil galvanometer

A **galvanometer** detects small currents or small p.d.s, often of the order of milliamperes (mA) or millivolts (mV).

In the moving-coil **pointer-type** meter, a coil is pivoted between the poles of a permanent magnet (Figure 47.1a). Current enters and leaves the coil by hair springs above and below it. When there is a current, a couple acts on the coil (as in an electric motor), causing it to rotate until stopped by the springs. The greater the current, the greater the deflection which is shown by a pointer attached to the coil.



a



b View from above

Figure 47.1 Moving-coil pointer-type galvanometer

The soft iron cylinder at the centre of the coil is fixed and along with the concave poles of the magnet it produces a **radial** field (Figure 47.1b), i.e. the field lines are directed to and from the centre of the cylinder. The scale on the meter is then even or linear, i.e. all divisions are the same size.

The sensitivity of a galvanometer is increased by having

(i) more turns on the coil,
(ii) a stronger magnet,
(iii) weaker hair springs or a wire suspension,
(iv) as a pointer, a long beam of light reflected from a mirror on the coil.

The last two are used in **light-beam** meters which have a full-scale deflection of a few microamperes (μA). ($1\,\mu A = 10^{-6}\,A$)

Ammeters and shunts

An **ammeter** is a galvanometer that has a known low resistance, called a **shunt**, in parallel with it to take most of the current (Figure 47.2). An ammeter is placed in series in a circuit and must have a *low resistance* otherwise it changes the current to be measured.

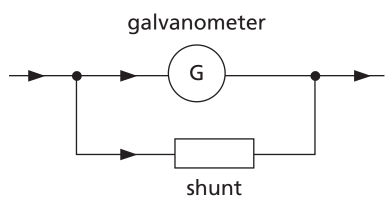


Figure 47.2 An ammeter

Voltmeters and multipliers

A **voltmeter** is a galvanometer having a known high resistance, called a **multiplier**, in series with it (Figure 47.3). A voltmeter is placed in *parallel* with the part of the circuit across which the p.d. is to be measured and must have a *high resistance* – otherwise the total resistance of the whole circuit is reduced so changing the current and the p.d. measured.

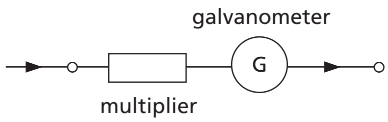


Figure 47.3 A voltmeter

Multimeters

A **multimeter** can have analogue or digital displays (see Figures 47.4a and 47.4b) and can be used to measure a.c. or d.c. currents or voltages and also resistance. The required function is first selected, say a.c. current, and then a suitable range chosen. For example if a current of a few milliamps is expected, the 10 mA range might be selected and the value of the current (in mA) read from the display; if the reading is off-scale, the sensitivity should be reduced by changing to the higher, perhaps 100 mA, range.

For the measurement of resistance, the resistance function is chosen and the appropriate range selected. The terminals are first short-circuited to check the zero of resistance, then the unknown resistance is disconnected from any circuit and reconnected across the terminals of the meter in place of the short circuit.

Figure 47.4a Analogue multimeter

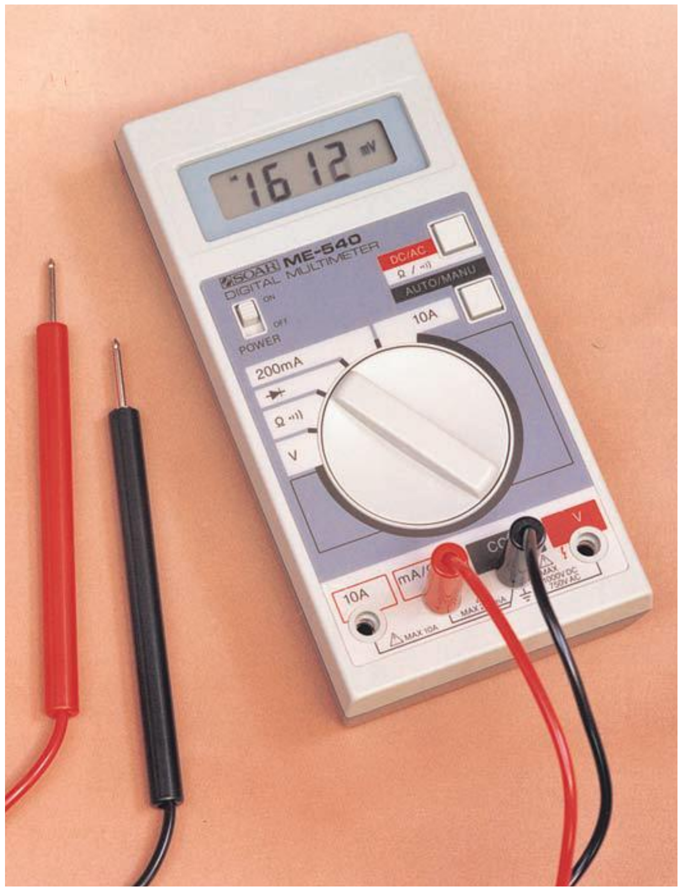


Figure 47.4b Digital multimeter

Analogue multimeters are adapted moving-coil galvanometers. Digital multimeters are constructed from integrated circuits. On the voltage setting they have a very high input resistance (10 MΩ), i.e. they affect most circuits very little and so give very accurate readings.

Reading a voltmeter

The face of an analogue voltmeter is represented in Figure 47.5. The voltmeter has two scales. The 0–5 scale has a **full-scale deflection** of 5.0 V. Each small division on the 0–5 scale represents 0.1 V. This voltmeter scale can be read to the nearest 0.1 V. However the human eye is very good at judging a half division, so we are able to estimate the voltmeter reading to the nearest 0.05 V with considerable precision.

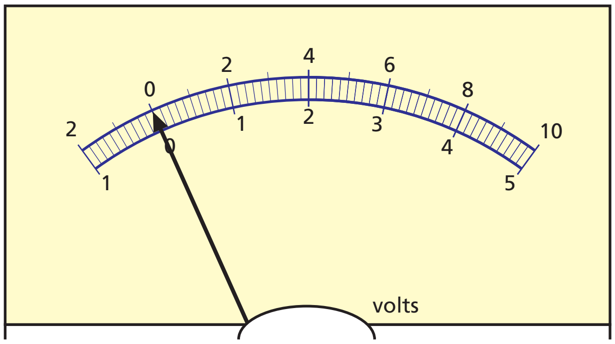


Figure 47.5 An analogue voltmeter scale

Every measuring instrument has a calibrated scale. When you write an account of an experiment (see p. x, *Scientific enquiry*) you should include details about each scale that you use.

Questions

1 What does a galvanometer do?

2 Why should the resistance of
  a an ammeter be very small,
  b a voltmeter be very large?

3 The scales of a voltmeter are shown in Figure 47.6.

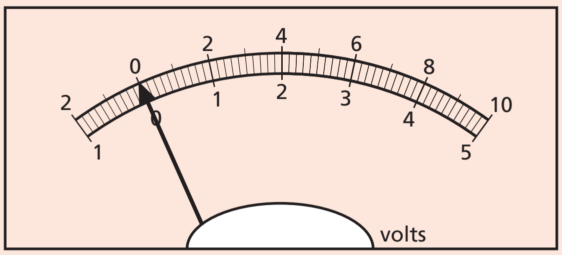


Figure 47.6

  a What are the two ranges available when using the voltmeter?
  b What do the small divisions between the numbers 3 and 4 represent?
  c Which scale would you use to measure a voltage of 4.6 V?
  d When the voltmeter reads 4.0 V where should you position your eye to make the reading?
  e When making the reading for 4.0 V an observer's eye is over the 0 V mark. Explain why the value obtained by this observer is higher than 4.0 V.

Checklist

After studying this chapter you should be able to

- draw a diagram of a simple moving-coil galvanometer and explain how it works,
- explain how a moving-coil galvanometer can be modified for use as (a) an ammeter and (b) a voltmeter,
- explain why (a) an ammeter should have a very low resistance and (b) a voltmeter should have a very high resistance.

48 Electrons

- Thermionic emission
- Cathode rays
- Deflection of an electron beam
- Cathode ray oscilloscope (CRO)
- Uses of the CRO
- X-rays
- Photoelectric effect
- Waves or particles?

The discovery of the **electron** was a landmark in physics and led to great technological advances.

Thermionic emission

The evacuated bulb in Figure 48.1 contains a small coil of wire, the **filament**, and a metal plate called the **anode** because it is connected to the positive of the 400 V d.c. power supply. The negative of the supply is joined to the filament which is also called the **cathode**. The filament is heated by current from a 6 V supply (a.c. or d.c.).

With the circuit as shown, the meter deflects, indicating current flow in the circuit containing the gap between anode and cathode. The current stops if *either* the 400 V supply is reversed to make the anode negative *or* the filament is not heated.

This demonstration shows that negative charges, in the form of electrons, escape from the filament when it is hot because they have enough energy to get free from the metal surface. The process is known as **thermionic emission** and the bulb as a thermionic diode (since it has two electrodes). There is a certain minimum **threshold energy** (depending on the metal) which the electrons must have to escape. Also, the higher the temperature of the metal, the greater the number of electrons emitted. The electrons are attracted to the anode if it is positive and are able to reach it because there is a vacuum in the bulb.

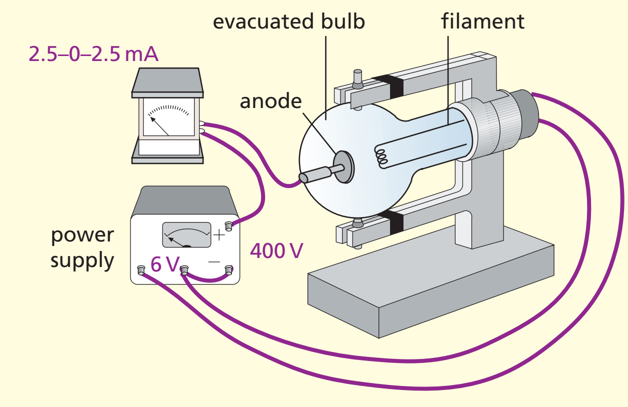


Figure 48.1 Demonstrating thermionic emission

Cathode rays

Beams of electrons moving at high speed are called **cathode rays**. Their properties can be studied using the 'Maltese cross tube' (Figure 48.2).

Electrons emitted by the hot cathode are accelerated towards the anode but most pass through the hole in it and travel on along the tube. Those that miss the cross cause the screen to fluoresce with green or blue light and cast a shadow of the cross on it. The cathode rays evidently travel in straight lines.

If the N pole of a magnet is brought up to the neck of the tube, the rays (and the fluorescent shadow) can be shown to move upwards. The rays are clearly deflected by a magnetic field and, using Fleming's left-hand rule (Chapter 46), we see that they behave like conventional current (positive charge flow) travelling from anode to cathode.

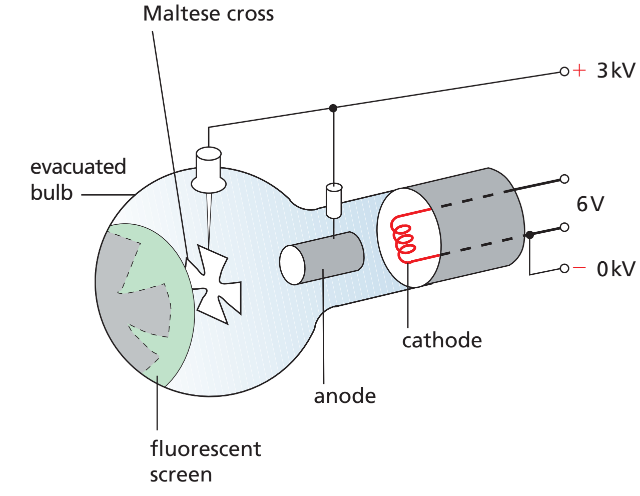


Figure 48.2 Maltese cross tube

There is also an optical shadow of the cross, due to light emitted by the cathode. This is unaffected by the magnet.

Deflection of an electron beam

a) By a magnetic field

In Figure 48.3 the evenly spaced crosses represent a uniform magnetic field (i.e. one of the same strength throughout the area shown) acting into and perpendicular to the paper. An electron beam entering the field at right angles to the field experiences a force due to the motor effect (Chapter 46) whose direction is given by Fleming's left-hand rule. This indicates that the force acts at right angles to the direction of the beam and makes it follow a *circular* path as shown (the beam being treated as conventional current in the opposite direction).

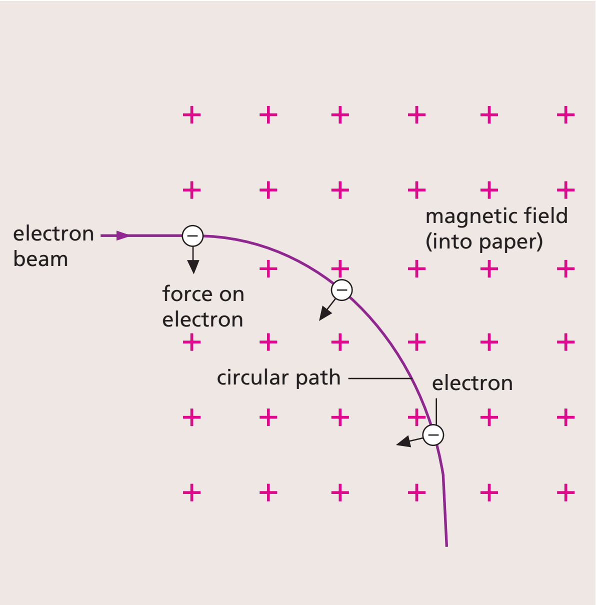


Figure 48.3 Path of an electron beam at right angles to a magnetic field

b) By an electric field

An electric field is a region where an electric charge experiences a force due to other charges (see p. 155). In Figure 48.4 the two metal plates behave like a capacitor that has been charged by connection to a voltage supply. If the charge is evenly spread over the plates, a uniform electric field is created between them and is represented by parallel, equally spaced lines; the arrows indicate the direction in which a positive charge would move.

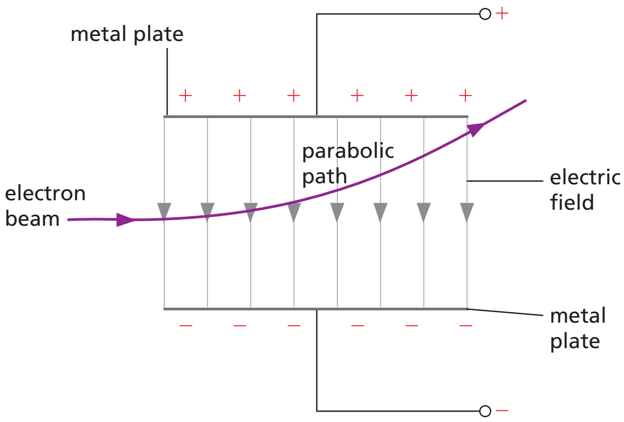


Figure 48.4 Path of an electron beam incident perpendicular to an electric field

If a beam of electrons enters the field in a direction perpendicular to the field, the negatively charged beam is attracted towards the positively charged plate and follows a **parabolic** path, as shown. In fact its behaviour is not unlike that of a projectile (Chapter 4) in which the horizontal and vertical motions can be treated separately.

c) Demonstration

The deflection tube in Figure 48.5 can be used to show the deflection of an electron beam in electric and magnetic fields. Electrons from a hot cathode strike a fluorescent screen S set at an angle. A p.d. applied across two horizontal metal plates Y_1Y_2 creates a *vertical* electric field which deflects the rays upwards if Y_1 is positive (as shown) and downwards if it is negative.

When there is current in the two coils X_1X_2 (in series) outside the tube, a *horizontal* magnetic field is produced across the tube. It can be used instead of a magnet to deflect the rays, or to cancel the deflection due to an electric field.

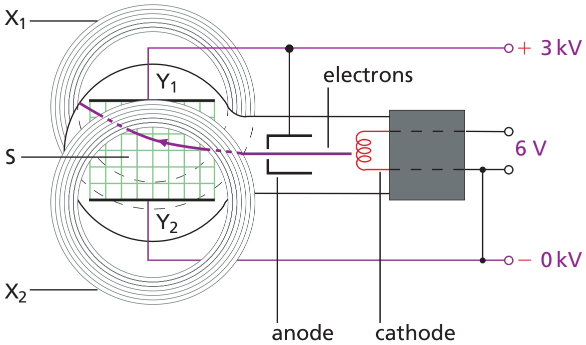


Figure 48.5 Deflection tube

Cathode ray oscilloscope (CRO)

Historically the CRO is one of the most important scientific instruments ever developed. It contains a cathode ray tube that has three main parts (Figure 48.6).

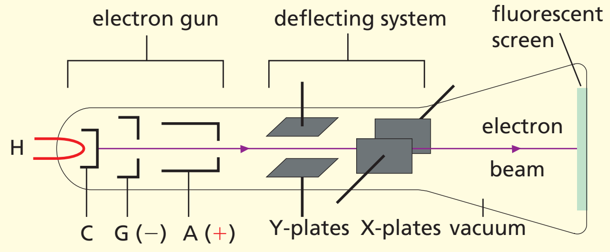


Figure 48.6 Main parts of a CRO

a) Electron gun

This consists of a **heater** H, a **cathode** C, another electrode called the **grid** G and two or three **anodes** A. G is at a negative voltage with respect to C and controls the number of electrons passing through its central hole from C to A; it is the **brilliance** or **brightness** control. The anodes are at high positive voltages relative to C; they accelerate the electrons along the highly evacuated tube and also **focus** them into a narrow beam.

b) Fluorescent screen

A bright spot of light is produced on the screen where the beam hits it.

c) Deflecting system

Beyond A are two pairs of deflecting plates to which p.d.s can be applied. The **Y-plates** are horizontal but create a vertical electric field which deflects the beam vertically. The **X-plates** are vertical and deflect the beam horizontally.

The p.d. to create the electric field between the Y-plates is applied to the **Y-input** terminals (often marked 'high' and 'low') on the front of the CRO. The input is usually amplified by an amount that depends on the setting of the **Y-amp gain** control, before it is applied to the Y-plates. It can then be made large enough to give a suitable vertical deflection of the beam.

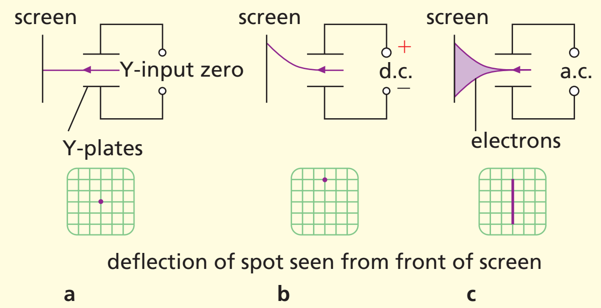


Figure 48.7 Deflection of the electron beam

In Figure 48.7a the p.d. between the Y-plates is zero, as is the deflection. In part b of the figure, the d.c. input p.d. makes the upper plate positive and it attracts the beam of negatively charged electrons upwards. In part c the 50 Hz a.c. input makes the beam move up and down so rapidly that it produces a continuous vertical line (whose length increases if the Y-amp gain is turned up).

The p.d. applied to the X-plates is also via an amplifier, the X-amplifier, and can either be from an external source connected to the **X-input** terminal or, more commonly, from the **time base** circuit in the CRO.

The time base deflects the beam horizontally in the X-direction and makes the spot sweep across the screen from left to right at a steady speed determined by the setting of the time base controls (usually 'coarse' and 'fine'). It must then make the spot 'fly back' very rapidly to its starting point, ready for the next sweep. The p.d. from the time base should therefore have a sawtooth waveform like that in Figure 48.8. Since AB is a straight line, the distance moved by the spot is directly proportional to time and the horizontal deflection becomes a measure of time, i.e. a time axis or base.

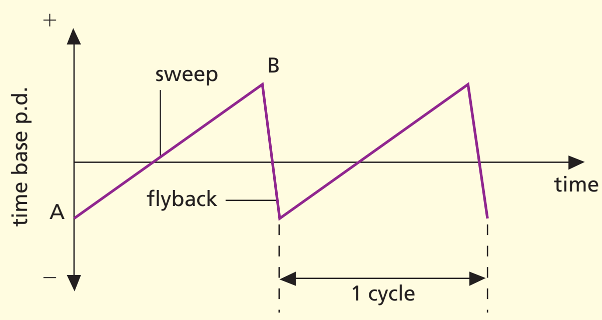
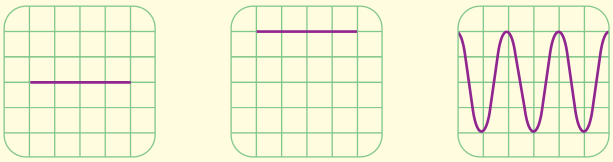


Figure 48.8 Time base waveform

In Figures 48.9a, b and c, the time base is on, applied to the X-plates. For the trace in part a, the Y-input p.d. is zero, for the trace in part b the Y-input is d.c. which makes the upper Y-plate positive. In both cases the spot traces out a horizontal line which appears to be continuous if the flyback is fast enough. For the trace in part c the Y-input is a.c., that is, the Y-plates are alternately positive and negative and the spot moves accordingly.



a b c

Figure 48.9 Deflection of the spot with time base on

Uses of the CRO

A small CRO is shown in Figure 48.10.

Figure 48.10 Single-beam CRO

a) Practical points

The **brilliance** or **intensity** control, which is sometimes the **on/off** switch as well, should be as low as possible when there is just a spot on the screen. Otherwise screen 'burn' occurs which damages the fluorescent material. If possible it is best to defocus the spot when not in use, or draw it into a line by running the time base.

When preparing the CRO for use, set the **brilliance**, **focus**, **X-shift** and **Y-shift** controls (which allow the spot to be moved 'manually' over the screen in the X and Y directions, respectively) to their mid-positions. The **time base** and **Y-amp gain** controls can then be adjusted to suit the input.

When the **a.c./d.c. selector** switch is in the 'd.c.' (or 'direct') position, both d.c. and a.c. can pass to the Y-input. In the 'a.c.' (or 'via C') position, a capacitor blocks d.c. in the input but allows a.c. to pass.

b) Measuring p.d.s

A CRO can be used as a d.c./a.c. voltmeter if the p.d. to be measured is connected across the Y-input terminals; **the deflection of the spot is proportional to the p.d.**

For example, if the Y-amp gain control is on, say, 1 V/div, a deflection of one vertical division on the screen graticule (like graph paper with squares for measuring deflections) would be given by a 1 V d.c. input. A line one division long (time base off) would be produced by an a.c. input of 1 V peak-to-peak, i.e. peak p.d. = 0.5 V.

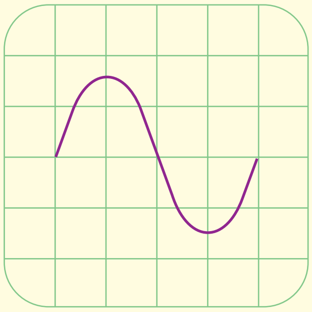
Increasingly the CRO is being replaced by a data-logger and computer with software which simulates the display on a CRO screen by plotting the p.d. against time.

c) Displaying waveforms

In this widely used role, the time base is on and the CRO acts as a 'graph-plotter' to show the waveform, i.e. the variation with time, of the p.d. applied to its Y-input. The displays in Figures 48.11a and b are of alternating p.d.s with sine waveforms. For the trace in part a, the time base frequency *equals* that of the input and one complete wave is obtained. For the trace in part b, it is *half* that of the input and two waves are formed. If the traces are obtained with the Y-amp gain control on, say, 0.5 V/div, the peak-to-peak voltage of the a.c. = 3 divs × 0.5 V/div, that is, 1.5 V, and the peak p.d. = 0.75 V.

Sound waveforms can be displayed if a microphone is connected to the Y-input terminals (see Chapter 33).

▶▶



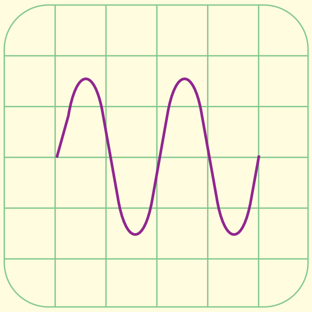


Figure 48.11 Alternating p.d. waveforms on the CRO

d) Measuring time intervals and frequency

These can be measured if the CRO has a calibrated time base. For example, when the time base is set on 10 ms/div, the spot takes 10 milliseconds to move one division horizontally across the screen graticule. If this is the time base setting for the waveform in Figure 48.11b then, since one complete wave occupies two horizontal divisions, we can say

$$\text{time for one complete wave} = 2\,\text{divs} \times 10\,\text{ms/div}$$
$$= 20\,\text{ms}$$
$$= \frac{20}{1000} = \frac{1}{50}\,\text{s}$$

∴ number of complete waves per second = 50
∴ frequency of a.c. applied to Y-input = 50 Hz

X-rays

X-rays are produced when high-speed electrons are stopped by matter.

a) Production

In an X-ray tube, Figure 48.12, electrons from a hot filament are accelerated across a vacuum to the anode by a large p.d. (up to 100 kV). The anode is a copper block with a 'target' of a high-melting-point metal such as tungsten on which the electrons are focused by the electric field between the anode and the concave cathode. The tube has a lead shield with a small exit for the X-rays.

The work done (see p. 163) in transferring a charge Q through a p.d. V is

$$E = Q \times V$$

This will equal the k.e. of the electrons reaching the anode if Q = charge on an electron ($= 1.6 \times 10^{-19}$ C) and V is the accelerating p.d. Less than 1% of the k.e. of the electrons becomes X-ray energy; the rest heats the anode which has to be cooled.

High p.d.s give short wavelength, very penetrating (**hard**) X-rays. Less penetrating (**soft**) rays, of longer wavelength, are obtained with lower p.d.s. The absorption of X-rays by matter is greatest by materials of high density having a large number of outer electrons in their atoms, i.e. of high atomic number (Chapter 50). A more intense beam of rays is produced if the rate of emission of electrons is raised by increasing the filament current.

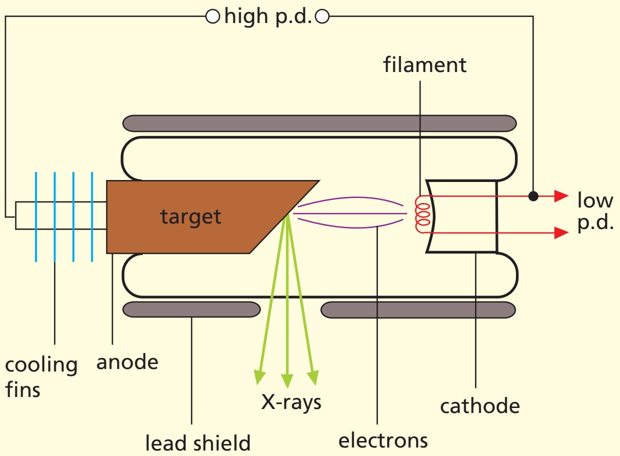


Figure 48.12 X-ray tube

b) Properties and nature

X-rays:

(i) readily penetrate matter – up to 1 mm of lead,
(ii) are not deflected by electric or magnetic fields,
(iii) ionise a gas, making it a conductor, e.g. a charged electroscope discharges when X-rays pass through the surrounding air,
(iv) affect a photographic film,

(v) cause fluorescence,
(vi) give interference and diffraction effects.

These facts (and others) suggest that X-rays are electromagnetic waves of very short wavelength.

c) Uses

These were considered earlier (Chapter 32).

Photoelectric effect

Electrons are emitted by certain metals when electromagnetic radiation of small enough wavelength falls on them. The effect is called **photoelectric emission**. It happens, for example, when zinc is exposed to ultraviolet.

The photoelectric effect only occurs for a given metal if the frequency of the incident electromagnetic radiation exceeds a certain **threshold frequency**. We can explain this by assuming that

(i) all electromagnetic radiation is emitted and absorbed as packets of energy, called **photons**, and
(ii) the energy of a photon is directly proportional to its frequency.

Ultraviolet (UV) photons would therefore have more energy than light photons since UV has a higher frequency than light. The behaviour of zinc (and most other substances) in not giving photoelectric emission with light but with UV would therefore be explained: a photon of light has less than the minimum energy required to cause the zinc to emit an electron.

The absorption of a photon by an atom results in the electron gaining energy and the photon disappearing. If the photon has more than the minimum amount of energy required to enable an electron to escape, the excess appears as k.e. of the emitted electron.

energy of photon = energy needed for electron to escape + k.e. of electron

The **photoelectric effect** is the process by which X-ray photons are absorbed by matter; in effect it causes **ionisation** (Chapter 49) since electrons are ejected and positive ions remain. Photons not absorbed by the metal pass through with unchanged energy.

Waves or particles?

The wave theory of electromagnetic radiation can account for properties such as interference, diffraction and polarisation which the photon theory cannot. On the other hand, the wave theory does not explain the photoelectric effect and the photon theory does.

It would seem that electromagnetic radiation has a dual nature and has to be regarded as waves on some occasions and as 'particles' (photons) on others.

Questions

1 a In Figure 48.13a, to which terminals on the power supply must plates A and B be connected to deflect the cathode rays downwards?

b In Figure 48.13b, in which direction will the cathode rays be deflected?

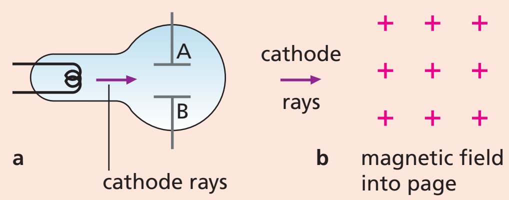


Figure 48.13

2 An electron, charge e and mass m, is accelerated in a cathode ray tube by a p.d. of 1000 V. Calculate
a the kinetic energy gained by the electron,
b the speed it acquires.
($e = 1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg)

Checklist

After studying this chapter you should be able to

- explain the term cathode rays,
- describe experiments to show that cathode rays are deflected by magnetic and electric fields.

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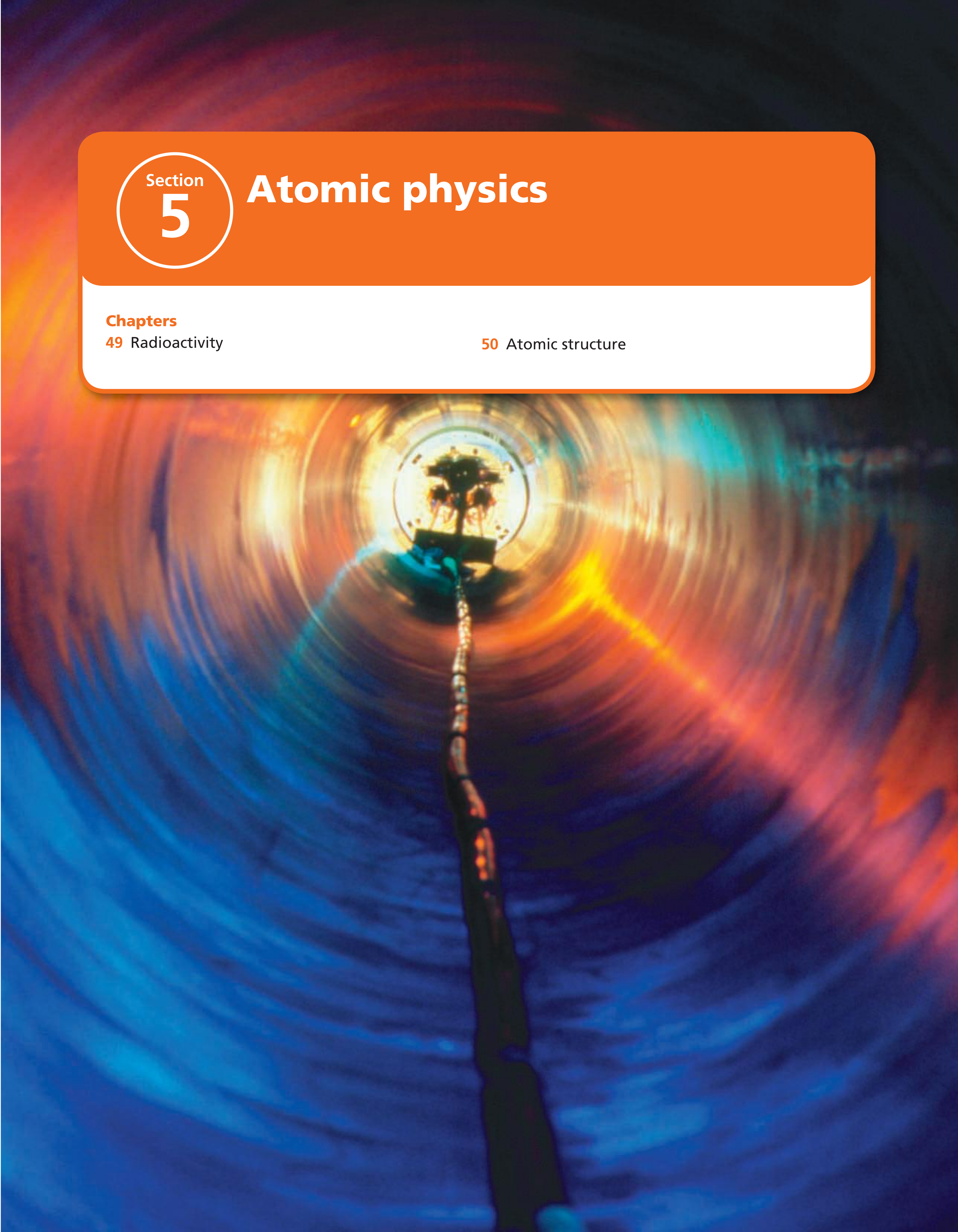
Section 5

Atomic physics

Chapters



49 Radioactivity

- Ionising effect of radiation
- Geiger–Müller (GM) tube
- Alpha, beta and gamma radiation
- Particle tracks
- Radioactive decay
- Uses of radioactivity
- Dangers and safety

The discovery of radioactivity in 1896 by the French scientist Becquerel was accidental. He found that uranium compounds emitted radiation that: **(i)** affected a photographic plate even when it was wrapped in black paper, and **(ii)** ionised a gas. Soon afterwards Marie Curie discovered the radioactive element radium. We now know that radioactivity arises from unstable nuclei (Chapter 50) which may occur naturally or be produced in reactors. Radioactive materials are widely used in industry, medicine and research.

We are all exposed to natural **background radiation** caused partly by radioactive materials in rocks, the air and our bodies, and partly by cosmic rays from outer space (see p. 235).

Ionising effect of radiation

A charged electroscope discharges when a lighted match or a radium source (**held in forceps**) is brought near the cap (Figures 49.1a and b).

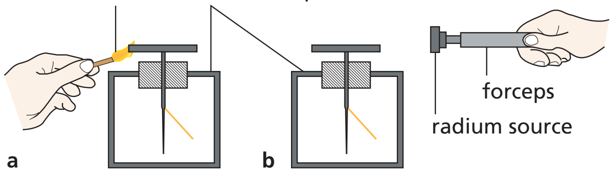


Figure 49.1

In the first case the flame knocks electrons out of surrounding air molecules leaving them as positively charged **ions**, i.e. air molecules which have lost one or more electrons (Figure 49.2); in the second case radiation causes the same effect, called **ionisation**. The positive ions are attracted to the cap if it is negatively charged; if it is positively charged the electrons are attracted. As a result in either case the charge on the electroscope is neutralised, i.e. it loses its charge.

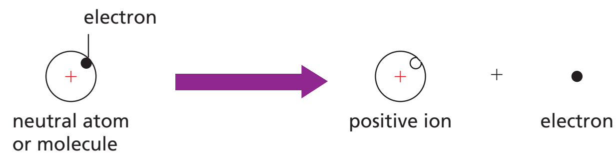


Figure 49.2 Ionisation

Geiger–Müller (GM) tube

The ionising effect is used to detect radiation.

When radiation enters a **GM tube** (Figure 49.3), either through a thin end-window made of mica, or, if the radiation is very penetrating, through the wall, it creates argon ions and electrons. These are accelerated towards the electrodes and cause more ionisation by colliding with other argon atoms.

On reaching the electrodes, the ions produce a current pulse which is amplified and fed either to a **scaler** or a **ratemeter**. A scaler counts the pulses and shows the total received in a certain time. A ratemeter gives the counts per second (or minute), or **count-rate**, directly. It usually has a loudspeaker which gives a 'click' for each pulse.

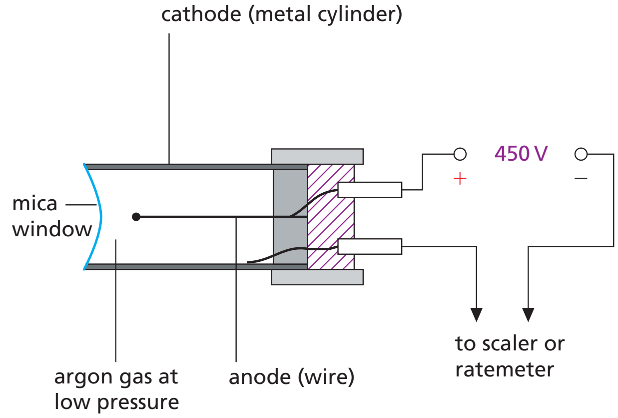


Figure 49.3 Geiger–Müller (GM) tube

Alpha, beta and gamma radiation

Experiments to study the penetrating power, ionising ability and behaviour of radiation in magnetic and electric fields show that a radioactive substance emits one or more of three types of radiation – called **alpha** (α), **beta** (β⁻ or β+) and **gamma** (γ) rays.

Penetrating power can be investigated as in Figure 49.4 by observing the effect on the count-rate of placing one of the following in turn between the GM tube and the lead sheet:

(i) a sheet of thick paper (the radium source, lead and tube must be close together for this part),
(ii) a sheet of aluminium 2 mm thick,
(iii) a further sheet of lead 2 cm thick.

Radium (Ra-226) emits α-particles, β-particles and γ-rays. Other sources can be tried, such as americium, strontium and cobalt.

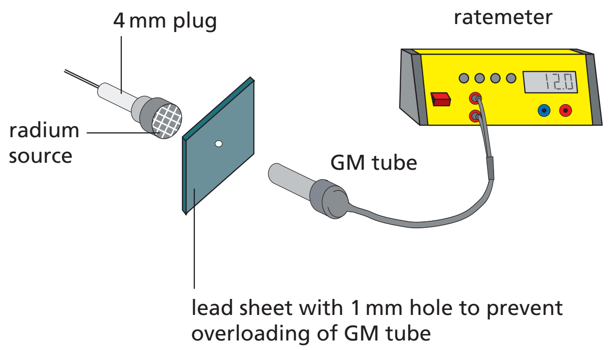


Figure 49.4 Investigating the penetrating power of radiation

a) Alpha particles

These are stopped by a thick sheet of paper and have a range in air of only a few centimetres since they cause intense ionisation in a gas due to frequent collisions with gas molecules. They are deflected by electric and strong magnetic fields in a direction and by an amount which suggests they are helium atoms minus two electrons, i.e. helium ions with a double positive charge. From a particular substance, they are all emitted with the same speed (about 1/20th of that of light).

Americium (Am-241) is a pure α source.

b) Beta particles

These are stopped by a few millimetres of aluminium and some have a range in air of several metres. Their ionising power is much less than that of α-particles. As well as being deflected by electric fields, they are more easily deflected by magnetic fields. Measurements show that β⁻-particles are streams of **high-energy electrons**, like cathode rays, emitted with a range of speeds up to that of light. Strontium (Sr-90) emits β⁻-particles only.

The magnetic deflection of β⁻-particles can be shown as in Figure 49.5. With the GM tube at A and without the magnet, the count-rate is noted. Inserting the magnet reduces the count-rate but it increases again when the GM tube is moved sideways to B.

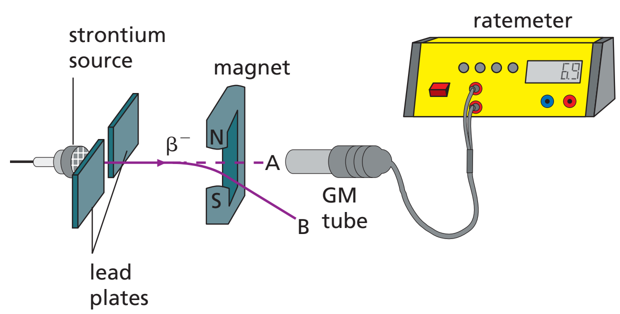


Figure 49.5 Demonstrating magnetic deflection of β⁻-particles

c) Gamma rays

These are the most penetrating and are stopped only by many centimetres of lead. They ionise a gas even less than β-particles and are not deflected by electric and magnetic fields. They give interference and diffraction effects and are electromagnetic radiation travelling at the speed of light. Their wavelengths are those of very short X-rays, from which they differ only because they arise in atomic nuclei whereas X-rays come from energy changes in the electrons outside the nucleus.

Cobalt (Co-60) emits γ-rays and β⁻-particles but can be covered with aluminium to provide pure γ-rays.

Comparing alpha, beta and gamma radiation

In a collision, α-particles, with their relatively large mass and charge, have more of a chance of knocking an electron from an atom and causing ionisation than the lighter β-particles; γ-rays, which have no charge, are even less likely than β-particles to produce ionisation.

A GM tube detects β-particles and γ-rays and energetic α-particles; a charged electroscope detects only α-particles. All three types of radiation cause fluorescence.

The behaviour of the three kinds of radiation in a magnetic field is summarised in Figure 49.6a. The deflections (not to scale) are found from Fleming's left-hand rule, taking negative charge moving to the right as equivalent to positive (conventional) current to the left.

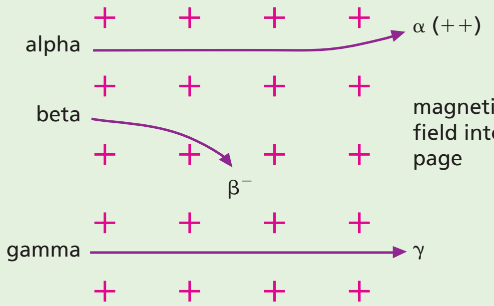


Figure 49.6a Deflection of α-, β- and γ-radiation in a magnetic field

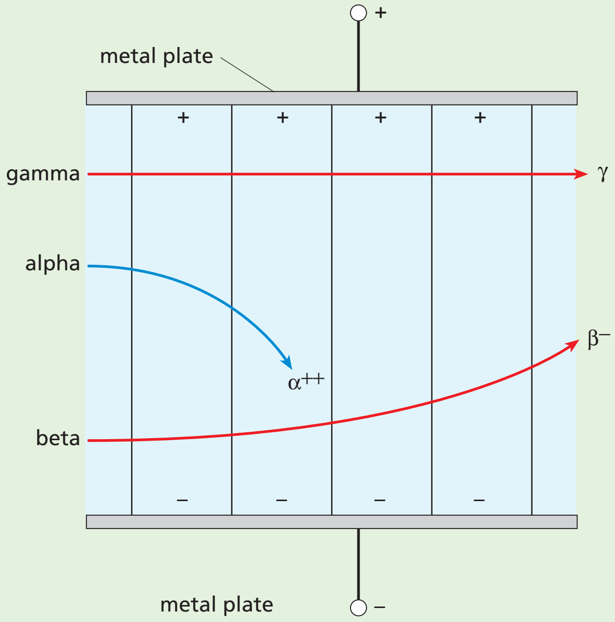


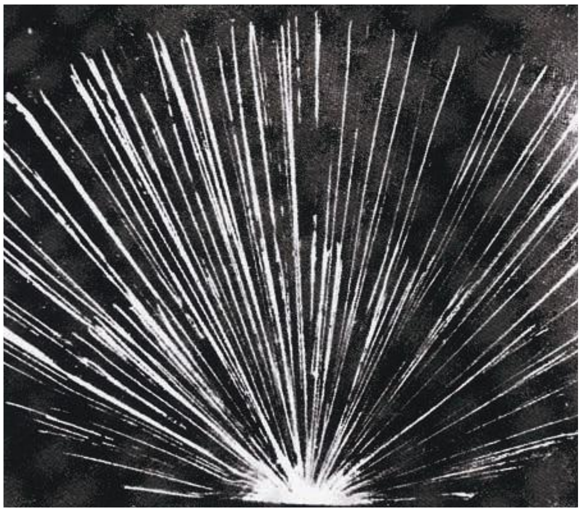
Figure 49.6b Deflection of α-, β- and γ-radiation in a uniform electric field

Figure 49.6b shows the behaviour of α-particles, β⁻-radiation and γ-rays in a uniform electric field: α-particles are attracted towards the negatively charged metal plate, β⁻-particles are attracted towards the positively charged plate and γ-rays pass through undeflected.

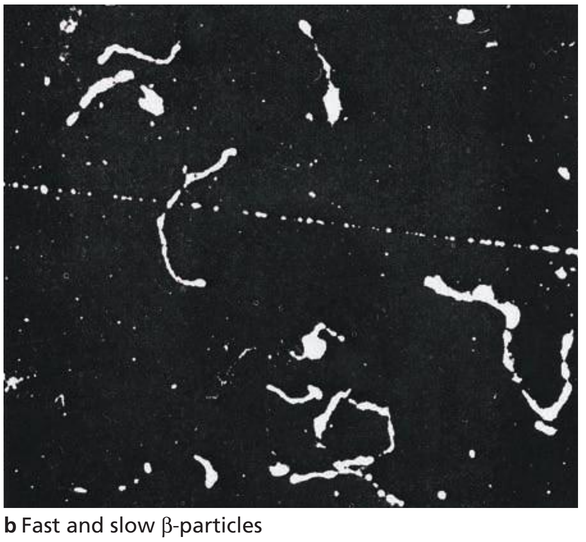
Particle tracks

The paths of particles of radiation were first shown up by the ionisation they produced in devices called **cloud chambers**. When air containing a vapour, alcohol, is cooled enough, saturation occurs. If ionising radiation passes through the air, further cooling causes the saturated vapour to condense on the ions created. The resulting white line of tiny liquid drops shows up as a track when illuminated.

In a **diffusion cloud chamber**, α-particles showed straight, thick tracks (Figure 49.7a). Very fast β-particles produced thin, straight tracks while slower ones gave short, twisted, thicker tracks (Figure 49.7b). Gamma-rays eject electrons from air molecules; the ejected electrons behaved like β⁻-particles in the cloud chamber and produced their own tracks spreading out from the γ-rays.



a α-particles



b Fast and slow β-particles

Figure 49.7 Tracks in a cloud chamber

The **bubble chamber**, in which the radiation leaves a trail of bubbles in liquid hydrogen, has now replaced the cloud chamber in research work. The higher density of atoms in the liquid gives better defined tracks, as shown in Figure 49.8, than obtained in a cloud chamber. A magnetic field is usually applied across the bubble chamber which causes charged particles to move in circular paths; the sign of the charge can be deduced from the way the path curves.

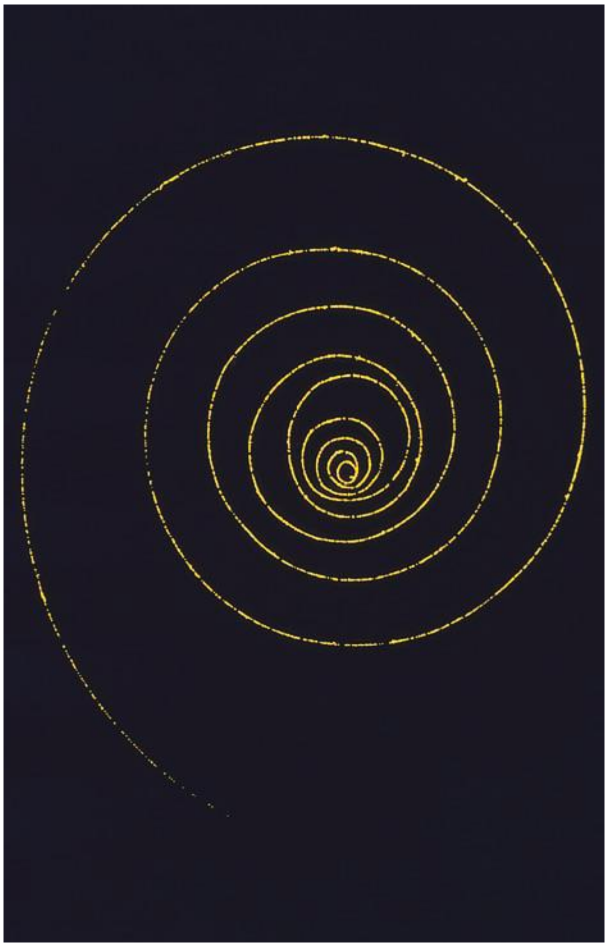


Figure 49.8 Charged particle track in a bubble chamber

Radioactive decay

Radioactive atoms have unstable nuclei and, when they emit α-particles or β-particles, they **decay** into atoms of different elements that have more stable nuclei. These changes are spontaneous and cannot be controlled; also, it does not matter whether the material is pure or combined chemically with something else.

Half-life

The **rate of decay** is unaffected by temperature but every radioactive element has its own definite decay rate, expressed by its **half-life**. This is the **average time for half the atoms in a given sample to decay**. It is difficult to know when a substance has lost all its radioactivity, but the time for its activity to fall to half its value can be found more easily.

Decay curve

The average number of disintegrations (i.e. decaying atoms) per second of a sample is its **activity**. If it is measured at different times (e.g. by finding the count-rate using a GM tube and ratemeter), a decay curve of activity against time can be plotted. The ideal curve for one element (Figure 49.9) shows that the activity decreases by the same fraction in successive equal time intervals. It falls from 80 to 40 disintegrations per second in 10 minutes, from 40 to 20 in the next 10 minutes, from 20 to 10 in the third 10 minutes and so on. The half-life is 10 minutes.

Half-lives vary from millionths of a second to millions of years. For radium it is 1600 years.

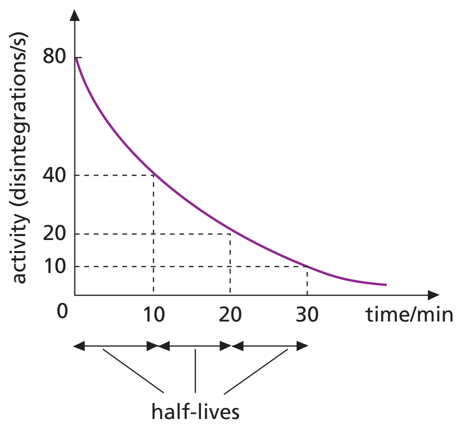


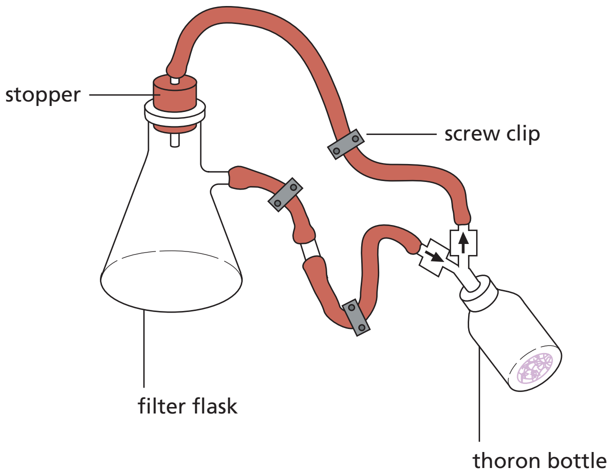
Figure 49.9 Decay curve

Experiment to find the half-life of thoron

The half-life of the α-emitting gas **thoron** can be found as shown in Figure 49.10. The thoron bottle is squeezed three or four times to transfer some thoron to the flask (Figure 49.10a). The clips are then closed, the bottle removed and the stopper replaced by a GM tube so that it seals the top (Figure 49.10b).

When the ratemeter reading has reached its maximum and started to fall, the count-rate is noted every 15 s for 2 minutes and then every 60 s for the next few minutes. (The GM tube is left in the flask for at least 1 hour until the radioactivity has decayed.)

A measure of the background radiation is obtained by recording the counts for a period (say 10 minutes) at a position well away from the thoron equipment. The count-rates in the thoron decay experiment are then corrected by subtracting the average background count-rate from each reading. A graph of the corrected count-rate against time is plotted and the half-life (52 s) estimated from it.



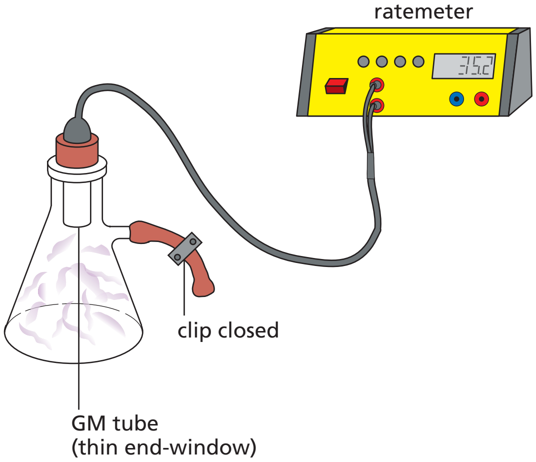


Figure 49.10

Random nature of decay

During the previous experiment it becomes evident that the count-rate varies irregularly: the loudspeaker of the ratemeter 'clicks' erratically, not at a steady rate. This is because radioactive decay is a **random** process, in that it is a matter of pure chance whether or not a particular atom will decay during a certain period of time. All we can say is that about half the atoms in a sample will decay during the half-life. We cannot say which atoms these will be, nor can we influence the process in any way. Radioactive emissions occur randomly over space and time.

● Uses of radioactivity

Radioactive substances, called **radioisotopes**, are now made in nuclear reactors and have many uses.

a) Thickness gauge

If a radioisotope is placed on one side of a moving sheet of material and a GM tube on the other, the count-rate decreases if the thickness increases. This technique is used to control automatically the thickness of paper, plastic and metal sheets during manufacture (Figure 49.11). Because of their range, β-emitters are suitable sources for monitoring the thickness of thin sheets but γ-emitters would be needed for thicker materials.

Flaws in a material can be detected in a similar way; the count-rate will increase where a flaw is present.

Figure 49.11 Quality control in the manufacture of paper using a radioactive gauge

b) Tracers

The progress of a small amount of a weak radioisotope injected into a system can be 'traced' by a GM tube or other detector. The method is used in medicine to detect brain tumours and internal bleeding, in agriculture to study the uptake of fertilisers by plants, and in industry to measure fluid flow in pipes.

A tracer should be chosen whose half-life matches the time needed for the experiment; the activity of the source is then low after it has been used and so will not pose an ongoing radiation threat. For medical purposes, where short exposures are preferable, the time needed to transfer the source from the production site to the patient also needs to be considered.

c) Radiotherapy

Gamma rays from strong cobalt radioisotopes are used in the treatment of cancer.

d) Sterilisation

Gamma rays are used to sterilise medical instruments by killing bacteria. They are also used to 'irradiate' certain foods, again killing bacteria to preserve the food for longer. They are safe to use as no radioactive material goes into the food.

e) Archaeology

A radioisotope of carbon present in the air, carbon-14, is taken in by living plants and trees along with non-radioactive carbon-12. When a tree dies no fresh carbon is taken in. So as the carbon-14 continues to decay, with a half-life of 5700 years, the amount of carbon-14 compared with the amount of carbon-12 becomes smaller. By measuring the residual radioactivity of carbon-containing material such as wood, linen or charcoal, the age of archaeological remains can be estimated within the range 1000 to 50 000 years (Figure 49.12). See Worked example 2, on p. 236.

The ages of rocks have been estimated in a similar way by measuring the ratio of the number of atoms of a radioactive element to those of its decay product in a sample. See Worked example 3, on p. 236.

Figure 49.12 The year of construction of this Viking ship has been estimated by radiocarbon techniques to be AD 800.

Dangers and safety

We are continually exposed to radiation from a range of sources, both natural ('background') and artificial, as indicated in Figure 49.13.

(i) Cosmic rays (high-energy particles from outer space) are mostly absorbed by the atmosphere and produce radioactivity in the air we breathe, but some reach the Earth's surface.

(ii) Numerous homes, particularly in Scotland, are built from granite rocks that emit radioactive radon gas; this can collect in basements or well-insulated rooms if the ventilation is poor.

(iii) Radioactive potassium-40 is present in food and is absorbed by our bodies.

(iv) Various radioisotopes are used in certain medical procedures.

(v) Radiation is produced in the emissions from nuclear power stations and in fall-out from the testing of nuclear bombs; the latter produce strontium isotopes with long half-lives which are absorbed by bone.

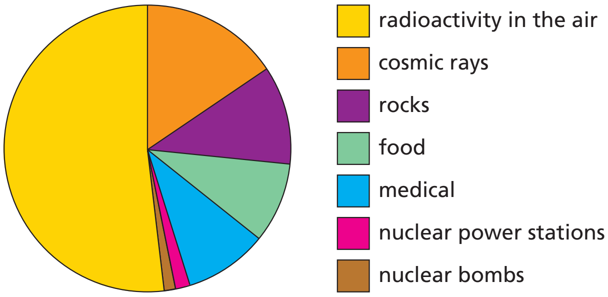


Figure 49.13 Radiation sources

We cannot avoid exposure to radiation in small doses but large doses can be dangerous to our health. The ionising effect produced by radiation causes damage to cells and tissues in our bodies and can also lead to the mutation of genes. The danger from α-particles is small, unless the source enters the body, but β- and γ-radiation can cause radiation burns (i.e. redness and sores on the skin) and delayed effects such as eye cataracts and cancer. Large exposures may lead to radiation sickness and death. The symbol used to warn of the presence of radioactive material is shown in Figure 49.14.

Figure 49.14 Radiation hazard sign

The increasing use of radioisotopes in medicine and industry has made it important to find ways of disposing of radioactive waste safely. One method is to enclose the waste in steel containers which are then buried in concrete bunkers; possible leakage is a cause of public concern, as water supplies could be contaminated allowing radioactive material to enter the food chain.

The weak sources used at school should always be:

- **lifted with forceps,**
- **held away from the eyes,** and
- **kept in their boxes when not in use**.

In industry, sources are handled by long tongs and transported in thick lead containers. Workers are protected by lead and concrete walls, and wear radiation dose badges that keep a check on the amount of radiation they have been exposed to over a period (usually one month). The badge contains several windows which allow different types of radiation to fall onto a photographic film; when the film is developed it is darkest where the exposure to radiation was greatest.

Worked examples

1 A radioactive source has a half-life of 20 minutes. What fraction is left after 1 hour?

After 20 minutes, fraction left = $1/2$
After 40 minutes, fraction left = $1/2 \times 1/2 = 1/4$
After 60 minutes, fraction left = $1/2 \times 1/4 = 1/8$

2 Carbon-14 has a half-life of 5700 years. A 10 g sample of wood cut recently from a living tree has an activity of 160 counts/minute. A piece of charcoal taken from a prehistoric campsite also weighs 10 g but has an activity of 40 counts/minute. Estimate the age of the charcoal.

After 1×5700 years the activity will be $160/2 = 80$ counts per minute
After 2×5700 years the activity will be $80/2 = 40$ counts per minute
The age of the charcoal is $2 \times 5700 = 11\,400$ years

3 The ratio of the number of atoms of argon-40 to potassium-40 in a sample of radioactive rock is analysed to be 1 : 3. Assuming that there was no potassium in the rock originally and that argon-40 decays to potassium-40 with a half-life of 1500 million years, estimate the age of the rock.

Assume there were N atoms of argon-40 in the rock when it was formed.

After 1×1500 million years there will be $N/2$ atoms of argon left and $N-(N/2) = N/2$ atoms of potassium formed, giving an Ar : K ratio of 1 : 1.

After $2 \times 1500 = 3000$ million years, there would be $(N/2)/2 = N/4$ argon atoms left and $N-(N/4) = 3N/4$ potassium atoms formed, giving an Ar : K ratio of 1 : 3 as measured.
The rock must be about 3000 million years old.

Questions

1 Which type of radiation from radioactive materials
   a has a positive charge?
   b is the most penetrating?
   c is easily deflected by a magnetic field?
   d consists of waves?
   e causes the most intense ionisation?
   f has the shortest range in air?
   g has a negative charge?
   h is not deflected by an electric field?

2 In an experiment to find the half-life of radioactive iodine, the count-rate falls from 200 counts per second to 25 counts per second in 75 minutes. What is its half-life?

3 If the half-life of a radioactive gas is 2 minutes, then after 8 minutes the activity will have fallen to a fraction of its initial value. This fraction is
   A 1/4 **B** 1/6 **C** 1/8 **D** 1/16 **E** 1/32

Checklist

After studying this chapter you should be able to

- recall that the radiation emitted by a radioactive substance can be detected by its ionising effect,
- explain the principle of operation of a Geiger–Müller tube and a diffusion cloud chamber,
- recall the nature of α-, β- and γ-radiation,
- describe experiments to compare the range and penetrating power of α-, β- and γ-radiation in different materials,
- recall the ionising abilities of α-, β- and γ-radiation and relate them to their ranges,
- predict how α-, β- and γ-radiation will be deflected in magnetic and electric fields,
- define the term half-life,
- describe an experiment from which a radioactive decay curve can be obtained,
- show from a graph that radioactive decay processes have a constant half-life,
- solve simple problems on half-life,
- recall that radioactivity is (a) a random process, (b) due to nuclear instability, (c) independent of external conditions,
- recall some uses of radioactivity,
- describe sources of radiation,
- discuss the dangers of radioactivity and safety precautions necessary.

50 Atomic structure

- Nuclear atom
- Protons and neutrons
- Isotopes and nuclides
- Radioactive decay
- Nuclear stability
- Models of the atom
- Nuclear energy

The discoveries of the electron and of radioactivity seemed to indicate that atoms contained negatively and positively charged particles and were not indivisible as was previously thought. The questions then were 'How are the particles arranged inside an atom?' and 'How many are there in the atom of each element?'

An early theory, called the 'plum-pudding' model, regarded the atom as a positively charged sphere in which the negative electrons were distributed all over it (like currants in a pudding) and in sufficient numbers to make the atom electrically neutral. Doubts arose about this model.

Nuclear atom

While investigating radioactivity, the physicist Rutherford noticed that not only could α-particles pass straight through very thin metal foil as if it weren't there but also that some were deflected from their initial direction. With the help of Geiger (of GM tube fame) and Marsden, Rutherford investigated this in detail at Manchester University using the arrangement in Figure 50.1. The fate of the α-particles after striking the gold foil was detected by the scintillations (flashes of light) they produced on a glass screen coated with zinc sulfide and fixed to a rotatable microscope.

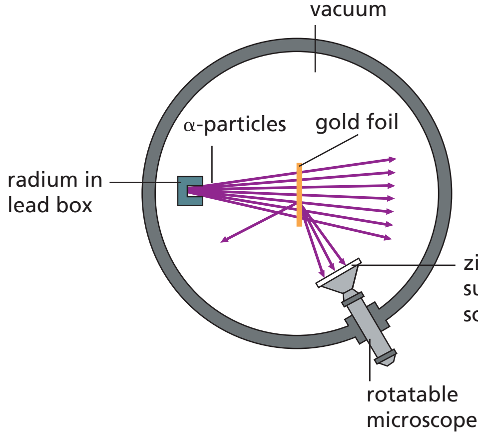


Figure 50.1 Geiger and Marsden's scattering experiment

They found that most of the α-particles were undeflected, some were scattered by appreciable angles and a few (about 1 in 8000) surprisingly 'bounced' back. To explain these results Rutherford proposed in 1911 a 'nuclear' model of the atom in which **all the positive charge and most of the mass of an atom** formed a dense core or **nucleus**, of very small size compared with the whole atom. The electrons surrounded the nucleus some distance away.

He derived a formula for the number of α-particles deflected at various angles, assuming that the electrostatic force of repulsion between the positive charge on an α-particle and the positive charge on the nucleus of a gold atom obeyed an inverse-square law (i.e. the force increases four times if the separation is halved). Geiger and Marsden's experimental results completely confirmed Rutherford's formula and supported the view that an atom is mostly empty space. In fact the nucleus and electrons occupy about one million millionth of the volume of an atom. Putting it another way, the nucleus is like a sugar lump in a very large hall and the electrons a swarm of flies.

Figure 50.2 shows the paths of three α-particles.

Particle 1 is clear of all nuclei and passes straight through the gold atoms.

Particle 2 is deflected slightly.

Particle 3 approaches a gold nucleus so closely that it is violently repelled by it and 'rebounds', appearing to have had a head-on 'collision'.

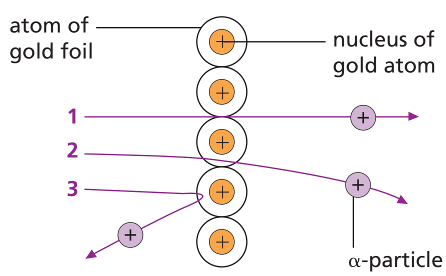


Figure 50.2 Electrostatic scattering of α-particles

Protons and neutrons

We now believe as a result of other experiments, in some of which α and other high-speed particles were used as 'atomic probes', that atoms contain three basic particles – protons, neutrons and electrons.

A **proton** is a hydrogen atom minus an electron, i.e. a positive hydrogen ion. Its charge is equal in size but opposite in sign to that of an electron but its mass is about 2000 times greater.

A **neutron** is uncharged with almost the same mass as a proton.

Protons and neutrons are in the nucleus and are called **nucleons**. Together they account for the mass of the nucleus (and most of that of the atom); the protons account for its positive charge. These facts are summarised in Table 50.1.

Table 50.1

Particle	Relative mass	Charge	Location
proton	1836	$+e$	in nucleus
neutron	1839	$+0$	in nucleus
electron	1	$-e$	outside nucleus

In a neutral atom the number of protons equals the number of electrons surrounding the nucleus. Table 50.2 shows the particles in some atoms. Hydrogen is simplest with one proton and one electron. Next is the inert gas helium with two protons, two neutrons and two electrons. The soft white metal lithium has three protons and four neutrons.

Table 50.2

	Hydrogen	Helium	Lithium	Oxygen	Copper
protons	1	2	3	8	29
neutrons	0	2	4	8	34
electrons	1	2	3	8	29

The atomic or proton number Z of an atom is the number of protons in the nucleus.

The **atomic number** is also the number of electrons in the atom. The electrons determine the chemical properties of an atom and when the elements are arranged in order of atomic number in the Periodic Table, they fall into chemical families.

In general, $A = Z + N$, where N is the **neutron number** of the element.

Atomic **nuclei** are represented by symbols. Hydrogen is written as ${}^{1}_{1}\mathrm{H}$, helium as ${}^{4}_{2}\mathrm{He}$ and lithium a ${}^{7}_{3}\mathrm{Li}$. In general atom X is written as ${}^{A}_{Z}\mathrm{X}$, where A is the nucleon number and Z the proton number.

The mass or nucleon number A of an atom is the number of nucleons in the nucleus.

Isotopes and nuclides

Isotopes of an element are atoms that have the same number of protons but different numbers of neutrons. That is, their proton numbers are the same but not their nucleon numbers.

Isotopes have identical chemical properties since they have the same number of electrons and occupy the same place in the Periodic Table. (In Greek, *isos* means same and *topos* means place.)

Few elements consist of identical atoms; most are mixtures of isotopes. Chlorine has two isotopes; one has 17 protons and 18 neutrons (i.e. $Z = 17$, $A = 35$) and is written ${}^{35}_{17}\mathrm{Cl}$, the other has 17 protons and 20 neutrons (i.e. $Z = 17$, $A = 37$) and is written ${}^{37}_{17}\mathrm{Cl}$. They are present in ordinary chlorine in the ratio of three atoms of ${}^{35}_{17}\mathrm{Cl}$ to one atom of ${}^{37}_{17}\mathrm{Cl}$, giving chlorine an average atomic mass of 35.5.

Hydrogen has three isotopes: ${}^{1}_{1}\mathrm{H}$ with one proton, **deuterium** ${}^{2}_{1}\mathrm{D}$ with one proton and one neutron and **tritium** ${}^{3}_{1}\mathrm{T}$ with one proton and two neutrons. Ordinary hydrogen consists 99.99 per cent of ${}^{1}_{1}\mathrm{H}$ atoms. Water made from deuterium is called 'heavy water' (D_2O); it has a density of 1.108 g/cm³, it freezes at 3.8 °C and boils at 101.4 °C.

Each form of an element is called a **nuclide**. Nuclides with the same Z number but different A numbers are isotopes. Radioactive isotopes are termed **radioisotopes** or **radionuclides**; their nuclei are unstable.

Radioactive decay

Radioactive atoms have unstable nuclei which change or 'decay' into atoms of a different element when they emit α- or β-particles. The decay is spontaneous and cannot be controlled; also it does not matter whether the material is pure or combined chemically with something else.

a) Alpha decay

An α-particle is a helium nucleus, having two protons and two neutrons, and when an atom decays by emission of an α-particle, its nucleon number decreases by four and its proton number by two. For example, when radium of nucleon number 226 and proton number 88 emits an α-particle, it decays to radon of nucleon number 222 and proton number 86. We can write:

$$^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$

The values of A and Z must balance on both sides of the equation since nucleons and charge are conserved.

b) Beta decay

In β^- decay a neutron changes to a proton and an electron. The proton remains in the nucleus and the electron is emitted as a β^--particle. The new nucleus has the same nucleon number, but its proton number increases by one since it has one more proton. Radioactive carbon, called carbon-14, decays by β^- emission to nitrogen:

$$^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\text{e}$$

A particle called an **antineutrino** ($\bar{\nu}$), with no charge and negligible mass, is also emitted in β^- decay. Note that a β^- decay is often referred to as just a β decay.

Positrons are subatomic particles with the same mass as an electron but with opposite (positive) charge. They are emitted in some decay processes as β^+-particles. Their tracks can be seen in bubble chamber photographs. The symbol for a positron is ${}^{0}_{+1}\text{e}$. In β^+- decay a proton in a nucleus is converted to a neutron and a positron, for example in the reaction:

$$^{64}_{29}\text{Cu} \rightarrow {}^{64}_{28}\text{N} + {}^{0}_{+1}\text{e}$$

A **neutrino** (ν) is also emitted in β^+ decay. Neutrinos are emitted from the Sun in large numbers, but they rarely interact with matter so are very difficult to detect. Antineutrinos and positrons are the 'antiparticles' of neutrinos and electrons, respectively. If a particle and its antiparticle collide, they annihilate each other, producing energy in the form of γ-rays.

c) Gamma emission

After emitting an α-particle, or β^-- or β^+-particles, some nuclei are left in an 'excited' state. Rearrangement of the protons and neutrons occurs and a burst of γ-rays is released.

Nuclear stability

The stability of a nucleus depends on both the number of protons (Z) and the number of neutrons (N) it contains. Figure 50.3 is a plot of N against Z for all known nuclides. The blue band indicates the region over which stable nuclides occur; unstable nuclides occur outside this band. The continuous line, drawn through the centre of the band, is called the stability line.

It is found that for **stable nuclides**:

(i) $N = Z$ for the lightest,
(ii) $N > Z$ for the heaviest,
(iii) most nuclides have *even* N and Z, implying that the α-particle combination of two neutrons and two protons is likely to be particularly stable.

For **unstable nuclides**:

(i) disintegration tends to produce new nuclides nearer the stability line and continues until a stable nuclide is formed,
(ii) a nuclide above the stability line decays by β^- emission (a neutron changes to a proton and electron) so that the N/Z ratio decreases,
(iii) a nuclide below the stability line decays by β^+ emission (a proton changes to a neutron and positron) so that the N/Z ratio increases,
(iv) nuclei with more than 82 protons usually emit an α-particle when they decay.

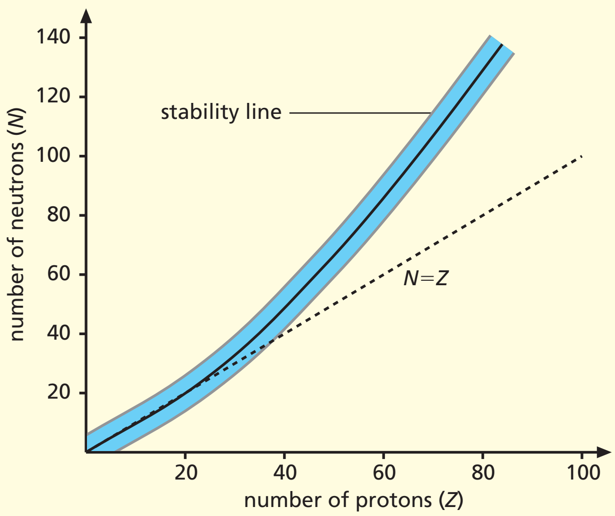


Figure 50.3 Stability of nuclei

Models of the atom

Rutherford–Bohr model

Shortly after Rutherford proposed his nuclear model of the atom, Bohr, a Danish physicist, developed it to explain how an atom emits light. He suggested that the electrons circled the nucleus at high speed, being kept in certain orbits by the electrostatic attraction of the nucleus for them. He pictured atoms as miniature solar systems. Figure 50.4 shows the model for three elements.

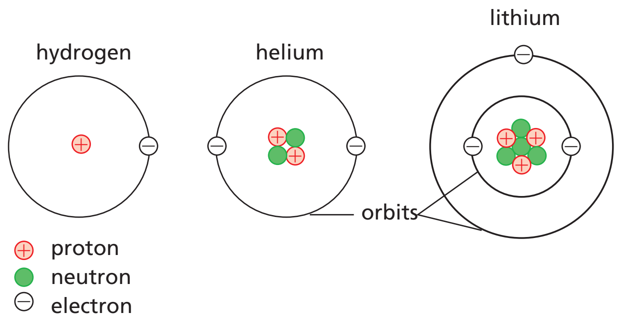


Figure 50.4 Electron orbits

Normally the electrons remain in their orbits but if the atom is given energy, for example by being heated, electrons may jump to an outer orbit. The atom is then said to be **excited**. Very soon afterwards the electrons return to an inner orbit and, as they do, they emit energy in the form of bursts of electromagnetic radiation (called **photons**), such as infrared light, ultraviolet or X-rays (Figure 50.5). The wavelength of the radiation emitted depends on the two orbits between which the electrons jump. If an atom gains enough energy for an electron to escape altogether, the atom becomes an ion and the energy needed to achieve this is called the **ionisation energy** of the atom.

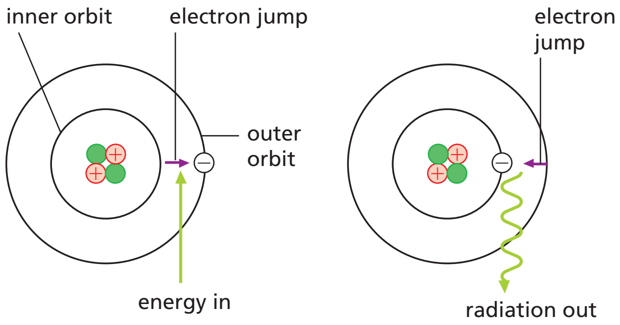


Figure 50.5 Bohr's explanation of energy changes in an atom

Schrödinger model

Although it remains useful for some purposes, the Rutherford–Bohr model was replaced by a mathematical model developed by Erwin Schrödinger, which is not easy to picture. The best we can do, without using advanced mathematics, is to say that the atom consists of a nucleus surrounded by a hazy cloud of electrons. Regions of the atom where the mathematics predicts that electrons are more likely to be found are represented by denser shading (Figure 50.6).

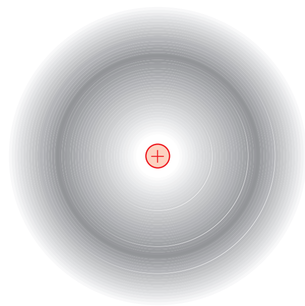


Figure 50.6 Electron cloud

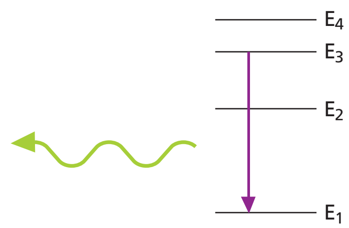


Figure 50.7 Energy levels of an atom

This theory does away with the idea of electrons moving in definite orbits and replaces them by **energy levels** that are different for each element. When an electron 'jumps' from one level, say E_3 in Figure 50.7, to a lower one E_1, a photon of electromagnetic radiation is emitted with energy equal to the difference in energy of the two levels. The frequency (and wavelength) of the radiation emitted by an atom is thus dependent on the arrangement of energy levels. For an atom emitting visible light, the resulting **spectrum** (produced for example by a prism) is a series of coloured **lines** that is unique to each element. Sodium vapour in a gas discharge tube (such as a yellow street light) gives two adjacent yellow–orange lines (Figure 50.8a). Light from the Sun is due to energy changes in many different atoms and the resulting spectrum is a **continuous** one with all colours (see Figure 50.8b).

Figure 50.8a Line spectrum due to energy changes in sodium

Figure 50.8b A continuous spectrum

Nuclear energy

a) $E = mc^2$

Einstein predicted that if the energy of a body changes by an amount E, its mass changes by an amount m given by the equation

$$E = mc^2$$

where c is the speed of light (3×10^8 m/s). The implication is that any reaction in which there is a decrease of mass, called a **mass defect**, is a source of energy. The energy and mass changes in physical and chemical changes are very small; those in some nuclear reactions, Such as radioactive decay, are millions of times greater. It appears that mass (matter) is a very concentrated form of energy.

b) Fission

The heavy metal uranium is a mixture of isotopes of which $^{235}_{92}U$, called uranium-235, is the most important. Some atoms of this isotope decay quite naturally, emitting high-speed neutrons. If one of these hits the nucleus of a neighbouring uranium-235 atom (being uncharged the neutron is not repelled by the nucleus), this may break (**fission** of the nucleus) into two nearly equal radioactive nuclei, often of barium and krypton, with the production of two or three more neutrons:

$$\underset{}{^{235}_{92}U} + \underset{\text{neutron}}{^{1}_{0}n} \rightarrow \underbrace{^{144}_{56}Ba + ^{90}_{36}Kr}_{\text{fission fragments}} + \underset{\text{neutrons}}{2\,^{1}_{0}n}$$

The mass defect is large and appears mostly as k.e. of the fission fragments. These fly apart at great speed, colliding with surrounding atoms and raising their average k.e., i.e. their temperature, so producing heat.

If the fission neutrons split other uranium-235 nuclei, a **chain reaction** is set up (Figure 50.9). In practice some fission neutrons are lost by escaping from the surface of the uranium before this happens. The ratio of those causing fission to those escaping increases as the mass of uranium-235 increases. This must exceed a certain **critical** value to sustain the chain reaction.

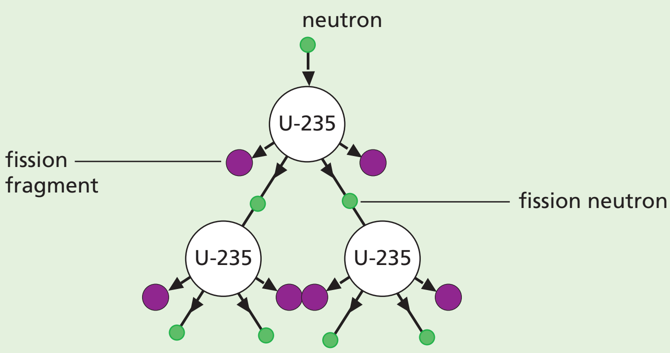


Figure 50.9 Chain reaction

c) Nuclear reactor

In a nuclear power station heat from a nuclear reactor produces the steam for the turbines. Figure 50.10 is a simplified diagram of one type of reactor.

The chain reaction occurs at a steady rate which is controlled by inserting or withdrawing neutron-absorbing rods of boron among the uranium rods. The graphite core is called the **moderator** and slows down the fission neutrons; fission of uranium-235 occurs more readily with slow than with fast neutrons. Carbon dioxide gas is pumped through the core and carries off heat to the **heat exchanger** where steam is produced. The concrete shield gives workers protection from γ-rays and escaping neutrons. The radioactive fission fragments must be removed periodically if the nuclear fuel is to be used efficiently.

In an **atomic bomb**, an increasing uncontrolled chain reaction occurs when two pieces of uranium-235 come together and exceed the critical mass.

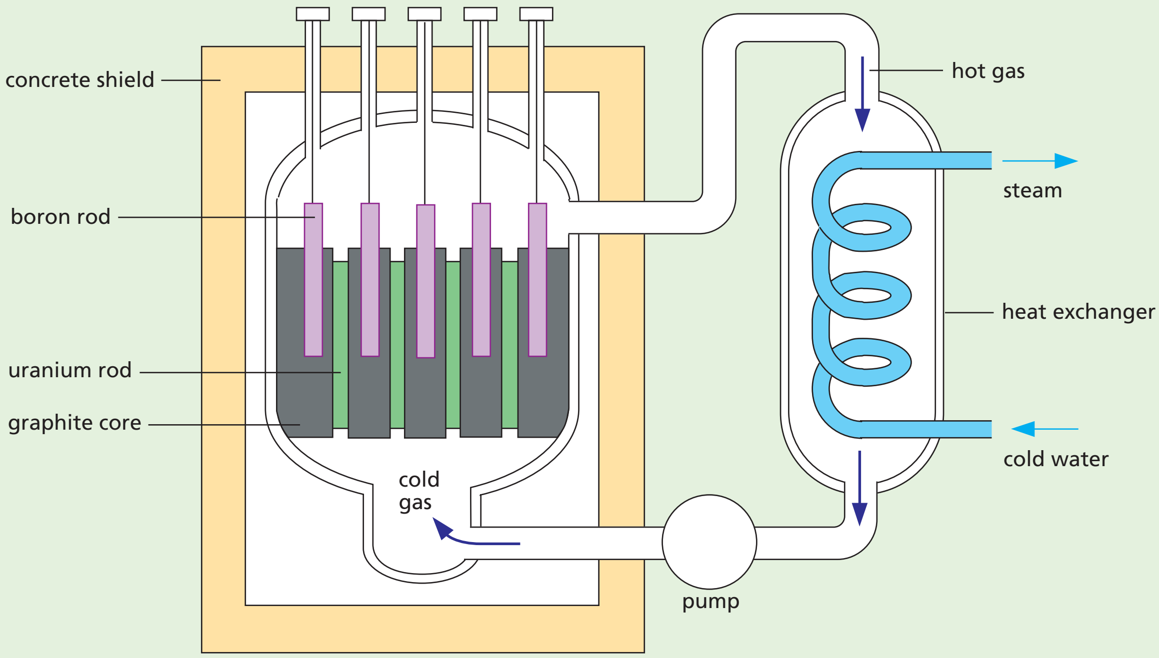


Figure 50.10 Nuclear reactor

d) Fusion

If light nuclei join together to make heavier ones, this can also lead to a loss of mass and, as a result, the release of energy. Such a reaction has been achieved in the **hydrogen bomb**. At present, research is being done on the controlled **fusion** of isotopes of hydrogen (deuterium and tritium) to give helium.

$$\underset{\text{deuterium}}{{}^{2}_{1}\mathrm{H}} + \underset{\text{tritium}}{{}^{3}_{1}\mathrm{H}} \rightarrow \underset{\text{helium}}{{}^{4}_{2}\mathrm{He}} + \underset{\text{neutron}}{{}^{1}_{0}\mathrm{n}}$$

Fusion can only occur if the reacting nuclei have enough energy to overcome their mutual electrostatic repulsion. This can happen if they are raised to a very high temperature (over 100 million °C) so that they collide at very high speeds. If fusion occurs, the energy released is enough to keep the reaction going; since heat is required, it is called **thermonuclear** fusion.

The source of the Sun's energy is nuclear fusion. The temperature in the Sun is high enough for the conversion of hydrogen into helium to occur, in a sequence of thermonuclear fusion reactions known as the 'hydrogen burning' sequence.

$${}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{2}_{1}\mathrm{H} + \text{positron } ({}^{1}_{0}\mathrm{e}) + \text{neutrino } (\nu)$$

$${}^{1}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + \gamma\text{-ray}$$

$${}^{3}_{2}\mathrm{He} + {}^{3}_{2}\mathrm{He} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H}$$

Each of these fusion reactions results in a loss of mass and a release of energy. Overall, tremendous amounts of energy are created that help to maintain the very high temperature of the Sun.

Questions

1 Which one of the following statements is *not* true?
   A An atom consists of a tiny nucleus surrounded by orbiting electrons.
   B The nucleus always contains protons and neutrons, called nucleons, in equal numbers.
   C A proton has a positive charge, a neutron is uncharged and their mass is about the same.
   D An electron has a negative charge of the same size as the charge on a proton but it has a much smaller mass.
   E The number of electrons equals the number of protons in a normal atom.

2 A lithium atom has a nucleon (mass) number of 7 and a proton (atomic) number of 3.
   1 Its symbol is $^{7}_{4}\mathrm{Li}$.
   2 It contains three protons, four neutrons and three electrons.
   3 An atom containing three protons, three neutrons and three electrons is an isotope of lithium.
   Which statement(s) is (are) correct?
   A 1, 2, 3 **B** 1, 2 **C** 2, 3 **D** 1 **E** 3

Checklist

After studying this chapter you should be able to

- describe how Rutherford and Bohr contributed to views about the structure of the atom,
- describe the Geiger–Marsden experiment which established the nuclear model of the atom,
- recall the charge, relative mass and location in the atom of protons, neutrons and electrons,
- define the terms proton number (Z), neutron number (N) and nucleon number (A), and use the equation $A=Z+N$,
- explain the terms isotope and nuclide and use symbols to represent them, e.g. $^{35}_{17}\mathrm{Cl}$,
- write equations for radioactive decay and interpret them,
- connect the release of energy in a nuclear reaction with a change of mass according to the equation $E=mc^2$,
- outline the process of fission,
- outline the process of fusion.

Revision questions

General physics

Measurements and motion

1 Which are the basic SI units of mass, length and time?

A kilogram, kilometre, second
B gram, centimetre, minute
C kilogram, centimetre, second
D gram, centimetre, second
E kilogram, metre, second

2 Density can be calculated from the expression

A mass/volume
B mass × volume
C volume/mass
D weight/area
E area × weight

3 Which of the following properties are the same for an object on Earth and on the Moon?

1 weight **2** mass **3** density

Use the answer code:

A 1, 2, 3 **B** 1, 2 **C** 2, 3 **D** 1 **E** 3

4 a The smallest division marked on a metre rule is 1 mm. A student measures a length with the ruler and records it as 0.835 m. Is he justified in giving three significant figures?

b The SI unit of density is

A kg m **B** kg/m^2 **C** $kg\,m^3$
D kg/m **E** kg/m^3

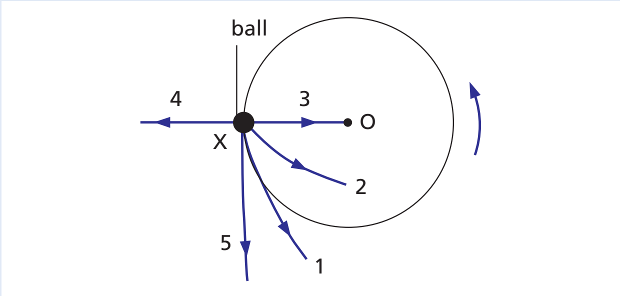
Forces and momentum

5 A 3 kg mass falls with its terminal velocity. Which of the combinations **A** to **E** gives its weight, the air resistance and the resultant force acting on it?

	Weight	Air resistance	Resultant force
A	0.3 N down	zero	zero
B	3 N down	3 N up	3 N up
C	10 N down	10 N up	10 N down
D	30 N down	30 N up	zero
E	300 N down	zero	300 N down

6 A boy whirls a ball at the end of a string round his head in a horizontal circle, centre O. He lets go of the string when the ball is at X in the diagram. In which direction does the ball fly off?

A 1 **B** 2 **C** 3 **D** 4 **E** 5



Energy, work, power and pressure

7 The work done by a force is

1 calculated by multiplying the force by the distance moved in the direction of the force
2 measured in joules
3 the amount of the energy changed.

Which statement(s) is (are) correct?

A 1, 2, 3 **B** 1, 2 **C** 2, 3 **D** 1 **E** 3

8 The main energy change occurring in the device named is

1 electric lamp — electrical to heat and light
2 battery — chemical to electrical
3 pile driver — k.e. to p.e.

Which statement(s) is (are) correct?

A 1, 2, 3 **B** 1, 2 **C** 2, 3 **D** 1 **E** 3

9 The efficiency of a machine which raises a load of 200 N through 2 m when an effort of 100 N moves 8 m is

A 0.5% **B** 5% **C** 50%
D 60% **E** 80%

10 Which one of the following statements is not true?

A Pressure is the force acting on unit area.
B Pressure is calculated from force/area.
C The SI unit of pressure is the pascal (Pa) which equals 1 newton per square metre ($1\,N/m^2$).
D The greater the area over which a force acts the greater is the pressure.
E Force = pressure × area.

11 A stone of mass 2 kg is dropped from a height of 4 m. Neglecting air resistance, the kinetic energy (k.e.) of the stone in joules just before it hits the ground is
A 6 **B** 8 **C** 16 **D** 80 **E** 160

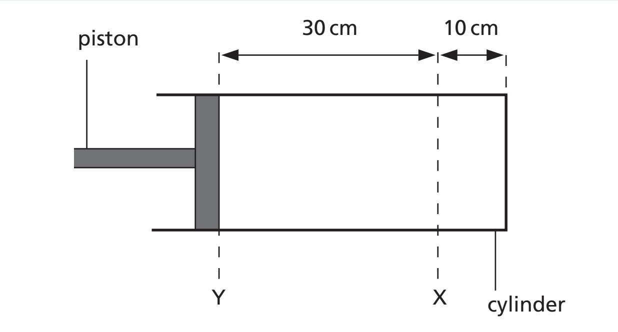
12 An object of mass 2 kg is fired vertically upwards with a k.e. of 100 J. Neglecting air resistance, which of the numbers in **A** to **E** below is
a the velocity in m/s with which it is fired,
b the height in m to which it will rise?
A 5 **B** 10 **C** 20 **D** 100 **E** 200

13 An object has k.e. of 10 J at a certain instant. If it is acted on by an opposing force of 5 N, which of the numbers **A** to **E** below is the furthest distance it travels in metres before coming to rest?
A 2 **B** 5 **C** 10 **D** 20 **E** 50

2 Thermal physics

Thermal properties and temperature

14 If the piston in the diagram is pulled out of the cylinder from position X to position Y, without changing the temperature of the air enclosed, the air pressure in the cylinder is
A reduced to a quarter
B reduced to a third
C the same
D trebled
E quadrupled.



15 Which one of the following statements is *not* true?
A Temperature tells us how hot an object is.
B Temperature is measured by a thermometer which uses some property of matter (e.g. the expansion of mercury) that changes continuously with temperature.
C Heat flows naturally from an object at a lower temperature to one at a higher temperature.
D The molecules of an object move faster when its temperature rises.
E Temperature is measured in °C, heat is measured in joules.

16 The pressure exerted by a gas in a container
1 is due to the molecules of the gas bombarding the walls of the container
2 decreases if the gas is cooled
3 increases if the volume of the container increases.
Which statement(s) is (are) correct?
A 1, 2, 3 **B** 1, 2 **C** 2, 3 **D** 1 **E** 3

17 A drink is cooled more by ice at 0 °C than by the same mass of water at 0 °C because ice
A floats on the drink
B has a smaller specific heat capacity
C gives out latent heat to the drink as it melts
D absorbs latent heat from the drink to melt
E is a solid.

Thermal processes

18 Which of the following statements is/are true?
1 In cold weather the wooden handle of a saucepan feels warmer than the metal pan because wood is a better conductor of heat.
2 Convection occurs when there is a change of density in parts of a fluid.
3 Conduction and convection cannot occur in a vacuum.
A 1, 2, 3 **B** 1, 2 **C** 2, 3 **D** 1 **E** 3

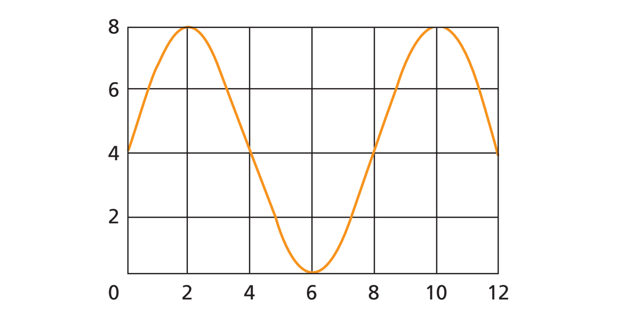
19 Which one of the following statements is *not* true?
A Energy from the Sun reaches the Earth by radiation only.
B A dull black surface is a good absorber of radiation.
C A shiny white surface is a good emitter of radiation.
D The best heat insulation is provided by a vacuum.
E A vacuum flask is designed to reduce heat loss or gain by conduction, convection and radiation.

3 Properties of waves

General wave properties

20 In the transverse wave shown below distances are in centimetres. Which pair of entries A to E is correct?

	A	B	C	D	E
Amplitude	2	4	4	8	8
Wavelength	4	4	8	8	12

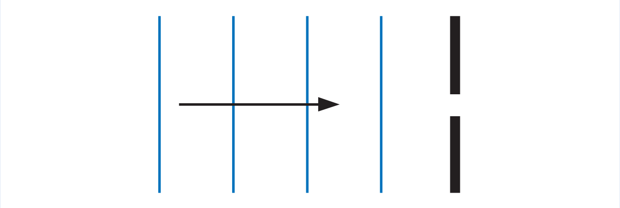


21 When a water wave goes from deep to shallow water, the changes (if any) in its speed, wavelength and frequency are

	Speed	Wavelength	Frequency
A	greater	greater	the same
B	greater	less	less
C	the same	less	greater
D	less	the same	less
E	less	less	the same

22 When the straight water waves in the diagram pass through the narrow gap in the barrier they are diffracted. What changes (if any) occur in

a the shape of the waves,
b the speed of the waves,
c the wavelength?

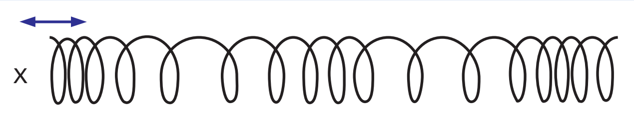


23 The diagram below shows the complete electromagnetic spectrum.

radio waves	microwaves	**A**	visible light	ultraviolet	**B**	γ rays

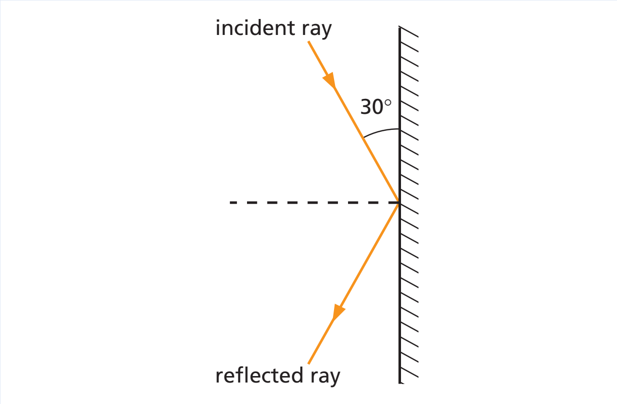
a Name the radiation found at
(i) **A**,
(ii) **B**.
b State which of the radiations marked on the diagram would have
(i) the lowest frequency,
(ii) the shortest wavelength.

24 The wave travelling along the spring in the diagram is produced by someone moving end X of the spring to and fro in the directions shown by the arrows.
a Is the wave longitudinal or transverse?
b What is the region called where the coils of the spring are **(i)** closer together, **(ii)** further apart, than normal?

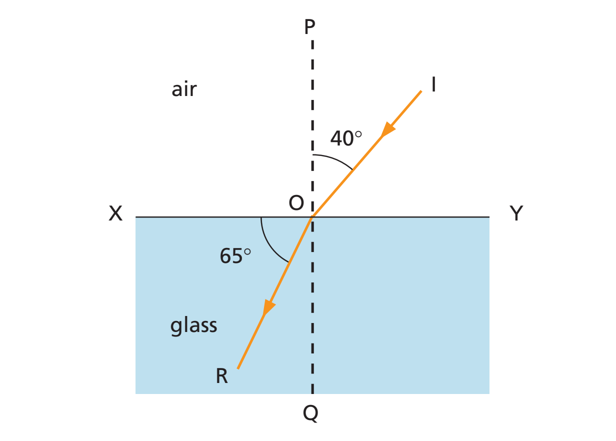


Light

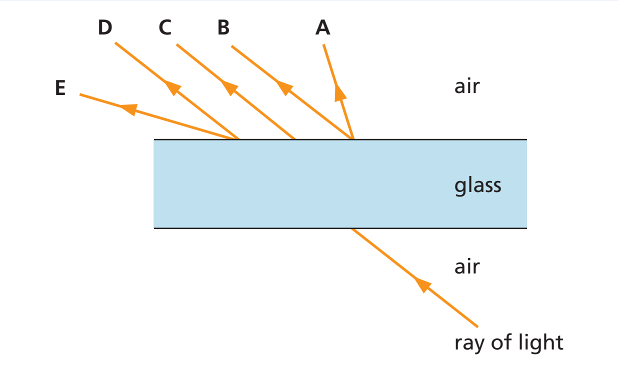
25 In the diagram a ray of light is shown reflected at a plane mirror. What is
a the angle of incidence,
b the angle the reflected ray makes with the mirror?



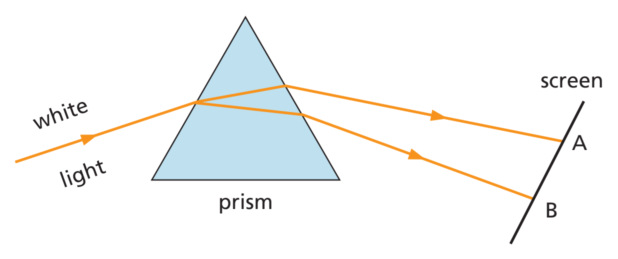
26 In the diagram below a ray of light IO changes direction as it enters glass from air.
a What name is given to this effect?
b Which line is the normal?
c Is the ray bent towards or away from the normal in the glass?
d What is the value of the angle of incidence in air?
e What is the value of the angle of refraction in glass?



27 In the diagram, which of the rays **A** to **E** is most likely to represent the ray emerging from the parallel-sided sheet of glass?



28 A narrow beam of white light is shown passing through a glass prism and forming a spectrum on a screen.
a What is the effect called?
b Which colour of light appears at **(i)** A, **(ii)** B?

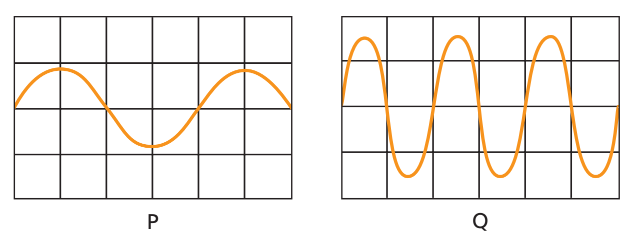


29 When using a magnifying glass to see a small object
1 an upright image is seen
2 the object should be less than one focal length away
3 a real image is seen.
Which statement(s) is (are) correct?
A 1, 2, 3 **B** 1, 2 **C** 2, 3 **D** 1 **E** 3

Sound

30 If a note played on a piano has the same pitch as one played on a guitar, they have the same
A frequency **B** amplitude
C quality **D** loudness
E harmonics.

31 The waveforms of two notes P and Q are shown below. Which one of the statements **A** to **E** is true?



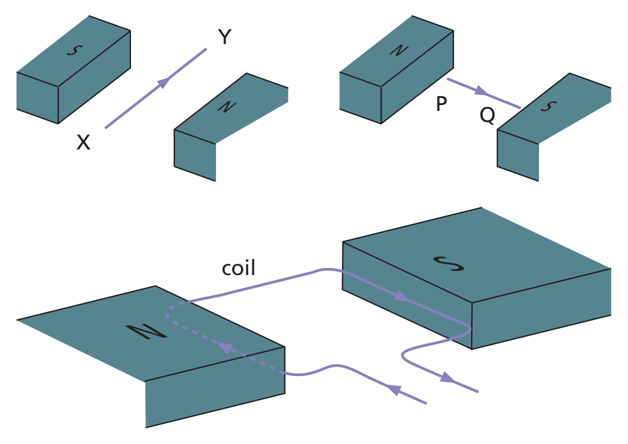
A P has a higher pitch than Q and is not so loud.
B P has a higher pitch than Q and is louder.
C P and Q have the same pitch and loudness.
D P has a lower pitch than Q and is not so loud.
E P has a lower pitch than Q and is louder.

32 Examples of transverse waves are
1 water waves in a ripple tank
2 all electromagnetic waves
3 sound waves.
Which statement(s) is (are) correct?
A 1, 2, 3 **B** 1, 2 **C** 2, 3 **D** 1 **E** 3

4 Electricity and magnetism

Simple phenomena of magnetism

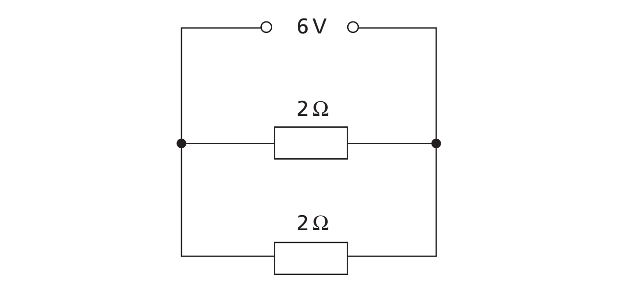
33 Which one of the following statements about the diagram below is *not* true?



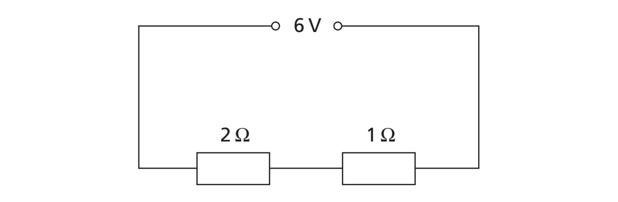
A If a current is passed through the wire XY, a vertically upwards force acts on it.
B If a current is passed through the wire PQ, it does not experience a force.
C If a current is passed through the coil, it rotates clockwise.
D If the coil had more turns and carried a larger current, the turning effect would be greater.
E In a moving-coil loudspeaker a coil moves between the poles of a strong magnet.

Electrical quantities and circuits

34 For the circuit below calculate
a the total resistance,
b the current in each resistor,
c the p.d. across each resistor.



35 Repeat question 33 for the circuit below.

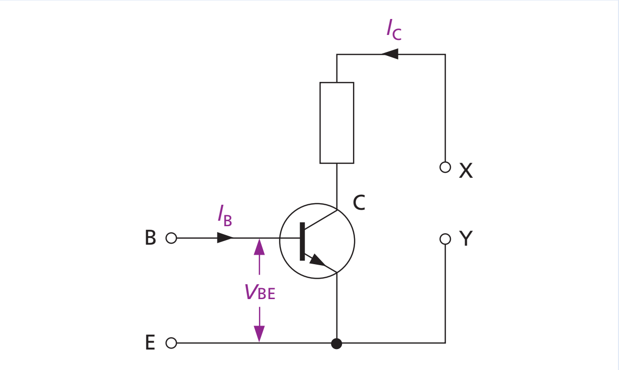


36 An electric kettle for use on a 230 V supply is rated at 3000 W. For safe working, the cable supplying it should be able to carry at least
A 2 A **B** 5 A **C** 10 A **D** 15 A **E** 30 A

37 Which one of the following statements is *not* true?
A In a house circuit, lamps are wired in parallel.
B Switches, fuses and circuit breakers should be placed in the neutral wire.
C An electric fire has its earth wire connected to the metal case to prevent the user receiving a shock.
D When connecting a three-core cable to a 13 A three-pin plug the brown wire goes to the live pin.
E The cost of operating three 100 W lamps for 10 hours at 10p per unit is 30p.

38 Which of the units **A** to **E** could be used to measure
a electric charge,
b electric current,
c p.d.,
d energy,
e power?
A ampere **B** joule **C** volt **D** watt
E coulomb

39 Which one of the following statements about the transistor circuit shown below is *not* true?



A The collector current I_C is zero until base current I_B flows.
B I_B is zero until the base–emitter p.d. V_{BE} is +0.6 V.
C A small I_B can switch on and control a large I_C.
D When used as an amplifier the input is connected across B and E.
E X must be connected to supply the – terminal and Y to the + terminal.

Electromagnetic effects

40 A magnet is pushed, N pole first, into a coil as in the diagram below. Which one of the following statements **A** to **E** is *not* true?

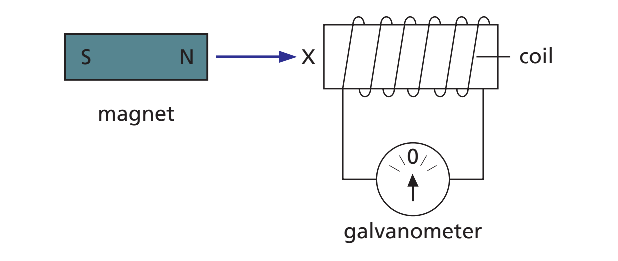
A A p.d. is induced in the coil and causes a current through the galvanometer.

B The induced p.d. increases if the magnet is pushed in faster and/or the coil has more turns.

C Mechanical energy is changed to electrical energy.

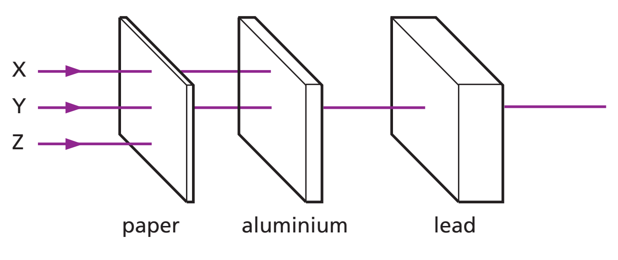
D The coil tends to move to the right because the induced current makes face X a N pole which is repelled by the N pole of the magnet.

E The effect produced is called electrostatic induction.



5 Atomic physics

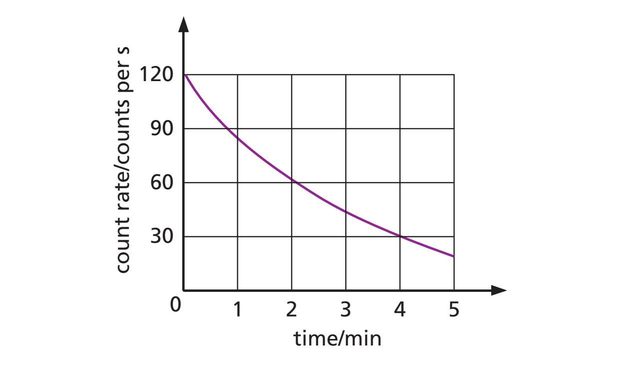
41 The diagram shows three types of radiation, X, Y and Z.



Which of the columns **A** to **E** correctly names the radiations X, Y and Z?

	A	B	C	D	E
X	alpha	beta	gamma	gamma	beta
Y	beta	alpha	alpha	beta	gamma
Z	gamma	gamma	beta	alpha	alpha

42 The graph shows the decay curve of a radioactive substance.



What is its half-life in minutes?

A 1 **B** 2 **C** 3 **D** 4 **E** 5

43 A radioactive source which has a half-life of 1 hour gives a count-rate of 100 counts per second at the start of an experiment and 25 counts per second at the end. The time taken by the experiment was, in hours,

A 1 **B** 2 **C** 3 **D** 4 **E** 5

44 Which symbol **A** to **E** below is used in equations for nuclear reactions to represent

a an alpha particle,

b a beta particle,

c a neutron,

d an electron?

A ${}^{0}_{-1}e$ **B** ${}^{1}_{0}n$ **C** ${}^{4}_{2}He$ **D** ${}^{1}_{-1}e$ **E** ${}^{1}_{1}n$

45 **a** Radon ${}^{220}_{86}Rn$ decays by emitting an alpha particle to form an element whose symbol is

A ${}^{216}_{85}At$ **B** ${}^{216}_{86}Rn$ **C** ${}^{218}_{84}Po$

D ${}^{216}_{84}Po$ **E** ${}^{217}_{85}At$

b Thorium ${}^{234}_{90}Th$ decays by emitting a beta particle to form an element whose symbol is

A ${}^{235}_{90}Th$ **B** ${}^{230}_{89}Ac$ **C** ${}^{234}_{89}Ac$

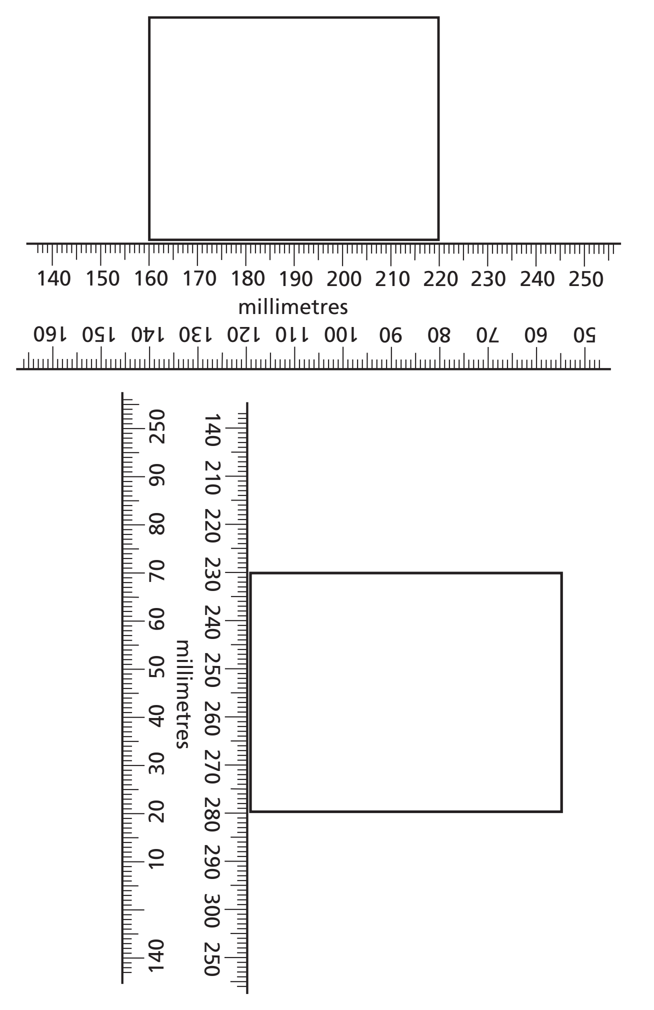
D ${}^{232}_{88}Ra$ **E** ${}^{234}_{91}Pa$

Cambridge IGCSE exam questions

1 General physics

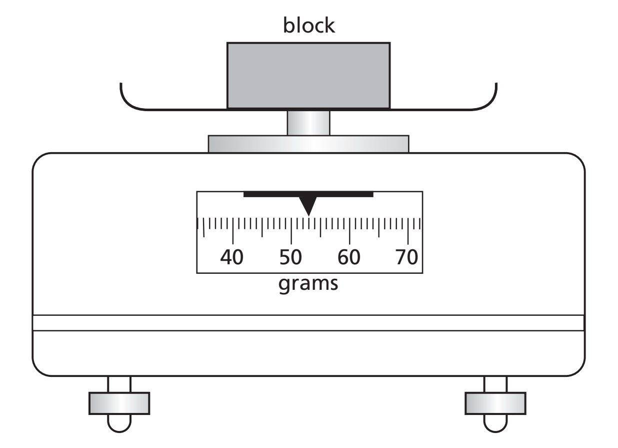
Measurements and motion

1 a (i) The two diagrams show the dimensions of a rectangular block being measured using a ruler. They are not shown full size.
Use the scales shown to find the length and the width of the block, giving your answers in cm. [2]



(ii) When the block was made, it was cut from a piece of metal 2.0 cm thick.
Calculate the volume of the block. [2]

b **Another** block has a volume of 20 cm³.
The diagram shows the reading when the block is placed on a balance.



Find the density of this block. [4]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 21 Q1 November 2010)

2 An engineering machine has a piston which is going up and down approximately 75 times per minute.
Describe carefully how a stopwatch may be used to find accurately the time for one up-and-down cycle of the piston. [4]

[Total: 4]

(Cambridge IGCSE Physics 0625 Paper 31 Q1 June 2009)

3 Imagine that you live beside a busy road. One of your neighbours thinks that many of the vehicles are travelling faster than the speed limit for the road.
You decide to check this by measuring the speeds of some of the vehicles.

a Which two quantities will you need to measure in order to find the speed of a vehicle, and which instruments would you use to measure them?

Quantity measured	Instrument used

[4]

b State the equation you would use to calculate the speed of the vehicle. If you use symbols, state what your symbols mean. [1]

c One lorry travels from your town to another town. The lorry reaches a top speed of 90 km/h, but its average speed between the towns is only 66 km/h.

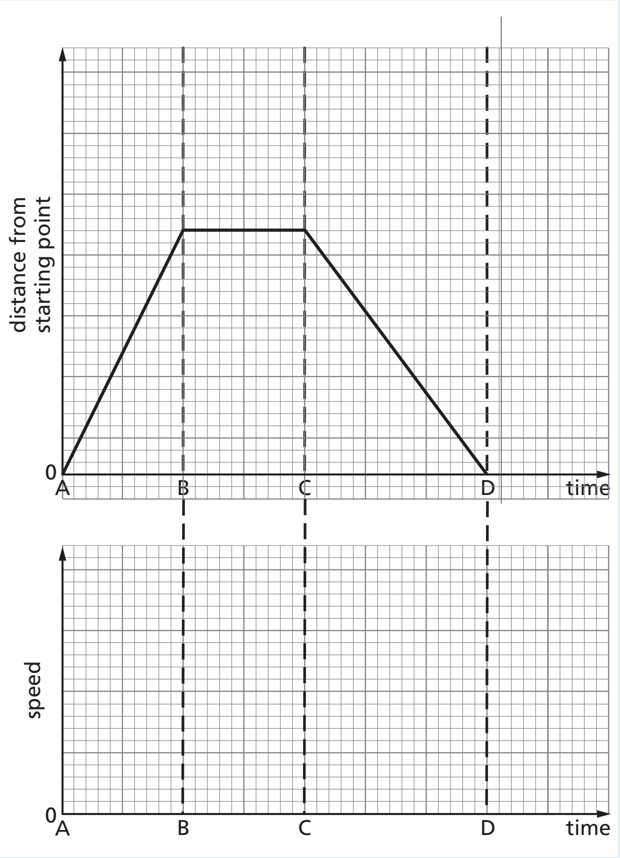
(i) Why is the average speed less than the top speed? [1]

(ii) The journey between the towns takes 20 minutes.
Calculate the distance between the towns. [3]

[Total: 9]

(Cambridge IGCSE Physics 0625 Paper 21 Q1 June 2010)

4 The top graph shows the distance/time graph for a girl's bicycle ride and the bottom graph gives the axes for the corresponding speed/time graph.



a Look at the distance/time graph that has been drawn for you.

(i) Answer the following questions for the time interval AB.

1 What is happening to the distance from the starting point? [2]

2 What can you say about the speed of the bicycle? [1]

(ii) On a copy of the speed/time axes on the bottom graph, draw a thick line that could show the speed during AB. [1]

b On your copy of the speed/time axes

(i) draw a thick line that could show the speed during BC, [1]

(ii) draw a thick line that could show the speed during CD. [2]

c How far from her starting point is the girl when she has finished her ride? [1]

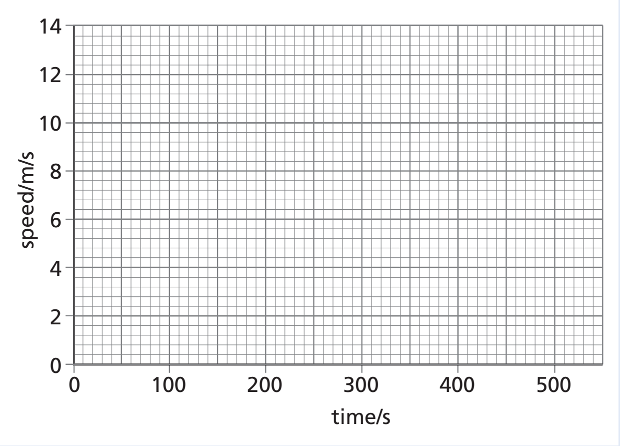
[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 02 Q3 November 2009)

5 In a training session, a racing cyclist's journey is in three stages.
Stage 1 He accelerates uniformly from rest to 12 m/s in 20 s.
Stage 2 He cycles at 12 m/s for a distance of 4800 m.
Stage 3 He decelerates uniformly to rest.
The whole journey takes 500 s.

a Calculate the time taken for stage 2. [2]

b On a copy of the grid below, draw a speed/time graph of the cyclist's ride. [3]



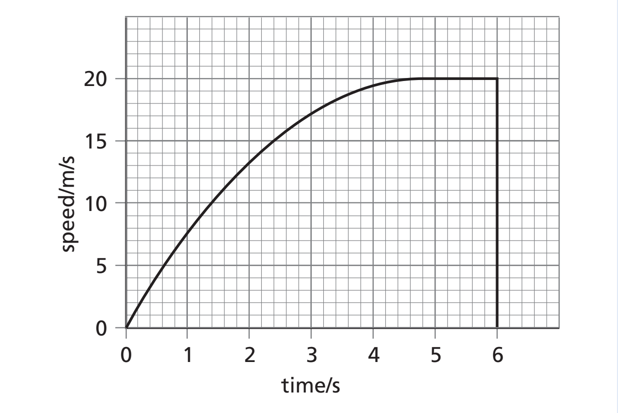
c Show that the total distance travelled by the cyclist is 5400 m. [4]

d Calculate the average speed of the cyclist. [2]

[Total: 11]

(Cambridge IGCSE Physics 0625 Paper 02 Q2 June 2007)

6 A large plastic ball is dropped from the top of a tall building. The diagram shows the speed/time graph for the falling ball until it hits the ground.



a From the graph estimate,
   (i) the time during which the ball is travelling with terminal velocity, [1]
   (ii) the time during which the ball is accelerating, [1]
   (iii) the distance fallen while the ball is travelling with terminal velocity, [2]
   (iv) the height of the building. [2]

b Explain, in terms of the forces acting on the ball, why
   (i) the acceleration of the ball decreases, [3]
   (ii) the ball reaches terminal velocity. [2]

[Total: 11]

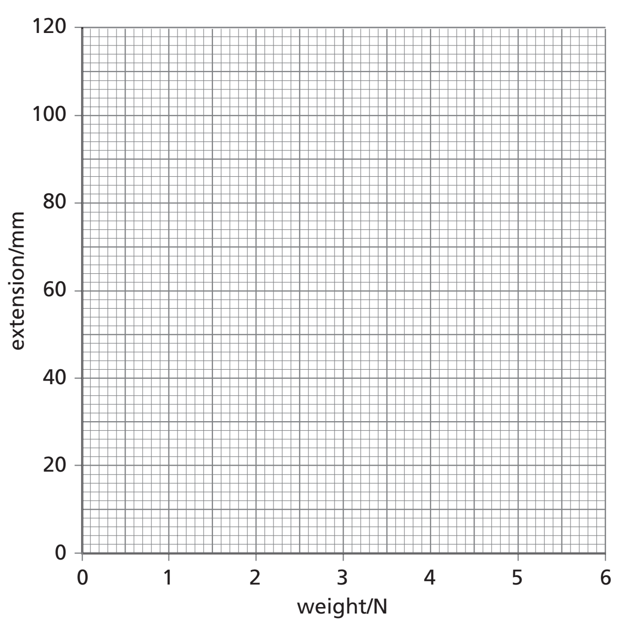
(Cambridge IGCSE Physics 0625 Paper 03 Q1 November 2007)

Forces and momentum

7 A student investigated the stretching of a spring by hanging various weights from it and measuring the corresponding extensions. The results are shown in the table below.

Weight/N	0	1	2	3	4	5
Extension/mm	0	21	40	51	82	103

a On a copy of the grid, plot the points from these results. Do not draw a line through the points yet. [2]



b The student appears to have made an error in recording one of the results. Which result is this? [1]

c Ignoring the incorrect result, draw the best straight line through the remaining points. [1]

d State and explain whether this spring is obeying Hooke's law. [2]

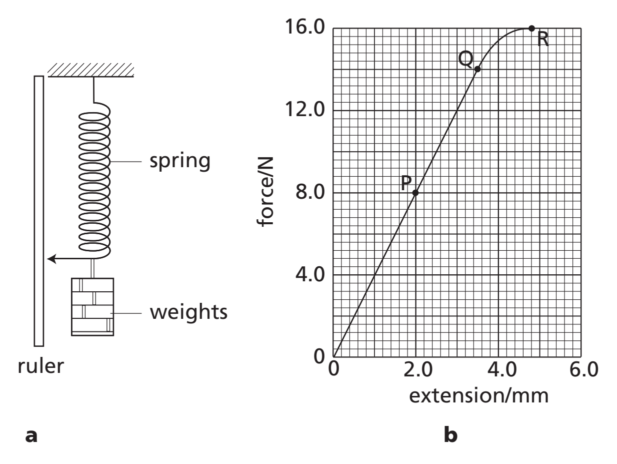
e Describe how the graph might be shaped if the student continued to add several more weights to the spring. [1]

f The student estimates that if he hangs a 45 N load on the spring, the extension will be 920 mm.
Explain why this estimate may be unrealistic. [1]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 31 Q3 November 2009)

8 In an experiment, forces are applied to a spring as shown in the diagram. The results of this experiment are shown on the graph.



a What is the name given to the point marked Q on the graph? [1]

b For the part OP of the graph, the spring obeys Hooke's law. State what this means. [1]

c The spring is stretched until the force and extension are shown by the point R on the graph. Compare how the spring stretches, as shown by the part of the graph OQ, with that shown by QR. [1]

d The part OP of the graph shows the spring stretching according to the expression

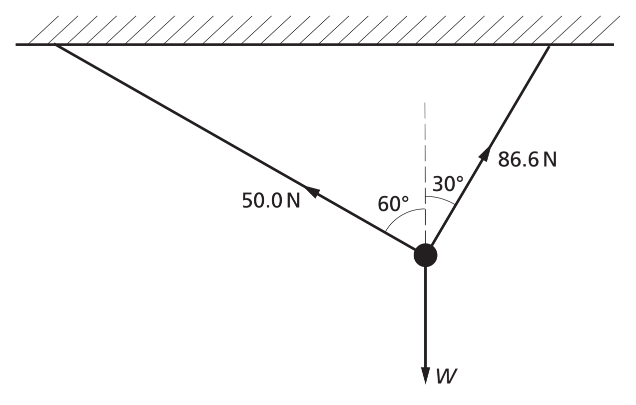
$$F = kx$$

Use values from the graph to calculate the value of k. [2]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 03 Q2 November 2006)

9 An object of weight W is suspended by two ropes from a beam, as shown in the diagram. The tensions in the ropes are 50.0 N and 86.6 N, as shown.



a On graph paper, draw a scale diagram to find the resultant of the two tensions.
Use a scale of 1.0 cm = 10 N.
Clearly label the resultant. [3]

b From your diagram, find the value of the resultant. [1]

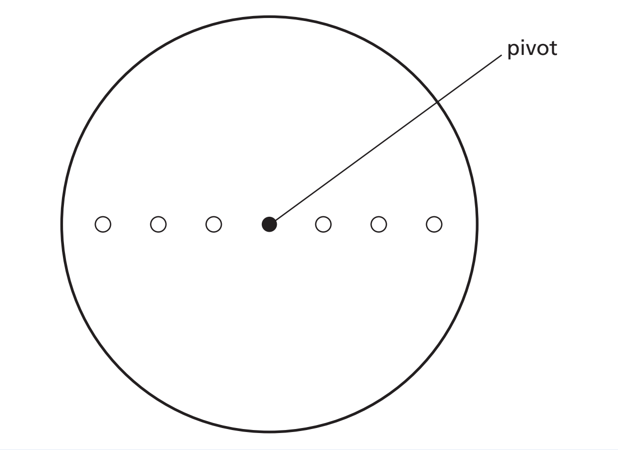
c State the direction in which the resultant is acting. [1]

d State the value of W. [1]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 31 Q1 November 2010)

10 The diagram shows a circular metal disc of mass 200 g, freely pivoted at its centre.



Masses of 100 g, 200 g, 300 g, 400 g, 500 g and 600 g are available, but only one of each value. These may be hung with string from any of the holes. There are three small holes on each side of the centre, one at 4.0 cm from the pivot, one at 8.0 cm from the pivot and one at 12.0 cm from the pivot.
The apparatus is to be used to show that there is no net moment of force acting on a body when it is in equilibrium.

a On a copy of the diagram, draw in **two different** value masses hanging from appropriate holes. The values of the masses should be chosen so that there is no net moment. Alongside the masses chosen, write down their values. [2]

b Explain how you would test that your chosen masses give no net moment to the disc. [1]

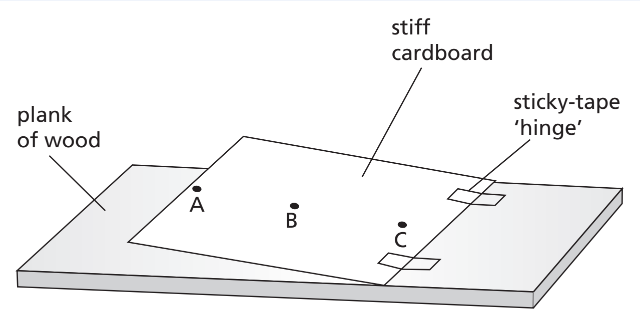
c Calculate the moments about the pivot due to the two masses chosen. [2]

d Calculate the force on the pivot when the two masses chosen are hanging from the disc. [2]

[Total: 7]

(Cambridge IGCSE Physics 0625 Paper 31 Q2 November 2008)

11 A piece of stiff cardboard is stuck to a plank of wood by means of two sticky-tape 'hinges'. This is shown in the diagram.

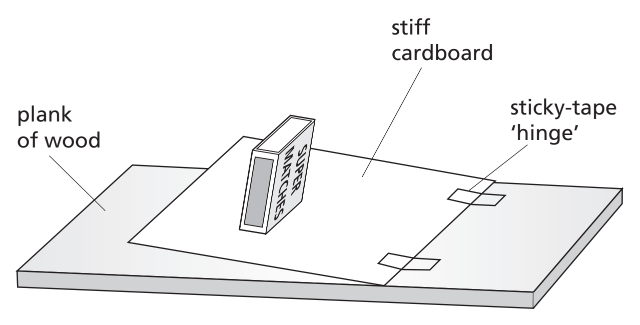


a The cardboard is lifted as shown, using a force applied either at A or B or C.

(i) On a copy of the diagram, draw the force in the position where its value will be as small as possible. [2]

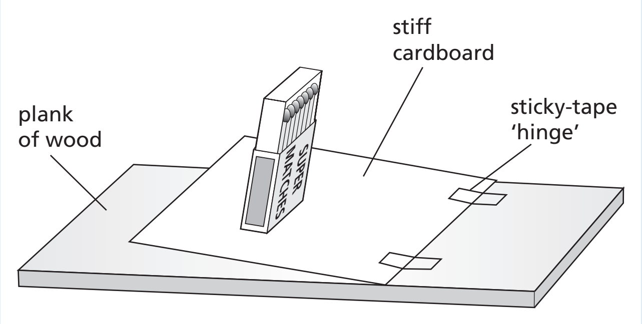
(ii) Explain why the position you have chosen in **a(i)** results in the smallest force. [1]

b Initially, the cardboard is flat on the plank of wood. A box of matches is placed on it. The cardboard is then slowly raised at the left-hand edge, as shown in the diagram below.



State the condition for the box of matches to fall over. [2]

c The box of matches is opened, as shown in the diagram below. The procedure in **b** is repeated.



(i) Copy and complete the sentence below, using either the words 'greater than' or 'the same as' or 'less than'.

When the box of matches is open, the angle through which the cardboard can be lifted before the box of matches falls is .... the angle before the closed box of matches falls. [1]

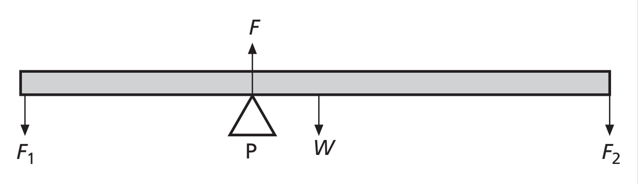
(ii) Give a reason for your answer to **c(i)**. [1]

[Total: 7]

(Cambridge IGCSE Physics 0625 Paper 02 Q3 June 07)

12 **a** State the two factors on which the turning effect of a force depends. [2]

b Forces F_1 and F_2 are applied vertically downwards at the ends of a beam resting on a pivot P. The beam has weight W.



(i) Copy and complete the statements about the two requirements for the beam to be in equilibrium.

1 There must be no resultant . . .

2 There must be no resultant . . . [2]

(ii) The beam is in equilibrium. F is the force exerted on the beam by the pivot P. Copy and complete the following equation about the forces on the beam.

$F =$ [1]

(iii) Which one of the four forces on the beam does **not** exert a moment about P? [1]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 02 Q5 November 2006)

13 Two students make the statements about acceleration that are given below.

Student A: For a given mass the acceleration of an object is proportional to the resultant force applied to the object.

Student B: For a given force the acceleration of an object is proportional to the mass of the object.

a One statement is correct and one is incorrect. Rewrite the incorrect statement, making changes so that it is now correct. [1]

b State the equation which links acceleration a, resultant force F and mass m. [1]

c Describe what happens to the motion of a moving object when

(i) there is no resultant force acting on it, [1]

(ii) a resultant force is applied to it in the opposite direction to the motion, [1]

(iii) a resultant force is applied to it in a perpendicular direction to the motion. [1]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 31 Q3 June 2010)

14 A car travels around a circular track at constant speed.

a Why is it incorrect to describe the circular motion as having constant velocity? [1]

b A force is required to maintain the circular motion.

(i) Explain why a force is required. [2]

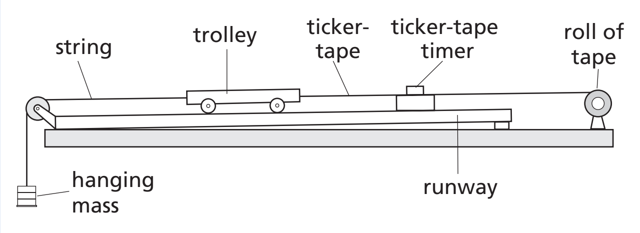
(ii) In which direction does this force act? [1]

(iii) Suggest what provides this force. [1]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 31 Q2 November 2010)

15 The diagram shows apparatus used to find a relationship between the force applied to a trolley and the acceleration caused by the force.



For each mass, hung as shown, the acceleration of the trolley is determined from the tape. Some of the results are given in the table below.

Weight of the hanging mass/N	Acceleration of the trolley/m/s²
0.20	0.25
0.40	0.50
0.70	
0.80	1.0

a **(i)** Explain why the trolley accelerates. [2]

(ii) Suggest why the runway has a slight slope as shown. [1]

b Calculate the mass of the trolley, assuming that the accelerating force is equal to the weight of the hanging mass. [2]

c Calculate the value missing from the table. Show your working. [2]

d In one experiment, the hanging mass has a weight of 0.4 N and the trolley starts from rest. Use data from the table to calculate

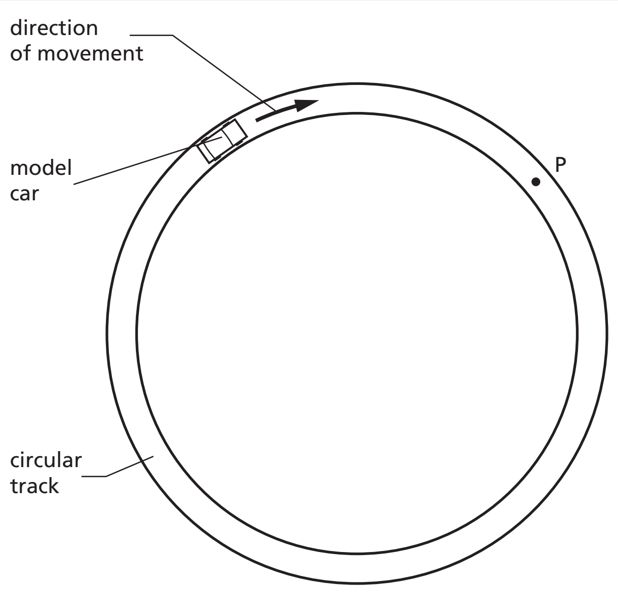
(i) the speed of the trolley after 1.2 s, [2]

(ii) the distance travelled by the trolley in 1.2 s. [2]

[Total: 11]

(Cambridge IGCSE Physics 0625 Paper 31 Q1 November 2008)

16 The diagram shows a model car moving clockwise around a horizontal circular track.



a A force acts on the car to keep it moving in a circle.

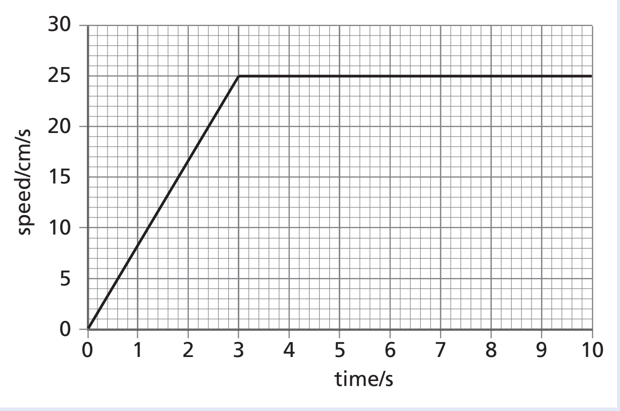
(i) Draw an arrow on a copy of the diagram to show the direction of this force. [1]

(ii) The speed of the car increases. State what happens to the magnitude of this force. [1]

b (i) The car travels too quickly and leaves the track at P. On your copy of the diagram, draw an arrow to show the direction of travel after it has left the track. [1]

(ii) In terms of the forces acting on the car, suggest why it left the track at P. [2]

c The car, starting from rest, completes one lap of the track in 10 s. Its motion is shown graphically in the graph below.



(i) Describe the motion between 3.0 s and 10.0 s after the car has started. [1]

(ii) Use the graph to calculate the circumference of the track. [2]

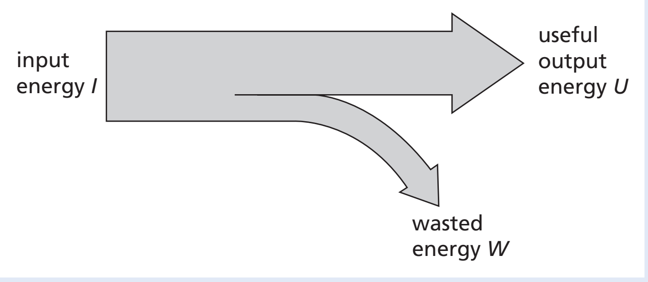
(iii) Calculate the increase in speed per second during the time 0 to 3.0 s. [2]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 03 Q1 June 2007)

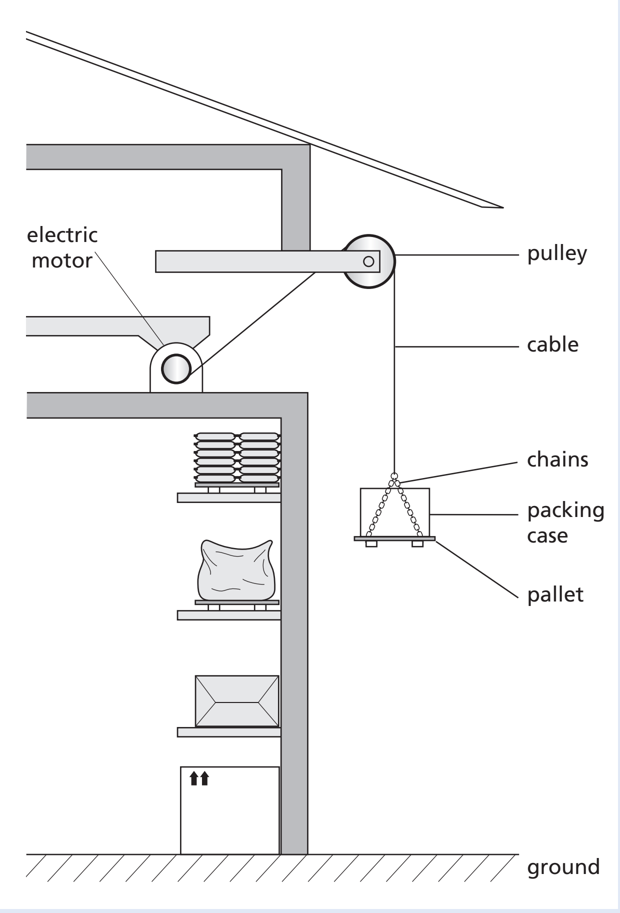
Energy, work, power and pressure

17 a The diagram represents the energy into and out of a machine.



Write down the equation linking *I*, *U* and *W*. [1]

b An electric motor and a pulley in a warehouse are being used to lift a packing case of goods from the ground up to a higher level. This is shown in the diagram.



The packing case of goods, the chains and the pallet together weigh 850 N.

(i) State the value of the tension force in the cable when the load is being lifted at a steady speed. [1]

(ii) When the load is just leaving the floor, why is the force larger than your answer to **b(i)**? [1]

(iii) The warehouse manager wishes to calculate the useful work done when the load is lifted from the ground to the higher level. Which quantity, other than the weight, does he need to measure? [1]

(iv) Which further quantity does the manager need to know, in order to calculate the power required to lift the load? [1]

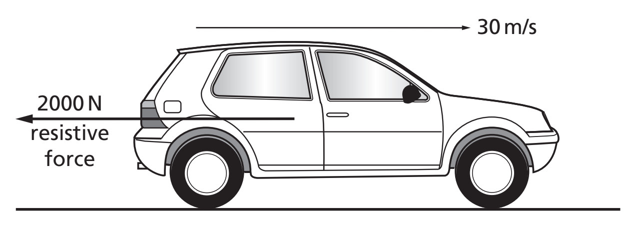
c How does the electrical energy supplied to the electric motor compare with the increase in energy of the load? Answer by copying and completing the sentence.

The electrical energy supplied to the motor is .... the increase in energy of the load. [1]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 21 Q3 June 2010)

18 A car of mass 900 kg is travelling at a steady speed of 30 m/s against a resistive force of 2000 N, as illustrated in the diagram.



a Calculate the kinetic energy of the car. [2]
b Calculate the energy used in 1.0 s against the resistive force. [2]
c What is the minimum power that the car engine has to deliver to the wheels? [1]
d What form of energy is in the fuel, used by the engine to drive the car? [1]
e State why the energy in the fuel is converted at a greater rate than you have calculated in **c**. [1]

[Total: 7]

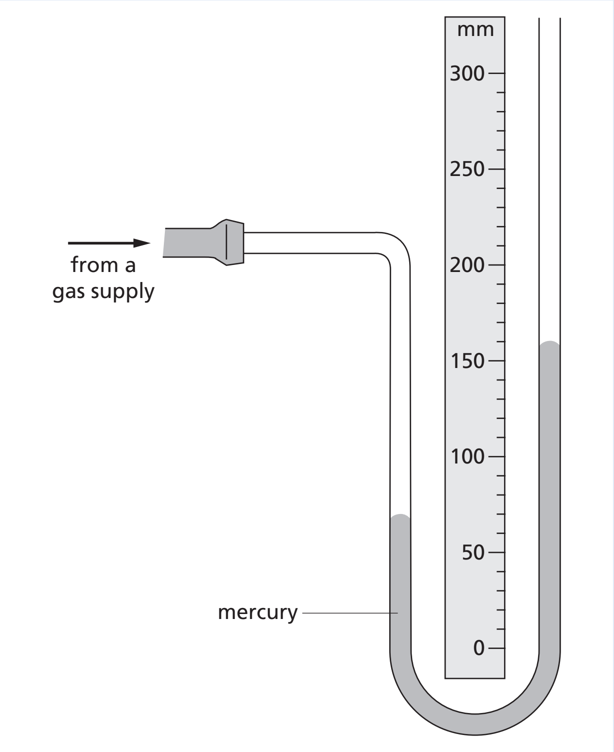
(Cambridge IGCSE Physics 0625 Paper 31 Q2 June 2010)

19 **a** Name three different energy resources used to obtain energy directly from water (not steam). [3]
b Choose one of the energy resources you have named in **a** and write a **brief** description of how the energy is converted to electrical energy. [3]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 21 Q3 November 2010)

20 The diagram shows a manometer, containing mercury, being used to monitor the pressure of a gas supply.

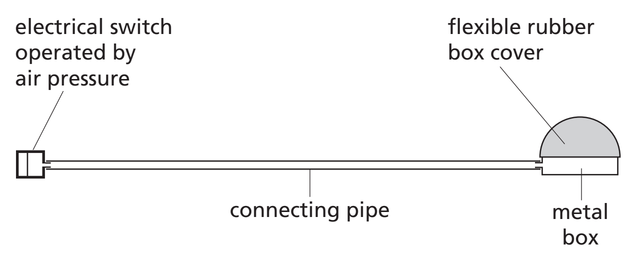


a Using the scale on the diagram, find the vertical difference between the two mercury levels. [1]
b What is the value of the excess pressure of the gas supply, measured in millimetres of mercury? [1]
c The atmospheric pressure is 750 mm of mercury.
Calculate the actual pressure of the gas supply. [1]
d The gas pressure now decreases by 20 mm of mercury. On a copy of the diagram, mark the new positions of the two mercury levels. [2]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 02 Q4 June 2009)

21 The diagram shows a design for remotely operating an electrical switch using air pressure.



The metal box and the pipe contain air at normal atmospheric pressure and the switch is off. When the pressure in the metal box and pipe is raised to 1.5 times atmospheric pressure by pressing down on the flexible rubber box cover, the switch comes on.

a Explain in terms of pressure and volume how the switch is made to come on. [2]

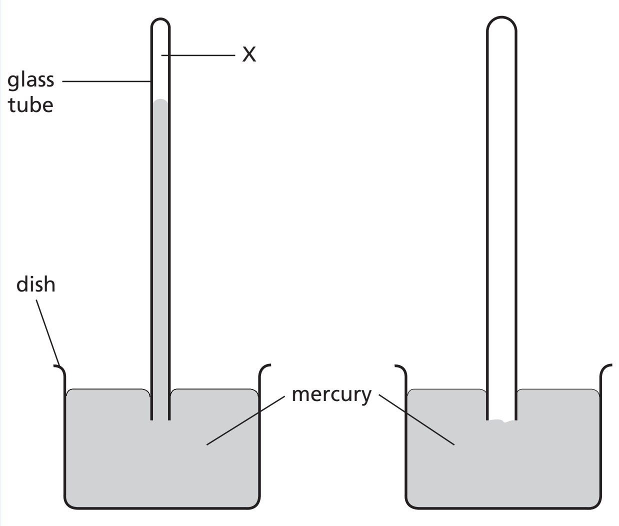
b Normal atmospheric pressure is 1.0×10^5 Pa. At this pressure, the volume of the box and pipe is $60\,cm^3$.
Calculate the **reduction** in volume that must occur for the switch to be on. [3]

c Explain, in terms of air particles, why the switch may operate, without the rubber cover being squashed, when there is a large rise in temperature. [2]

[Total: 7]

(Cambridge IGCSE Physics 0625 Paper 31 Q4 June 2008)

22 The diagram shows two mercury barometers standing side-by-side. The right-hand diagram is incomplete. The space labelled X is a vacuum.



a On a copy of the left-hand barometer, carefully mark the distance that would have to be measured in order to find the value of the atmospheric pressure. [2]

b A small quantity of air is introduced into X.

(i) State what happens to the mercury level in the tube. [1]

(ii) In terms of the behaviour of the air molecules, explain your answer to **b(i)**. [2]

c The space above the mercury in the right-hand barometer is a vacuum.
On a copy of the right-hand diagram, mark the level of the mercury surface in the tube. [1]

d The left-hand tube now has air above the mercury; the right-hand tube has a vacuum. complete the table below, using words chosen from the following list, to indicate the effect of changing the external conditions.

rises **falls** **stays the same**

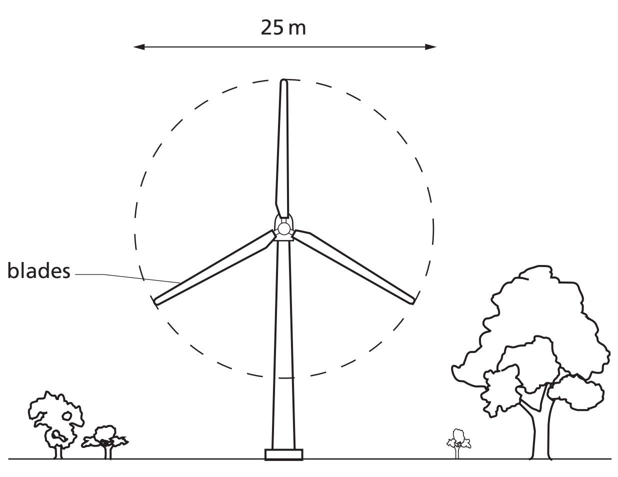
change	effect on the level of the mercury in the left-hand tube	effect on the level of the mercury in the right-hand tube
atmospheric pressure rises		
temperature rises		

[4]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 02 Q6 November 2008)

23 A wind turbine has blades, which sweep out an area of diameter 25 m as shown in the diagram.



a The wind is blowing directly towards the wind turbine at a speed of 12 m/s. At this wind speed, 7500 kg of air passes every second through the circular area swept out by the blades.

(i) Calculate the kinetic energy of the air travelling at 12 m/s, which passes through the circular area in 1 second. [3]

(ii) The turbine converts 10% of the kinetic energy of the wind to electrical energy. Calculate the electrical power output of the turbine. State any equation that you use. [3]

b On another day, the wind speed is half that in **a**.

(i) Calculate the mass of air passing through the circular area per second on this day. [1]

(ii) Calculate the power output of the wind turbine on the second day as a fraction of that on the first day. [3]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 31 Q5 June 2009)

2 Thermal physics

Simple kinetic molecular model of matter

24 The whole of a sealed, empty, dusty room is kept at a constant temperature of 15 °C. Light shines into the room through a small outside window. An observer points a TV camera with a magnifying lens into the room through a second small window, set in an inside wall at right angles to the outside wall.
Dust particles in the room show up on the TV monitor screen as tiny specks of light.

a Draw a diagram to show the motion of one of the specks of light over a short period of time. [1]

b After a period of one hour the specks are still observed, showing that the dust particles have not fallen to the floor. Explain why the dust particles have not fallen to the floor. You may draw a labelled diagram to help your explanation. [2]

c On another day, the temperature of the room is only 5 °C. All other conditions are the same and the specks of light are again observed. Suggest any differences that you would expect in the movement of the specks when the temperature is 5 °C, compared to before. [1]

[Total: 4]

(Cambridge IGCSE Physics 0625 Paper 31 Q4 November 2008)

25 **a** Here is a list of descriptions of molecules in matter.

Description	Solid	Gas
free to move around from place to place		
can only vibrate about a fixed position		
closely packed		
relatively far apart		
almost no force between molecules		
strong forces are involved between molecules		

Copy the table and in the columns alongside the descriptions, put ticks next to those which apply to the molecules in
(i) a solid, **(ii)** a gas. [4]

b The water in a puddle of rainwater is evaporating.
Describe what happens to the molecules when the water evaporates. [2]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 02 Q5 June 2007)

Thermal properties and temperature

26 A certain substance is in the solid state at a temperature of −36 °C. It is heated at a constant rate for 32 minutes. The record of its temperature is given in the table at the bottom of the page.

a State what is meant by the term *latent heat*. [2]

b State a time at which the energy is being supplied as latent heat of fusion. [1]

c Explain the energy changes undergone by the molecules of a substance during the period when latent heat of vaporisation is being supplied. [2]

d **(i)** The rate of heating is 2.0 kW.
Calculate how much energy is supplied to the substance during the period 18–22 minutes. [2]

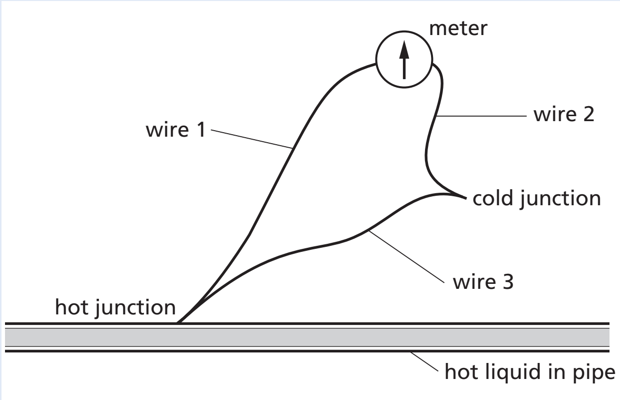
(ii) The specific heat capacity of the substance is 1760 J/(kg°C). Use the information in the table for the period 18–22 minutes to calculate the mass of the substance being heated. [3]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 31 Q5 June 2010)

Time/min	0	1	2	6	10	14	18	22	24	26	28	30	32
Temperature/°C	−36	−16	−9	−9	−9	−9	32	75	101	121	121	121	121

27 Three wires and a meter are used to construct a thermocouple for measuring the surface temperature of a pipe carrying hot liquid, as shown in the diagram.



a Copper wire and constantan wire are used in the construction of the thermocouple.
State which metal might be used for
wire 1 ....
wire 2 ....
wire 3 .... [1]

b State what type of meter is used. [1]

c State one particular advantage of thermocouples for measuring temperature. [1]

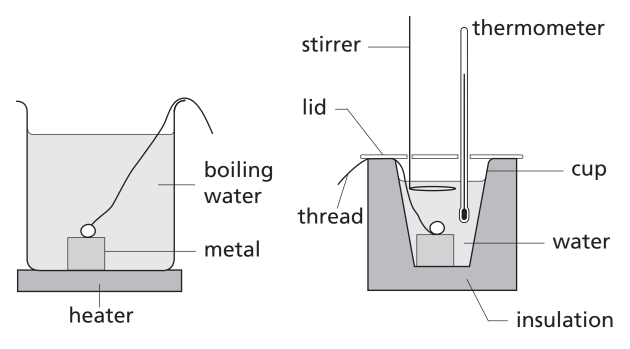
[Total: 3]

(Cambridge IGCSE Physics 0625 Paper 31 Q7 November 2009)

28 **a** State what is meant by *specific heat capacity*. [2]

b Water has a very high specific heat capacity. Suggest why this might be a disadvantage when using water for cooking. [1]

c The diagram illustrates an experiment to measure the specific heat capacity of some metal.



The piece of metal is heated in boiling water until it has reached the temperature of the water. It is then transferred rapidly to some water in a well-insulated cup. A very sensitive thermometer is used to measure the initial and final temperatures of the water in the cup.

specific heat capacity of water = 4200 J/(kg K)

The readings from the experiment are as follows.

mass of metal = 0.050 kg

mass of water in cup = 0.200 kg

initial temperature of water in cup = 21.1 °C

final temperature of water in cup = 22.9 °C

(i) Calculate the temperature rise of the water in the cup and the temperature fall of the piece of metal. [1]

(ii) Calculate the thermal energy gained by the water in the cup. State the equation that you use. [3]

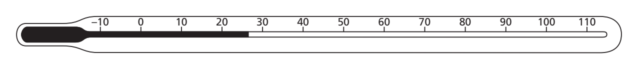
(iii) Assume that only the water gained thermal energy from the piece of metal. Making use of your answers to **c(i)** and **c(ii)**, calculate the value of the specific heat capacity of the metal. Give your answer to three significant figures. [2]

(iv) Suggest one reason why the experiment might not have given a correct value for the specific heat capacity of the metal. [1]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 31 Q9 November 2009)

29 **a** The thermometer shown below is calibrated at two fixed points, and the space between these is divided into equal divisions.



A thermometer is being calibrated with the Celsius scale.

(i) **1** Write down another name for the lower fixed point. [1]

2 How is this temperature achieved? [2]

3 What is the temperature of this fixed point? [1]

(ii) **1** Write down another name for the upper fixed point. [1]

2 How is this temperature achieved? [2]

3 What is the temperature of this fixed point? [2]

b A block of copper and a block of aluminium have identical masses. They both start at room temperature and are given equal quantities of heat. When the heating is stopped, the aluminium has a lower temperature than the copper.

Fill in the missing words in the sentence below, to explain this temperature difference.

The aluminium block has a smaller temperature rise than the copper block because the aluminium block has a larger

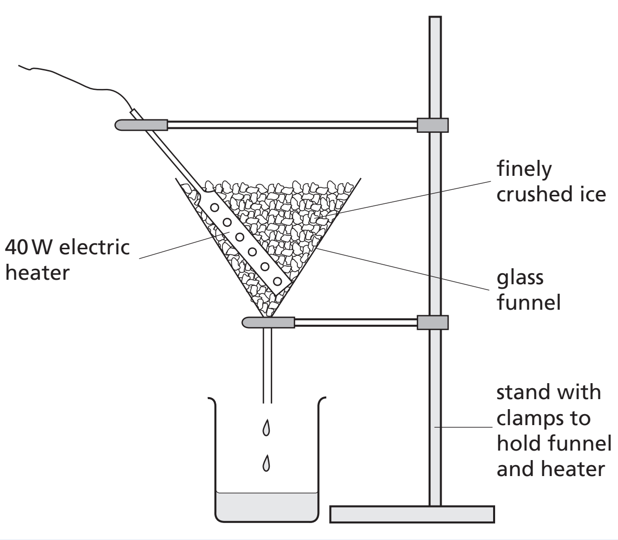
....

than the copper block. [1]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 02 Q8 June 2008)

30 The diagram shows apparatus that could be used to determine the specific latent heat of fusion of ice.



a In order to obtain as accurate a result as possible, state why it is necessary to

(i) wait until water is dripping into the beaker at a constant rate before taking readings, [1]

(ii) use finely crushed ice rather than large pieces. [1]

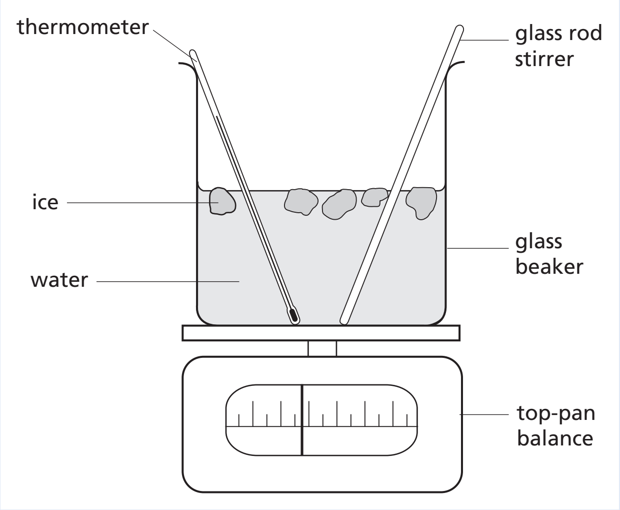
b The power of the heater and the time for which water is collected are known. Write down all the other readings that are needed to obtain a value for the specific latent heat of fusion of ice. [2]

c Using a 40 W heater, 16.3 g of ice is melted in 2.0 minutes. The heater is then switched off. In a further 2.0 minutes, 2.1 g of ice is melted. Calculate the value of the specific latent heat of fusion of ice from these results. [4]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 31 Q5 November 2008)

31 The diagram shows a student's attempt to estimate the specific latent heat of fusion of ice by adding ice at 0 °C to water at 20 °C. The water is stirred continuously as ice is slowly added until the temperature of the water is 0 °C and all the added ice has melted.



a Three mass readings are taken. A description of the first reading is given.
Write down descriptions of the other two.

reading 1: the mass of the beaker + stirrer + thermometer

reading 2: ....

reading 3: .... [2]

b Write down word equations which the student could use to find

(i) the heat lost by the water as it cools from 20 °C to 0 °C, [1]

(ii) the heat gained by the melting ice. [1]

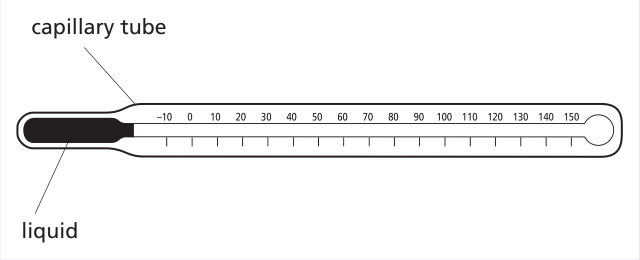
c The student calculates that the water loses 12 800 J and that the mass of ice melted is 30 g. Calculate a value for the specific latent heat of fusion of ice. [2]

d Suggest two reasons why this value is only an approximate value. [2]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 03 Q4 June 2007)

32 The diagram shows a liquid-in-glass thermometer.



a The thermometer is used for measuring temperatures in school laboratory experiments. State the units in which the temperatures are measured. [1]

b On a copy of the diagram, mark where the liquid thread will reach when the thermometer is placed in

(i) pure melting ice (label this point ICE), [1]

(ii) steam above boiling water (label this point STEAM). [1]

c A liquid-in-glass thermometer makes use of the expansion of a liquid to measure temperature. Other thermometers make use of other properties that vary with temperature. In a copy of the table below, write in two properties, other than expansion of a liquid, that can be used to measure temperature.

example	*expansion*	OF	*a liquid*
1.		OF	
2.		OF	

[2]

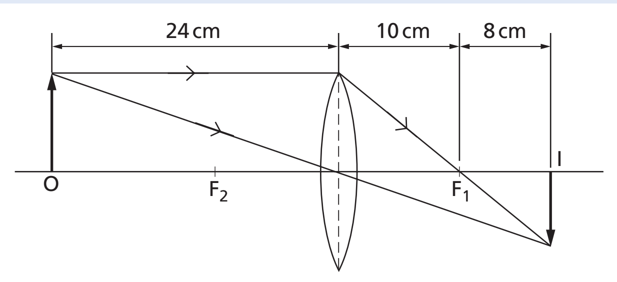
[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 02 Q5 November 2007)

3 Properties of waves

Light

33 The diagram shows how an image is formed by a converging lens.



a State the value of the focal length of the lens. [1]

b The object O is moved a small distance to the left.
State two things that happen to the image I. [2]

c Points F_1 and F_2 are marked on the diagram.

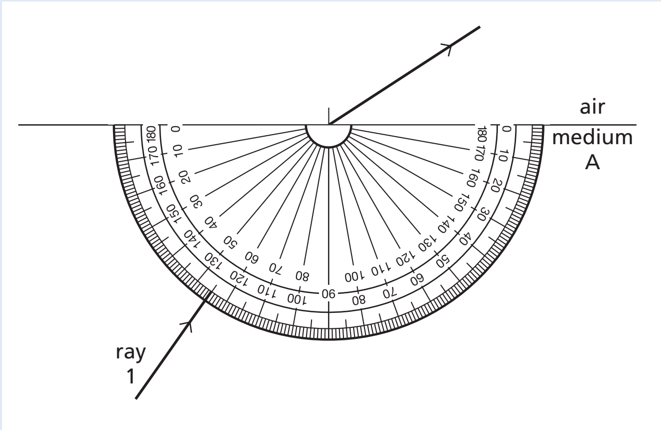
(i) State the name we give to these two points. [1]

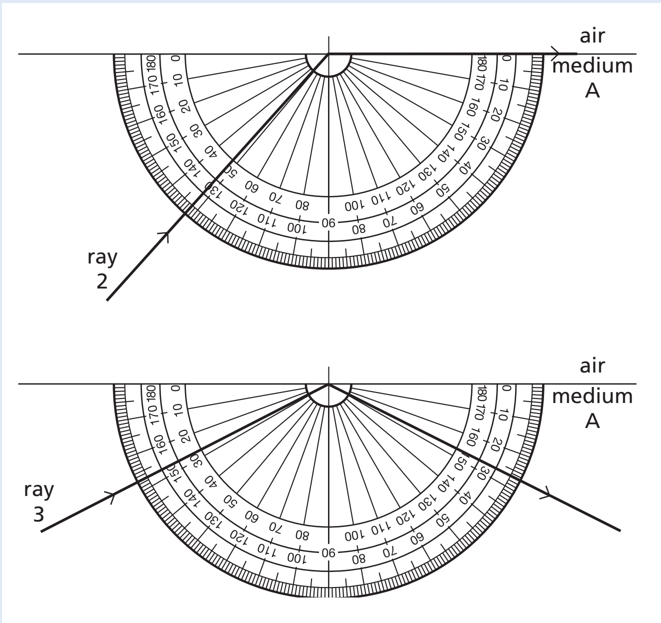
(ii) On a copy of the diagram, draw the ray from the top of the object which passes through F_2. Continue your ray until it meets the image. [4]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 21 Q8 June 2010)

34 In an optics lesson, a Physics student traces the paths of three rays of light near the boundary between medium A and air. The student uses a protractor to measure the various angles.
The diagrams below illustrate the three measurements.





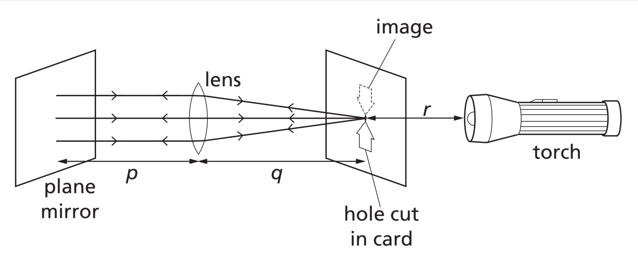
a State which is the optically denser medium, A or air, and how you can tell this. [1]

b State in which medium the light travels the faster, and how you know this. [1]
c State the critical angle of medium A. [1]
d State the full name for what is happening to ray 3 in the third diagram. [1]
e The refractive index of medium A is 1.49. Calculate the value of the angle of refraction of ray 1, showing all your working. [2]
f The speed of light in air is 3.0×10^8 m/s. Calculate the speed of light in medium A, showing all your working. [2]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 31 Q8 June 2009)

35 The diagram shows an experiment in which an image is being formed on a card by a lens and a plane mirror.



The card and the mirror are shown angled, so that you can see what is happening. In a real experiment they are each roughly perpendicular to the line joining the torch bulb and the centre of the lens.

a State which of the three marked distances, p, q and r, is the focal length of the lens. [1]
b On a copy of the diagram clearly mark a principal focus of the lens, using the letter F. [1]
c Which two features describe the image formed on the card?

erect

inverted

real

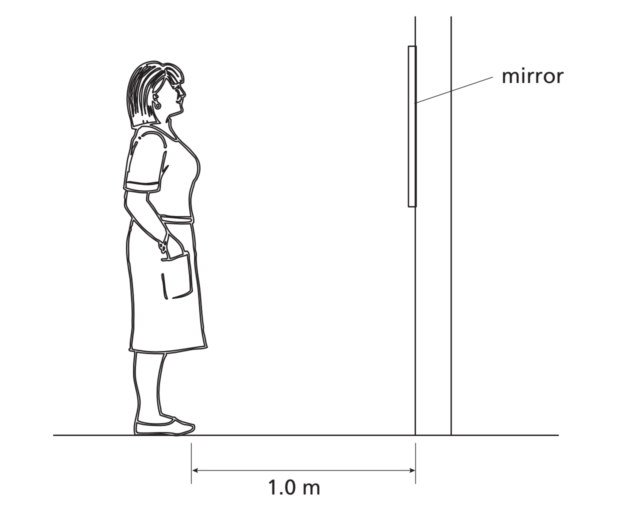
virtual [2]

d What can be said about the size of the image, compared with the size of the object? [1]
e In the experiment, the plane mirror is perpendicular to the beam of light. State what, if anything, happens to the image on the card if
(i) the plane mirror is moved slightly to the left, [1]
(ii) the lens is moved slightly to the left. [1]

[Total: 7]

(Cambridge IGCSE Physics 0625 Paper 02 Q7 November 2009)

36 A woman stands so that she is 1.0 m from a mirror mounted on a wall, as shown below.

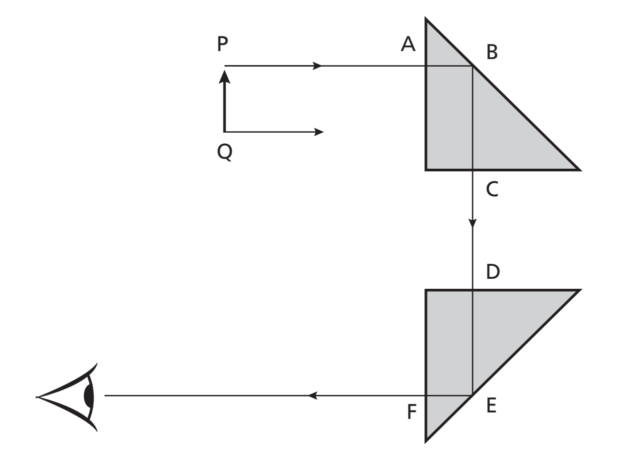


a Copy the diagram and carefully draw
(i) a clear dot to show the position of the image of her eye,
(ii) the normal to the mirror at the bottom edge of the mirror,
(iii) a ray from her toes to the bottom edge of the mirror and then reflected from the mirror. [5]
b Explain why the woman cannot see the reflection of her toes. [1]
c **(i)** How far is the woman from her image?
(ii) How far must the woman walk, and in what direction, before the distance between her and her image is 6.0 m? [4]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 02 Q6 November 2006)

37 The diagram shows a ray of light, from the top of an object PQ, passing through two glass prisms.



a Copy the sketch and complete the path through the two prisms of the ray shown leaving Q. [1]

b A person looking into the lower prism, at the position indicated by the eye symbol, sees an image of PQ. State the properties of this image. [2]

c Explain why there is no change in direction of the ray from P at points A, C, D and F. [1]

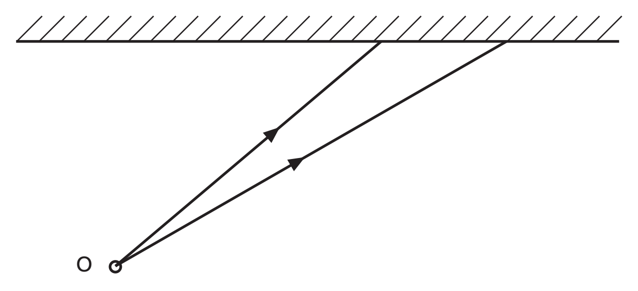
d The speed of light as it travels from P to A is 3×10^8 m/s and the refractive index of the prism glass is 1.5. Calculate the speed of light in the prism. [2]

e Explain why the ray AB reflects through 90° at B and does not pass out of the prism at B. [2]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 03 Q6 November 2006)

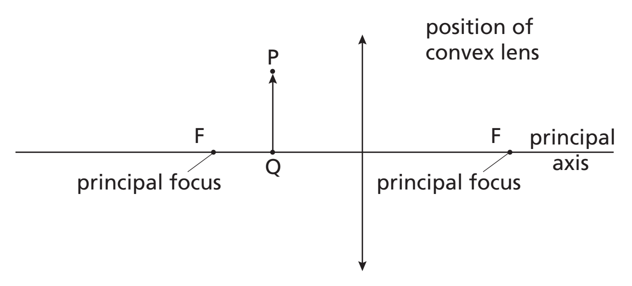
38 **a** The sketch shows two rays of light from a point O on an object. These rays are incident on a plane mirror.



(i) Copy the diagram and continue the paths of the two rays after they reach the mirror. Hence locate the image of the object O. Label the image I.

(ii) Describe the nature of the image I. [4]

b The diagram below is drawn to scale. It shows an object PQ and a convex lens.



(i) Copy the diagram and draw two rays from the top of the object P that pass through the lens. Use these rays to locate the top of the image. Label this point T.

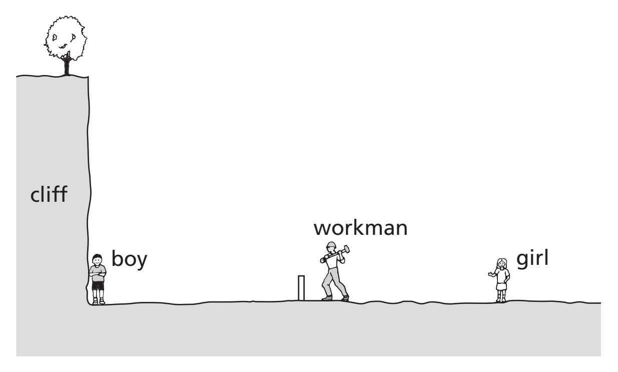
(ii) Draw an eye symbol to show the position from which the image T should be viewed. [4]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 03 Q7 November 2005)

Sound

39 The diagram shows a workman hammering a metal post into the ground. Some distance away is a vertical cliff.



a A boy is standing at the foot of the cliff. The speed of sound in air is 330 m/s. It takes 1.5 s for the sound of the hammer hitting the post to reach the boy.

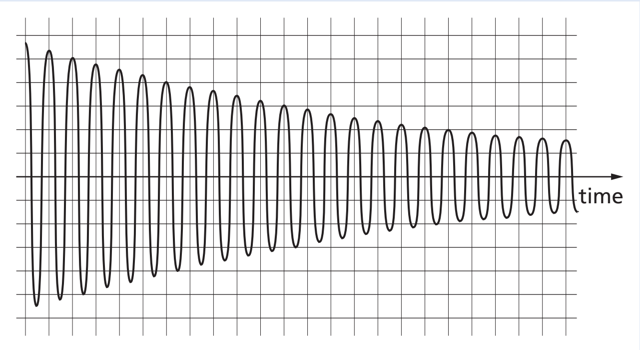
(i) What does the boy hear after he sees each strike of the hammer on the post? [1]
(ii) Calculate the distance between the post and the boy. [3]

b A girl is also watching the workman. She is standing the same distance behind the post as the boy is in front of it. She hears two separate sounds after each strike of the hammer on the post.
(i) Why does she hear **two** sounds? [2]
(ii) How long after the hammer strike does the girl hear each of these sounds?
girl hears first sound after ....s
girl hears second sound after .... s [2]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 21 Q8 November 2010)

40 The trace shows the waveform of the note from a bell. A grid is given to help you take measurements.



a (i) State what, if anything, is happening to the loudness of the note. [1]
(ii) State how you deduced your answer to **a(i)**. [1]

b (i) State what, if anything, is happening to the frequency of the note. [1]
(ii) State how you deduced your answer to **b(i)**. [1]

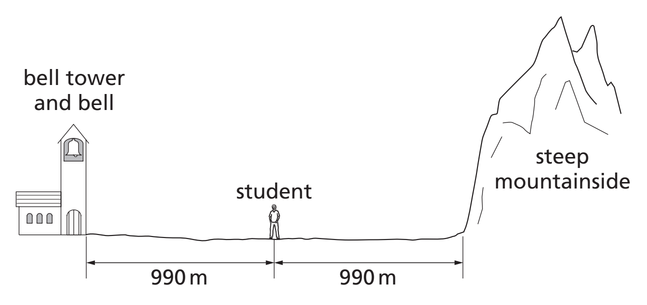
c (i) How many oscillations does it take for the amplitude of the wave to decrease to half its initial value? [1]
(ii) The wave has a frequency of 300 Hz.
1 What is meant by a frequency of 300 Hz? [1]
2 How long does 1 cycle of the wave take? [1]
3 How long does it take for the amplitude to decrease to half its initial value? [2]

d A student says that the sound waves, which travelled through the air from the bell, were longitudinal waves, and that the air molecules moved repeatedly closer together and then further apart.
(i) Is the student correct in saying that the sound waves are longitudinal?
(ii) Is the student correct about the movement of the air molecules?
(iii) The student gives light as another example of longitudinal waves.
Is this correct? [2]

[Total: 11]

(Cambridge IGCSE Physics 0625 Paper 02 Q6 June 2009)

41 The diagram shows a student standing midway between a bell tower and a steep mountainside.



The bell rings once, but the student hears two rings separated by a short time interval.

a Explain why the student hears two rings. [2]

b State which of the sounds is louder, and why. [2]

c Sound in that region travels at 330 m/s.
(i) Calculate the time interval between the bell ringing and the student hearing it for the **first** time. [2]
(ii) Calculate the time interval between the bell ringing and the student hearing it for the **second** time. [1]
(iii) Calculate the time interval between the two sounds. [1]

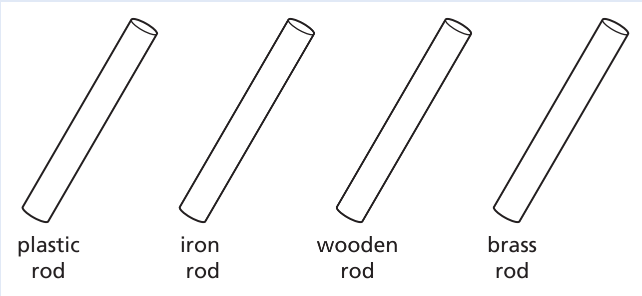
[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 02 Q8 November 2009)

4 Electricity and magnetism

Simple phenomena of magnetism

42 **a** Four rods are shown in the diagram.

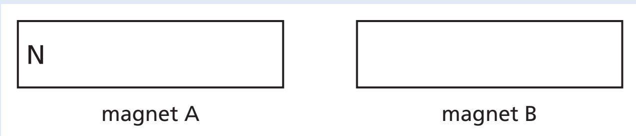


State which of these could be held in the hand at one end and be

(i) magnetised by stroking it with a magnet, [1]

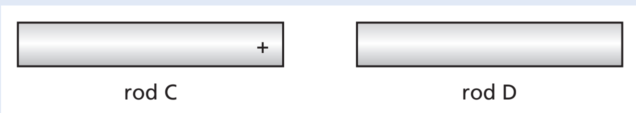
(ii) charged by stroking it with a dry cloth. [1]

b Magnets A and B below are repelling each other.



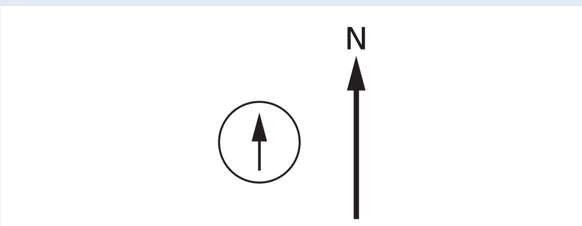
The north pole has been labelled on magnet A. On a copy of the diagram, label the other three poles. [1]

c Charged rods C and D below are attracting each other.

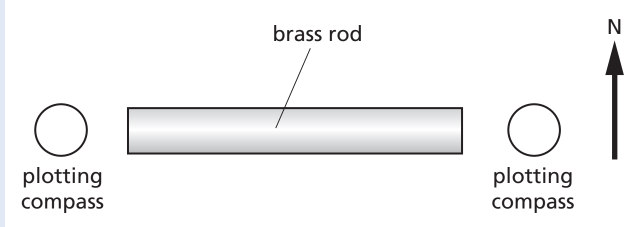


On a copy of the diagram, show the charge on rod D. [1]

d A plotting compass with its needle pointing north is shown below.



A brass rod is positioned in an east–west direction. A plotting compass is put at each end of the brass rod, as shown below.

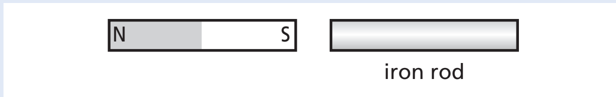


On a copy of the diagram, mark the position of the pointer on each of the two plotting compasses. [2]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 02 Q8 June 2009)

43 **a** An iron rod is placed next to a bar magnet, as shown in the diagram.



(i) On a copy of the diagram above, mark clearly the north pole and the south pole that are induced in the iron rod. [1]

(ii) What happens to the magnet and the rod? Tick the correct option below.

nothing ☐

they attract ☐

they repel ☐ [1]

b A second bar magnet is now placed next to the iron rod, as shown below.

(i) On a copy of the diagram above, mark clearly the magnetic poles induced in the iron rod. [1]

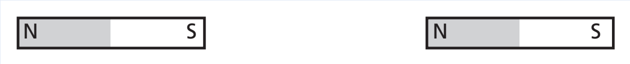
(ii) What happens to the iron rod and the second magnet?

nothing

they attract

they repel [1]

c The iron rod is removed, leaving the two magnets, as shown below.



What happens to the two magnets?
nothing

they attract

they repel [1]

d The second magnet is removed and replaced by a charged plastic rod, as shown below.

What happens to the magnet and the plastic rod?
nothing

they attract

they repel [1]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 02 Q8 November 2008)

Electrical quantities and circuits

44 **a** A warning on the packaging of a light switch purchased from an electrical store reads

Safety warning
This push-button switch is not suitable for use in a washroom.
Lights in washrooms should be operated by pull-cord switches.

(i) Explain why it might be dangerous to use a push-button switch in a washroom. [2]
(ii) Why is it safe to use a pull-cord switch in a washroom? [1]

b An electric heater, sold in the electrical store, has a current of 8 A when it is working normally. The cable fitted to the heater has a maximum safe current of 12 A.
Which of the following fuses would be most suitable to use in the plug fitted to the cable of the heater?

5 A 10 A 13 A 20 A

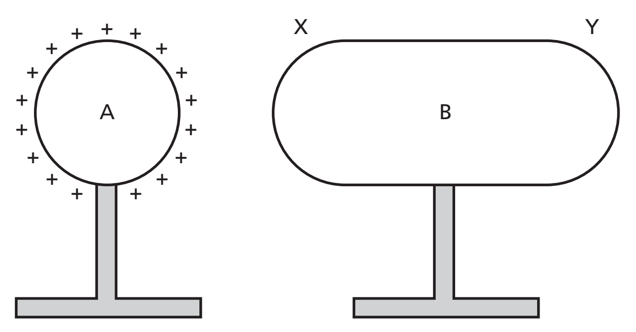
[1]

c The cable for connecting an electric cooker is much thicker than the cable on a table lamp.
(i) Why do cookers need a much thicker cable? [1]
(ii) What would happen if a thin cable were used for wiring a cooker to the supply? [1]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 21 Q9 June 2010)

45 In the diagram, A and B are two conductors on insulating stands. Both A and B were initially uncharged.



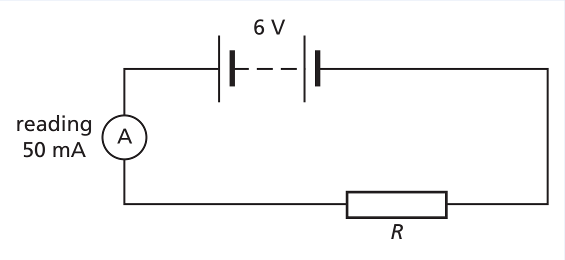
a Conductor A is given the positive charge shown on the diagram.
(i) On a copy of the diagram, mark the signs of the charges induced at end X and at end Y of conductor B. [1]
(ii) Explain how these charges are induced. [3]
(iii) Explain why the charges at X and at Y are equal in magnitude. [1]

b B is now connected to earth by a length of wire. Explain what happens, if anything, to
(i) the charge at X, [1]
(ii) the charge at Y. [2]

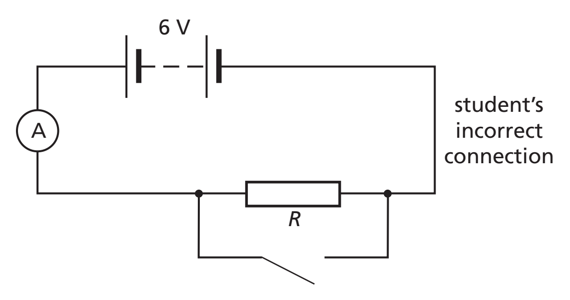
[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 31 Q9 November 2010)

46 The diagram shows a simple circuit.



a What is the value of
 (i) the e.m.f. of the battery,
 (ii) the current in the circuit? [2]
b Calculate the resistance R of the resistor. [3]
c State how the circuit could be changed to
 (i) halve the current in the circuit, [2]
 (ii) reduce the current to zero. [1]
d A student wishes to include a switch in the circuit, but mistakenly connects it as shown below.

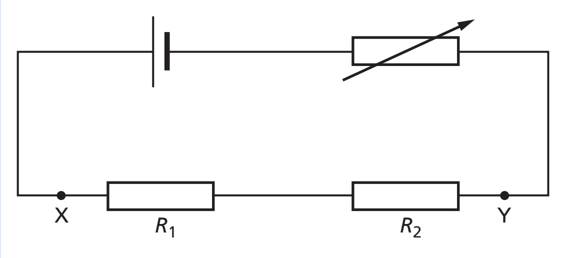


 (i) Comment on the size of the current in the circuit if the student closes the switch. [1]
 (ii) What effect would this current have on the circuit? [2]

[Total: 11]

(Cambridge IGCSE Physics 0625 Paper 02 Q9 June 2009)

47 The diagram shows a series circuit.



Resistance $R_1 = 25\,\Omega$ and resistance $R_2 = 35\,\Omega$.
The cell has zero resistance.

a Calculate the combined resistance of R_1 and R_2. [2]
b On a copy of the diagram, use the correct circuit symbol to draw a voltmeter connected to measure the potential difference between X and Y. [1]
c The variable resistor is set to zero resistance. The voltmeter reads 1.5 V.
 (i) Calculate the current in the circuit. [4]
 (ii) State the value of the potential difference across the cell. [1]
d The resistance of the variable resistor is increased.
 (i) What happens to the current in the circuit? Tick the correct option below.

increases ☐

stays the same ☐

decreases ☐ [1]

 (ii) What happens to the voltmeter reading?

increases

stays the same

decreases [1]

 (iii) State the resistance of the variable resistor when the voltmeter reads 0.75 V. [1]

[Total: 11]

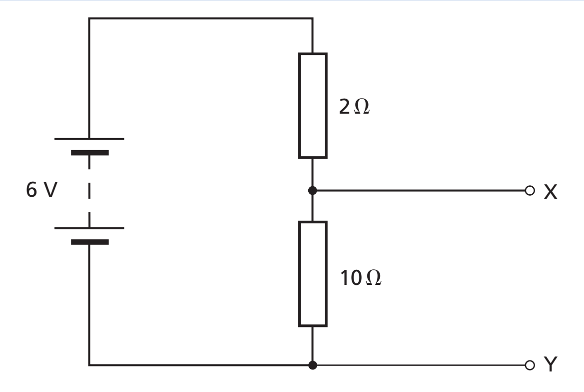
(Cambridge IGCSE Physics 0625 Paper 02 Q10 June 2008)

48 **a** Draw the symbol for a NOR gate. [1]
b Describe the action of a NOR gate in terms of its inputs and output. [2]
c A chemical process requires heating at low pressure to work correctly.
When the heater is working, the output of a temperature sensor is high. When the pressure is low enough, a pressure sensor has a low output. Both outputs are fed into a NOR gate. A high output from the gate switches on an indicator lamp.
 (i) Explain why the indicator lamp is off when the process is working correctly. [1]
 (ii) State whether the lamp is on or off in the following situations.
  1 The pressure is low enough, but the heater stops working.
  2 The heater is working, but the pressure rises too high. [2]

[Total: 6]

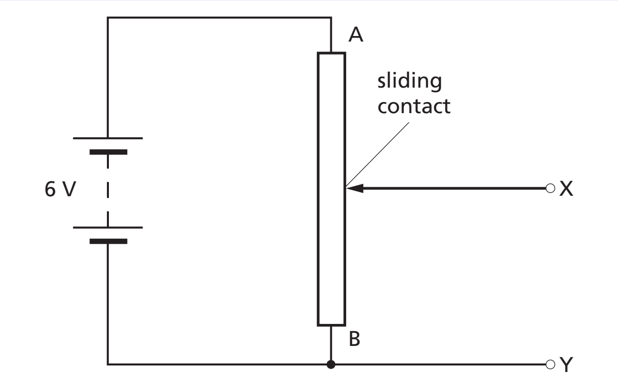
(Cambridge IGCSE Physics 0625 Paper 31 Q10 June 2008)

49 **a** The circuit shows two resistors connected to a 6 V battery.



(i) What name do we use to describe this way of connecting resistors? [1]
(ii) Calculate the combined resistance of the two resistors. [1]
(iii) Calculate the current in the circuit. [4]
(iv) Use your answer to **a(iii)** to calculate the potential difference across the 10 Ω resistor. [2]
(v) State the potential difference between terminals X and Y. [1]

b The circuit shown is similar to the circuit above, but it uses a resistor AB with a sliding contact.

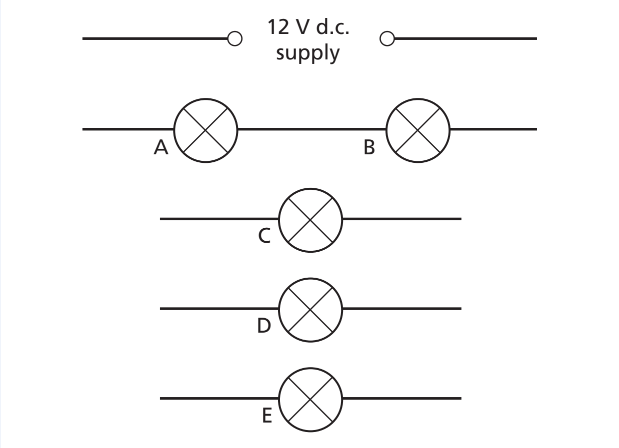


(i) State the potential difference between X and Y when the sliding contact is at
1 end A of the resistor, ... V
2 end B of the resistor. .... V [2]
(ii) The sliding contact of the resistor AB is moved so that the potential difference between X and Y is 5 V. On a copy of the circuit mark with the letter C the position of the sliding contact. [1]

[Total: 12]

(Cambridge IGCSE Physics 0625 Paper 02 Q9 June 2007)

50 The diagram shows part of a low-voltage lighting circuit containing five identical lamps.



a Copy and complete the circuit, by the addition of components as necessary, so that
(i) the total current from the supply can be measured,
(ii) the brightness of lamp E only can be varied,
(iii) lamps C and D may be switched on and off together whilst lamps A, B and E remain on. [4]

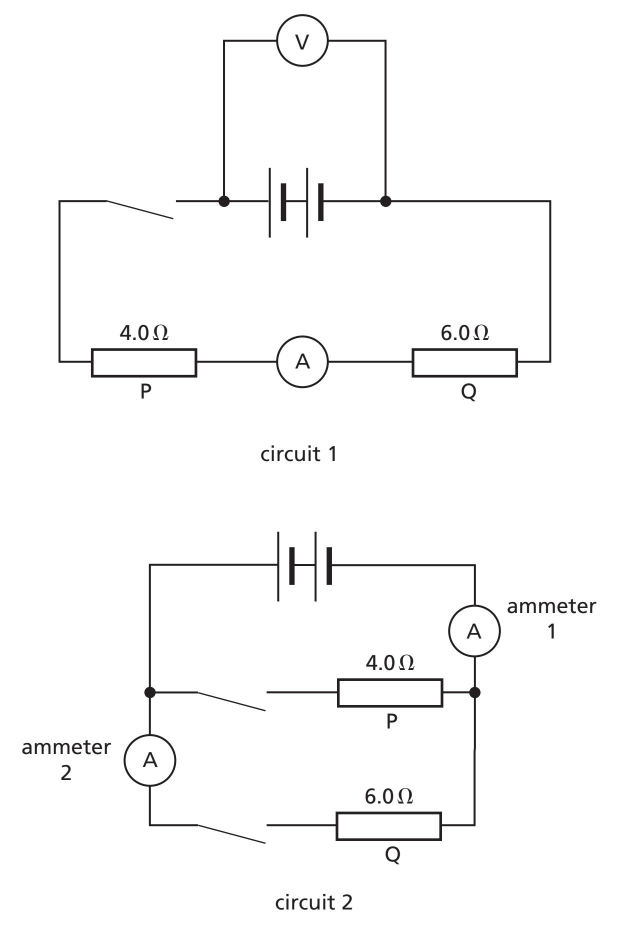
b All five lamps are marked 12 V, 36 W. Assume that the resistance of each lamp is the same fixed value regardless of how it is connected in the circuit.
Calculate
(i) the current in one lamp when operating at normal brightness, [1]
(ii) the resistance of one lamp when operating at normal brightness, [1]
(iii) the combined resistance of two lamps connected in parallel with the 12 V supply, [1]
(iv) the energy used by one lamp in 30 s when operating at normal brightness. [1]

c The whole circuit is switched on. Explain why the brightness of lamps A and B is much less than that of one lamp operating at normal brightness. [2]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 03 Q8 June 2007)

51 The diagram shows two electrical circuits.
The batteries in circuit 1 and circuit 2 are identical.



a Put ticks in a copy of the table below to describe the connections of the two resistors P and Q.

	Series	Parallel
circuit 1		
circuit 2		

[1]

b The resistors P and Q are used as small electrical heaters. State two advantages of connecting them as shown in circuit 2. [2]

c In circuit 1, the ammeter reads 1.2 A when the switch is closed. Calculate the reading of the voltmeter in this circuit. [2]

d The two switches in circuit 2 are closed. Calculate the combined resistance of the two resistors in this circuit. [2]

e When the switches are closed in circuit 2, ammeter 1 reads 5 A and ammeter 2 reads 2 A.

Calculate

(i) the current in resistor P, [1]

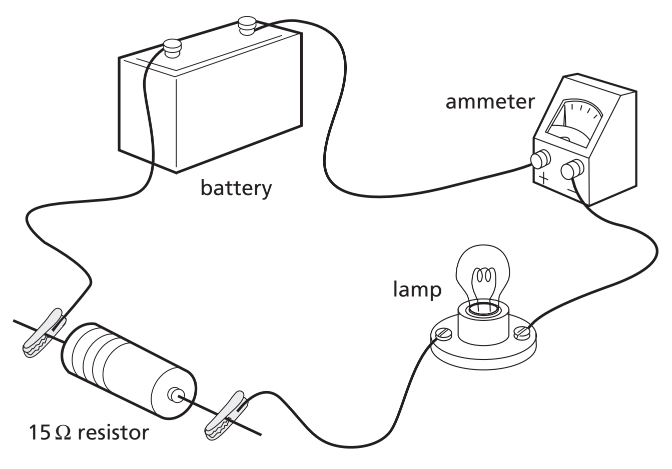
(ii) the power supplied to resistor Q, [1]

(iii) the energy transformed in resistor Q in 300 s. [1]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 03 Q8 November 2007)

52 The diagram shows an electric circuit.



a The lamp lights, but the ammeter needle moves the wrong way. What change should be made so that the ammeter works correctly? [1]

b What does an ammeter measure? [1]

c Draw a circuit diagram of the circuit in the diagram, using correct circuit symbols. [2]

d **(i)** Name the instrument that would be needed to measure the potential difference (p.d.) across the 15 Ω resistor.

(ii) Using the correct symbol, add this instrument to your circuit diagram in **c**, in a position to measure the p.d. across the 15 Ω resistor. [2]

e The potential difference across the 15 Ω resistor is 6 V.
Calculate the current in the resistor. [3]

f Without any further calculation, state the value of the current in the lamp. [1]

g Another 15 Ω resistor is connected in parallel with the 15 Ω resistor that is already in the circuit.

(i) What is the combined resistance of the two 15 Ω resistors in parallel?
30 Ω, 15 Ω, 7.5 Ω or zero?

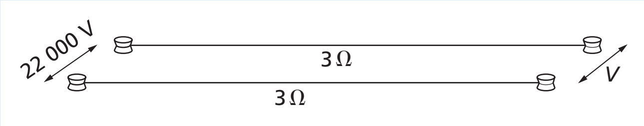
(ii) State what effect, if any, adding this extra resistor has on the current in the lamp. [2]

[Total: 12]

(Cambridge IGCSE Physics 0625 Paper 02 Q12 November 2006)

Electromagnetic effects

53 Alternating current electricity is delivered at 22 000 V to a pair of transmission lines. The transmission lines carry the electricity to the customer at the receiving end, where the potential difference is V. This is shown in the diagram. Each transmission line has a resistance of 3 Ω.



a The a.c. generator actually generates at a much lower voltage than 22 000 V.

(i) Suggest how the voltage is increased to 22 000 V. [1]

(ii) State one advantage of delivering electrical energy at high voltage. [1]

b The power delivered by the generator is 55 kW.
Calculate the current in the transmission lines. [2]

c Calculate the rate of loss of energy from one of the 3 Ω transmission lines. [2]

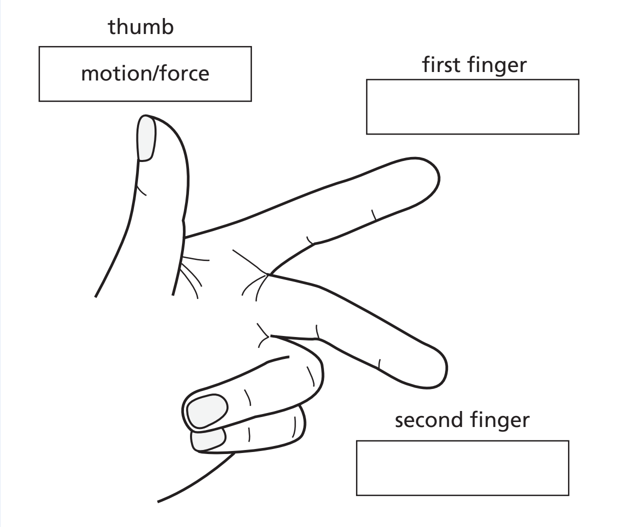
d Calculate the voltage drop across one of the transmission lines. [2]

e Calculate the potential difference V at the receiving end of the transmission lines. [2]

[Total: 10]

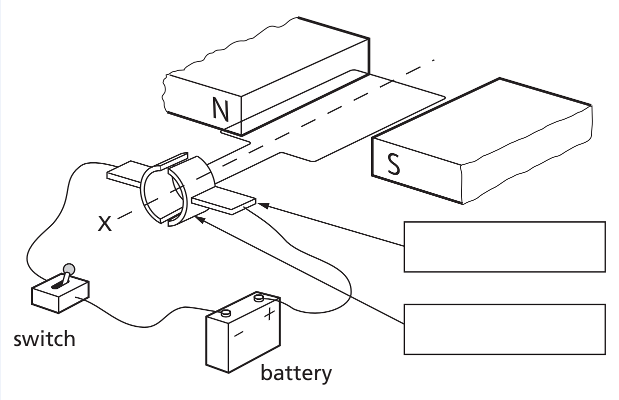
(Cambridge IGCSE Physics 0625 Paper 31 Q10 November 2009)

54 a The diagram illustrates the left-hand rule, which helps when describing the force on a current-carrying conductor in a magnetic field.



One direction has been labelled for you. In each of the other two boxes, write the name of the quantity that direction represents. [1]

b The diagram below shows a simple d.c. motor connected to a battery and a switch.



(i) On a copy of the diagram, write in each of the boxes the name of the part of the motor to which the arrow is pointing. [2]

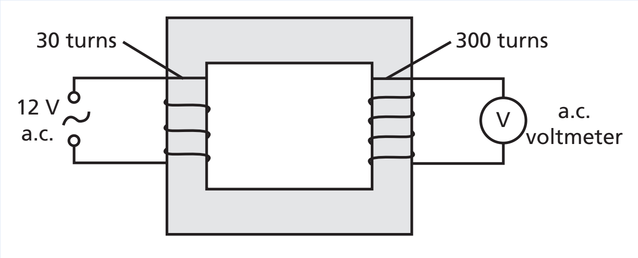
(ii) State which way the coil of the motor will rotate when the switch is closed, when viewed from the position X. [1]

(iii) State two things which could be done to increase the speed of rotation of the coil. [2]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 31 Q9 June 2010)

55 The diagram shows a transformer.

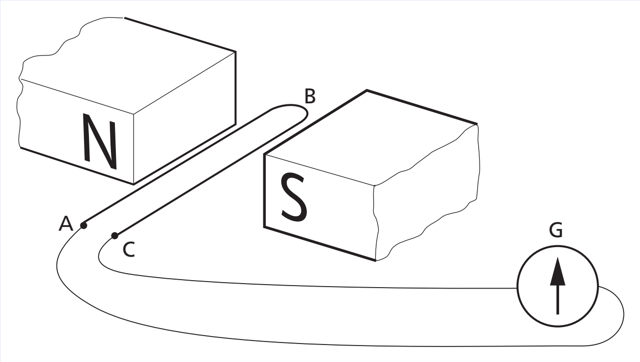


a **(i)** On a copy of the diagram, clearly label the core of the transformer. [1]
(ii) Name a suitable material from which the core could be made. [1]
(iii) State the purpose of the core. [1]
b Calculate the reading on the voltmeter. [3]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 02 Q10 November 2009)

56 **a** An experimenter uses a length of wire ABC in an attempt to demonstrate electromagnetic induction. The wire is connected to a sensitive millivoltmeter G as shown in the diagram.

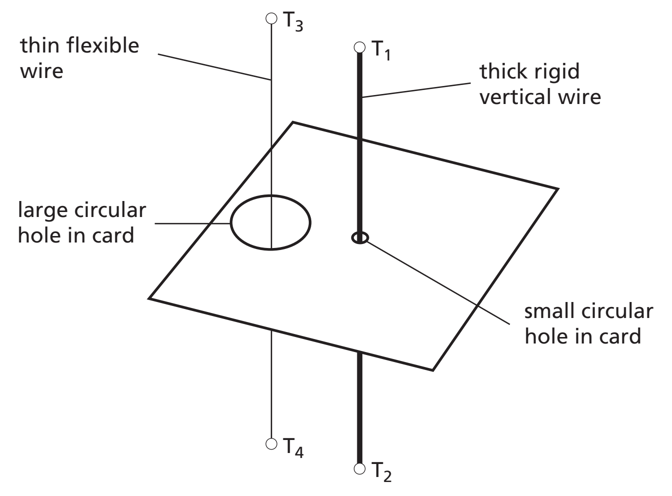


Using the arrangement in the diagram, the experimenter finds that she does not obtain the expected deflection on G when she moves the wire ABC down through the magnetic field.
(i) Explain why there is no deflection shown on G. [2]
(ii) What change should be made in order to observe a deflection on G? [1]
b Name one device that makes use of electromagnetic induction. [1]

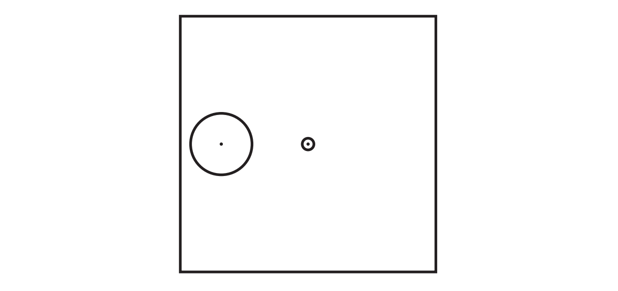
[Total: 4]

(Cambridge IGCSE Physics 0625 Paper 02 Q11 June 2008)

57 The diagram shows apparatus used to investigate electromagnetic effects around straight wires.



The diagram below is a view looking down on the apparatus shown above.



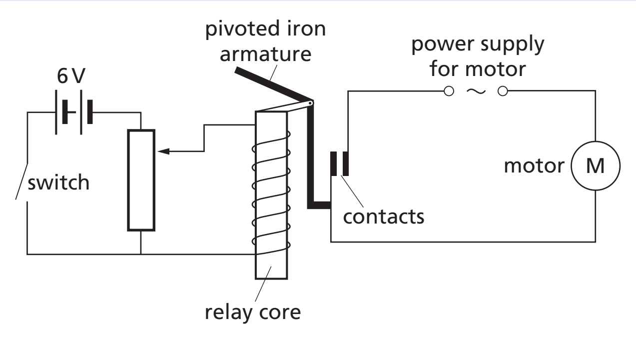
a A battery is connected to T_1 and T_2 so that there is a current vertically down the thick wire. On a copy of the diagram of the view looking down, draw three magnetic field lines and indicate, with arrows, the direction of all three. [2]
b Using a variable resistor, the p.d. between terminals T_1 and T_2 is gradually reduced. State the effect, if any, that this will have on
(i) the strength of the magnetic field, [1]
(ii) the direction of the magnetic field. [1]
c The battery is now connected to terminals T_3 and T_4, as well as to terminals T_1 and T_2, so that there is a current down both wires. This causes the flexible wire to move.
(i) Explain why the flexible wire moves. [2]
(ii) State the direction of the movement of the flexible wire. [1]

(iii) The battery is replaced by one that delivers a smaller current. State the effect that this will have on the force acting on the flexible wire. [1]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 31 Q9 June 2008)

58 The circuit in the diagram shows an electromagnetic relay being used to switch an electric motor on and off. The relay coil has a much greater resistance than the potential divider.



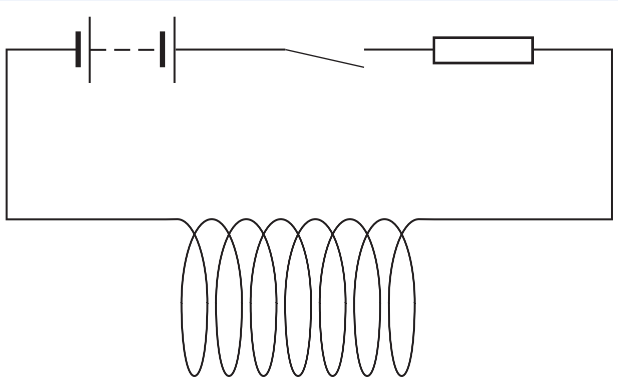
a The relay operates when there is a potential difference of 3 V across the coil. On a copy of the diagram, mark the position of the slider of the potential divider when the relay just operates. [1]

b Describe how the relay closes the contacts in the motor circuit. [3]

[Total: 4]

(Cambridge IGCSE Physics 0625 Paper 02 Q10 November 2008)

59 A coil of insulated wire is connected in series with a battery, a resistor and a switch as shown below.

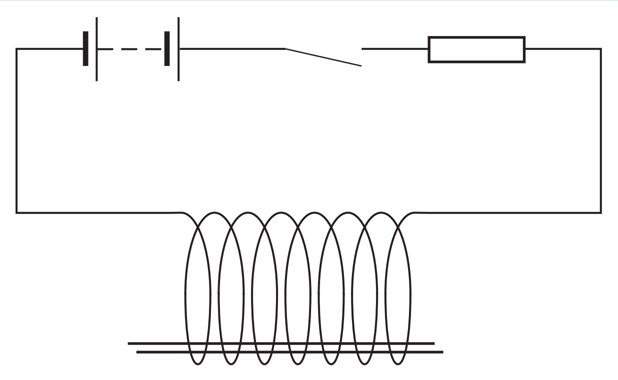


a The switch is closed and the current in the coil creates a magnetic field.

(i) On a copy of the diagram, draw the shape of the magnetic field, both inside and outside the coil. [4]

(ii) A glass bar, an iron bar and a Perspex bar are placed in turn inside the coil. Which one makes the field stronger? [1]

b Two thin iron rods are placed inside the coil as shown below. The switch is then closed.



The iron rods move apart. Suggest why this happens. [3]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 02 Q10 November 2007)

60 Electromagnetic induction may be demonstrated using a magnet, a solenoid and other necessary apparatus.

a Explain what is meant by *electromagnetic induction*. [2]

b Draw a labelled diagram of the apparatus set up so that electromagnetic induction may be demonstrated. [2]

c Describe how you would use the apparatus to demonstrate electromagnetic induction. [2]

d State two ways of increasing the magnitude of the induced e.m.f. in this experiment. [2]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 03 Q9 November 2007)

5 Atomic physics

61 Here is a list of different types of radiation.
alpha (α), beta (β), gamma (γ), infra-red, radio, ultra-violet, visible, X-rays

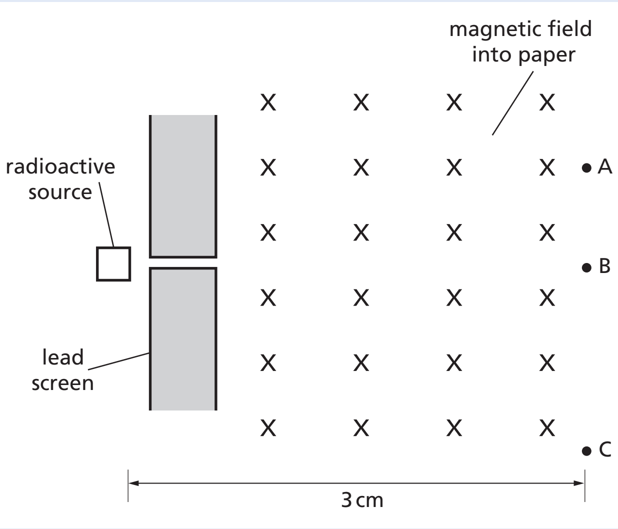
a List all those radiations in the list which are **not** electromagnetic radiations. [2]

b Which radiation is the most penetrating? [1]
c Which radiation has the longest wavelength? [1]
d Which radiation consists of particles that are the same as ^{4}He nuclei? [1]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 21 Q5 November 2010)

62 Emissions from a radioactive source pass through a hole in a lead screen and into a magnetic field, as shown in the diagram.



Radiation detectors are placed at A, B and C. They give the following readings:

A	B	C
32 counts/min	543 counts/min	396 counts/min

The radioactive source is then completely removed, and the readings become:

A	B	C
33 counts/min	30 counts/min	31 counts/min

a Explain why there are still counts being recorded at A, B and C, even when the radioactive source has been removed, and give the reason for them being slightly different. [2]
b From the data given, deduce the type of emission being detected, if any, at A, at B and at C when the radiation source is present.
State the reasons for your answers.
detector at A .... [2]
detector at B .... [3]
detector at C .... [3]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 31 Q10 November 2010)

63 A beam of ionising radiation, containing α-particles, β-particles and γ-rays, is travelling left to right across the page. A magnetic field acts perpendicularly into the page.
a In a copy of the table below, tick the boxes that describe the deflection of each of the types of radiation as it passes through the magnetic field. One row has been completed to help you. [3]

	not deflected	deflected towards top of page	deflected towards bottom of page	large deflection	small deflection
α-particles		✓			✓
β-particles					
γ-rays					

b An electric field is now applied, in the same region as the magnetic field and at the same time as the magnetic field.
What is the direction of the electric field in order to cancel out the deflection of the α-particles? [2]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 31 Q11 June 2009)

64 **a** The table shows how the activity of a sample of a radioactive substance changes with time.

Time /minutes	Activity /counts/s
0	128
30	58
60	25
90	11
120	5

Use the data in the table to estimate the half-life of the radioactive substance. [2]

b The half-lives of various substances are given below.

radon-220	55 seconds
iodine-128	25 minutes
radon-222	3.8 days
strontium-90	28 years

(i) If the radioactive substance in **a** is one of these four, which one is it? [1]

(ii) A sample of each of these substances is obtained. Which sample will have the greatest proportion of decayed nuclei by the end of one year, and why? [2]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 02 Q12 June 2008)

65 a Chlorine has two isotopes, one of nucleon number 35 and one of nucleon number 37. The proton number of chlorine is 17. The table refers to neutral atoms of chlorine. Copy and complete the table.

	Nucleon number 35	**Nucleon number 37**
number of protons		
number of neutrons		
number of electrons		

[3]

b Some isotopes are radioactive. State the three types of radiation that may be emitted from radioactive isotopes. [1]

c (i) State one practical use of a radioactive isotope. [1]

(ii) Outline how it is used. [1]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 31 Q11 June 2008)

66 The nucleus of one of the different nuclides of polonium can be represented by the symbol $^{218}_{84}\text{Po}$.

a State the proton number of this nuclide. [1]

b State the nucleon number of this nuclide. [1]

c The nucleus decays according to the following equation.

$$^{218}_{84}\text{Po} \rightarrow {}^{214}_{82}\text{Pb} + \text{emitted particle}$$

(i) State the proton number of the emitted particle. [1]

(ii) State the nucleon number of the emitted particle. [1]

(iii) Name the emitted particle. Choose from the following:

α-particle ☐

β-particle ☐

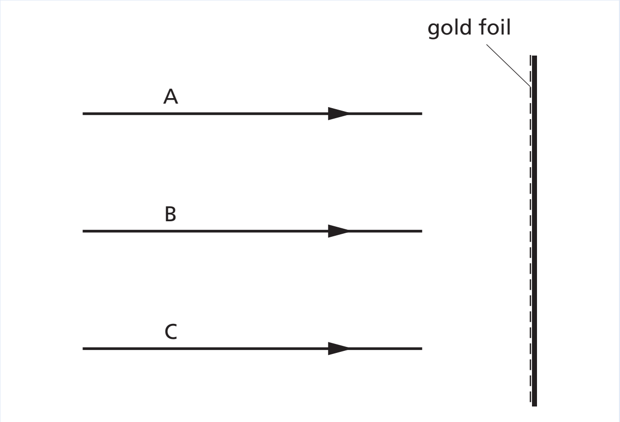
neutron ☐

proton ☐ [1]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 02 Q12 November 2008)

67 The diagram shows the paths of three α-particles moving towards a thin gold foil.



Particle A is moving directly towards a gold nucleus.
Particle B is moving along a line which passes close to a gold nucleus.
Particle C is moving along a line which does not pass close to a gold nucleus.

a On a copy of the diagram, complete the paths of the α-particles A, B and C. [3]

b State how the results of such an experiment, using large numbers of α-particles, provides evidence for the existence of nuclei in gold atoms. [3]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 03 Q11 June 2007)

68 The activity of a sample of radioactive material is determined every 10 minutes for an hour. The results are shown in the table.

Time / minutes	0	10	20	30	40	50	60
Activity / counts/s	461	332	229	162	106	81	51

a From the figures in the table, estimate the half-life of the radioactive material. [1]

b A second experiment is carried out with another sample of the same material. At the start of the experiment, this sample has twice the number of atoms as the first sample.
Suggest what values might be obtained for

(i) the activity at the start of the second experiment, [1]

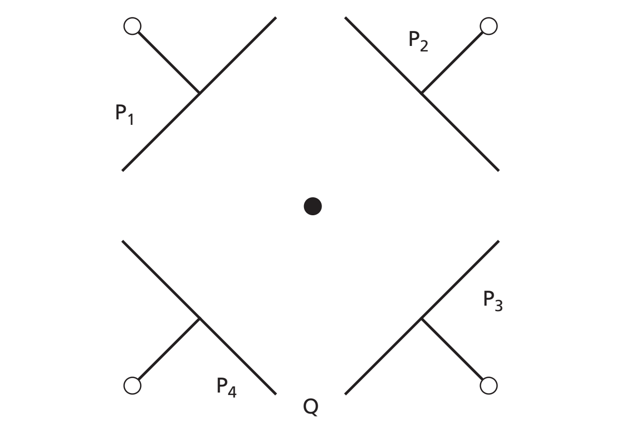
(ii) the half-life of the material in the second experiment. [1]

c Name one type of particle that the material might be emitting in order to cause this activity. [1]

[Total: 4]

(Cambridge IGCSE Physics 0625 Paper 02 Q11 November 2007)

69 A beam of cathode rays is travelling in a direction perpendicularly out of the page. The beam is surrounded by four metal plates P_1, P_2, P_3 and P_4 as shown in the diagram.
The beam is shown as the dot at the centre.



a Cathode rays are produced by thermionic emission.
What is the name of the particles which make up cathode rays? [1]

b A potential difference is applied between P_1 and P_3, with P_1 positive with respect to P_3. State what happens to the beam of cathode rays. [2]

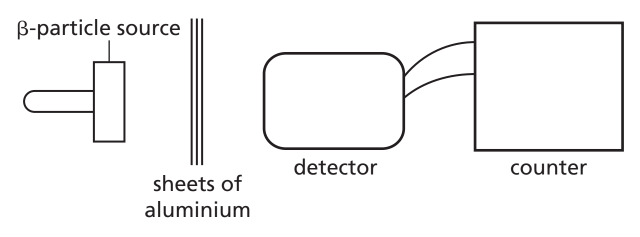
c The potential difference in **b** is removed. Suggest how the beam of cathode rays can now be deflected down the page towards Q. [2]

d Cathode rays are invisible. State one way to detect them. [1]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 02 Q12 November 2007)

70 The diagram shows an experiment to test the absorption of β-particles by thin sheets of aluminium.
Ten sheets are available, each 0.5 mm thick.



a Describe how the experiment is carried out, stating the readings that should be taken. [4]

b State the results that you would expect to obtain. [2]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 03 Q11 November 2007)

Mathematics for physics

USE THIS SECTION AS THE NEED ARISES

Solving physics problems

When tackling physics problems using mathematical equations it is suggested that you **do not substitute numerical values until you have obtained the expression in symbols which gives the answer**. That is, work in symbols until you have solved the problem and only then insert the numbers in the expression to get the final result.

This has two advantages. First, it reduces the chance of errors in the arithmetic (and in copying down). Second, you write less since a symbol is usually a single letter whereas a numerical value is often a string of figures.

Adopting this 'symbolic' procedure frequently requires you to change round an equation first. The next two sections and the questions that follow them are intended to give you practice in doing this and then substituting numerical values to get the answer.

Equations – type 1

In the equation $x = a/b$, the subject is x. To change it we **multiply or divide both** sides of the equation by the same quantity.

To change the subject to a

We have

$$x = \frac{a}{b}$$

If we multiply both sides by b, the equation will still be true.

$$\therefore \qquad x \times b = \frac{a}{b} \times b$$

The b's on the right-hand side cancel

$$\therefore \qquad b \times x = \frac{a}{b} \times b = a$$

and

$$a = b \times x$$

To change the subject to b

We have

$$x = \frac{a}{b}$$

Multiplying both sides by b as before, we get

$$a = b \times x$$

Dividing both sides by x:

$$\frac{a}{x} = \frac{b \times x}{x} = \frac{b \times x}{x} = b$$

$$\therefore \qquad b = \frac{a}{x}$$

Note that the **reciprocal** of x is $1/x$.

Can you show that

$$\frac{1}{x} = \frac{b}{a}?$$

Now try the following questions using these ideas.

Questions

1 What is the value of x if

a $2x = 6$ b $3x = 15$ c $3x = 8$

d $\frac{x}{2} = 10$ e $\frac{x}{3} = 4$ f $\frac{2x}{3} = 4$

g $\frac{4}{x} = 2$ h $\frac{9}{x} = 3$ i $\frac{x}{6} = \frac{4}{3}$

2 Change the subject to

a f in $v = f\lambda$ b λ in $v = f\lambda$

c I in $V = IR$ d R in $V = IR$

e m in $d = \frac{m}{V}$ f V in $d = \frac{m}{V}$

g s in $v = \frac{s}{t}$ h t in $v = \frac{s}{t}$

3 Change the subject to

a I^2 in $P = I^2R$ b I in $P = I^2R$

c a in $s = \frac{1}{2}at^2$ d t^2 in $s = \frac{1}{2}at^2$

e t in $s = \frac{1}{2}at^2$ f v in $\frac{1}{2}mv^2 = mgh$

g y in $\lambda = \frac{ay}{D}$ h ρ in $R = \frac{\rho l}{A}$

4 By replacing (substituting) find the value of $v = f\lambda$ if

a $f = 5$ and $\lambda = 2$ b $f = 3.4$ and $\lambda = 10$

c $f = 1/4$ and $\lambda = 8/3$ d $f = 3/5$ and $\lambda = 1/6$

e $f = 100$ and $\lambda = 0.1$ f $f = 3 \times 10^5$ and $\lambda = 10^3$

5 By changing the subject and replacing find

a f in $v = f\lambda$, if $v = 3.0 \times 10^8$ and $\lambda = 1.5 \times 10^3$

b h in $p = 10hd$, if $p = 10^5$ and $d = 10^3$

c a in $n = a/b$, if $n = 4/3$ and $b = 6$

d b in $n = a/b$, if $n = 1.5$ and $a = 3.0 \times 10^8$

e F in $p = F/A$ if $p = 100$ and $A = 0.2$

f s in $v = s/t$, if $v = 1500$ and $t = 0.2$

Equations – type 2

To change the subject in the equation $x = a + by$ **we add or subtract the same quantity from each side**. We may also have to divide or multiply as in type 1. Suppose we wish to change the subject to y in

$$x = a + by$$

Subtracting a from both sides,

$$x - a = a + by - a = by$$

Dividing both sides by b,

$$\frac{x-a}{b} = \frac{by}{b} = y$$

$$\therefore \quad y = \frac{x-a}{b}$$

Questions

6 What is the value of x if

a $x + 1 = 5$ **b** $2x + 3 = 7$ **c** $x - 2 = 3$

d $2(x - 3) = 10$ **e** $\frac{x}{2} - \frac{1}{3} = 0$ **f** $\frac{x}{3} + \frac{1}{4} = 0$

g $2x + \frac{5}{3} + 6$ **h** $7 - \frac{x}{4} = 11$ **i** $\frac{3}{x} + 2 = 5$

7 By changing the subject and replacing, find the value of a in $v = u + at$ if

a $v = 20$, $u = 10$ and $t = 2$

b $v = 50$, $u = 20$ and $t = 0.5$

c $v = 5/0.2$, $u = 2/0.2$ and $t = 0.2$

8 Change the subject in $v^2 = u^2 + 2as$ to a.

Proportion (or variation)

One of the most important mathematical operations in physics is finding the relation between two sets of measurements.

a) Direct proportion

Suppose that in an experiment two sets of readings are obtained for the quantities x and y as in Table M1 (units omitted).

Table M1

x	1	2	3	4
y	2	4	6	8

We see that when x is doubled, y doubles; when x is trebled, y trebles; when x is halved, y halves; and so on. There is a one-to-one correspondence between each value of x and the corresponding value of y.

We say that y is **directly proportional** to x, or y **varies directly** as x. In symbols

$$y \propto x$$

Also, the ratio of one to the other, e.g. y to x, is always the same, i.e. it has a constant value which in this case is 2. Hence

$$\frac{y}{x} = \text{a constant} = 2$$

The constant, called the **constant of proportionality** or **constant of variation**, is given a symbol, e.g. k, and the relation (or law) between y and x is then summed up by the equation

$$\frac{y}{x} = k \quad \text{or} \quad y = kx$$

Notes

1 In practice, because of inevitable experimental errors, the readings seldom show the relation so clearly as here.

2 If instead of using numerical values for x and y we use letters, e.g. x_1, x_2, x_3, etc., and y_1, y_2, y_3, etc., then we can also say

$$\frac{y_1}{x_1} = \frac{y_2}{x_2} = \frac{y_3}{x_3} = \ldots = k$$

or

$$y_1 = kx_1,\ y_2 = kx_2,\ y_3 = kx_3, \ldots$$

b) Inverse proportion

Two sets of readings for the quantities p and V are given in Table M2 (units omitted).

Table M2

p	3	4	6	12
V	4	3	2	1

There is again a one-to-one correspondence between each value of p and the corresponding value of V, but when p is doubled, V is halved, when p is trebled, V has one-third its previous value, and so on.

We say that V is **inversely proportional** to p, or V **varies inversely** as p, i.e.

$$V \propto \frac{1}{p}$$

Also, the **product** $p \times V$ is always the same (=12 in this case) and we write

$$V = \frac{k}{p} \quad \text{or} \quad pV = k$$

where k is the constant of proportionality or variation and equals 12 in this case.

Using letters for values of p and V we can also say

$$p_1 V_1 = p_2 V_2 = p_3 V_3 = \ldots. = k$$

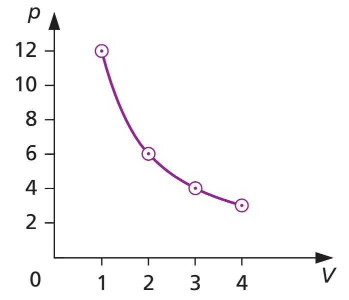


Figure M2

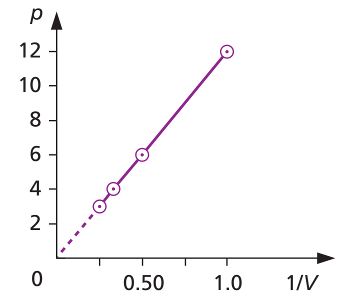


Figure M3

Graphs

Another useful way of finding the relation between two quantities is by a graph.

a) Straight line graphs

When the readings in Table M1 are used to plot a graph of y against x, a **continuous** line joining the points is **a straight line passing through the origin** as in Figure M1. Such a graph shows there is direct proportionality between the quantities plotted, i.e. $y \propto x$. But note that the line must go through the origin.

A graph of p against V using the readings in Table M2 is a curve, as in Figure M2. However if we plot p against $1/V$ (Table M3) (or V against $1/p$) we get a straight line through the origin, showing that $p \propto V$, as in Figure M3 (or $V \propto 1/p$).

Table M3

p	*V*	1/*V*
3	4	0.25
4	3	0.33
6	2	0.50
12	1	1.00

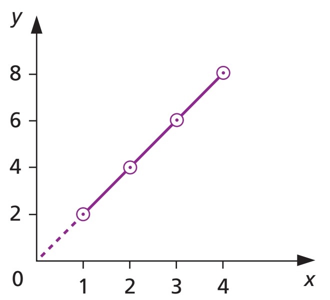


Figure M1

b) Slope or gradient

The slope or gradient of a straight line graph equals the constant of proportionality. In Figure M1, the slope is $y/x = 2$; in Figure M3 it is $p/(1/V) = 12$.

In practice, points plotted from actual measurements may not lie exactly on a straight line due to experimental errors. The 'best straight line' is then drawn 'through' them so that they are equally distributed about it. This automatically averages the results. Any points that are well off the line stand out and may be investigated further.

c) Variables

As we have seen, graphs are used to show the relationship between two physical quantities. In an experiment to investigate how potential difference, V, varies with the current, I, a graph can be drawn of V/V values plotted against the values of I/A. This will reveal how the potential difference depends upon the current (see Figure M4).

In the experiment there are two **variables**. The quantity I is varied and the value for V is dependent upon the value for I. So V is called the **dependent variable** and I is called the **independent variable**.

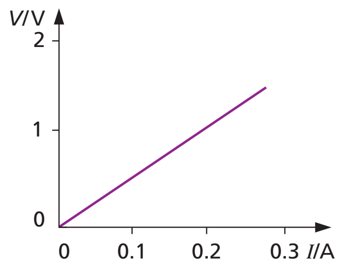


Figure M4

Note that in Figure M4 each axis is labelled with the quantity *and* the unit. Also note that there is a scale along each axis. The statement V/V *against* I/A means that V/V, the dependent variable, is plotted along the y-axis and the independent variable I is plotted along the x-axis (see Figure M5).

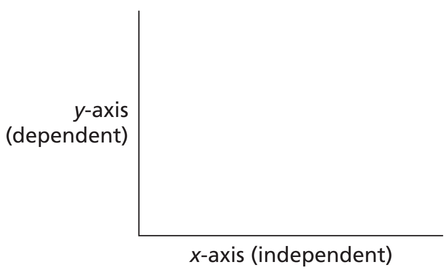


Figure M5

d) Practical points

(i) The axes should be labelled giving the quantities being plotted and their units, e.g. I/A meaning current in amperes.

(ii) If possible the origin of both scales should be on the paper and the scales chosen so that the points are spread out along the graph. It is good practice to draw a large graph.

(iii) The scale should be easy to use. A scale based on multiples of 10 or 5 is ideal. Do not use a scale based on a multiple of 3; such scales are very difficult to use.

(iv) Mark the points ⊙ or ×.

Questions

9 In an experiment different masses were hung from the end of a spring held in a stand and the extensions produced were as shown below.

Mass/g	100	150	200	300	350	500	600
Extension/cm	1.9	3.1	4.0	6.1	6.9	10.0	12.2

a Plot a graph of extension along the vertical (y) axis against mass along the horizontal (x) axis.

b What is the relation between extension and mass? Give a reason for your answer.

10 Pairs of readings of the quantities m and v are given below.

m	0.25	1.5	2.5	3.5
v	20	40	56	72

a Plot a graph of m along the vertical axis and v along the horizontal axis.

b Is m directly proportional to v? Explain your answer.

c Use the graph to find v when $m = 1$.

11 The distances s (in metres) travelled by a car at various times t (in seconds) are shown below.

s/m	0	2	8	18	32	50
t/m	0	1	2	3	4	5

Draw graphs of

a s against t,

b s against t^2.

What can you conclude?

Further experimental investigations

Stretching of a rubber band

Set up the equipment as shown in Chapter 6 (Figure 6.3, p. 25) but replace the spring with a thick rubber band. Draw up a table in which to record stretching force/N, scale reading/mm and total extension/mm. Take readings for increasing loads on the hanger.

Plot a graph with stretching force/N along the *x*-axis and extension/mm along the *y*-axis. Draw the best straight line through your points; are your results consistent with Hooke's law for all loads?

(If weights and a hanger are not available you could use coins (all similar) in a paper cup instead; in this case the stretching force would be proportional to the number of coins used.)

Toppling

The stability of a body can be investigated using a 1 litre drinks carton or can as shown in Figure E1a. When the carton is tilted so that the centre of mass moves outside the base, the carton will topple over.

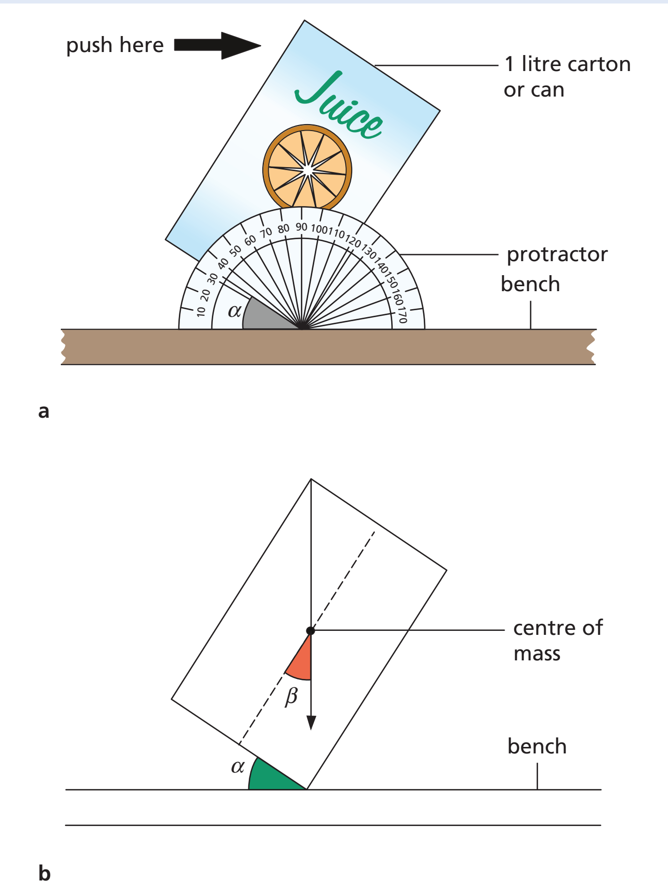


Figure E1

(i) Attach a protractor to the bench with Blu-tack. Fill a carton with water and gently push it at the top so that it tilts. Measure the maximum angle, α, that the carton can be tilted through without toppling; repeat your measurement several times and obtain an average value for α.

(ii) Draw a full-size diagram of the face of the carton; mark the centre of mass on the face and measure the angle β between the long side and a diagonal as shown in Figure E1b; how do your values for α and β compare?

(iii) Repeat part **(i)** with the carton half full, a quarter full and empty. Draw up a table of your results as shown below.

Liquid volume/litres	$\alpha_1/°$	$\alpha_2/°$	$\alpha_3/°$	Average $\alpha/°$
1.0				
0.5				
0.25				
0.0				
0.5 (frozen)				

Where is the centre of mass of an empty carton? Plot a graph with volume/litres on the *y*-axis and $\alpha/°$ on the *x*-axis. What angle of topple would you expect if the carton was one third full of water? How does changing the position of the centre of mass affect the stability of the carton?

(iv) Put a half-full carton in the freezer; when the water is fully frozen repeat part **(i)**; add your results to the table.
Will the carton be more or less stable when the water has melted? How are the centre of mass and the angle of topple changed by freezing the water?

(v) Turn a full carton on its side and repeat steps **(i)** and **(ii)**. Is the carton more or less stable than when upright? Explain why.

Summarise the factors that influence the stability of a body.

Cooling and evaporation

For this experiment you will need two heat sensors connected to a datalogger and computer. Use some cotton thread to tie a piece of tissue paper loosely over one of the heat sensors. Insert both heat sensors into a beaker of hot water and wait until they reach a constant temperature.

Experiment 1: With the datalogger running, remove the heat sensors from the water and quickly dry the sensor that is not covered by tissue paper. Hang each sensor on a retort stand and allow each to cool to room temperature. Use the computer to record a graph of temperature (on the y-axis) versus time (on the x-axis) for each sensor – these are 'cooling curves'.

Discuss the general shape of the cooling curves – when do the bulbs cool most rapidly? How do the cooling curves differ for the 'wet' compared with the 'dry' heat sensor? Which sensor reaches the lower temperature – can you explain why?

Experiment 2: Repeat the first experiment but this time hang the sensors in a draught to cool. An artificial draught can be produced by an electric cooling fan. Compare the cooling curves recorded by the computer with those obtained when there was no draught (Experiment 1). Comment on how the rate of cooling and the lowest temperature reached have changed for each sensor and try to explain your results.

From your findings, summarise the factors that affect the rate at which an object cools.

(If dataloggers and computers are not available this experiment could be done with mercury thermometers and a 'team' of students to help record temperatures manually every 15 seconds!)

Variation of the resistance of a wire with length

Several different lengths of resistance wire (constantan SWG 34 is suitable) are needed, in addition to the equipment shown in Chapter 38 (Figure 38.6, p. 168).

Cut the following lengths (l) of resistance wire: 20 cm, 40 cm, 60 cm, 80 cm and 100 cm. Wind each wire into a coil, ensuring that adjacent turns do not touch if the wire is not insulated. Set up the circuit shown in Figure 38.6 with the shortest coil in position R. (Set the rheostat near the midway position.) Draw up a table in which to record l, I, V and R for each coil. Determine R ($= V/I$) from your readings; repeat the measurements and calculation of R for each coil.

Draw a graph with average R values on the y-axis and l values on the x-axis. Is it consistent with the relation $R = \rho l$? Calculate the slope of the graph.

Measure the diameter of the constantan wire with a micrometer screw gauge and determine a value for the resistivity, ρ, of the wire.

Practical test questions

1 In this experiment, you are to investigate the stretching of springs. You have been provided with the apparatus shown in Figure P1.

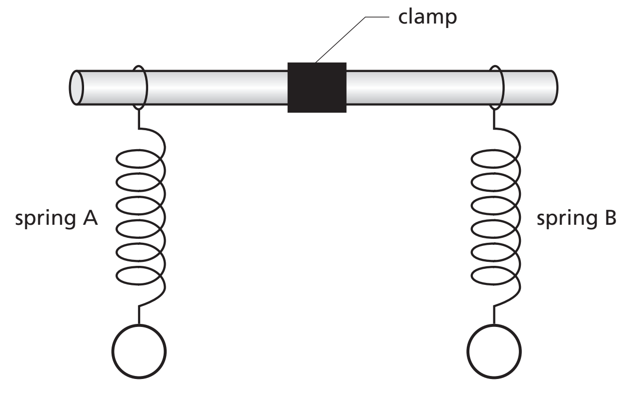


Figure P1

a (i) Measure the length l_A of spring **A**.
(ii) On a copy of Figure P1 show clearly where you decided to start and end the length measurement l_A.
(iii) Hang the 200 g mass on spring **A**. Measure the new length l of the spring.
(iv) Calculate the extension e_A of spring **A** using the equation $e_A = (l - l_A)$. [3]

b (i) Measure the length l_B of spring **B**.
(ii) Hang the 200 g mass on spring **B**. Measure the new length l of the spring.
(iii) Calculate the extension e_B of spring **B** using the equation $e_B = (l - l_B)$. [2]

c Use the small length of wooden rod provided to hang the 400 g mass midway between the springs as shown in Figure P2.

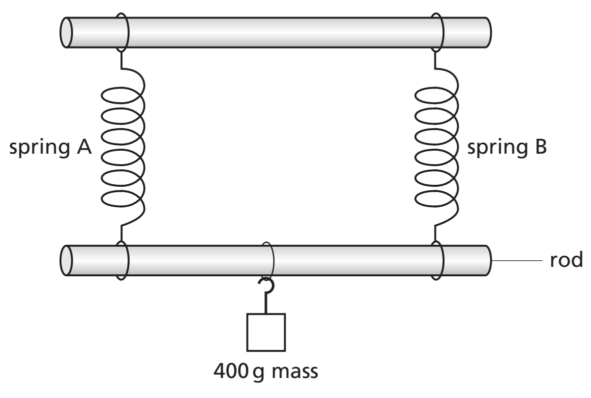


Figure P2

(i) Measure the new lengths of each of the springs.
(ii) Calculate the extension of each spring using the appropriate equation from parts **a** and **b**.
(iii) Calculate the average of these two extensions e_{av}. Show your working. [2]

d Theory suggests that

$$\frac{(e_a + e_b)}{2} = e_{av}$$

State whether your results support this theory and justify your answer with reference to the results. [2]

e Describe briefly one precaution that you took to obtain accurate length measurements. [1]

[Total 10]

(Cambridge IGCSE Physics 0625 Paper 51 Q1 June 2010)

2 In this experiment, you will investigate the effect of the length of resistance wire in a circuit on the potential difference across a lamp.
The circuit has been set up for you.

a Figure P3 shows the circuit without the voltmeter.
Draw on a copy of the circuit diagram the voltmeter as it is connected in the circuit. [2]

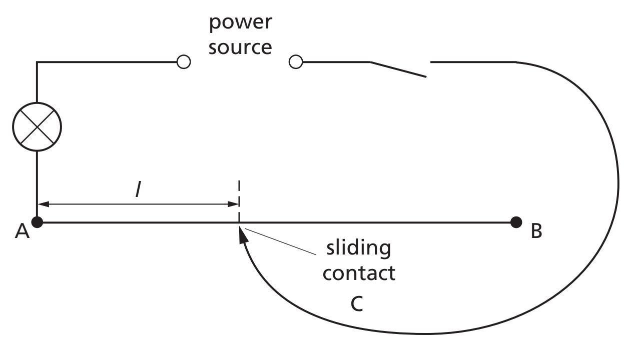


Figure P3

b (i) Switch on and place the sliding contact **C** on the resistance wire at a distance $l = 0.150$ m from end **A**. Record the value of l and the potential difference V across the lamp in the table. Switch off.

(ii) Repeat step **(i)** using the following values of l:
$0.350\,\text{m}$, $0.550\,\text{m}$, $0.750\,\text{m}$ and $0.950\,\text{m}$.
Record all the values of l and V in a copy of the table.

l/m	V/V	V/l

(iii) For each pair of readings in the table calculate and record in the table the value of V/l.

(iv) Complete the table by writing in the unit for V/l. [5]

c A student suggests that the potential difference V across the lamp is directly proportional to the length l of resistance wire in the circuit. State whether or not you agree with this suggestion and justify your answer by reference to your results. [2]

d State one precaution that you would take in order to obtain accurate readings in this experiment. [1]

[Total 10]

(Cambridge IGCSE Physics 0625 Paper 51 Q3 June 2010)

3 In this experiment you will investigate the rate of heating and cooling of a thermometer bulb. Carry out the following instructions referring to Figure P4. You are provided with a beaker of hot water.

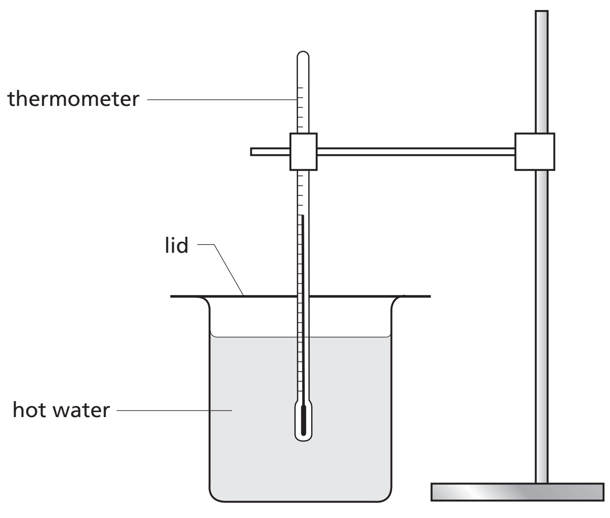


Figure P4

a Record the room temperature θ_r. [1]

b (i) Place the thermometer into the water as shown in Figure P4. When the temperature shown on the thermometer stops rising, record the temperature θ in a copy of Table A at time $t = 0\,\text{s}$.

(ii) Remove the thermometer from the beaker of water and immediately start the stopclock. Record in Table A the temperature shown on the thermometer as it cools in the air. Take readings at 30 s intervals from $t = 30\,\text{s}$ until you have a total of seven values up to time $t = 180\,\text{s}$. [2]

c (i) Set the stopclock back to zero. With the thermometer still out of the beaker, record in a copy of Table B the temperature θ shown on the thermometer at time $t = 0\,\text{s}$.

(ii) Replace the thermometer in the beaker of hot water as shown in Figure P4 and immediately start the stopclock. Record in Table B the temperature shown by the thermometer at 10 s intervals until you have a total of seven values up to time $t = 60\,\text{s}$.

Table A		Table B	
t/	θ/	t/	θ/

[2]

d Copy and complete the column headings in both tables. [1]

e Estimate the time that would be taken in part **b** for the thermometer to cool from the reading at time $t = 0\,\text{s}$ to room temperature θ_r. [1]

f State in which table the rate of temperature change is the greater. Justify your answer by reference to your readings. [1]

g If this experiment were to be repeated in order to determine an average temperature for each time, it would be important to control the conditions. Suggest two such conditions that should be controlled. [2]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 51 Q2 November 2010)

4 In this experiment you will investigate reflection of light through a transparent block.
Carry out the following instructions referring to Figure P5.

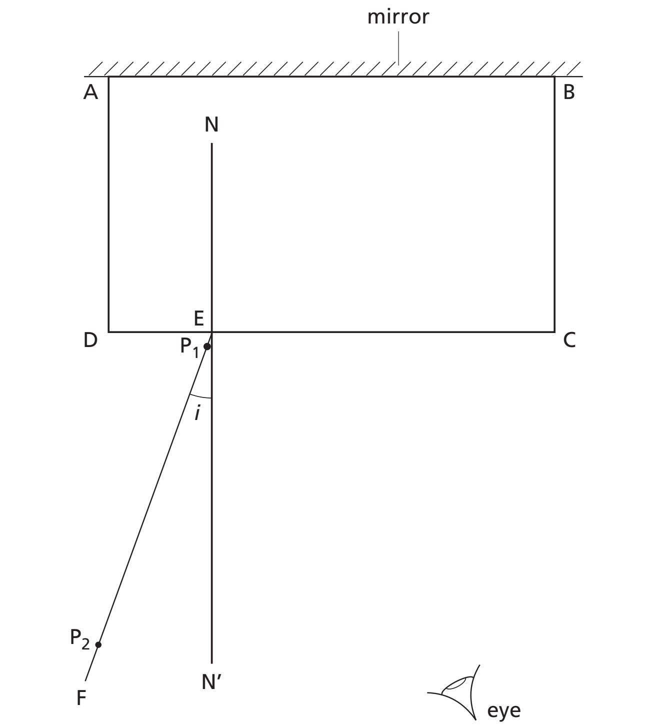


Figure P5

a Place the transparent block, largest face down, on the ray-trace sheet supplied. The block should be on the top half of the paper. Draw the outline of the block and label it **ABCD**.

b Remove the block and draw the normal **NN′** to side **CD** so that the normal is 2.0 cm from **D**. Label the point **E** where **NN′** crosses **CD**.

c Draw the line **EF** at an angle of incidence $i = 20°$ as shown in Figure P5.

d Place the paper on the pinboard. Stand the plane mirror vertically and in contact with face **AB** of the block as shown in Figure P5.

e Push two pins $\mathbf{P_1}$ and $\mathbf{P_2}$ into line **EF**. Pin $\mathbf{P_1}$ should be about 1 cm from the block and pin $\mathbf{P_2}$ some distance from the block.

f Replace the block and observe the images of $\mathbf{P_1}$ and $\mathbf{P_2}$ through side **CD** of the block from the direction indicated by the eye in Figure P5 so that the images of $\mathbf{P_1}$ and $\mathbf{P_2}$ appear one behind the other.
Push two pins $\mathbf{P_3}$ and $\mathbf{P_4}$ into the surface, between your eye and the block, so that $\mathbf{P_3}$, $\mathbf{P_4}$ and the images of $\mathbf{P_1}$ and $\mathbf{P_2}$, seen through the block, appear in line.
Mark the positions of $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$ and $\mathbf{P_4}$.
Remove the block.

g Continue the line joining the positions of $\mathbf{P_1}$ and $\mathbf{P_2}$ so that it crosses **CD** and extends as far as side **AB**.

h Draw a line joining the positions of $\mathbf{P_3}$ and $\mathbf{P_4}$. Continue the line so that it crosses **CD** and extends as far as side **AB**. Label the point **G** where this line crosses the line from $\mathbf{P_1}$ and $\mathbf{P_2}$.

i Remove the pins, block and mirror from the ray trace sheet. Measure the acute angle θ between the lines meeting at **G**. [1]

j Calculate the difference $(\theta - 2i)$. [1]

k Repeat steps **c** to **j** using an angle of incidence $i = 30°$. [1]

l Theory suggests that $\theta = 2i$. State whether your result supports the theory and justify your answer by reference to your results. [2]
[5]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 51 Q4 November 2010)

5 In this experiment, you are to make two sets of measurements as accurately as you can in order to determine the density of glass.
Carry out the following instructions referring to Figure P6.

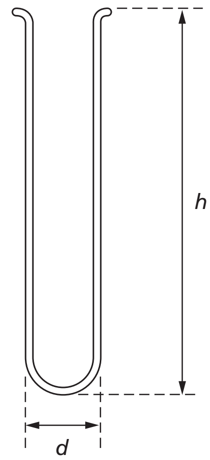


Figure P6

Method 1

a (i) Use the two blocks of wood and the rule to measure the external diameter d of the test tube in cm.

(ii) Draw a labelled diagram to show how you used the blocks of wood and the rule to find, as accurately as possible, a value for the external diameter of the test tube.

(iii) Measure the height h of the test tube in cm.

(iv) Calculate the external volume V_e of the test tube using the equation

$$V_e = \frac{\pi d^2 h}{4}$$ [3]

b Use the balance provided to measure the mass m_1 of the test tube. [1]

c (i) Completely fill the test tube with water. Pour the water into the measuring cylinder and record the volume V_i of the water.

(ii) Calculate the density ρ of the glass using the equation [1]

$$\rho = \frac{m_1}{(V_e - V_i)}$$

Method 2

d (i) Pour water into the measuring cylinder up to about the 175 cm³ mark. Record this volume V_1.

(ii) Carefully lower the test tube, open end uppermost, into the measuring cylinder so that it floats. Record the new volume reading V_2 from the measuring cylinder.

(iii) Calculate the difference in volumes $(V_2 - V_1)$.

(iv) Calculate the mass m_2 of the test tube using the equation $m_2 = k(V_2 - V_1)$ where $k = 1.0\ \text{g/cm}^3$. [3]

e (i) Use the wooden rod to push the test tube, open end uppermost, down to the bottom of the measuring cylinder so that the test tube is full of water and below the surface. Remove the wooden rod. Record the new volume reading V_3 from the measuring cylinder.

(ii) Calculate the density ρ of the glass using the equation

$$\rho = \frac{m_1}{(V_3 - V_1)}$$ [2]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 51 Q1 June 2009)

6 In this experiment, you are to determine the focal length of a converging lens.
Carry out the following instructions referring to Figure P7.

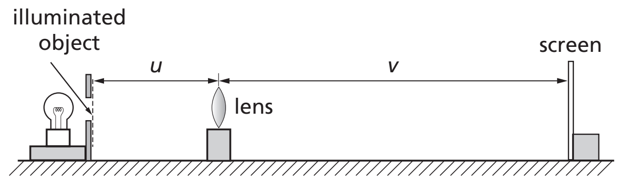


Figure P7

a Place the lens so that its centre is a distance $u = 25.0$ cm from the illuminated object.

b In a copy of the table record the distance u in cm from the centre of the lens to the illuminated object, as shown in Figure P7.

c Place the screen close to the lens. Move the screen away from the lens until a focused image of the object is seen on the screen.

d Measure and record in your table the distance v in cm from the centre of the lens to the screen.

u/cm	v/cm	f/cm

e Calculate and record in your table the focal length f of the lens using the equation

$$f = \frac{uv}{(u + v)}$$ [5]

f Place the lens so that its centre is 45.0 cm from the illuminated object.

g Repeat steps **b** to **e**.

h Calculate the average value of the focal length. [3]

i State and briefly explain one precaution you took in order to obtain reliable measurements. [2]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 51 Q4 June 2009)

7 In this experiment, you are to investigate the period of oscillation of a simple pendulum. Carry out the following instructions referring to Figure P8 and Figure P9.
The pendulum has been set up for you. Do not adjust the position of the clamp supporting the pendulum.

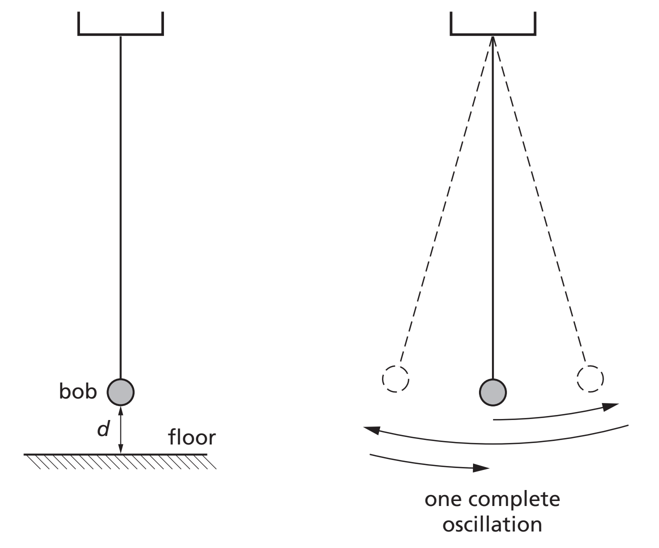


Figure P8 **Figure P9**

a Measure and record in a copy of the table the vertical distance d from the floor to the bottom of the pendulum bob.
b Displace the pendulum bob slightly and release it so that it swings. Measure and record in your table the time t for 20 complete oscillations of the pendulum (see Figure P9).
c Calculate the period T of the pendulum. The period is the time for one complete oscillation. Record the value of T in the table.
d Without changing the position of the clamp supporting the pendulum, adjust the length until the vertical distance d from the floor to the bottom of the pendulum bob is about 20 cm. Measure and record in the table the actual value of d to the nearest 0.1 cm. Repeat steps **b** and **c**.
e Repeat step **d** using d values of about 30 cm, 40 cm and 50 cm.

d/cm	*t*/s	*T*/s

[4]

f Plot a graph of T/s (y-axis) against d/cm (x-axis). [5]
g State whether or not your graph shows that T is directly proportional to d. Justify your statement by reference to the graph. [1]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 51 Q1 November 2009)

8 In this experiment, you are to compare the combined resistance of lamps arranged in series and in parallel.
Carry out the following instructions, referring to Figure P10 and Figure P11.
The circuit shown in Figure P10 has been set up for you.

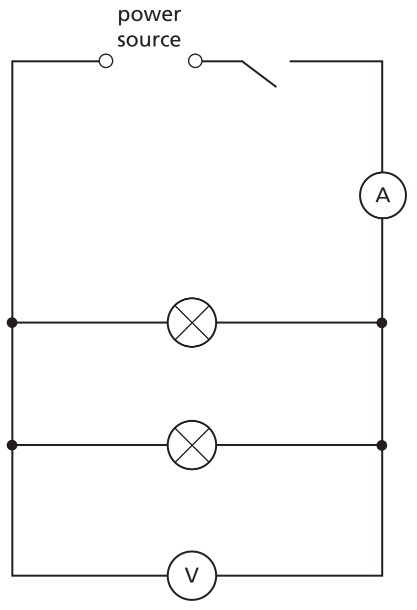


Figure P10

a Switch on. Measure and record in a copy of the table the current I in the circuit and the p.d. V across the two lamps. Switch off.
b Calculate the combined resistance R of the two lamps using the equation

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

Record this value of R in your table.

	V/	*I*/	*R*/
Figure P10			
Figure P11			

[4]

c Complete the column headings in the table.

d Disconnect the lamps and the voltmeter. Set up the circuit shown in Figure P11.

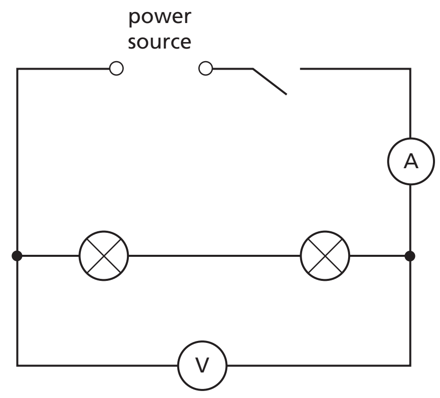


Figure P11

e Switch on. Measure and record in the table the current I in the circuit and the p.d. V across the two lamps. Switch off.

f Calculate the combined resistance R of the two lamps using the equation

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

Record this value of R in the table.

g Using the values of resistance obtained in **b** and **f**, calculate the ratio y of the resistances using the equation

$$y = \frac{\text{resistance of lamps in series}}{\text{resistance of lamps in parallel}}$$ [3]

h **(i)** Figure P12a shows a circuit including two motors A and B.
Draw a diagram of the circuit using standard circuit symbols. The circuit symbol for a motor is shown in Figure P12b.

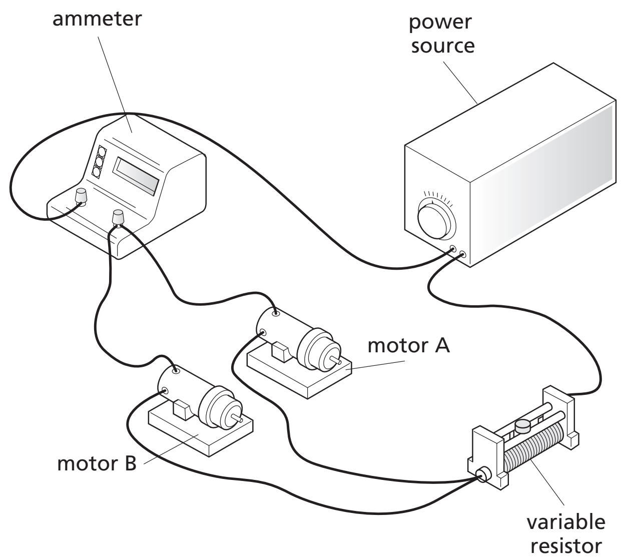


Figure P12a

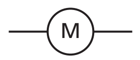


Figure P12b

(ii) An engineer wishes to measure the voltage across motor A.
On a copy of Figure P12a mark with the letters X and Y where the engineer should connect the voltmeter.

(iii) State the purpose of the variable resistor. [3]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 51 Q3 November 2009)

1 The IGCSE class is investigating the cooling of water. Figure P13 shows the apparatus used.

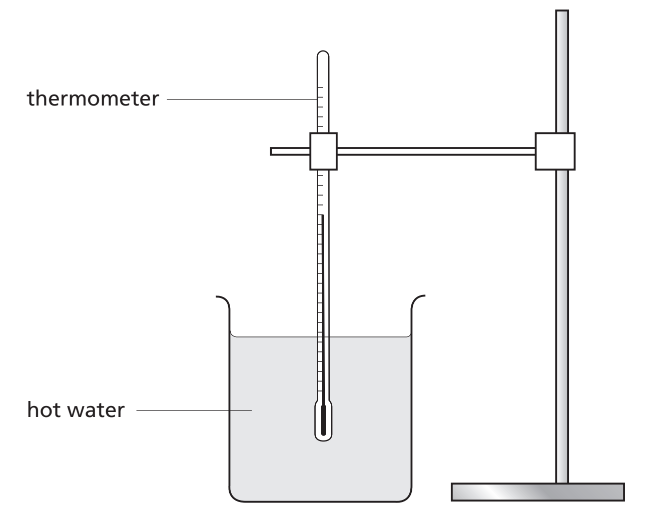


Figure P13

Hot water is poured into the beaker and temperature readings are taken as the water cools.
The table shows the readings taken by one student.

t/s	θ/°C
0	85
30	78
60	74
90	71
120	69
150	67
300	63

a (i) Using the information in the table, calculate the temperature change T_1 of the water in the first 150 s.

(ii) Using the information in the table, calculate the temperature change T_2 of the water in the final 150 s. [3]

b Plot a graph of θ/°C (y-axis) against t/s (x-axis) for the first 150 s. [5]

c During the experiment the rate of temperature change decreases.

(i) Describe briefly how the results that you have calculated in part **a** show this trend.

(ii) Describe briefly how the graph line shows this trend. [2]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 61 Q2 June 2010)

2 The IGCSE class is investigating the current in a circuit when different resistors are connected in the circuit.
The circuit is shown in Figure P14. The circuit contains a resistor **X**, and there is a gap in the circuit between points **A** and **B** that is used for adding extra resistors to the circuit.

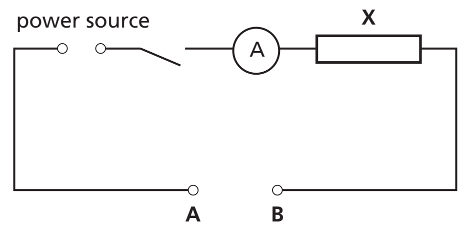


Figure P14

a A student connects points **A** and **B** together, switches on and measures the current I_0 in the circuit.
The reading is shown on the ammeter in Figure P15.
Write down the ammeter reading. [1]

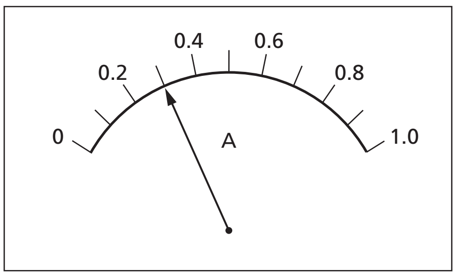


Figure P15

b The student connects a 3.3 Ω resistor between points **A** and **B**, switches on and records the current I. He repeats the procedure with a 4.7 Ω resistor and then a 6.8 Ω resistor.
Finally he connects the 3.3 Ω resistor and the 6.8 Ω resistor in series between points **A** and **B**, and records the current I.

(i) Complete the column headings in a copy of the table. [1]

R/	I/
3.3	0.23
4.7	0.21
6.8	0.18
	0.15

(ii) Write the combined resistance of the 3.3 Ω resistor and the 6.8 Ω resistor in series in the space in the resistance column of the table. [1]

c Theory suggests that the current will be 0.5 I_0 when the total resistance in the circuit is twice the value of the resistance of resistor **X**. Use the readings in the table, and the value of I_0 from **a**, to estimate the resistance of resistor **X**. [2]

d On a copy of Figure P14 draw two resistors in parallel connected between **A** and **B** and also a voltmeter connected to measure the potential difference across resistor **X**. [3]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 61 Q3 November 2010)

3 The IGCSE class is investigating the reflection of light by a mirror as seen through a transparent block. Figure P16 shows a student's ray-trace sheet.

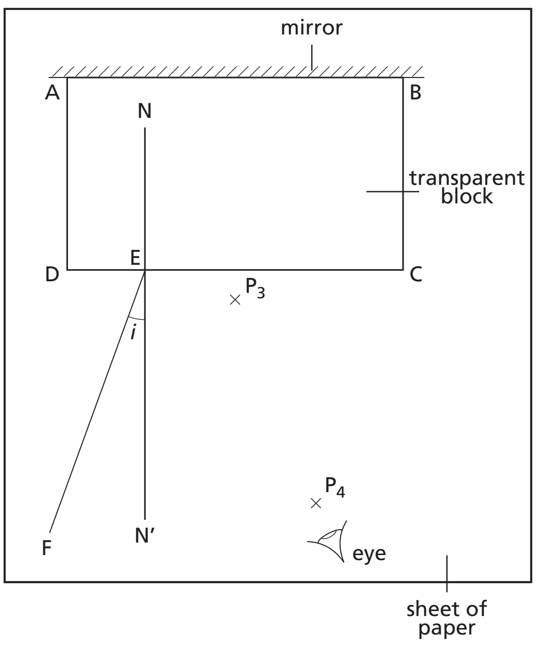


Figure P16

a A student draws the outline of the transparent block **ABCD** on the ray-trace sheet. He draws the normal **NN'** to side **CD**. He draws the incident ray **EF** at an angle of incidence $i = 20°$. He pushes two pins $\mathbf{P_1}$ and $\mathbf{P_2}$ into line **EF** and places the block on the sheet of paper. He then observes the images of $\mathbf{P_1}$ and $\mathbf{P_2}$ through side **CD** of the block from the direction indicated by the eye in Figure P16 so that the images of $\mathbf{P_1}$ and $\mathbf{P_2}$ appear one behind the other. He pushes two pins $\mathbf{P_3}$ and $\mathbf{P_4}$ into the surface, between his eye and the block, so that $\mathbf{P_3}$, $\mathbf{P_4}$ and the images of $\mathbf{P_1}$ and $\mathbf{P_2}$, seen through the block, appear in line. (The plane mirror along side **AB** of the block reflects the light.)
The positions of $\mathbf{P_3}$ and $\mathbf{P_4}$ are marked on Figure P16.

(i) Make a copy of Figure P16. On line **EF**, mark with neat crosses (×) suitable positions for the pins $\mathbf{P_1}$ and $\mathbf{P_2}$.

(ii) Continue the line **EF** so that it crosses **CD** and extends as far as side **AB**.

(iii) Draw a line joining the positions of $\mathbf{P_4}$ and $\mathbf{P_3}$. Continue the line so that it crosses **CD** and extends as far as side **AB**. Label the point **G** where this line crosses the line from $\mathbf{P_1}$ and $\mathbf{P_2}$. [4]

(iv) Measure the acute angle θ between the lines meeting at **G**.

(v) Calculate the difference $(\theta - 2i)$. [2]

b The student repeats the procedure using an angle of incidence $i = 30°$ and records the value of θ as 62°.

(i) Calculate the difference $(\theta - 2i)$.

(ii) Theory suggests that $\theta = 2i$. State whether the results support the theory and justify your answer by reference to the results. [3]

c To place the pins as accurately as possible, the student views the bases of the pins. Explain briefly why viewing the bases of the pins, rather than the tops of the pins, improves the accuracy of the experiment. [1]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 61 Q4 November 2010)

4 An IGCSE student is investigating moments using a simple balancing experiment.
He uses a pivot on a bench as shown in Figure P17.
First, the student balances the metre rule, without loads, on the pivot. He finds that it does not balance at the 50.0 cm mark, as he expects, but it balances at the 49.7 cm mark.
Load **Q** is a metal cylinder with diameter a little larger than the width of the metre rule, so that it covers the markings on the rule. Load **Q** is placed carefully on the balanced metre rule with its centre at the 84.2 cm mark. The rule does not slip on the pivot.

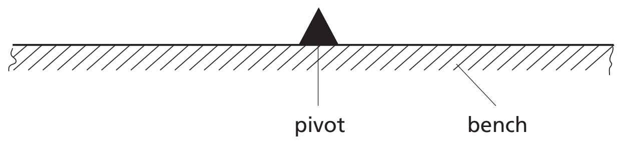


Figure P17

a Draw on a copy of Figure P17 the metre rule with load **Q** on it. [2]

b Explain, using a labelled diagram, how the student would ensure that the metre rule reading at the centre of **Q** is 84.2 cm. [2]

c Calculate the distance between the pivot and the centre of load **Q**. [1]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 61 Q5 June 2009)

5 The IGCSE class is investigating the period of oscillation of a simple pendulum. Figure P18 shows the set-up.

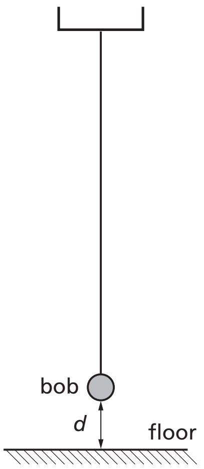


Figure P18

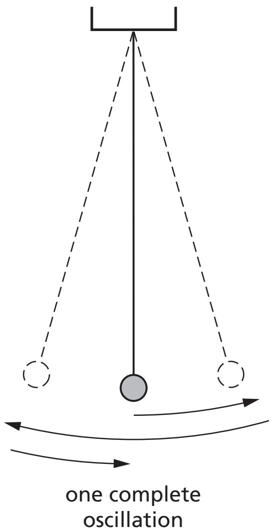


Figure P19

a (i) On Figure P18, measure the vertical distance *d* from the floor to the bottom of the pendulum bob.

(ii) Figure P18 is drawn one twentieth actual size. Calculate the actual distance *x* from the floor to the bottom of the pendulum bob. Enter this value in the top row of a copy of the table.
The students displace the pendulum bob slightly and release it so that it swings. They measure and record in the table the time *t* for 20 complete oscillations of the pendulum (see Figure P19).

x/cm	t/s	T/s	T^2/s^2
	20.0		
20.0	19.0		
30.0	17.9		
40.0	16.8		
50.0	15.5		

[4]

b (i) Copy the table and calculate the period T of the pendulum for each set of readings. The period is the time for one complete oscillation. Enter the values in the table.

(ii) Calculate the values of T^2. Enter the T^2 values in the table.

c Use your values from the table to plot a graph of T^2/s^2 (y-axis) against x/cm (x-axis). Draw the best-fit line. [5]

d State whether or not your graph shows that T^2 is directly proportional to x. Justify your statement by reference to the graph. [1]

[Total: 10]

(Cambridge IGCSE Physics 0625 Paper 61 Q1 November 2009)

6 An IGCSE student is carrying out an optics experiment.
The experiment involves using a lens to focus the image of an illuminated object onto a screen.

a Copy and complete Figure P20 to show the apparatus you would use. Include a metre rule to measure the distances between the object and the lens and between the lens and the screen. The illuminated object is drawn for you. [3]

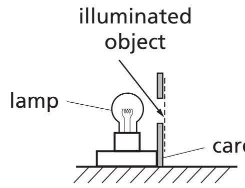


Figure P20

b State two precautions that you would take to obtain accurate results in this experiment. [2]

[Total: 5]

(Cambridge IGCSE Physics 0625 Paper 61 Q5 November 2009)

7 The IGCSE class is comparing the combined resistance of resistors in different circuit arrangements. The first circuit is shown in Figure P21.

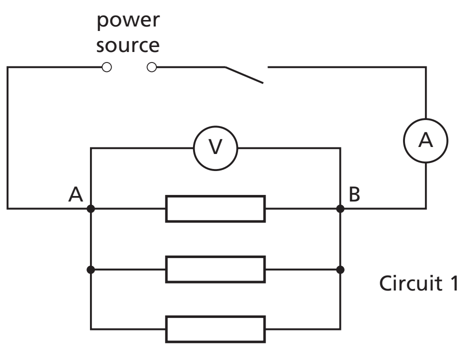


Figure P21

a The current I in the circuit and the p.d. V across the three resistors are measured and recorded. Three more circuit arrangements are used. For each arrangement, a student disconnects the resistors and then reconnects them between points **A** and **B** as shown in Figures P22–24.

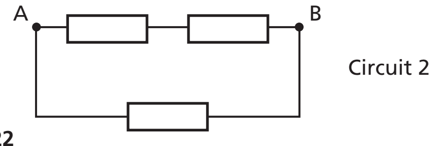


Figure P22

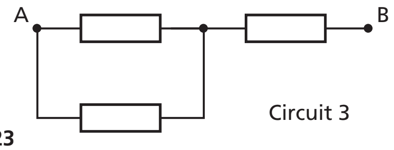


Figure P23

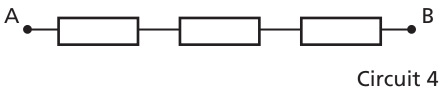


Figure P24

The voltage and current readings are shown in the table.

Circuit	*V*/	*I*/	*R*/
1	1.87	1.68	
2	1.84	0.84	
3	1.87	0.37	
4	1.91	0.20	

(i) Copy and complete the column headings for each of the V, I and R columns of the table.

(ii) For each circuit, calculate the combined resistance R of the three resistors using the equation

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

Record these values of R in your table. [3]

b Theory suggests that, if all three resistors have the same resistance under all conditions, the combined resistance in circuit 1 will be one half of the combined resistance in circuit 2.

(i) State whether, within the limits of experimental accuracy, your results support this theory. Justify your answer by reference to the results.

(ii) Suggest one precaution you could take to ensure that the readings are as accurate as possible. [3]

[Total: 6]

(Cambridge IGCSE Physics 0625 Paper 61 Q2 June 2008)

8 The IGCSE class is investigating the change in temperature of hot water as cold water is added to the hot water.
A student measures and records the temperature θ of the hot water before adding any of the cold water available.
He then pours $20\,cm^3$ of the cold water into the beaker containing the hot water. He measures and records the temperature θ of the mixture of hot and cold water.
He repeats this procedure four times until he has added a total of $100\,cm^3$ of cold water.
The temperature readings are shown in the table.
V is the volume of cold water added.

***V*/**	***θ*/**
0	82
	68
	58
	50
	45
	42

a (i) Copy and complete the column headings in the table.
(ii) Enter the values for the volume of cold water added. [2]

b Use the data in the table to plot a graph of temperature (y-axis) against volume (x-axis). Draw the best-fit curve. [4]

c During this experiment, some heat is lost from the hot water to the surroundings. Also, each time the cold water is added, it is added in quite large volumes and at random times. Suggest two improvements you could make to the procedure to give a graph that more accurately shows the pattern of temperature change of the hot water, due to addition of cold water alone. [2]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 61 Q3 November 2008)

9 a The table shows some measurements taken by three IGCSE students. The second column shows the values recorded by the three students. For each quantity, underline the value most likely to be correct.
The first one is done for you.

Quantity measured	**Recorded values**
The mass of a wooden metre rule	<u>0.112 kg</u> 1.12 kg 11.2 kg
The weight of an empty $250\,cm^3$ glass beaker	0.7 N 7.0 N 70 N
The volume of one sheet of this paper	$0.6\,cm^3$ $6.0\,cm^3$ $60\,cm^3$
The time taken for one swing of a simple pendulum of length 0.5 m	0.14 s 1.4 s 14 s
The pressure exerted on the ground by a student standing on one foot	$0.4\,N/cm^2$ $4.0\,N/cm^2$ $40\,N/cm^2$

[4]

b (i) A student is to find the value of the resistance of a wire by experiment. Potential difference V and current I can be recorded. The resistance is then calculated using the equation

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

The student knows that an increase in temperature will affect the resistance of the wire.
Assuming that variations in room temperature will not have a significant effect, suggest two ways by which the student could minimise temperature increases in the wire during the experiment. [2]

(ii) Name the circuit component that the student could use to control the current. [1]

[Total: 7]

(Cambridge IGCSE Physics 0625 Paper 61 Q5 November 2008)

10 The IGCSE class is investigating the resistance of a wire. The circuit is as shown in Figure P25.

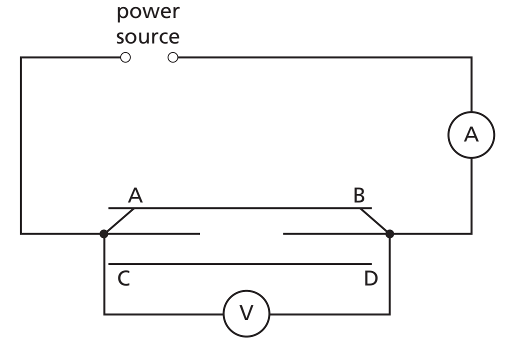


Figure P25

a A student uses the switches to connect the wire **AB** into the circuit and records the p.d. V across the wire between **A** and **B**. He also records the current I in the wire.
The student then repeats the measurements using the wire **CD** in place of wire **AB**.
The readings are shown in the table.

Wire	*V*/	*I*/	*R*/
AB	1.9	0.24	
CD	1.9	0.96	

[3]

(i) Calculate the resistance R of each wire, using the equation $R = V/I$.
Record the values in a copy of the table.

(ii) Complete the column headings in your table.

b The two wires **AB** and **CD** are made of the same material and are of the same length. The diameter of wire **CD** is twice the diameter of wire **AB**.

(i) Look at the results in the table. Below are four possible relationships between R and the diameter d of the wire. Which relationship best matches the results?

R is proportional to d

R is proportional to $1/d$

R is proportional to d^2

R is proportional to $1/d^2$

(ii) Explain briefly how the results support your answer in part **b(i)**. [2]

c Following this experiment, the student wishes to investigate whether two lamps in parallel with each other have a smaller combined resistance than the two lamps in series. Draw one circuit diagram showing

(i) two lamps in parallel with each other connected to a power source,

(ii) an ammeter to measure the total current in the circuit,

(iii) a voltmeter to measure the potential difference across the two lamps. [3]

[Total: 8]

(Cambridge IGCSE Physics 0625 Paper 61 Q3 June 2007)

11 a An IGCSE student is investigating the differences in density of small pieces of different rocks. She is using an electronic balance to measure the mass of each sample and using the 'displacement method' to determine the volume of each sample. Figure P26 shows the displacement method.

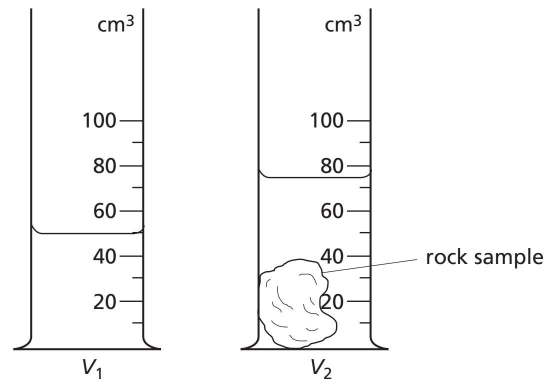


Figure P26

(i) Write down the volume shown in each measuring cylinder.

(ii) Calculate the volume V of the rock sample.

(iii) Calculate the density of sample **A** using the equation

$$\text{density} = \frac{m}{V}$$

where the mass m of the sample of rock is 109 g. [4]

b The table shows the readings that the student obtains for samples of rocks **B** and **C**. Copy and complete the table by

(i) inserting the appropriate column headings with units,

(ii) calculating the densities using the equation

$$\text{density} = \frac{m}{V}$$

Sample	*m*/g			*V*/	Density/
B	193	84	50	34	
C	130	93	50	43	

[4]

c Explain briefly how you would determine the density of sand grains. [1]

[Total: 9]

(Cambridge IGCSE Physics 0625 Paper 61 Q5 November 2007)

Answers

Higher level questions are marked with *. The questions, example answers, marks awarded and/or comments that appear in this book were written by the authors. In examination the way marks would be awarded to answers like these may be different. Cambridge International Examinations bears no responsibility for the example answers to questions taken from its past question papers which are contained in this publication.

General physics

Measurements and motion

1 Measurements

1 a 10
b 40
c 5
d 67
e 1000

2 a 3.00
b 5.50
c 8.70
d 0.43
e 0.1

3 a 1.0×10^5; 3.5×10^3; 4.28×10^8; 5.04×10^2; 2.7056×10^4
b 1000; 2 000 000; 69 200; 134; 1 000 000 000

4 a 1×10^{-3}; 7×10^{-5}; 1×10^{-7}; 5×10^{-5}
b 5×10^{-1}; 8.4×10^{-2}; 3.6×10^{-4}; 1.04×10^{-3}

5 10 mm

6 a Two
b Three
c Four
d Two

7 24 cm^3

8 40 cm^3; 5

9 80

10 a 250 cm^3
b 72 cm^3

11 a 53.3 mm
b 95.8 mm

12 a 2.31 mm
b 14.97 mm

13 a Metre, kilogram, second
b Different number of significant figures
c (i) πr^2
(ii) $\frac{4}{3}\pi r^3$
(iii) $\pi r^2 h$

2 Speed, velocity and acceleration

1 a 20 m/s
b 6.25 m/s

2 a 15 m/s
b 900 m

3 2 m/s^2

4 50 s

5 a 6 m/s
b 14 m/s

6 4 s

7 a Uniform acceleration
b 75 cm/s^2

8 a 1 s
b (i) 10 $cm/tentick^2$
(ii) 50 cm/s per tentick
(iii) 250 cm/s^2
c 0

9 A

10 E

3 Graphs of equations

1 a 60 km
b 5 hours
c 12 km/h
d 2
e $1\frac{1}{2}$ hours
f 60 km/$3\frac{1}{2}$ h = 17 km/h
g Steepest line: EF

2 a 100 m
b 20 m/s
c Slows down

3 a $\frac{5}{4}$ m/s^2
b (i) 10 m
(ii) 45 m
c 22 s

4 a (i) OA, BC: accelerating;
(ii) DE: decelerating;
(iii) AB, CD: uniform velocity
b OA: $a = +80\ km/h^2$;
AB: $v = 80$ km/h;
BC: $a = +40\ km/h^2$;
CD: $v = 100$ km/h;
DE: $a = -200\ km/h^2$
c OA 40 km; AB 160 km; BC (5 + 40) = 45 km; CD 100 km; DE 25 km
d 370 km
e 74 km/h

5 a Uniform velocity
b 600 m
c 20 m/s

4 Falling bodies

1 a (i) 10 m/s
(ii) 20 m/s
(iii) 30 m/s
(iv) 50 m/s
b (i) 5 m
(ii) 20 m
(iii) 45 m
(iv) 125 m

2 3 s; 45 m

5 Density

1 a (i) 0.5 g
(ii) 1 g
(iii) 5 g
b (i) 10 g/cm^3
(ii) 3 kg/m^3
c (i) 2.0 cm^3
(ii) 5.0 cm^3

2 a 8.0 g/cm^3
b $8.0 \times 10^3\ kg/m^3$

3 15 000 kg

4 130 kg

5 1.1 g/cm^3

6 Density of ice is less than density of water

Forces and momentum

6 Weight and stretching

1 a 1 N
b 50 N
c 0.50 N

2 a 120 N
b 20 N

3 a 2000 N/m
b 50 N/m

4 A

7 Adding forces

1 40 N
2 50 N
3 25 N
4 50 N at an angle of 53° to the 30 N force
5 a 7 N
  b 13 N

8 Force and acceleration

1 D
2 20 N
3 a 5000 N
  b 15 m/s^2
4 a 4 m/s^2
  b 2 N
5 a 0.5 m/s^2
  b 2.5 m/s
  c 25 m
6 a 1000 N
  b 160 N
7 a 5000 N
  b 20 000 N; 40 m/s^2
8 a (i) Weight
  (ii) Air resistance
  b Falls at constant velocity (terminal velocity)

9 Circular motion

1 Force is greater than string can bear
2 a Sideways friction between tyres and road
  b (i) Larger
  (ii) Smaller
  (iii) Larger
3 Slicks allow greater speed in dry conditions but in wet conditions treads provide frictional force to prevent skidding
4 5000 s (83 min)

10 Moments and levers

1 E
2 (i) C
  (ii) A
  (iii) B

11 Centres of mass

1 a B
  b A
  c C
2 Tips to right

12 Momentum

1 a 50 kg m/s
  b 2 kg m/s
  c 100 kg m/s
2 2 m/s
3 4 m/s
4 0.5 m/s
5 2.5 m/s
6 a 40 kg m/s
  b 80 kg m/s
  c 20 kg m/s^2
  d 20 N
7 2.5 m/s

Energy, work, power and pressure

13 Energy transfer

1 a Electrical to sound
  b Sound to electrical
  c k.e. to p.e.
  d Electrical to light (and heat)
  e Chemical to electrical to light and heat
2 A chemical; B heat; C kinetic; D electrical
3 180 J
4 1.5×10^5 J
5 a 150 J
  b 150 J
  c 10 W
6 500 W
7 a $(300/1000) \times 100 = 30\%$
  b Heat
  c Warms surroundings
8 a Electricity transferred to k.e. and heat
  b Electricity transferred to heat
  c Electricity transferred to sound
9 3.5 kW

14 Kinetic and potential energy

1 a 2 J
  b 160 J
  c $100\,000 = 10^5$ J
2 a 20 m/s
  b (i) 150 J
  (ii) 300 J
3 a 1.8 J
  b 1.8 J
  c 6 m/s
  d 1.25 J
  e 5 m/s
4 3.5×10^9 W = 3500 MW

15 Energy sources

1 a 2%
  b Water
  c Cannot be used up
  d Solar, wind
  e All energy ends up as heat which is difficult to use and there is only a limited supply of non-renewable sources
2 Renewable, non-polluting (i.e. no CO_2, SO_2 or dangerous waste), low initial building cost of station to house energy converters, low running costs, high energy density, reliable, allows output to be readily adjusted to varying energy demands

16 Pressure and liquid pressure

1 a (i) 25 Pa
  (ii) 0.50 Pa
  (iii) 100 Pa
  b 30 N
2 a 100 Pa
  b 200 N
3 a A liquid is nearly incompressible
  b A liquid transfers the pressure applied to it
4 1 150 000 Pa (1.15×10^6 Pa) (ignoring air pressure)
5 a Vacuum
  b Atmospheric pressure
  c 740 mmHg
  d Becomes less; atmospheric pressure lower

6 E
7 B

Thermal physics

Simple kinetic molecular model of matter

17 Molecules

1 B
2 a Air is readily compressed
b Steel is not easily compressed

18 The gas laws

1 a 15 cm³
b 6 cm³

Thermal properties and temperature

19 Expansion of solids, liquids and gases

2 Aluminium
3 B
4 A

20 Thermometers

1 a 1530 °C
b 19 °C
c 0 °C
d −12 °C
e 37 °C
2 C
3 a Property must change continuously with temperature
b Volume of a liquid, resistance, pressure of a gas
c (i) Platinum resistance
(ii) Thermocouple
(iii) Alcohol

21 Specific heat capacity

1 15 000 J, 1500 J/°C
2 A = 2000 J/(kg °C);
B = 200 J/(kg °C);
C = 1000 J/(kg °C)
3 Specific heat capacity of jam is higher than that of pastry so it cools more slowly

22 Specific latent heat

1 a 3400 J
b 6800 J
2 a $5 \times 340 + 5 \times 4.2 \times 50 = 2750$ J
b 1700 J
3 680 s
4 a 0 °C
b 45 g
5 a 9200 J
b 25 100 J
6 157 g
7 a Ice has a high specific latent heat of fusion
b Water has a high specific latent heat of vaporisation
8 Heat drawn from the water when it evaporates
9 Heat drawn from the milk when the water evaporates
10 1200 J

Thermal processes

23 Conduction and convection

1 a Newspaper is a poor conductor of heat
b The fur would trap more air, which is a good insulator, and so keep wearer warmer
c Holes in a string vest trap air, which is a poor conductor, next to the skin
3 a If small amounts of hot water are to be drawn off frequently it may not be necessary to heat the whole tank
b If large amounts of hot water are needed it will be necessary to heat the whole tank
4 Metal is a better conductor of heat than rubber

24 Radiation

1 Black surfaces absorb radiation better than white ones so the ice on the black sections of the canopy melts faster than on the white sections
2 a The Earth radiates energy back into space
b Clouds reduce the amount of energy radiated into space, keeping the ground warmer

Properties of waves

General wave properties

25 Mechanical waves

1 a 1 cm
b 1 Hz
c 1 cm/s
2 A, C
3 a Speed of ripple depends on depth of water
b AB since ripples travel more slowly towards it, therefore water shallower in this direction
4 a Trough
b (i) 3.0 mm
(ii) 15 mm/s
(iii) 5 Hz

Light

26 Light rays

1 Larger, less bright
2 a Four images
b Brighter but blurred
3 C
4 Before; sound travels slower than light

27 Reflection of light

1 a 40°
c 40°, 50°, 50
d Parallel
2 A
3 Top half

28 Plane mirrors

1 B
2 D
3 4 m towards mirror
4 B

29 Refraction of light

3 250 000 km/s
4 C
6 E
7 A

30 Total internal reflection

1 a Angle of incidence = 0
  b Angle of incidence > critical angle
3 Periscope, binoculars
4 a Ray passes into air and is refracted away from the normal
  b Total internal reflection occurs in water
5 48.6°

31 Lenses

1 Parallel
2 a Converging
  c Image 9 cm from lens, 3 cm high
3 Distance from lens:
  a beyond 2F
  b 2F
  c between F and 2F
  d nearer than F
4 Towards
5 a 4 cm
  b 8 cm behind lens, virtual, $m = 2$
6 A: converging $f = 10$ cm
  B: converging $f = 5$ cm

32 Electromagnetic radiation

1 a 0.7 µm
  b 0.4 µm
2 a B
  b D
3 a Ultraviolet
  b Microwaves
  c Gamma rays
  d Infrared
  e Infrared/microwaves
  f X-rays
4 a 3 m
  b 2×10^{-4} s
5 E

Sound

33 Sound waves

1 1650 m (about 1 mile)
2 a $2 \times 160 = 320$ m/s
  b $240/(3/4) = 320$ m/s
  c 320 m
3 a Reflection, refraction, diffraction, interference
  b Vibrations are perpendicular to rather than along the direction of travel of the wave; longitudinal
4 b (i) 1.0 m
  (ii) 2.0 m

Electricity and magnetism

Simple phenomena of magnetism

34 Magnetic fields

1 C

Electrical quantities and circuits

35 Static electricity

1 D
2 Electrons are transferred from the cloth to the polythene
3 C

36 Electric current

1 a 5 C
  b 50 C
  c 1500 C
2 a 5 A
  b 0.5 A
  c 2 A
3 B
4 C
5 All read 0.25 A

37 Potential difference

1 a 12 J
  b 60 J
  c 240 J
2 a 6 V
  b (i) 2 J
  (ii) 6 J
3 B
4 b Very bright
  c Normal brightness
  d No light
  e Brighter than normal
  f Normal brightness
5 a 6 V
  b 360 J
6 $x = 18$, $y = 2$, $z = 8$

38 Resistance

1 3 Ω
2 20 V
3 C
4 A = 3 V; B = 3 V; C = 6 V
5 2 Ω
6 a 15 Ω
  b 1.5 Ω
7 D
8 a (i) ohm's law
  (ii) 2 Ω
9 B

39 Capacitors

2 a (i) Maximum
  (ii) Zero
  b (i) Maximum
  (ii) Zero

40 Electric power

1 a 100 J
  b 500 J
  c 6000 J
2 a 24 W
  b 3 J/s
3 C
4 2.99 kW
5 Fuse is in live wire in **a** but not in **b**
7 a 3 A
  b 13 A
  c 13 A
8 40p
9 a (i) 2 kW
  (ii) 60 W
  (iii) 850 W
  b 4 A

41 Electronic systems

1 b L_1 lights, L_2 does not
  c L_1 and L_2 light
  d L_1 lights, L_2 does not
2 a $V_1 = V_2 = 3$ V
  b $V_1 = 1$ V, $V_2 = 5$ V
  c $V_1 = 4$ V, $V_2 = 2$ V

42 Digital electronics

1 A AND
B OR
C NAND
D NOR
2 A OR
B NOT
C NAND
D NOR
E AND

Electromagnetic effects

43 Generators

1 a A: slip rings, B: brushes
b Increase the number of turns on the coil, the strength of the magnet and the speed of rotation of the coil.
2 The galvanometer needle swings alternately in one direction and then the other as the rod vibrates. This is due to a p.d. being induced in the metal rod when it cuts the magnetic field lines; current flows in alternate directions round the circuit as the rod moves up or down

44 Transformers

2 B
3 a 24
b 1.9 A
4 B

45 Electromagnets

1 a North
b East
2 S
3 a To complete the circuits to the battery negative
b One contains the starter switch and relay coil; the other contains the relay contacts and starter motor
c Carries much larger current to starter motor
d Allows wires to starter switch to be thin since they only carry the small current needed to energise the relay

46 Electric motors

1 E
2 Clockwise
3 E

47 Electric meters

3 a 0–5 V, 0–10 V
b 0.1 V
c 0–5 V
d Above the 4
e Parallax error introduced

48 Electrons

1 a A −ve, B +ve
b Down
2 a 1.6×10^{-16} J
b 1.9×10^{7} m/s

Atomic physics

49 Radioactivity

1 a α
b γ
c β
d γ
e α
f α
g β^-
h γ
2 25 minutes
3 D

50 Atomic structure

1 B
2 C (symbol is ${}^{7}_{3}\text{Li}$)

Revision questions

1 E
2 A
3 C
4* a Yes, 1 mm = 0.001 m
b E
5 D
6 E
7 A
8 B
9 C
10 D
11 D
12 a B
b A
13 A
14 A
15 C
16 B
17 D
18 C
19 C
20 C
21 E
22 a Become circular
b No change
c No change
23 a (i) Infrared
(ii) X-rays
b (i) Radio
(ii) γ-rays
24 a Longitudinal
b (i) Compression
(ii) Rarefaction
25 a 60°
b 30°
26 a Refraction
b POQ
c Towards
d 40°
e 90 − 65 = 25°
27 C
28 a Dispersion
b (i) Red
(ii) Violet
29 B
30 A
31 D
32 B
33 C
34 a 1 Ω
b 3 A
c 6 V
35 a 3 Ω
b 2 A
c 4 V across 2; 2 V across 1
36 D
37 B
38 a E
b A
c C
d B
e D
39 E

40 E
41 E
42 B
43 B
44 a C
b A
c B
d A
45 a D
b E

Cambridge IGCSE exam questions

1 General physics

Measurements and motion

1 a (i) 6 cm and 5 cm
(ii) 60 cm^3
b 2.65 g/cm^3
2* Time 10 cycles and calculate the average

3 a

Distance	Tape measure
Time	Stopwatch

b Speed = distance/time
c (i) Some distances at slower speeds
(ii) 22 km
4 a (i) 1 Increasing
2 Constant
c Zero distance
5 a 400 s
d 10.8 m/s
6* a (i) 1.6 s
(ii) 4.2 s
(iii) 32 m
(iv) 70−95 m (area under graph)
b (i) Weight of ball down, air resistance up
(ii) Up force = down force

Forces and momentum

7* b 3 N reading
d Straight line through the origin shows Hooke's law
e Graph curves
f Exceeded elastic limit
8* a Limit of proportionality
b Force proportional to extension
c OQ extension proportional to force
QR extension/unit force greater
d 4.0 N/mm
9* b 98 N–102 N
c Vertically upwards
d 98 N–102 N
10* c Mass × distance
11 a (i) At A
(ii) Greatest distance from the hinge
b When centre of mass is outside base
c (i) Less than
(ii) Centre of mass of matchbox has been raised
12 a Force, perpendicular distance from pivot
b (i) Force, moment
(ii) $F_1 + F_2 + W$
(iii) F
13* a Student B: force inversely proportional to mass
b $F = ma$
c (i) Nothing or as before
(ii) Slows down
(iii) Moves in a circle
14* a The direction is changing
b (i) Force needed to change direction
(ii) Towards the centre
(iii) Friction between tyres and the road
15* a (i) Resultant force
(ii) To overcome friction
b 0.8 kg
c 0.875 m/s^2
d (i) 0.6 m/s
(ii) 0.36 m
16* a (ii) It gets larger
b (ii) Friction is too small
c (i) Constant speed
(ii) 212.5 cm
(iii) 8.33 cm/s

Energy, work, power and pressure

17 a $I = U + W$
b (i) 850 N
(ii) Force needed to get it started
(iii) Height
(iv) Time
c Greater than
18* a 405 000 J
b 60 000 J
c 60 000 W
d Chemical
e Energy lost as heat, sound, etc.
19 a Tidal, wave, hydroelectric
20 a 88–92
b 88–92 mm
c 840
21* a Volume reduced, pressure goes up
b 20 cm^3
c Speed of particles greater at higher temperature
22 b (i) Falls
(ii) Air molecules cause pressure on mercury

d

rises	rises
falls	stays the same

23* a (i) 540 kJ
(ii) $W = E/t$, 54 kW
b (i) 3750 kg
(ii) 12.5%

2 Thermal physics

Simple kinetic and molecular model of matter

24* b Air molecules hit dust particles
c Slower movement
25 a Solid: 2, 3 and 6
Gas: 1, 4 and 5
b Molecules break free of surface

Thermal properties and temperature

26* a Energy needed to change state

b Any time between 1.6 min and 18 min
c P.e of molecules increases and they escape from the liquid
d (i) 480 kJ
(ii) 6.65 kg
27* a Copper or constantan
Copper or constantan
Constantan or copper
28* a Heat required to produce 1 °C rise in 1 kg
b Long time to heat up
c (i) 1.8 °C and 77.1 °C
(ii) 1512 J
(iii) 392 J/kg K
29* a (i) 1 Melting point of ice
2 Pure melting ice
3 0 °C
(ii) 1 Boiling point of water
2 Steam
3 100 °C
b Thermal capacity
30* a (i) Funnel no longer giving heat to ice
(ii) Better contact between heater and ice
b Mass of beaker
c 338 J/g
31* a Total mass before ice added
Total mass after all ice melted
b (i) Mass × sp. heat capacity × change in temp
(ii) Mass × sp. latent heat of fusion of ice
c 427 J/g
32 a °C

3 Properties of waves

Light

33 a 10 cm
b Gets smaller and closer to lens
c (i) Principal focus
34* a A
b Air
c 42°–43°
d Total internal reflection
e 58.7°
f 2.01343×10^8

35 a q
c Inverted, real
d Same
e (i) Nothing
(ii) Blurred image
36 c (i) 2 m
(ii) 2 m away from mirror
37* b Virtual, inverted, same size as object
c Ray strikes glass normally
d 2×10^8 m/s
e i is greater than c so total internal reflection occurs
38*a (ii) Virtual, upright, same size, same distance from mirror

Sound

39 a (i) One sound
(ii) 495 m
b (i) One sound plus echo
(ii) 1.5 s and 4.5 s
40 a (i) Decreasing
(ii) Waves get smaller
b (i) Nothing
(ii) Wavelength the same
c (i) 12–14
(ii) 1 300 waves per second
2 1/300 s
3 0.04 s
d (i) Yes
(ii) Yes
(iii) No
41 a One sound plus echo
b First
c (i) 3 s
(ii) 9 s
(iii) 6 s

4 Electricity and magnetism

Simple phenomenon of magnetism

42 a (i) Iron rod
(ii) Plastic rod
b S S N
43 a (i) N at left and S at right
(ii) They attract
b (i) N at left and S at right
(ii) They attract
c They attract
d Nothing

Electrical quantities and circuits

44 a (i) Water conducts electricity
(ii) Cord not a conductor
b 10 A
c (i) Larger current
(ii) Cable would melt
45* a (i) X negative; Y positive
(ii) +ve charge on A attracts −ve charge on B
(iii) B is neutral
b (i) Nothing
(ii) +ve charge is cancelled
46 a (i) 6 V
(ii) 50 mA
b 120 Ω
47 a 60 Ω
c (i) 0.025 A
(ii) 1.5 V
d (i) Decreases
(ii) Decreases
(iii) 60 Ω
48* c (i) One input is high and output is low
(ii) 1 On
2 Off
49 a (i) Series
(ii) 12 Ω
(iii) 0.5 A
(iv) 5 V
(v) 5 V
b (i) 1 6 V
2 0 V
50* b (i) 3 A
(ii) 4 Ω
(iii) 2 Ω
(iv) 1080 J
51* a Circuit 1: series
Circuit 2: parallel
c 12 V
d 2.4 Ω
e (i) 3 A
(ii) 24 W
(iii) 7200 J

52 a Interchange connections on ammeter or battery
b Current
d (i) Voltmeter
e 0.4 A
f 0.4 A
g (i) 7.5 Ω
(ii) Increases

Electromagnetic effects

53* a (i) Step-up transformer
(ii) Less heat/energy lost
b 2.5 A
c 18.75 W
d 7.5 V
e 21 985 V
54* a First finger – field
Second finger – current
b (i) Contact
Commutator
(ii) Clockwise
55 a (ii) Iron
(iii) Magnetic linkage
b 120 V
56 a (i) e.m.f. induced in **AB** cancelled by e.m.f. induced in **BC**
(ii) Straighten out **ABC**
b Transformer, generator, dynamo, microphone, alternator
57* b (i) Reduced
(ii) Same or none
c (i) Thin wire is a current-carrying conductor in a magnetic field
(ii) Towards the thick wire
(iii) Smaller force
58 a Contact position at centre of potential divider
b Current in coil magnetises core, armature pivots closing contacts
59 a (ii) Iron bar
b Rods become magnetised and repel
60* a Magnetic field cut by conductor induces a current
c Move magnet in and out of solenoid
d Move magnet faster, stronger magnet, more turns of solenoid

5 Atomic physics

61 a Alpha and beta
b Gamma
c Radio
d Alpha
62* a Background radiation
b A Only background as reading constant
B Gamma as not affected by magnetic field
C Beta as deflected by magnetic field
63* a Beta – third and fourth column
Gamma – first column
64 a Between 22 and 27 minutes
b (i) Iodine-128
(ii) Radon-220 as shortest half-life
65* a Protons: 17 and 17
Neutrons: 18 and 20
Electrons: 17 and 17
b Alpha, beta and gamma
66 a 84
b 218
c (i) 2
(ii) 4
(iii) Alpha particle
67* A rebounds
B carries on, slightly deflected
C carries straight on
68 a Between 18 and 20 minutes
b (i) About 922
(ii) Between 18 and 20 minutes
c Alpha or beta
69 a Electrons
b Moves towards P_1
c By making P_3 or P_4 positive
d Fluorescent screen
70* a Measure background reading
No aluminium – take count
Aluminium – take count
Subtract background reading
b Count decreases with more aluminium

Mathematics for physics

1 a 3
b 5
c 8/3
d 20
e 12
f 6
g 2
h 3
i 8
2 a $f = v/\lambda$
b $\lambda = v/f$
c $I = V/R$
d $R = V/I$
e $m = d \times V$
f $V = m/d$
g $s = vt$
h $t = s/v$
3 a $I^2 = P/R$
b $I = \sqrt{(P/R)}$
c $a = 2s/t^2$
d $t^2 = 2s/a$
e $t = \sqrt{(2s/a)}$
f $v = \sqrt{(2gh)}$
g $y = D\lambda/a$
h $\rho = AR/l$
4 a 10
b 34
c 2/3
d 1/10
e 10
f 3×10^8
5 a 2.0×10^5
b 10
c 8
d 2.0×10^8
e 20
f 300
6 a 4
b 2
c 5
d 8
e 2/3
f −3/4

g 13/6
h −16
i 1
7 $a = (v - u)/t$
a 5
b 60
c 75
8 $a = (v^2 - u^2)/2s$
9 b Extension ∝ mass because the graph is a straight line through the origin
10 b No: graph is a straight line but does not pass through the origin
c 32
11 a Graph is a curve
b Graph is a straight line through the origin, therefore $s \propto t^2$ or s/t^2 = a constant = 2

Alternative to practical test questions

1 a (i) T_1 18 °C
(ii) T_2 4 °C
c (i) T_1 is much greater than T_2
(ii) Graph has a decreasing gradient
2 a 0.3
b (i) Ω A
(ii) 10.1
c 10 Ω
3 b (i) 2°
(ii) Yes, results are close enough
c Doesn't matter if pins not vertical
4 c 34.5 cm
5 a (i) 0.5 cm
(ii) 10 cm
b

T/s	T^2/s^2
1.0	1.0
0.95	0.90
0.9	0.81
0.84	0.71
0.78	0.61

7 a (i) V, A, Ω
(ii) 1.11, 2.19, 5.05, 9.55
b (i) Yes, as within 10%
8 a (i) cm^3, °C
(ii) 20, 40, 60, 80, 100
c Avoid heat loss to the surroundings
9 a 0.7 N, 6 cm^3, 1.4 s, 4.0 N/cm^3
b (i) Minimum current, switch off regularly, turn down power supply
(ii) Variable resistor or rheostat
10 a (i) 7.92 Ω, 1.98 Ω
(ii) V, A, Ω
b (i) *R* is proportional to $1/d^2$
(ii) The first *R* is about ¼ of the second
11 a (i) 50 cm^3, 75 cm^3
(ii) 25 cm^3
(iii) 4.36 g/cm^3
b (i) V_2/cm^3, V_1/cm^3, cm^3, g/cm^3
(ii) 5.66 g/cm^3, 3.02 g/cm^3
c Same method but lots of grains

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