Electric Lights

Contents: Home survey, reading and questions concerning artificial electric lighting.

Time: Homework plus 2 periods.

Intended use: GCSE Physics and Integrated Science. Links with work on light, current electricity, heating effect of electric current, electric discharge, efficiency of energy conversions.

Aims:

- To complement certain work on light, electricity and energy conversions
- To develop awareness of the range of different types of artificial electric lighting
- To show the role of lighting engineers in developing new methods of lighting
- To show the factors involved in making decisions on which type of lighting to use
- To provide opportunities to practise skills in reading, comprehension, data collection and data analysis.

Requirements: Students' worksheets No. 704. Examples of the different types of light to show the class — fluorescent, tungsten filament and tungsten-halogen. Other types might also be shown, for example, neon indicator lamp, light-emitting diode.

In Part 1, students carry out a survey of the different kinds of electric light in their home. It would be helpful if they could be shown beforehand examples of the three main types of light they are looking for — fluorescent, tungsten filament and tungsten-halogen. The least common will be the tungsten-halogen bulb, though these may be found in projectors and car headlamps. Students may confuse tungsten filament strip-lights with fluorescent tubes. The former, often found over bathroom mirrors, give a yellowish light and do not flicker when switched on.

Notes on some of the questions

Q.3 Other types of light might include red neon indicator lights (used to show when a socket or appliance is switched on), light-emitting diodes (in watches or calculators) and electroluminescent panels (on car dashboards).

Q.4 Tungsten filament bulbs (also called 'incadescent' bulbs) are popular because they are cheap to buy (though not to run) and cheap to install — they need no extra electrical equipment beyond a socket. They also give a warm yellowish light which is popular in British homes. In hotter climates, colder, bluish lights are more popular.

Q.5 The rattling of a 'blown' bulb is usually caused by loose pieces of filament.

The evaporation of tungsten from the filament accentuates any uneveness of thickness: the thinner parts of the filament get hotter because of their higher resistance, and therefore evaporate faster, making them thinner still. It is at one of these thin spots that breakage eventually occurs.

Q.7 The earliest filament bulbs, first demonstrated in 1879, used a carbon filament in an evacuated bulb. The high melting point and good electrical conductivity of carbon make it suitable for this purpose, but it began to be replaced by tungsten from about 1906, once the difficulties of working with this hard, high-melting metal had been overcome.

Teachers might be interested to give students some of the historical background to electric lighting. The 'incandescent' filament bulb was preceded by the arc light, but filament bulbs marked the beginning of widespread electric lighting. When they first appeared, mains electricity was of course non-existent and generators were needed. This is why electric lighting tended to be used first for ships, trains and in places which had their own power supply. (The Titanic is said to have gone down in 1912 with her electric lights burning.)

An 1883 catalogue of the Swan Electric Light Company gives the breakdown of the cost of installing electric lighting as follows:

Capital cost of boiler and dynamos	£1470
Yearly running costs:	
Wages for engine driver at 30 shillings per week	£ 78
39 tons of coal at 20 shilling per ton	£ 39
155 replacement light bulbs at 5 shillings each	£ 39

Q.8 Tungsten-halogen lights are very bright, and are also compact light sources which can be accurately focused by lenses and reflectors. This makes them particularly useful for applications such as projectors, spotlights, car headlamps and floodlights.

An explanation of the working of tungsten-halogen bulbs is given on page iii of these teachers' notes.

Tungsten-halogen bulbs are often made with the reflector as an integral part. An interesting recent development is the 'dichroic' reflector, which reflects visible light but allows infra red radiation to pass out of the back of the reflector, thus reducing the heating effect of the lamp. The reflector is made of a laminate of thin layers of zinc sulphide, sandwiched with magnesium fluoride. The thickness of the layer determines the frequency of the light it reflects. By selecting the right thicknesses for the layers, it can be arranged that only visible frequencies are reflected.

Q.10 A fluorescent tube would be bent into the shape of the initials, before evacuating the tube and treating it with phosphor. The bent tube would be run as a normal fluorescent lamp, with electrodes at each end.

Q.11

(a) Costs of 2000 hours' use:

Compact fluorescent tube = £2 + £8 + 20 × £0.10 = £12

Filament bulb = 2 × £0.35 + 20 × £0.50 = £10.70

(b) Costs of 4000 hours' use:

Compact fluorescent tube = £2 + £8 + 40 × £0.10 = £14

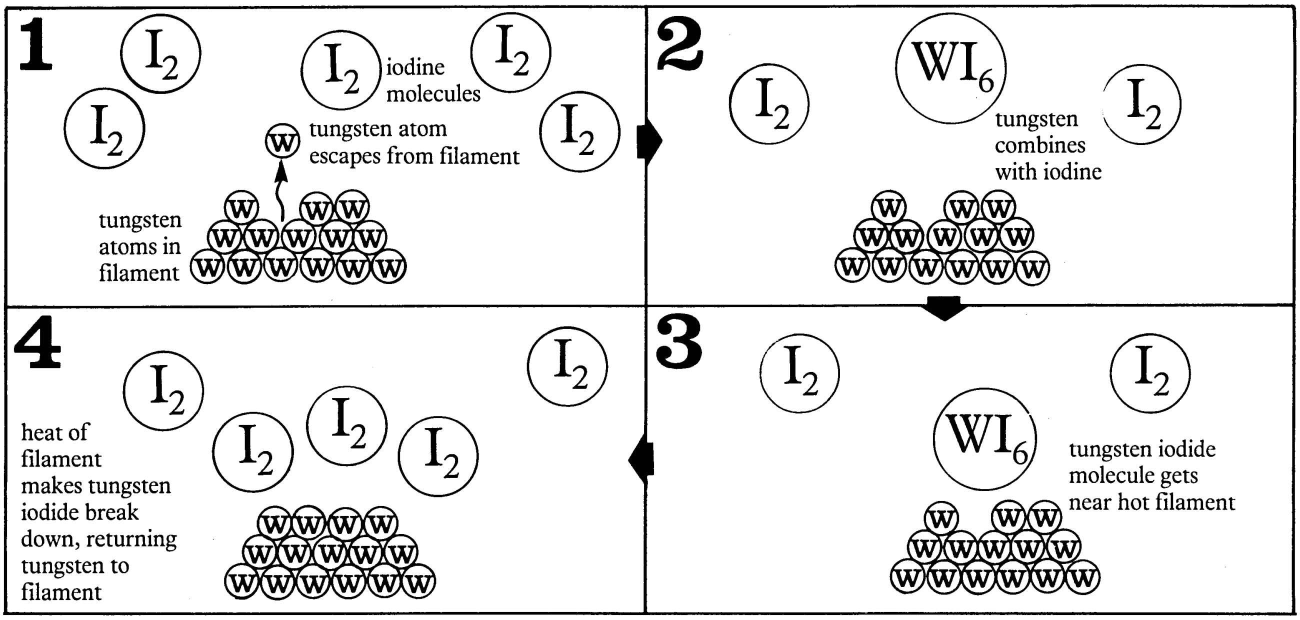
Filament bulb = 4 × £0.35 + 40 × £0.50 = £21.40

(c) Thus the fluorescent tube is cheaper if used for more than about 2200 hours — just over a year of heavy use.

Notes on the working of the tungsten-halogen bulb

The principle of the tungsten-halogen bulb is an interesting application of chemical equilibrium. The diagrams in the box below illustrate how the iodine or other halogen 'collects' evaporated tungsten atoms and returns them to the hot filament. The hotter the filament, the more tungsten gets deposited. The halogen cycle thus deposits tungsten preferentially on the hotter 'thin spots' of the filament, prolonging its life still further.

How a halogen cuts down the loss of tungsten



Further activities

1 There is plenty of scope for simple calculations on the cost of lighting. For example:

If a family leaves a 100 watt bathroom light on for 10 hours during the night, how much will this cost in electricity?

2 If a light meter or photographic exposure meter is available, a good deal of simple experimental work can be done. For example:

(a) Comparing the light intensity at a distance of 20 cm from (i) a filament bulb, (ii) a fluorescent tube of the same wattage.

(b) Comparing the intensity of daylight and artificial lighting in various parts of the classroom.

(c) Checking the effectiveness of a light shade in increasing the light intensity from a filament bulb. Checking the effect of lining the shade with aluminium foil.

(d) Investigating the effect of different coloured walls on light intensity in a room (use flat wooden test pieces painted different colours, and measure the intensity of light reflected from them).

3 Experiments can also be done using lights and dimmer switches, for example, to see whether using the dimmer switch saves more electricity than changing to a lower power bulb. Use a joule meter in the circuit, or an ammeter and voltmeter.

Further details of such experiments can be found in the 'Energy in the House' unit of the PLON physics project from the Netherlands. An English translation of this unit is available from: Dr Robin Millar, Education Department, University of York, York YO1 5DD.

Acknowledgement Figure 1 supplied by Thorn EMI Lighting.

ELECTRIC LIGHTS

Electric lights are everywhere. Think how many you switch on each day. In this unit we will be comparing different types of electric lights. In Part 1 you will look at the lights in your home. Part 2 has reading and questions about different types of lights.

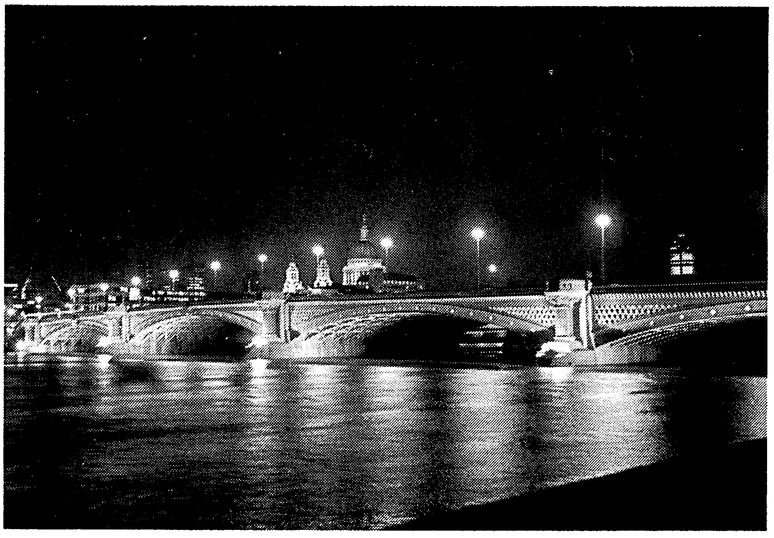
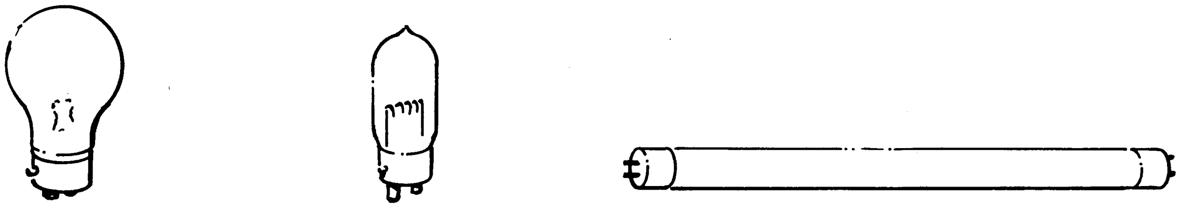


Figure 1 Electricity lights up Blackfrairs Bridge, London

Part 1 Lights in your home

See how many different electric lights there are in your home. The three most common types you are likely to find are shown in Figure 2.



(a) Ordinary tungsten filament bulb. Gives yellowish light.

(b) Tungsten-halogen bulb. Small but very bright.

(c) Fluorescent tube (may be bent into other shapes). Flickers when first switched on.

Figure 2 The most common types of electric light in homes

Draw up a table like Table 1 and fill it in. Look all around your home, including the garage and car if you have one. Remember that lights are not just fixed to ceilings and walls — they are also found in equipment such as torches.

Table 1 Electric lights in your home

Type	*Total number*	*Places found*
(a) Ordinary tungsten filament bulbs		
(b) Tungsten-halogen bulb		
(c) Fluorescent tube		
(d) Other		

Compare your results with other members of the class, then answer questions 1 to 3.

Questions

1 *Which is the commonest type of electric light?*

2 *Whereabouts in the home are fluorescent tubes most commonly found?*

3 *Apart from the three types already described, what other types of electric light were found?*

Part 2 How do the different types of electric light work?

Figure 3 illustrates the main types of electric light.

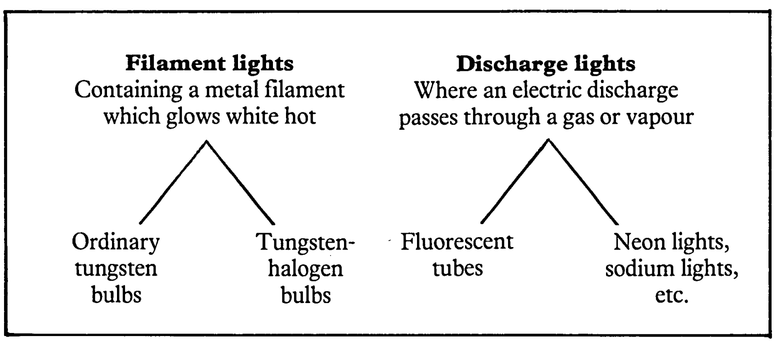


Figure 3 The main types of electric light

Table 2 compares the different types of light. The **efficiency** is a measure of how well it converts electricity to light. All electric lights produce more heat than light, but some are more efficient than others. The **lifetime** shows how long the bulb will run on average before it needs replacing.

Table 2 Comparison of different electric lights

Type of light	*Efficiency when new (%)*	*Lifetime*
Ordinary tungsten filament	3	1000 hours
Tungsten-halogen	5	2000 hours
Fluorescent tube	25	5000 hours
Sodium discharge tube	34	20 000 hours

Ordinary tungsten filament lights

Figure 4 shows what is inside one of these lights.

Electricity is passed through the tungsten filament. The filament gets hot because of its high resistance. A tungsten light filament is the hottest thing you are likely to see in normal life. It reaches 2500°C, which is hot enough to melt brick. Tungsten is used for the filaments because its melting point (3410°C) is the highest of all metals.

To get the correct resistance, the tungsten wire needs to be thinner than a human hair and over a metre long. To make it fit inside the bulb, it is made into a 'coiled coil'.

There are two problems with tungsten at such a high temperature. First, it oxidizes rapidly if exposed to air. Second, it slowly evaporates. To get over these problems, the glass bulb contains the unreactive gases argon and nitrogen, at low pressure. Even so, the tungsten still evaporates away slowly. The vaporized tungsten recondenses on the inside of the glass bulb, making it darken.

As the tungsten evaporates, the filament gets thinner. This makes its resistance higher, so it gets even hotter and evaporates even faster. Eventually the filament breaks. The bulb has then 'blown' and must be replaced.

Tungsten filament bulbs are inefficient and have a short lifetime. But they are very cheap. They work straight off the mains electricity supply with no extra equipment.

Now try to answer questions 4 to 7.

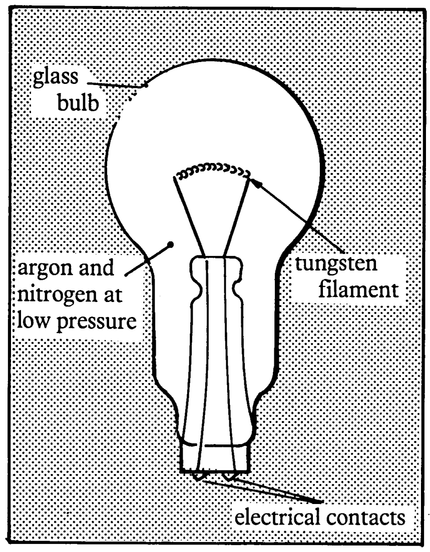


Figure 4 A tungsten filament bulb

Questions

4 *Why are ordinary tungsten filament bulbs so common, in spite of their shortcomings?*

5 *When a bulb of this kind has 'blown', it often rattles when shaken. Why is this?*

6 *The efficiency of an ordinary tungsten filament bulb is 3 per cent. In a 100W ordinary tungsten filament bulb, how many watts of visible light are given out? What happens to the rest of the electrical energy used by the bulb?*

7 *The first light bulbs used carbon for the filament instead of tungsten. What property of carbon makes it suitable for this use?*

Tungsten-halogen bulbs

Lighting engineers soon realized that the evaporation of tungsten was a real nuisance. It cuts down the life of a bulb. It also means the filament cannot be allowed to get as hot as engineers would have liked. Higher filament temperature would give a brighter and more efficient light.

Lighting engineers solved this problem by developing the tungsten-halogen light (Figure 5). As well as argon and nitrogen, the gas inside the bulb contains a halogen such as bromine or iodine. This halogen helps cut down the loss of tungsten through evaporation.

This means the filament can run at a higher temperature, so the light is brighter and more efficient. It also lasts longer, though the bulbs are more expensive than ordinary filament bulbs.

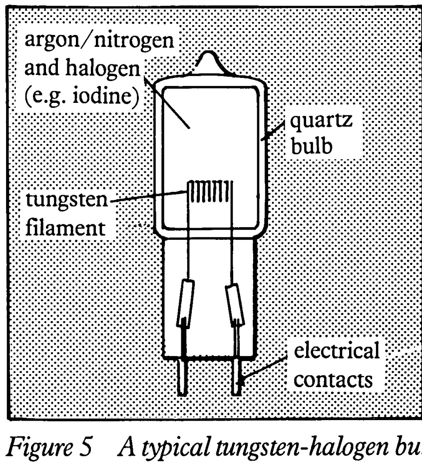


Figure 5 A typical tungsten-halogen bulb

With the filament at such a high temperature, the bulb would crack or even melt if it was made from ordinary glass. To get over this, the bulb is made from quartz instead. These bulbs are sometimes called 'quartz-iodine' bulbs. Quartz is tougher and expands less than glass. But it is very hard, and has to be cut by laser.

Answer questions 8 and 9.

Questions

8 *Tungsten-halogen bulbs are often used in projectors and car headlamps. Why are they especially useful in these cases?*

9 *People do not often use tungsten-halogen bulbs to light rooms inside their homes. Apart from cost, what reason can you suggest for this?*

Discharge lights

In a discharge tube, a voltage is applied to a gas at low pressure (Figure 6). If the voltage is high, a current flows through the gas and the gas glows. The colour of the glow depends on the gas. For example, neon glows red. Neon lights are used in advertising signs. Sometimes a metal vapour is used instead of a gas. Mercury vapour gives a bluish glow and also gives off a lot of ultra-violet light. Sodium vapour glows yellow.

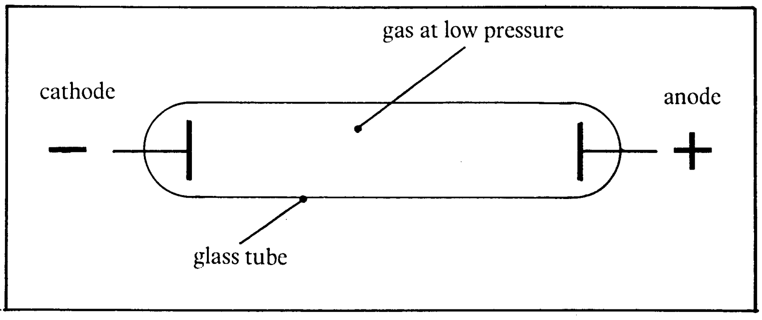


Figure 6 A gas discharge tube

Sodium vapour lights are very efficient. They are often used in street lighting. When first turned on, sodium vapour lights glow red. This is because they contain neon to get them started. When they are hot enough to vaporize the sodium they give their normal yellow colour. Sodium is a very reactive metal, and sodium vapour at 800°C is particularly reactive. There are difficult engineering problems to be solved in designing lights that contain this vapour.

Fluorescent lights

Most people like white or pale yellow light in their homes, so sodium lights and neon lights are not often used indoors. Instead fluorescent tubes are used (Figure 7).

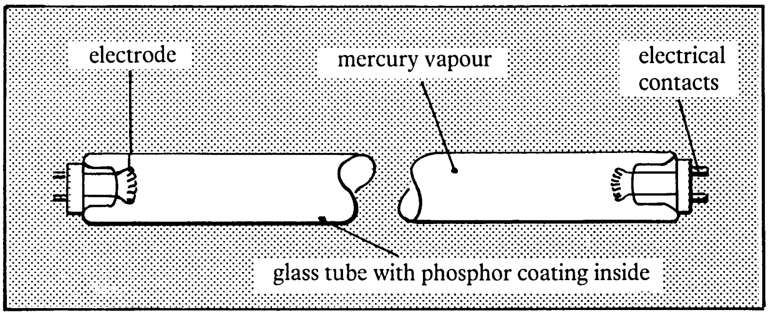


Figure 7 A fluorescent tube

The tube contains mercury vapour. When a voltage is applied, the mercury vapour gives out ultra-violet radiation. The inside of the tube is coated with a **phosphor** powder. The phosphor absorbs ultra-violet radiation, and gives it out again as visible light. This is called **fluorescence**. The light is bluish-white, which is very suitable for shops and offices. However, for homes people prefer a warmer, yellower colour, which can be produced by adding certain chemicals to the phosphor powder.

Fluorescent tubes cast very little shadow, so they are very suitable for working areas like factories, shops, offices and kitchens. They are more efficient than filament lamps, and they last longer.

However, fluorescent tubes cannot be run straight off the ordinary mains supply. They need thousands of volts to start the discharge. This requires special equipment to adapt the mains. Special equipment is also needed to limit the current once it has started. This adds to the cost of installing the tube, but the lower running costs usually make up for it.

Now answer question 10.

Question

10 Suppose you wanted to display your initials in fluorescent light on the front of your school. Sketch a modified version of Figure 7 to show how you would do it.

Figure 8 shows a compact fluorescent tube that can be used to replace tungsten filament bulbs. Table 3 gives some information about its cost compared with an ordinary tungsten filament bulb with the same output.

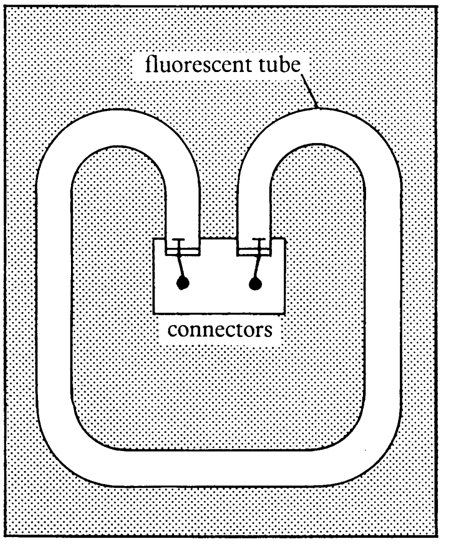


Figure 8 A compact fluorescent tube

Use Table 3 to answer question 11.

Table 3 Costs of a compact fluorescent tube and an ordinary filament bulb

Compact tube	
Cost of the tube	£2.00
Cost of extra electrical equipment for tube (once bought, lasts indefinitely)	£8.00
Cost of electricity to run tube for 100 hours	£0.10
Lifetime of tube	5000 hours
Filament bulb with same light output	
Cost of bulb	£0.35
Cost of electricity to run bulb for 100 hours	£0.50
Lifetime of bulb	1000 hours

Question

11 Using Table 3,

(a) Work out the cost of buying and running each light for 2000 hours (this is about a year's heavy use).

(b) Work out the cost of buying and running each light for 4000 hours.

(c) Is it worth buying the fluorescent tube? Explain your answer.

Physics in Playgrounds

Contents: A series of structured questions on energy, forces and motion based upon the experiences children gain using swings, slides and see-saws.

Time: 2 periods or more, depending on number of parts used.

Intended use: GCSE Physics and Integrated Science. Links with work on forces, energy, oscillation and translational motion. May be particularly useful during revision.

Aims:

- To complement and revise prior work on forces, energy and motion
- To show that scientific laws apply to everyday experiences
- To link the world of the laboratory to the world of play
- To provide opportunities to practise skills in comprehension and application of knowledge.

Requirements: Students' worksheets No. 705

Although the students using this unit will probably be too old to visit playgrounds, they are likely to have recent memories of their experiences. It would be helpful to visit playgrounds when using the unit, and students could be encouraged to 'revise' by watching or helping young children at play.

There is a general introduction followed by three sections: Slides, Swings and See-saws. These sections can be used independently of each other. The questions in each section vary in difficulty: in general, the questions become progressively more difficult. The See-saw section may only be suitable for more able students.

Other playground activities provide suitable illustrations of physics. Roundabouts, for example, are a good illustration of rotational motion, though much of the physics may be beyond most students at this level.

Notes on some of the questions

Q.3 Students may only answer this at a superficial level. In general, speed is exciting for its own sake, partly because of the risk involved. In addition, for many playground rides higher speeds mean greater forces acting on the body.

Q.4 Public playgrounds are generally built and maintained by the local council. (District Council, Parish Council, Borough Council, etc.) Playgrounds have regular inspection and maintenance by the council. In effect, they are paid for out of rates.

Q.SL6 For a long slide it is possible to reach a terminal velocity where frictional forces (air resistance and surface friction) balance that part of the gravitational pull acting down the slope.

Qs SW1-SW3 As for any pendulum, the frequency of oscillation stays approximately constant, but its amplitude (size) gets less as it slows down. The frequency should be independent of the mass of the child, provided the centre of gravity remains in the same position.

Qs SW6-SW9 A perfectly frictionless swing interconverts kinetic energy and gravitational potential energy without loss. Kinetic energy is at a maximum at the bottom of each swing and at a minimum at the top; for gravitational potential energy it is the other way round. In practice, some energy is lost as heat due to friction, which is why the swing eventually stops.

Q.SW10 Apparent weight (the push of the seat on the child's bottom) is at a minimum at each extreme of the swing, when acceleration is greatest. This can be thought of as the point where the swing seat is 'falling away' from the rider. Maximum apparent weight is experienced at the trough of the swing, where centripetal acceleration is effectively pushing the seat upwards against the rider's bottom.

Q.SW11 The rope is most likely to break at the trough of the swing. This is the point at which the tension in the rope is greatest, for the reasons outlined in the answer to question SW10.

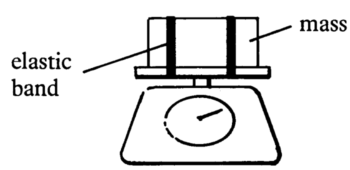
Q.SW12 There appear to be two methods for making oneself swing: (a) the leg swing method, where the legs are thrown forward during a forward swing, and back during a backwards swing; (b) the rope-pull method, where the ropes are pulled to raise the centre of gravity slightly at the beginning and end of each swing. Each method depends on raising the centre of gravity and hence increasing gravitational potential energy, which is transferred to the oscillation of the swing. If the movements are repeated at the resonant frequency, the swing goes higher and higher.

Q.SS3 This question brings out the point that we can detect accelerated motion but not steady motion. The force on the rider's bottom is greatest at the bottom of the oscillation and least at the top.

Q.SS4 Heavier: during A and D; lighter: during B and C.

Further activities

The question of 'apparent weight' can be investigated using an 'apparent weight meter'. This is simply constructed from a top-pan kitchen balance, relabelled if necessary to read in newtons. Select a convenient mass which gives a whole number reading on the scale — a mass of about 2 kg is suitable. Fix the mass onto the pan, for example with strong elastic bands.



The apparatus can then be used to investigate changes in apparent weight. For example:

1 Hold the 'apparent weight meter' steadily and note the reading. Accelerate the meter upwards and note the reading. Accelerate it downwards and again note the reading.

2 Make a model swing using, for example, an old cardboard box. Put the meter in the swing and use it to check the answers to question SW10. Further questions to investigate:

   (a) Does the apparent weight ever equal the real weight? If so, where?
   (b) How much bigger than the real weight is the greatest reading during a swing?
   (c) How much less than the real weight is the smallest reading?
   (d) Try to draw a rough sketch graph of the change of apparent weight during one half swing left to right.

3 Field work:
   (a) Take the 'apparent weight meter' to a playground. Take it onto a swing and carry out the same readings as in (2) above. Take it onto a see-saw and use it to check answers to question SS4.
   (b) Try taking the meter on other 'rides', for example, in a lift.

Acknowledgement Figures2, 3 and 4 drawn by Laurie Fahy.

PHYSICS IN PLAYGROUNDS

Playing in a giant's laboratory

You can probably remember your visits to children's playgrounds when you were younger. Maybe you still go for a quick slide or swing occasionally. Either way, you will know that playgrounds can provide children with the excitement of speed and strange forces.

There is a lot of physics to be learnt in playgrounds. Swings, slides, see-saws and roundabouts enable you to experiment with equipment large enough for a giant's laboratory.

Answer questions 1 to 5.

Figure 1 A large children's playground

Questions

1 *Where is your nearest playground?*

2 *Which was (or is) your favourite piece of playground equipment? Why?*

3 *Playground rides are generally more exciting (and more dangerous) the faster you go. Why is this?*

4 *Playgrounds are expensive to set up. Once set up, they need regular repair and maintenance. Who pays for your local playground?*

5 *Why do adults think it is worth the expense of providing playgrounds? What benefits do they think children get from them?*

Slides

Figure 2

Questions

SL1 *You need energy to climb to the top of a slide. Where do you get the energy from?*

SL2 *What has happened to the energy used for climbing by the time you have reached the top?*

SL3 *What force causes you to move and accelerate down the slide?*

SL4 *What would happen if the slide were steeper? Why?*

SL5 *Name the forces which oppose your motion down the slide.*

SL6 *If the slide is long and shallow, you may eventually stop accelerating and reach a constant speed. Explain why this happens.*

SL7 *What has happened to all your energy by the time you have stopped at the bottom of the slide?*

Swings

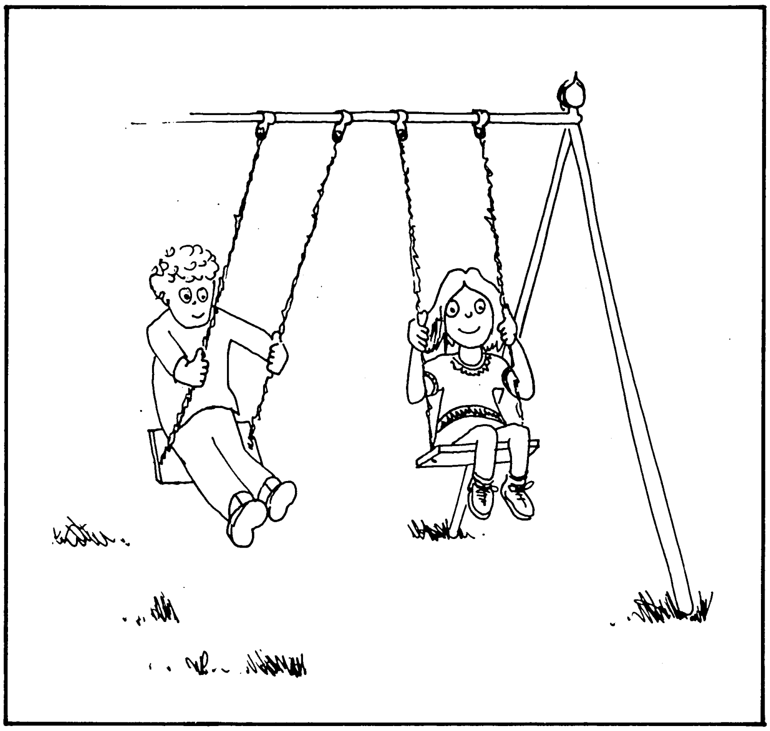


Figure 3

Questions

SW1 *When a small child is pushed on a swing, does the swing oscillate with a constant frequency?*

SW2 *If pushing is stopped, what happens to:*
(a) the size, (b) the frequency of the oscillations?

SW3 *If a heavier child uses the swing is its frequency of oscillation (a) less, (b) the same, (c) more?*

SW4 *What difference do you feel between pushing an empty swing and pushing a swing with a child on it? Which swing has the greater inertia?*

SW5 *Suppose you want to measure a swing's period of oscillation using a watch with a second hand. Explain why it is:*
(a) difficult to time just one swing accurately
(b) more accurate to time 20 swings and find the average
(c) better to start timing as it passes through the middle of its swing, rather than starting at either end.

SW6 *When you pull a swing back, ready to release it, you are transferring energy to the swing. This is because you have done work to raise the swing. What form of energy does the swing possess in this state?*

More questions on the next sheet.

Questions

SW7 (a) When the swing is released, what causes it to move downwards?
(b) Why does it not stop at the bottom of its swing?
(c) Why does it climb equally high on the other side?

SW8 At what part of its oscillation does a swing have:
(a) greatest velocity
(b) zero velocity
(c) most kinetic energy
(d) no kinetic energy but maximum gravitational potential energy (g.p.e.)?

SW9 What can you say about the total of
k.e. + g.p.e.
for the swinging system if the oscillations remain the same size?

Questions SW10, SW11 and SW12 are harder.

SW10 If you swing really high, the speeding up and slowing down of the swing during its oscillation makes your weight seem to change. During which parts of its oscillation do you feel:
(a) almost weightless; (b) heavier than usual?
Try to explain why you have these sensations at these times.

SW11 Suppose a swing has a frayed rope. At what point in its oscillation is the rope most likely to break? Why?

SW12 Children eventually learn the art of swinging themselves without being pushed. What do you have to do to keep yourself swinging? How does it work?

See-saws

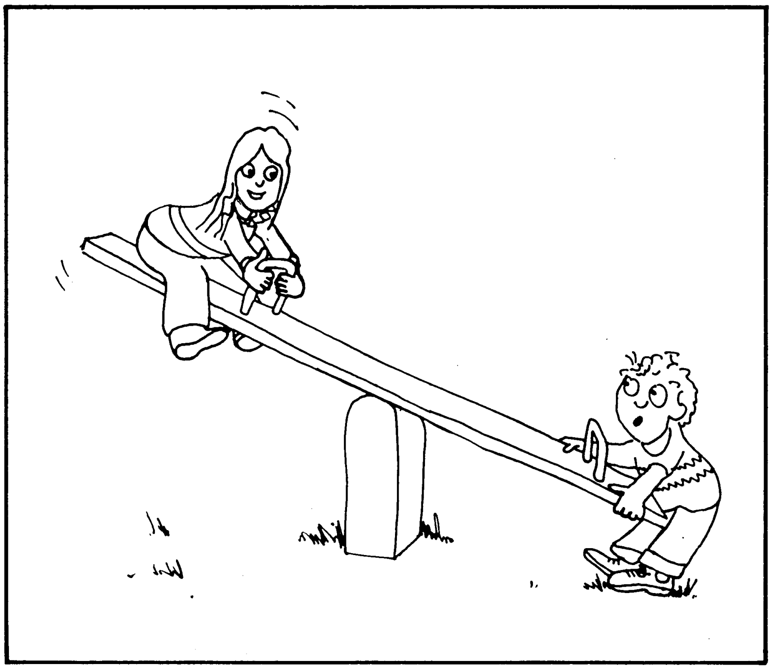


Figure 4

Questions

SS1 *People of the same weight can balance on a see-saw by sitting at the same distance on opposite sides of the pivot.*

- *(a)* *How can two people of* different *weights arrange to balance?*
- *(b)* *What physical quantity must have the same value but opposite sense on both sides of the pivot?*

SS2 *See-saws can be dangerous if children play too vigorously. You may remember having to hold on tight at the top of the see-saw's movement to stop yourself leaving the seat. Explain why this happens.*

SS3 *Imagine you are riding on a see-saw with your eyes closed.*

- *(a)* *How can you tell you are not on a steady seat?*
- *(b)* *Describe how the force between your bottom and the see-saw varies as you move.*

SS4 *Your motion on a see-saw can be divided into four stages:*
A — accelerating as you push off
B — decelerating upwards as you near the top
C — accelerating downwards from the top
D — decelerating downwards as you near the ground.

During which parts of the motion do you feel:

- *(a)* *heavier than normal*
- *(b)* *lighter than normal?*

Dry Cells

Contents: Reading, questions and practical work concerning the nature of dry cells.

Time: 2 periods or more, depending on amount of practical work done.

Intended use: GCSE Chemistry and Integrated Science. Links with work on electrochemistry and electrochemical cells, tests for anions and cations and reactions of metals. May be particularly useful during revision.

Aims:

- To complement and revise work on electrochemical cells, and to revise work on tests for anions and cations
- To show the variety and importance of dry cells in everyday life
- To show the varied technology of dry cells
- To provide opportunities to practise skills in comprehension, collection of information and certain practical laboratory skills.

Requirements: Students' worksheets No. 706. If possible, a representative selection of dry cells. See below for practical work requirements.

Suggested use of the unit

The unit is in three parts:

Part 1 *Different kinds of cells.* An introductory survey at home or school of different types of dry cells.
Part 2 *How do different types of cells work?* A description of the construction and function of some common types of dry cell.
Part 3 *Practical investigation of a cell.*

The three parts are independent and it is not necessary to do all three parts if there is insufficient time.

The practical work in Part 3 can be used in a number of ways. It is principally intended as an investigative exercise to address the question, 'What's inside a dry cell?'. If it is used in this way, it should be attempted *before* Part 2, since Part 2 gives the answer to the question. It could alternatively be used *after* Part 2, as a way of *confirming* the identity of the dry cell contents. More notes on Part 3 appear below.

Notes on Part 1

This is intended as an opening exercise to give students an idea of the different types of dry cell in everyday use. It is best done at home, but students could be encouraged to bring different types of cells to school to enable the class to pool results. Alternatively, the teacher could provide a representative selection of cells. Ideally these should include all the different types described in Part 2.

Students are likely to find it difficult to distinguish between the different types of cell since classification is complicated by the range of sizes and brands encountered. The teacher may wish to draw things together at the end of the exercise.

Some of the more important types of dry cell are described in the table below.

Type of cell	*Voltage*	*Used for*	*Price (1985)*
zinc-carbon, ordinary quality (e.g. Ever Ready Blue Seal, Boots SP)	1.5V	torches, radios	£0.35 (SP2 size)
zinc-carbon, top quality (e.g. Ever Ready Silver Seal, Boots HP)	1.5V	cassette players, calculators, motorized toys	£0.50 (SP2 size)
alkaline-manganese (e.g. Duracell, Ever Ready Gold Seal, Boots Alkaline Power Cell)	1.6V	cassette players, motorized toys, other applications involving heavy continuous use	£1 (SP2 size)
silver oxide button cell	1.5V	calculators, watches	varies widely according to size
mercury oxide button cell	1.35V	hearing aids, photographic equipment	varies widely according to size
zinc-air button cell	1.5V	hearing aids	varies widely according to size
nickel-cadmium rechargeable	1.3V	applications involving heavy current discharge e.g. motorized toys, cassette players	£3.30 (SP2 size)

Q.3 Comparing 'value for money' is difficult, because the effective capacity of a cell depends on a number of factors. These include:

(a) The design and quality of manufacture
(b) The physical size of the cell
(c) The voltage at which the appliance ceases to work properly
(d) The age of the cell
(e) The rate at which the cell is discharged
(f) The period of time per day for which the cell is used
(g) The temperature.

Comparisons therefore give different results depending on the appliance in use, the time for which it runs, etc. In principle, however, comparisons can be made by running different batteries through the same cycle of operations under the same conditions, and comparing useful lifetimes.

Notes on Part 2

Q.4 In the zinc-carbon cell, the outer zinc casing is dissolved away during the cell reaction. Eventually holes appear and the electrolyte leaks out, though it may still be confined inside the outer steel container. In the alkaline manganese cell, the zinc is present as a powder, and is not part of the casing.

Q.5 See note on question 3 above.

Q.6 The main reason is simply size.

Q.8 This question is intended to remind students of the toxic nature of mercury compounds. Similar considerations apply to the rechargeable nickel-cadmium cell.

Q.9 Desirable features for the 'ideal' dry cell might include low cost, long lifetime for small size, ability to cope with heavy discharge for extended periods, ability to supply steady current, long shelf-life, etc.

Notes on Part 3

Depending on the ability of the students, the practical could be presented as a problem-solving exercise, with groups of students designing their own investigations. In this case, students need only be given page 6. Alternatively, students could be given pages 7 and 8, which include detailed instructions for the practical investigation.

The components of the zinc-carbon cell are:

Negative electrode — zinc
Black paste — mixture of manganese(IV) oxide and powdered carbon (positive electrode) with ammonium chloride and zinc chloride (electrolyte).

Using the suggested investigation, only partial identification of these components is possible. The teacher may care to suggest further tests to enable students to make a fuller identification.

Safety

The zinc casing contains very small quantities of toxic mercury, since quantities of mercury salts are added to the electrolyte to form an amalgam with the zinc case in order to inhibit corrosion. Students should wash their hands after practical work and be informed of the nature of the materials.

Warning Alkaline-manganese cells should *not* be opened for investigation. They contain 35 per cent potassium hydroxide solution, which is highly corrosive. Gas pressure can build up in the cell, causing the alkaline electrolyte to spurt out when the cell is opened.

Requirements for the investigation

Each group of students will need:

eye protection
100cm^3 beaker, test tubes, boiling tubes, filtering equipment, universal indicator paper, splints, wire wool, spatula, glass rod, half an ordinary zinc-carbon 1.5V cell.
(These should be prepared before the practical. The outer steel casing should be carefully prised off before clamping the inner cell in a vice and sawing it in half lengthways. Unused cells should be used since cell components change on discharge.)
newspaper to place on bench when dissecting cell (messy!)
hydrogen peroxide solution (20-volume)
dilute hydrochloric acid (2M)
dilute silver nitrate solution
dilute nitric acid (2M)
dilute sodium hydroxide (2M)
distilled water
access to tin snips or similar metal-cutting equipment.

In order to show that the casing is zinc, *clean* strips of the metal can be heated strongly in a crucible. This should be done as a demonstration *in the fume cupboard*. Yellow zinc oxide can be seen on the surface of the molten metal. The yellow colour disappears on cooling.

Further resources

Ever Ready Ltd will provide detailed information on the working of batteries. Technical Division, Ever Ready Ltd, Tanfield Lea, Stanley, Co. Durham DH9 9QF.

Duracell (UK) Ltd produce a useful pack called *Cells and Batteries*. It contains suggested experimental work, information, workcards and slides. From: Duracell (UK), Duracell House, Church Road, Lowfield Heath, Crawley, Sussex RH11 0PQ.

Acknowledgements Figure 1 supplied by Philips Consumer Electronics; Figures 3, 4 and 5 are reproduced with permission from the Duracell pack mentioned above.

DRY CELLS

On average each person in Britain uses somewhere between 8 and 15 dry cells each year. Dry cells are more commonly known as batteries. There are many different types, and in this unit we will look at some of them.

Figure 1 One popular use of the dry cell — in the personal stereo radio cassette

Part 1 Different kinds of cells

Look around your home, school or local electrical shop. See how many different kinds of batteries you can find. For each type of battery, try to find its voltage, what it is used for, and its price.

After completing your survey of batteries, answer questions 1 to 3.

Questions

1 *Which is the commonest type of battery?*

2 *Why are some batteries cheaper than others?*

3 *How would you set about comparing 'value for money' of different batteries?*

Producing electricity

All electric cells have certain basic features (Figure 2). A **negative electrode** releases electrons. These electrons flow down a wire to a **positive electrode**, which accepts them. This flow of electrons is the electric current. The two electrodes are placed in an **electrolyte**. In the earliest cells, the electrolyte was a solution in water. These **wet cells** were a bit messy. **Dry cells** still have water in the electrolyte, but it is a paste rather than a solution.

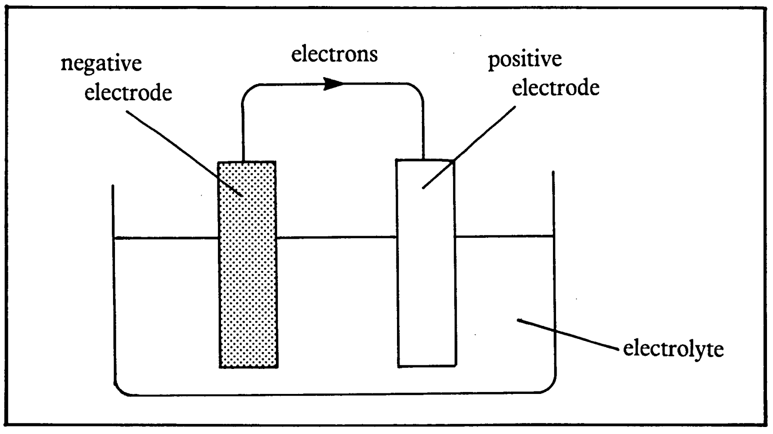


Figure 2 The basic features of an electric cell

Part 2 How do different types of cells work?

As you discovered in Part 1, there are many different types of cell, suitable for different uses. **Primary cells** are not rechargeable. Once used, they have to be thrown away. **Secondary cells** can be recharged.

The zinc-carbon cell (Leclanché cell)

This is the familiar round cell used in torches. It is the commonest and cheapest type of primary cell. Examples of common brands are Ever Ready Blue Seal and Silver Seal and Boots SP and HP. Figure 3 shows the main features of a zinc-carbon cell.

The reactions in the cell are rather complicated, but they can be summarised as shown below. The negative electrode is made of zinc. Zinc loses electrons to form zinc ions:

$$Zn \rightarrow Zn^{2+} + 2e^-$$

These electrons flow round the external circuit to the positive electrode. This is made from manganese(IV) oxide. Manganese(IV) oxide contains Mn^{4+} ions, which accept the electrons. They form Mn^{3+} ions.

$$2Mn^{4+} + 2e^- \rightarrow 2Mn^{3+}$$

The overall reaction in the cell is

$$Zn + 2Mn^{4+} \rightarrow Zn^{2+} + 2Mn^{3+}$$

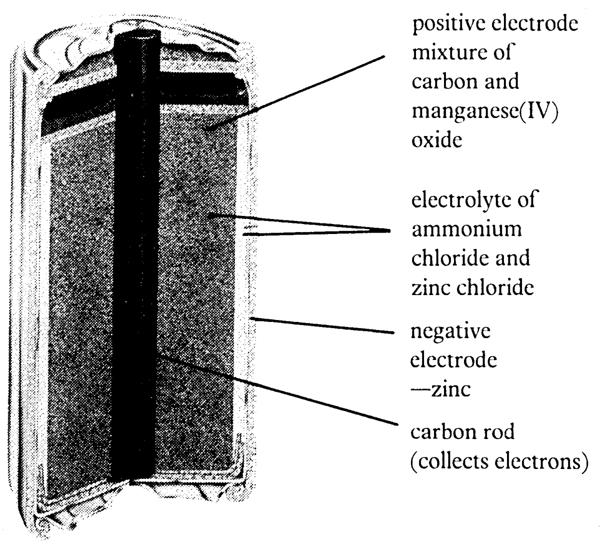


Figure 3 The zinc-carbon cell

Zinc-carbon cell

Voltage:	1.5V
Advantages:	Cheap
Disadvantages:	Comparatively short life. Zinc case dissolves away during reaction, causing leakages.
Uses:	Where the total power needed is fairly low, for example, torches and transistor radios.

The alkaline-manganese cell

This is an improvement on the zinc-carbon cell because it lasts longer. Examples of common brands are Duracell, Ever Ready Gold Seal and Boots Alkaline Powercell. Figure 4 shows the main features.

The basic chemical reaction in the alkaline cell is the same as for the zinc-carbon cell. The negative electrode is still zinc, but in a powdered form. The positive electrode is still manganese(IV) oxide, but in compressed pellet form. The zinc powder is on the inside, and the manganese(IV) oxide on the outside. The electrolyte is potassium hydroxide, which soaks both the zinc and the manganese(IV) oxide. The outer case is steel and is not part of the reaction, so it does not leak.

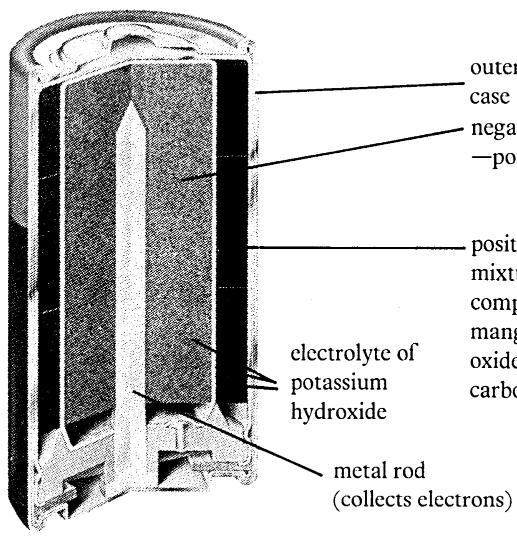


Figure 4 The alkaline manganese cell

Alkaline cell	
Voltage:	1.6V
Advantages:	Lifetime 1.5 to 2 times that of zinc-carbon cell. Less likely to leak. Can be stored with little loss of lifetime.
Disadvantages:	Expensive
Uses:	Where there is a heavy or continuous use, for example, toys, cassette recorders.

Answer questions 4 and 5.

Questions

4 *Explain why zinc-carbon cells often leak when they are exhausted, but alkaline-manganese cells do not.*

5 *An alkaline-manganese cell is advertised as having 'up to three times the life of an ordinary cell'. Describe how you would try to test this claim.*

Button cells

Some appliances need a very small cell that has a long life and gives a steady current. These use a **mercury cell** or a **silver cell**, both of which have the button shape.

Once again the negative electrode is zinc powder, but the positive electrode is mercury(II) oxide or silver oxide. The electrolyte is potassium hydroxide solution. The top and bottom are nickel or steel. Figure 5 shows the details for a mercury cell.

As before, the zinc loses electrons, forming zinc ions. In a mercury cell, the electrons are accepted by mercury ions in the mercury oxide.

$$Hg^{2+} + 2e^- \rightarrow Hg$$

The overall reaction is

$$Zn + Hg^{2+} \rightarrow Zn^{2+} + Hg$$

The silver cell is very similar, but electrons are accepted by silver ions instead of mercury ions.

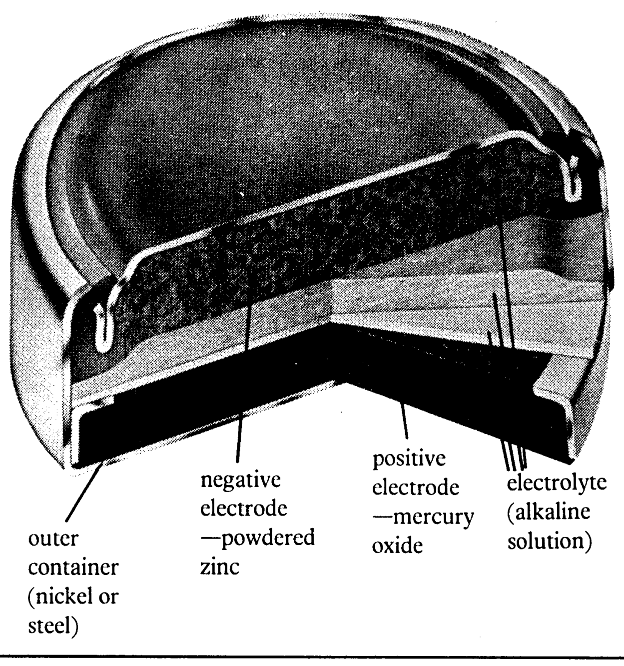


Figure 5 A mercury cell

Mercury oxide cell	
Voltage:	1.35V
Advantages:	Small. Lasts for a long time giving a steady current. Can be stored with little loss of lifetime.
Disadvantages:	Expensive
Uses:	Where long life and steady current are important, for example, hearing aids.

Answer questions 6 to 8.

Questions

6 *Why are zinc-carbon cells unsuitable for use in digital watches?*

7 *Give two reasons why mercury button cells are unsuitable for use in torches.*

8 *Why is particular care needed when disposing of used mercury cells?*

Rechargeable cells

All the cells described so far have to be thrown away when they are run down. Rechargeable cells get over this problem. The most important type of rechargeable dry cell is the **nickel-cadmium cell**. These cells can be made in the familiar, round shape suitable for torches, calculators, cassette players, etc. The negative electrode is cadmium, which releases electrons. The positive electrode contains nickel ions, Ni^{4+}, which accept electrons, forming Ni^{2+}. The cell can be recharged over 500 times, but it is very expensive to buy in the first place. A special transformer is needed for recharging.

Cells for the future

Scientists are constantly looking for new, better cells. Some new developments are:

1 *Zinc-air cells* (1.5V) These last twice as long as the mercury cell. Used in hearing aids.

2 *Lithium cells* (3V or 1.5V) Long lasting and perform well at low temperatures. Used in watches and calculators.

3 *Sodium-sulphur cells* (2.1V) Under development for use in electrically powered vehicles. Rechargeable and relatively low cost but work at temperature of 350°C.

Answer questions 9 and 10.

Questions

9 *Describe the 'ideal dry cell' of the future. What features would it have?*

10 *What would life be like without dry cells? What important things would we have to do without?*

Part 3 Practical investigation of a cell

> **Safety warning** Although zinc-carbon batteries can be quite safely opened, alkaline-manganese type batteries (Duracell, Ever Ready Gold Seal) should **not** be opened. They contain dangerously corrosive concentrated alkali.

In this investigation you will be looking at the commonest type of dry cell, the Leclanché cell. You will be trying to answer these questions.

1 What is the negative electrode made of?

2 What is the mixture that makes up the positive electrode and the electrolyte?

You will be given a dry cell which has been cut in half. Examine it carefully and compare it with Figure 6. Discuss with the rest of your group the tests you could do to answer the two questions above. When you have decided on a plan, discuss it with your teacher. Your teacher may let you try your own method, or alternatively you could follow the method given on pages 7 and 8.

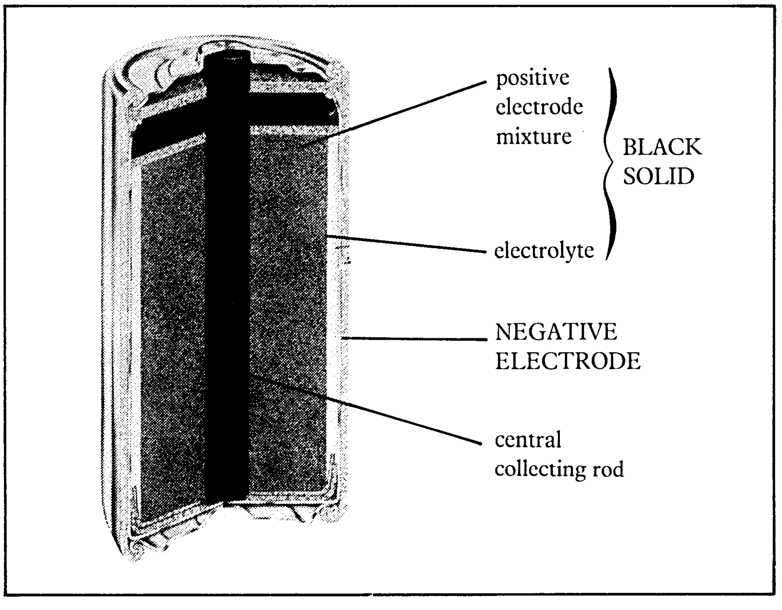


Figure 6 A dry cell

Experimental investigation of a dry cell

CAUTION	**Eye protection must be worn throughout this practical**

1 The negative electrode

Use snips to cut a strip of the metal that makes up the negative electrode. The strip should be about 3-4cm^2 in area. Test it as described below.

(a) *Reaction with acid*

(i) Clean the strip of metal with wire wool and put it in a boiling tube. Add about 5cm^3 of dilute hydrochloric acid (**CARE**). Warm gently, but do not allow it to boil. A gas will be evolved. Hold your thumb over the end of the tube to collect some of the gas. Test the gas with a burning splint. What happens? What is the gas? What does this tell you about the metal?

(ii) After the metal has reacted with acid for a while, pour off 2cm^3 or 3cm^3 of the resulting solution into a test tube. Carefully and gradually add sodium hydroxide solution until the solution is neutral. You can test to see if it is neutral by removing drops on a glass rod and testing with universal indicator paper. When the solution is neutral, add a *few more* drops of sodium hydroxide solution. What happens? Now add excess sodium hydroxide solution. What happens now? What do these tests tell you about the metal that makes up the negative electrode?

(b) *Effect of heat*

Your teacher may demonstrate the effect of heating the metal.

2 The black solid/paste

The black pasty solid inside the battery is a mixture of two things:

(i) The electrolyte
(ii) The chemicals which act as the positive electrode, accepting electrons.

(a) *Separating the positive electrode materials from the electrolyte*

Place 2 spatula loads of the black paste in a 100cm^3 beaker. Add 50cm^3 of distilled water and stir thoroughly. Filter. Keep both the residue and the filtrate.

(b) *What is the residue?*

Place 2cm depth of hydrogen peroxide solution (**CARE**) in a test tube. Add 1 spatula measure of the residue. Hold a glowing splint at the mouth of the tube. What gas is evolved? Explain what has occurred. Does this help you to identify one of the substances in the residue?

(c) *What is the filtrate?*

The filtrate is a solution containing positive and negative ions.

(i) Place 2cm depth of filtrate in a test tube. Add about 1cm of dilute nitric acid (**CARE**). Now add a small amount of silver nitrate solution. Describe what happens. Use this result to identify a negative ion present in the filtrate mixture.

(ii) Divide the remainder of the filtrate into two portions. To one portion add sodium hydroxide solution (**CARE**), a few drops at first, then in excess. Describe what happens. Use this result to identify a positive ion present in the filtrate mixture.

(iii) To the other portion add an excess of sodium hydroxide solution, then warm gently (**GREAT CARE**. Hot sodium hydroxide solution is dangerously corrosive. Eye protection is essential.) What gas is given off? Use this result to identify another positive ion present in the filtrate mixture.

Safety warning Zinc-carbon cells contain traces of poisonous mercury. Wash your hands after the practical.