12 Electrochemistry

Planning page

Getting started

- Investigate 26 Voltages of electric cells
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12.1 Cells and batteries page 284

- Animation: How an electric cell works
- Assessment task 12: Cells and batteries

- Investigate 28 Copper plating
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Main ideas

- Chapter 12 crossword

Review

- Chapter 12 test

Essential Learnings for Chapter 12

Essential Learnings	References		
	Student book (page number)	***Workbook (page number)***	***Teacher Edition CD (Assessment task)***
Knowledge and understanding *Natural and processed materials* Chemical reactions can be described using word and balanced equations	pp. 286–301	p. 92	
Energy and change Energy is conserved when it is transferred or transformed	pp. 284–297	p. 95	Assessment task 12 Cells and batteries
Ways of working Select and use scientific equipment and technologies to enhance the reliability and accuracy of data collected in investigations	Investigations pp. 285, 290, 294, 296, 302 Experiment p. 299		
Draw conclusions that summarise and explain patterns, and that are consistent with the data and respond to the question	Investigate 26 p. 285 Investigate 27 p. 290 Investigate 29 p. 296	Exercise 7 pp. 97–98	
Plan investigations guided by scientific concepts and design and carry out fair tests	Corrosion of iron p. 299	p. 99	
Communicate scientific ideas, explanations, conclusions, decisions and data, using scientific argument and terminology, in appropriate formats		p. 93 p. 97	Assessment task 12 Cells and batteries

QSA Science Essential Learnings by the end of Year 9

Vocabulary

anode
anodising
chromium
corrosion
electrochemical
electrode
electrolyte
electroplating
manganese dioxide
multimeter
nickel-cadmium
oxidation
phenolphthalein
platinum
polyvinyl chloride (PVC)
rechargeable
sacrificial protection
voltmeter

Focus for learning

Make a simple electrical cell from a lemon, a piece of copper wire and a strip of magnesium (page 283).

Equipment and chemicals (per group)

Investigate 26 page 285 large test tubes, test tube rack, strips of metal, strips of filter paper (about as wide as and slightly longer than the test tubes), voltmeter (0–2 V scale) or multimeter, connecting wires, dilute sulfuric acid (0.1 M), steel wool or emery paper
Try this: other solutions (eg dilute hydrochloric acid, sodium chloride, copper sulfate, dilute sodium hydroxide)

Investigate 27 page 290 2 clean lead strips, 100 mL beaker, power pack, 5 connecting wires, 1.5 V torch bulb in holder, voltmeter or multimeter, switch, 1 M sulfuric acid

Investigate 28 page 294 acidified copper sulfate solution (dissolve 250 g of $CuSO_4.5H_2O$ in 500 mL water, add 50 mL of 3 M sulfuric acid and dilute to 1 L), 250 mL beaker, carbon rod, copper strip, power pack, 2 connecting wires
Try this: metal objects and steel wool for electroplating

Investigate 29 page 296 power pack, 2 connecting wires, large evaporating basin, large filter paper, white tile or similar, large shiny nail, aluminium foil, potassium iodide solution (0.5 M), sodium thiosulfate solution (0.5 M), starch suspension (1% freshly prepared), phenolphthalein, disposable gloves

Experiment page 299* 4 test tubes and rack, 4 large nails, copper wire, magnesium ribbon, steel wool, sodium chloride solution (1 M), distilled water, digital camera (optional)

Investigate 30 page 302 piece of aluminium (eg 5 cm × 1 cm), aluminium foil, 2 beakers (100 mL), 2 M sulfuric acid, metal tongs, safety glasses and disposable gloves, hotplate (or burner, tripod and gauze), power pack and connecting wires, fabric or food dye solution, stand and clamp, detergent, bench mat, tissues

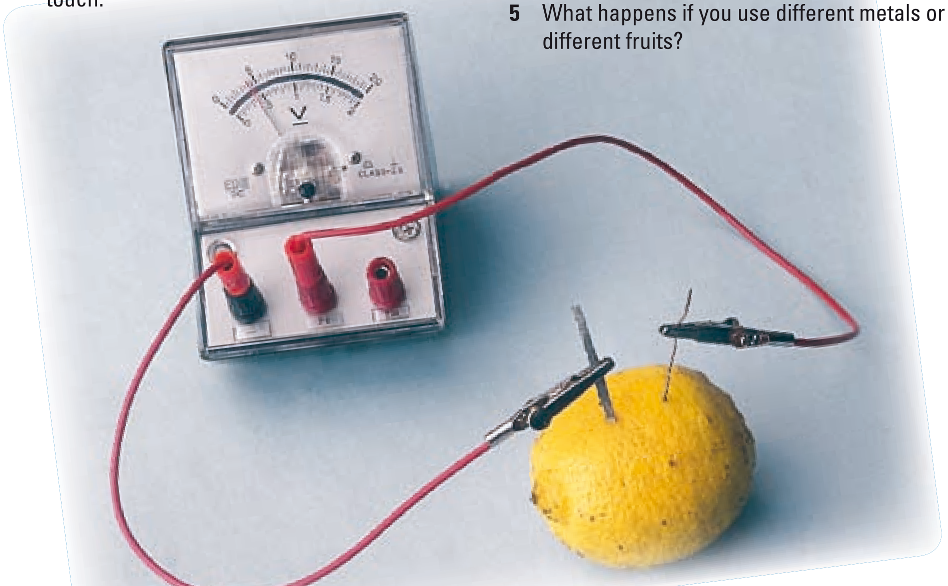
* Students to list the equipment they will need, which may be different from what is listed here.

12 Electrochemistry

Getting Started

You can make a simple electrical cell from a lemon, a thick piece of copper wire and a strip of magnesium.

1. Clean the copper wire and the magnesium strip with steel wool.
2. Push the wire and the strip into the lemon, about 2 cm apart, making sure they do not touch.
3. Connect the copper wire to the positive terminal of a sensitive voltmeter or multimeter as shown, and the magnesium to the negative terminal.
   What voltage is produced? Does the voltage stay the same? How many lemon cells would you need to make a 12 volt battery?
4. Does it make any difference how far apart the copper wire and the magnesium strip are, or how far you push them into the lemon?
5. What happens if you use different metals or different fruits?



Starting point

1. If students are using a multimeter for this activity, they should use the lowest voltage setting. A microgalvanometer could be used. Bananas and potatoes also work quite well.
2. Students could set goals for this topic about *what* they want to learn and *how* they could learn it. About 10 goals are sufficient—five for what they want to learn, and five for how they could learn it. Ask the students to scan through the chapter before writing their goals. Alternatively, they could construct a KWHL chart (see Learning experience, page 53) and review it at the end of the chapter.
3. Concept maps are a great tool to establish what students already know. Use words from the vocabulary lists at the start of Chapters 10, 11 and 12 in the *Teacher Edition*. The task could be given as a pre-test, or students could add to the map progressively throughout the chapter.
   - Begin the map by randomly selecting students to suggest linking sentences, and continue to construct the class map in this way. Encourage multiple connecting sentences.
   - An interactive whiteboard can be useful here as it allows you to save documents and modify them at a later date.
   - The final map could be printed out and used as a student revision tool.
   - A good idea is blanking out the key words so that students have to finish the map by correctly filling in the missing words.
   - If students do the map as a pre-test, make sure you give positive feedback about their work so that they have the opportunity to show improvement when they do the post-test.

Hints and tips

Students may need a refresher lesson to review the meanings of *electrical current* and *voltage*. Remind them that current is the flow of charge and is not the voltage.

12.1 Cells and batteries

What is an electric cell?

Do you have any grey amalgam fillings in your teeth? If so, have you ever bitten on a piece of metal foil and felt a tingle? This is caused by a small electric current in your mouth. All that is needed to produce this current is two different metals and a conducting solution.

When two different metals are placed in a conducting solution and connected together, an *electrochemical cell* is made. It is called an **electric cell** or voltaic cell. The conducting solution is called an **electrolyte** (ee-LEK-tro-lite). It conducts electricity because it contains ions. The metal strips are called **electrodes**.

In Getting Started the lemon, the copper wire and the magnesium strip form an electric cell. At the magnesium electrode a chemical reaction produces electrons which flow through the wire and voltmeter to the copper electrode where another chemical reaction uses up these electrons. Ions carry the electric current through the electrolyte in the lemon to complete the circuit.

The voltage produced by an electric cell depends on a number of variables. In Investigate 26 you can investigate what happens when you use different metals as the electrodes.

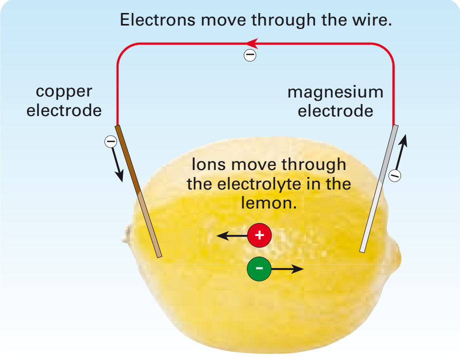


Fig 2 An electric cell is a device which uses chemical reactions to produce an electric current.

Science in action

Luigi Galvani

In the late 1700s Luigi Galvani, an Italian biologist, made a great discovery. While dissecting a frog, he noticed that its leg twitched when he held the knife and probe in a certain way. He inferred that the twitch was due to 'animal electricity' generated in the tissues of the frog's leg. Many people accepted this inference, but Alessandro Volta, a young Italian physicist, did not. He said that the source of electricity was not the frog but the two different metals in Galvani's dissecting instruments.

Galvani still believed he was right and eventually managed to get the same effect with two pieces of the *same* metal. But Volta wasn't convinced, saying that the metals must be somehow different. So Galvani got rid of the metals altogether and produced the twitch by tying the nerve of the frog's leg to the other end of the muscle. To answer this, Volta produced an electric current using two different metals and an electrolyte, and no frog at all! He then went on to make the first battery, a pile of silver and zinc disks with pieces of cloth soaked in salty water between the disks. He took his 'pile' to France where Napoleon Bonaparte was so impressed with it he made Volta a count. Science later honoured Volta by naming the volt after him.

Galvani was shattered by Volta's discovery and died soon after. However, his animal electricity wasn't all wrong. We now know that electricity is generated by the nerve cells in our body. It regulates the beating of our heart and the operation of our brain and muscles.

Homework

Have students explain why water is not used as an electrolyte. The explanation should include a definition of *electrolyte* and some examples.

Learning experience

The students could write about the life of Luigi Galvani. They may like to present their information as a series of diary entries or a narrative of his life and works. Other options might be for students to draw a cartoon strip explaining Galvani's contributions to science, or to write an article for a science magazine announcing Galvani's findings. Cartoon strips could be collated into a book to have on display.

Learning experience

Ask students to list as many items as they can think of that are battery-operated. Which item is the most common? Which items use rechargeable batteries? How often do students use the item? What is the estimated lifespan of the batteries before they need to be replaced or recharged? Are the batteries easily replaced? Are they costly? Can they think of a way to represent their data graphically?

Investigate
26 VOLTAGES OF ELECTRIC CELLS

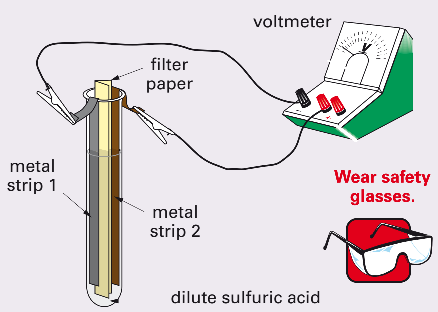
Aim
To investigate how the voltage of an electric cell varies, depending on the electrodes used.

Materials
- large test tubes and test tube rack
- strips of metal, eg aluminium, copper, iron, lead, magnesium, zinc
- strips of filter paper (about as wide as and slightly longer than the test tubes)
- voltmeter (2 V–20 V) or multimeter
- connecting wires
- dilute **sulfuric acid** (0.1M) Toxic
- steel wool or emery paper

Planning and Safety Check
- Read the investigation carefully and design a suitable data table to record your results.
- What safety precautions will be necessary?

Method
1 Clean the metal strips by rubbing them with sandpaper or steel wool.

2 Select a pair of different metal strips and place them in a test tube. Bend the tops of the strips over the edge of the test tube, as shown.



3 Fold a strip of filter paper and push it down between the metal strips. This is to prevent the strips from touching.

4 Two-thirds fill the test tube with dilute sulfuric acid.

5 Attach the connecting wires from the metal strips to the voltmeter. If there is no reading, reverse the connections so that you have the positive electrode connected to the positive terminal of the voltmeter. This is how you tell which metal strip is positive and which is negative.
Record the reading on the voltmeter, and which metal is positive and which is negative.
Did the voltage remain constant or did it change?

6 Repeat, using other combinations of metal strips. Include at least one with both metals the same.
For each pair of metals, record the voltage, which metal was positive and which was negative.

Discussion
1 Which pair of metals produced the largest voltage?

2 Did a particular metal always have the same charge? For example, was the zinc electrode always negative?

3 What happened when you used two strips of the same metal? Why is this?

4 If you wanted to light a small bulb or LED using one of your cells, which metals would you use, and why? (You could try this.)

try this
1 Investigate whether it makes any difference what the electrolyte is. Instead of dilute sulfuric acid you could use dilute hydrochloric acid, sodium chloride solution, copper sulfate solution or dilute sodium hydroxide.

2 What happens when you connect two or more cells together? Does it matter which way they are connected?

Lab notes
- Disposable gloves could be worn when handling the lead strip.
- The most common problem with this investigation is when strips touch at the bottom of the test tube, or come into contact with each other.
- Small beakers could be used as an alternative to the test tubes. Beakers allow for greater separation so filter paper will not be needed.

Hints and tips

Students need to know the difference between an electric cell and a battery. In earlier studies of science they were probably told, but it is a good idea to reinforce it.

Homework

Fig 5 shows how a simple electric cell works. There is a copper electrode and a zinc electrode. Ask students to explain why two different metals are used as electrodes.

How an electric cell works

If you made an electric cell using zinc and copper strips in dilute sulfuric acid in Investigate 26, you should have made several observations.

- When the negative terminal of the voltmeter is connected to the zinc and the positive terminal to the copper, the cell produces about 1 volt (to start with).
- The copper is the positive electrode, and bubbles of gas are produced there.
- The zinc is the negative electrode and slowly dissolves in the acid.

We can explain these observations as follows. The dilute sulfuric acid contains H^+ ions and SO_4^{2-} ions ($H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$). These ions allow the solution to conduct an electric current.

The zinc strip is more reactive than the copper strip. As a result the zinc atoms lose electrons to become positive ions Zn^{2+}. This loss of electrons is called *oxidation*. The ionic equation for this reaction is:

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

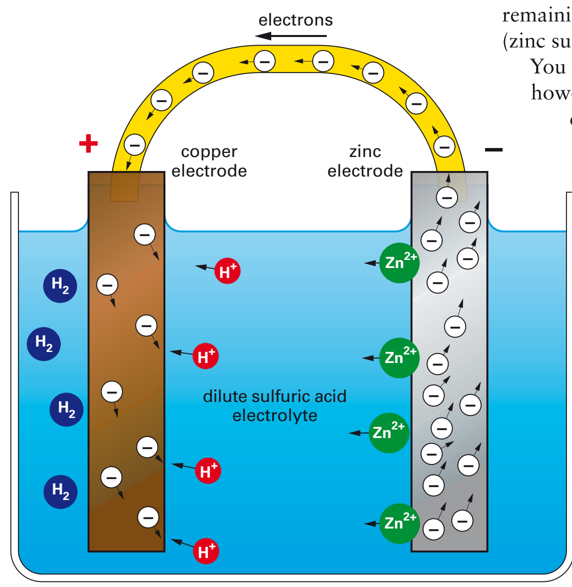


Fig 5 How a simple electric cell works

The Zn^{2+} ions move into the electrolyte, leaving the electrons behind.

When the zinc strip is connected to the copper strip, the electrons from the zinc strip flow through the wire from the zinc to the copper. Positive H^+ ions from the electrolyte around the copper electrode use these electrons to form hydrogen atoms. The hydrogen atoms then combine with each other to form molecules of hydrogen gas. This gain of electrons by the hydrogen ions is called *reduction*.

$$2H^+ + 2e^- \rightarrow 2H \rightarrow H_2$$

Notice that oxidation occurs at one electrode and reduction at the other. The electrons produced at the negative electrode are used up at the positive electrode. There is now a continuous flow of electrons through the wire, and a continuous flow of positive and negative ions in the electrolyte.

Zinc ions are produced, and hydrogen ions are used up. In theory, the cell will continue to produce electricity until all the zinc or all the H^+ ions from the electrolyte are used up. The solution remaining will contain zinc ions and sulfate ions (zinc sulfate).

You may have noticed in Investigate 26, however, that the voltage produced by the cell drops fairly rapidly. This is because the positive electrode becomes covered with bubbles of hydrogen which block the hydrogen ions in the solution from reacting with the electrons on the copper strip.

To see an animation of this, open **How an electric cell works** on the CD. Working with technology

Learning experience

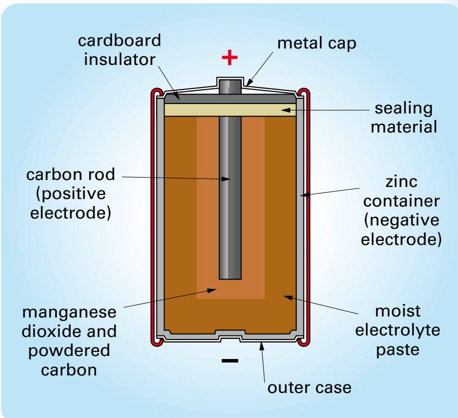
Have students construct a '5W chart' around the theme of electric cells. The five Ws are 'Who', 'When', 'Where', 'What' and 'Why'. 'Electric cell' should be the central term on the page, with five branches or balloons extending from it. Students then develop a series of questions using the five Ws and write them in the balloons. For example:

- *Who* were the first people to use electric cells?
- *Who* uses them now?
- *When* are they used?
- *Where* are they used?
- *What* chemistry is needed to explain them?
- *Why* are they used in this way?

This is an effective strategy to help students identify the important aspects of the topic. You can add another dimension to the task by asking students to draw clearly labelled diagrams explaining how some electric cells work. What other areas of science (apart from chemistry) link with electric cells? Get the students to work in small groups. They could construct their chart on poster or butcher's paper, or use ICT to create a multimedia presentation.

Dry cells

The cells used in torches and portable radios are called **dry cells**. This is because the liquid electrolyte has been replaced by a moist electrolyte paste in a sealed container.



The outside case is made of zinc. This is the negative electrode, and it loses electrons (oxidation) to form zinc ions.

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

The positive electrode is a carbon rod surrounded by manganese(IV) oxide. (Carbon is a good conductor of electricity.) The reduction reaction at this electrode is complicated, but it can be simplified as:

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

The manganese dioxide also removes any hydrogen formed at the positive electrode by reacting with it. The electrolyte paste conducts the electricity.

A carbon–zinc dry cell produces 1.5 volts. Batteries are made by connecting several cells together. For example, a 9 V battery consists of six 1.5 V cells connected together as shown in Fig 7 (6 × 1.5 volts = 9 volts). In everyday language the word battery is also used for a single cell.

Fig 7 A 9 V battery cut open showing the six individual 1.5 V cells

Suppose you have a CD player that needs six 1.5 V dry cells. The cells have to be connected in series so that the top positive terminal of one touches the bottom negative terminal of the next. In the appliance illustrated below there are two rows of 3 cells, one row on top of the other. The total voltage is 1.5 V × 6 = 9 V.

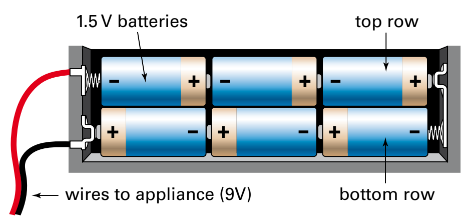


Fig 9 When putting batteries into an appliance you must be careful to put them in the right way round.

Hints and tips

The internet has many sites related to electrochemistry. Find some useful sites that explain how different types of electric cells function, or have the students find them. In particular, look for sites with animations or interactive features.

Research

Have students research one or more different types of cells/batteries, such as dry cells, alkali cells, button cells, rechargeable batteries and fuel cells. Consider handing out a criteria sheet for the class to follow. (Giving students a rubric is a good idea—it can also serve as a marking sheet.) Incorporate a section or question that requires students to complete a self-assessment.

Students should respond to the investigation using the appropriate language outlined in this chapter and could be allowed to choose the format for their presentation. Encourage them to select a presentation format that they have not used very often.

When students do their own research, they need to devise a good set of questions. A combination of factual and extended answers is ideal. Ask questions like:

1. What was/is the need for the cell/battery?
2. Who discovered/invented it?
3. How was it tested?
4. Is it being used today?
5. What is its application?
6. What modifications have been made to the original design?
7. Has its use caused any unforeseen problems? If so, what are they and have they been fixed?
8. How do you see its future?
9. How might life change if we no longer had it?

Assessment task 12: Cells and batteries is a similar activity.

Learning experience

Construct a class chart listing different electric cells/batteries. For each type of cell or battery, have students identify which electrode is positive and which is negative, the type of cell and its main application (what it is used in). They should also write the chemical process (words or equations). The following cells/batteries could be included:

- carbon–zinc
- alkaline
- lithium
- nickel-cadmium (rechargeable)
- lead–acid
- nickel-metal hydride (used in hybrid cars).

The chart can be added to progressively as students work through the chapter.

Learning experience

Worksheets are a good way to summarise and simplify information. Design some with diagrams of how electric cells work, leaving spaces for labels that students can fill in.

If students are using the internet to investigate electrochemistry, consider creating a worksheet based on a specific website.

Hints and tips

You might like to show students how to check if a car battery has enough water in it, and explain why water occasionally needs to be added. At the start of the lesson you could take the class down to your car, if possible, and show them. This is a practical application of the theory and will help to consolidate it. Ask students why they think distilled water is recommended.

Issues

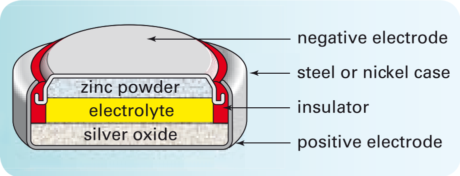
How are batteries disposed of? Are they safe for normal landfill? Is there one type of battery that is more toxic than the others? What other questions can students think of relating to the disposal of batteries?

Students could investigate the idea that discarded batteries cause environmental and health issues. Let them explore the idea further via an issues map, issues circle or Round Table activity. Allow sufficient time for brainstorming and gathering resources. Students could write a user guide entitled *What you need to know before disposing of that battery!* Their work could be presented as a PowerPoint presentation, booklet or video.

Homework

How many items can students think of that use rechargeable batteries? What are some common items and not-so-common items? What are the largest and smallest items they can think of?

Small button cells are used in watches, calculators, cameras, hearing aids and hand-held electronic games. One type consists of an outer container of nickel or steel, with zinc powder and silver oxide separated by an electrolyte. The zinc is oxidised and the silver ions in the silver oxide are reduced to silver atoms.



Rechargeable batteries

The cells discussed so far have a major disadvantage. Once the chemicals in them have reacted the cells go 'flat' and have to be thrown away. However, with some cells it is possible to reverse these reactions by passing electricity through them in the opposite direction. Rechargeable cells are widely used in mobile phones, laptop computers, cordless drills and radio-controlled model cars and aeroplanes. Two common rechargeable cells are nickel-cadmium (NiCad) and lithium ion. Most space satellites also use rechargeable batteries, using electricity produced by solar cells to recharge them.

Fig 11 When this red nickel-cadmium battery is recharged, the chemical reactions that produced electricity in the electric drill are reversed.

The most common rechargeable battery is the car battery. It has electrodes of lead and lead oxide (PbO_2) in a sulfuric acid electrolyte. The battery produces an electric current to start the engine, but once the engine is running, an alternator (generator) is used to pass current back through the battery. In this way the chemical reactions that produced the battery current are reversed, and the battery is restored to full charge.

In theory, lead–acid batteries can be used and recharged forever. In practice, however, batteries last only 2–5 years. This is because small amounts of lead sulfate fall from the electrodes and collect on the bottom of the cells. Eventually there is not enough lead sulfate to produce lead on recharging.

During recharging the battery becomes quite warm, causing some of the water in the electrolyte to evaporate. This is why with most batteries you need to check the battery occasionally and add distilled water to keep the acid at the correct concentration.

In Investigate 27 you can make a small lead–acid battery and charge and discharge it.

Fig 12 Topping up a car battery with distilled water

Learning experience

Have a selection of some different cells/batteries for students to view. If it is possible, some could be cut in half so that students can see what they look like inside. Cutting them can be tricky, so do this ahead of time. You will probably need to use a hacksaw. Be careful not to let students touch the halved batteries.

Under no circumstances should a nickel-cadmium battery be cut in half.

Learning experience

Ask students to suggest why it is not a good idea to touch the inside of a cell/battery. Why does a battery 'go flat'? To encourage cooperative learning and deeper thinking, this could be done as a Think/Pair/Share activity.

extra for experts

A car battery consists of six cells connected together, as shown on the right. Each cell produces about 2 volts and contains two electrodes. The negative electrodes are lead and the positive electrodes are lead(IV) oxide PbO_2. These electrodes are immersed in fairly concentrated sulfuric acid, containing H^+ ions and SO_4^{2-} ions.

At the negative electrodes the lead atoms lose electrons (oxidation) to form lead ions.

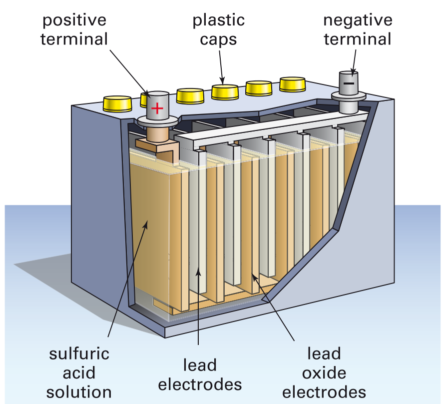
$$Pb \rightarrow Pb^{2+} + 2e^-$$

At the positive electrodes Pb^{4+} ions gain electrons (reduction) to form Pb^{2+} ions.

$$Pb^{4+} + 2e^- \rightarrow Pb^{2+} + 2H_2O$$

During discharge the Pb^{2+} ions react with the sulfuric acid to form lead sulfate (an insoluble white solid) which builds up on the electrodes. The reverse reaction occurs when the battery is recharged (whenever the engine of the car is running).

When you recharge a battery or jump start a car, the water in the battery is electrolysed to hydrogen and oxygen gases. For this reason it is important to leave the caps off and keep away from any sources of ignition such as a burning cigarette.



Science in action

Batteries for hybrid cars

With the cost of petrol increasing and carbon dioxide from car exhausts contributing to global warming, more people are buying hybrid cars. These cars have an electric motor as well as a normal petrol engine. They also have a battery pack which fits under the floor in the back. When you accelerate, the battery powers the electric motor. When you reach cruising speed the petrol engine starts up as well. Then, when you slow down, the electric motor acts in reverse. It acts as a generator and recharges the battery. This way you use much less petrol and produce less exhaust gas. Hybrid cars at present use nickel-metal hydride battery packs. For example, the Toyota Prius has a sealed 168-cell nickel-metal hydride battery which produces 201.6 volts. Scientists and technologists are constantly experimenting with new types of batteries.

Fig 14 The dashboard display in a Toyota Prius hybrid car

Hints and tips

Present to the class some interesting facts about hybrid cars. Did they know that hybrid cars use nickel-metal hydride batteries, which are less toxic than the conventional nickel-cadmium or lead–acid batteries commonly used in electrical appliances and in cars? Did they know that the batteries are fully recyclable? Did they know that the batteries are expected to last the lifetime of the car, and are under warranty for up to 10 years?

Research

Students could research more about hybrid cars, and focus their investigation on the cars' power source. They might like to do comparisons between the models currently on the market. Students could design their own advertisement for one of the cars, explaining the electrochemistry involved in its operation.

Learning experience

If you jump-start a car battery, why is it important to leave the caps off and not have any sources of ignition close by, such as a burning cigarette? Have students design a poster to explain the dangers. Coloured poster paper could be used, or students could present their information in an electronic format. Display the posters around the school, or put electronic presentations on the school's intranet.

Lab notes

- Disposable gloves could be worn when handling the lead strips.
- Make sure the lead strips do not touch each other.
- Check the clips for good connections, and make sure the light bulb works.
- Use a bench mat to sit the beaker of sulfuric acid on.
- For an extension activity, have students investigate charging time versus discharging time.

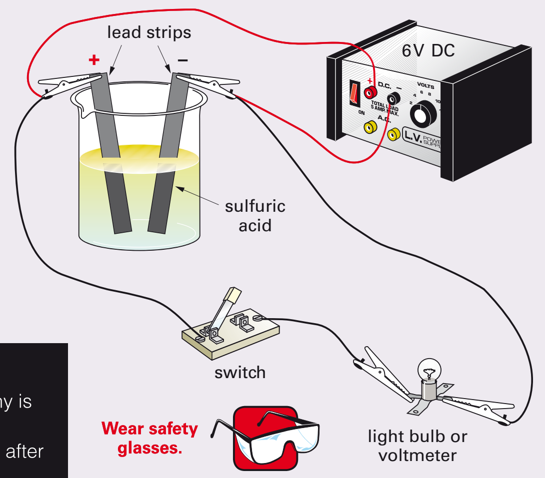
Investigate
27 A MODEL CAR BATTERY

Aim

To make a model lead–acid car battery and investigate how it works.

Materials

- 2 clean **lead** strips, eg 5 cm × 1 cm — **Toxic**
- 100 mL beaker
- power pack
- 5 connecting wires
- 1.5 volt torch bulb in holder
- voltmeter or multimeter
- switch
- 1M **sulfuric acid** — **Corrosive**



Planning and Safety Check

- 1M sulfuric acid is very corrosive. If any is spilt, what should you do?
- Why should you wash your hands well after handling the lead strips?
- Why is it important to make sure that the lead strips do not touch during charging or discharging?

Method

1. Connect up the electric circuit as shown, and have your teacher check it. The lead electrode connected to the positive terminal of the power pack is the positive electrode.
2. Set the power pack to 6 V DC and turn it on to charge your 'battery'.
3. After 5 minutes, turn off the power pack and turn on the switch to connect the battery to the light bulb. The battery is now discharging.
   How long does the bulb glow?
4. Recharge the battery by turning off the light bulb switch and turning the power pack on again for 5 minutes.
5. Remove the torch bulb and replace it with a voltmeter. Make sure the positive terminal of the voltmeter is connected to the positive electrode of the battery.
6. Switch on the voltmeter circuit.
   Record the voltage of the battery.
   What happens to the voltage as the battery continues to discharge?

Discussion

1. What evidence of chemical reactions did you observe during charging and discharging?
2. Explain in your own words the difference between charging and discharging.
3. Would you get as much energy out of the battery as you put into it? Explain your answer.

try this

Use your battery to investigate the effect of one or more of these variables on its performance:

- the charging time and voltage used
- the distance between the lead strips
- the size of the strips.

Fuel cells

Fuel cells are electrochemical cells that produce electricity continuously and do not need to be recharged.

Hydrogen–oxygen fuel cells were used on the *Apollo* missions which put people on the Moon, and they are currently used in the Space Shuttle. Each cell consists of two electrodes separated by an electrolyte (see Fig 16). Hydrogen (the fuel) is fed into one electrode and oxygen (air) into the other.

At the negative electrode the hydrogen gives up electrons (is oxidised):

$$2H_2 \rightarrow 4H^+ + 4e^-$$

At the positive electrode the oxygen accepts electrons (is reduced):

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

Adding these two equations together, the overall reaction is:

$$2H_2 + O_2 \rightarrow 2H_2O$$

A big advantage of this fuel cell is that the only waste product is water. In fact, the fuel cells on the Space Shuttle are used to produce drinking water as well as electricity. At present fuel cells are too expensive for general use, but they are being trialled in buses in Perth. It may not be long before they are widely used, eg in hydrogen cars and mobile phones.

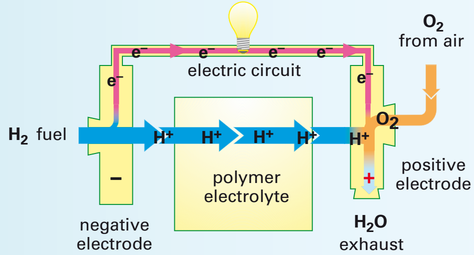


Fig 16 This type of fuel cell generates 0.7 volts. The electrodes contain a platinum catalyst and the electrolyte is made of a conducting plastic similar to Teflon. Many of these cells stacked together can be used to power a hydrogen car (below).

WEBwatch

Use the internet to research fuel cells and write a report which includes:

- types of fuel cells
- their advantages and disadvantages
- where they are used.

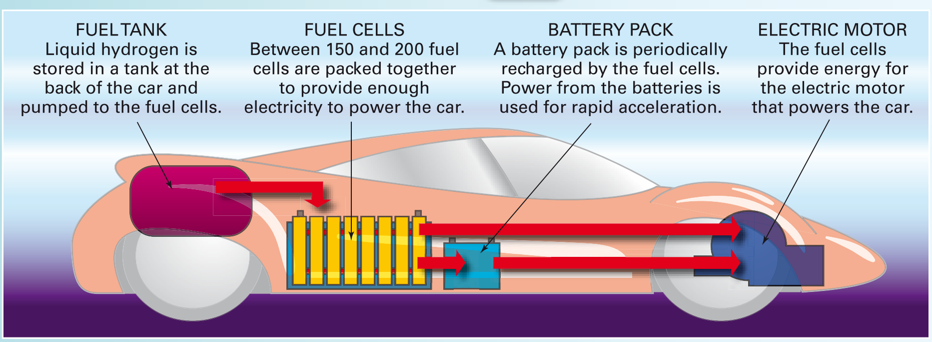
Go to www.scienceworld.net.au and follow the links to these useful websites:

Fuelling the 21st century

Fuel cell technology

How fuel cells work

Fig 17 How a hydrogen car works



Hints and tips

Before starting any new material, have students document the key points from the last few lessons. How much they can recall will determine how much time you need to spend on review before moving on to more advanced concepts.

Homework

Ask students to find out more about how hydrogen–oxygen fuel cells are used in space travel. Information could be presented as a series of dot-point facts to be posted on the school intranet or science noticeboard. This activity links with Chapter 13 Space Science.

Learning experience

Do the Webwatch if you have access to computers in class, or give it as a homework exercise.

Learning experience

There are some good YouTube videos showing how fuel cells work. Run a fuel cell video search in YouTube or TeacherTube and preview the material before showing the class.

Learning experience

Students could make their own hydrogen–oxygen fuel cell, and record it for a YouTube or TeacherTube video. The electrolytes used can be hazardous so it may be best to do a teacher demonstration.

To do the demonstration, you will need a plastic disposable cup, 2 semi-micro test tubes, 2 carbon electrodes (not too thick), 1 M potassium hydroxide solution, power pack, leads and voltmeter. Ensure that disposable gloves and safety glasses are worn.

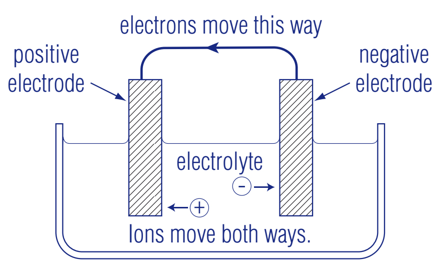
1 Push the two electrodes up through the base of the cup, leaving the ends exposed on the outside of the base.
2 Use a silicon sealant to seal the base of the cup around the electrodes.
3 Connect the electrodes to the DC terminals of the power pack. A cup-holder or stand might be needed to hold the cup in an upright position.
4 Fill a test tube with potassium hydroxide solution. Carefully invert it over one of the carbon electrodes. Surface tension should hold the solution in the inverted test tube. (Alternatively, plastic wrap can be placed over the filled test tube before inverting it, then carefully punched open with the electrode when it is inverted.)
5 Repeat the procedure with the other test tube for the second electrode.
6 Turn on the power pack to 6 volts. Gas will form at both electrodes.
7 When both electrodes are exposed to gas, turn the power pack off and connect the leads to a voltmeter.

Carbon (graphite) electrodes are used because they are cheap, they conduct electricity and they are unreactive.

Check! solutions

1 The foil contains the metal silver or another metal, and your fillings contain a mixture of other metals including mercury. Your saliva and cells act as an electrolyte and the pain you feel is a small electric current because your mouth is actually a small electric cell.

2



A simple electric cell requires two electrodes and a solution that will conduct electricity (the electrolyte) as shown in the diagram above. At one electrode there is a chemical which produces electrons that flow to the other electrode through the connecting wire. At the other electrode a reaction occurs which uses these electrons. Ions carry the electric current through the solution to complete the circuit.

3 A carbon–zinc dry cell produces 1.5 volts. If you have several of these joined together it is called a battery. For example, if there are six joined together the voltage is 9 volts.

4 You would need to join three of these together to form a battery that will produce 4.5 volts.

5 In a dry cell the central (+) electrode is made of carbon and the outside (–) electrode is made of zinc.

6 The electrolyte in a car battery is sulfuric acid.

7 They are called storage batteries because they can store electrical energy as chemical energy for later conversion back to electrical energy.

8 A battery becomes flat when one of the chemicals in an electrode or in the electrolyte is used up.

9 In an electrolyte the electric current is carried by ions. In a connecting wire, however, the current is carried by electrons, which travel from the negative electrode to the positive electrode.

Check!

1 If you have amalgam fillings in your teeth and you bite on a piece of foil covering a chocolate bar, you feel a tingle of charge. Why is this so?

2 Draw a diagram of a simple electric cell and explain how it works.

3 Most people incorrectly refer to 1.5 V dry cells as batteries. Why is this incorrect?

4 How could you make a 4.5 V battery from 1.5 V dry cells?

5 What are the two electrodes in a dry cell made of?

6 What is the electrolyte in a car battery?

7 Why are lead–acid batteries often referred to as storage batteries?

8 What has happened when a battery is flat?

9 Explain how the flow of electric current in an electrolyte differs from that in the wire connecting the electrodes.

challenge

1 I-Chung put a zinc strip and a copper strip in a test tube and added water. When he connected a voltmeter the reading was zero. How can you explain I-Chung's result?

2 Tanya decides to make a simple cell spillproof by sealing it with a rubber stopper. However, the rubber stopper keeps popping out. Suggest why this happens.

3 A copper–zinc cell gives a voltage of about one volt while a copper–lead cell gives a voltage of less than 0.5 V. Write an inference to explain these observations.

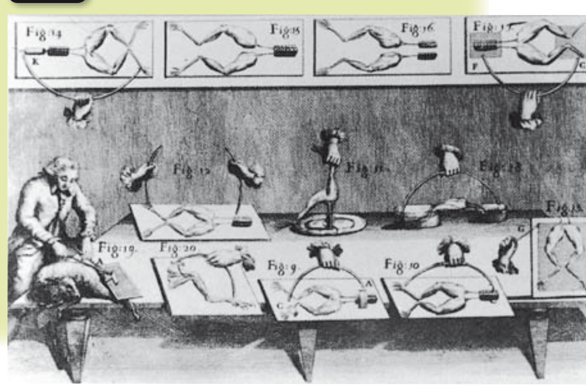
4 Alistair wants to recharge his car battery using a battery charger.
   a To which battery terminals should the positive and negative terminals of the battery charger be connected?
   b What would be the effect on the battery if the charger was connected incorrectly?
   c Why is it important to remove the plastic caps on each cell of the battery during recharging?
   d Explain why smoking during this procedure is hazardous.

5 In Getting Started you made an electric cell by putting a copper wire and a magnesium strip in a lemon (containing citric acid). Use what you have learnt in this section to answer these questions.
   a What is the electrolyte in this cell?
   b What reaction occurs at the magnesium electrode? Is this electrode positive or negative?
   c What reaction occurs at the copper electrode? Is this electrode positive or negative?

6 A torch bulb is connected to a copper–zinc cell. At first the bulb glows brightly, but it gradually becomes dimmer. Explain why this happens.

7 In 1780 Luigi Galvani investigated animal electricity. He connected different metals such as copper and iron to the hind legs of dead frogs, as shown in Fig 18. He found that the legs twitched.
   a Use what you have learnt in this chapter to explain Galvani's observation.
   b Look at Fig 9 in the illustration below. It shows an iron bracelet (A) connected to a copper bracelet (C) by a curved wire. Redraw this, labelling the two electrodes and the direction of the current flow.

Fig 18 Galvani's experiments on animal electricity



Challenge solutions

1 Pure water contains very few ions and is a poor conductor of electricity. If he had added a small amount of acid, he may have noticed a small voltage.

2 The rubber stopper keeps popping out because a gas is being produced by the chemical reaction between one of the electrodes and the electrolyte. This gas is often hydrogen, which is flammable and can be dangerous.

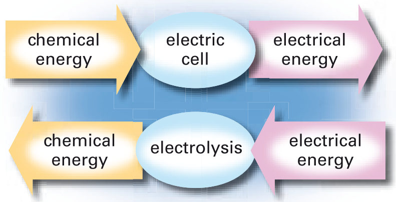
3 The voltage produced by a simple cell depends on the different activities of the two metals involved. The difference in the voltages produced with copper and zinc is greater than that produced by copper and lead because they are further apart on the activity table (see page 300).

4 a The rule is positive to positive (red) and negative to negative (black).
   b If the charger is connected incorrectly it will cause a short circuit and sparks, which could be dangerous.
   c The caps should be removed because, during charging, gases (hydrogen and oxygen) are produced that should be allowed to escape into the air.
   d Smoking is hazardous because the hydrogen produced is very flammable and could cause an explosion.

12.2 Electrolysis

Electroplating

If you browse through a jeweller's shop you will find many shiny 'silver' articles such as bracelets, necklaces, cutlery, trays and jugs. The silver on these objects is usually only a thin coating about 0.01–0.05 mm thick on top of an inexpensive metal such as copper, zinc or nickel. The coating has been put on by electrolysis, a process in which electricity is used to cause chemical reactions. It is the reverse of what happens in electric cells.



Putting a layer of metal on the surface of another metal is called **electroplating**. To put a coating of silver on a teapot you would use the apparatus in Fig 21. The teapot is connected to the negative terminal of a power supply and immersed in an electrolyte such as silver nitrate, which contains ions of the metal that is to form the coating. The positive electrode is a rod of silver. When the power is turned on, the positive silver ions in the electrolyte are attracted to the negative electrode (the teapot), where they accept electrons and are reduced to silver atoms.

$$Ag^+ + e^- \rightarrow Ag$$

At the positive silver electrode the silver atoms release electrons and are oxidised to silver ions.

$$Ag \rightarrow Ag^+ + e^-$$

The negative nitrate ions move towards the positive electrode but do not take part in any reaction. The overall result is that the silver rod slowly dissolves, and the teapot is coated with silver.

Fig 20 This motorcycle fuel tank has been electroplated with a thin layer of chromium (chrome) by placing it in a vat containing chrome solution and passing an electric current through it.

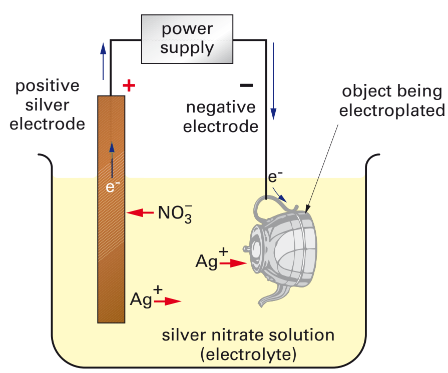


Fig 21 This teapot is being electroplated with a layer of silver.

Hints and tips

Have students do some reflective thinking about this chapter so far. You could prepare a worksheet that they can take home to answer. Include questions that allow students to reflect on the material covered and their involvement in group activities. Here are some possible questions:

- What did you learn from the work you have done in this chapter?
- Why is being able to solve a problem an important science skill?
- Why do you think understanding electric cells and electroplating is important? Has our understanding of both improved the quality of our life?
- What is an example of a problem solved or an everyday application in this chapter?
- How did you feel when you had to share your ideas in a group?
- What did you learn about yourself during this group activity?
- What role did you have in your group, and how did you assist the group?
- What have you found the most interesting/least interesting about this chapter?
- What did you find was the best way to learn things in this chapter?

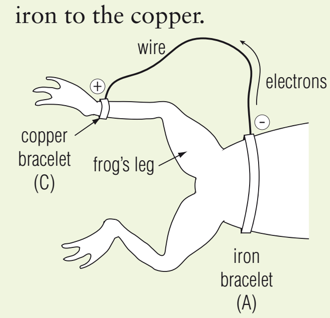
5 a The electrolyte in this simple cell is citric acid. This electric cell is similar to the zinc–copper cell on page 286. At the magnesium electrode, magnesium atoms each lose two electrons to become magnesium ions. This electrode is negative. The equation is: $Mg \rightarrow Mg^{2+} + 2e^-$

c At the copper electrode, hydrogen ions each gain an electron to form hydrogen atoms, which combine to form hydrogen molecules. This electrode is positive. The equation is: $2H^+ + 2e^- \rightarrow 2H$ (ie H_2).

6 The voltage produced by this cell drops because the positive electrode becomes covered with bubbles of hydrogen. These bubbles block the hydrogen ions in the electrolyte and prevent the ions from reacting with the electrons in the strip. If these bubbles are removed with a depolariser the cell will work for a longer time.

7 a When Galvani connected different metals to the hind legs of dead frogs, he was actually making a simple electric cell which produced a small electric current. This small current was sufficient to cause the muscles to twitch and the legs to move.

b This electric cell is similar to the one with the lemon in Getting Started. It is also similar to the zinc–copper cell on page 286. In both of these cells the copper is positive. From this you can infer that the electrons flow from the iron to the copper.



Lab notes

- Disposable gloves should be worn when handling the solution.
- Lower voltage over a longer time will give better plating.
- Make sure the metal strips do not touch each other.
- Check the clips for good connections and make sure the copper is connected to the positive terminal.
- Use a bench mat to stand the beaker on.
- If you want to remove the copper from the object, simply reverse the polarity.

Learning experience

What items around the home, work and school are electroplated? Get students to compile a list of items they think have been electroplated. Are there any unusual items? Which item is most common? Develop a class table to see how many different items can be identified.

Investigate 28 COPPER PLATING

Aim

To investigate the electrolysis of copper sulfate solution.

Materials

- **acidified copper sulfate solution** (1M) Toxic
- 250 mL beaker
- carbon rod
- copper strip
- power pack
- 2 connecting wires

Planning and Safety Check

- Read the investigation carefully and design a suitable data table to record your results.
- What safety precautions will be necessary?
- Discuss with your teacher how you will dispose of the copper sulfate solution.

Discussion

1 What ions are present in the copper sulfate solution?

2 Which electrode is negative in Step 2? Write an equation for the reaction that occurred there.

3 The copper sulfate tends to lose its blue colour after a while. Write an inference to explain this.

4 Did you observe bubbles of gas at the positive electrode? Infer what this gas is and where it came from.

5 How could you test your inference in Question 4?

6 Explain what happened in Step 5 when you reversed the connections.

7 The copper is always deposited at the same electrode. Which one is it—the positive or the negative?

Method

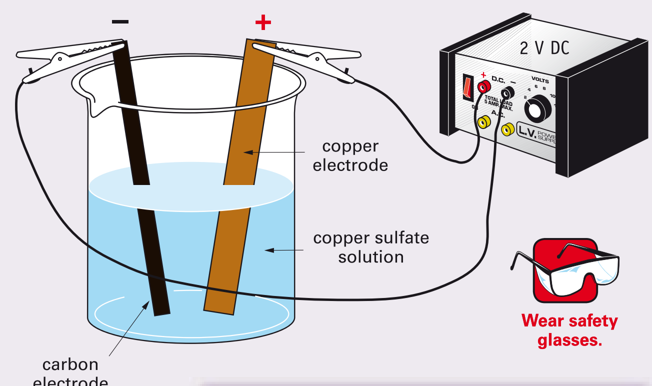
1 Set up the equipment as shown, with the carbon electrode connected to the negative terminal of the power supply.

2 Set the power supply to 2 V DC and turn it on for 3 to 4 minutes. *Don't let the electrodes touch.*
Observe the electrodes while the current is turned on.

3 Remove the electrodes, wash and inspect them.
What do you think the coating on the negative electrode is?

4 Reverse the connections to the electrodes so that the carbon electrode is connected to the positive terminal.

5 Allow the current to flow for 3 or 4 minutes.
Describe what happens this time.



try this

Plan and carry out an experiment to electroplate various metal objects with copper. To get an even coating of copper, clean the metal to be plated with steel wool or dip it in nitric acid (caution) before you start. Use a low voltage (2 V DC) and leave for at least 20 minutes.

Learning experience

Gifted and talented students could find out why some cleaning products are damaging to electroplated items. Which products should be avoided when cleaning such items? Which products are recommended to be used, and which are to be avoided? Students could write their own cleaning product guide for householders or jewellers.

Electrolysis in industry

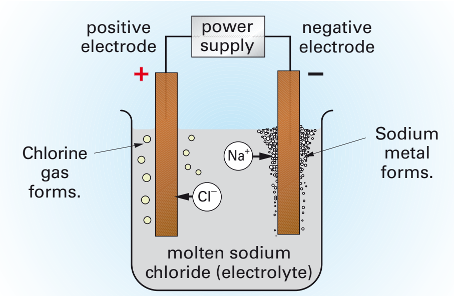
Electrolysis is widely used in industry to produce the materials we use in everyday life. For example, if you melt sodium chloride it conducts an electric current and can be electrolysed as shown on the right. The electrodes are made of an unreactive material such as carbon.

The positive ions move to the negative electrode where they accept electrons to form sodium metal.

$$2Na^+ + 2e^- \rightarrow 2Na$$

The molten sodium is less dense than the molten sodium chloride and floats to the top of the cell, where it can be collected.

The negative chloride ions move to the positive electrode, where they give up their electrons to form chloride atoms which immediately form molecules of chlorine gas.



$$2Cl^- \rightarrow Cl_2 + 2e^-$$

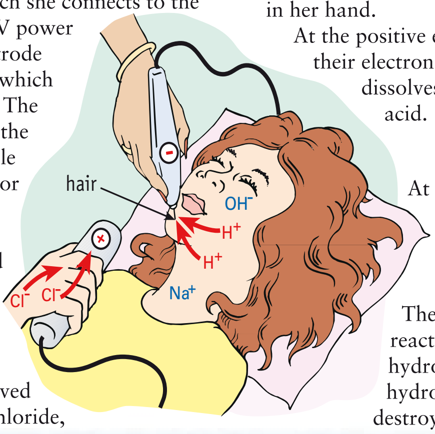
Sodium is a very reactive metal. It is used in sodium vapour lamps. Chlorine is a toxic greenish-yellow gas used to sterilise drinking water and in the manufacture of polyvinyl chloride (PVC) and various pesticides.

science bits

Hair removal by electrolysis

Linda is always pulling hairs from her face, and has gone to the beauty salon to have the hairs removed permanently. The beautician uses a very fine gold needle which she connects to the negative terminal of a 9 V power supply. The positive electrode is a shiny metal cylinder which Linda holds in her hand. The beautician gently pushes the needle into the hair follicle and turns on the power for about 10 seconds. This is repeated 3 or 4 times. Finally, tweezers are used to remove the hair easily and painlessly. But how does the process work?

Your body tissues contain water, and dissolved in this water is sodium chloride, present as Na^+ ions and Cl^- ions. Some of the water molecules also break into H^+ ions and OH^- ions. So, when the electrolysis equipment is connected and turned on, Linda's body conducts an electric current. The positive ions move to the negative electrode in the hair follicle, and the negative ions move to the positive electrode held in her hand.



At the positive electrode the Cl^- ions give up their electrons to form chlorine gas, which dissolves in water to form hydrochloric acid.

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

At the negative electrode the H^+ ions accept electrons to form hydrogen gas.

$$2H^+ + 2e^- \rightarrow H_2$$

The Na^+ and OH^- ions do not react, but together form sodium hydroxide (NaOH). This sodium hydroxide is alkaline and gradually destroys the root of the hair.

Hints and tips

Conduct a quiz based on this chapter so far. A true/false format would work well: see the Learning experience on page 138 for one way to conduct an interactive true/false quiz. You might like to reward the winner with a treat, like a metal pen or electroplated key ring.

Research

Ask students to prepare a presentation on electrolysis and the beauty industry, or electroplating and the car industry. Have students find out as much as they can about one of the industries and present their findings in a simple way that a Year 8 student would understand. The project should be directly related to this chapter. A variety of presentation formats can be used: multimedia presentation, video, audio file for MP3 or MP4 players, a role play of a mock interview, or a song.

Homework

Ask students to find out how the *Queen Mary II* ocean liner gets its drinking water and disposes of its sewage.

Learning experience

Students could make a video or slide show of how electroplating works. They could take progressive photos of Investigate 28 and use these in their presentation. Make sure they explain not only the process but the science behind it. Software like Movie Maker or Photo Story could be used. You might like to encourage students by uploading some of the best presentations to YouTube.

Lab notes

- It is a good idea to read the method as a class before students begin the investigation.
- Disposable gloves should be worn.
- Remind students not to apply too much pressure to the filter paper with the nail or they risk tearing the paper.
- If the phenolphthalein indicator turns pink, it indicates a base (presence of OH^- ions).

Investigate

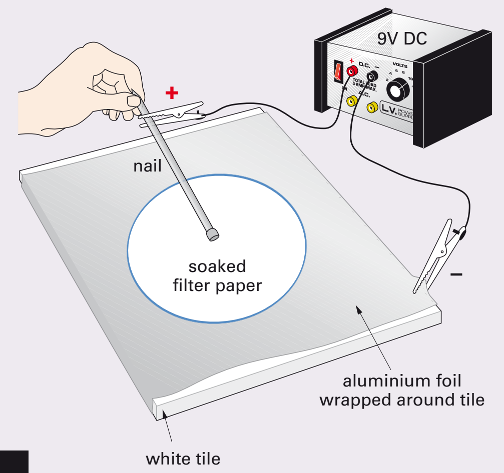
29 DRAWING BY ELECTROLYSIS

Aim

To electrolyse potassium iodide solution and explain what happens.

Materials

- power pack
- 2 connecting wires
- large evaporating basin
- large filter paper
- white tile or similar
- large shiny nail
- aluminium foil
- **potassium iodide** solution (0.5M) Toxic
- sodium thiosulfate solution (0.5M)
- starch suspension (1% freshly prepared)
- phenolphthalein indicator
- disposable gloves



Planning and Safety Check

Why is it important to wear disposable gloves for this experiment?

Method

1. Set up the equipment as shown.
2. Mix the following solutions in an evaporating basin:
   10 mL potassium iodide
   5 mL sodium thiosulfate
   5 drops starch
   5 drops phenolphthalein
3. Soak a large filter paper in the solution in the dish.
4. Wear gloves to remove the soaked filter paper from the dish, drain off any excess liquid, then place the filter paper on the aluminium foil wrapped around the tile. Press it down to make sure it has good contact with the foil.
5. Switch on the power pack and use the nail to draw a letter or shape on the damp filter paper. *Be careful not to tear it.*
6. Switch off, reverse the connections, and try again.

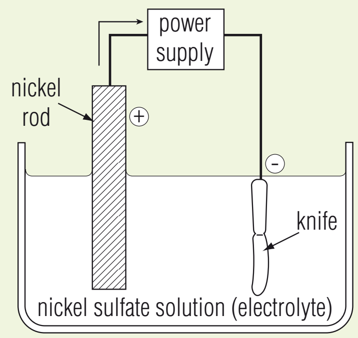
Discussion

To start with the filter paper contains equal numbers of K^+ and I^- ions from the potassium iodide. It also contains equal numbers of H^+ and OH^- ions from the water.

1. When the nail is positive it produces a blue-black colour where it touches the filter paper. What can you infer from this blue-black colour? (Hint: the solution on the filter paper contains starch.)
2. Write an equation for what happens when iodide ions I^- give up electrons at the positive electrode. (Hint: it is similar to what happens with Cl^- ions—see page 295.)
3. When the nail is negative it produces a pink colour. What can you infer from this pink colour? (Hint: the solution on the filter paper contains phenolphthalein, an acid–base indicator.)
4. Write the equation for the reaction when H^+ ions accept electrons at the negative electrode. (Hint: see page 286.)
5. If H^+ ions are removed at the negative electrode, why would the phenolphthalein indicator change colour from colourless to pink?

Challenge solutions (page 297)

1 a



b The positive electrode would be made of nickel metal.

c At the positive electrode, the equation would be:
$Ni \rightarrow Ni^{2+} + 2e^-$
At the negative electrode, the opposite reaction occurs. The equation would be:
$Ni^{2+} + 2e^- \rightarrow Ni$

2 During electroplating the metal ions must travel from one electrode to the other in the same direction. This requires an electric current that is always going in the same direction rather than an alternating current which is going back and forth. With an alternating current there would be no deposition of the metal on the cathode.

3 When removing hair by electrolysis:

a You need to connect one electrode to another part of your body so that electricity will be conducted between it and the gold needle, which is the other electrode.

b The shiny metal cylinder is a good conductor of electricity.

c Your body has resistance to the flow of electricity and this produces heat. The chemical reactions that occur at the negative electrode also produce heat.

d The hydrogen gas that is produced will simply be released into the air and will diffuse away.

e When the chemical reactions take place around the root of the hair, sodium ions (Na^+) and hydroxide ions (OH^-) are left over. These ions combine to form sodium hydroxide ($NaOH$), which is alkaline and causes irritation on the skin.

f When the electrical connections are reversed, chlorine gas is produced at the gold needle near the destroyed hair follicle. This gas dissolves in water to form hydrochloric acid, which neutralises the sodium hydroxide.

4 One way to do this would be to attach a leaf to the negative terminal of a power supply and conduct electrolysis using a gold anode and a solution of gold chloride. You may need to coat the leaf with a conductive gel. Once the process is completed the object could be placed in a solution of weak acid, which would destroy the leaf tissue but not affect the gold.

5 In the electrolysis of molten sodium chloride:

a Electricity can only be conducted in the molten state because in the solid state the ions are fixed in a regular lattice and unable to move and conduct electricity.

Check!

1 Explain the terms:
  a electrolysis
  b electrolyte
2 a How is electrolysis different from what happens in an electric cell?
  b Is electrolysis an exothermic or an endothermic reaction? Explain.
3 a Which of the following materials could be used as an electrode for electrolysis: carbon, zinc, plastic, copper? Explain.
  b Which of the following liquids could be used as an electrolyte in electrolysis: dilute sulfuric acid, distilled water, lead sulfate solution, methylated spirits, sugar solution?
4 Why is it that one Cu^{2+} ion combines with two electrons?
5 In the electrolysis of aluminium, aluminium ions Al^{3+} accept electrons to become aluminium atoms. Write an equation for this reaction.
6 How could you coat a spoon with copper?
7 a Which ions exist in a copper sulfate solution?
  b When electricity is passed through copper sulfate solution, what happens at the negative electrode? Write an equation.

challenge

1 A steel knife is to be electroplated with nickel using nickel sulfate solution.
  a Draw a diagram showing how this would be done.
  b What would the positive electrode be made of?
  c Write equations for the reactions occurring at both electrodes. (Nickel ions are Ni^{2+}.)
2 Why is a direct current and not an alternating current used in electroplating metals?
3 Use the explanation of hair removal by electrolysis on page 295 to answer these questions.
  a When the beautician is removing hairs from your face why do you need to hold the other electrode?
  b Why is a shiny metal cylinder used as the positive electrode?
  c Why does the area around the hair becomes quite warm during the treatment?
  d What happens to the hydrogen gas produced at the negative electrode?
  e Why is it that the root of the hair becomes alkaline during the treatment?
  f The electrical connections are sometimes reversed briefly at the end of the treatment. Suggest a reason for this.
4 The gold pendant below was made from a leaf. Suggest how this would have been done.

5 In the electrolysis of molten sodium chloride (page 295), explain the following.
  a Why is electricity conducted in the molten state but not in the solid state?
  b Why are the products formed only around the electrodes and not throughout the liquid?
  c What causes the electric current to flow in the liquid and in the connecting wires?
  d What are the similarities and differences between the electrolysis of molten sodium chloride and hair removal by electrolysis?
6 Predict what would happen if you electrolysed molten lead(II) bromide $PbBr_2$. Write equations.

Check! solutions

1 a Electrolysis is a process in which electricity is used to cause chemical reactions.
  b An electrolyte is any liquid that conducts electricity.
2 a Electrolysis is basically the opposite of what happens in an electric cell. Electrical energy is supplied and, as it passes through the solution, several chemical reactions occur. Some of these reactions may produce useful products.
  b Electrolysis is an endothermic reaction because it requires electrical energy to make it happen.
3 a Only plastic could not be used as an electrode because it does not conduct electricity. All other substances are electrical conductors.
  b Only dilute sulfuric acid and lead sulfate solution could be used as an electrolyte because they both contain ions which carry the electric current between the electrodes.
4 Each copper ion must combine with two electrons so that it once again becomes a neutral atom of copper. The equation is:
  $Cu^{2+} + 2e^- \rightarrow Cu$
5 The equation is:
  $Al^{3+} + 3e^- \rightarrow Al$
6 A spoon could be plated with copper if you made it the negative electrode in a circuit and placed it in a solution of copper sulfate with a copper strip as the positive electrode (see page 294).
7 a In a solution of copper sulfate there are copper ions (Cu^{2+}) and sulfate ions (SO_4^{2-}).
  b The copper ions are attracted to the negative electrode where they each gain two electrons. In doing so, they become copper atoms, as shown in this equation:
  $Cu^{2+} + 2e^- \rightarrow Cu$

  b The products are formed at the electrodes because that is where they lose or gain electrons and reactions occur.
  c In the liquid the electric current is carried by sodium and chloride ions, whereas in the connecting wires the current is carried by electrons.
  d The similarities are that there are two electrodes, both involve sodium and chloride ions and chlorine gas is produced. The main difference is that during hair removal by electrolysis, hydrogen is formed at the cathode, whereas during the electrolysis of molten sodium chloride, sodium metal is formed.
  In addition, a greater voltage and a much higher temperature (approximately 600°C) is required for the molten sodium chloride.
6 You would predict that the electrolysis of lead bromide would produce a deposit of lead metal at the negative electrode, as shown by the equation:
  $Pb^{2+} + 2e^- \rightarrow Pb$
  Bromine gas would be produced at the positive electrode, as shown by the equation:
  $2Br^- \rightarrow Br_2 + 2e^-$

Hints and tips

There are some good commercial DVDs available on corrosion, particularly rusting. Consider showing the class one as this will break up the theory components and make the topic feel more real. You could also search the internet for short, informative videos.

Fig 27 When iron rusts it reacts slowly with air and water to form brown iron oxide. This ship was wrecked in 1893.

12.3 Corrosion of metals

Rusting

A big problem with metals is that they corrode; that is, they react chemically with moist air. Metallic corrosion and its prevention costs Australia hundreds of millions of dollars every year.

Corrosion is a reaction between a metal and moist air. For example, when iron rusts it reacts with oxygen to form iron oxide Fe_2O_3. This is the brown coating we call rust.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

For rusting to occur both air and water are necessary. This is why objects made of iron and steel do not rust in the desert or in space.

The rusting of iron and steel is an electrochemical process. Consider a drop of water on a piece of iron. The water, which contains dissolved carbon dioxide and other gases from the air, acts as the electrolyte. Near the centre of the drop the iron atoms lose electrons to form Fe^{2+} ions, which move into the water. The metal in the centre of the drop becomes negatively charged.

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

Electrons flow across the surface of the iron to the edges of the drop, which have a positive charge. Here there is a high concentration of dissolved oxygen, and the oxygen molecules gain electrons to form hydroxide ions.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

These OH^- ions then react with the Fe^{2+} ions to form iron hydroxide then iron oxide Fe_2O_3. Salt water accelerates the corrosion because it is a very good conductor of electricity.

The presence of carbon in steel tends to accelerate corrosion. Other metals can either accelerate or slow down the corrosion. If conditions favour the loss of electrons, the rate of corrosion is increased, but if iron can be prevented from losing its electrons, corrosion can be slowed down or prevented.

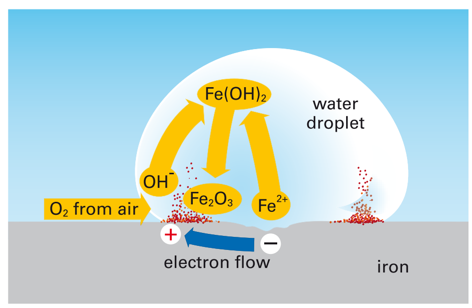


Fig 28 The corrosion of iron is similar to what happens in an electric cell.

Learning experience

How can concrete rust? When concrete is poured for buildings, paths, driveways and so on, it is reinforced with metal mesh or rods. The steel reinforcement is added so that the concrete can support heavy loads. Ask students to find out what conditions cause the steel to rust. What is 'carbonation'? Can anything be done to prevent the rusting?

In pairs, students could write a report about rusting concrete. They should respond to the questions using the appropriate language from this chapter.

Learning experience

In coastal areas, what types of building materials should be used and what types should be avoided? Are there any advantages associated with metal corrosion? Ask students to explain.

Learning experience

Gifted and talented students might like to find out more about redox reactions. What are they, and how are they relevant to this chapter?

Learning experience

Consider organising a field trip to some known sites where there are displays of metal corrosion (a shipwreck, rusty cars, old sheds or buildings). Students could take some digital photos and compile a photo record, displaying their images in a book or an online photo exhibition.

Experiment
CORROSION OF IRON

Research questions
1 You suspect that iron rusts faster if you are near the coast where the air is salty. Is this true?

2 You have read that if iron is touching another metal it rusts faster or slower, depending on the metal. Is this true?

Design your experiment
1 Work in a small group to design an experiment to answer the two questions above. Use the diagram and the hints below as a guide.

2 Write out the method for your experiment. Make sure your tests are fair. Which variables will you control? Which variable will you change?

3 Make a list of the materials you will need.

4 Discuss how you are going to record your observations. You could use a digital camera to record the corrosion of the nails.

5 Do a risk assessment for your experiment.

Hints
1 Use steel wool to clean the nails, copper and magnesium thoroughly before you start.

2 The copper and magnesium need to be in tight contact with the nail.

3 It is best to continue the experiment for several days, up to a week. You will need to put your experiment somewhere it will not be disturbed.

Discussion
1 Use your results to answer research Question 1—does iron rust more rapidly in salt water? Are your results reliable? Should you do more tests?

2 What effect did the copper have on the rusting of the nail? What effect did the magnesium have?

3 Write inferences to explain why copper and magnesium affect the rusting of iron.

4 Use your results to list the three metals (iron, copper and magnesium) from most reactive to least reactive.

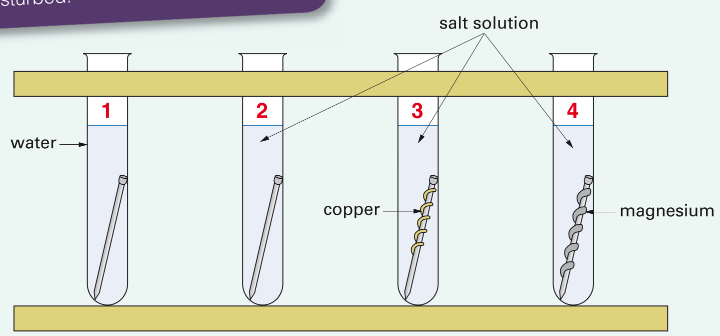
5 If you did the experiment again, could you improve your method? Explain.

6 Can you suggest ways of extending your experiment? Suggest other questions you could investigate.

Write your report
Write a full report of your experiment, using the usual headings. In your conclusion, make sure you answer the two research questions.

Applying what you have learnt
1 Where would you expect iron to rust more rapidly—in a river or in the ocean? Explain.

2 Predict what would happen if you used copper screws in a steel boat in salt water. Explain your prediction.



Lab notes
- Suggest students use distilled water for the control test tube.
- This experiment will result in a lot of test tubes with rust marks in them. These marks can be removed by careful use of concentrated hydrochloric acid. Do this in a fume cabinet or outside the building, as the hydrochloric acid is liable to fume. If time permits, soaking them for longer in weaker acid will achieve the same result.
- This activity will take about a week to give good results.
- Conducting this experiment means that your test tube holders will be unavailable for other uses during this time. You could use alternative holders to sit the test tubes in, such as polystyrene blocks that have been drilled into, empty plastic containers with holes in the lids, or large beakers.
- An additional variable is oxygen, which can be removed by boiling, then excluded with paraffin wax on top of the water.

Hints and tips

Review the concepts covered so far in this chapter. Ask each student to write down about five questions, with answers, on a piece of paper. Allow only a few minutes to do this. Collect the papers, then run a short quiz. You may need to be selective with your questions. Spend no more than about 15 minutes on this activity.

Preventing corrosion

The results of your experiment from the previous page can be explained in terms of how chemically reactive the metals are.

Sodium and gold are both metals. Yet sodium reacts so quickly with air that it has to be stored in kerosene. On the other hand, gold and silver coins can lie on the ocean floor for hundreds of years without corroding. The metals can be arranged in a list with the most reactive at the top and the least reactive at the bottom. This is the **activity series**. It can be used to predict reactions of metals, eg which will react most rapidly with an acid.

Activity series

most reactive

(lose electrons most readily)

potassium	K	$K \rightarrow K^+ + e^-$
calcium	Ca	$Ca \rightarrow Ca^{2+} + 2e^-$
sodium	Na	$Na \rightarrow Na^+ + e^-$
magnesium	Mg	$Mg \rightarrow Mg^{2+} + 2e^-$
aluminium	Al	$Al \rightarrow Al^{3+} + 3e^-$
zinc	Zn	$Zn \rightarrow Zn^{2+} + 2e^-$
iron	Fe	$Fe \rightarrow Fe^{3+} + 3e^-$
tin	Sn	$Sn \rightarrow Sn^{2+} + 2e^-$
lead	Pb	$Pb \rightarrow Pb^{2+} + 2e^-$
copper	Cu	$Cu \rightarrow Cu^{2+} + 2e^-$
silver	Ag	$Ag \rightarrow Ag^+ + e^-$

least reactive

You can see from the activity series that iron is more reactive than copper. So, when iron is in contact with copper in salt solution the iron rapidly loses electrons to form Fe^{3+} and the electrons are transferred to the copper, as in an electric cell. So the iron corrodes more rapidly than normal, and the copper does not corrode.

When the iron is in contact with magnesium, it is the magnesium that loses electrons (because it is more reactive). The magnesium therefore corrodes rapidly and electrons are transferred to the iron, stopping it from corroding. This process is called *sacrificial protection* because the magnesium is sacrificed to protect the iron

Another metal that slows down the corrosion of iron is zinc. Iron used on roofs is coated with zinc or a zinc–aluminium alloy to prevent the iron corroding. This zinc-coated iron is called galvanised iron, and a coloured version is available as *Colorbond*. Because the zinc is more reactive than iron, it slowly corrodes in preference to the iron.

Lumps of zinc or magnesium are often attached to the steel hulls of ships to protect them from rusting. Because zinc is more reactive than the iron, it is corroded in preference to the iron. Once the zinc blocks have corroded they have to be replaced.

Tin cans are made of iron (steel) coated with a thin layer of tin. Tin is a very unreactive metal, so it corrodes very slowly. The inside of the can is often coated with a thin layer of plastic to give extra protection from corrosion. However, if the can is damaged the plastic and tin layers may be

Fig 31 The zinc blocks fitted to this ship corrode in preference to the steel in the hull.

Homework

Ask students to find out some specific facts about corrosion and prepare a fact sheet to share with the class. You could pin the sheets around the room for the students to read. Electronic versions of the fact sheets could be put on the school intranet, or students could record an audio file for others to listen to on MP3 or MP4 players.

Learning experience

Set students a higher order thinking task. For example, ask them to imagine that the activity series was reversed in order, so that silver was the most reactive and potassium the least. Ask them to suggest how our lives might be affected. Allocate brainstorming time, during which students should list a set of questions to answer. They could approach this task using a PMI chart, and record possible consequences. Alternatively, they could use the Jigsaw model, where each member of the team assumes responsibility for a specific section of the problem. Each student is responsible not just for mastering or knowing their component, but for explaining the information to their team members. The team then works cooperatively to put the 'jigsaw' together and complete the problem. Students could give an oral presentation, justifying their explanation.

broken, exposing the iron. Iron is higher on the activity series than tin, so it reacts rapidly with the contents of the can. Poisonous gases may be produced and these may get into the food. So beware of scratched and dented cans.

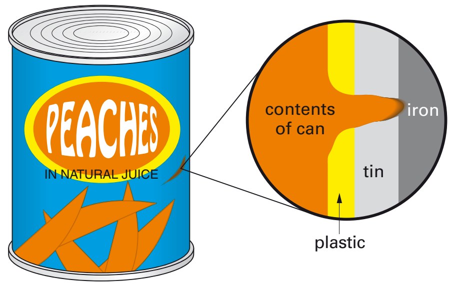


Fig 32 Magnified cross-section of the wall of a damaged tin can. When this happens the contents of the can may react with the iron.

Corrosion of aluminium

Aluminium is a very reactive metal yet it does not seem to need any special protection from corrosion. The secret is a very thin layer of aluminium oxide which forms on the surface of a freshly cut piece of aluminium when it is left in air. This layer of oxide sticks to the aluminium and prevents water and air attacking the uncorroded aluminium underneath. The aluminium has formed its own protective layer. See the diagram below.

To protect the aluminium even more, the oxide layer can be made thicker. This is done by an electrolysis process called **anodising**. The aluminium article is thoroughly cleaned and dipped in a dilute sulfuric acid electrolyte. It is then made the positive electrode (anode) by connecting it to the positive side of a power supply. Hydroxide ions from the water are attracted to the positive electrode where they give up electrons and form oxygen atoms.

$$2OH^- \rightarrow O + H_2O + 2e^-$$

These oxygen atoms then react with the aluminium anode to form aluminium oxide. This oxide coating can be dyed, so aluminium articles can be anodised different colours.

Fig 34 Anodised cups

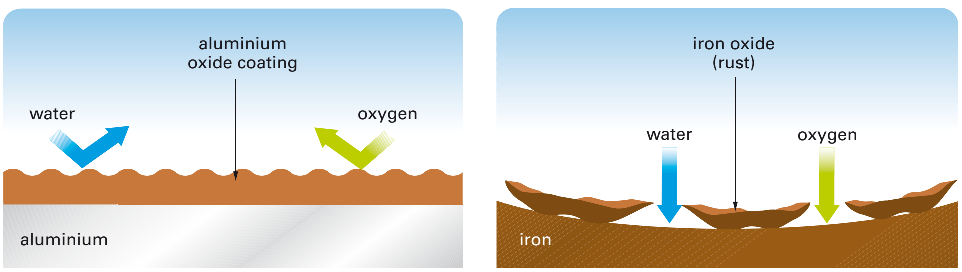


Fig 33 Aluminium oxide forms a protective coating on aluminium, but rust is flaky and does not keep the air and water from the iron underneath.

Hints and tips

Chapter evaluations are always useful for you as a teacher. Have students prepare a half-page evaluation on this chapter. They could reflect on the areas they found interesting, any areas they found challenging and where improvements in their learning could be made. Have students name at least two points or areas that they knew nothing about at the beginning of the chapter, but now do. Encourage them to try to balance their positives and negatives.

Learning experience

Crosswords are always a fun activity. Get students to make their own about this chapter, then swap crosswords with the person next to them and complete them.

Learning experience

Now would be a good time for students to finish the concept map they started at the beginning of the chapter. If the task was given as a pre-test, have them do it again for their post-test.

Learning experience

A good revision tool is to do the following challenge with the class. It takes some teacher preparation time but is well worth it.

1 Prepare four sets of recall or closed-style questions on an A4 sheet of paper divided into quadrants, with one set of questions in each quadrant.
2 Divide the class evenly into four groups, each containing students of mixed abilities, and assign a corner of the room to each group.
3 Each student takes a question sheet, folds it into four so that the first set of questions is showing, then individually answers the question set.
4 Students then swap their question paper with someone from a different group, who will mark it.
5 The marks for each group are tallied on the board. Use a ratio marking scheme if the groups are not all the same size.
6 The students then go back to their corners and complete the second set of questions. The process is repeated until all the question sets are completed.
7 The group with the highest score wins the competition. You may like to give out small prizes, such as stickers or other treats.

Lab notes

- This is an interesting and useful activity if the instructions are followed carefully (especially step 3).
- Reinforce that the suspended piece of aluminium in the centre of the beaker must not touch the aluminium foil.
- 2 M sulfuric acid is very hazardous and small beakers should be used, preferably in trays.
- Gloves, lab coats and safety glasses are essential.

Investigate

30 ANODISING ALUMINIUM

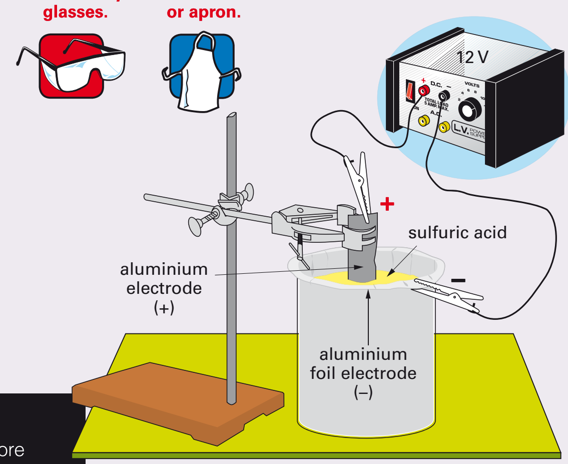
Wear safety glasses. Wear a lab coat or apron.

Aim

To anodise a piece of aluminium.

Materials

- piece of aluminium, eg 5 cm x 1 cm
- aluminium foil
- 2 beakers (100 mL)
- **2M sulfuric acid**  **Corrosive**
- metal tongs
- safety glasses and disposable gloves
- hotplate (or burner, tripod and gauze)
- power pack and connecting wires
- fabric or food dye solution
- stand and clamp
- detergent
- bench mat
- tissues



Planning and Safety Check

- Read the investigation carefully before you start. There are many steps and you will need to be very safety conscious and well organised. You may want to do the investigation as part of a science project on anodising.
- Ask your teacher what you should do with the leftover sulfuric acid.

Method

1 Line a beaker with aluminium foil, then carefully three-quarters fill it with 2M sulfuric acid.

2 Connect the aluminium foil to the negative terminal of the power supply (without allowing the alligator clip to dip into the acid).

3 Thoroughly clean the piece of aluminium to be anodised. Scrub it with warm water and detergent and dry with a tissue. Once cleaned, the aluminium must be handled only with clean metal tongs.

4 Use the stand and clamp to suspend the piece of aluminium in the centre of the beaker *so that it does not touch the aluminium foil.* Connect the piece of aluminium to the positive terminal of the power pack.

5 Turn on the power supply and increase the voltage slowly to 12 volts. Leave for about 15 minutes, then use the tongs to remove the piece of aluminium and wash it in water.

What did you observe during the electrolysis?

How has the aluminium changed?

6 In a second beaker heat a prepared dye solution until it is almost boiling.

7 Immerse the anodised aluminium in the dye solution and leave for 10 minutes, or until the aluminium has a permanent colour.

8 Rinse the aluminium and allow it to cool.

9 Seal the coloured oxide layer by immersing the aluminium in boiling water for 10 minutes.

10 Rinse the aluminium in water and dry it.

Discussion

1 Why do you think it was necessary to clean the aluminium in Step 3?

2 Why shouldn't you touch the aluminium with your fingers after Step 3?

3 Are you happy with your final product? Could you improve your method? How?

Challenge solutions (page 303)

1 You should not use iron screws or nails because they will cause corrosion of the aluminium and a leaking roof. It is better to use aluminium nails or screws.

2 If the air is polluted, some of these chemicals will dissolve in rainwater. This makes the water a better electrolyte, in the same way that salt does. This means that rusting will occur more rapidly.

3 Zinc is a very reactive metal and will react with the food and the water, and perhaps the food in the cans. This would cause a health risk to people eating the food.

4 You can infer that somehow some water and oxygen must have penetrated the paint layer and come in contact with steel in the car body and started the rusting reaction. Once this has started, the rust forms flakes, which lift the paint and form 'bubbles'.

5 a Zinc is a more reactive metal than iron and will lose electrons more easily to form zinc ions. These electrons are then available to the iron atoms, preventing or at least slowing down the rusting process.

b If Sue used a block of lead instead, it would not work because lead is less reactive than iron. It would probably make the iron rust more rapidly.

Check!

1 An iron bar might last 20 years, a bar of aluminium 100 years and a gold bar thousands of years. Why is this so?

2 Use the activity series to place these metals in order from most reactive to least reactive:

copper gold magnesium sodium zinc

3 What is the chemical formula for rust?

4 a Which two substances are needed for rusting to occur?
  b List two things that speed up the rusting of iron.

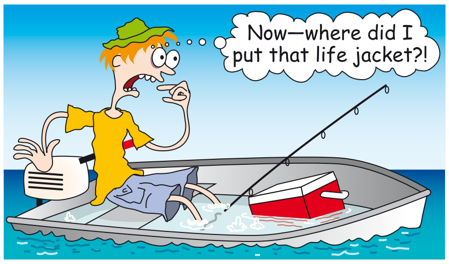
5 How does painting iron and steel prevent it from rusting?

6 What is the process of galvanising? How does it prevent iron from rusting?

7 The Water Board wants to protect its steel pipes from rusting. To do this they want to attach blocks of another metal to the pipes. They are considering three different metals—lead, magnesium and zinc. Which would be the best metal to use? Why?

8 Why does metal guttering on houses near the coast rust more quickly than guttering on houses in inland areas?

9 Alfredo left some lead sinkers in the bottom of his aluminium dingy the last time he went fishing.
  a Write an inference to explain why his boat leaked the next time he used it.
  b Design an experiment to test your inference.



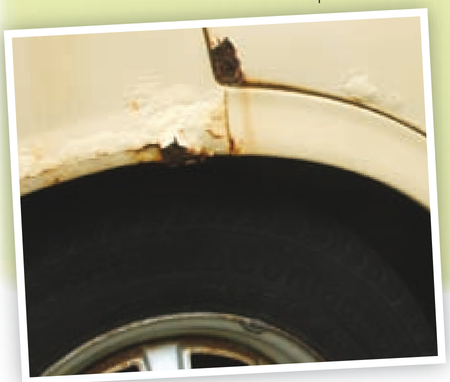
challenge

1 If you were going to put aluminium sheeting on a roof, would you use iron nails? Explain.

2 Why does iron rust more rapidly if the air is polluted?

3 Bethanie wonders why food cans are not covered with zinc, like galvanised iron roofs. Explain why zinc-coated cans wouldn't work.

4 Infer how rust bubbles form under paint.



5 Sue bought an expensive piece of art made from iron. To stop it rusting she attached a small block of zinc to it by wire.
  a How does this prevent the iron art from rusting?
  b Predict what would happen if she used a block of lead instead of zinc.
  c Suggest other ways Sue could stop the art from rusting.

6 When iron rusts what change takes place in the iron atoms? Write an equation.

7 Write a balanced equation for the corrosion of aluminium when it reacts with oxygen. (Hint: the valency of aluminium is 3+.)

8 Look at your results from Investigate 26 showing the voltages produced by different pairs of metals. How can you use the activity series to predict which pair of metals will produce the highest voltage?

9 Design a controlled experiment to compare the rate of corrosion of aluminium, copper and iron indoors and outdoors. If possible, carry out your experiment.

c Another way to stop the rusting would be to paint or spray a thin transparent coating over the iron. You can buy spray cans that can be used to do this.

6 The iron atoms lose electrons and are oxidised as shown in the equation:

$Fe \rightarrow Fe^{3+} + 3e^-$

The rusting of iron is referred to as oxidation because the iron atoms lose electrons. (This is the definition of oxidation.)

7 The balanced equation is:

$2Al + 3O_2 \rightarrow 2Al_2O_3$

8 The voltage produced by the apparatus will depend on the difference in the 'reactivity' of the two metals used. You can predict that the further apart two metals are on the 'reactivity series', the higher the voltage produced.

9 There are many ways to do this but the main thing to remember is that everything should be the same except for the metals used. For example, you could get a sample of each metal and put them close to each other, either inside or outside. Then you could expose them to some water, and possibly salt spray, and carefully observe any changes over several days and weeks.

Check! solutions

1 The reason is that iron reacts with moist air to form rust, which flakes off and reduces the size of the bar over several years. Aluminium, which is more reactive, produces a layer of aluminium oxide. This provides protection against the further action of water and air. Gold, however, is very unreactive and is not affected by air or water.

2 The order is sodium, magnesium, zinc, copper and gold.

3 The chemical formula for rust is Fe_2O_3.

4 a The two substances needed for iron to rust are water and oxygen.
  b Two things that will speed up the rusting of iron are salt water and impurities in the iron. A higher temperature will also speed up rusting.

5 Painting iron and steel prevents rusting because it reduces the amount of water and oxygen coming into contact with the metal surface.

6 The process of galvanising involves coating the iron with a layer of zinc. This prevents the iron from rusting because zinc is a more active metal than iron and will react with oxygen and water and corrode instead of the iron.

7 The best metal to use is magnesium because it is much more reactive than iron (steel) and will corrode more readily. In doing so, it will reduce the corrosion of the steel water pipes.

8 If the house is near the beach, the air and water will contain salt, making it a better electrolyte, which will speed up corrosion. This means that rusting will occur more rapidly.

9 a If a lead sinker is left in water in the bottom of an aluminium boat it will act as a simple cell and electrolysis will occur. The atoms in the aluminium metal will lose electrons to form aluminium ions and the result could be a hole in the boat!
  b A simple experiment could be done by weighing and then placing a lead sinker and a piece of aluminium together in a container of salt water. After several days you could remove, dry and weigh the pieces of metal to see whether the aluminium had lost weight. You should also use a control, which would be a similar piece of aluminium placed in salt water without any lead.

Main ideas solutions

1 cell, electrolyte
2 recharged
3 electrolysis, chemical reactions
4 electroplating
5 electrons, gained
6 oxygen, oxides
7 water
8 activity, reactive

Review solutions

1 B—using the activity series on page 300
2 A—The electroplating solution must contain copper ions.
3 A—will work
B—will not work because the metal strips are the same
C—will not work because distilled water is a poor conductor of electricity
D—will not work because the metal strips are not connected.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 An electric _____ consists of two different conductors (electrodes) immersed in a conducting solution (_____).
2 Most dry cells cannot be _____, but the lead–acid batteries used in cars can be.
3 _____ is the process in which electricity is passed through an electrolyte to cause _____.
4 _____ is an electrolysis process in which a metal is coated with a thin layer of another metal.
5 In an electric cell and in electrolysis, _____ are lost at one electrode (oxidation) and _____ at the other electrode (reduction).
6 Iron and aluminium corrode by reacting with _____ in moist air to form _____.
7 To prevent iron rusting it is essential to stop oxygen and _____ from reaching the metal.
8 The _____ series lists the metals from the most reactive to the least reactive. When two different metals are in contact in moist air or in water, the more _____ metal corrodes.

activity
cell
chemical reactions
electrolysis
electrolyte
electrons
electroplating
gained
oxides
oxygen
reactive
recharged
water

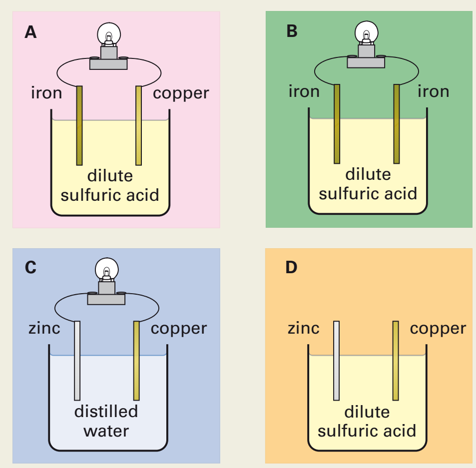
Try doing the Chapter 12 crossword on the CD. Working with technology

REVIEW

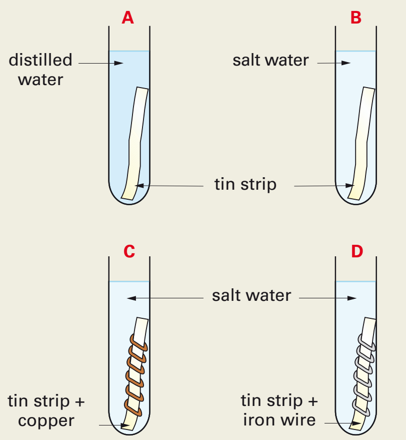
1 Predict which of the following metals will react most rapidly with dilute sulfuric acid.
A aluminium
B magnesium
C lead
D silver

2 To coat a piece of zinc with copper, which liquid would you use in the electroplating bath?
A copper sulfate solution
B zinc sulfate solution
C hydrochloric acid
D distilled water

3 Predict which set-up on the right will act as an electric cell. Explain why each of the other set-ups will *not* work.



4 To investigate the corrosion of metals Allison set up four test tubes as shown below.
   a Use the activity series on page 300 to work out which strip of tin would corrode the most.
   b Which strip of tin would corrode the least? Why?



5 If an electric current is passed between two carbon electrodes placed in concentrated sodium chloride solution, chlorine gas is produced at the positive electrode. Which one of the following inferences best explains why this happens?
   A Chlorine gas is dissolved in the solution, and when an electric current is passed through it, chlorine gas is forced out.
   B Hydrogen ions from the water react with chloride ions to form hydrochloric acid, which in turn forms chlorine gas.
   C When an electric current is passed through water, gases are given off and one of these is chlorine.
   D Negative chloride ions from the solution move to the positive electrode and release electrons to form chlorine gas.

6 List at least three important differences between a car battery and a torch cell.

7 Consider this list of metals and alloys: aluminium, bronze (copper-tin), calcium, gold, iron, magnesium, steel, tin.
   a Three of these are more resistant to corrosion than the others. Which are they?
   b Suggest why each is resistant to corrosion.
   c Which one of the other metals or alloys will corrode most quickly? Explain your answer.

8 Magnesium chloride is melted and electricity passed through the liquid.
   a Which ions will be in the liquid?
   b At which electrode will magnesium metal be formed? Explain your answer.
   c Which element will be formed at the other electrode? Write an ionic equation for the reaction that occurs.

9 The photo below shows an iron pillar in Delhi in central India. It shows little sign of rust, even though it is about 1500 years old. Write at least one inference to explain the absence of rust.

Check your answers on page 339.

REVIEW

4 **a** C—The tin and copper in contact in salt water act like an electrochemical cell. Because the tin is more reactive than copper it corrodes rapidly.
   b D—Because the iron is more reactive than tin, it corrodes in preference to the tin. Hence the tin corrodes only slowly.

5 D

6

Car battery	Torch cell
number of connected cells	single cell
usually 12 volts	usually 1.5 volts
can be recharged	cannot be recharged
contains acid	dry cell (no liquid)
bulky and heavy	compact

7 **a** aluminium, bronze and gold
   b Aluminium forms a protective layer of aluminium oxide (see page 301).
   Bronze is an alloy of copper and tin.
   Gold is a very unreactive metal.
   c Calcium is very reactive and will therefore corrode quickly.

8 The electrolysis of molten magnesium chloride is similar to the electrolysis of molten sodium chloride (see page 295).
   a Magnesium ions Mg^{2+} and chloride ions Cl^-.
   b Magnesium metal will be formed at the negative electrode since the Mg^{2+} ions are attracted to it.
   c The Cl^- ions will be attracted to the positive electrode where they give up electrons to form chlorine gas: $2Cl^- \rightarrow Cl_2 + 2e^-$

9 Some possible inferences are:
   - It is very dry in central India (very little water in the air to cause rusting).
   - The iron is very pure (contains no carbon).
   - The iron has a coating of oil from people's hands which acts as a protective coating.