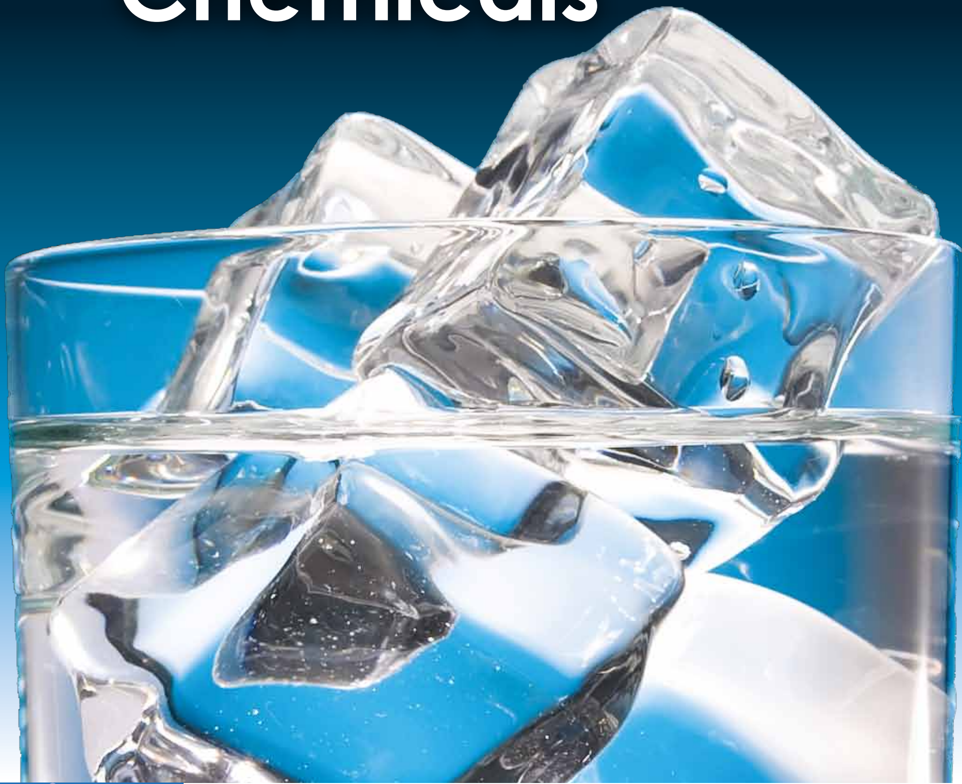
19 Energy from Chemicals



Introduction

Students will already have observed energy changes during reactions, involving, for example, heat, electricity, light and sound and in neutralisation reactions. This chapter formalises such work and leads to an understanding of overall energy change in terms of the energy changes associated with the breaking and making of covalent bonds. In doing this, terms such as *exothermic*, *endothermic*, *enthalpy change* *(heat of reaction)* and *activation energy* are introduced.

Chapter Opener (page 285)

1. Begin the chapter by discussing the following questions. Precise answers are not needed at this stage.

What is the difference between exothermic and endothermic reactions?

Answer: Refer to Section 19.2 in the Textbook.

What are examples of exothermic and endothermic reactions?

Answer: All burning reactions are exothermic. Reactions that require heating are endothermic.

What bonds are broken and what bonds are formed in a chemical reaction? What energy changes take place?

Answer: Consider the burning of hydrogen in oxygen. H – H and O = O bonds are broken and O – H bonds are made in this reaction. When chemical bonds are made, energy is given out. When chemical bonds are broken, energy is absorbed.

Hydrogen does not burn by itself even though it is in contact with air. What is needed to start the reaction?

Answer: An electric spark or a burning splint is needed to start the reaction. This is called activation energy.

2. Carry out an 'Inquiry Preview.'

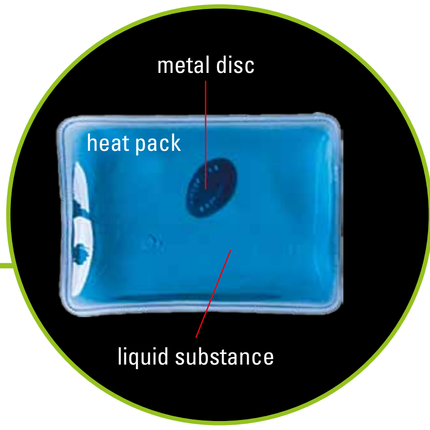
Learning Outcomes

After completing this chapter, you should be able to:

- recognise that reactions can give out or take in energy
- state that during a chemical reaction, bonds and broken and new bonds are formed
- describe the term exothermic and endothermic in relation to processes or reactions in which energy is transferred to or from the environment
- describe the meaning of enthalpy change in terms of exothermic and endothermic reactions
- represent energy changes by energy profile diagrams
- describe bond breaking as an endothermic process and bond making as an exothermic process
- explain overall enthalpy changes in terms of the energy changes associated with the breaking and making of covalent bonds
- construct energy profile diagrams to include activation energy
- describe hydrogen, derived from water or hydrocarbons, as a potential fuel, reacting with oxygen to generate electricity directly in a fuel cell

ChemMystery (page 286)

How does a reusable heat pack work?



Initial Investigation

- Crystallisation
- Heat is produced when the liquid in the pack crystallises.
- To change the solid crystals back into a liquid and to add energy that will be given out again when the heat pack is next used.

Teaching pointers

19.1 What Happens to Energy During a Change? (page 287)

Stimulation

Demonstrate a reaction that gives out a lot of energy. An example is the burning of magnesium in air which gives out heat and light energy. Then, heat copper(II) carbonate to show that some reactions absorb heat when they react.

Skills Practice (page 287)

1. In a physical change, no new substance is formed; there is a change of state only. A chemical change is one in which new substances form.
2. All combustion reactions give out heat. For example, the burning of metals in air, the burning of alkali metals in chlorine and the burning of fuels in air. Neutralisation reactions and reactions of alkali metals with water also give out heat.
3. For example, a reaction container feels hot, we feel the heat from a reaction, we see a flame which indicates heat and we detect a rise in temperature using a thermometer.
4. $CuCO_3(s) \longrightarrow CuO(s) + CO_2(g)$
5. (a) Bonds between atoms in the metal and the O = O covalent bonds in the oxygen molecules are broken.
   (b) Ionic bonds between magnesium ions and oxide ions are made.
6. Energy is absorbed.

Teaching pointers

19.2 What are Exothermic and Endothermic Changes? (page 287)

1. Get students to carry out a word analysis of the terms *exothermic* and *endothermic* and then work out the meanings of these terms (Refer to the textbook margin page 288).
2. Link changes of state to the earlier work in Chapter 3, especially in relation to the energy changes during the change of state.
3. Students investigate heat changes in Experiment 19.1 of the Practical Workbook. If this is not done as a class experiment, demonstrate some of the reactions and get students to take note of the heat changes.
4. When dissolving solid anhydrous sodium carbonate and ammonium chloride in water, a noticeable temperature change is observed if the ratio of solid to water is about 2:1. After mixing, stopper the tube and shake to dissolve the solid. The sodium carbonate tube feels hot while the ammonium chloride tube feels quite cold. The thermometer readings will confirm the temperature changes.
5. *Endothermic* reactions are rare as they absorb heat, the temperature falls and the reaction slows down. The reaction will eventually stop unless heat is provided from outside. A fuller explanation relates to the free energy change, ΔG, but this is beyond the scope of students at 'O' Level.
6. Some other examples of exothermic reactions are:
   - Reactions of metals with water (page 193 of the Textbook).
   - Reactions of metals and acids (page 194 of the Textbook).
   - Reaction of sodium with chlorine (pages 85–86, 180 of the Textbook).
   - Haber Process reaction (page 262 of the Textbook).
7. Some other examples of endothermic reactions are:
   - Electrolysis (Chapter 22).
   - Reaction of carbon dioxide with carbon to produce carbon monoxide in the blast furnace (page 210 of the Textbook).

Skills Practice (page 290)

1. **(a)** Endothermic **(b)** Exothermic **(c)** Exothermic **(d)** Endothermic

(page 287)

Mystery Clue

The pack feels hot because heat is given out as the substance crystallises. To renew it for future use, the pack is placed in boiling water; the substance in the pack absorbs energy as it changes from a solid to a solution again.

Teaching pointers

19.3 How Can Enthalpy Changes be Represented? (page 291)

Ensure students can understand the way positive and negative signs are used for energy change and can link this with the energy difference between the reactants and products. Some students have the misconception that when energy is given out, it is added to the environment and so the sign must be positive.

(page 291)

Mystery Clue

The reactants lose energy. The energy level diagram would the same as for the exothermic change in Figure 19.10.

Skills Practice (page 292)

1. (a) Exothermic. (Neutralisation reactions give out heat.)
   (b) Heat energy obtained = (2 × 114) kJ = 228 kJ (assuming it reacts with 4 moles of NaOH).
2. (a) $2Al(s) + Fe_2O_3(s) \longrightarrow 2Fe(l) + Al_2O_3(s)$
   (b) Exothermic, as a lot of heat energy is given out.
   (c) Negative, as this is an exothermic reaction and the energy of the products is less than the energy of the reactants.

Teaching pointers

19.4 How are Chemical Bonds Related to Heat Energy? (page 292)

1. An analogy using magnets could be used to illustrate the breaking of bonds. Begin with two magnets attached to each other to represent a (diatomic) molecule. Separating the magnets requires energy and is analogous to bond breaking.
2. Again, you may use the overhead transparency and coloured transparent plastic discs representing atoms to simulate the bond breaking and bond-making process as shown in Figure 19.13 on page 293 of the Textbook.

(page 292)

Mystery Clue

During crystallisation, bonds form between the molecules in the liquid. When heat is added during the renewal process, the bonds between the particles in the solid break.

Skills Practice (page 294)

1. (a) Exothermic – energy is given out.
   (b) ΔH is negative as the products of the reaction have less energy than the reactants.
2. (a) Endothermic – energy is absorbed
   (b) ΔH is positive as the products of the reaction have more energy than the reactants.
3. (a) Exothermic (bond making)
   (b) Endothermic (bond breaking)
   (c) Exothermic (bond making)
   (d) Endothermic (bond breaking)
4. (a) The H – H and C*l* – C*l* covalent bonds are broken.
   (b) Two H – C*l* covalent bonds are made.
   (c) More energy is given out in making the two H – C*l* bonds than is taken in when breaking the H – H and C*l* – C*l* bonds.
   Note: Remind students that hydrogen chloride (a gas) contains the H – C*l* covalent bond.

Teaching pointers

19.5 What is Activation Energy? (page 294)

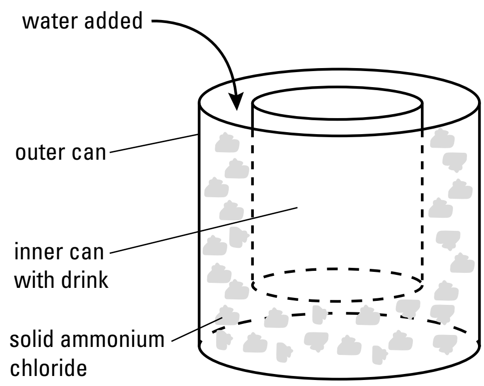
1. To introduce the idea of activation energy, hold up a non-safety or 'strike-anywhere' match (the type used in survival kits for camping). Pose this question to the class: Why does the match not light up?

   Discuss the idea that although the match is in contact with the oxygen in the air which is needed for it to burn, it still needs energy to begin the reaction. Then ignite the match and interpret what has happened using the energy level diagram in Figure 19.15 on page 295 of the Textbook.
2. You may use a safety match instead. In this case, the friction produced when the match is scraped against the matchbox produces the heat energy needed to light the match.
3. Demonstrate the use of a spark to ignite Bunsen burner gas as in Figure 19.17 on the Textbook. In this case, the heat from the electric spark provides the energy to start the burning. Igniting the gas with a burning splint or match does not make the point as clearly as students know that 'fire spreads.'

Additional Exercise 1: Designing a 'Self-cooling' Soft Drink Can

An additional exercise is provided at the end of this chapter in which students can work in groups to design a method of keeping cans of drink cool when no refrigerator or ice is available. This design is essentially the reverse of the purpose of the heat pack in the Chem Mystery. The worksheet may be photocopies and distributed to the class.

Two cans are needed such that one of them fits inside the other. Solid ammonium chloride is placed between the two cans. When water, which can be obtained from a stream, is added to the ammonium chloride, the solid dissolves. As this is an endothermic reaction, the temperature is lowered. This cools the inner drink can.



Skills Practice (page 296)

1. The heat energy needed to ignite the chemicals in the match head comes from friction when the match is rubbed on the side of the matchbox.
2. The covalent bond in the N_2 molecule must be very strong.
   Note: This is why nitrogen gas is unreactive.
3. The heat energy from the flame is needed to supply the activation energy to break the H – H and O = O bonds in hydrogen and oxygen respectively.

Notes for Teachers

The need for activation energy
Almost all reactions need activation energy to break the bonds in the reacting molecules. They get this energy from the kinetic energy of the molecules when they collide. However, there is usually not enough kinetic energy available when the molecules collide (e.g. when oxygen molecules collide with the match head), so no reaction takes place. This is why the match head must be heated up by friction. The heat provides the activation energy for some molecules to react and the heat given out in the reaction can then be used by other molecules in their reactions.

Note: 'Safety' matches have a chemical on the box so they will not ignite by friction alone, but this does not affect the argument that if you supply enough heat the match will still catch fire.

Teaching pointers

19.6 How is Hydrogen Used as a Fuel? (page 297)

1. Ensure students appreciate that the burning of hydrogen in air and the reaction between hydrogen and oxygen in a fuel cell are both exothermic reactions with heat energy being produced in the former and electrical energy in the latter.
2. The first fuel cell was made in 1839. Modern fuel cells were developed by NASA in the 1950s and 1960s for use in spacecraft. Many kinds of fuel cells have been made. Besides hydrogen, propane and methanol have been used as fuels.
3. Singapore is one of several countries in which fuel cells are being tested in cars. The Singapore government is encouraging these trials as it seeks to find alternatives to conventional vehicles, which add pollutants to the air.

Skills Practice (page 299)

1. (a) Both are endothermic reactions as energy is given out.
   (b) Similarities: Hydrogen and oxygen react, energy is given out. Differences: In burning, heat is produced whereas in a fuel cell, electricity is produced.
2. Large amounts of hydrogen and oxygen can be produced by the electrolysis of water using electricity generated by solar power (refer to page 352 of the Textbook).
3. Oxygen comes from the atmosphere.
4. Five alternative fuels have been mentioned, namely: The sap from Copaiba tree and palm oil as alternatives to diesel, ethanol and gasohol as alternatives to petrol and hydrogen as a vehicle fuel and for fuel cells.

Chemistry in Society (page 299)

Uses of Fuel Cell Technology in Singapore

Exercise

1. Reduce air pollution, conserve petroleum, reduce noise pollution (electric motors are quieter than petrol engines), to adopt efficient energy-producing technologies.
2. The only reaction in the fuel cell is between hydrogen and oxygen.
3. *Advantages*: Reduces air pollution caused by burning fossil fuels; can be used in areas without mains electricity; if the hydrogen used comes from the electrolysis of water, then using fuel cells eliminates greenhouse gases; fuel cells operate quietly.

   Disadvantages: At present they are still expensive; there are few hydrogen filling stations; hydrogen is flammable (but so is petrol!).

   The following website provides information on fuel cells, their history, applications and benefits:

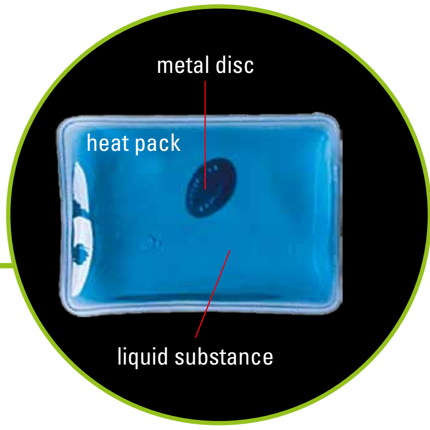
   http://www.fuelcelltoday.com/about-fuel-cells/introduction

Notes for Teachers

Demonstrating a fuel cell
A simple fuel cell can be demonstrated using the apparatus shown in Figure 19.21. However, it is only possible if schools have hydrogen electrodes and cylinders of hydrogen and oxygen. The hydrogen and oxygen should be bubbled through the solution at about 1 – 2 bubbles per second. Connect a high-resistance voltmeter to the two electrodes.

Apparatus and chemicals
Safety spectacles
1 beaker (400 – 500 cm^3)
2 hydrogen electrodes (platinum black electrodes)
2 connecting wires with crocodile clips
1 high resistance voltmeter
hydrogen cylinder
oxygen cylinder
connecting tubing
sodium hydroxide solution (2 mol/dm^3), 200 – 250 cm^3

Solving the Mystery (page 300)



How does a reusable heat pack work?

The sodium ethanoate heat pack works from the changes in energy during changes of state. When the sodium ethanoate in the solution changes into a solid, heat energy is given out. When it changes back to a solution, heat energy is absorbed. Such a heat pack is reusable. Single use heat packs usually involve the mixing of two chemicals that react to produce heat. Once the chemicals have reacted, they cannot be changed back again. For the design of a simple disposable heat pack, refer to Experiment 19.1B in the Practical Workbook.

Infer
No. Cold packs are essentially the reverse of heat packs. When in use, a (chemical) reaction absorbs heat energy from the surroundings to keep the environment cool.

Connect
Heat packs are used by athletes to minimise swelling of injuries such as muscle and joint sprains and to warm ourselves when the weather is cold. Useful energy changes can, for example, generate light in a light stick or aid in super glue setting by forming very strong bonds between the surfaces to be glued together.

Further Thought
They need to be boiled for them to be reused; they are expensive; the exothermic reaction does not last for a long period.

IT Link

How the sodium ethanoate heat pack works

http://www.howstuffworks.com/question290.htm

http://www.howstuffworks.com/framed.htm?parent=question290.htm&url=http://thermo-pad.com/faq.htm%20

19 Chapter Review

Self-Management

Misconception Analysis (page 301)

1. **False** Physical reactions can also involve changes in heat energy. For example, when sodium carbonate dissolves in water, heat is given out.

2. **False** As heat is given out in an exothermic reaction, the products have less energy than the reactants.

3. **True** Bond forming is always endothermic and bond breaking is exothermic.

4. **True** The activation energy is different for different reactions. If it is high, a lot of energy (usually heat) is needed to start the reaction (but not to keep it going).

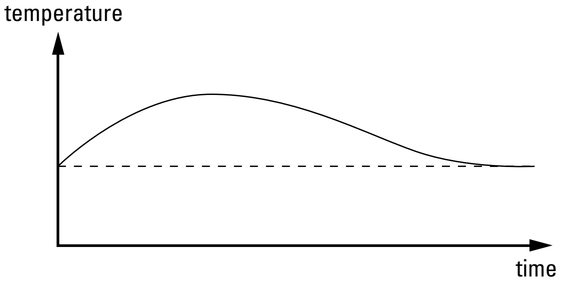
Practice

Structured Questions (page 302– 303)

1.

Change	Type of change
1. Forming a covalent bond	exothermic
2. Mixing hydrogen and oxygen together	no heat change
3. Reacting hydrogen with oxygen	exothermic
4. Forming chlorine atoms from chlorine molecules	endothermic
5. Forming bromine vapour from liquid bromine	endothermic
6. Reacting sodium with cold water	exothermic

2. (a) Graph A
   (b)

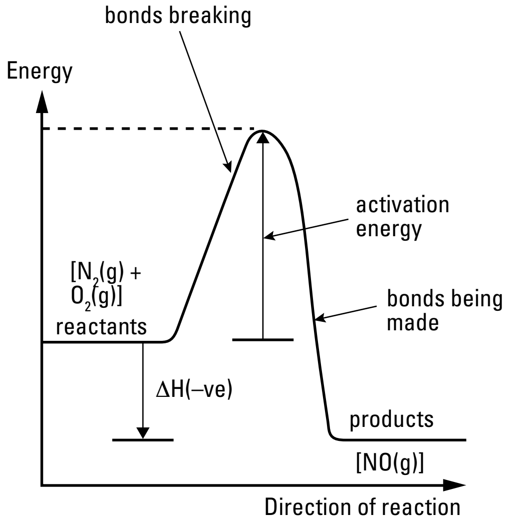


3. (a) Exothermic, as it is a combustion reaction.
   (b) (i) C – H, C – C and C – O covalent bonds are broken.
       (ii) C = O and O – H bonds are formed.
   (c) (i) M_r of ethanol = 2(12) + 6(1) + 16
       = 46
       (ii) Number of moles of 1.00 g of ethanol
       = 1 ÷ 46 = 0.0217
       ΔH for the reaction = 30 ÷ 0.0217 = 1380 kJ/mol

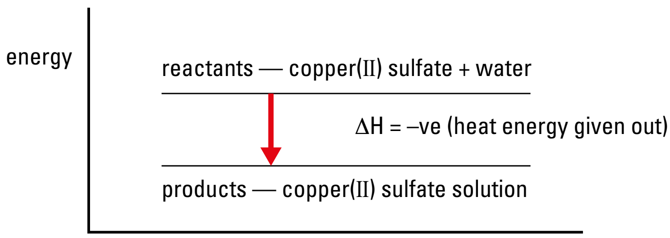
4. (a) Exothermic, because ΔH is negative.
   (b) Amount of heat energy given out in producing
   1 mole of iron = 27 ÷ 2
   = 13.5 kJ
   (c) (i) Number of moles of iron produced = 27 000 ÷ 13.5
       = 2000 moles
       (ii) Mass of iron produced = 2000 × 56
       = 112 000 g or 112 kg

5. **Note:** Before attempting part (b), remind students that the equation in part (a) contains 2 moles of CH_3OH and not 1 mole.
   (a) $2CH_3OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 4H_2O(l)$
   (b) ΔH for the equation above = 2 (–715)
   = – 1430 kJ/mol
   (c) (i) Relative molecular mass of CH_3OH = 12 + 3 + 16 + 1
       = 32
       Number of moles of methanol = 400 ÷ 32
       = 12.5 moles
       (ii) Heat obtained = 12.5 × 715
       = 8937.5 kJ
       = 8940 kJ (to 3 significant figures)

6. (a) $N_2(g) + O_2(g) \longrightarrow 2NO(g)$
   (b) The reaction gives out heat energy, as it is exothermic.
   (c) The reactants have more energy, as energy is given out
   (d) (i) The covalent bonds in the N_2 and O_2 molecules are broken.
       (ii) The covalent bonds between the N and O atoms in NO are formed.
   (e)



7. (a) (i) It is an exothermic reaction.
       (ii) Calcium chloride.
   (b) The noodles would become cooler as the reaction between ammonium nitrate and water is endothermic.
   (c)



Free Response Questions (page 303)

1. Responses to this question may include the following points:
   - The reaction occurs when the reactants are heated to a high temperature (and under high pressure).
   - The heat added provides the activation energy needed to break the bonds in the N_2 and H_2 molecules before new bonds can be formed. As heat energy is absorbed, this bond breaking is an endothermic process.
   - New bonds are formed between the N and H atoms to produce NH_3 molecules. Bond making is exothermic, that is, heat energy is given out.
   - As ΔH, the heat of reaction, is negative, the overall reaction is exothermic. Therefore, the heat given out in making bonds is greater than the heat absorbed in breaking bonds. Some of this extra heat is used as activation energy to keep the N_2 and H_2 molecules reacting.

2. Responses to this question may include the following points:
   - As the activation energy for the reaction is high, the energy from collisions between the nitrogen and oxygen molecules is insufficient for bond breaking and there is no reaction.
   - If the activation energy for this reaction was small, the energy from collisions would be sufficient for the nitrogen and oxygen molecules to react. Therefore, the reaction would occur spontaneously.
   - As air contains less oxygen than nitrogen, all the oxygen would react with nitrogen to produce nitrogen oxides. After some time, there would be no oxygen remaining in the air.

Note: A more rigorous response may include a discussion on the chemical reactions involved.

$N_2(g) + O_2(g) \longrightarrow 2NO(g)$ (nitrogen monoxide — colourless)
$2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$ (nitrogen dioxide — brown)

Overall, 2 volumes of oxygen are needed to react with every 1 volume of nitrogen, that is, in the ratio 2:1. However, the volume ratio of oxygen to nitrogen in the air is only about 1:4. As more oxygen than nitrogen reacts, eventually all the oxygen in the air will be used up.

Extension (page 303)

1. **Heat from Reacting Metals**
   (a) 1. Weigh out equal masses of each metal (lithium, sodium and potassium).
   2. Put 500 cm^3 of water into a large beaker and measure its temperature.
   3. Add the piece of lithium to the beaker. Record the new temperature when the reaction is completed.
   4. Repeat the experiment with another 500 cm^3 of water, but now add the piece of sodium.
   5. Repeat the experiment with another 500 cm^3 of water, but now add the piece of potassium.
   (b) The volume of water used should be kept constant.
   (c) Calculate the temperature rise in each experiment. Put the temperature rises in descending order. The larger the temperature rise, the greater is the amount of heat produced. The temperature rises should be in the order (from greatest to smallest): potassium; sodium; lithium.

   Note: This is the order of reactivity of the metals stated on page 195 of the Textbook.

2. **Comparing Reactions on Two Planets**
   (a) Methane would have to be stored in air-free containers. No flame or spark would be needed to ignite it as it would catch fire spontaneously upon release into the air.
   (b) (i) All chemical reactions would happen the moment the chemicals are mixed so it would be easy to make substances, Less time would be needed to make substances.
   (ii) It would be a strange place to live as there would be no paper or wood (they would catch fire in air immediately). It would also be a dangerous place as spontaneous reactions could happen whenever chemicals come into contact. For example, magnesium would have to be stored under oil as it would catch fire immediately in air.

Additional Teaching Material

Additional Exercise 1: Designing a 'Self-cooling' Drink Can

Objectives

- To design a 'self-cooling' soft drink can for use when no ice or refrigerators are available

Key Competencies

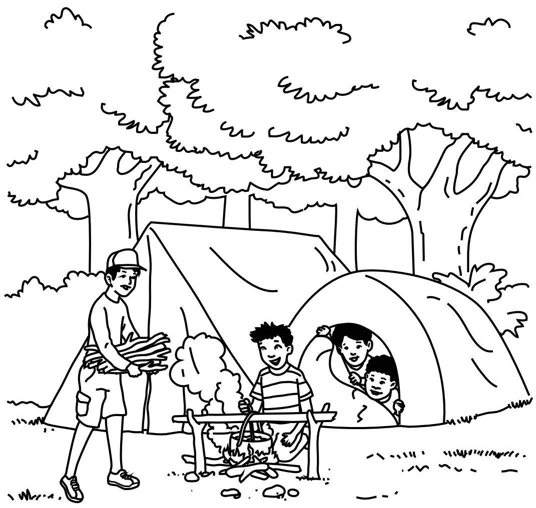
CIT: reflective thinking, creativity [*designing an object*]
ICS: communicating effectively [*collaborating with other*], openness [*willingness to receive, explore and respond to opinions, peer review*]

In the middle of the 20th century, self-heating cans of soup were invented. They were used by the crew of unheated high altitude aircraft. They are not needed in the 21st Century as the cockpits of aircraft are now pressurised and heated. Later, the self-cooling drink can was invented. Several different methods are used to cool the drink.

You are to design a 'self-cooling' soft drink can which could be used on a camping trip to Pulau Ubin, where there are no refrigerators and there is no ice available.

The basic idea is to use endothermic reactions to cool a can. The design must have the features listed below:

- Any chemicals you use must not get mixed with the actual drink.
- It must be simple to use.
- The only substance you can add to the can during the camping trip is water from a stream.



1. In your groups, discuss how you will design the drink can. Describe your design and if it is helpful, include a diagram of your design.

2. Share your design with another group and get them to comment on it and suggest ways to improve it. Then modify your design.

3. Prepare a short talk (3 to 4 minutes) to present your group's design to the class. This can be given by one member of your group or by several members.

Additional Teaching Material

Additional Exercise 2: Use of Mapping

Objectives

- To create a mind map

Key Competencies

CIT: self awareness [*reflect on learning*]
ICS: communicating effectively [*use of mapping software, collaborating with others*], openness [*willingness to receive, explore and respond to opinions, peer review*]

1. In the space below, construct a mind map on 'Energy from Chemicals'. You may use words, pictures and colour. Here are some ideas you might include in your mind map:

exothermic reaction and endothermic reaction and examples of each, enthalpy change, energy level diagram, heat of reaction, bond enthalpy, activation energy, fuel cells

Energy from Chemicals

2. **(a)** Get a classmate to comment on your mind map. At the same time, comment on your classmate's mind map and suggest how it might be improved.

(b) From your classmate's comments and suggestions, revise your mind map. Then use mapping software to draw and print the revised version.