

# Mastering Chemistry

- Book      3C
- Topic 8      Chemical Reactions  
and Energy



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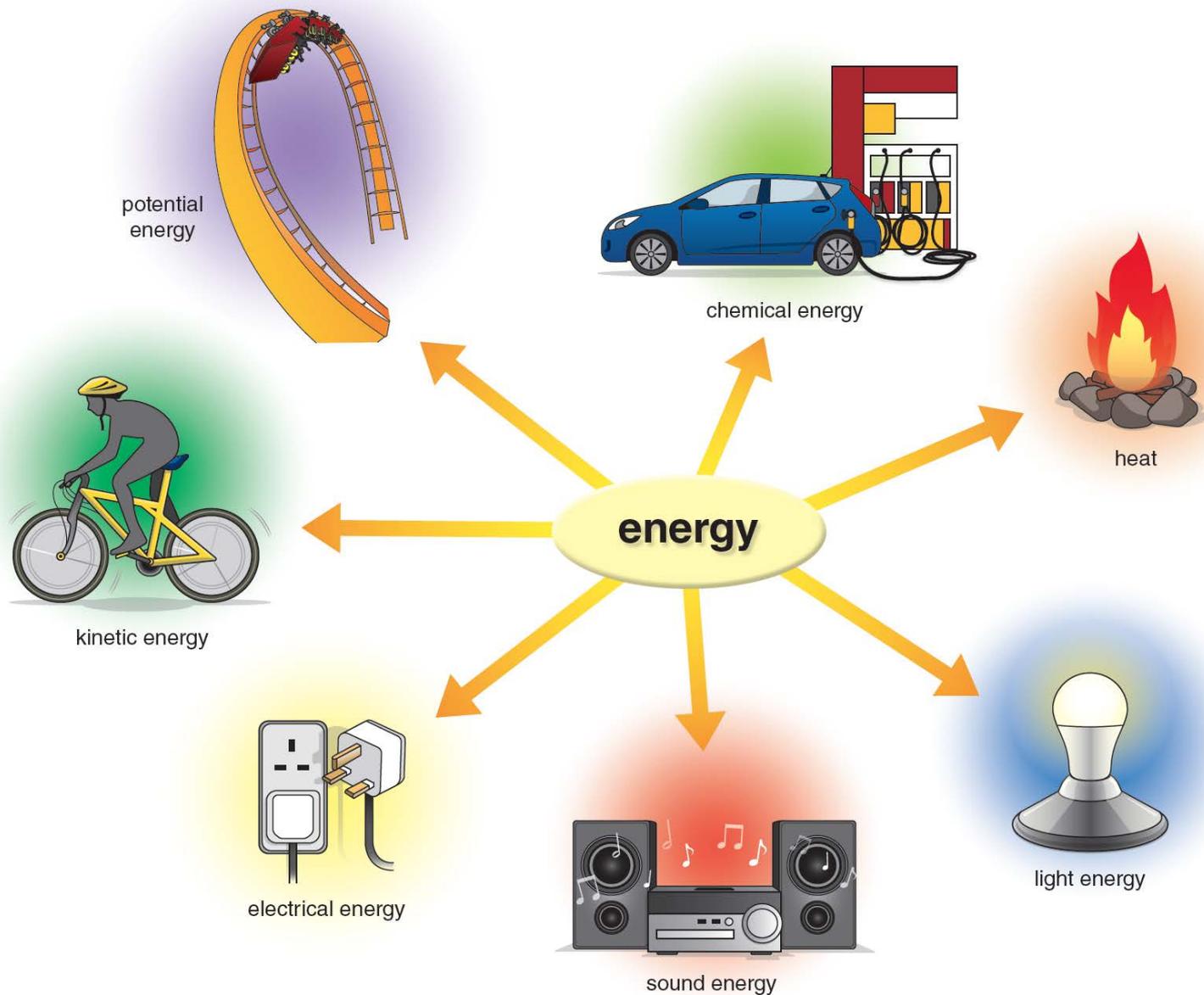
## Content

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## 34.1 What is energy (p.2)

- ◆ Energy is the capacity to transfer heat or to do work.
- ◆ Common forms of energy include heat, light energy, sound energy, electrical energy, kinetic energy, potential energy and chemical energy.
- ◆ The unit of energy is the **joule (焦耳)**, symbol J.





## 34.2 Heat capacity and specific heat capacity (p.3)

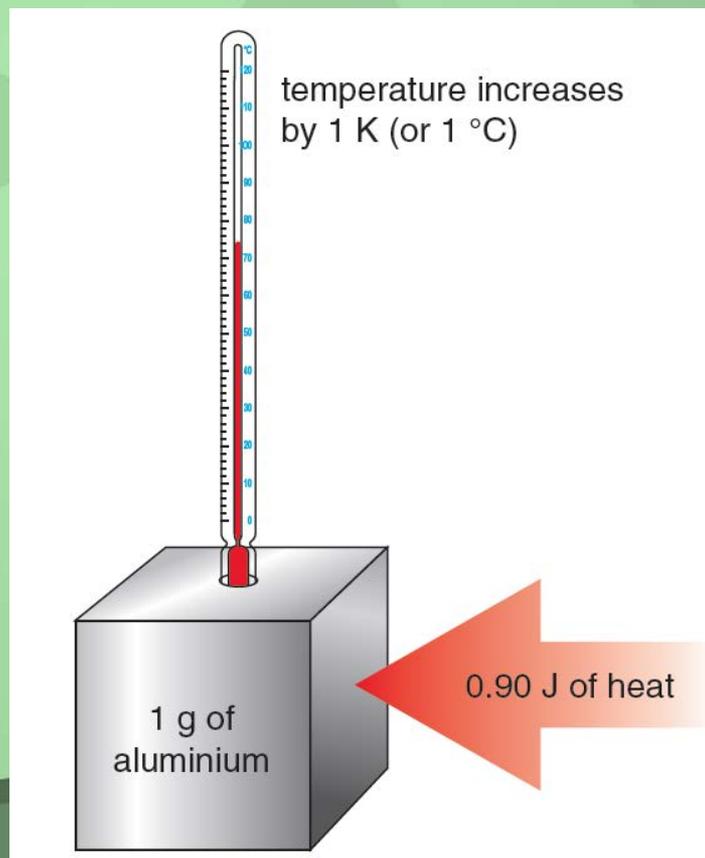
- ◆ The amount of heat required to change the temperature of a substance depends on what the substance is, how much of it is heated and the temperature rise aimed at.
- ◆ The heat required to raise the temperature of a substance by 1 K (or 1 °C) is called the **heat capacity** (熱容量) of the substance. Heat capacity is expressed in the units of joule per Kelvin,  $\text{J K}^{-1}$ .
- ◆ However, a more useful quantity is the heat required to raise the temperature of 1 g of substance by 1 K (or 1 °C).



## 34.2 Heat capacity and specific heat capacity (p.3)

The **specific heat capacity** (比熱容), symbolised  $c$ , of a substance is the amount of heat required to raise the temperature of 1 g of the substance by 1 K (or 1 °C).

- Specific heat capacity is expressed in the units of joule per gram per Kelvin,  $\text{J g}^{-1} \text{K}^{-1}$ .





## 34.2 Heat capacity and specific heat capacity (p.3)

- ◆ The lower the specific heat capacity of a substance, the greater is its temperature rise for the same amount of heat taken in.
- ◆ Good conductors of heat, such as metals, have small values of  $c$ . In most experiments, you will be measuring the temperature change of water or aqueous solutions.

For water,  $c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$ .

**amount of heat required**

**= mass x specific heat capacity x temperature change**

**=  $m \times c \times \Delta T$**

where  $\Delta T$  is the temperature change

( $\Delta T = T_f - T_i = \text{final temperature} - \text{initial temperature}$ )



## 34.2 Heat capacity and specific heat capacity (p.3)

### Q (Example 34.1)

Calculate the amount of heat required to increase the temperature of 100.0 cm<sup>3</sup> of water from 17.6 °C to 50.4 °C.  
(Density of water = 1.00 g cm<sup>-3</sup> ; specific heat capacity of water = 4.18 J g<sup>-1</sup> K<sup>-1</sup>)

### A

$$\text{Mass of water} = 100.0 \text{ cm}^3 \times 1.00 \text{ g cm}^{-3} = 100.0 \text{ g}$$

$$\Delta T = (50.4 - 17.6) \text{ }^\circ\text{C} = 32.8 \text{ }^\circ\text{C} \text{ (or } 32.8 \text{ K)}$$

$$\text{Amount of heat required} = m \times c \times \Delta T$$

$$= 100.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times 32.8 \text{ K}$$

$$= 13\,700 \text{ J}$$

$$= 13.7 \text{ kJ}$$

∴ 13.7 kJ of heat are required.



## 34.2 Heat capacity and specific heat capacity (p.3)

### Practice 34.1

1 What is the amount of heat required to raise the temperature of 50.0 g of water from 0 °C to 100 °C?

(Specific heat capacity of water = 4.18 J g<sup>-1</sup> K<sup>-1</sup>)

Amount of heat required =  $m \times c \times \Delta T$

= 50.0 g x 4.18 J g<sup>-1</sup> K<sup>-1</sup> x 100 K

= 20 900 J

= 20.9 kJ

2 208 J of heat raise the temperature of 15.0 g of copper from 25.0 °C to 60.7 °C. What is the specific heat capacity of copper?

Let  $c$  be the specific heat capacity of copper.

Amount of heat = 208 J =  $m \times c \times \Delta T$

= 15.0 g x  $c$  x (60.7 – 25.0) K

$c = 0.388 \text{ J g}^{-1} \text{ K}^{-1}$



## 34.2 Heat capacity and specific heat capacity (p.3)

- 3 The initial temperature of 150.0 g of ethanol is 22.0 °C. The ethanol takes in 3 220 J of heat. What is the final temperature of the ethanol?  
(Specific heat capacity of ethanol = 2.41 J g<sup>-1</sup> K<sup>-1</sup>)

$$\text{Amount of heat} = 3\,220 \text{ J} = m \times c \times \Delta T$$

$$= 150.0 \text{ g} \times 2.41 \text{ J g}^{-1} \text{ K}^{-1} \times \Delta T$$

$$\Delta T = 8.9 \text{ K}$$

$$\therefore \text{final temperature} = (22.0 + 8.9) \text{ }^\circ\text{C}$$

$$= 30.9 \text{ }^\circ\text{C}$$

- 4 How much heat is released when 3.00 kg of lead cool from 1 000 °C to 398 °C?  
(Specific heat capacity of lead = 0.160 J g<sup>-1</sup> K<sup>-1</sup>)

$$\text{Amount of heat released}$$

$$= m \times c \times \Delta T$$

$$= 3.00 \times 1\,000 \text{ g} \times 0.160 \text{ J g}^{-1} \text{ K}^{-1} \times (1\,000 - 398) \text{ K}$$

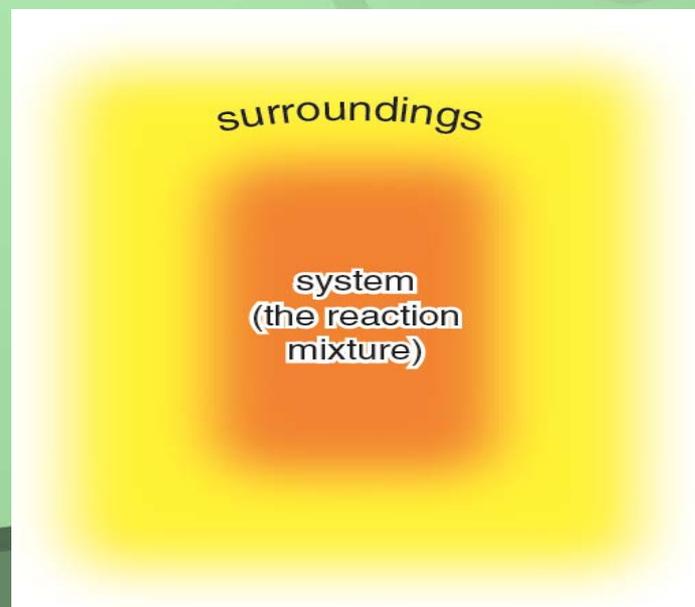
$$= 289\,000 \text{ J}$$

$$= 289 \text{ kJ}$$



## 34.3 Conservation of energy (p.6)

- ◆ The law of **conservation of energy** (能量守恆) states that energy cannot be created or destroyed. It can only be converted from one form to another.
- ◆ A chemical reaction in general is accompanied by an energy change involving transfer of energy between the **system** (體系) and its **surroundings** (外界). The system refers to the reaction mixture. Everything outside of the system is called the surroundings.





## 34.3 Conservation of energy (p.6)

- ◆ Consider the decomposition of sodium azide ( $\text{NaN}_3$ ) inside safety airbags installed in vehicles.



- ◆ The decomposition is set off by a small amount of electrical energy. Heat is produced, which is transferred to the surroundings and raises the temperature, as sodium azide loses energy. The nitrogen gas produced in the reaction does work by filling the airbags so as to protect the driver and the passengers.





## 34.3 Conservation of energy (p.6)

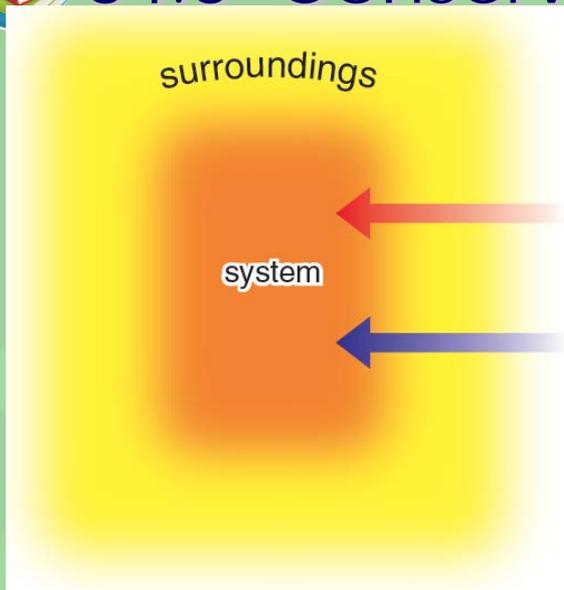
- ◆ Energy transfer can be done in one of the two ways:
  - heat ( $q$ ) can flow from the system to the surroundings (or vice versa); or
  - work ( $w$ ) can be done by the system on the surroundings (or vice versa).

### Internal energy of a system

- ◆ The **internal energy** (內能) of a system is the sum of the kinetic and potential energies of the particles that form the system.
- ◆ For a reaction, the relationship between the change in internal energy of the system, and the heat and work exchange of the system with the surroundings is:  $\Delta E = q + w$ .



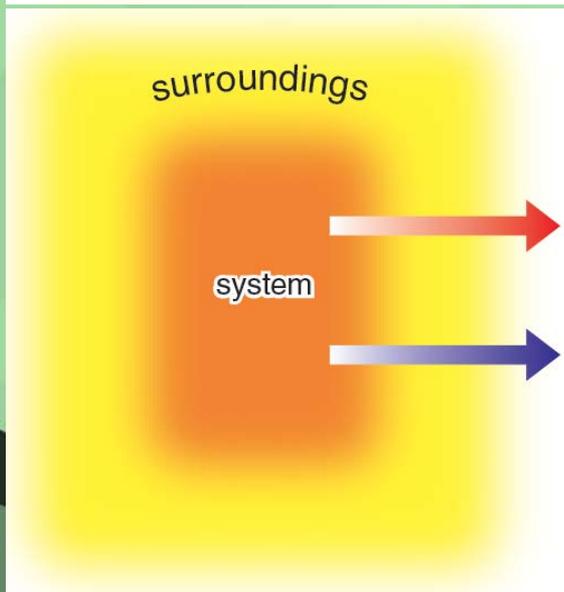
## 34.3 Conservation of energy (p.6)



heat ( $q > 0$ ), i.e. heat taken in by system

work ( $w > 0$ ), i.e. work done on system

$\Delta E > 0$ , i.e. system gains energy from surroundings



heat ( $q < 0$ ), i.e. heat released by system

work ( $w < 0$ ), i.e. work done by system

$\Delta E < 0$ , i.e. system loses energy to surroundings



## 34.4 Enthalpy changes (p.8)

- ◆ All the chemical reactions that are discussed in this topic are carried out in containers that are open. This means that they take place at constant pressure (1 atm). The heat released or taken in by a system kept at constant pressure is given a special name, **enthalpy change** (焓變), symbolised  $\Delta H$ .

**An enthalpy change,  $\Delta H$ , is the heat released or taken in during any change in a system, provided that the system is kept at constant pressure.**



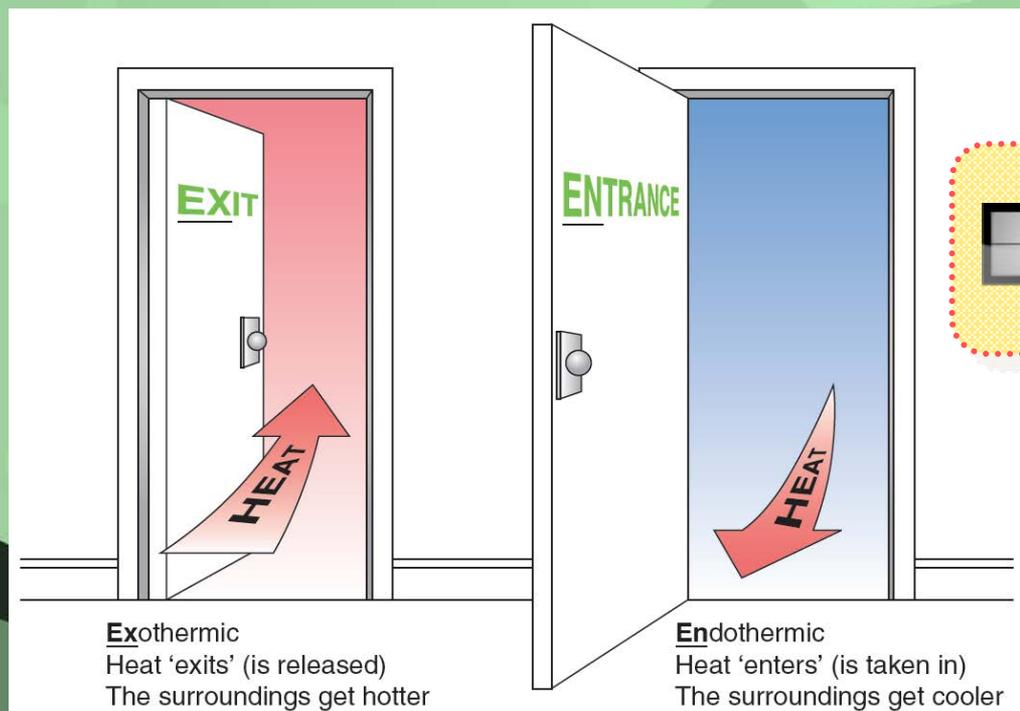
## 34.4 Enthalpy changes (p.8)

- ◆ The enthalpy of a substance, sometimes called its heat content, is an indication of its energy content. Absolute enthalpy values cannot be found. The only value that can be measured is the change in enthalpy when a reaction or a physical change takes place. ( $\Delta H = H_{\text{products}} - H_{\text{reactants}}$ )
- ◆ The difference between the enthalpy change ( $\Delta H$ ) and internal energy change ( $\Delta E$ ) is usually small in most cases. Thus, the value of  $\Delta H$  can give a very good indication of the internal energy change of a system during a reaction.



## 34.5 Exothermic and endothermic reactions (p.8)

- ◆ In an **exothermic** (放熱) reaction, a system releases heat to the surroundings—the surroundings get hotter.
- ◆ In an **endothermic** (吸熱) reaction, a system takes in heat from the surroundings—the surroundings get cooler.



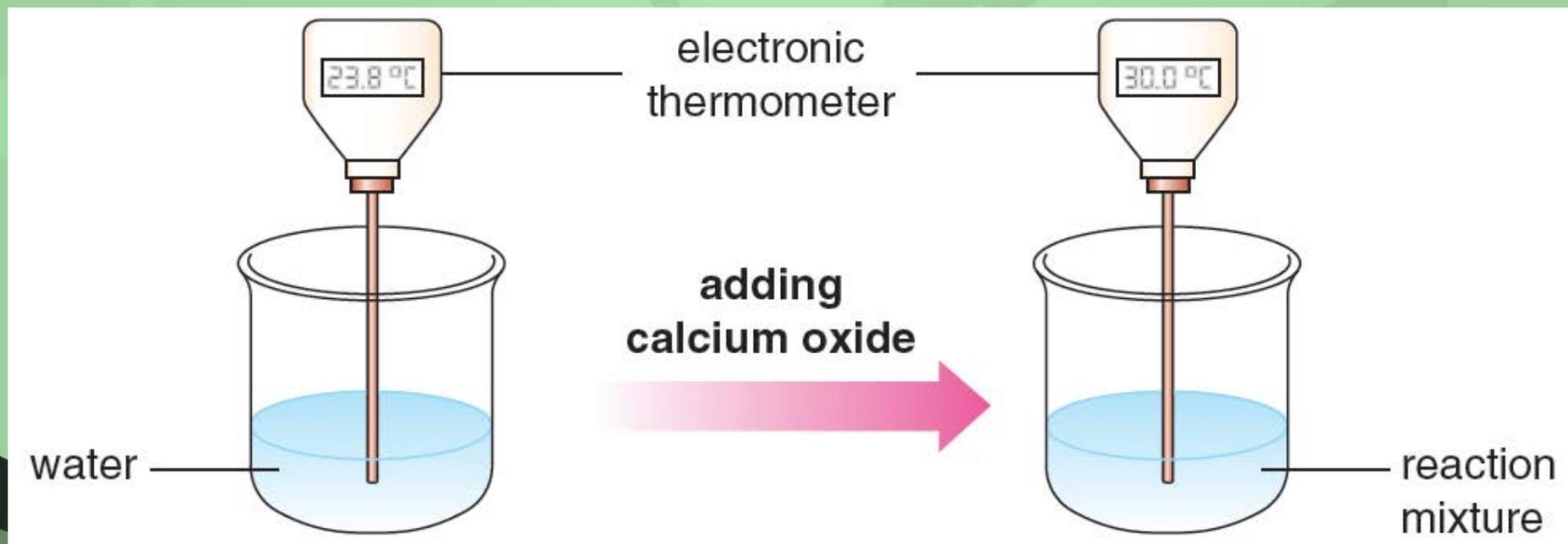
Classifying whether reactions are exothermic or endothermic



## 34.5 Exothermic and endothermic reactions (p.8)

### Exothermic reactions

- ◆  $\text{CaO(s)}$  dissolved in water
- ◆ Combustion of petrol

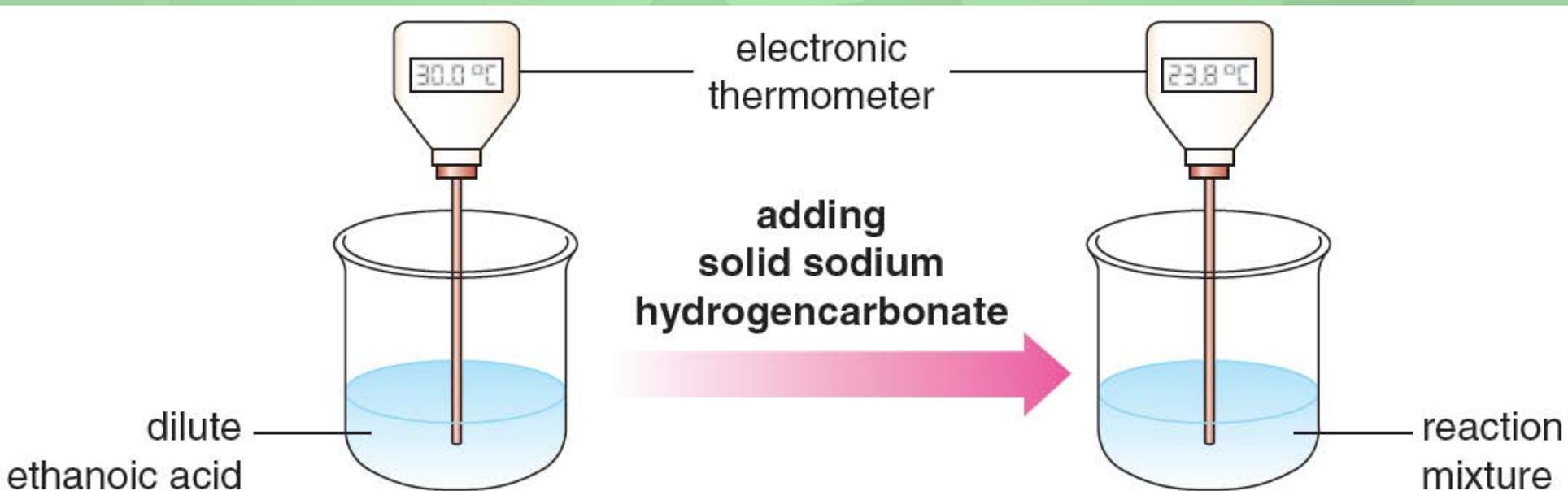




## 34.5 Exothermic and endothermic reactions (p.8)

### Endothermic reactions

- ◆  $\text{NaHCO}_3(\text{s})$  + dilute ethanoic acid
- ◆ Decomposition of limestone by heat or photosynthesis





## 34.5 Exothermic and endothermic reactions (p.8)

### Practice 34.2

1 Classify each of the following reactions as exothermic or endothermic.

a) Burning of methane in air **Exothermic**

b) Cracking of naphtha **Endothermic**

c) Neutralising dilute hydrochloric acid with dilute sodium hydroxide solution **Exothermic**

2 Sherbet is a solid mixture of sodium hydrogencarbonate and citric acid. If you put sherbet in your mouth and mix it with saliva, your mouth will feel cold. Explain why.

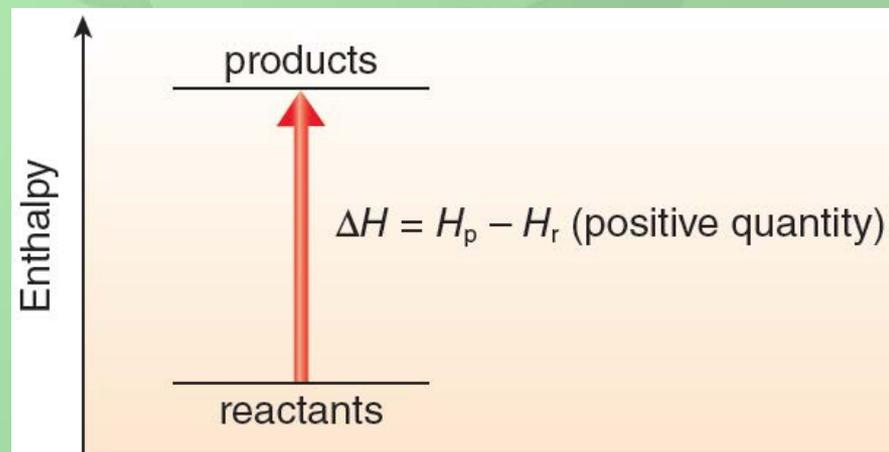
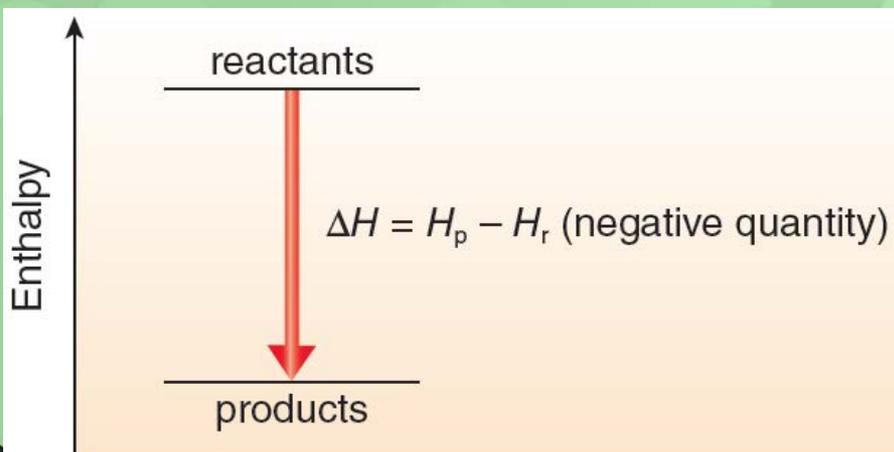
**Citric acid exhibits typical properties of an acid in the presence of water (saliva).**

**Reaction between the acid and sodium hydrogencarbonate is endothermic. Thus, the mouth feels cold.**



## 34.6 Enthalpy level diagrams (p.12)

- ◆ You can show the enthalpy change in a reaction on an **enthalpy level diagram (焓級圖)**.
- ◆ For an **exothermic reaction**, the products have less enthalpy than the reactants. So  $\Delta H < 0$ .
- ◆ For an **endothermic reaction**, the products have more enthalpy than the reactants. So  $\Delta H > 0$ .





## 34.6 Enthalpy level diagrams (p.12)

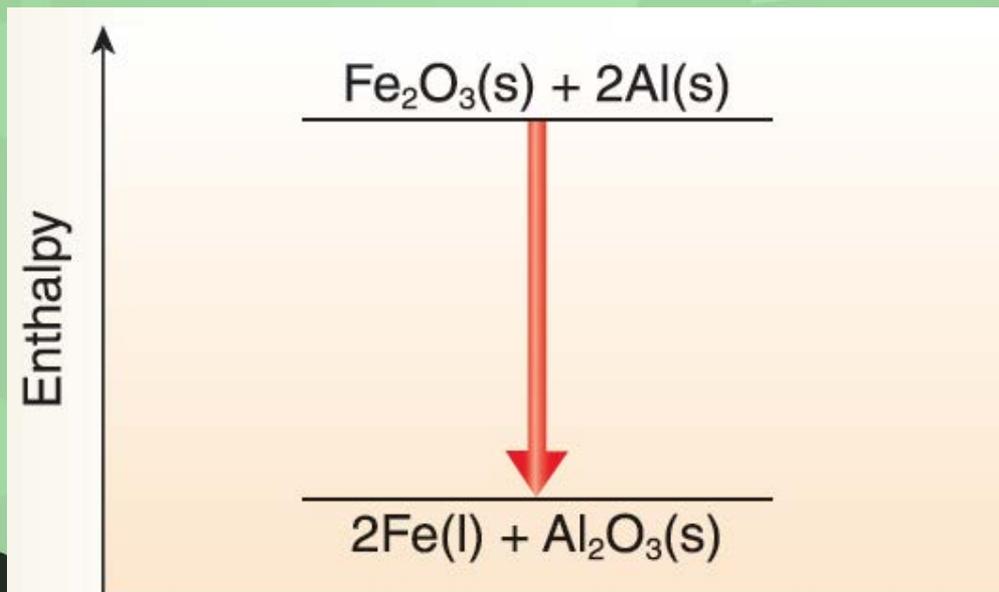
### Q (Example 34.2)

Consider the exothermic reaction between aluminium powder and iron(III) oxide.



Sketch a labelled enthalpy level diagram for this reaction.

A





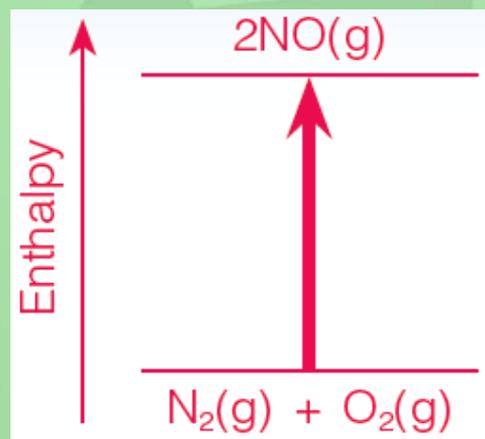
## 34.6 Enthalpy level diagrams (p.12)

### Practice 34.3

The reaction between nitrogen and oxygen to form nitrogen monoxide is endothermic.



Sketch a labelled enthalpy level diagram for this reaction.





## 34.7 Energy changes and bonding (p.13)

- ◆ During chemical reactions, the bonds in reactants break and new bonds are formed to make products.
- ◆  $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$

Bonds in the  $\text{H}_2$  and  $\text{O}_2$  molecules break to form H and O atoms. This takes energy. New bonds then form between the H and O atoms to produce  $\text{H}_2\text{O}$  molecules. This releases energy.

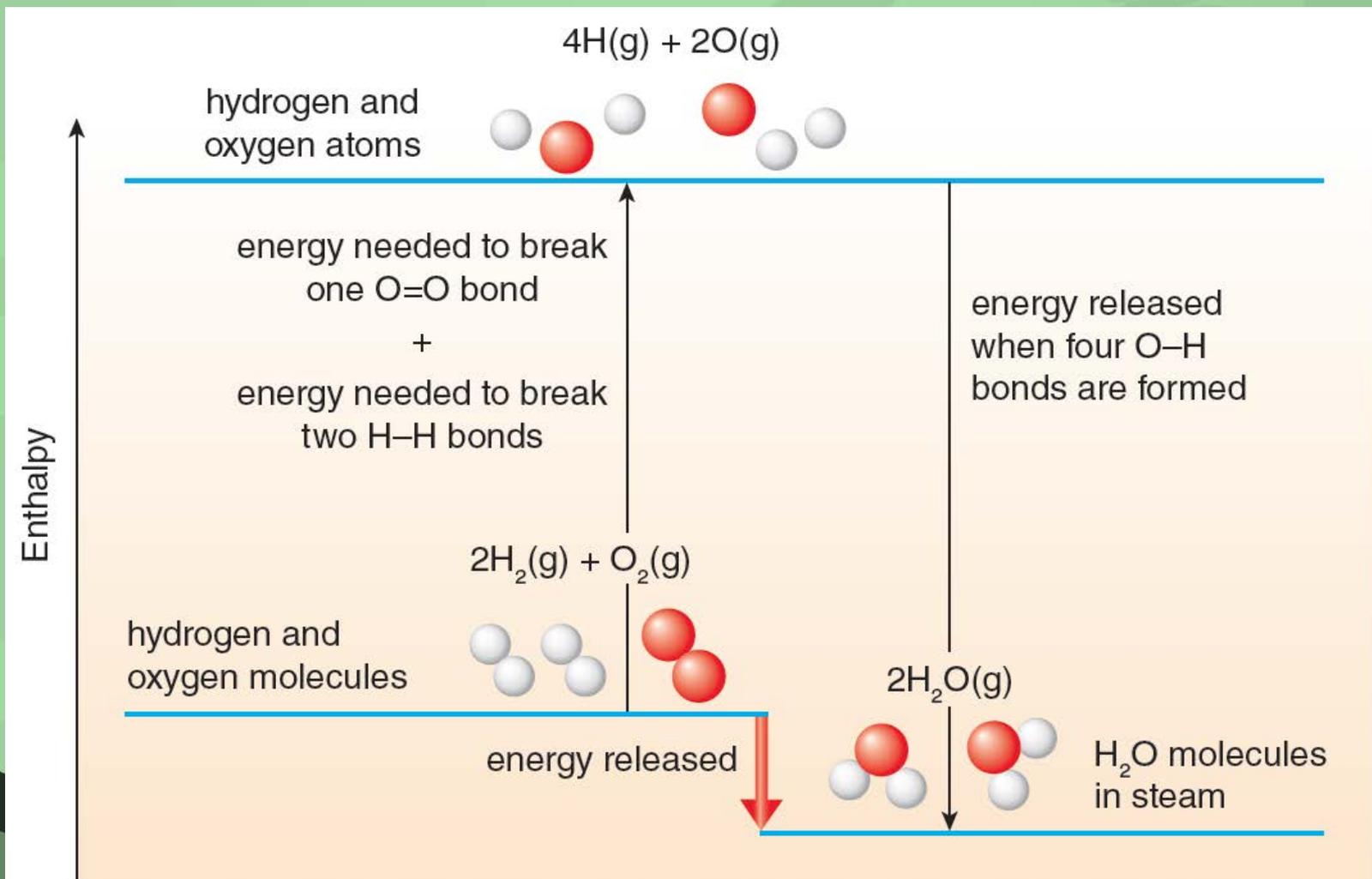


**Chemical changes associated with breaking and forming of chemical bonds** [Ref.](#)



## 34.7 Energy changes and bonding (p.13)

- ◆ The overall reaction is exothermic.





## 34.7 Energy changes and bonding (p.13)

- ◆ In an exothermic reaction,  
total energy released in bond forming  $>$   
total energy required in bond breaking.
- ◆ In an endothermic reaction,  
total energy released in bond forming  $<$   
total energy required in bond breaking.



## 34.7 Energy changes and bonding (p.13)

### Practice 34.4

The combustion of propane is an exothermic reaction. Its chemical equation is shown:

$$\text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{l})$$

- a) State all the covalent bonds that are broken and formed during the combustion of propane.

**Covalent bonds broken: C–C, C–H and O=O**

**Covalent bonds formed: C=O and H–O**

- b) Suggest why the combustion is exothermic in terms of the breaking and forming of covalent bonds.

**The total energy released in the bond forming process is greater than the total energy required in the bond breaking process.**



## 34.8 Thermochemical equations (p.15)

- ◆ A **thermochemical equation** (熱化學方程式) is a balanced chemical equation that includes the value of  $\Delta H$ .
- ◆  $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \quad \Delta H = -890 \text{ kJ mol}^{-1}$

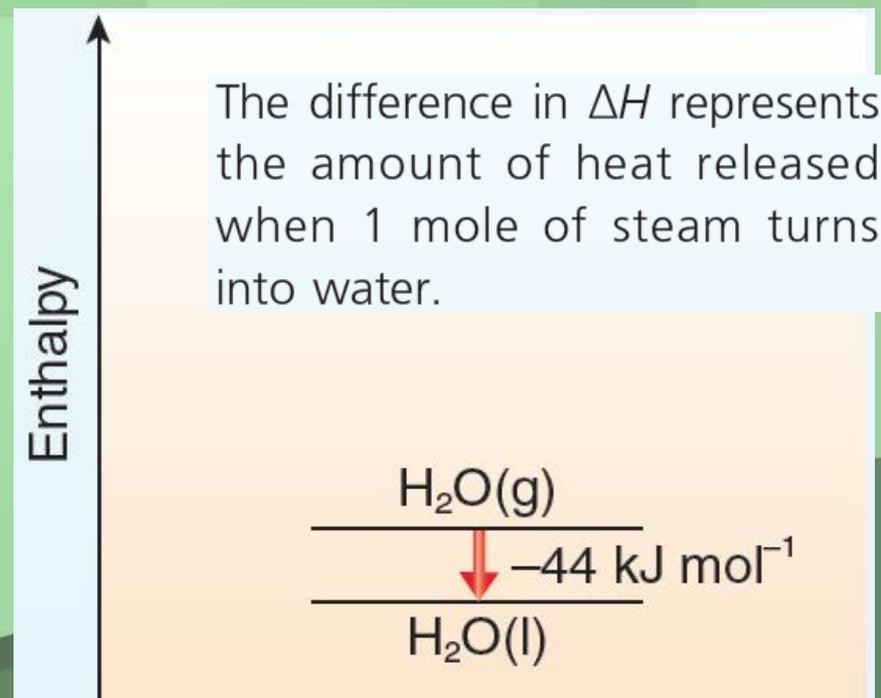
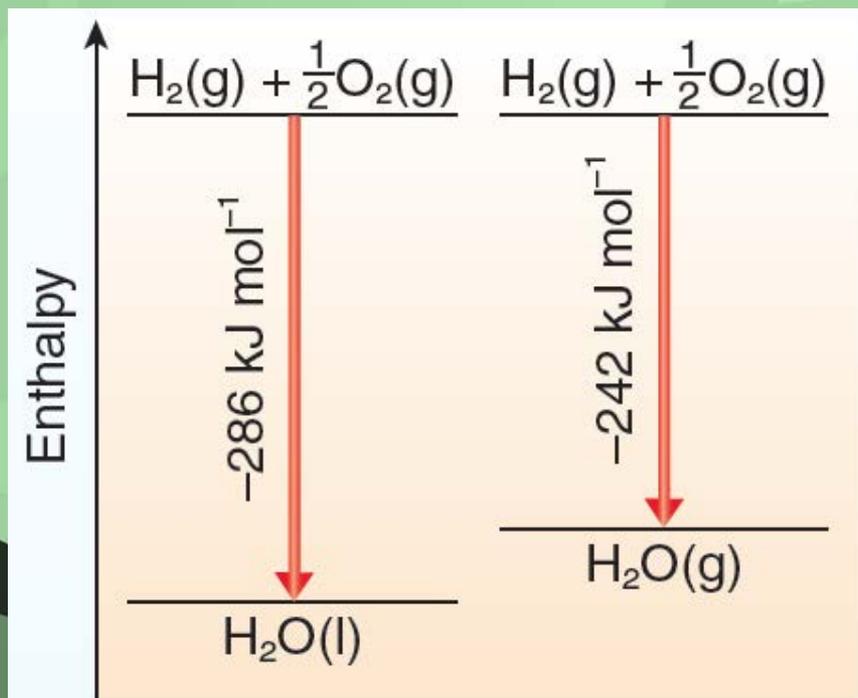
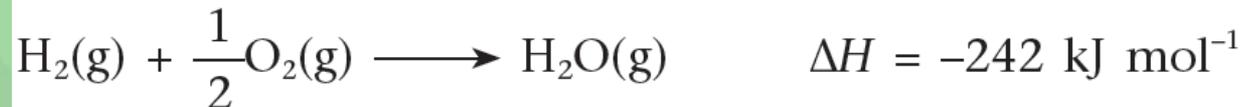
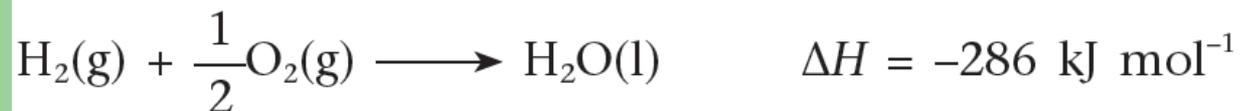
This equation tells that 890 kJ of heat are released when 1 mole of methane burns in 2 moles of oxygen.

- ◆ The physical states (gas, liquid or solid) of the reactants and products affect the enthalpy change of a reaction. This means that you must always include state symbols in your thermochemical equations.



## 34.8 Thermochemical equations (p.15)

- For example, hydrogen may burn in oxygen to form liquid water or steam:





## 34.8 Thermochemical equations (p.15)

- Some reactions occur in both 'forward' and 'backward' directions.



- Notice that  $\Delta H$  of the second reaction has the same numerical but negative value as that of the first reaction.



## 34.9 Standard enthalpy changes (p.16)

- ◆ Enthalpy changes have different values, depending on the conditions under which they are measured. To make enthalpy changes transferrable, they are all quoted for the same set of conditions, which is called **standard conditions** (標準條件).
- ◆ The standard conditions are:
  - at a temperature of 298 K (25 °C);
  - at a pressure of 1 atmosphere (atm);
  - all substances in their standard states, i.e. the most stable physical state at 298 K and 1 atm;
  - all solutions at a concentration of 1 mol dm<sup>-3</sup>.

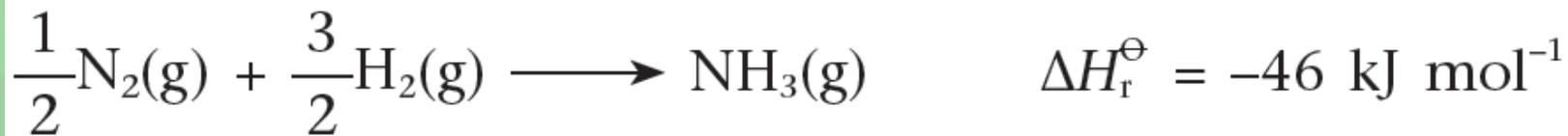
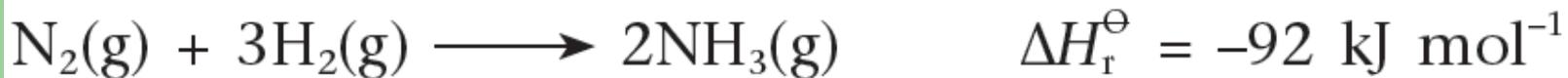
When an enthalpy change is measured under standard conditions, it is written as  $\Delta H_{298}^{\ominus}$  or simply  $\Delta H^{\ominus}$ .



## 34.10 Standard enthalpy change of reaction (p.16)

The **standard enthalpy change of reaction** (標準反應焓變),  $\Delta H_r^\ominus$ , is the enthalpy change when molar quantities of reactants, as stated in the equation, react together under standard conditions to give products.

- ◆  $\Delta H_r^\ominus$  always refers to a stated equation and its value depends on the balancing coefficients.





## 34.11 Standard enthalpy change of formation (p.208)

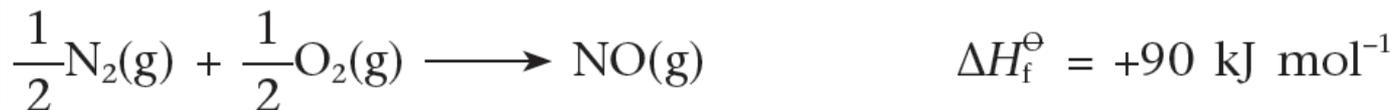
The **standard enthalpy change of formation** (標準生成焓變),  $\Delta H_f^\ominus$ , of a substance is the enthalpy change when one mole of the substance is formed from its elements in their standard states under standard conditions.

- ◆  $\text{C}(\text{graphite}) + 2\text{H}_2(\text{g}) \rightarrow \text{CH}_4(\text{g}) \quad \Delta H_f^\ominus = -74.8 \text{ kJ mol}^{-1}$   
or  $\Delta H_f^\ominus [\text{CH}_4(\text{g})] = -74.8 \text{ kJ mol}^{-1}$
- ◆ All elements (in their standard states) have an enthalpy change of formation of  $0 \text{ kJ mol}^{-1}$ , as there is no change involved in their formation.



## 34.11 Standard enthalpy change of formation (p.208)

- ◆ Enthalpy changes of formation are usually negative, that is, the corresponding reactions are exothermic. However, some compounds have positive enthalpy changes of formation, for example, benzene and nitrogen monoxide.

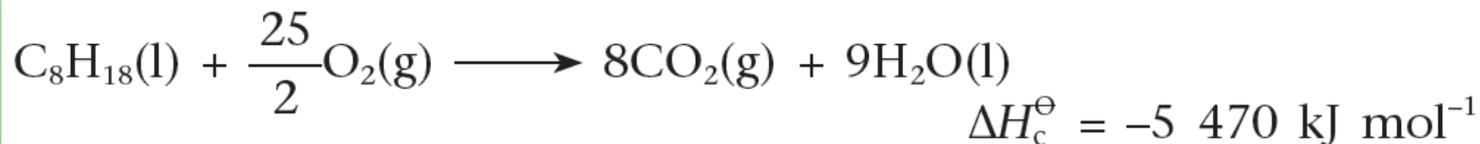
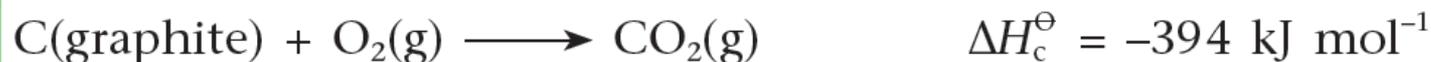


- ◆ Substances with higher energy are less stable. Hence these compounds are energetically unstable relative to their constituent elements.



## 34.12 Standard enthalpy change of combustion (p.18)

The **standard enthalpy change of combustion** (標準燃燒焓變),  $\Delta H_c^\ominus$ , of a substance is the enthalpy change when one mole of the substance is completely burnt in oxygen under standard conditions.



- ◆  $\Delta H_c^\ominus < 0$  since combustion is always exothermic.
- ◆ Always balance the equation to show only one mole of the substance combusted.



## 34.12 Standard enthalpy change of combustion (p.18)

### Practice 34.5

1 Heptane (C<sub>7</sub>H<sub>16</sub>) is a component of petrol. Using heptane as an example, state the meaning of each term with the aid of a chemical equation.

a) Standard enthalpy change of formation

The standard enthalpy change of formation,  $\Delta H_f^\ominus$ , of a substance is the enthalpy change when one mole of the substance is formed from its elements in their standard states under standard conditions.



b) Standard enthalpy change of combustion

The standard enthalpy change of combustion,  $\Delta H_c^\ominus$ , of a substance is the enthalpy change when one mole of the substance is completely burnt in oxygen under standard conditions.





## 34.12 Standard enthalpy change of combustion (p.18)

2 N<sub>2</sub>(g) and O<sub>2</sub>(g) react to form NO<sub>2</sub>(g) according to the equation below.



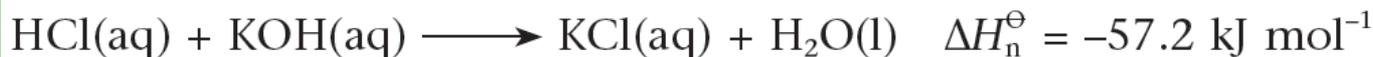
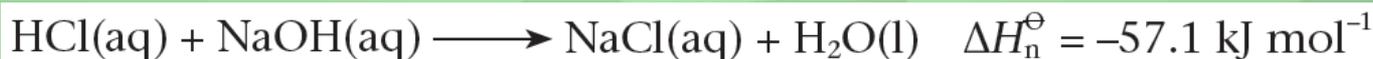
What is the standard enthalpy change of formation of NO<sub>2</sub>(g)?

**+34 kJ mol<sup>-1</sup>**



## 34.13 Standard enthalpy change of combustion (p.19)

The **standard enthalpy change of neutralisation** (標準中和焓變),  $\Delta H_n^\ominus$ , is the enthalpy change when an acid reacts with an alkali to form one mole of water under standard conditions.

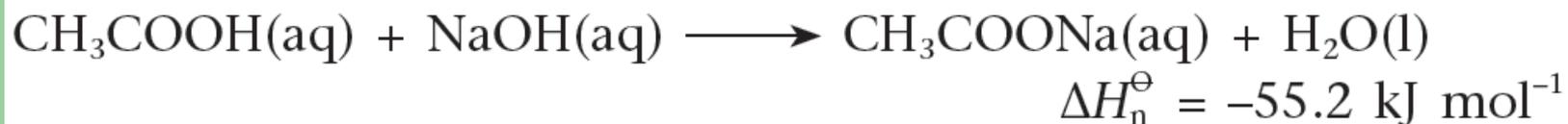


- ◆ These strong monobasic acids and strong alkalis give similar  $\Delta H_n^\ominus$  values since they dissociate completely and the same chemical change takes place:  $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \longrightarrow \text{H}_2\text{O}(\text{l})$ .



## 34.13 Standard enthalpy change of combustion (p.19)

- ◆ However, when a neutralisation involves a weak acid, a weak alkali, or both, the standard enthalpy change of neutralisation will be smaller in magnitude than  $-57 \text{ kJ mol}^{-1}$ .
- ◆ For example, the standard enthalpy change of neutralisation for ethanoic acid and sodium hydroxide solution is  $-55.2 \text{ kJ mol}^{-1}$  because some heat is absorbed for ionisation of the weak acid.





## 33.14 Determining an enthalpy change of combustion (p.20)

- The enthalpy change of combustion of a reaction can be measured by its effect on a known volume of water in a container known as a calorimeter (熱量計).

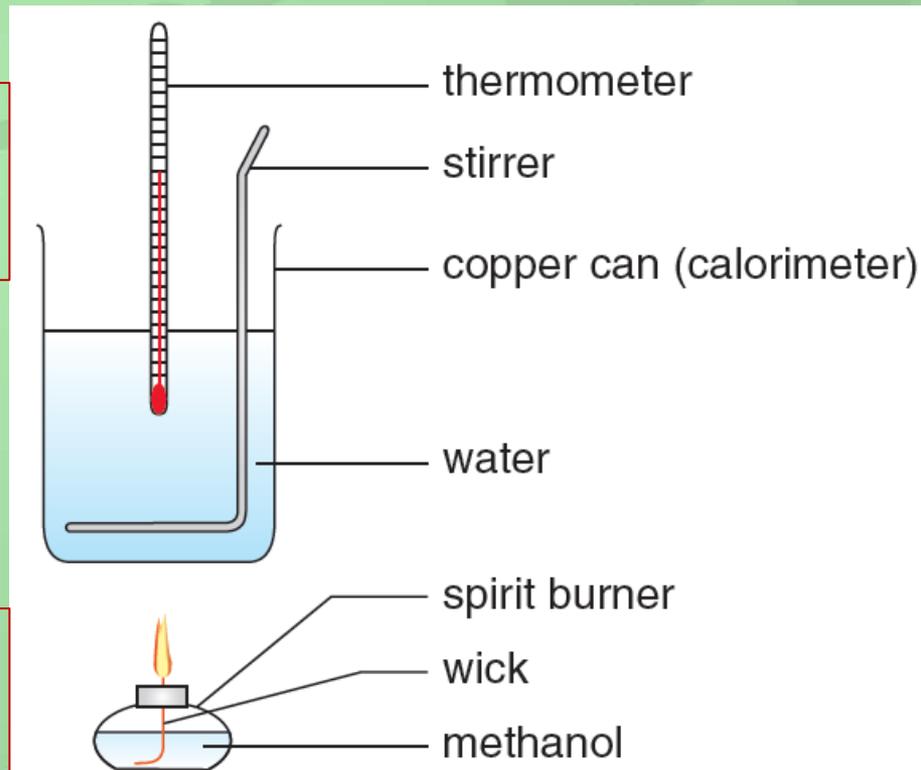
**Heat transferred to the water**

$$= m \times c \times \Delta T$$

on

**Effect:**

Number of moles of methanol combusted





## 33.14 Determining an enthalpy change of combustion (p.20)

- ◆ Mass of spirit burner and methanol before burning = 198.77 g  
Mass of spirit burner and methanol after burning = 197.08 g  
Initial temperature of water = 24.5 °C  
Final temperature of water = 69.6 °C
- ◆ Number of moles of methanol combusted =  $\frac{(198.77 - 197.08) \text{ g}}{32.0 \text{ g mol}^{-1}} = 0.0528 \text{ mol}$
- ◆ Heat transferred to the water =  $m \times c \times \Delta T$   
= 150 g x 4.18 J g<sup>-1</sup> K<sup>-1</sup> x (69.6 – 24.5) K = 28 300 J = 28.3 kJ
- ◆  $\Delta H_c [\text{CH}_3\text{OH(l)}] = \frac{28.3 \text{ kJ}}{0.0528 \text{ mol}} = 536 \text{ kJ mol}^{-1}$



Determining the enthalpy changes of combustion of some alcohols



## 33.14 Determining an enthalpy change of combustion (p.20)

- ◆ The data book value for  $\Delta H_c^\ominus$  of methanol is  $-726 \text{ kJ mol}^{-1}$ . This seems very different from the experimental value of  $-536 \text{ kJ mol}^{-1}$ .
- ◆ Data book values are obtained using much more sophisticated apparatus than a spirit burner and a copper can of water.
- ◆ Clearly much less heat was transferred to the water in the experiment than expected.



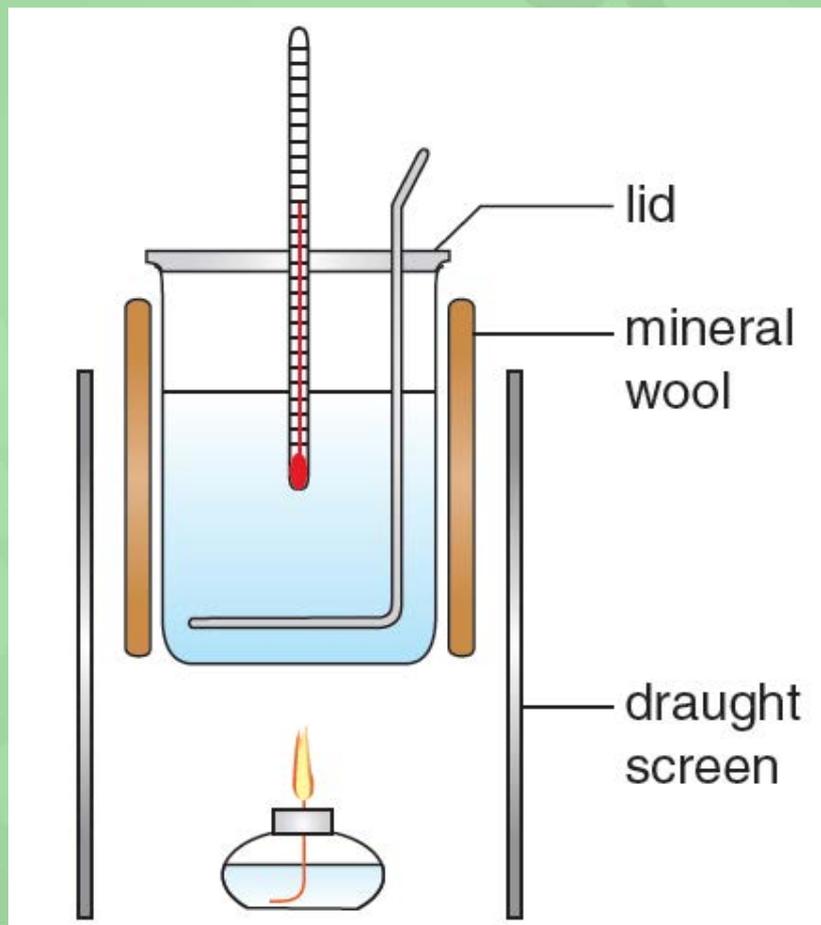
## 33.14 Determining an enthalpy change of combustion (p.20)

- ◆ Possible reasons are listed below:
  - heat loss to the surroundings other than the water;
  - incomplete combustion of methanol;
  - evaporation of methanol from the wick;
  - non-standard conditions.
- ◆ All but the last of the above reasons would lead to a value for  $\Delta H_c$  that is less than expected.



# 33.14 Determining an enthalpy change of combustion (p.20)

- ◆ An improved set-up to prevent heat loss:

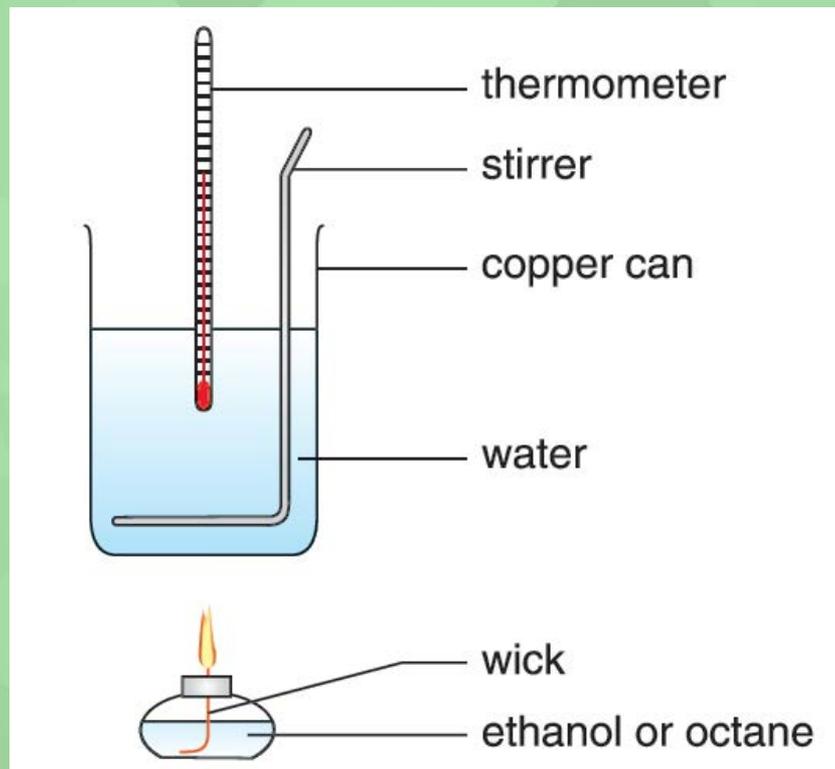




## 33.14 Determining an enthalpy change of combustion (p.20)

### Q (Example 34.3)

Burning octane ( $C_8H_{18}$ ) releases energy. The enthalpy change of combustion of octane was determined using the set-up shown below:





## 33.14 Determining an enthalpy change of combustion (p.20)

- Step 1* The copper can with a fixed mass of water was heated by burning ethanol. The temperature of water increased by  $25.8\text{ }^{\circ}\text{C}$  after  $1.84\text{ g}$  of ethanol were burnt.
- Step 2* The copper can with the same mass of water in *Step 1* was heated by burning octane. The temperature of water increased by  $34.4\text{ }^{\circ}\text{C}$  after  $1.60\text{ g}$  of octane were burnt.

It is known that under the conditions of experiment, the enthalpy change of combustion of ethanol is  $-1\ 360\text{ kJ mol}^{-1}$ .

(Relative molecular masses: ethanol = 46.0, octane = 114.0)

- Calculate the heat capacity of the copper can and its contents.
- Calculate the enthalpy change of combustion of octane, in  $\text{kJ mol}^{-1}$ , under the experimental conditions.



## 33.14 Determining an enthalpy change of combustion (p.20)

A

a) Amount of heat transferred to copper can and its contents in *Step 1*

$$= 1\,360 \text{ kJ mol}^{-1} \times \frac{1.84 \text{ g}}{46.0 \text{ g mol}^{-1}}$$

$$= 54.4 \text{ kJ}$$

$$\begin{aligned} \text{Heat capacity of copper can and its contents} &= \frac{54.4 \text{ kJ}}{25.8 \text{ K}} \\ &= 2.11 \text{ kJ K}^{-1} \end{aligned}$$

b) Amount of heat transferred to copper can and its contents in *Step 2* =  $2.11 \text{ kJ K}^{-1} \times 34.4 \text{ K}$   
= 72.6 kJ

$$\begin{aligned} \text{Number of moles of C}_8\text{H}_{18} \text{ burnt} &= \frac{1.60 \text{ g}}{114.0 \text{ g mol}^{-1}} \\ &= 0.0140 \text{ mol} \end{aligned}$$

$$\begin{aligned} \text{Enthalpy change of combustion of C}_8\text{H}_{18} &= \frac{-72.6 \text{ kJ}}{0.0140 \text{ mol}} \\ &= -5\,190 \text{ kJ mol}^{-1} \end{aligned}$$



## 33.14 Determining an enthalpy change of combustion (p.20)

### Practice 34.6

1 Under standard conditions, complete combustion of 0.0500 mole of propan-1-ol gives 101 kJ of heat. What is the standard enthalpy change of combustion of propan-1-ol?

Standard enthalpy change of combustion of propan-1-ol

$$= \frac{-101 \text{ kJ}}{0.0500 \text{ mol}} = -2\,020 \text{ kJ mol}^{-1}$$



## 33.14 Determining an enthalpy change of combustion (p.20)

2 The standard enthalpy change of combustion of an unsaturated hydrocarbon X is  $-2\,059\text{ kJ mol}^{-1}$ .

In an experiment, 0.470 g of X was completely burnt in oxygen. The heat produced raised the temperature of 150.0 g of water by  $36.7\text{ }^{\circ}\text{C}$ .

a) Calculate the amount of heat transferred to the water.  
(Specific heat capacity of water =  $4.18\text{ J g}^{-1}\text{ K}^{-1}$ )

$$\begin{aligned}\text{Amount of heat} &= m \times c \times \Delta T \\ &= 150.0\text{ g} \times 4.18\text{ J g}^{-1}\text{ K}^{-1} \times 36.7\text{ K} \\ &= 23\,000\text{ J} \\ &= 23.0\text{ kJ}\end{aligned}$$



## 33.14 Determining an enthalpy change of combustion (p.20)

b) Calculate the relative molecular mass of X.

Let  $m$  be the relative molecular mass of X.

$$\text{Number of moles of X burnt} = \frac{0.470}{m} \text{ mol}$$

$$\text{Amount of heat} = -2\,059 \text{ kJ mol}^{-1} \times \frac{0.470}{m} \text{ mol} = 23.0 \text{ kJ}$$

$$m = 42.1$$

c) Deduce the molecular formula of X.

(Relative atomic masses: H = 1.0, C = 12.0)

Suppose X is an alkene.

Let  $C_nH_{2n}$  be the molecular formula of X.

$$\text{Relative molecular mass of X} = 12n + 2n = 42.1$$

$$n = 3$$

$\therefore$  the molecular formula of X is  $C_3H_6$ .



## 33.15 Determining enthalpy changes of reactions (p.25)

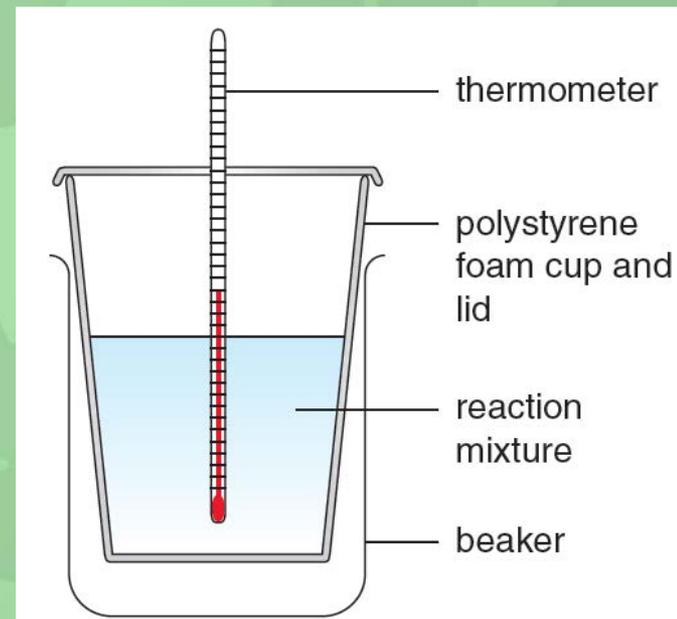
- ◆ Many reactions take place between two solutions, or between a solid and a solution. The enthalpy changes of these reactions can be determined using an insulated polystyrene foam cup as a calorimeter.
- ◆ Polystyrene foam is an excellent thermal insulator and it has negligible specific heat capacity. Hence there is less heat transferred to the surroundings and the cup.
- ◆ If the reaction is exothermic, the heat released is used to raise the temperature of the contents of the polystyrene foam cup.



## 33.15 Determining enthalpy changes of reactions (p.25)

### Determining $\Delta H_n$

- ◆  $\text{HCl(aq)} + \text{NaOH(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$
- ◆ 25.0 cm<sup>3</sup> of 1 M HCl(aq) + 25.0 cm<sup>3</sup> of 1 M NaOH(aq) + Stir
- ◆ Initial temperature of acid = 26.6 °C  
Initial temperature of alkali = 26.8 °C  
Maximum temperature reached = 33.3 °C



Determining the enthalpy change of a reaction



Determining the enthalpy changes of neutralisation [Ref.](#)



## 33.15 Determining enthalpy changes of reactions (p.25)

### ◆ Heat transferred:

$$\text{Mean initial temperature} = \frac{(26.6 + 26.8) \text{ }^\circ\text{C}}{2} = 26.7 \text{ }^\circ\text{C}$$

$$\text{Temperature change } \Delta T = (33.3 - 26.7) \text{ }^\circ\text{C} = +6.6 \text{ }^\circ\text{C} = +6.6 \text{ K}$$

$$\text{Volume of the reaction mixture} = (25.0 + 25.0) \text{ cm}^3 = 50.0 \text{ cm}^3$$

$$\text{Mass of the reaction mixture} = 50.0 \text{ g}$$

(assuming that the density of the reaction mixture is  $1.00 \text{ g cm}^{-3}$ )

Assume specific heat capacity of the reaction mixture is  $4.18 \text{ J g}^{-1} \text{ K}^{-1}$ .

$$\text{Amount of heat transferred to the reaction mixture} = m \times c \times \Delta T$$

$$= 50.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times 6.6 \text{ K} = 1\,380 \text{ J} = 1.38 \text{ kJ}$$



## 33.15 Determining enthalpy changes of reactions (p.25)

- ◆ Amount of water formed:

Number of moles of HCl reacted = number of moles of NaOH reacted

$$= 1.00 \text{ mol dm}^{-3} \times \frac{25.0}{1000 \text{ dm}^3} = 0.0250 \text{ mol}$$

0.0250 mole of HCl reacted with 0.0250 mole of NaOH to produce 0.0250 mole of H<sub>2</sub>O.

- ◆  $\Delta H_n$  :

$$= \frac{1.38 \text{ kJ}}{0.0250 \text{ mol}} = 55.2 \text{ kJ mol}^{-1}$$



## 33.15 Determining enthalpy changes of reactions (p.25)

### Determining $\Delta H_r$ of a displacement reaction

- ◆ For fast reactions, such as neutralisations, accurate results can be obtained by using simple calorimeters (e.g. a polystyrene foam cup fitted with a lid).
- ◆ However, for slower reactions, such as displacement reactions, the results will be less accurate with the same apparatus. This is because there is much heat loss to the surroundings.



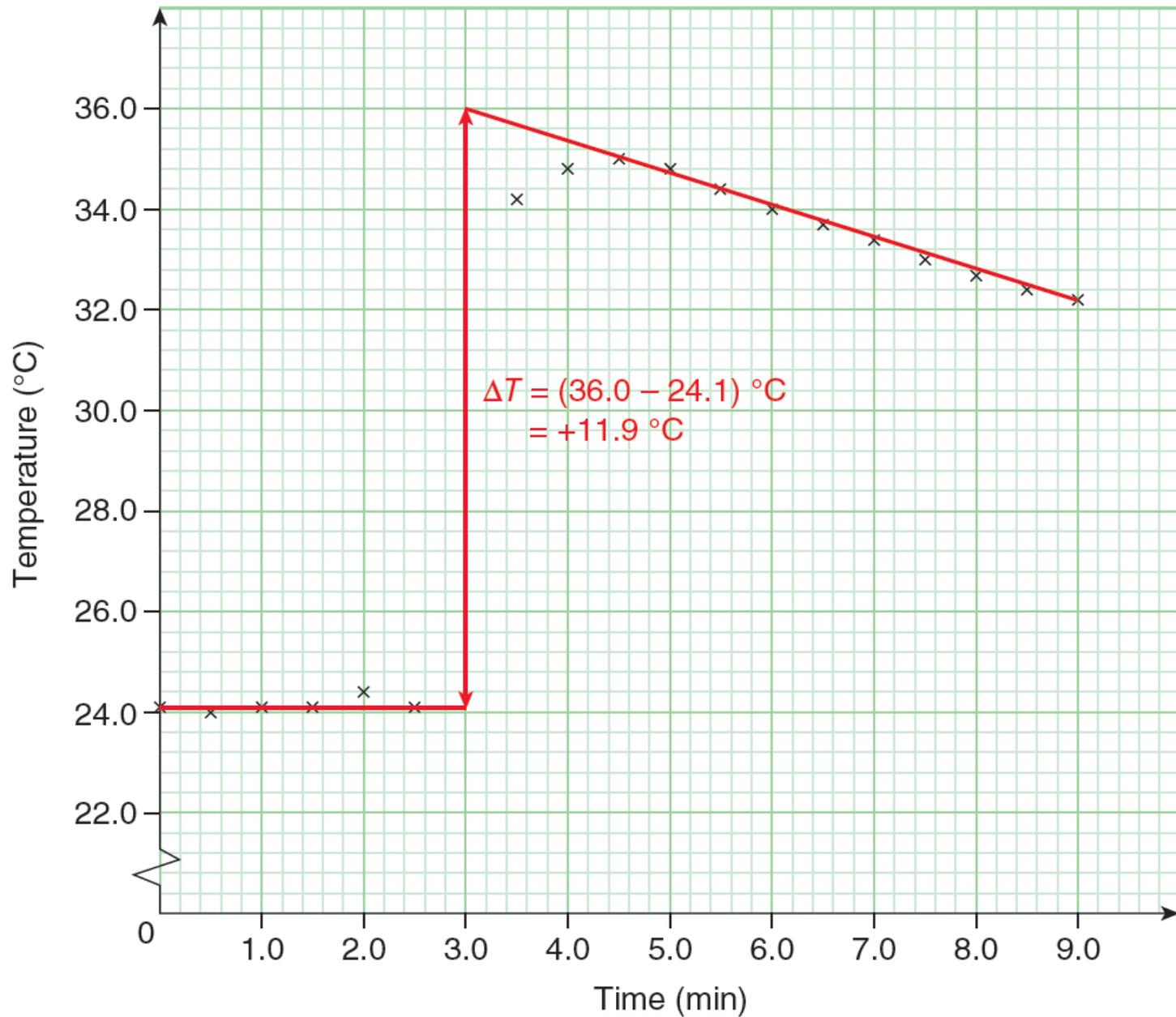
## 33.15 Determining enthalpy changes of reactions (p.25)

- ◆ Consequently, the temperature rise observed is not as high as it should be. However, an allowance can be made for this by plotting a temperature-time graph.
- ◆ This method is used in the experiment for determining the enthalpy change of the displacement reaction between zinc and copper(II) sulphate solution outlined below.



## 33.15 Determining enthalpy changes of reactions (p.25)

- ◆  $\text{Zn(s)} + \text{CuSO}_4(\text{aq}) \rightarrow \text{ZnSO}_4(\text{aq}) + \text{Cu(s)}$
- ◆ 1 Place  $50.0 \text{ cm}^3$  of  $0.250 \text{ mol dm}^{-3}$  copper(II) sulphate solution in a polystyrene foam cup.
- 2 Weigh out  $2.0 \text{ g}$  zinc powder (excess).
- 3 Measure the temperature of the copper(II) sulphate solution every 30 seconds for 2.5 minutes.
- 4 At 3.0 minutes, add the zinc to the solution and stir the mixture.
- 5 Measure the temperature of the reaction mixture every 30 seconds for a further of 6.0 minutes.





## 33.15 Determining enthalpy changes of reactions (p.25)

### ◆ Getting $\Delta T$ :

- Draw a straight line through the first six points and extrapolate the line to the 3.0 minutes.
- Extrapolate the graph backwards from 9.0 minutes to the 3.0 minutes. This gives an estimate of the maximum temperature if the reactants had reacted at once and there was no loss of heat to the surroundings.
- Measure the difference in height between these two lines at the time that the zinc was added (3.0 minutes). This height is  $\Delta T$ .

$$\begin{aligned}\Delta T &= (36.0 - 24.1) \text{ }^\circ\text{C} \\ &= +11.9 \text{ }^\circ\text{C} \\ &= +11.9 \text{ K}\end{aligned}$$



## 33.15 Determining enthalpy changes of reactions (p.25)

### ◆ Heat transferred:

$$\begin{aligned} \text{Amount of heat transferred to the reaction mixture} &= m \times c \times \Delta T \\ &= 52.0 \text{ g} \times 4.2 \text{ J g}^{-1} \text{ K}^{-1} \times 11.9 \text{ K} = 2\,600 \text{ J} = 2.60 \text{ kJ} \end{aligned}$$

since

$$\text{Mass of the reaction mixture} = 52.0 \text{ g}$$

$$\text{Specific heat capacity of the reaction mixture} = 4.2 \text{ J g}^{-1} \text{ K}^{-1}$$

### ◆ Amount of $\text{CuSO}_4(\text{s})$ reacted:

$$\text{Number of moles of } \text{CuSO}_4 = 0.250 \text{ mol dm}^{-3} \times \frac{50.0}{1\,000} \text{ dm}^3 = 0.0125 \text{ mol}$$

### ◆ $\Delta H_r$ , in $\text{kJ mol}^{-1}$ :

$$= \frac{2.60 \text{ kJ}}{0.0125 \text{ mol}} = 208 \text{ kJ mol}^{-1}$$



## 33.15 Determining enthalpy changes of reactions (p.25)

### Practice 34.7

A thermometric titration was carried out using  $1.00 \text{ mol dm}^{-3}$  sodium hydroxide solution and dilute hydrochloric acid of unknown concentration.

$50.0 \text{ cm}^3$  of the sodium hydroxide solution was placed in a suitable apparatus.  $5.00 \text{ cm}^3$  portions of the hydrochloric acid were added. The mixture was stirred after each addition of acid and the temperature of the reaction mixture was measured. Both the acid and the alkali were initially at  $20.0 \text{ }^\circ\text{C}$ .



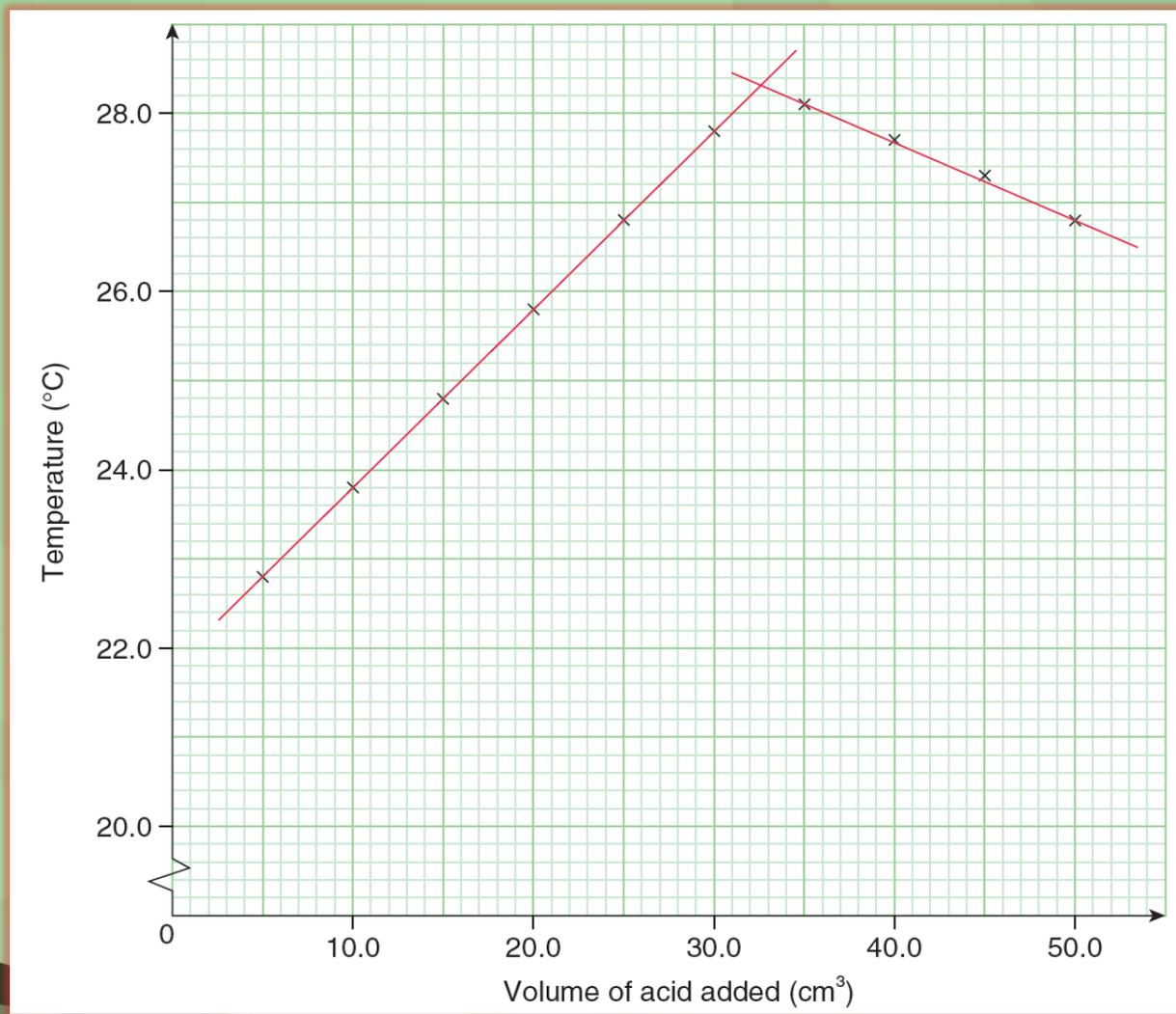
## 33.15 Determining enthalpy changes of reactions (p.25)

The graph shows the results obtained.

- Suggest a suitable apparatus for carrying out the above experiment.
- What is the greatest temperature rise of the reaction mixture as estimated from the graph?
- Determine the concentration, in  $\text{mol dm}^{-3}$ , of the hydrochloric acid.
- Calculate the enthalpy change of neutralisation of hydrochloric acid with sodium hydroxide solution.  
(Specific heat capacity of reaction mixture =  $4.18 \text{ J g}^{-1} \text{ K}^{-1}$ ; density of reaction mixture =  $1.00 \text{ g cm}^{-3}$ )
- In a further experiment, the enthalpy change of neutralisation of the following reaction was determined, again using  $1.00 \text{ mol dm}^{-3}$  solutions at  $20^\circ \text{C}$ :  
 $\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{NH}_4\text{Cl(aq)} \quad \Delta H_n = -52.2 \text{ kJ mol}^{-1}$   
Suggest why this value is different from that for  $\text{HCl(aq)}$  and  $\text{NaOH(aq)}$ .



## 33.15 Determining enthalpy changes of reactions (p.25)





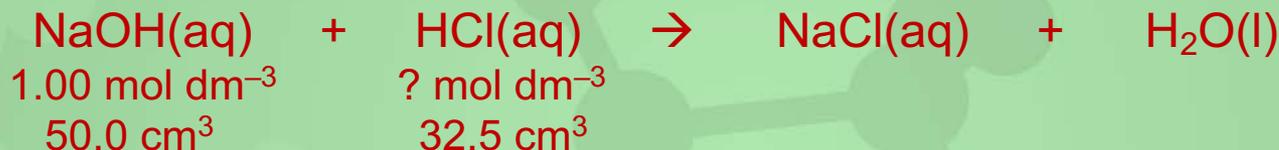
## 33.15 Determining enthalpy changes of reactions (p.25)

a) Polystyrene foam cup

b) The maximum temperature reached = 28.3 °C

The greatest temperature rise of reaction mixture = (28.3 – 20.0) °C = 8.3 °C

c) Volume of hydrochloric acid used for neutralisation = 32.5 cm<sup>3</sup>



Number of moles of NaOH in 50.0 cm<sup>3</sup> solution =  $1.00 \text{ mol dm}^{-3} \times \frac{50.0}{1000} \text{ dm}^3$   
 = 0.0500 mol

According to the equation, 1 mole of NaOH requires 1 mole of HCl for neutralisation.  
 i.e. number of moles of HCl = 0.0500 mol

Concentration of hydrochloric acid =  $(0.0500 \text{ mol}) / \left(\frac{32.5}{1000}\right) \text{ dm}^3$   
 = 1.54 mol dm<sup>-3</sup>



## 33.15 Determining enthalpy changes of reactions (p.25)

d) Volume of reaction mixture =  $(50.0 + 32.5) \text{ cm}^3 = 82.5 \text{ cm}^3$

Mass of reaction mixture = 82.5 g

Amount of heat =  $m \times c \times \Delta T$

=  $82.5 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times (28.3 - 20.0) \text{ K} = 2860 \text{ J} = 2.86 \text{ kJ}$

Number of moles of water formed = number of moles of NaOH reacted  
= 0.0500 mol

Enthalpy change of neutralisation =  $\frac{-2.86 \text{ kJ}}{0.0500 \text{ mol}} = -57.2 \text{ kJ mol}^{-1}$

e)  $\text{NH}_3(\text{aq})$  is a weak alkali.

Some of the heat released on neutralisation is used to produce hydroxide ions.

## Key terms (p.32)

joule	焦耳	endothemic	吸熱
heat capacity	熱容量	enthalpy level diagram	焓級圖
specific heat capacity	比熱容	thermochemical equation	熱化學方程式
conservation of energy	能量守恆	standard condition	標準條件
system	體系	standard enthalpy change of reaction	標準反應焓變
surroundings	外界	standard enthalpy change of formation	標準生成焓變
internal energy	內能	standard enthalpy change of combustion	標準燃燒焓變
enthalpy change	焓變	standard enthalpy change of neutralisation	標準中和焓變
exothermic	放熱	calorimeter	熱量計





## Summary (p.33)

- 1 The specific heat capacity, symbol  $c$ , of a substance is the amount of heat required to raise the temperature of 1 g of the substance by 1 K (or 1 °C).

amount of heat required to raise the temperature of a substance  
= mass x specific heat capacity x temperature change  
=  $m \times c \times \Delta T$

where  $\Delta T$  is the temperature change

- 2 An enthalpy change,  $\Delta H$ , is the heat released or taken in during any change in a system, provided that the system is kept at constant pressure.



## Summary (p.33)

3 The following table shows a comparison between exothermic and endothermic reactions.

Reaction	Exothermic	Endothermic
Heat exchange with the surroundings	heat is released to the surroundings	heat is taken in from the surroundings
Equation of enthalpy change ( $\Delta H$ )	$\Delta H = H_p - H_r$	
Sign convention for $\Delta H$	a negative quantity	a positive quantity



## Summary (p.33)

4 In an exothermic reaction, the total energy released in the bond forming process is larger than the total energy required in the bond breaking process.

In an endothermic reaction, the total energy released in the bond forming process is smaller than the total energy required in the bond breaking process.

5 The standard enthalpy change of reaction,  $\Delta H_r^\ominus$ , is the enthalpy change when molar quantities of reactants, as stated in the equation, react together under standard conditions to give products.

6 The standard enthalpy change of formation of a substance,  $\Delta H_f^\ominus$ , is the enthalpy change when one mole of the substance is formed from its elements in their standard states under standard conditions.



## Summary (p.33)

- 7 The standard enthalpy change of combustion of a substance,  $\Delta H_c^\ominus$ , is the enthalpy change when one mole of the substance is completely burnt in oxygen under standard conditions.
- 8 The standard enthalpy change of neutralisation,  $\Delta H_n^\ominus$ , is the enthalpy change when an acid reacts with an alkali to form one mole of water under standard conditions.
- 9 Follow the steps listed below to calculate the enthalpy change of combustion from experimental results.
- Step 1* Calculating the amount of heat transferred to the water
- Step 2* Calculating the number of moles of fuel combusted
- Step 3* Calculating  $\Delta H_c$  in  $\text{kJ mol}^{-1}$



## Summary (p.33)

10 Follow the steps listed below to calculate the enthalpy change of neutralisation from experimental results.

*Step 1* Calculating the amount of heat transferred to the reaction mixture

*Step 2* Calculating the number of moles of water formed

*Step 3* Calculating  $\Delta H_n$  in  $\text{kJ mol}^{-1}$

11 Follow the steps listed below to calculate the enthalpy change of a displacement reaction from experimental results.

*Step 1* Calculating the amount of heat transferred to the reaction mixture

*Step 2* Calculating the amount of reactant reacted

*Step 3* Calculating  $\Delta H_r$  in  $\text{kJ mol}^{-1}$



## Unit Exercise (p.35)

**Note: Questions are rated according to ascending level of difficulty (from 1 to 5):**



question targeted at level 3 and above;



question targeted at level 4 and above;



question targeted at level 5.

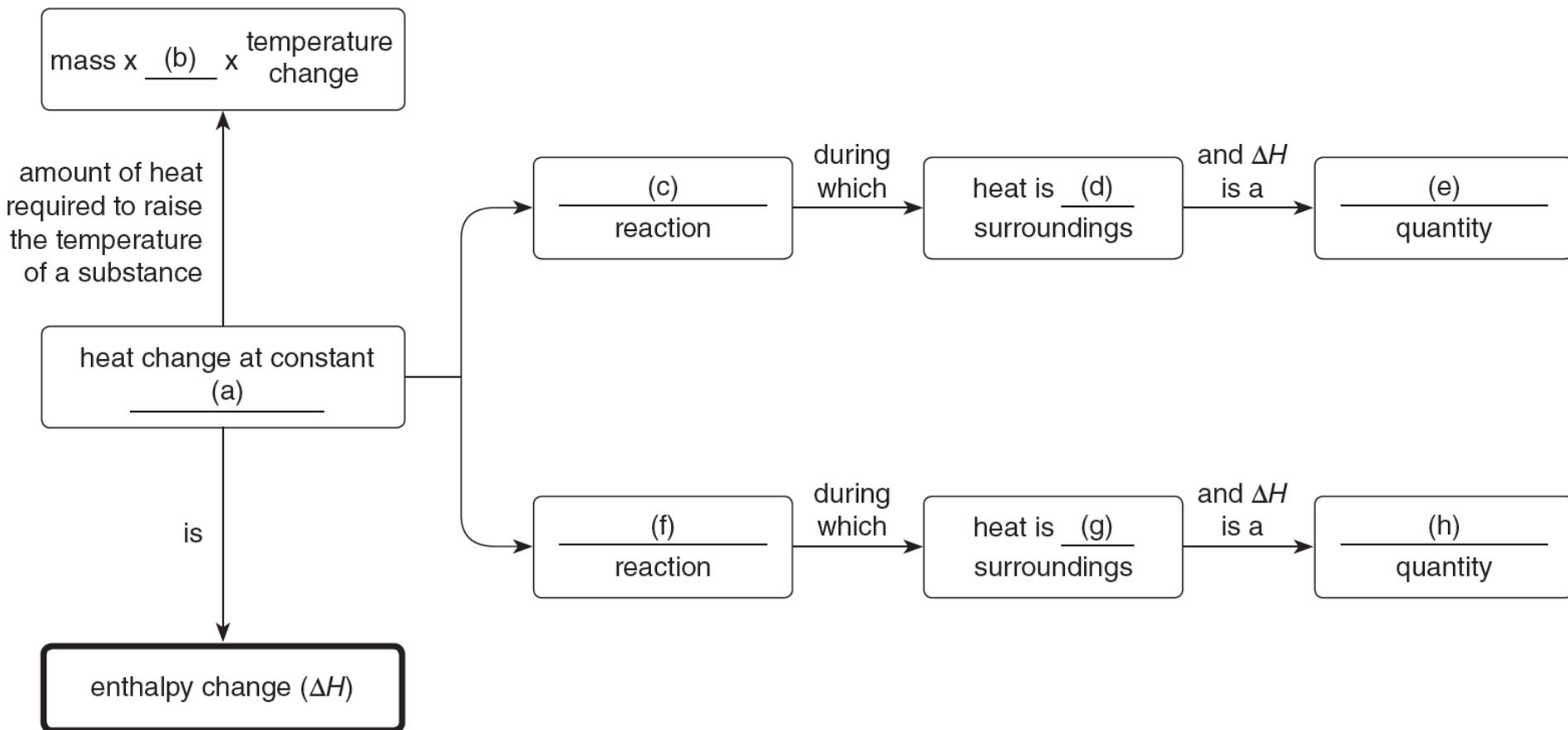
‘ \* ’ indicates 1 mark is given for effective communication.



# Unit Exercise (p.35)

## PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.





## Unit Exercise (p.35)

- a) pressure
- b) specific heat capacity
- c) exothermic / endothermic
- d) released to / taken in from
- e) negative / positive
- f) endothermic / exothermic
- g) taken in from / released to
- h) positive / negative



 Unit Exercise (p.35)**PART II MULTIPLE CHOICE QUESTIONS**

2 A hot tub contains  $1.20 \times 10^6$  g of water. What is the amount of heat required to warm the water from  $22.0^\circ\text{C}$  to  $40.0^\circ\text{C}$ ?  
(Specific heat capacity of water =  $4.18 \text{ J g}^{-1} \text{ K}^{-1}$ )

- A  $6.74 \times 10^7 \text{ J}$
- B  $9.03 \times 10^7 \text{ J}$
- C  $1.41 \times 10^8 \text{ J}$
- D  $1.60 \times 10^8 \text{ J}$

**Answer : B****Explanation :**

Amount of heat

$$= m \times c \times \Delta T$$

$$= 1.20 \times 10^6 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times (40 - 22) \text{ K}$$

$$= 9.03 \times 10^7 \text{ J}$$

 Unit Exercise (p.35)

3 The standard enthalpy change of combustion of ethanol is  $-1\,368\text{ kJ mol}^{-1}$ .

153 kJ of heat are released when a sample of ethanol is burnt under standard conditions.

What is the mass of ethanol burnt?

(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0)

Answer: D

A 1.12 g

B 2.53 g

C 4.55 g

D 5.14 g

Explanation:

$$\text{Number of moles of ethanol burnt} = \frac{153\text{ kJ}}{1\,368\text{ kJ mol}^{-1}}$$

Molar mass of  $\text{C}_2\text{H}_5\text{OH}$

$$\begin{aligned} &= (2 \times 12.0 + 6 \times 1.0 + 16.0)\text{ g mol}^{-1} \\ &= 46.0\text{ g mol}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Mass of ethanol burnt} &= \frac{153\text{ kJ}}{1\,368\text{ kJ mol}^{-1}} \times 46.0\text{ g mol}^{-1} \\ &= 5.14\text{ g} \end{aligned}$$



## Unit Exercise (p.35)

4 The specific heat capacities of some metals are given below.



<u>Metal</u>	<u>Specific heat capacity (J g<sup>-1</sup> K<sup>-1</sup>)</u>
copper	0.39
magnesium	1.0
mercury	0.14
platinum	0.13

**Answer: B**

100 J of heat are added to 10.0 g samples of each of the metals, which are all at 25 °C. Which of the metals will have the SMALLEST temperature change?

- A Copper
- B Magnesium
- C Mercury
- D Platinum



## Unit Exercise (p.35)

5 A cold pack for treating sport injuries contains ammonium nitrate and water kept in different chambers. When the pack is needed, the chambers are broken and the ammonium nitrate dissolves in the water. The dissolving process is

A exothermic, releases heat and has a positive  $\Delta H$  value.

B endothermic, releases heat and has a negative  $\Delta H$  value.

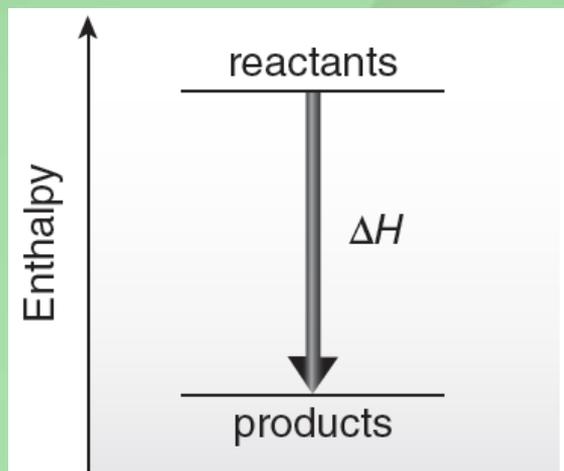
C exothermic, takes in heat and has a negative  $\Delta H$  value.

D endothermic, takes in heat and has a positive  $\Delta H$  value.

Answer: D

 Unit Exercise (p.35)

6 Consider the enthalpy level diagram shown below.



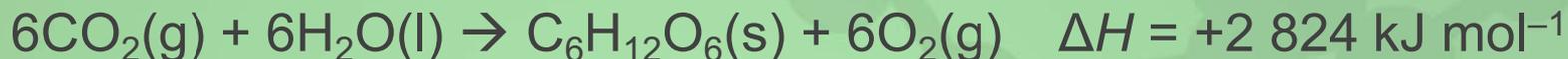
Answer: C

Which of the following combinations about the relative stability of the reactants and products, and the sign of  $\Delta H$  is correct?

	<u>Relative stability</u>	<u>Sign of <math>\Delta H</math></u>
A	reactants more stable	-
B	reactants more stable	+
C	products more stable	-
D	products more stable	+

 Unit Exercise (p.35)

- 7 Consider the production of glucose ( $C_6H_{12}O_6$ ) from carbon dioxide and water.



What is the enthalpy change associated with the production of 10.0 g of  $C_6H_{12}O_6(s)$ ?

(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0)

**Answer: A**

**Explanation:**

- A 157 kJ    **Molar mass of  $C_6H_{12}O_6$**   
B 434 kJ    **= (6 x 12.0 + 12 x 1.0 + 6 x 16.0) g mol<sup>-1</sup>**  
C 508 kJ    **= 180.0 g mol<sup>-1</sup>**  
D 637 kJ

**Enthalpy change associated with production of 10.0 g of  $C_6H_{12}O_6(s)$**

$$= \frac{10.0 \text{ g}}{180.0 \text{ g mol}^{-1}} \times 2\,824 \text{ kJ mol}^{-1} = 157 \text{ kJ}$$

 Unit Exercise (p.35)

8 Consider the reaction between  $\text{SO}_2(\text{g})$  and  $\text{O}_2(\text{g})$ .



Which of the following statements is correct?

A 198 kJ of heat are released for every mole of  $\text{SO}_2(\text{g})$  reacted.

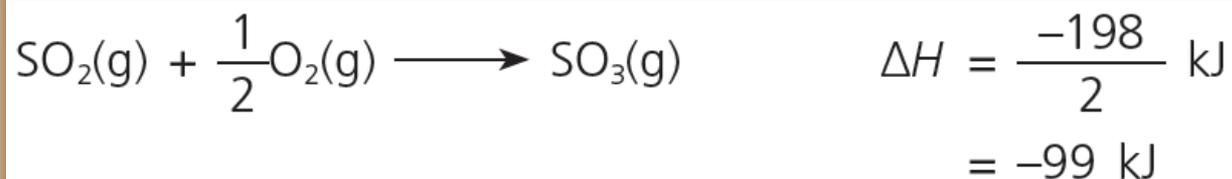
B 198 kJ of heat are taken in for every mole of  $\text{SO}_2(\text{g})$  reacted.

C 99 kJ of heat are released for every mole of  $\text{SO}_2(\text{g})$  reacted.

D 99 kJ of heat are taken in for every mole of  $\text{SO}_2(\text{g})$  reacted.

**Answer: C**

**Explanation:**



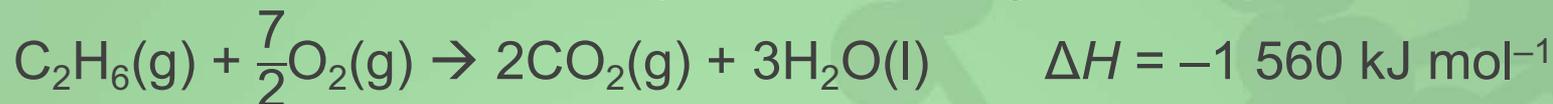
$\therefore$  99 kJ of heat are released for every mole of  $\text{SO}_2(\text{g})$  reacted.



## Unit Exercise (p.35)

Answer: B

9 The combustion of ethane takes place according to the equation below.



What is the value of  $\Delta H$ , in  $\text{kJ mol}^{-1}$ , for the reaction below?



A +1 560

B +3 120

C -3 150

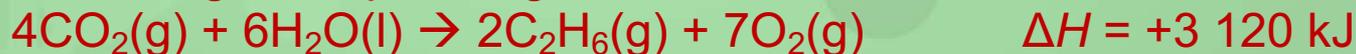
D -7 020

**Explanation:**

When two moles of  $\text{C}_2\text{H}_6(\text{g})$  burn in 7 moles of  $\text{O}_2(\text{g})$ , 3 120 kJ of heat are released.



Reversing the equation gives:





## Unit Exercise (p.35)

10 Consider the following reactions:



Which of the following represents enthalpy change of neutralisation?

A  $\Delta H_1$

B  $\Delta H_2$

C  $\Delta H_3$

D  $\Delta H_4$

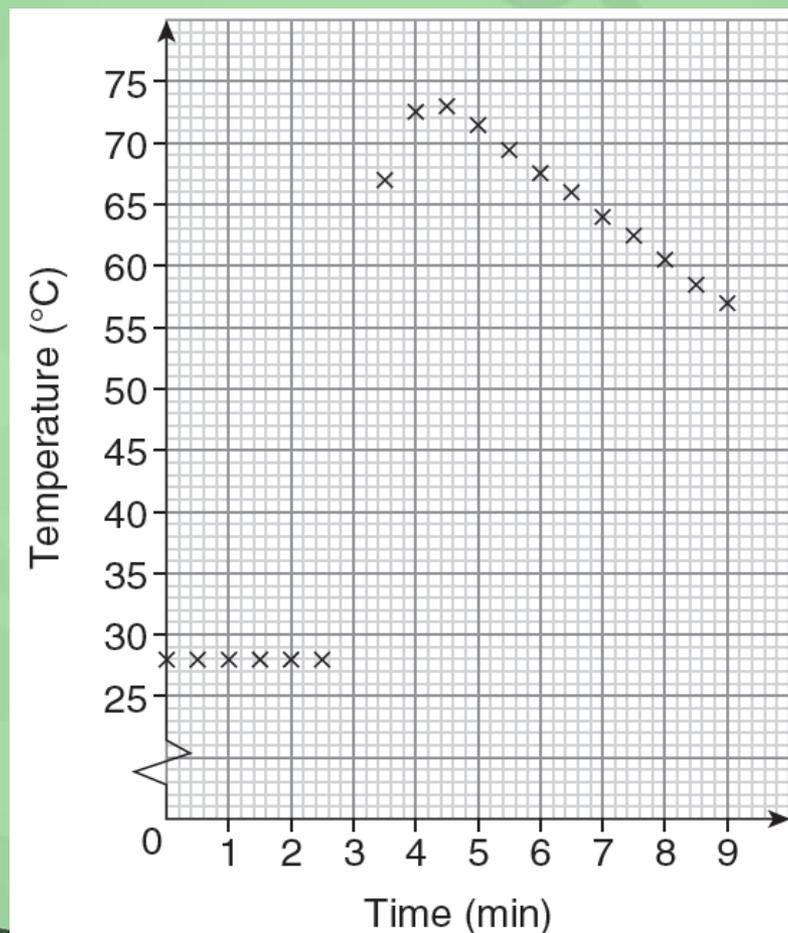
(HKDSE, Paper 1A, 2015, 12)

**Answer: C**



## Unit Exercise (p.35)

- 11 In an experiment for studying the enthalpy change of a reaction, the variation of the temperature of the content in the reaction container with time was plotted in a graph as shown below:





## Unit Exercise (p.35)

The reaction starts at the third minute. Which of the following combinations is correct?

The greatest temperature rise of the content

- A 51 °C
- B 45 °C
- C 51 °C
- D 45 °C

Enthalpy change of the reaction

- negative
- negative
- positive
- positive

*(HKDSE, Paper 1A, 2017, 7)*

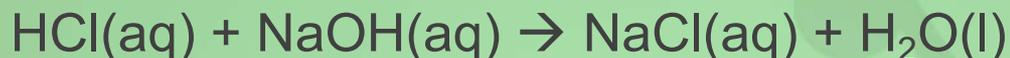
**Answer: A**



## Unit Exercise (p.35)



12 When 10 cm<sup>3</sup> of 2 mol dm<sup>-3</sup> HCl(aq) react with 10 cm<sup>3</sup> of 2 mol dm<sup>-3</sup> NaOH(aq), the temperature change is  $\Delta T$ .



The reaction is repeated using 20 cm<sup>3</sup> of 1 mol dm<sup>-3</sup> HCl(aq) and 20 cm<sup>3</sup> of 1 mol dm<sup>-3</sup> NaOH(aq). What is the temperature change?

A  $\Delta T$

B  $2\Delta T$

C  $\frac{\Delta T}{2}$

D  $2 \times 10 \times \Delta T$

Answer: C



## Unit Exercise (p.35)

### Explanation:

Mixture	Volume of mixture	Number of moles of water formed	Heat released	Temperature rise
10 cm <sup>3</sup> of 2 mol dm <sup>-3</sup> HCl(aq) + 10 cm <sup>3</sup> of 2 mol dm <sup>-3</sup> NaOH(aq)	20 cm <sup>3</sup>	0.02	0.02 × ΔH <sub>n</sub>	ΔT
20 cm <sup>3</sup> of 1 mol dm <sup>-3</sup> HCl(aq) + 20 cm <sup>3</sup> of 1 mol dm <sup>-3</sup> NaOH(aq)	40 cm <sup>3</sup>	0.02	0.02 × ΔH <sub>n</sub>	?

The same amount of heat was transferred to 40 cm<sup>3</sup> of solution, rather than 20 cm<sup>3</sup> of solution. Thus, the temperature rise is  $\frac{\Delta T}{2}$ .



## Unit Exercise (p.35)

13 Which of the following processes are endothermic?



- (1) Conversion of graphite to diamond
- (2) Electrolysis of water
- (3) Sublimation of dry ice

- A (1) and (2) only
- B (1) and (3) only
- C (2) and (3) only
- D (1), (2) and (3)

(1) At 25 °C and 1 atm, graphite is the more stable allotropic form of carbon compared with diamond.

Answer: D



## Unit Exercise (p.35)

14 Which of the following processes are exothermic?



- (1) Placing calcium oxide in water
- (2) Placing a zinc strip in a copper(II) sulphate solution
- (3) Passing hydrogen chloride gas into a sodium hydroxide solution

- A (1) and (2) only
- B (1) and (3) only
- C (2) and (3) only
- D (1), (2) and (3)

**Answer: D**

*(HKDSE, Paper 1A, 2016, 22)*



## Unit Exercise (p.35)

15 Consider the following information:



$$\Delta H^\ominus = +x \text{ kJ mol}^{-1}$$

Which of the following statements is / are correct?

- (1) The standard enthalpy change of formation of  $\text{H}_2\text{O}(\text{l})$  is  $-0.5x \text{ kJ mol}^{-1}$ .
- (2) The standard enthalpy change of formation of  $\text{H}_2\text{O}(\text{l})$  is  $+0.5x \text{ kJ mol}^{-1}$ .
- (3) The standard enthalpy change of combustion of  $\text{H}_2(\text{g})$  is  $-x \text{ kJ mol}^{-1}$ .

- A (1) only  
B (2) only  
C (1) and (3) only  
D (2) and (3) only

*(HKDSE, Paper 1A, 2018, 18)*

 Unit Exercise (p.35)**PART III STRUCTURED QUESTIONS**

16 In lightning, the temperature can reach 30 000 °C. This causes nitrogen and oxygen in the air to react, producing nitrogen monoxide.

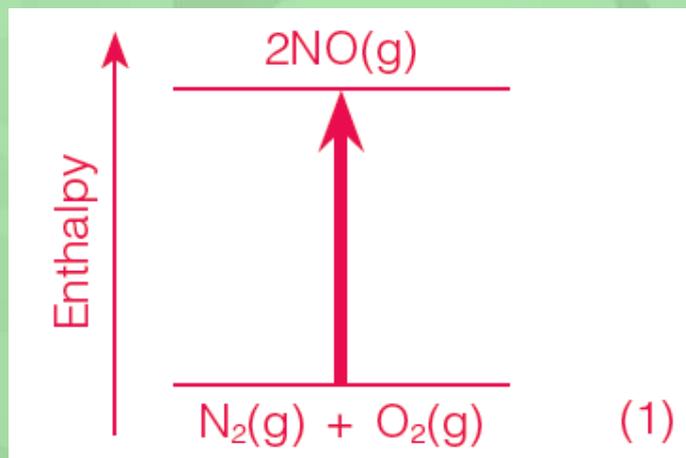


The reaction is endothermic.

a) Explain the meaning of the term 'endothermic'.

In an endothermic process, a system takes in heat from the surroundings. (1)

b) Draw a labelled enthalpy level diagram to represent the reaction.

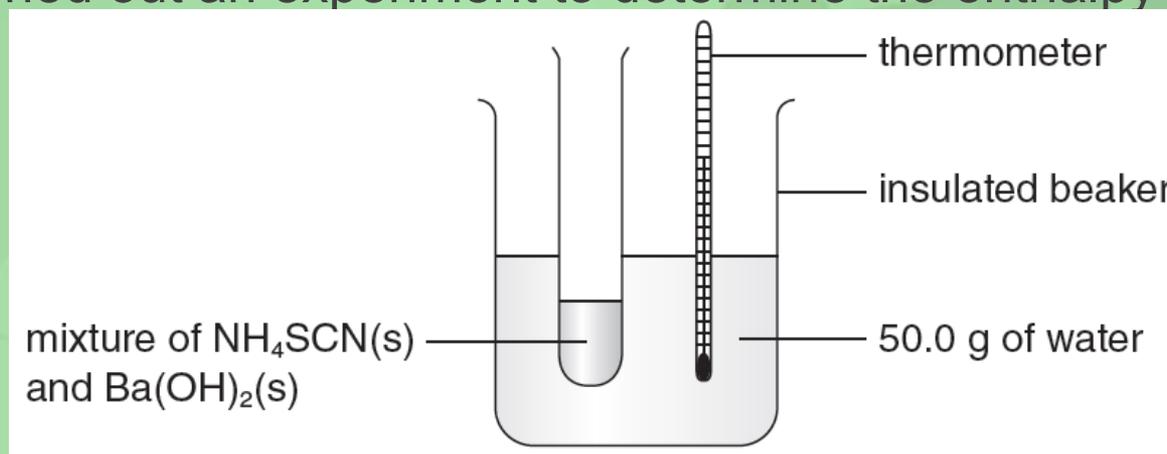


 Unit Exercise (p.35)

17 Solid ammonium thiocyanate ( $\text{NH}_4\text{SCN}$ ) reacts with barium hydroxide according to the equation below.



A chemist carried out an experiment to determine the enthalpy change of this reaction.



In the experiment, 22.8 g of  $\text{NH}_4\text{SCN}(\text{s})$  reacted with a slight excess of  $\text{Ba}(\text{OH})_2(\text{s})$ . The 50.0 g of water cooled from  $30.1\text{ }^\circ\text{C}$  to  $14.3\text{ }^\circ\text{C}$ .

Calculate the enthalpy change of this reaction, in  $\text{kJ mol}^{-1}$ .

(Relative atomic masses:  $\text{H} = 1.0$ ,  $\text{C} = 12.0$ ,  $\text{N} = 14.0$ ,  $\text{S} = 32.1$ ; specific heat capacity of water =  $4.18\text{ J g}^{-1}\text{ K}^{-1}$ )

 Unit Exercise (p.35)

$$\begin{aligned} \text{Amount of heat taken in from water} &= m \times c \times \Delta T \\ &= 50.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times (30.1 - 14.3) \text{ K} = 3\,300 \text{ J} = 3.30 \text{ kJ} \quad (1) \end{aligned}$$

$$\begin{aligned} \text{Molar mass of NH}_4\text{SCN(s)} &= (2 \times 14.0 + 4 \times 1.0 + 32.1 + 12.0) \text{ g mol}^{-1} \\ &= 76.1 \text{ g mol}^{-1} \end{aligned}$$

$$\text{Number of moles of NH}_4\text{SCN(s) reacted} = \frac{22.8 \text{ g}}{76.1 \text{ g mol}^{-1}} = 0.300 \text{ mol}$$

$$\text{Enthalpy change of reaction} = 2 \times \frac{+3.30 \text{ kJ}}{0.300 \text{ mol}} = +22.0 \text{ kJ mol}^{-1} \quad (1)$$

∴ the enthalpy change of this reaction is +22.0 kJ mol<sup>-1</sup>.



## Unit Exercise (p.35)

18 Ethene reacts with steam at 300 °C and 65 atm to form ethanol.



This reaction is exothermic.

a) Complete the table below by stating all the covalent bond(s) that are broken and formed during the reaction.

Covalent bond(s) broken	C-C, C-H, H-O	(1)
Covalent bond(s) formed	C-C, C-H, C-O, H-O	(1)

b) Suggest why the reaction is exothermic in terms of the breaking and forming of covalent bonds.

The total energy released in the bond forming process is greater than the total energy required in the bond breaking process. (1)



## Unit Exercise (p.35)

19 The standard enthalpy change of formation of water is  $-286 \text{ kJ mol}^{-1}$ .



a) State the standard conditions of temperature and pressure.

298 K  
1 atmosphere } (1)

b) Calculate the enthalpy change when 1.0 g of hydrogen burns in oxygen. What assumptions have you made?  
(Relative atomic mass: H = 1.0)

$$\text{Number of moles of H}_2 \text{ burnt} = \frac{1.0 \text{ g}}{2.0 \text{ g mol}^{-1}} = 0.50 \text{ mol}$$

$$\text{Enthalpy change} = -286 \text{ kJ mol}^{-1} \times 0.50 \text{ mol} = -143 \text{ kJ (1)}$$

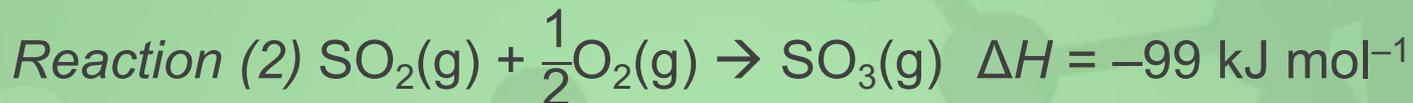
Assumptions:

- Complete combustion occurs. (1)
- No heat is lost to the surroundings. (1)



## Unit Exercise (p.35)

20 The equations of two reactions involved in the manufacture of sulphuric acid are shown below.



a) State, with a reason, whether *Reaction (1)* would be accompanied by a decrease or increase in temperature.

An increase in temperature The reaction is exothermic. /  $\Delta H$  is a negative quantity. (1)

b) At room temperature, sulphur trioxide is a solid. Deduce, with a reason, whether the  $\Delta H$  value would be more negative or less negative if  $\text{SO}_3\text{(s)}$  instead of  $\text{SO}_3\text{(g)}$  were formed in *Reaction (2)*.

More negative (1)

Heat is released when a gas changes to a solid / a solid has less enthalpy than a gas. (1)



## Unit Exercise (p.35)

21 One route to the production of hydrocarbons is the Fischer-Tropsch process, which uses hydrogen and carbon monoxide as starting materials to produce a range of compounds. The equation below shows the production of hexane by this route.



a) State the temperature and pressure used as standard conditions.

**298 K, 1 atmosphere (1)**

b) Using hexane as an example, state the meaning of the term 'standard enthalpy change of combustion' with the aid of a chemical equation.

**The standard enthalpy change of combustion of a substance,  $\Delta H_c^\ominus$ , is the enthalpy change when one mole of the substance is completely burnt in oxygen under standard conditions. (1)**



c) State why the standard enthalpy of formation of hydrogen gas is

**0 kJ mol<sup>-1</sup>. Hydrogen gas is an element in its standard state. (1)**



## Unit Exercise (p.35)

22 A student carried out an experiment to determine the enthalpy change of the following reaction.



- The student measured the initial temperature of 50.0 cm<sup>3</sup> of 0.500 mol dm<sup>-3</sup> CuSO<sub>4</sub>(aq).
- The student added 1.00 g of magnesium powder and stirred the mixture.
- The student measured the maximum temperature of the mixture.

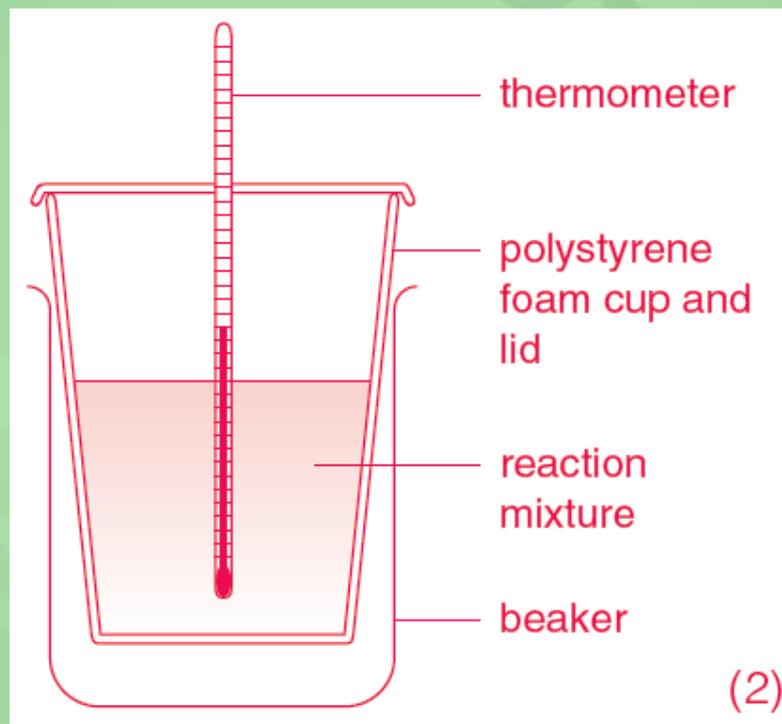
### Results

Initial temperature of the solution = 21.5 °C

Maximum temperature of the mixture = 74.3 °C

 Unit Exercise (p.35)

- a) Draw a labelled diagram of the experimental set-up that could have been used to carry out the experiment.





## Unit Exercise (p.35)

- b) Show, by calculations, that  $\text{CuSO}_4(\text{aq})$  was the limiting reactant.  
(Relative atomic mass of Mg = 24.3)

$$\text{Number of moles of Mg} = \frac{1.00 \text{ g}}{24.3 \text{ g mol}^{-1}} = 0.0412 \text{ mol}$$

$$\text{Number of moles of CuSO}_4 = 0.500 \text{ mol dm}^{-3} \times \frac{50.0}{1\,000} \text{ dm}^3 = 0.0250 \text{ mol}$$

According to the equation, 1 mole of Mg reacts with 1 mole of  $\text{CuSO}_4$ .

In this reaction, 0.0250 mole of Mg reacted with 0.0250 mole of  $\text{CuSO}_4$ . (1)

Thus, Mg was in excess.  $\text{CuSO}_4(\text{aq})$  was the limiting reactant.

- c) Assuming that the heat capacity of the mixture was  $214 \text{ J K}^{-1}$ , calculate the enthalpy change of this reaction, in  $\text{kJ mol}^{-1}$ .

$$\begin{aligned} \text{Enthalpy change when 0.0250 mole of Mg reacts with 0.0250 mole of CuSO}_4 \\ = 214 \text{ J K}^{-1} \times (74.3 - 21.5) \text{ K} = 11\,300 \text{ J} = 11.3 \text{ kJ} \quad (1) \end{aligned}$$

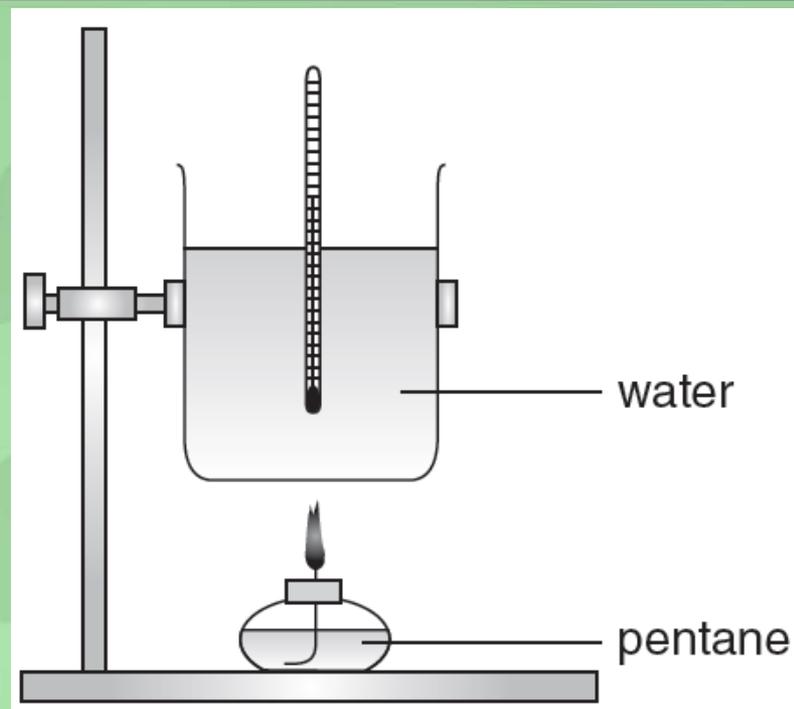
$$\text{Enthalpy change of reaction} = \frac{-11.3 \text{ kJ}}{0.0250 \text{ mol}} = -452 \text{ kJ mol}^{-1} \quad (1)$$

$\therefore$  the enthalpy change of the reaction is  $-452 \text{ kJ mol}^{-1}$ .

 Unit Exercise (p.35)

23 The enthalpy change of combustion of pentane ( $C_5H_{12}$ ) was measured using the apparatus shown below.

The results of the experiment are shown below.



Mass of pentane burnt	0.756 g
Mass of water in calorimeter	150.0 g
Initial temperature of water	22.5 °C
Final temperature of water	56.8 °C

 Unit Exercise (p.35)

a) Assuming that the heat capacity of the calorimeter is negligible, calculate the enthalpy change of combustion of pentane, in  $\text{kJ mol}^{-1}$ , under the experimental conditions.

(Specific heat capacity of water =  $4.18 \text{ J g}^{-1} \text{ K}^{-1}$ )

$$\text{Amount of heat} = m \times c \times \Delta T$$

$$= 150.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times (56.8 - 22.5) \text{ K} = 21\,500 \text{ J} = 21.5 \text{ kJ (1)}$$

$$\text{Molar mass of pentane} = (5 \times 12.0 + 12 \times 1.0) \text{ g mol}^{-1}$$

$$= 72.0 \text{ g mol}^{-1}$$

$$\text{Number of moles of pentane burnt} = 0.756 \text{ g}$$

$$72.0 \text{ g mol}^{-1}$$

$$= 0.0105 \text{ mol}$$

$$\text{Enthalpy change of combustion} = -21.5 \text{ kJ}$$

$$0.0105 \text{ mol}$$

$$= -2\,050 \text{ kJ mol}^{-1} \text{ (1)}$$

$\therefore$  the enthalpy change of combustion of pentane is  $-2\,050 \text{ kJ mol}^{-1}$ .

 Unit Exercise (p.35)

b) The data book value for the standard enthalpy change of combustion of pentane is  $-3\,509\text{ kJ mol}^{-1}$ . List THREE ways in which the design of the experiment causes the results to be so different from the data book value.

Any THREE of the following:

- Heat loss from the beaker / beaker not insulated / no lid on beaker (1)
- Incomplete combustion of pentane / formation of soot on beaker (1)
- Not all the energy from the flame is used to heat the water (1)
- Heat capacity of the beaker is neglected (1)
- Evaporation of hot pentane / water (1)
- Non-standard conditions (1)

 Unit Exercise (p.35)

c) Suggest a reason why this experiment would be too hazardous to carry out in a school laboratory.

Any one of the following:

- Pentane is very volatile / has a low boiling point.

So there is a risk of explosion. (1)

- Pentane has a high flammability. (1)

d) i) Write the equation for the complete combustion of pentane.

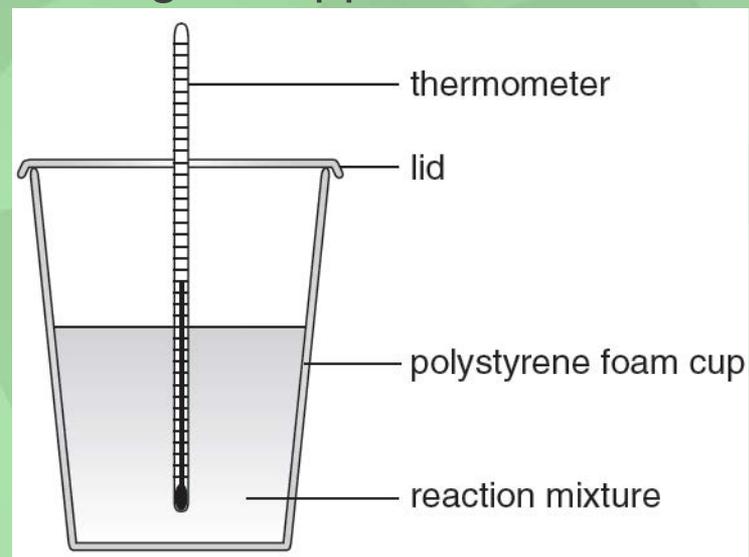
ii) Explain why the enthalpy change of combustion of pentane is exothermic.

i)  $C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(l)$  (1)

ii) The total energy released in the bond forming process is greater than the total energy required in the bond breaking process. (1)

 Unit Exercise (p.35)

24 A student measured the enthalpy change of the reaction between sodium hydrogencarbonate and citric acid solution using the apparatus shown below.

**Procedure**

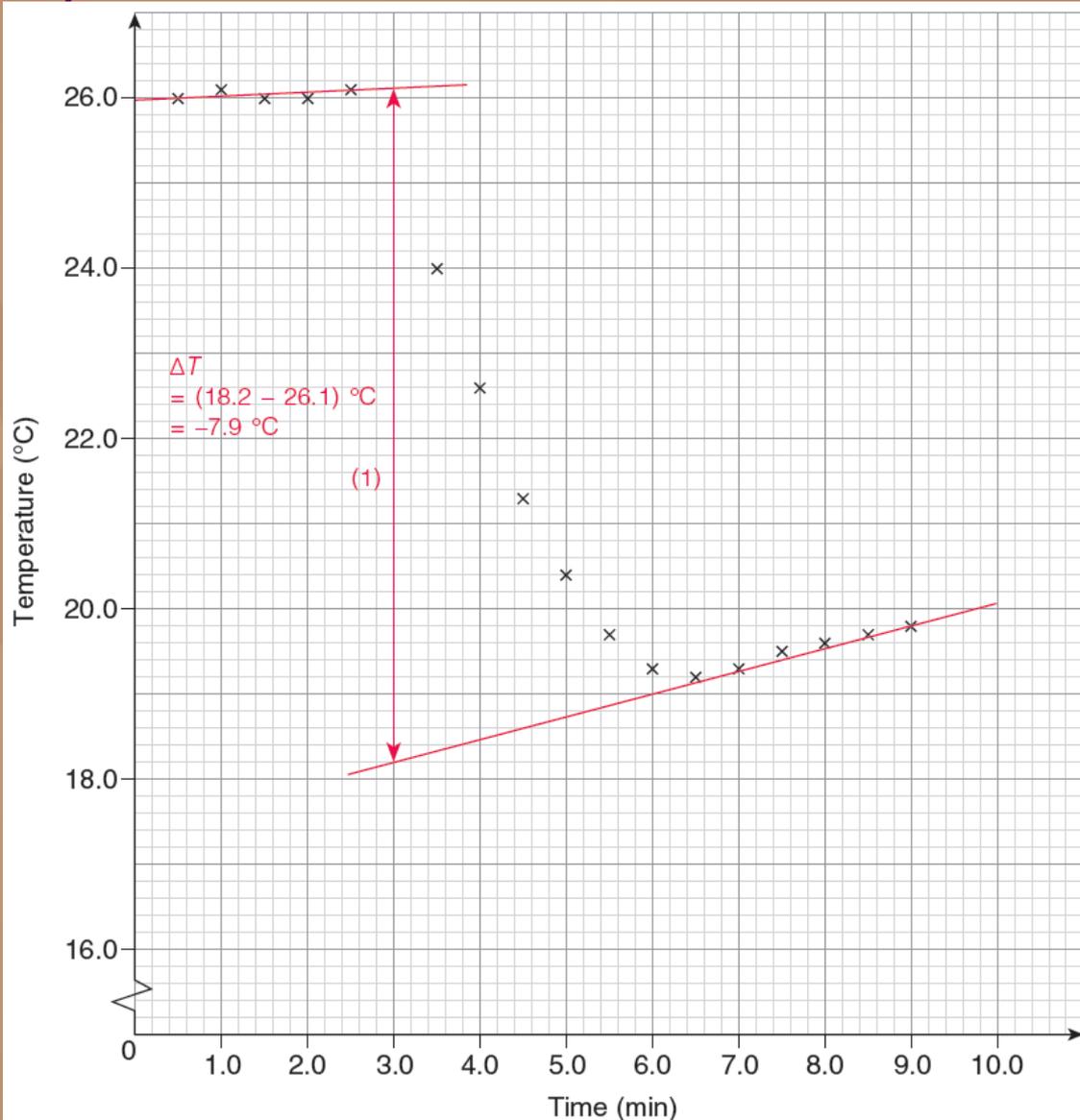
- 1 Place a sample of citric acid solution (excess) in a polystyrene foam cup.
- 2 Weigh out 12.0 g of sodium hydrogencarbonate.
- 3 Measure the temperature of the citric acid solution every 30 seconds for 2.5 minutes. At 3.0 minutes, add the sodium hydrogencarbonate to the solution and stir the mixture.
- 4 Measure the temperature every 30 seconds for a further of 6.0 minutes.

The graph below shows the results obtained.

 Unit Exercise (p.35)

The graph below shows the results obtained.

- a) Estimate, from the graph, the maximum temperature change of the reaction mixture.



 Unit Exercise (p.35)

b) The mass of the reaction mixture was 52.0 g.

Assuming that the specific heat capacity of the reaction mixture is  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$ , calculate the heat transferred from the reaction mixture.

Amount of heat taken in =  $m \times c \times \Delta T$

$$= 52.0 \times 4.2 \text{ J g}^{-1} \text{ K}^{-1} \times 7.9 \text{ K} = 1730 \text{ J} = 1.73 \text{ kJ (1)}$$

c) Calculate the enthalpy change,  $\Delta H$ , per mole of sodium hydrogencarbonate in this reaction.

(Relative atomic masses: H = 1.0, C = 12.0, Na = 23.0)

Molar mass of  $\text{NaHCO}_3$

$$= (23.0 + 1.0 + 12.0 + 3 \times 16.0) \text{ g mol}^{-1} = 84.0 \text{ g mol}^{-1}$$

$$\text{Number of moles of NaHCO}_3 \text{ reacted} = \frac{12.0 \text{ g}}{84.0 \text{ g mol}^{-1}} = 0.143 \text{ mol}$$

$$\text{Enthalpy change per mole of NaHCO}_3 = \frac{+1.73}{0.143 \text{ mol}} = +12.1 \text{ kJ mol}^{-1} \text{ (1)}$$

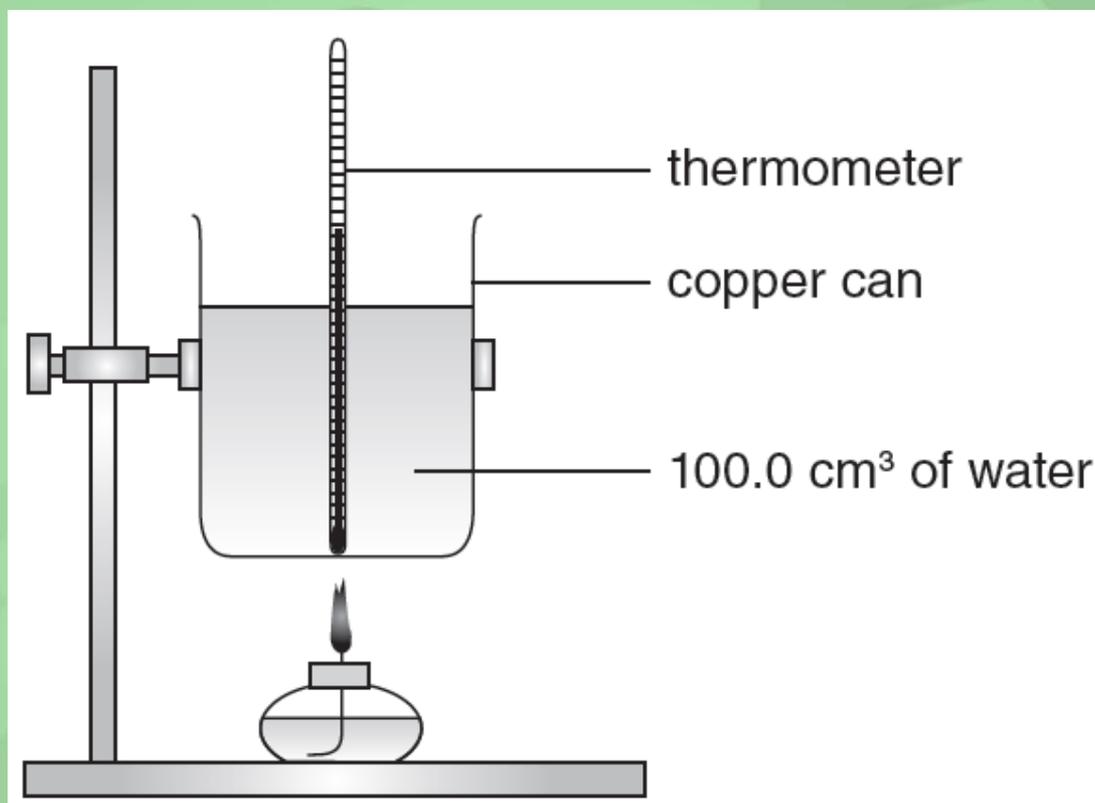
$\therefore$  the enthalpy change per mole of sodium hydrogencarbonate in this reaction is  $+12.1 \text{ kJ mol}^{-1}$ .



## Unit Exercise (p.35)



25 A student carried out an experiment to measure the enthalpy changes of combustion of methanol, ethanol and propan-1-ol. The experimental set-up shown below was used. The heating conditions were kept the same for the three alcohols.



 Unit Exercise (p.35)

- a) The teacher suggested that the thermometer had been placed in a wrong position. Suggest why the student's placing of the thermometer was incorrect.

The thermometer touching the bottom / directly above flame /  
the temperature rise recorded would be greater than expected. (1)

- b) The student always used 100.0 cm<sup>3</sup> of water. State another variable that the student should have kept constant.

Any one of the following:

- Distance between flame and copper can (1)
- Height of wick in burner (1)
- Same draught proofing (1)
- Height of copper can (1)

 Unit Exercise (p.35)

c) The student combusted 1.47 g of methanol and recorded a temperature rise of 25.8 °C.

Calculate the enthalpy change of combustion of methanol.

(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0; density of water = 1.00 g cm<sup>-3</sup>; specific heat capacity of water = 4.18 J g<sup>-1</sup> K<sup>-1</sup>)

Amount of heat =  $m \times c \times \Delta T = 100.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times 25.8 \text{ K} = 10\,800 \text{ J} = 10.8 \text{ kJ}$  (1)

Molar mass of CH<sub>3</sub>OH = (12.0 + 4 × 1.0 + 16.0) g mol<sup>-1</sup> = 32.0 g mol<sup>-1</sup>

Number of moles of CH<sub>3</sub>OH combusted =  $\frac{1.47 \text{ g}}{32.0 \text{ g mol}^{-1}} = 0.0459 \text{ mol}$

Enthalpy change of combustion of methanol =  $\frac{-10.8 \text{ kJ}}{0.0459 \text{ mol}} = -235 \text{ kJ mol}^{-1}$  (1)

∴ the enthalpy change of combustion of methanol is -235 kJ mol<sup>-1</sup>.

d) It was found that as the number of carbon atoms per molecule increased, the value of the enthalpy change of combustion became more negative.

Explain why the enthalpy change of combustion of ethanol is more negative than that of methanol.

More bonds are broken and made in ethanol. Thus, more heat is released. (1)



## Unit Exercise (p.35)

26 a) Write the definition of the term 'enthalpy change of neutralisation'.



The standard enthalpy change of neutralisation,  $\Delta H_n^\ominus$ , is the enthalpy change when an acid reacts with an alkali to form one mole of water under standard conditions. (1)

b) A student determined the enthalpy change of neutralisation between hydrochloric acid and sodium hydroxide solution by the procedure below.

### Procedure

- 1 25.0 cm<sup>3</sup> of 2.00 mol dm<sup>-3</sup> hydrochloric acid were transferred to a polystyrene foam cup and its temperature was recorded.
- 2 25.0 cm<sup>3</sup> of 2.00 mol dm<sup>-3</sup> sodium hydroxide solution were placed in another polystyrene foam cup and its temperature was recorded.
- 3 The two solutions were mixed, with stirring, and the maximum temperature was recorded.

### Results

Initial temperatures of both HCl(aq) and NaOH(aq) = 21.0 °C

Maximum temperature reached after mixing the solutions = 34.4 °C

 Unit Exercise (p.35)**Assumptions**

Specific heat capacity of all solutions =  $4.18 \text{ J g}^{-1} \text{ K}^{-1}$

Density of all solutions =  $1.00 \text{ g cm}^{-3}$

- i) Calculate the enthalpy change of neutralisation between hydrochloric acid and sodium hydroxide solution.

Volume of reaction mixture =  $(25.0 + 25.0) \text{ cm}^3 = 50.0 \text{ cm}^3$

Mass of reaction mixture =  $50.0 \text{ g}$

Amount of heat released =  $m \times c \times \Delta T = 50.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times (34.4 - 21.0) \text{ K}$   
 $= 2800 \text{ J} = 2.80 \text{ kJ} \text{ (1)}$

Number of moles of HCl reacted = number of moles of NaOH reacted

$= 2.00 \text{ mol dm}^{-3} \times \frac{25.0}{1000} \text{ dm}^3 = 0.0500 \text{ mol} = \text{number of moles of H}_2\text{O formed}$

Enthalpy change of neutralisation =  $\frac{-2.80 \text{ kJ}}{0.0500 \text{ mol}} = -56.0 \text{ kJ mol}^{-1} \text{ (1)}$

$\therefore$  the enthalpy change of neutralisation between hydrochloric acid and sodium hydroxide solution is  $-56.0 \text{ kJ mol}^{-1}$ .

 Unit Exercise (p.35)

- ii) The student repeated the experiment using 50.0 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> hydrochloric acid instead of 25.0 cm<sup>3</sup> of 2.00 mol dm<sup>-3</sup> hydrochloric acid. 25.0 cm<sup>3</sup> of 2.00 mol dm<sup>-3</sup> sodium hydroxide solution were still used. Explain why the temperature rise was less, and predict what the temperature would be.

The same amount of heat was spread over a larger volume of reaction mixture. (1)

$$\text{Volume of reaction mixture} = (50.0 + 25.0) \text{ cm}^3 = 75.0 \text{ cm}^3$$

$$\text{Mass of reaction mixture} = 75.0 \text{ g}$$

$$\text{Amount of heat released} = -2.80 \text{ kJ}$$

$$= 75.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times \Delta T$$

$$\Delta T = 8.9 \text{ }^\circ\text{C}$$

$$\text{Maximum temperature reached} = (21.0 + 8.9) \text{ }^\circ\text{C}$$

$$= 29.9 \text{ }^\circ\text{C} \text{ (1)}$$



## Unit Exercise (p.35)



\*27 You are provided with common laboratory apparatus, and ethanol and water. Outline how you would perform an experiment to determine the enthalpy change of combustion of ethanol.

Briefly describe the calculations involved.

### Procedure

- 1 Place a certain volume of water in a copper can used as a calorimeter. Measure the initial temperature of the water. (1)
- 2 Add ethanol to the spirit burner. Weigh the spirit burner containing the ethanol. (1)
- 3 Place the spirit burner under the copper can. Light the burner and burn the ethanol whilst stirring the water with the stirrer. (1)
- 4 After about three minutes, extinguish the flame. Immediately measure the maximum temperature of the water.
- 5 Reweigh the spirit burner containing the ethanol. (1)



## Unit Exercise (p.35)

### Experimental results and calculations

Suppose mass of water in copper can =  $m_w$

mass of ethanol burnt =  $m_e$

temperature change of water =  $\Delta T$

specific heat capacity of water =  $c$

Amount of heat transferred to water =  $m_w \times c \times \Delta T$  (1)

Number of moles of ethanol burnt =  $\frac{m_e}{\text{molar mass of ethanol}}$

Enthalpy change of combustion of ethanol =  $-\frac{\text{amount of heat transferred to water}}{\text{number of moles of ethanol burnt}}$  (1)

Communication mark (1)