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Friday 27 May 2022 – Afternoon

AS Level Chemistry B (Salters)

H033/02 Chemistry in depth

Time allowed: 1 hour 30 minutes

You must have:
- the Data Sheet for Chemistry B

You can use:
- a scientific or graphical calculator
- an HB pencil

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number | | | | | | Candidate number | | | | |

First name(s) _____

Last name StemUp Model Solution

INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION
- The total mark for this paper is **70**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **20** pages.

ADVICE
- Read each question carefully before you start your answer.

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Answer **all** the questions.

1 The element magnesium is an important Group 2 metal. Its presence in distant stars has been shown using atomic emission spectra.

(a) **(i)** The atomic **emission** spectrum of an element shows a series of coloured lines on a black background.

Describe how the appearance of the **absorption** spectrum of the element is similar to **and** different from its **emission** spectrum.

Similar Lines are in the same positions (same wavelengths / frequencies).

Different Black (dark) lines on a coloured background (continuous spectrum).

[2]

(ii) What evidence for the structure of atoms is provided by atomic spectra?

Electrons exist in quantised (discrete, specific) energy levels in atoms.

[1]

(b) Ionisation enthalpies have also been used to develop theories about atomic structure.

(i) Write an equation for the reaction that represents the first ionisation enthalpy of magnesium.

Include state symbols.

$Mg(g) \rightarrow Mg^{+}(g) + e^{-}$

[2]

(ii) The first ionisation enthalpies of the elements of Period 3 show a general increase across the period.

Explain this increase.

Across the period the number of protons increases, so the nuclear charge increases.

The outer electrons are in the same shell (same distance from the nucleus) with no increase in shielding.

So the outer electrons are attracted more strongly to the nucleus and it gets harder to remove the outer electron. **[3]**

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(c) The mass spectrum of magnesium shows that it has three stable isotopes as shown below.

Isotope	Abundance / %
^{24}Mg	78.60
^{25}Mg	10.11
^{26}Mg	11.29

Calculate a value for the relative atomic mass of magnesium based on these data.

Give your answer to **two** decimal places.

$A_r = [(78.60 \times 24) + (10.11 \times 25) + (11.29 \times 26)] / 100$

$A_r = (1886.4 + 252.75 + 293.54) / 100$

$A_r = 2432.69 / 100 = 24.3269 = 24.33$ (2 d.p.)

relative atomic mass = ...24.33..... **[2]**

(d) Magnesium-24 is formed in some stars by nuclear fusion of two identical carbon nuclei.

Complete the nuclear equation for the formation of this isotope.

$$2\ {}^{12}_{6}C \rightarrow {}^{24}_{12}Mg$$ **[1]**

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(e) A student is asked to prepare a sample of hydrated magnesium chloride crystals (containing water of crystallisation) starting from solid magnesium oxide.

The student adds magnesium oxide to hot hydrochloric acid until the oxide is in excess.

The student then evaporates the mixture until just a solid is left.

Explain why this procedure would **not** produce hydrated magnesium chloride crystals and give a correct method.

Evaporating to dryness gives magnesium chloride contaminated with the excess (unreacted) magnesium oxide, and it drives off the water of crystallisation.

Correct method: filter the mixture to remove the excess magnesium oxide.

Heat the filtrate to evaporate about half of the solution (until it is concentrated).

Leave the filtrate to cool and crystallise, then filter off the crystals of hydrated magnesium chloride and air dry them (between filter papers).

[4]

(f) Calcium and barium are two other Group 2 elements.

A student places a small piece of calcium into 100 cm^3 of cold water in a beaker. A steady fizzing occurs, the calcium disappears and a white, cloudy mixture of pH 11 is left. The temperature increases by 26 °C.

The student then repeats the experiment with an equal amount of barium.

Describe **two** differences that the student would observe when comparing the reaction of barium with that of calcium.

1 Faster fizzing (effervescence), and the barium disappears more quickly.

2 A clearer (less cloudy) solution forms and the temperature rise is greater than 26 °C.

[2]

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(g) Another student is provided with samples of magnesium carbonate and strontium carbonate and asked to identify which is which. The student heats equal amounts of each carbonate in separate test tubes using the same Bunsen flame. The student measures the time taken for the gas evolved to turn limewater cloudy.

The student says that the time taken will be shorter when strontium carbonate is heated because strontium is more reactive than magnesium.

Comment on the student's statement, giving the correct chemistry where necessary.

The student is correct that Sr is more reactive than Mg, but reactivity does not explain the trend.

Magnesium carbonate is less thermally stable, so it will turn the limewater cloudy in the shortest time (not strontium carbonate).

The Mg^{2+} ion is smaller (higher charge density) than Sr^{2+}, so it polarises (distorts) the large carbonate ion more. **[3]**

(h) Complete the electronic configuration for the magnesium **ion**, Mg^{2+}.

$1s^2$ $2s^2$ $2p^6$ **[1]**

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2 Heterogeneous catalysts are used on a large scale for catalytic cracking in industry.

(a) A student sets up the apparatus shown in **Fig. 2.1** to investigate the cracking of 'liquid paraffin'.

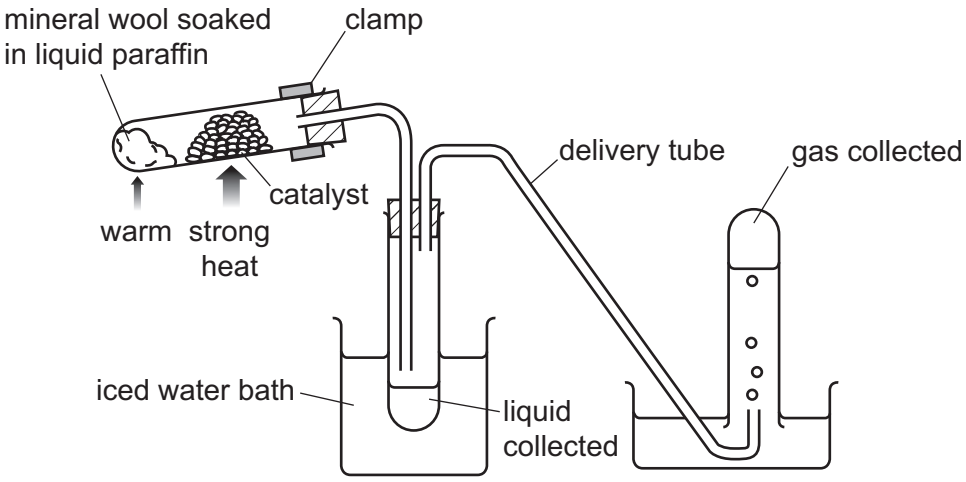

Fig. 2.1

(i) Explain why the catalyst is described as **heterogeneous**.

The catalyst and the reactants are in different states (phases): the catalyst is a solid and the reactants are gases. **[1]**

(ii) The catalyst gets coated with carbon over time and becomes less effective.

Give the general name of a substance that reduces the function of a catalyst in this way.

A (catalyst) poison **[1]**

(iii) The compounds below **might** be found in the apparatus in **Fig. 2.1** when it is in use.

Match the appropriate formula with the places from **Fig. 2.1**:

C_2H_4	C_6H_{14}	$C_{12}H_{26}$

Liquid paraffin ...$C_{12}H_{26}$.....

Liquid collected ...C_6H_{14}.....

Gas collected ...C_2H_4..... **[1]**

(iv) The gas collected is found to turn bromine water from orange/brown to colourless.

What can the student deduce from this?

The gas is unsaturated: it contains alkenes (C=C bonds). **[1]**

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(b) In cordless hair straighteners, butane is passed over a platinum coil that acts as a heterogeneous catalyst.

Butane reacts with oxygen in the air and releases thermal energy.

(i) Explain how a catalyst increases the rate of a chemical reaction.

It provides an alternative reaction pathway of lower activation energy.

..... **[1]**

(ii) Complete the missing stages in the mechanism of heterogeneous catalysis given below.

Stage 1 Reactants diffuse to and are adsorbed onto the catalyst surface.

Stage 2 Bonds in the reactants weaken and break.

.....

Stage 3 New bonds form to make the products.

.....

Stage 4 Products are desorbed from the catalyst surface and diffuse away.

[1]

(iii) Butane reacts with oxygen according to the following equation.

$C_4H_{10} + 6½O_2 \rightarrow 4CO_2 + 5H_2O$

Calculate the volume of oxygen, in m^3 (measured at RTP), required for the complete reaction of 1.0 g butane with oxygen.

Give your answer to an **appropriate** number of significant figures.

$M_r\ C_4H_{10} = (4 \times 12.0) + (10 \times 1.0) = 58.0$

$n(C_4H_{10}) = 1.0 / 58.0 = 1.72 \times 10^{-2}$ mol

$n(O_2) = 6.5 \times 1.72 \times 10^{-2} = 0.112$ mol

$V(O_2) = 0.112 \times 24.0 = 2.69\ dm^3$

$= 2.69 \times 10^{-3}\ m^3 = 2.7 \times 10^{-3}\ m^3$ (2 s.f.)

volume of oxygen = 2.7×10^{-3} m^3 **[4]**

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(c) Catalytic reactions also occur in the stratosphere where chlorine radicals are formed from the breakdown of chlorofluorocarbons, CFCs.

Chlorine radicals take part in the catalytic cycle shown:

$Cl + O_3 \longrightarrow ClO + O_2$

$ClO + O \longrightarrow Cl + O_2$

(i) Give the overall equation for the reaction that occurs in the cycle.

$O_3 + O \rightarrow 2O_2$

[1]

(ii) What is acting as a catalyst in this catalytic cycle and what **type** of catalysis is involved?

Chlorine (Cl radicals) act as the catalyst; homogeneous catalysis.....

..... **[1]**

(d) A CFC has the following percentage composition by mass:

C, 11.7%; F, 18.8%; Cl, 69.5%.

The relative molecular mass of this CFC is 204.

Calculate the molecular formula of this CFC.

C : F : Cl = 11.7/12.0 : 18.8/19.0 : 69.5/35.5

= 0.975 : 0.989 : 1.96

= 1.00 : 1.01 : 2.01, so empirical formula = $CFCl_2$

M_r of $CFCl_2$ = 12.0 + 19.0 + 71.0 = 102; 204 / 102 = 2

molecular formula = ...$C_2F_2Cl_4$..... **[3]**

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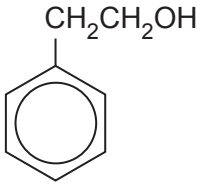
3 This question concerns some reactions of compound **A**.

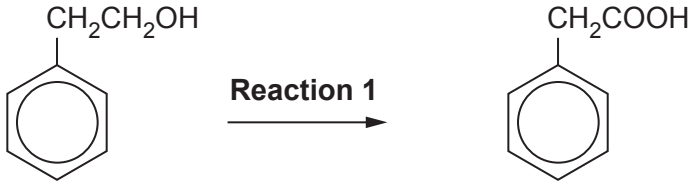


Compound A

Compound **A** is found in extract of orange blossom. A group of chemists carry out some reactions with this compound.

(a) Reaction 1

Compound **A** can be converted to an acid, compound **B**, as shown.



Compound A **Compound B**

(i) Explain why the alcohol functional group in compound **A** is classified as **primary**.

The OH is on a carbon atom that has two H atoms attached. **[1]**

(ii) Give the reagents and conditions required for **reaction 1**.

Reagents Acidified potassium dichromate(VI) (dilute H_2SO_4)

Conditions Heat under reflux

[1]

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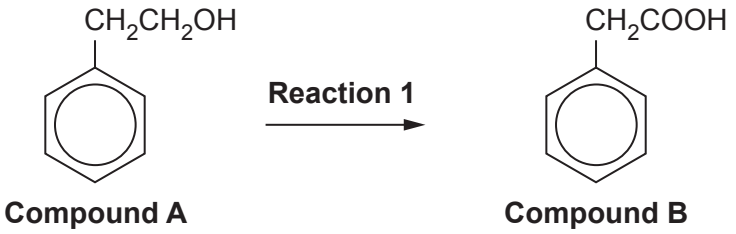
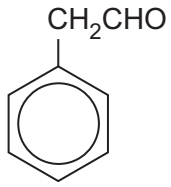
Reaction 1 (repeated)



(iii) **Reaction 1** occurs via the formation of compound **C**.



Compound C

The chemists use infrared spectroscopy to find out whether the conversion of compound **A** into compound **B** (**reaction 1**) is complete after 10 minutes. They set up a reaction mixture and analyse it after 10 minutes.

The infrared spectrum of the mixture shows absorptions at the wavenumbers shown in **Table 3.1**.

Type of absorption	Wavenumber / cm^{-1}
sharp	1200
several in a range	1500–1600
sharp	1710
sharp	1730
broad	2900
broad	3300

Table 3.1

Use the information from **Table 3.1** to determine whether the conversion is complete after 10 minutes.

Give the relevant bonds for any wavenumbers you refer to.

The reaction has not gone to completion after 10 minutes.

The sharp peak at 1730 cm^{-1} is C=O in an aldehyde, so some compound C (aldehyde) is still present.

The broad peak at 3300 cm^{-1} is O–H in a carboxylic acid (COOH), so some compound B has formed; 1710 cm^{-1} is C=O in COOH.

..... **[3]**

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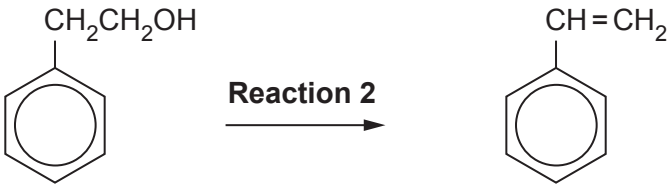
(b) Reaction 2

Compound **A** can be dehydrated as shown.



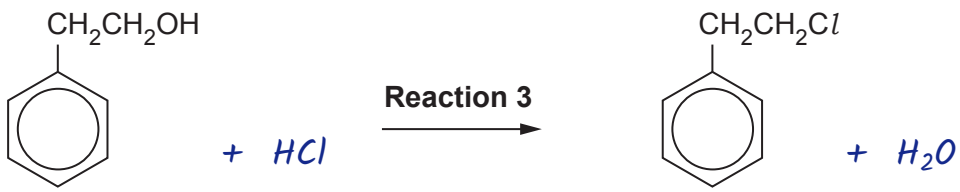
What **type** of reaction is this dehydration?

..Elimination..... **[1]**

(c) Reaction 3

Compound **A** can be reacted with hydrochloric acid.

An incomplete equation is shown below.



Complete the balanced equation for this reaction.

[1]

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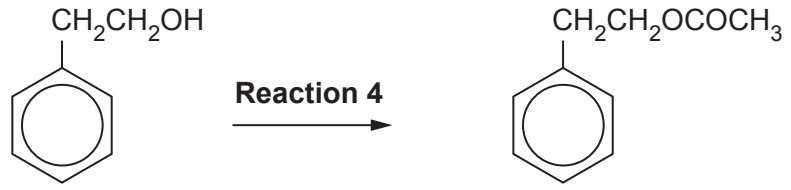
(d)* Reaction 4

Compound **A** can be converted to an ester, compound **D**, as shown.



Compound A **Compound D**

A student attempts to carry out **reaction 4** using two different methods.

In one method the student uses equimolar amounts of compound **A** and ethanoic acid.

In the other method, equimolar amounts of compound **A** and ethanoic anhydride are used.

At the end of each reaction the mixture is analysed using thin-layer chromatography. The results of this analysis are shown below in **Fig. 3.1**.

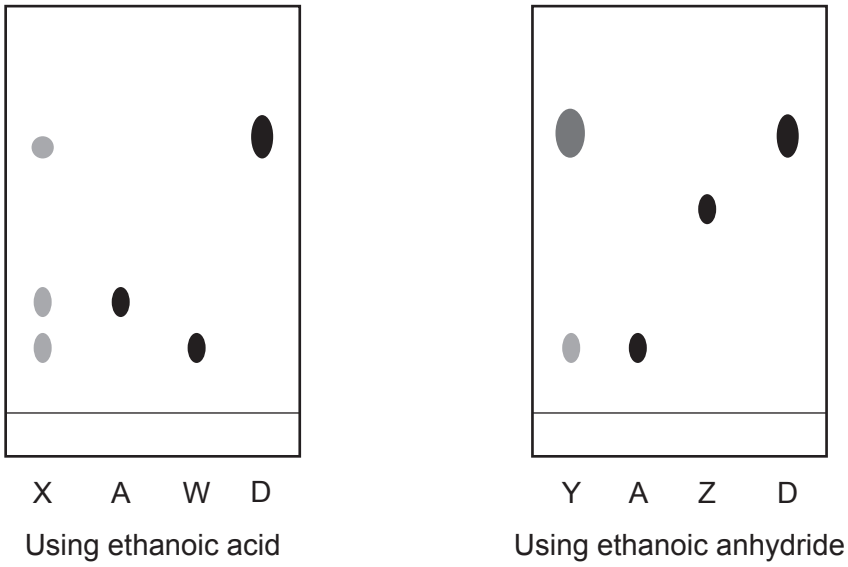


Fig. 3.1

Key to chromatograms in Fig. 3.1

X = recrystallised product from ethanoic acid

Y = recrystallised product from ethanoic anhydride

A = Compound **A**

W = ethanoic acid

Z = ethanoic anhydride

D = Compound **D**

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Describe how the student would run the chromatograms once the substances have been spotted onto the thin-layer plates.

Use **Fig. 3.1** to explain how well ethanoic acid and ethanoic anhydride work at carrying out **reaction 4**.

Running: place the plate in a beaker containing a small amount of solvent, with the solvent level below the pencil line (start line), and cover the beaker with a lid (watch glass).

Remove the plate when the solvent front is near the top of the plate and mark (in pencil) how far the solvent has reached. Allow the plate to dry.

Locate the spots using iodine or under a UV lamp.

Analysis: both ethanoic acid and ethanoic anhydride have produced compound D, because X and Y each have a spot at the same height as D.

X has three components (all reactants and product): spots level with A, W and D, so with ethanoic acid some compound A and ethanoic acid remain.

The reaction is incomplete and the spot level with D is small, so ethanoic acid gives a lower yield of D.

Y has only two components (one reactant and the product): there is no spot level with Z, so the ethanoic anhydride has reacted completely, and only a faint spot level with A remains. **[6]**

Additional answer space if required.

The spot level with D from Y is bigger and darker than the one from X, so more D is made.

Conclusion: ethanoic anhydride works better than ethanoic acid at carrying out reaction 4.

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4 Vehicles using petrol as fuel will still be on the roads for some time to come.

It is important that developments continue to improve fuel efficiency and further reduce harmful emissions.

(a) Petrol is a complex mixture of compounds, mainly hydrocarbons.

(i) One of the hydrocarbons in petrol is octane, C_8H_{18}.

Write an equation for the complete combustion of octane.

$C_8H_{18} + 12\frac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$

[1]

(ii) Oxides of nitrogen (NO_x) which can lead to acid rain are also produced in a petrol engine.

Give the conditions in the engine that cause the usually unreactive nitrogen to react with oxygen.

The high temperature in the engine (about 1000 °C or more).

..... **[1]**

(b) 4.3 g of another liquid hydrocarbon present in petrol produce 554 cm^3 of vapour at 60 °C and 250 kPa.

Use these data to work out the M_r of the hydrocarbon.

$pV = nRT$, so $n = pV / RT$

$p = 250 \times 10^3$ Pa, $V = 554 \times 10^{-6}$ m^3, $T = 60 + 273 = 333$ K

$n = (250 \times 10^3 \times 554 \times 10^{-6}) / (8.314 \times 333)$

$n = 138.5 / 2768.6 = 0.0500$ mol

M_r = mass / n = 4.3 / 0.0500 = 86

M_r = ...86..... **[4]**

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(c) The alcohol methanol is a liquid oxygenate that is used in petrol to reduce the amount of incomplete combustion that occurs.

(i) Methanol burns in oxygen as shown in **equation 4.1**.

$CH_3OH(g) + 1\frac{1}{2}O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$ $\Delta_c H_{298} = -676\,kJ\,mol^{-1}$ **Equation 4.1**

Some average bond enthalpy data are given in **Table 4.1**.

Bond	Average bond enthalpy / kJ mol^{-1}
C–O	+358
O–H	+464
O=O	+498
C=O	+805

Table 4.1

Calculate a value for the average bond enthalpy of the C–H bond in methanol.

Use the data in **Table 4.1** and the value of $\Delta_c H_{298}$ in **equation 4.1**.

$\Delta_c H$ = (bonds broken) – (bonds made), x = C–H

bonds broken = 3x + 358 + 464 + 1.5(498) = 3x + 1569

bonds made = 2(805) + 4(464) = 1610 + 1856 = 3466

–676 = 3x + 1569 – 3466

3x = 1221, so x = +407 kJ mol^{-1}

average bond enthalpy of C–H = ...+407..... kJ mol^{-1} **[3]**

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(ii) The **standard** enthalpy change of combustion of methanol ($\Delta_c H^{\ominus}_{298}$) is **not** the same as the value given in **equation 4.1**.

Give a reason for this.

Under standard conditions methanol and water are liquids; energy is needed to turn them into gases (bond enthalpies are averages for gases). **[1]**

(iii) There are two carbon-oxygen bonds listed in **Table 4.1**.

Explain why the C=O double bond is shorter than the C–O single bond.

More electrons between the atoms in the double bond give greater attraction to the bonded nuclei, pulling the atoms closer together. **[2]**

(d) A student carries out an experiment to measure $\Delta_c H$ for methanol, CH_3OH. The student burns the methanol in a spirit burner below a beaker containing 100 cm^3 water, as shown in **Fig. 4.1** on page 18.

The following measurements are recorded:

mass of spirit burner and methanol before combustion	12.58 g
mass of spirit burner and methanol after combustion	11.62 g
temperature of water before combustion	17.0 °C
temperature of water after combustion	45.0 °C

Use these measurements to calculate a value for $\Delta_c H$ of methanol in kJ mol^{-1}.

$q = mc\Delta T = 100 \times 4.18 \times (45.0 - 17.0) = 11704\ J = 11.704\ kJ$

mass of methanol = 12.58 − 11.62 = 0.96 g; M_r CH_3OH = 32.0

$n = 0.96 / 32.0 = 0.030$ mol

$\Delta_c H = -11.704 / 0.030 = -390\ kJ\ mol^{-1}$

$\Delta_c H$ of CH_3OH = −390 kJ mol^{-1} **[3]**

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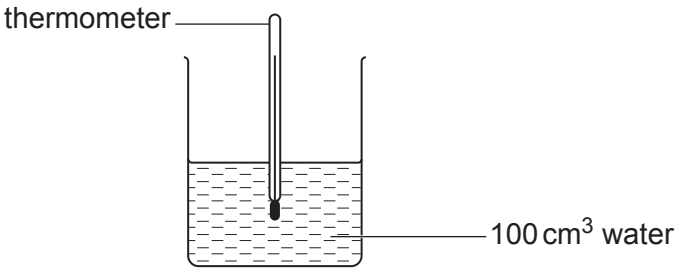
(e)* The student uses the following procedure to obtain the measurements in **part (d)**.



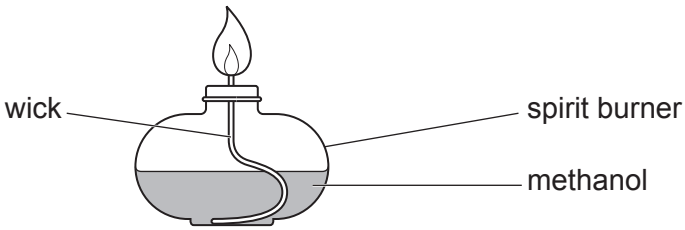


Fig. 4.1

Procedure:

1 The mass of a spirit burner containing methanol is measured and recorded.

2 100 cm^3 of water is measured into a 250 cm^3 glass beaker using the graduations on the beaker.

3 The temperature of the water is measured and recorded.

4 The apparatus is set up as shown in **Fig. 4.1**, with the beaker being held in position using a clamp, boss and stand (not shown).

5 The wick of the spirit burner is ignited.

6 When the temperature of the water in the beaker has risen by about 30 °C, the flame on the spirit burner is blown out.

7 After the water is emptied out of the beaker and the apparatus has been put away, the mass of the spirit burner is measured and recorded again.

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The student wants to improve the accuracy of the calculated enthalpy change of combustion by changing the method.

Suggest and explain possible improvements to the procedure on page 18.

Measure the 100 cm^3 of water with a measuring cylinder or pipette (or weigh it on a balance), which has less uncertainty than the beaker graduations.

Use a copper can instead of a glass beaker: copper is a better thermal conductor (lower specific heat capacity), so more heat goes into the water.

Put a lid on the can to reduce evaporation of water and heat loss. Stir the water throughout heating so the heat is evenly distributed.

Reduce the distance between the top of the flame and the bottom of the can, and put a draught shield around the apparatus, so less heat is lost to the surroundings.

Fit a cap on the spirit burner when it is not lit, and replace the cap straight after blowing out the flame, then weigh it at once (not after putting the apparatus away), to reduce loss of methanol by evaporation.

Record the highest temperature reached by the water, because heat continues to transfer from the can to the water after the flame is out.

Ideally use a bomb calorimeter, which removes most heat loss and gives better heat transfer. **[6]**

Additional answer space if required.

END OF QUESTION PAPER

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ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).

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