1. Zinc reacts with copper(II) sulfate solution, $CuSO_4(aq)$.

Which apparatus could be used to determine the effect of the concentration of $CuSO_4(aq)$ on the rate of reaction?

A balance

B gas syringe

C colorimeter

D pH meter

Your answer ☐

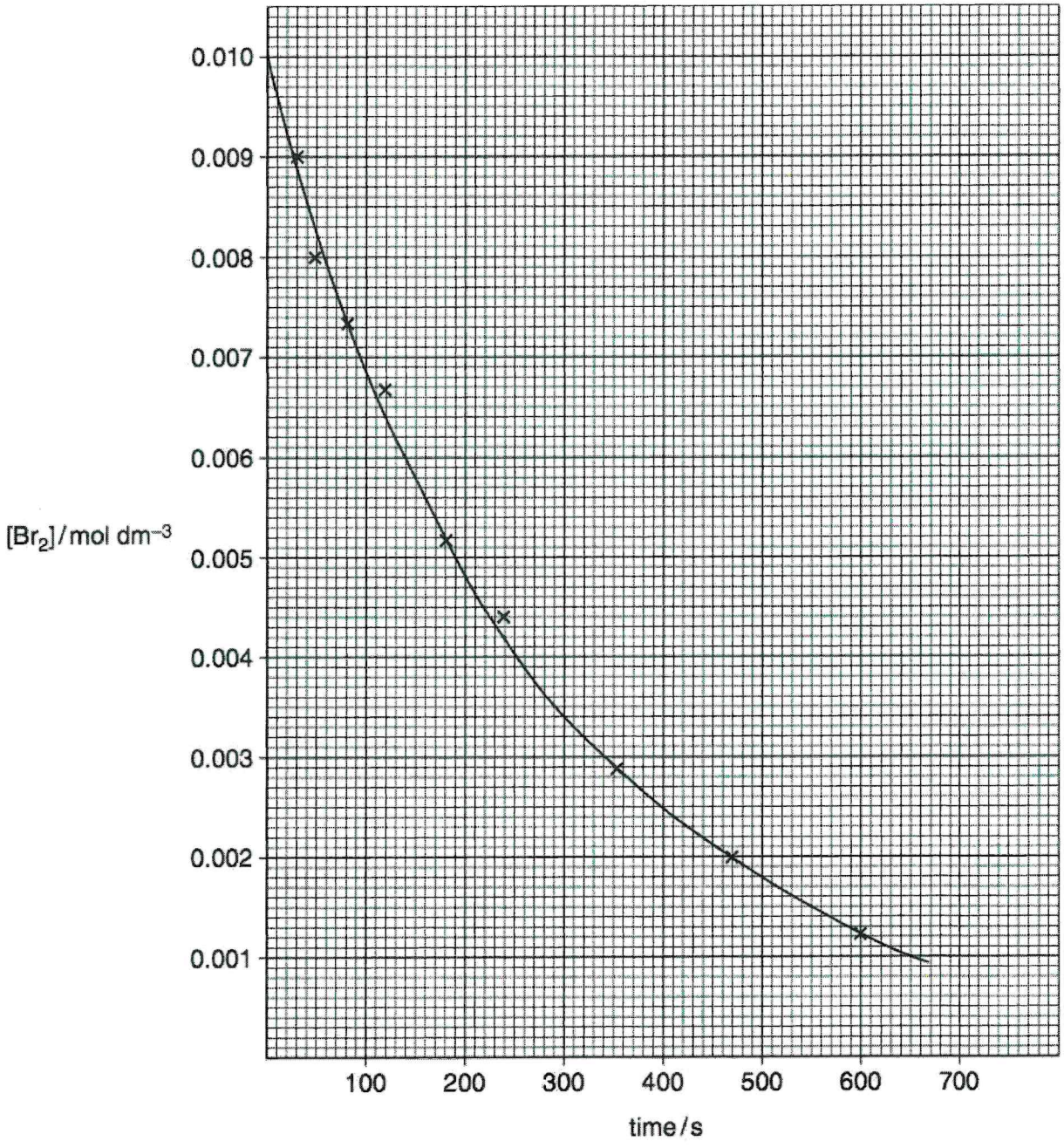
[1]

2 Methanoic acid and bromine react as in the equation below.

$$Br_2(aq) + HCOOH(aq) \rightarrow 2H^+(aq) + 2Br^-(aq) + CO_2(g)$$

A student investigates the rate of this reaction by monitoring the concentration of bromine over time. The student uses a large excess of HCOOH to ensure that the order with respect to HCOOH will be effectively zero.

From the experimental results, the student plots the graph below.



(a) Suggest how the concentration of the bromine could have been monitored.

.....

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

(b) Suggest a different experimental method that would allow the rate of this reaction to be followed over time.

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

(c) Why would use of excess HCOOH ensure that the order with respect to HCOOH is effectively zero?

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

(d)* Using the graph, determine

- the initial rate of reaction
- the rate constant.

Your answer must show full working using the graph and the lines below as appropriate.

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..... **[6]**

3. A student plans to determine the enthalpy change of **reaction 3.1** shown below.

$$Na_2O(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l)$$ **reaction 3.1**

This enthalpy change can be determined indirectly using Hess' Law from the enthalpy changes of **reaction 3.2** and **reaction 3.3** shown below.

$$Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$$ **reaction 3.2**

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) \quad \Delta_r H = -57.6\,kJ\,mol^{-1}$$ **reaction 3.3**

The student will determine the enthalpy change of **reaction 3.2** as outlined below.

- Weigh a bottle containing $Na_2O(s)$ and weigh a polystyrene cup.
- Add about $25\,cm^3$ of water to the polystyrene cup and measure its temperature.
- Add the $Na_2O(s)$, stir the mixture, and measure the maximum temperature reached.
- Weigh the empty bottle and weigh the polystyrene cup with the final solution.

Mass readings

Mass of bottle + $Na_2O(s)$	= 16.58 g
Mass of empty bottle	= 15.34 g
Mass of empty polystyrene cup	= 21.58 g
Mass of polystyrene cup + final solution	= 47.33 g

Temperature readings

Initial temperature of water	= 20.5 °C
Maximum temperature of final solution	= 55.5 °C

The density and specific heat capacity, *c*, of the solution are the same as for water.

4 This question is about the halogen group of elements and some of their compounds.

(a) The halogens show trends in their properties down the group.

The boiling points of three halogens are shown below.

Halogen	Boiling point/°C
Chlorine	–35
Bromine	59
Iodine	184

Explain why the halogens show this trend in boiling points.

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

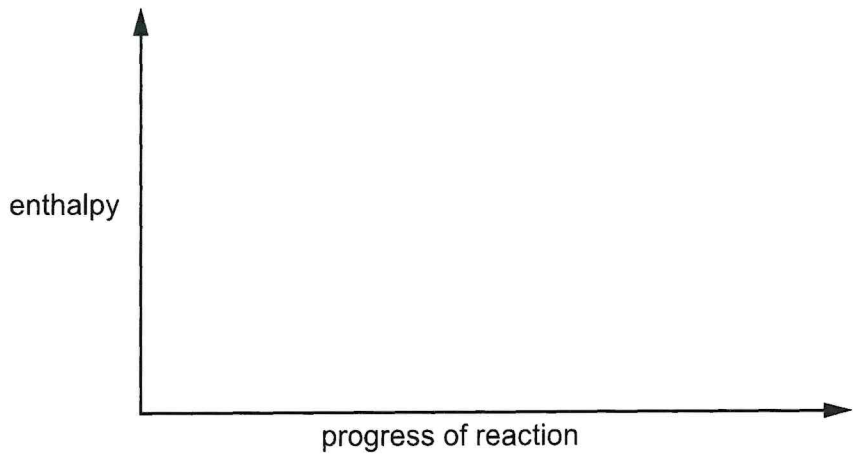
(b) Hydrogen iodide, HI, is decomposed by heat into its elements:

$$2HI(g) \rightarrow H_2(g) + I_2(g) \qquad \Delta H = +9.5\,kJ\,mol^{-1}$$

The decomposition is much faster in the presence of a platinum catalyst.

Complete the enthalpy profile diagram for this reaction using formulae for the reactants and products.

- Use E_a to label the activation energy **without** a catalyst.
- Use E_c to label the activation energy **with** a catalyst.
- Use ΔH to label the enthalpy change of reaction.



[3]

(c) Compound **A** is an oxide of chlorine that is a liquid at room temperature and pressure and has a boiling point of 83 °C.

When 0.4485 g of **A** is heated to 100 °C at 1.00×10^5 Pa, 76.0 cm^3 of gas is produced.

Determine the molecular formula of compound **A**.

Show all your working.

molecular formula of **A** = ... **[4]**

(d) Compound **B** is an iodate(V) salt of a Group 1 metal.
The iodate(V) ion has the formula IO_3^-.

A student carries out a titration to find the formula of compound **B**.

Step 1: The student dissolves 1.55 g of **B** in water and makes up the solution to 250.0 cm^3 in a volumetric flask.

Step 2: The student pipettes 25.00 cm^3 of the solution of **B** into a conical flask, followed by 10 cm^3 of dilute sulfuric acid and an excess of KI(aq).

The iodate(V) ions are reduced to iodine, as shown below.

$$IO_3^-(aq) + 6H^+(aq) + 5I^-(aq) \rightarrow 3I_2(aq) + 3H_2O(l)$$

Step 3: The resulting mixture is titrated with 0.150 mol dm^{-3} $Na_2S_2O_3(aq)$.

$$2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$

The student repeats **step 2** and **step 3** until concordant titres are obtained.

Titration readings

Titration	**Trial**	**1**	**2**	**3**
Final burette reading / cm^3	24.00	47.40	23.75	47.05
Initial burette reading / cm^3	0.00	24.00	0.00	23.20
Titre / cm^3				

Table 20.1

(i) Complete **Table 20.1** and calculate the mean titre that the student should use for analysing the results.

mean titre = ... cm^3 **[2]**

(ii) The uncertainty in each burette reading is ±0.05 cm^3.

Calculate the percentage uncertainty in the titre obtained from **titration 1**.

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

percentage uncertainty = ... % **[1]**

(iii) Describe and explain how the student should determine the end point of this titration accurately.

.....

.....

..... **[2]**

(iv) Determine the relative formula mass and formula of the Group 1 iodate(V), **B**.

Show your working.

relative formula mass of **B** = ...

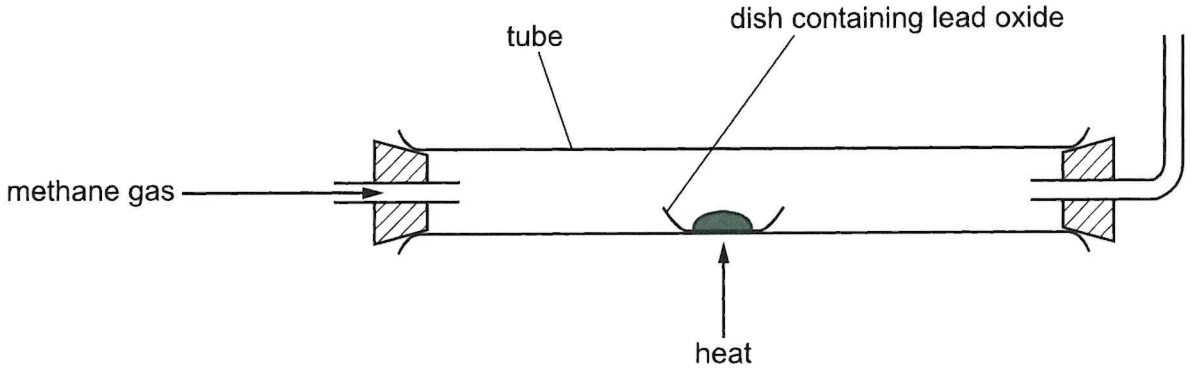
formula of **B** = ... **[5]**

5 This question is about elements and compounds in Group 14 (Group 4) of the periodic table.

(a) There are four oxides of lead: PbO, PbO_2, Pb_2O_3 and Pb_3O_4.

A student carries out an experiment to identify an unknown lead oxide, which is one of the four oxides of lead shown above.

The student plans to reduce the unknown lead oxide to lead by heating the lead oxide in a stream of methane gas, CH_4. The apparatus is shown below.



Student's method

- Weigh an empty dish.
  Add the lead oxide to the dish and reweigh.
- Set up the apparatus and pass methane gas through the tube as shown.
  Heat the dish for 10 minutes.
- Pass cold air through the tube to cool the dish and contents.
- Weigh the dish and contents.

(i) Write the equation for the reduction of Pb_2O_3 with CH_4.

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

(ii) The student uses safety glasses and a lab coat.

State, with a reason, **one** other important safety precaution the student should take when carrying out this experiment.

.....

.....

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

(iii) The student was not sure that all the oxygen had been removed from the lead oxide.

Suggest **two** modifications that the student could make to their method to be confident that all the oxygen had been removed. Explain your reasoning.

1 .....

.....

2 .....

.....

[2]

(iv) The student makes suitable modifications to the method and repeats the experiment to obtain the accurate results shown below.

Mass of dish/g	8.364
Mass of dish + lead oxide/g	11.818
Mass of dish + lead at end of experiment/g	11.496

Calculate the empirical formula of the lead oxide.

empirical formula = ... **[2]**

(b) SiO_2 and CO_2 are oxides of other Group 14 (Group 4) elements.

Solid SiO_2 melts at 2156 °C. Solid CO_2 melts at −56 °C.

Suggest the type of lattice structure in solid SiO_2 and in solid CO_2 and explain the difference in melting points in terms of the types of force within each lattice structure.

Structure in SiO_2(s) .....

Structure in CO_2(s) .....

Explanation .....

.....

.....

..... **[4]**

6 Several students titrate 25.00 cm^3 of the same solution of sodium hydroxide, NaOH(aq) with hydrochloric acid, HCl(aq).

One student obtains a smaller titre than the other students.

Which procedure explains the smaller titre?

A The burette readings are taken from the top of the meniscus instead of the bottom of the meniscus.

B The conical flask is rinsed with water before carrying out the titration.

C An air bubble is released from the jet of the burette during the titration.

D The pipette is rinsed with water before filling with NaOH(aq).

Your answer ☐ **[1]**

7 A student carries out an investigation to identify two metals, **M** and **X**, by two different methods.

(a) The student is provided with a sample of metal **M**.

The student analyses metal **M** using a 'back-titration' technique:

- The metal is reacted with excess acid.
- The resulting solution is titrated to determine the amount of acid remaining after the reaction.

Stage 1
The student adds 100 cm^3 of 2.10 mol dm^{-3} HC*l*(aq) to 6.90 g of **M**.
An excess of HC*l*(aq) has been used to ensure that all of metal **M** reacts.

A redox reaction occurs, forming a solution containing **M** in the +2 oxidation state.

Stage 2
The resulting solution from **Stage 1** is made up to 250.0 cm^3 with distilled water.

Stage 3
A 25.00 cm^3 sample of the diluted solution from **Stage 2** is titrated with 0.320 mol dm^{-3} NaOH(aq).

The NaOH(aq) reacts with excess HC*l*(aq) that remains in **Stage 1**:

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

The student repeats the titration to obtain concordant titres.

Titration results (The trial titre has been omitted.)
The burette readings have been recorded to the nearest 0.05 cm^3.

	1	2	3
Final reading / cm^3	27.80	37.55	32.20
Initial reading / cm^3	0.50	10.00	5.00

(i) In **Stage 1**, a redox reaction takes place between **M** and HC*l*(aq), forming hydrogen and a solution containing **M** in the +2 oxidation state.

Write an overall equation, with state symbols, for this reaction. Write half-equations for the oxidation and reduction processes.

Overall equation .....

Oxidation half-equation .....

Reduction half-equation .....

[3]

(ii) In **Stage 1**, suggest **two** observations that would confirm that all of metal **M** has reacted.

1 .....

.....

2 .....

.....

[2]

(iii) In **Stage 3**, write the ionic equation for the reaction taking place in the titration.

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

(iv) Metal **M** can be identified following the steps below.

1. The amount, in mol, of excess HC*l*(aq) that remains after the reaction of **M** with HC*l*(aq).
2. The amount, in mol, of HC*l*(aq) that reacted with **M**.
3. The identity of metal **M**.

Analyse the results to identify metal **M**.

Metal **M** = ... **[6]**

(b) The student is provided with the carbonate of an unknown metal, $\mathbf{X}_2CO_3$.

The student measures the mass loss when the $\mathbf{X}_2CO_3$ is reacted with an **excess** of hydrochloric acid. The equation is shown below.

$\mathbf{X}_2CO_3(s) + 2HCl(aq) \rightarrow 2\mathbf{X}Cl(aq) + CO_2(g) + H_2O(l)$

The reaction is carried out using this method:

Step 1 Add $100\,cm^3$ $HCl(aq)$ to a conical flask and weigh.

Step 2 Add $\mathbf{X}_2CO_3$ to the conical flask and immediately reweigh.

Step 3 After 5 minutes, reweigh the conical flask and contents.

Results

Mass of conical flask + $HCl(aq)$	172.93 g
Mass of conical flask + $\mathbf{X}_2CO_3$ + $HCl(aq)$ before reaction	187.50 g
Mass of conical flask + contents after 5 minutes	184.75 g

(i) Calculate the amount, in mol, of CO_2 released in the reaction.

Amount of CO_2 = ... mol **[1]**

(ii) Calculate the molar mass of $\mathbf{X}_2CO_3$ and identify metal **X**.

Molar mass of $\mathbf{X}_2CO_3$ = ... $g\,mol^{-1}$ Metal **X** = ...**[3]**

(c) After analysing the results, the student was told that their molar mass of $\mathbf{X}_2CO_3$ was incorrect.

The student evaluated the experiment for possible reasons for the incorrect result.

(i) The student wondered whether the reaction was complete when the mass was recorded after 5 minutes (**Step 3**).

How could the student modify the experimental procedure to be confident that the reaction was complete?

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

(ii) The student finds out that carbon dioxide is slightly soluble in water.

State and explain how the solubility of CO_2 would affect the calculated molar mass of $\mathbf{X}_2CO_3$.

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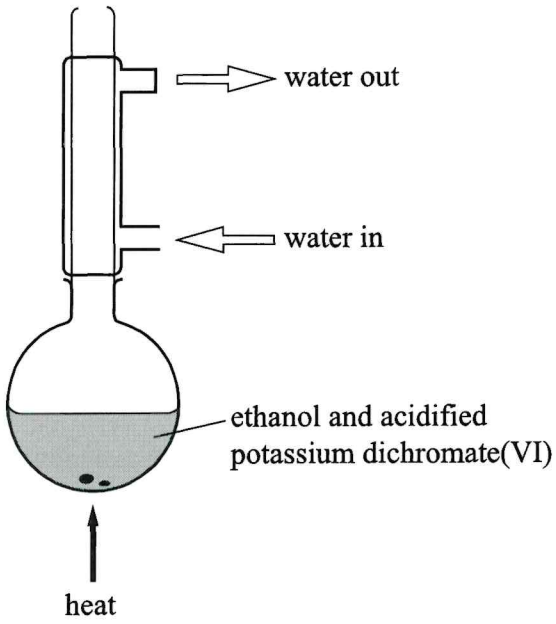
..... **[2]**

8 Ethanol is oxidised to ethanoic acid using acidified potassium dichromate(IV) solution. The reaction is heated under reflux using the equipment shown in the diagram below.



What is the reason for heating under reflux?

A to ensure even heating

B to prevent any substances escaping

C to boil the mixture at a higher temperature

D to allow efficient mixing

Your answer ☐

[1]

(b) Ethanedioic acid removes excess dichromate ions, $Cr_2O_7^{2-}$, as in the equation below.

$$3(COOH)_2 + Cr_2O_7^{2-} + 8H^+ \rightarrow 6CO_2 + 2Cr^{3+} + 7H_2O$$

Suggest how you could tell when the excess dichromate has completely reacted with the ethanedioic acid.

.....

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

(c) A student monitors the course of this reaction using thin-layer chromatography (TLC).

Outline how TLC could be used to monitor the course of the reaction.

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..... **[2]**

(d) Plan an experiment that would allow the student to confirm the identity of the pure organic product by means of a chemical test.

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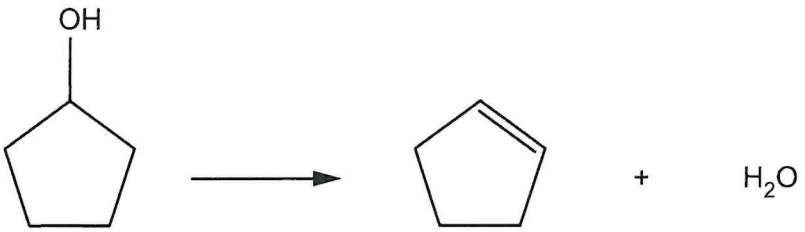
..... **[3]**

10 Cyclopentanol can be reacted to form cyclopentene.
Cyclopentene is a liquid with a boiling point of 44 °C and a density of 0.74 g cm^{-3}.

A student plans to prepare 4.00 g of cyclopentene by reacting cyclopentanol (boiling point 140 °C) with an acid catalyst.

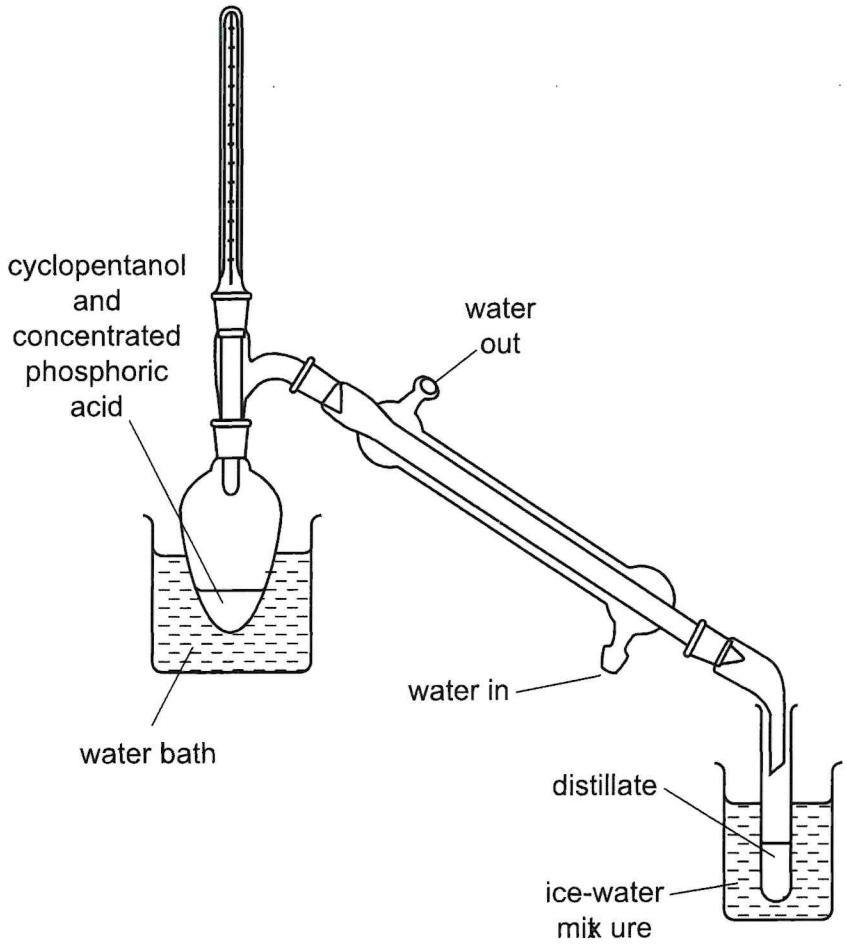
Equation



The expected percentage yield of cyclopentene is 64.0%.

Method
The student carries out the preparation using apparatus set up for distillation, as shown below.

1 The reaction mixture is heated gently, and a distillate containing impure cyclopentene is collected.

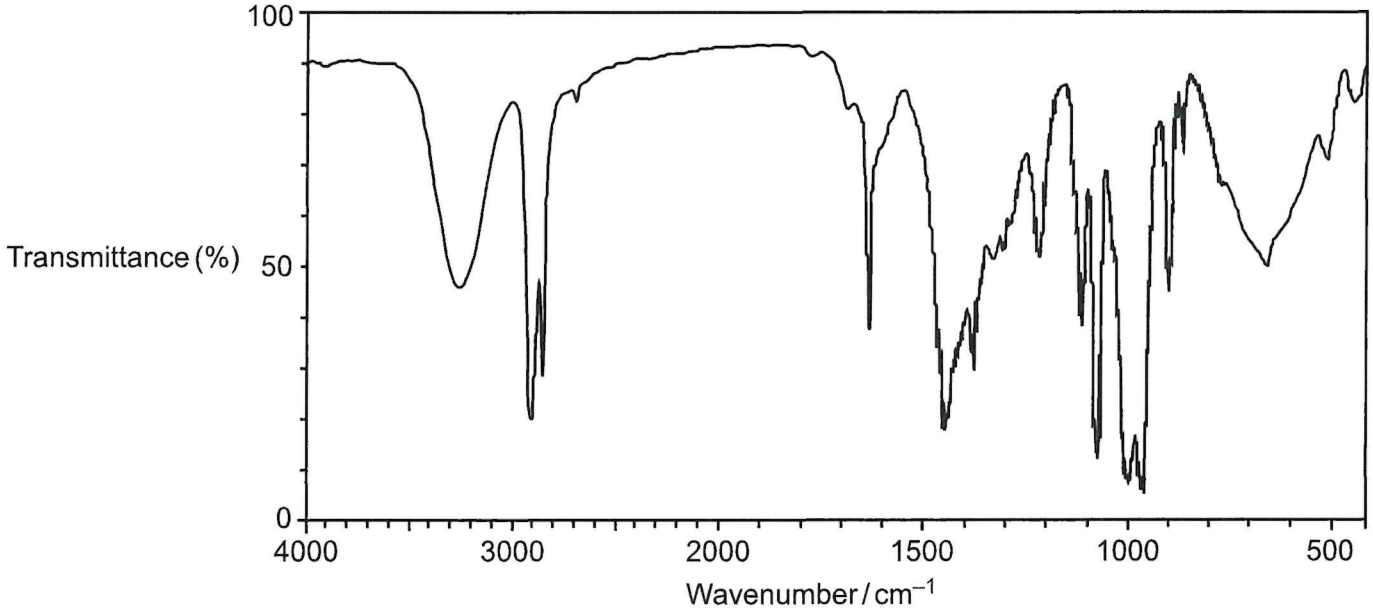


2 The distillate has an aqueous layer and an organic layer.
The student purifies the cyclopentene from the distillate.

(a)* Calculate the mass of cyclopentanol that the student should use and explain how pure cyclopentene could be obtained from the distillate. **[6]**

Additional answer space if required

(b) The organic layer in the distillate was analysed by IR spectroscopy.
The IR spectrum is shown below.



Explain how the IR spectrum of the organic layer suggests that cyclopentene has been formed and that the reaction is incomplete.

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..... **[2]**