Questions

Q1.

(a) State what is meant by the term **molar volume of a gas**.

(1)

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(b) The following steps were carried out by a student to find the molar mass of a gas. The experiment was carried out at 20 °C and one atmosphere pressure. The dry gas was supplied in a plastic bag fitted with a self-sealing device. The student had a choice of two different gas syringes. The student decided to use a 50 cm^3 syringe.

Step **1.** The 50 cm^3 syringe was fitted with a needle and then emptied of air by pushing in the plunger to zero. The needle was sealed by pushing the needle into a rubber bung and the syringe and bung were then weighed on a balance.

Step **2.** The syringe was checked for leaks by pulling the plunger out by about 10 cm^3 for a few seconds before releasing it.

Step **3.** The rubber bung was removed from the needle which was then inserted through the self-sealing device in the plastic bag of the dry gas.

Step **4.** 50 cm^3 of the dry gas was withdrawn from the plastic bag into the syringe and the needle resealed with the same rubber bung used in step **1**.

Step **5.** The syringe and rubber bung were then reweighed on the balance.

Results

volume of gas used	50 cm^3
initial mass of empty syringe	107.563 g
final mass of syringe + gas	107.655 g

(i) The gas syringe has a total uncertainty of ±0.5 cm^3.
Each reading on the balance has an uncertainty of ±0.0005 g.
Calculate the percentage uncertainty in the measurement of the volume and mass of gas used in this procedure.

(2)

(ii) The student repeated the experiment with 100 cm^3 of the gas using a 100 cm^3 syringe.
The total uncertainty for this larger syringe was also ±0.5 cm^3.
Determine the effect, if any, on the volume and mass uncertainties.

(2)

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(iii) Calculate the molar mass of the gas used in the procedure outlined in part (b). You may assume that one mole of gas occupies 24 000 cm^3 under these conditions. Give your answer to an appropriate number of significant figures and include units in your answer.

(2)

(iv) Explain how the student would know if the syringe had a leak in step **2** and what effect this leak would have on the molar mass determined in part (b)(iii).

(2)

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(c) If the temperature had been less than 20 °C and the pressure remained at one atmosphere, deduce the effect, if any, on the molar mass calculated in part (b)(iii).

(2)

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(d) Give a reason why the gas should be dry.

(1)

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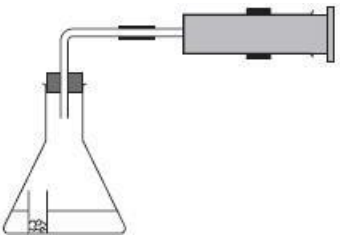
(Total for question = 12 marks)

Q2.

A student wanted to measure the volume of a gas and use the results to find the volume occupied by one mole of the gas. The following method was used.

- A sample of calcium carbonate was weighed out in a small plastic container.
- 20 cm^3 of hydrochloric acid of concentration 2.00 mol dm^{-3} was added to a conical flask. A small pinch of calcium carbonate was added to the acid.
- The container was placed in the conical flask and a gas syringe was connected to the top of the conical flask.
- The flask was carefully shaken so that the small plastic container fell over, allowing the acid and calcium carbonate to mix.

The apparatus set up is shown.



The student repeated the experiment five times using different masses of calcium carbonate on each occasion, with the concentration and volume of the hydrochloric acid constant.

Experiment number	Mass / g	Volume of CO_2 / cm^3
1	0.10	23
2	0.20	44
3	0.30	67
4	0.40	96
5	0.50	115

(a) (i) Write the equation for the reaction between calcium carbonate and hydrochloric acid. Include state symbols.

(2)

(ii) Calculate the molar mass of calcium carbonate.

(1)

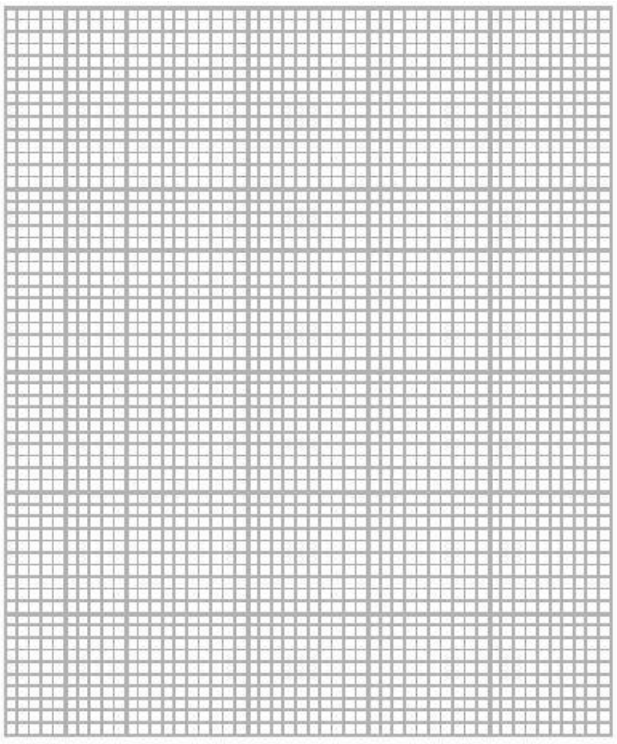
. .....g mol^{-1}

(iii) Show that, in each experiment, the hydrochloric acid is in excess.

(2)

(b) (i) Plot a graph of volume of carbon dioxide produced against mass of calcium carbonate on the grid. Include a line of best fit.

(2)



(ii) State how your graph supports the idea that the volume of gas produced depends directly on the mass of calcium carbonate added.

(1)

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(c) Calculate the volume, under these conditions, of one mole of carbon dioxide gas from these data. Give your answer in dm^3 to **two** significant figures.

(2)

(d) Give a reason why the student added a small pinch of calcium carbonate to the acid before starting the reaction.

(1)

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(Total for question = 11 marks)

Q3.

Ethanol, C_2H_5OH, is a member of the homologous series of alcohols.

Calculate the number of molecules in 55.2kg of ethanol.

[Avogadro Constant = 6.02×10^{23} mol^{-1}]

(2)

(Total for question = 2 marks)

Q4.

Sulfur is a bright yellow crystalline solid at room temperature.

Sulfur forms rings of 8 sulfur atoms so the formula of the yellow solid is S_8.

Compound **X** is an oxide of sulfur. A gaseous sample of 0.318 g of **X** occupied a volume of 132 cm^3 at a temperature of 420 K and pressure of 105 kPa.

The number of moles of a gas and the volume occupied by it can be found using the ideal gas equation

$$pV = nRT$$

Calculate the relative molecular mass of **X** and hence its molecular formula.
You must show **all** your working.

[R = 8.31 J mol^{-1} K^{-1}]

(5)

(Total for question = 5 marks)

Q5.

This question is about alkenes with the molecular formula C_5H_{10}.

A sample of pent-1-ene, with a mass of 1.33 g, is warmed to 60 °C in a sealed container.
The volume of the container is 500 cm^3.

Calculate the pressure inside the container.
Include units and give your answer to an appropriate number of significant figures.

[Gas constant (R) = 8.31 J mol^{-1} K^{-1}]

(4)

(Total for question = 4 marks)

Q6.

In an experiment, 1.000 g of a hydrocarbon, **A**, was burned completely in oxygen to produce 3.143 g of carbon dioxide and 1.284 g of water.

In a different experiment, the molar mass of the hydrocarbon, **A**, was found to be 84.0 g mol^{-1}.

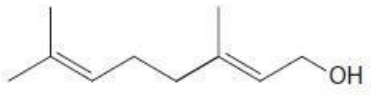
Calculate the empirical formula and the molecular formula of the hydrocarbon, **A**.

(4)

(Total for question = 4 marks)

Q7.

The characteristic smell of pine wood is due, partly, to the presence of a group of compounds called terpenes. One of the simpler terpenes is a compound called geraniol, which is an oily liquid at room temperature and pressure. The structure of geraniol is



Deduce the molecular formula of geraniol. Use your answer to calculate the molar mass of geraniol in g mol^{-1}.

(2)

(Total for question = 2 marks)

Q8.

Boron and aluminium are in the same group of the Periodic Table. Both form compounds with chlorine and with fluorine.

Aluminium also reacts directly with chlorine to form a compound, aluminium chloride, containing only aluminium and chlorine.

A 0.500 g sample of aluminium chloride was analysed and found to contain 0.101 g of aluminium.

Another 0.500 g sample was heated to 473 K. The gas produced occupied a volume of 73.6 cm^3 at a pressure of 1.00×10^2 kPa.

Determine the molecular formula of the gas.

You will need to use the equation $pV = nRT$ and $R = 8.31$ J mol^{-1} K^{-1}

(6)

(Total for question = 6 marks)

Q9.

A group of students analysed a hydrated salt with the formula $KH_3(C_2O_4)_y$. zH_2O where **y** and **z** are whole numbers.

The students carried out experiments to determine the values of **y** and **z**.

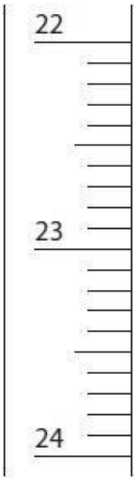
(a) Experiment 1 – to determine the value of **y**

One student was provided with a 0.0235 mol dm^{-3} solution of the salt.
25.0 cm^3 portions of the salt solution were acidified with excess dilute sulfuric acid and heated to about 60 °C.
Each portion was titrated with 0.0203 mol dm^{-3} potassium manganate(VII).
The results of four titrations are shown in the table.

Titration number	1	2	3	4
Final burette reading / cm^3	23.85	47.20	24.05	48.10
Initial burette reading / cm^3	0.00	24.00	0.50	25.00
Titre / cm^3	23.85	23.20	23.55	23.10

(i) Complete the diagram to show the final burette reading in **Titration 1**.

(2)



(ii) Explain why this student should use a mean titre of 23.15 cm^3 and not 23.43 cm^3 in the calculation.

(2)

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(iii) The uncertainty in each burette reading is ±0.05 cm^3.
Calculate the percentage uncertainty in the titre volume of potassium manganate(VII) solution used in **Titration 2**.

(1)

(iv) The equation for the reaction is

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

Deduce, by calculation, the value of **y**, to the nearest whole number, in the formula $KH_3(C_2O_4)_{\mathbf{y}}$. $\mathbf{z}H_2O$.
Use the mean titre of 23.15 cm^3 and other data from **Experiment 1**.
You **must** show your working.

(4)

(b) **Experiment 2** – to determine the value of **z**

Another student wrote an account of the method for this experiment.

A crucible was weighed.

A sample of the hydrated salt was added to the crucible and it was reweighed.

The crucible and salt were heated to remove the water of crystallisation and then allowed to cool.

The crucible and contents were weighed again.

Results

Mass of crucible	*= 19.56 g*
Mass of crucible + $KH_3(C_2O_4)_y.zH_2O$	*= 22.97 g*
Mass of crucible + $KH_3(C_2O_4)_y$	*= 22.52 g*

(i) Deduce, by calculation, the value of **z**, to the nearest whole number, in the formula $KH_3(C_2O_4)_y.\ zH_2O$.
You must use the data from **Experiment 2** and your value of **y** in (a)(iv).
You **must** show your working.

(3)

(ii) A third student carried out Experiment 2 and calculated a value of **z** that was lower than expected.

This student evaluated the experiment and gave two suggestions for **z** being lower.

Suggestion **1**

"Some of the crystals jumped out of the crucible while it was being heated."

Suggestion **2**

"It was difficult to tell when all the water of crystallisation had been lost."

Evaluate these two suggestions to decide whether they could account for the lower value of **z** obtained from the experimental results.

Include an explanation of the effect each suggestion would have on the calculated value of **z** and how the method could be improved to prevent these errors.

(5)

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(Total for question = 17 marks)

Q10.

Sulfur reacts with fluorine to form a number of different compounds.

One compound contains 45.79% sulfur and 54.21% fluorine by mass.
Calculate the empirical formula of this compound.

(2)

(Total for question = 2 marks)

Q11.

This question is about isotopes, mass spectra and hydrocarbons.

1.00 g of a **different** hydrocarbon, **W**, was burnt in oxygen.
Analysis of the combustion products showed that complete combustion produced 3.14 g of carbon dioxide and 1.29 g of water.

Water and carbon dioxide were the only products of combustion.

Calculate the **empirical** formula of hydrocarbon **W**.
You **must** show your working.

(4)

(Total for question = 4 marks)

Q12.

This question is about equilibrium systems.
Sulfur dioxide and oxygen form an equilibrium with sulfur trioxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The composition of an equilibrium mixture at 698 K and a total pressure of 2.40 atm is shown in the table.

Substance	$SO_2(g)$	$O_2(g)$	$SO_3(g)$
Number of moles /mol	0.0160	0.0120	0.772

(i) Calculate the value of K_p at this temperature.
Include units, if appropriate.

(5)

(ii) Calculate the number of sulfur dioxide molecules present in this equilibrium mixture.

(1)

(iii) Deduce, by referring to K_p, how the number of sulfur dioxide molecules will change if more oxygen is added to the equilibrium mixture.

(2)

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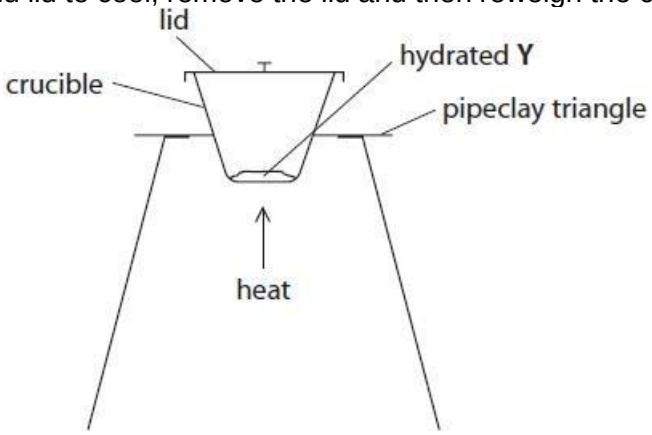
(Total for question = 8 marks)

Q13.

Y is identified as hydrated potassium carbonate, $K_2CO_3 \cdot nH_2O$.
Two of the students were asked to determine the number of moles of water of crystallisation, *n*, in **Y** using the procedure shown:

- weigh a sample of hydrated **Y** into a pre-weighed crucible
- place a lid loosely on the crucible and heat it for five minutes to remove the water of crystallisation
- allow the crucible and lid to cool, remove the lid and then reweigh the crucible with its contents.



(i) The first student carried out the experiment but forgot to use the lid.

Explain how this mistake would affect the calculated value of *n*.

(2)

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(ii) The second student carried out the experiment but heated the apparatus for only **one** minute.

Explain how this mistake would affect the calculated value of *n*.

(2)

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(iii) In an accurate experiment, **Y** is found to consist of 71.9% K_2CO_3 by mass.

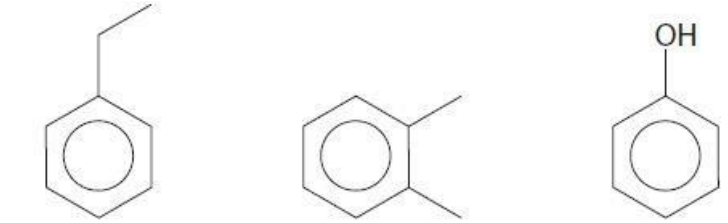
Calculate the value of *n*.

(3)

(Total for question = 7 marks)

Q14.

This question is about the arenes, ethylbenzene, xylene, and phenol, which can be identified in wine samples using gas chromatography.



ethylbenzene xylene phenol

A student carried out an experiment to determine the molar mass of xylene.

The student's sample of xylene vapour had a mass of 0.271 g.

At a temperature of 165 °C and a pressure of 118 kPa, this sample had a volume of 70.5 cm^3.

Use the Ideal Gas Equation to calculate the molar mass, in g mol^{-1}, of this sample.

Give your answer to an appropriate number of significant figures.

You **must** show your working.

(4)

(Total for question = 4 marks)

Q15.

This question is about the identification of an alcohol, **X**.

(a) Alcohol **X** has the following percentage composition by mass:

carbon, C	= 68.2%
hydrogen, H	= 13.6%
oxygen, O	= 18.2%

The molecular ion peak in the mass spectrum for alcohol **X** occurs at m/z = 88.
Use all of these data to show that the molecular formula for alcohol **X** is $C_5H_{12}O$. Include your working.

(2)

(b) (i) When alcohol **X** is oxidised, a carboxylic acid is formed.

State what information this gives about alcohol **X**.

(1)

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(ii) Draw the **displayed** formulae of the four possible structural isomers that could be alcohol **X**.

(3)

Alcohol 1	Alcohol 2
Alcohol 3	**Alcohol 4**

(iii) The mass spectrum of alcohol **X** has a major peak at *m*/*z* = 45.
Draw the structure of the species that could give this peak.

(1)

(iv) Alcohol **X** has a branched chain.
Identify alcohol **X**, explaining your reasoning.

(2)

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(Total for question = 9 marks)

Q16.

This question is about nitrogen and some nitrogen compounds.

A study of one brand of crisps found that each packet contained 0.420 g of nitrogen gas at a pressure of 120 kPa and a temperature of 20°C.

(i) Calculate the volume of nitrogen gas, in **cm^3**, in one packet of crisps.

[R = 8.31 J mol^{-1} K^{-1}]

(4)

(ii) Give a possible reason why nitrogen gas and not air is used in packets of crisps.

(1)

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(Total for question = 5 marks)

Q17.

This question is about organic compounds containing fluorine and chlorine.

The use of chlorofluorocarbons as refrigerants has ceased due to concerns about their effects on the ozone layer. One such compound is dichlorodifluoromethane.

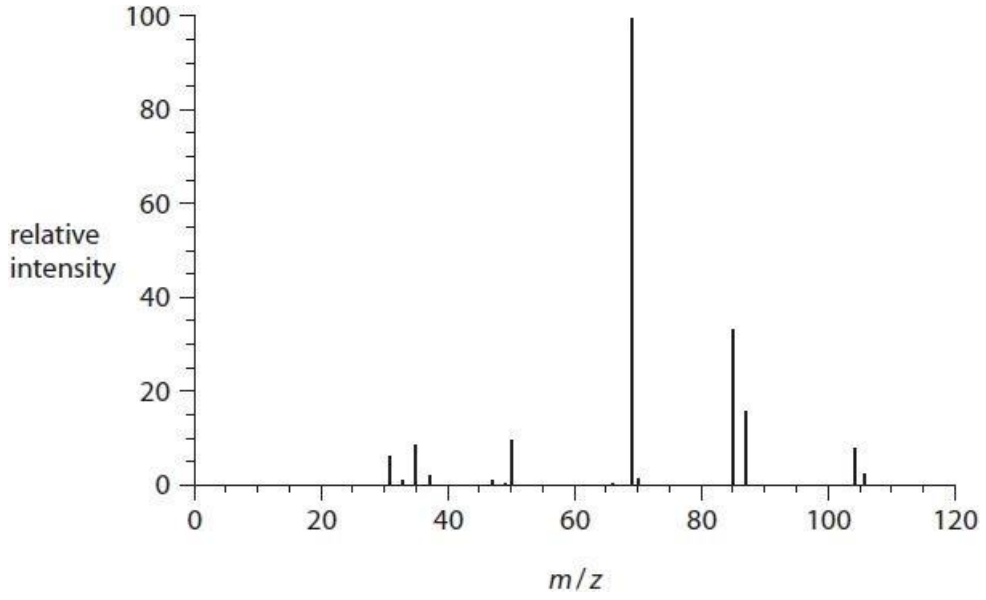
(i) A different refrigerant contains 34.0% chlorine and 54.5% fluorine by mass, with the remainder carbon.

Calculate the empirical formula of this compound.

(3)

(ii) Use the mass spectrum to show that the empirical and the molecular formulae of this compound are the same.

(1)



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(iii) Suggest the species responsible for the peak at $m / z = 69$.

(1)

(Total for question = 5 marks)

Q18.

This question is about sodium carbonate.

Sodium carbonate forms a number of hydrates with the general formula $Na_2CO_3.xH_2O$.

A 250 cm^3 standard solution of one of these hydrates contained 10.0 g of the compound.

In an experiment, the M_r of a **different** hydrated sodium carbonate was found to be 286 g mol^{-1}.

(i) Calculate the relative formula mass of anhydrous sodium carbonate, Na_2CO_3 .

(1)

(ii) Calculate the number of molecules of water of crystallisation, *x*, for this hydrated sodium carbonate, $Na_2CO_3.xH_2O$.

(1)

(Total for question = 2 marks)

Q19.

This question is about extracting benzoic acid from a mixture of benzoic acid, C_6H_5COOH, and phenol, C_6H_5OH.

The following steps were carried out.

Step **1** A suitable mass of the mixture was placed in a separating funnel and some ether added. The funnel was shaken to dissolve the mixture.

Step **2** Aqueous sodium hydrogencarbonate was added to the separating funnel, and the contents shaken.

Step **3** Once the reaction was complete, the two layers were allowed to separate.

Step **4** The lower aqueous layer was removed and placed in a beaker.

Step **5** The ether layer in the separating funnel was washed with deionised water and the washings added to the beaker.

Step **6** Hydrochloric acid was added to the aqueous solution in the beaker to precipitate the benzoic acid.

Step **7** The impure benzoic acid was filtered under reduced pressure.

Step **8** The impure benzoic acid was purified by recrystallisation.

Step **9** The melting temperature of the purified benzoic acid was measured and compared with the literature value of 122 °C.

Benzoic acid can be purified in Step **8** because of its high solubility in hot water and low solubility in cold water.

Calculate the maximum number of benzoic acid molecules that can dissolve in 50.0 cm^3 of cold water if the solubility is 1.70 g per 1000 cm^3.

(3)

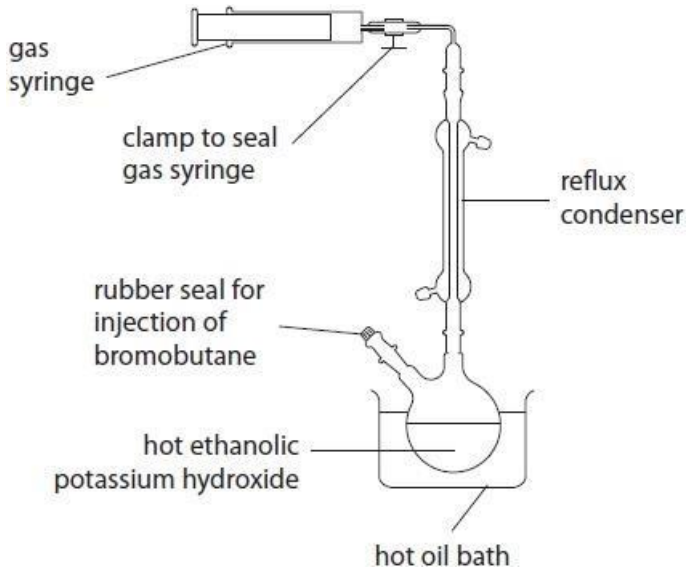
(Total for question = 3 marks)

Q20.

Bromobutanes react with hot ethanolic potassium hydroxide solution to produce gaseous butenes.

$$C_4H_9Br + OH^- \rightarrow C_4H_8 + Br^- + H_2O$$

Apparatus



Procedure

- 0.0080 mol of liquid 1-bromobutane was injected into a round bottom flask containing hot ethanolic potassium hydroxide.
- After the reaction, the syringe was sealed using a clamp.
- The syringe was then removed from the apparatus and allowed to cool to room temperature (298 K).

Result

The final volume of but-1-ene collected was 22.0 cm^3.

Before cooling, the volume of but-1-ene in the gas syringe was 24.0 cm^3.

Calculate the temperature of the gas in the syringe before it cooled.

[Assume no loss from the gas syringe during cooling, and a constant pressure]

(2)

(Total for question = 2 marks)

Q21.

Ice has a density of 0.92 g cm^{-3} and water has a density of 1.00 g cm^{-3}.

Calculate how many **more** molecules there are in 5.00 cm^3 of water compared to 5.00 cm^3 of ice.

(3)

(Total for question = 3 marks)

Q22.

This question is about the molar volume of gases.

(i) Calculate the volume of one mole of an ideal gas, **A**, at 60 °C and 500 kPa pressure.

Give your answer to two significant figures and include units.
[The ideal gas equation is $pV = nRT$. Gas constant (R) = 8.31 J K^{-1} mol^{-1}]

(3)

(ii) At room temperature and pressure (r.t.p) another gas **B**, with formula XH_3 , has a density of 1.42 g dm^{-3}.

Calculate the molar mass of the gas XH_3 and deduce the identity of the element X.
[The molar volume of gas **B** = 24 000 cm^3 mol^{-1} at r.t.p.]

(2)

(Total for question = 5 marks)

Q23.

Traditionally, high-flying aircraft and Formula 1 racing cars have had their tyres inflated with nitrogen gas instead of air. Recently, this practice has been extended to some other cars.

A car tyre is filled with nitrogen gas to a volume of 8.98 dm^3 and a pressure of 207 kPa at 20 °C.

(i) Using the Ideal Gas Equation, calculate the mass of nitrogen gas, in grams, present in the car tyre under these conditions. Give your answer to an appropriate number of significant figures.

(3)

(ii) During a car journey, the tyres become warm. Use the Ideal Gas Equation to deduce the effect that this has on the pressure in the tyres.

(1)

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(Total for question = 4 marks)