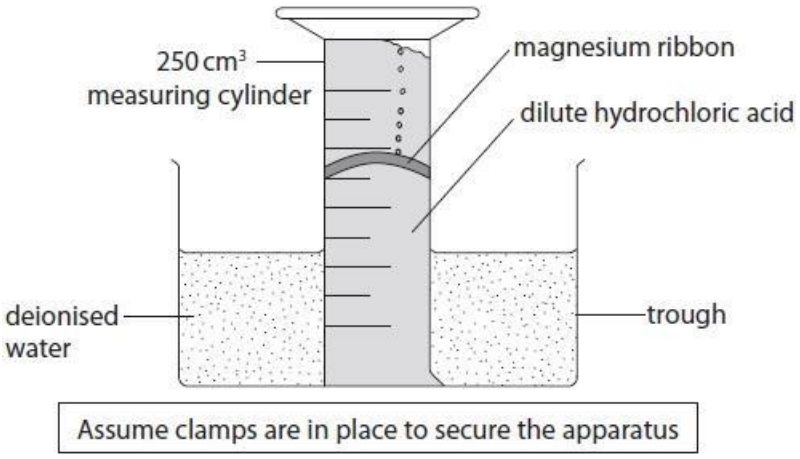
## Questions

**Q1.**

A student used the apparatus in the diagram to determine the molar volume of a gas.




The student used a piece of magnesium ribbon, which was about 5 cm in length, and the dilute hydrochloric acid was in excess. The experiment was repeated three times at 24°C and the following results were obtained.

| | Experiment 1 | Experiment 2 | Experiment 3 |
|---|---|---|---|
| Mass of magnesium / g | 0.04 | 0.04 | 0.04 |
| Volume of hydrogen gas / $cm^3$ | 31 | 25 | 32 |

The equation for the reaction is

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

(a) (i) Calculate the number of moles of magnesium used by the student in each experiment.

**(1)**

(ii) Use your answer from part (a)(i) to deduce the number of moles of hydrogen gas that should be produced.

**(1)**

(iii) Calculate, using the Ideal Gas Equation, the volume of hydrogen gas, in **cm$^3$**, that should be produced in each of these experiments.
[$pV = nRT$ $R = 8.31$ J mol$^{-1}$ K$^{-1}$ $p = 101\,000$ Pa]

**(4)**

(b) Give a reason why the student repeated the experiment three times.

**(1)**

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(c) Give three reasons for the difference between your calculated value in (a)(iii) and the actual volumes of hydrogen gas obtained by the student.

For each reason, identify a change to either the apparatus or the chemicals that could be made by the student to improve the result.

**(6)**

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**(Total for question = 13 marks)**

CC BY NC ND

**Q2.**

Pineapple juice contains the weak acids citric acid ($C_6H_8O_7$) and ascorbic acid ($C_6H_8O_6$). The amount of each compound in a sample of 150 $cm^3$ of pineapple juice can be determined by titration.

Experiment **1** is designed to determine the total amount of acid. 10.0 $cm^3$ samples of pineapple juice are transferred to separate conical flasks and titrated with a solution of sodium hydroxide of known concentration.

The total amount of acid in the 150 $cm^3$ sample of pineapple juice is $8.00 \times 10^{-3}$ mol.

(i) Give a reason why methyl orange would **not** be a suitable indicator to use in this titration.

**(1)**

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(ii) A student did not notice an air bubble in the tip of the burette **before** carrying out one of their accurate titrations. During this titration, the air bubble escaped.

Explain the effect this mistake would have on the value of this titre.

**(2)**

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**(Total for question = 3 marks)**

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**Q3.**

(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)**

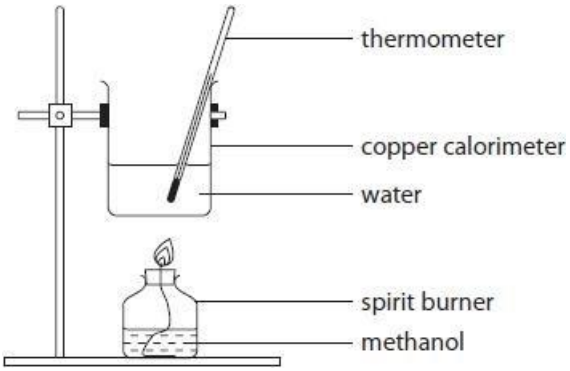
**Q4.**

This question is about the enthalpy change of combustion of methanol.

A teacher asked two students to carry out a practical task to determine the enthalpy change of combustion of methanol.
Both students were provided with the same apparatus and chemicals.
The following procedure was provided for the students.

**Procedure**

- Measure out 150 $cm^3$ of distilled water, using a 250 $cm^3$ measuring cylinder.
- Transfer the water to a copper calorimeter and note the initial temperature of the water (to the nearest 0.5°C) in **Table 1**.
- Weigh the spirit burner containing methanol and record its mass in **Table 1**.
- Place the spirit burner under the copper calorimeter, as shown in the diagram.
- Ignite the spirit burner and burn the methanol, whilst stirring the water with the thermometer.
- After heating the water for three minutes, extinguish the flame and immediately record the **highest** temperature reached by the water.
- As soon as possible, reweigh the spirit burner containing the methanol and record its mass in **Table 1**.




The results of Student 1 are recorded in **Table 1**.

| | |
|---|---|
| Mass of spirit burner plus methanol before burning / g | 213.47 |
| Mass of spirit burner plus methanol after burning / g | 211.87 |
| Mass of methanol burned / g | |
| Highest temperature of the water / °C | 64.5 |
| Initial temperature of the water / °C | 22.0 |
| Temperature change of the water / °C | |

**Table 1**

(a) Complete **Table 1**, giving the values to an appropriate number of decimal places.

**(2)**

(b) Write the equation that represents the reaction that occurs when the standard enthalpy change of combustion of methanol, $CH_3OH(l)$, is measured. Include state symbols.

**(2)**

(c) Use Student 1's result to calculate the enthalpy change of combustion of methanol in kJ $mol^{-1}$.
Give your answer to an appropriate number of significant figures.

Specific heat capacity of water = 4.18 J $g^{-1}$ °$C^{-1}$
Density of water = 1.00 g $cm^{-3}$

**(4)**

CC BY NC ND

(d) Student 1 compared the experimental value for the enthalpy change of combustion of methanol obtained in part (c) with the standard value given on the internet.
The student's value was **less exothermic** than the standard value.

Student 1 decided to evaluate the uncertainty in the measurements made in this experiment.

(i) Student 1 used a 250 $cm^3$ measuring cylinder to measure the volume of 150 $cm^3$ distilled water. The uncertainty in this volume measurement is ±1 $cm^3$.
Calculate the percentage uncertainty in the volume of distilled water that Student 1 measured in the experiment.

**(1)**

(ii) Compare and contrast the use of a 250 $cm^3$ measuring cylinder to measure out the 150 $cm^3$ distilled water with the use of a 25 $cm^3$ measuring cylinder (uncertainty ±0.2 $cm^3$ for each volume measurement) six times to measure the same volume.

**(3)**

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(iii) Student 1 calculated the uncertainties in the remaining measurements. However, Student 1 realised that the measurement uncertainties did **not** explain the difference between the experimental value for the enthalpy change of combustion of methanol calculated in part (c) and the value obtained from the internet.
Other than human error, give **three** reasons for the difference in the values.

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(e) Student 1 decided to repeat the experiment.

Student 1 used the copper calorimeter and water from the first experiment and recorded the initial temperature as 60.0°C.
Student 1 burned **exactly** the same mass of methanol as in the first experiment.
Explain, with a reason, how the value for the enthalpy change of combustion of methanol from this experiment would differ, if at all, from the value obtained in the first experiment.

**(2)**

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(f) Student 2 followed the **original** instructions provided, but extinguished the flame after **four** minutes rather than after three minutes.

Explain how the value calculated by Student 2 for the enthalpy change of combustion of methanol compared with that obtained in Student 1's first experiment.

**(2)**

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(g) Another student, Student 3, used the results from Student 1's first experiment to find the enthalpy change of combustion of methanol. Student 3 incorrectly used a value of 46.0 g $mol^{-1}$ for the molar mass of methanol.

State and justify how this mistake would affect the calculated value for the enthalpy change of combustion of methanol.

**(2)**

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**(Total for question = 21 marks)**

CC BY NC ND

**Q5.**

A student carried out an investigation to determine the value of ***x*** in hydrated magnesium nitrate(III), $Mg(NO_2)_2 \bullet xH_2O$, using three different methods.

**Method 1**

- The student prepared an aqueous solution by dissolving 1.15 g of $Mg(NO_2)_2 \bullet xH_2O$ in distilled water, making up the solution to 250.0 $cm^3$ in a volumetric flask and shaking the mixture.
- The student titrated this solution against 25.0 $cm^3$ portions of an acidified solution of 0.0200 mol $dm^{-3}$ potassium manganate(VII), $KMnO_4(aq)$.

**Method 2**

- The student mixed a solution of $Mg(NO_2)_2 \bullet xH_2O$ with an excess of aqueous sodium carbonate solution, $Na_2CO_3(aq)$.
- The student obtained a precipitate of magnesium carbonate, $MgCO_3(s)$, and determined the mass of this precipitate.

**Method 3**

- The student heated a known mass of $Mg(NO_2)_2 \bullet xH_2O(s)$.
- The student determined the mass of the anhydrous residue formed.

**Method 1 – Titration**

The student filled the burette with the solution made from $Mg(NO_2)_2 \bullet xH_2O$.

In each titration

- 25.0 $cm^3$ of 0.0200 mol $dm^{-3}$ $KMnO_4(aq)$ was transferred to a conical flask using a pipette.
- An excess of dilute sulfuric acid was added to the conical flask and the mixture heated.
- $Mg(NO_2)_2(aq)$ was added from the burette until the end-point was reached.

The student's titration results are shown in the table (the rough titration results have **not** been included in the table).

| Titration number | 1 | 2 | 3 |
|---|---|---|---|
| Final burette reading / $cm^3$ | 23.95 | 48.05 | 23.85 |
| Initial burette reading / $cm^3$ | 0.80 | 24.50 | 0.65 |
| Titre / $cm^3$ | | | |
| Concordant titres (✓) | | | |
| Mean titre / $cm^3$ | | | |

(a) Complete the table.

**(2)**

(b) Deduce the colour change that the student would see at the end-point in this titration.

**(1)**

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(c) In the titration reaction, 2 mol $MnO_4^-$ react with 5 mol $NO_2^-$.

Calculate the number of moles of $NO_2^-$, in the 250 $cm^3$ of solution prepared by the student and hence the value of ***x*** in $Mg(NO_2)_2 \cdot xH_2O$.
Give your answer to the nearest whole number.

**(5)**

(d) The half-equations for the reaction in the titration are

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$
$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$
Use these half-equations to derive the overall ionic equation for the reaction between manganate(VII) and nitrate(III) ions in acidic conditions.
State symbols are not required.

**(2)**

**Method 2 – Precipitation**

The student used the following procedure.

- Dissolve a known mass of $Mg(NO_2)_2 \bullet \boldsymbol{x}H_2O$ in distilled water.
- Add an excess of aqueous sodium carbonate solution, $Na_2CO_3(aq)$, to obtain a precipitate of magnesium carbonate, $MgCO_3(s)$.

$$Mg^{2}+(aq) + CO_3^{2-}(aq) \rightarrow MgCO_3(s)$$

- Weigh a piece of filter paper.
- Filter the mixture from the above reaction through the pre-weighed filter paper.
- Wash the precipitate of $MgCO_3(s)$ with distilled water.
- Dry the filter paper and precipitate in a desiccator.
- Reweigh the filter paper and the precipitate.
- Calculate the value of ***x*** from the results obtained.

The student found that the value of ***x*** calculated using **Method 2** was different from that obtained using **Method 1**. This difference occurred despite having used a pure sample of the hydrated salt and without making any errors in technique during the experiment.

The student found out from a data book that the compound magnesium carbonate is very slightly soluble in water.

(e) Explain how, if at all, the very slight solubility of magnesium carbonate in water would affect the value calculated for ***x***.

**(2)**

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(f) The student planned to obtain any dissolved magnesium carbonate by evaporating the filtrate, and then weighing the residue.

Criticise this student's plan.

**(2)**

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**Method 3 – Thermal decomposition**

**NOTE:** On heating, $Mg(NO_2)_2 \bullet xH_2O(s)$ loses its water of crystallisation and **then** undergoes further decomposition to give magnesium oxide, MgO.

The student used the following procedure.

- Weigh an empty crucible.
- Add some $Mg(NO_2)_2 \bullet xH_2O(s)$ and then reweigh the crucible plus contents.
- Heat the crucible plus contents and allow to cool.
- Weigh the crucible plus magnesium oxide residue.
- Use these data to calculate a value for ***x***.

The student's results are shown in the table.

| | |
|---|---|
| Mass of crucible / g | 18.02 |
| Mass of crucible + $Mg(NO_2)_2 \cdot xH_2O$ / g | 18.84 |
| Mass of crucible + MgO residue / g | 18.27 |

(g) Identify how the student should ensure that the hydrated salt was fully decomposed.

**(1)**

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(h) The student carried out an evaluation of the results obtained from **Method 3**

Identify **two** modifications to the method that would enable the student to lower the percentage uncertainty in the measurement of the mass of the solid residue.

**(2)**

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**(Total for question = 17 marks)**

CC BY NC ND

**Q6.**

The gas phase reaction between hydrogen and iodine is reversible.

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

(a) (i) Write the expression for the equilibrium constant, $K_c$, for this reaction.

**(1)**

(ii) If the starting concentration of both hydrogen and iodine was **a** mol dm$^{-3}$ and it was found that 2**y** mol dm$^{-3}$ of hydrogen iodide had formed once equilibrium had been established, write the $K_c$ expression in terms of **a** and **y**.

**(2)**

(b) The expression for the equilibrium constant in (a)(ii) can be rearranged as shown.

$$\mathbf{y} = \frac{\mathbf{a}\sqrt{K_c}}{2+\sqrt{K_c}}$$

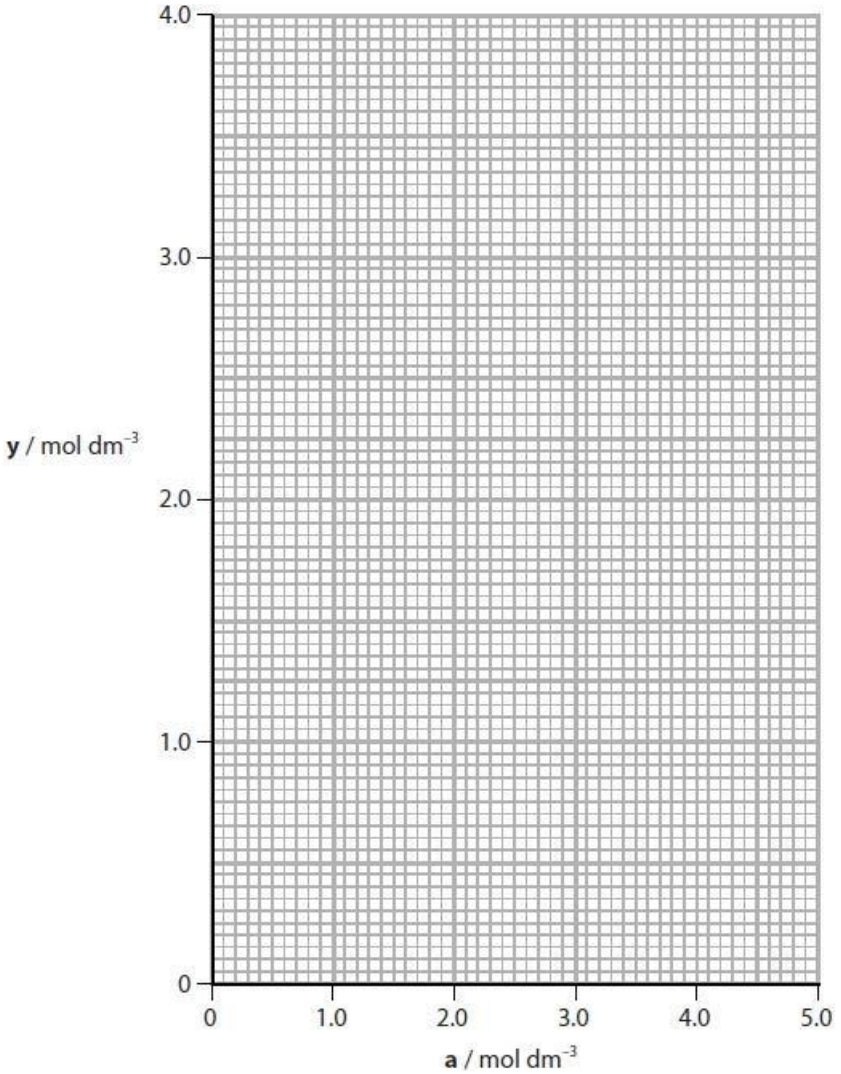
In an experiment, air was removed from a 1 dm$^3$ flask and amounts of hydrogen and iodine gases were mixed together such that their initial concentrations were both **a** mol dm$^{-3}$. This mixture was allowed to reach equilibrium at 760 K. The equilibrium concentration of iodine was then measured.
The experiment was repeated for various initial concentrations, **a** mol dm$^{-3}$, and the results recorded in the table.
(i) Complete the table to give the two remaining values of **y** mol dm$^{-3}$, to **two** decimal places.

**(1)**

| a / mol dm$^{-3}$ | $[I_2]_{eq}$ / mol dm$^{-3}$ | y / mol dm$^{-3}$ |
|---|---|---|
| 0.20 | 0.02 | 0.18 |
| 0.80 | 0.25 | 0.55 |
| 1.50 | 0.37 | |
| 2.10 | 0.57 | 1.53 |
| 2.80 | 0.65 | 2.15 |
| 3.80 | 0.87 | |
| 4.90 | 1.15 | 3.75 |

(ii) Plot a graph to show how **y** mol $dm^{-3}$ varies with the initial concentrations of hydrogen and iodine, **a** mol $dm^{-3}$.

**(2)**




(iii) Determine the gradient of your graph.
Show your working on the graph.

**(2)**

(iv) Use your answer to (b)(iii) and the expression $y = \frac{a\sqrt{K_c}}{2+\sqrt{K_c}}$ to calculate the value of $K_c$.

**(2)**

(c) Identify a safety issue associated with this experiment.

**(1)**

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(d) One of the experiments in part (b) was repeated using the same molar quantities of hydrogen and iodine but in a 500 $cm^3$ flask instead of the 1 $dm^3$ flask.

Deduce the effect, if any, that this would have on the rate of reaction and on the value of $K_c$ calculated.

**(2)**

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(e) The equation for the reaction between hydrogen and iodine is

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $\Delta H = -9.6$ kJ $mol^{-1}$

(i) Explain the effect, if any, on the value of $K_c$ when the temperature is increased.

**(2)**

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(ii) On your graph in (b)(ii), draw and label the line you would expect if the experiment was carried out at 1000 K instead of 760 K.

**(1)**

**(Total for question = 16 marks)**

CC BY NC ND

**Q7.**

When solid calcium sulfate dihydrate, $CaSO_4 \cdot 2H_2O$, is heated in a crucible, it forms solid calcium sulfate hemihydrate, $CaSO_4 \cdot \frac{1}{2}H_2O$.

When water is added to calcium sulfate hemihydrate, there is a rise in temperature.

A student decided to investigate this reaction using the following procedure:

Step **1** $10\,cm^3$ of distilled water is measured using a measuring cylinder having an uncertainty of $\pm 0.5\,cm^3$, and is placed in an insulated cup with a lid.

Step **2** A thermometer with an uncertainty of $\pm 0.5\,°C$ is placed in the water.

Step **3** Exactly 10.00 g of calcium sulfate hemihydrate is weighed out using a balance with an uncertainty of $\pm 0.005$ g.

Step **4** The weighed quantity of calcium sulfate hemihydrate is added to the water in the insulated cup.

Step **5** The mixture in the insulated cup is stirred until no further temperature change is observed.

**Results**

| | |
|---|---|
| Temperature of the water before adding the solid | = 23.5 °C |
| Maximum temperature of the mixture after adding the solid | = 26.3 °C |

**Other data**

| | |
|---|---|
| Molar mass of calcium sulfate hemihydrate, $CaSO_4 \cdot \frac{1}{2}H_2O$ | = 145.2 g mol$^{-1}$ |
| Density of water | = 1.00 g cm$^{-3}$ |

(i) Calculate the minimum volume of water needed to convert 10.00 g of $CaSO_4 \cdot \frac{1}{2}H_2O$ into $CaSO_4 \cdot 2H_2O$.

**(2)**

(ii) Calculate the enthalpy change, in kJ $mol^{-1}$, for this reaction.
Include a sign in your answer and give your answer to an appropriate number of significant figures.

Assume that the liquid has a mass of 10.00 g and a specific heat capacity of 4.18 J $g^{-1}$ $°C^{-1}$.

**(4)**

(iii) Deduce which measurement has the greatest uncertainty in this experiment. Justify your answer by calculating the percentage uncertainty of this piece of apparatus.

**(2)**

**(Total for question = 8 marks)**

CC BY NC ND

**Q8.**

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**.

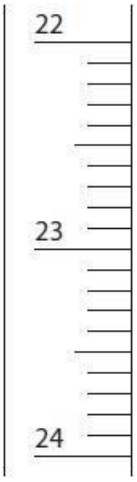
**(a) Experiment 1** – to determine the value of **y**

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)**

CC BY NC ND

(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)**

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(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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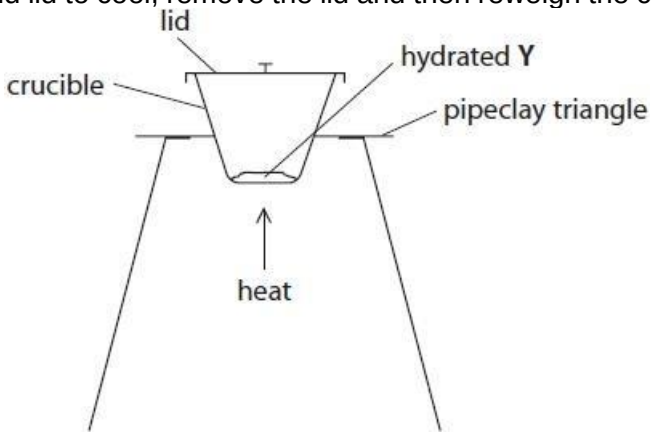
**(Total for question = 17 marks)**

CC BY NC ND

**Q9.**

**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)**

CC BY NC ND

**Q10.**

This question concerns alkenes and some halogen compounds.

The halogenoalkane chloroethene is used to make the important polymer poly(chloroethene), PVC.

(i) Draw a **displayed** formula of two repeat units of poly(chloroethene).

**(1)**

(ii) Some polymers are disposed of by incineration. Ignoring any economic considerations, explain why incineration is **not** a suitable method for the disposal of poly(chloroethene).

**(2)**

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(iii) Chloroethene has a boiling temperature of 260 K and is known to be carcinogenic. Use these facts to state **one** precaution that chemists should take when using this compound.

**(1)**

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**(Total for question = 4 marks)**

CC BY NC ND

**Q11.**

This question is about redox chemistry.

(i) Bromine can be extracted from seawater containing bromide ions using chlorine.

Write the ionic equation for this reaction. State symbols are not required.

**(1)**

(ii) Identify **one** hazard associated with carrying out this reaction in a school laboratory and a safety precaution other than wearing a laboratory coat and eye protection.

**(2)**

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**(Total for question = 3 marks)**

CC BY NC ND

**Q12.**

This question is about the identification of a Group 2 carbonate.

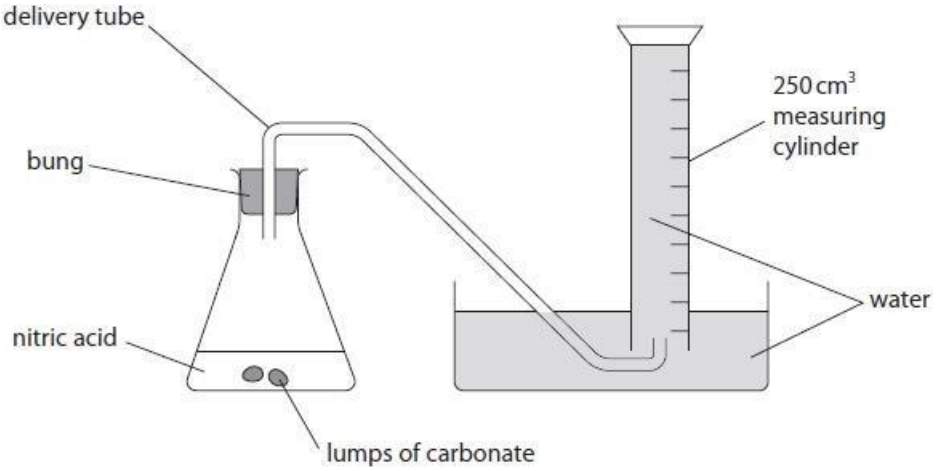
A chemistry teacher found a bottle containing lumps of a white solid. The original label was missing from the bottle. However, someone had written 'Group 2 carbonate' on the bottle. The lumps of the anhydrous white solid were pure and dry.

The chemistry teacher tried to identify the carbonate with the help of three students. The three students worked under identical conditions and shared the same weighing balance.

Student **1** recognised that if an acid is added to a carbonate, carbon dioxide is evolved. The student decided to measure the volume of carbon dioxide evolved when the Group 2 carbonate reacts with excess nitric acid.

The student knew that 1 mol of a Group 2 carbonate produces 1 mol of carbon dioxide.

Student **1** set up the apparatus shown below.




- Student **1** weighed out some of the Group 2 carbonate and added it to a 250 $cm^3$ conical flask.
- Student **1** then added 100 $cm^3$ of 0.200 mol $dm^{-3}$ nitric acid to the conical flask and replaced the bung.
- Student **1** measured the volume of gas collected in the inverted measuring cylinder at room temperature and pressure (r.t.p.) when all the Group 2 carbonate had reacted.
- Student **1** obtained the results shown in Table 1.

| Measurement | | Value |
|---|---|---|
| Mass of weighing bottle and carbonate | / g | 13.247 |
| Mass of empty weighing bottle | / g | 12.431 |
| Mass of carbonate used | / g | ..... |
| Volume of acid used | / $cm^3$ | 100 |
| Volume of gas collected | / $cm^3$ | 225 |

**Table 1**

(a) Complete Table 1 to show the mass of the carbonate used.

**(1)**

(b) Calculate the amount, in moles, of carbon dioxide collected in the measuring cylinder at r.t.p.

**(1)**

(c) Calculate the molar mass of the Group 2 carbonate to an appropriate number of significant figures and hence deduce the identity of the Group 2 metal.

**(4)**

(d) Student **2** carried out the same experiment as Student **1**, using the same mass of the Group 2 carbonate.

Student **2** made no errors in their measurements or calculations but obtained a value for the molar mass which was 10 g $mol^{-1}$ greater than the value obtained by Student **1**.

(i) Explain **one** procedural error which could have resulted in Student **2** obtaining a molar mass greater than that of Student **1**.

**(2)**

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(ii) It was later discovered that Student **2** had used 110 $cm^3$ of 0.200 mol $dm^{-3}$ dilute nitric acid, instead of 100 $cm^3$ of 0.200 mol $dm^{-3}$ dilute nitric acid.

Give a reason why this mistake would **not** have affected Student **2**'s result.

No calculation is required.

**(1)**

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(iii) The teacher noticed that Student **2** had used the Group 2 carbonate in powdered form rather than in lumps.
Explain how, if at all, this would affect the rate of reaction and the final volume of gas produced in the reaction.

**(2)**

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(e) Student **3** suggested a different experiment.

Student **3** realised that, by heating the carbonate, carbon dioxide would be lost and an oxide would remain.
Student **3** decided to measure the change in mass of the carbonate and to use this information to calculate its molar mass.

- Student **3** weighed an empty test tube.
- Using a spatula, Student **3** added some of the carbonate to the test tube.
- The test tube containing the carbonate was then weighed.
- The test tube and its contents were heated to constant mass.
- The results obtained by Student **3** are shown in Table 2.

| Measurement | | Value |
|---|---|---|
| Mass of carbonate + test tube | / g | 20.447 |
| Mass of oxide + test tube | / g | 20.205 |
| Mass of empty test tube | / g | 19.996 |

**Table 2**

(i) Write an equation, including state symbols, for the thermal decomposition of a Group 2 carbonate, $MCO_3$, where M represents the metal.

**(1)**

(ii) Using Student **3**'s results, calculate the molar mass of the Group 2 carbonate.

**(3)**

(f) Student **3** used the same balance as Student **1**.

Give a reason why the mass of the carbonate measured by Student **3** has a greater percentage uncertainty than that measured by Student **1**.

**(1)**

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(g) Student **3** noticed that on heating the test tube some solid was lost.

Explain how this would affect the calculated value for the molar mass of the Group 2 carbonate.

**(2)**

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**(Total for question = 18 marks)**

CC BY NC ND

**Q13.**

This question is about the titration of a weak acid with a strong base.

The uncertainty in each burette reading is ± 0.05 $cm^3$. The uncertainty in the pipette volume is ± 0.06 $cm^3$.

(i) Calculate the percentage uncertainties for titre 4, and the pipette volume.

**(2)**

(ii) Which of the following changes would halve the percentage uncertainty in the volume of liquid measured by the burette?

**(1)**

- ☐ **A** halve the acid concentration and halve the acid volume
- ☐ **B** double the acid concentration and leave the acid volume unchanged
- ☐ **C** double the acid concentration and halve the acid volume
- ☐ **D** halve the acid concentration and leave the acid volume unchanged

**(Total for question = 3 marks)**

CC BY NC ND

**Q14.**

Ammonia reacts with sodium to form sodium amide, $NaNH_2$, and hydrogen.

Give a possible reason why samples of sodium amide are stored in oil.

**(1)**

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**(Total for question = 1 mark)**

CC BY NC ND

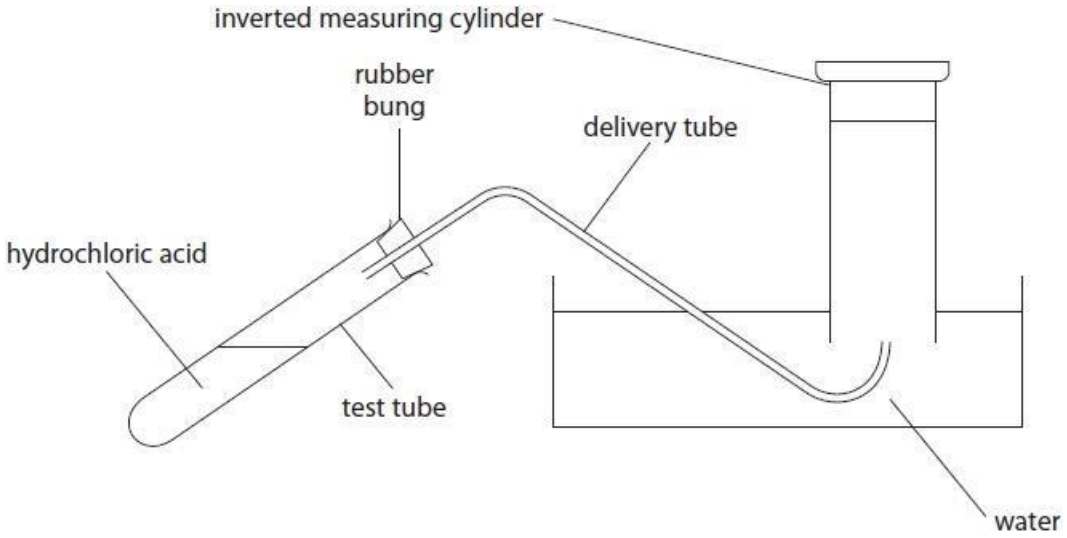
**Q15.**

(a) This question is about the reaction of magnesium with dilute hydrochloric acid.

Write an equation for the reaction of magnesium with hydrochloric acid. Include state symbols.

**(2)**

(b) The apparatus shown in the diagram can be used to collect the gas produced during the reaction of magnesium with dilute hydrochloric acid.




The following procedure was used.

Step **1** The apparatus was set up as shown in the diagram. The test tube contained 10.0 $cm^3$ of 0.20 mol $dm^{-3}$ hydrochloric acid.

Step **2** A piece of magnesium ribbon was weighed. It had a mass of 0.12 g.

Step **3** The delivery tube and bung were removed from the test tube, the magnesium ribbon was added and the delivery tube and bung quickly replaced.

Step **4** When the reaction was complete, the final volume of gas was recorded.

(i) A measuring cylinder was used to measure the 10.0 $cm^3$ of dilute hydrochloric acid in Step **1**. The uncertainty for a volume measurement is ± 0.5 $cm^3$.
Calculate the percentage uncertainty in the volume of hydrochloric acid.

**(1)**

(ii) Determine which reactant is in excess by calculating the number of moles of magnesium and of hydrochloric acid used in the experiment.

**(3)**

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(iii) Calculate the maximum number of moles of gas that could be produced, using your answers to (a) and (b)(ii).

**(1)**

(iv) Under the conditions of the experiment, the temperature was 23°C and the pressure 98 000 Pa.
Calculate the maximum volume of gas, **in $cm^3$**, that could be produced using your answer in (b)(iii).
Give your answer to an appropriate number of significant figures.
[The ideal gas equation is $pV = nRT$. Gas constant ($R$) = 8.31 J $mol^{-1}$ $K^{-1}$]

**(4)**

CC BY NC ND

(c) (i) Deduce **two** possible reasons why the volume of gas collected in the experiment was smaller than that calculated in (b)(iv).

**(2)**

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(ii) Describe **two** changes to the procedure that would enable the volume of gas collected to be closer to that calculated in (b)(iv).

**(2)**

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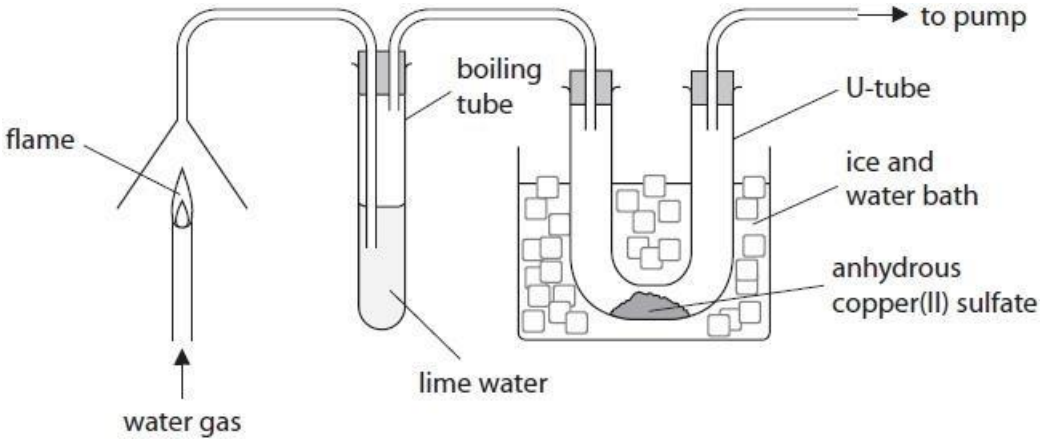
**(Total for question = 15 marks)**

CC BY NC ND

**Q16.**

The complete combustion of water gas produces carbon dioxide and water.
A student drew a diagram of the apparatus to attempt to identify the combustion products.




Evaluate whether the student's apparatus is suitable for identifying both of the combustion products. Include any improvements needed.

**(5)**

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**(Total for question = 5 marks)**

CC BY NC ND

**Q17.**

Malachite is a green mineral with the formula $Cu_2CO_3(OH)_2$ . It has a molar mass of 221 g $mol^{-1}$.

(i) When malachite is heated to approximately 300 °C, water, carbon dioxide and copper(II) oxide are formed.

The equation for this decomposition is

$$Cu_2CO_3(OH)_2 \rightarrow 2CuO + CO_2 + H_2O$$

Calculate the maximum volume of carbon dioxide that could be produced when 0.810 g of malachite is thermally decomposed.
Assume that the gas is collected at a temperature of 25 °C and 101 kPa pressure.
Give your answer to an appropriate number of significant figures and state the units.
[The ideal gas equation is $pV = nRT$. Gas constant ($R$) = 8.31 J $mol^{-1}$ $K^{-1}$]

**(5)**

(ii) The gas was collected in a gas syringe with a stated accuracy of ± 0.5 $cm^3$.

Calculate the percentage uncertainty in the volume of gas collected.

**(1)**

(iii) Malachite ore is a mixture of malachite and rock. A 0.810 g sample of malachite ore was thermally decomposed, producing 0.571 g of copper(II) oxide.

Calculate the percentage purity of this malachite ore sample. Give your answer to an appropriate number of significant figures.

**(3)**

**(Total for question = 9 marks)**

**Q18.**

This question is about a titration experiment carried out by a group of students to determine the concentration of a solution of ethanoic acid using sodium hydroxide.

A student weighed about 4.00 g of sodium hydroxide pellets and added them to a beaker containing 50 $cm^3$ of deionised water.

The mixture was stirred with a glass rod to dissolve the pellets and to give a homogenous solution.

The solution was poured through a funnel into a 250.0 $cm^3$ volumetric flask and deionised water was added up to the mark and then the flask was shaken.

(i) Describe how you would ensure that all the sodium hydroxide was transferred to the volumetric flask.

**(2)**

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(ii) A student adds deionised water above the mark and shakes the flask.

State why the procedure has to be restarted rather than using a teat pipette to remove the excess water.

**(1)**

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**(Total for question = 3 marks)**

CC BY NC ND

**Q19.**

This question is about a titration experiment carried out by a group of students to determine the concentration of a solution of ethanoic acid using sodium hydroxide.

Two students each cleaned a burette, then poured sodium hydroxide solution into their burettes.

(i) Student 1 used a funnel to pour sodium hydroxide solution into the burette.

Give **two** steps needed before the student takes the initial burette reading.

**(2)**

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(ii) Student 2 cleaned the burette by rinsing it with deionised water immediately before filling it with the sodium hydroxide solution.

Give the effect, if any, on the value of the first titre. Justify your answer.

**(1)**

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**(Total for question = 3 marks)**

CC BY NC ND

**Q20.**

This question is about a titration experiment carried out by a group of students to determine the concentration of a solution of ethanoic acid using sodium hydroxide.

Each student used a pipette to measure 25.0 $cm^3$ of the ethanoic acid solution into four separate conical flasks and added an indicator.

The results of one student's titrations are shown in the table.

| Titration number | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Final burette reading / $cm^3$ | 13.00 | 25.50 | 37.90 | 50.00 |
| Initial burette reading / $cm^3$ | 0.25 | 13.00 | 25.50 | 37.90 |
| Titre / $cm^3$ | | | | |
| Concordant titres (✓) | | | | |

(i) Complete the table.

**(1)**

(ii) The low titre for titration **4** was queried by the teacher. The student had wanted to refill the burette and continue the
titration but had been told the measurement uncertainty would increase if this was done.

Calculate the total percentage measurement uncertainty if the burette had been refilled to 0.00, and then a further 0.30 $cm^3$ had been added from the burette, to the conical flask. The measurement uncertainty for each burette reading is ±0.05 $cm^3$.

**(1)**

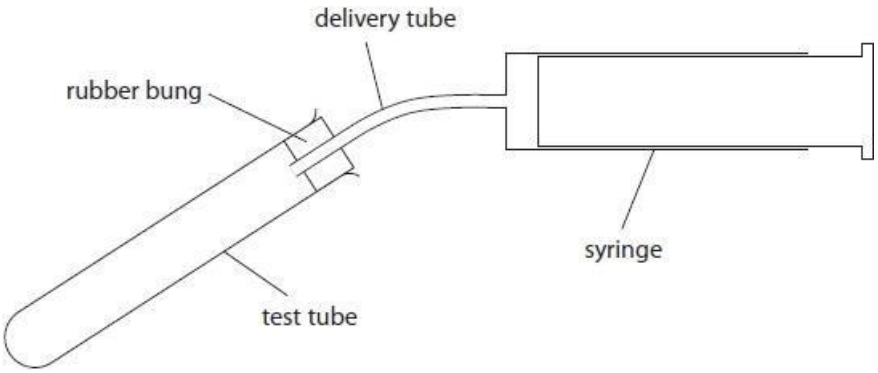
**(Total for question = 2 marks)**

CC BY NC ND

**Q21.**

This question is about the molar volume of gases.

The apparatus shown was used to measure the volume of gas evolved when a weighed mass of sodium carbonate reacted with dilute hydrochloric acid.




The following procedure was used.

Step **1** Solid sodium carbonate was placed in a container and weighed accurately.

Step **2** The delivery tube and rubber bung were removed and the sodium carbonate was transferred to the test tube.

Step **3** The container was then reweighed.

Step **4** The syringe plunger was pushed in, to zero the syringe.

Step **5** 10.0 $cm^3$ of 0.400 mol $dm^{-3}$ hydrochloric acid was then added to the sodium carbonate and the rubber bung and delivery tube rapidly replaced.

Step **6** The mixture was shaken and, when the reaction had finished, the reading of the syringe was noted.

**Results**

| | | |
|---|---|---|
| Mass of container and sodium carbonate before transfer | = | 20.135 g |
| Mass of container after transfer of the sodium carbonate | = | 19.893 g |
| Mass of sodium carbonate used | = | 0.242 g |

The equation for the reaction is

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + CO_2(g) + H_2O(l)$$

(i) Calculate the moles of hydrochloric acid and the moles of sodium carbonate used in this experiment.

Use your answers to decide which reactant is in excess.
Calculate the maximum volume of carbon dioxide which could be produced.

[Molar mass of $Na_2CO_3$ = 106.0 g $mol^{-1}$
Molar volume of gas = 24 000 $cm^3$ $mol^{-1}$ at r.t.p.]

**(5)**

(ii) The actual volume of carbon dioxide collected was less than calculated.

Give **two** reasons for this.

**(2)**

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**(Total for question = 7 marks)**

CC BY NC ND

**Q22.**

(a) This question is about the analysis of an unknown carboxylic acid **X** by three students.

The students analyse the mass spectrum of **X** and find that it has a molecular ion peak at *m* / *z* = 116.

The three students each propose a different structural formula for compound **X**.

**Structure 1** HOOCCH==CHCOOH
**Structure 2** $HOCH_2CH{=}{=}CHCH_2COOH$
**Structure 3** $CH_3CH_2CH_2CH_2CH_2COOH$

The students are given the infrared spectrum of **X**.

(i) State **two** wavenumber ranges of the infrared absorptions providing evidence that compound **X** is a carboxylic acid. Include the bonds responsible.

**(2)**

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(ii) One of the students suggests that this infrared spectrum and the data in the Data Booklet **alone** could be used to identify which of the three proposed structures is **X**. Show that this student's suggestion is correct. Include relevant infrared data in your answer.

**(3)**

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(b) The students decide to carry out an acid-base titration to obtain further information about compound **X**.

Each student uses solid sodium hydroxide, NaOH, to prepare a solution of concentration 0.140 mol $dm^{-3}$.
Calculate the mass, in grams, of solid sodium hydroxide that each student should weigh out to prepare 250.0 $cm^3$ of a 0.140 mol $dm^{-3}$ solution.

**(2)**

(c) Each of the students makes up 250.0 $cm^3$ of 0.140 mol $dm^{-3}$ sodium hydroxide solution in a volumetric flask and titrates this solution with the same solution of **X** of known concentration.

**Student A**

- correctly prepares the 0.140 mol $dm^{-3}$ sodium hydroxide solution and pipettes a volume of 10.0 $cm^3$ of the solution into a conical flask
- fills a burette with the solution of **X** and carries out a titration
- repeats the procedure until obtaining concordant results
- obtains a mean titre of 10.20 $cm^3$.

**Student B**

- dissolves the sodium hydroxide in distilled water and transfers the solution to a volumetric flask
- adds more distilled water to the volumetric flask and mixes the solution
- notices that the volumetric flask has been filled with distilled water several $cm^3$ beyond the graduation mark
- realises the mistake, removes the extra solution and discards it
- pipettes 10.0 $cm^3$ of the sodium hydroxide solution into a conical flask and titrates this with the solution of **X**.

**Student C**

- correctly prepares the 0.140 mol $dm^{-3}$ sodium hydroxide solution
- washes a conical flask thoroughly with distilled water and pipettes 10.0 $cm^3$ of the sodium hydroxide solution into the wet conical flask
- titrates the contents of the conical flask with the solution of **X**.

(i) Explain how, if at all, Student **B**'s mistake affects the value of the titre.

**(2)**

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(ii) Explain how, if at all, Student **C**'s use of a wet conical flask affects the value of the titre.

**(2)**

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(iii) Student **A** uses three pieces of apparatus to measure volumes in this experiment.

- The burette has an uncertainty of ±0.05 $cm^3$ for each volume reading
- The volumetric flask has an uncertainty of ±0.30 $cm^3$ for the volume
- The pipette has an uncertainty of ±0.04 $cm^3$ for the volume

Show by calculation which volume measurement has the lowest percentage uncertainty.

**(3)**

(d) Student **A** calculates the correct value for the molar mass of compound **X**, using the mean titre of 10.20 $cm^3$. The results indicate that **X** has **structure 1**.

**Structure 1** HOOCCH==CHCOOH
**Structure 2** $HOCH_2CH{=}{=}CHCH_2COOH$
**Structure 3** $CH_3CH_2CH_2CH_2CH_2COOH$

(i) Write the equation for the reaction between **structure 1** and sodium hydroxide solution. State symbols are not required.

**(2)**

(ii) Deduce the value that would have been obtained for the mean titre if the structural formula of **X** had been **structure 2**.
Justify your answer.

**(2)**

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(e) The students could have identified the three structures using chemical tests.

Complete the table to show whether or not the suggested structures react with bromine water and when heated with acidified potassium dichromate(VI).
Use a tick (✓) if a reaction occurs.
Use a cross (✗) if no reaction occurs.

**(2)**

| Structure | Test with bromine water | Test with acidified potassium dichromate(VI) |
|---|---|---|
| HOOCCH═CHCOOH | | |
| $HOCH_2CH{=}{=}CHCH_2COOH$ | | |
| $CH_3CH_2CH_2CH_2CH_2COOH$ | | |

CC BY NC ND

(f) The structure HOOCCH==CHCOOH has two stereoisomers.

(i) Draw the structures of these stereoisomers.

**(2)**

***E*-isomer**

***Z*-isomer**

(ii) State why HOOCCH==CHCOOH has *E*/*Z* isomers.

**(2)**

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**(Total for question = 24 marks)**

CC BY NC ND

**Q23.**

Ethanedioic acid has two carboxylic acid groups.

(a) Ethanedioic acid, $H_2C_2O_4$, can be prepared from ethane-1,2-diol.

Give the reagents and condition required for this reaction.

**(2)**

Reagents

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Condition

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(b) The formula for ethanedioic acid crystals is $H_2C_2O_4.nH_2O$.

To determine the number of moles of water of crystallisation, n, in 1 mol of ethanedioic acid crystals, a student carried out the following procedure.

- Prepare 250.0cm$^3$ of a solution containing a known mass of about 1g of ethanedioic acid crystals.
- Titrate 25.0cm$^3$ portions of the ethanedioic acid solution with 0.103 mol dm$^{-3}$ sodium hydroxide solution, using phenolphthalein as indicator.

The student obtained these results:
mass of ethanedioic acid crystals = 1.09g
mean titre = 16.20cm$^3$
The equation for the reaction is

$$H_2C_2O_4 + 2NaOH \rightarrow Na_2C_2O_4 + 2H_2O$$

(i) Describe how the student should prepare the 250.0 cm$^3$ of ethanedioic acid solution.

**(4)**

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(ii) Give the colour change at the end-point in this titration.

**(1)**

From ..... to .....

(iii) Calculate a value of n in the formula $H_2C_2O_4.nH_2O$ from these data.

**(5)**

(iv) The student thought that the ethanedioic acid crystals used may have been slightly damp.
Explain the effect of using damp crystals on the titre and on the value of n.

**(2)**

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**(Total for question = 14 marks)**

CC BY NC ND