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9701/51

October/November 2017

1 hour 15 minutes

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

DO **NOT** WRITE IN ANY BARCODES.

Answer **all** questions.

Electronic calculators may be used.

You may lose marks if you do not show your working or if you do not use appropriate units.

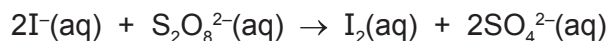
Use of a Data Booklet is unnecessary.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [] at the end of each question or part question.

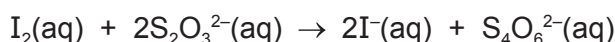
This document consists of **11** printed pages and **1** blank page.

- 1 Iodide ions, I^- , and persulfate ions, $\text{S}_2\text{O}_8^{2-}$, react according to the following equation.



The rate of reaction between these ions can be determined from the time it takes for a certain amount of iodine, $\text{I}_2(\text{aq})$, to be produced.

- A mixture of solutions is prepared, containing known volumes of
 - aqueous ammonium persulfate, $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{aq})$,
 - aqueous sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$,
 - starch indicator.
- A known volume of aqueous potassium iodide, $\text{KI}(\text{aq})$, is added to this mixture and a timer is started.
- After the reactants are mixed, they react slowly to produce iodine, $\text{I}_2(\text{aq})$.
- Any iodine initially produced is removed by a reaction with thiosulfate ions.



- Iodine, $\text{I}_2(\text{aq})$, is continuously removed until all of the thiosulfate ions have been used up.
- After that time any $\text{I}_2(\text{aq})$ that is produced turns the starch indicator blue.
- The time of the first appearance of the blue colour is recorded.
- This procedure is repeated with different volumes of reactants, keeping the total volume of the reaction mixture constant by adding the required volume of distilled water.

You are to plan a series of experiments to determine the effect of changing the concentration of iodide ions on the rate of reaction.

You are provided with the following materials.

solid ammonium persulfate, $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{s})$

0.20 mol dm^{-3} aqueous KI , a source of $\text{I}^-(\text{aq})$

$0.0050 \text{ mol dm}^{-3}$ aqueous $\text{Na}_2\text{S}_2\text{O}_3$, a source of $\text{S}_2\text{O}_3^{2-}(\text{aq})$

starch indicator

- (a) (i) Calculate the mass of $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{s})$ that would be required to prepare 250 cm^3 of a standard solution of concentration 1.00 mol dm^{-3} .

[A_r values: N, 14.0; H, 1.0; S, 32.1; O, 16.0]

mass of $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{s}) = \dots\dots\dots \text{ g [1]}$

- (ii) Describe how, after weighing the mass calculated in (i), you would prepare this standard solution for use in your experiment.

Give the name and capacity, in cm^3 , of any apparatus used.

.....

.....

.....

.....

..... [2]

- (iii) Explain how the use of starch solution improves the accuracy of the experiment.

.....

.....

..... [1]

- (b) A student planned five experiments to investigate the effect of iodide concentration, $[\text{I}^-]$, on the rate of reaction. The table shows the volumes used in experiment 1.

Complete the table for experiments 2 to 5.

experiment	volume of 1.00 mol dm^{-3} $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{aq})$ $/\text{cm}^3$	volume of 0.20 mol dm^{-3} $\text{KI}(\text{aq})$ $/\text{cm}^3$	volume of water $/\text{cm}^3$	volume of $0.0050 \text{ mol dm}^{-3}$ $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ $/\text{cm}^3$	volume of starch solution $/\text{cm}^3$
1	25.0	10.0	0.0	5.0	1.0
2				5.0	1.0
3				5.0	1.0
4				5.0	1.0
5				5.0	1.0

[3]

(c) In a different experiment, a student mixed the following solutions and measured the time taken for the reaction.

- 10.0 cm³ of 1.00 mol dm⁻³ (NH₄)₂S₂O₈(aq)
- 5.0 cm³ of 0.0050 mol dm⁻³ Na₂S₂O₃(aq)
- 5.0 cm³ of 0.20 mol dm⁻³ KI(aq)
- 1.0 cm³ of starch indicator

(i) The time taken for the blue colour to appear was 134 seconds (to the nearest second).

Calculate the rate of production of moles of I₂, in mol dm⁻³ s⁻¹.

rate of production of moles of I₂ = ... mol dm⁻³ s⁻¹ [3]

(ii) What should the student have done to make sure that the results were reliable?

.....
 [1]

(iii) The 5.0 cm³ of 0.0050 mol dm⁻³ Na₂S₂O₃(aq) was measured using a 50 cm³ burette which had graduations every 0.1 cm³.

Calculate the maximum percentage error in the measured volume of this solution.

percentage error = ... % [1]

(d) A second student tried to perform the same experiment but found that the reaction mixture turned blue immediately after KI(aq) was added.

State what error the student had made.

.....
 [1]

- (e) The following information gives some of the hazards associated with the chemicals used in the procedure.

Ammonium persulfate	Solid is oxidising and hazardous to the environment. Contact with combustible material may cause fire. It is classified as health hazard, is harmful if swallowed and is irritating to eyes, respiratory system and skin. Solutions equal to or more concentrated than 0.2mol dm^{-3} should be labelled health hazard and hazardous to the environment. Solutions equal to or more concentrated than 0.05mol dm^{-3} but less concentrated than 0.2mol dm^{-3} should be labelled health hazard.
Potassium iodide	All solutions are low hazard.
Sodium thiosulfate	All solutions are low hazard.

Describe **one** relevant precaution, other than eye protection and a lab coat, that should be taken to keep the risk associated with the chemicals used to a minimum. Explain your answer.

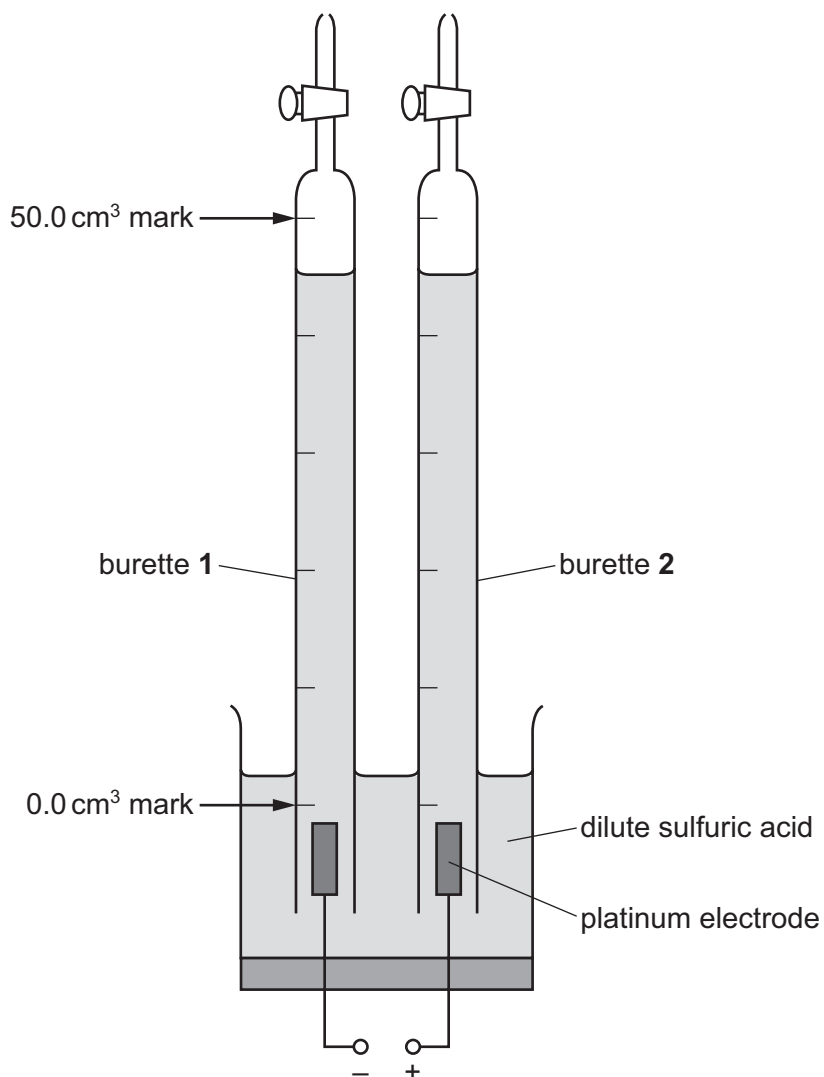
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.....

..... [1]

[Total: 14]

- 2 Dilute sulfuric acid, $\text{H}_2\text{SO}_4(\text{aq})$, can be electrolysed using platinum electrodes and a direct current. Hydrogen gas is produced at the cathode and oxygen gas is produced at the anode. The two gases are collected separately in burettes filled with dilute sulfuric acid placed over each electrode.



reaction at electrode in burette 1: $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$

reaction at electrode in burette 2: $\text{H}_2\text{O}(\text{l}) \rightarrow \frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$

The production of hydrogen gas over time can be measured, and the data used to determine the charge of one mole of electrons, known as the Faraday constant, F .

- (a) The volumes of hydrogen gas produced during the electrolysis process are recorded in the table.

Process the results to calculate the volume of hydrogen gas produced, in cm^3 , and the charge passed, in coulombs, C.

$$\text{charge (C)} = \text{current (A)} \times \text{time (s)}$$

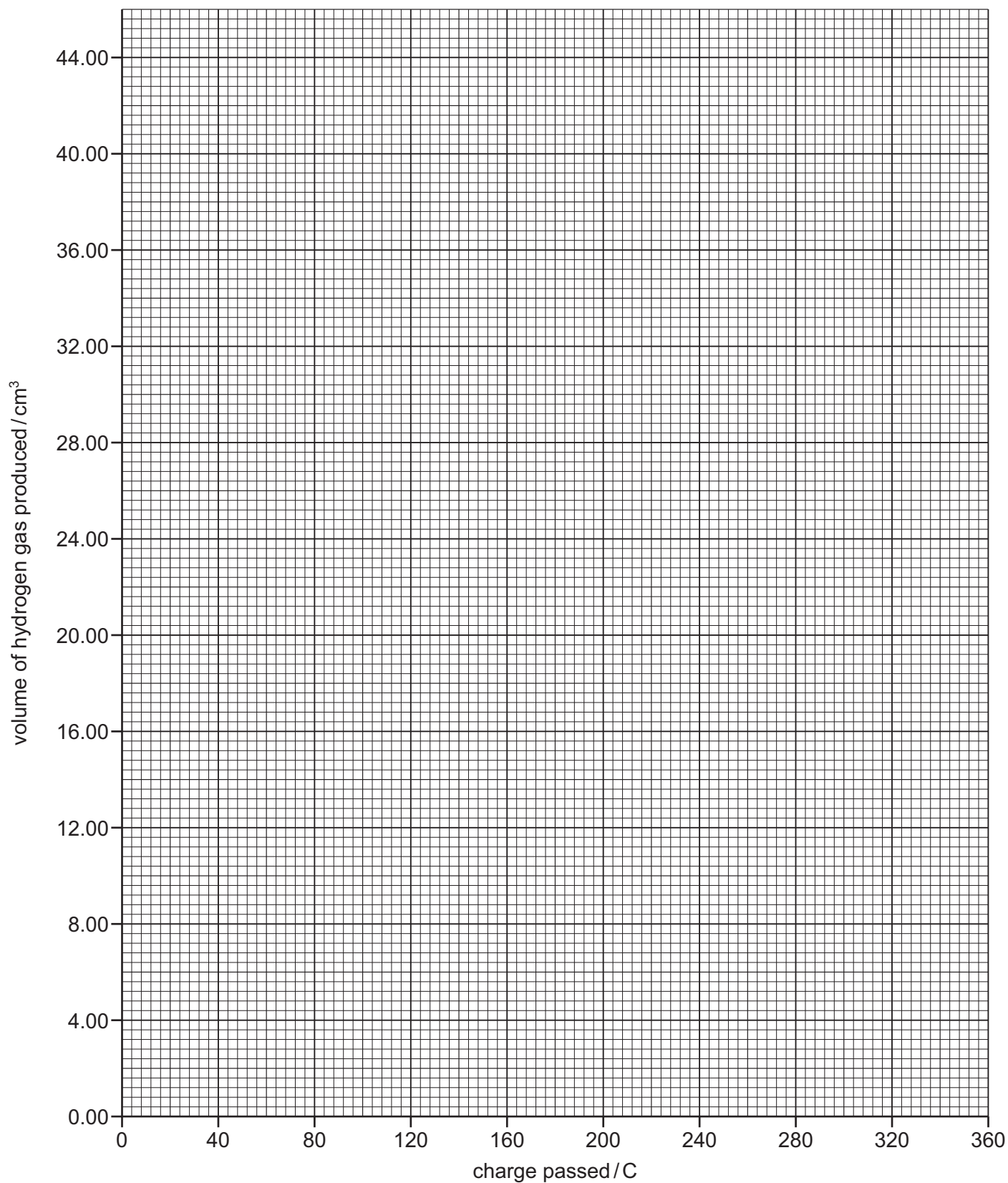
The current was kept constant at 0.80A.

time/s	reading on burette 1/ cm^3	volume of hydrogen gas produced/ cm^3	charge passed /C
0	46.20	0.00	
50	41.20		
100	36.20		
150	31.45		
200	25.80		
250	20.80		
300	16.40		
350	11.45		
400	6.80		
450	1.50		

[2]

- (b) Plot a graph on the grid to show the relationship between volume of hydrogen gas produced and charge passed.

Use a cross (×) to plot each data point. Draw the straight line of best fit.



[2]

(c) Do you think the results obtained in (a) are reliable? Explain your answer.

.....

 [1]

(d) (i) The gradient of the line of best fit gives the volume of hydrogen gas produced per coulomb.

Use the graph to determine the gradient of the line of best fit.

State the co-ordinates of both points you used in your calculation.

co-ordinates 1 co-ordinates 2

gradient = ... $\text{cm}^3 \text{C}^{-1}$
 [2]

(ii) Calculate the number of moles of hydrogen gas produced per coulomb.

If you were unable to obtain an answer for (d)(i), you may use the value $0.148 \text{ cm}^3 \text{C}^{-1}$, but this is not the correct answer.

[The molar volume of gas = 24.0 dm^3 at room temperature and pressure.]

..... mol C^{-1} [1]

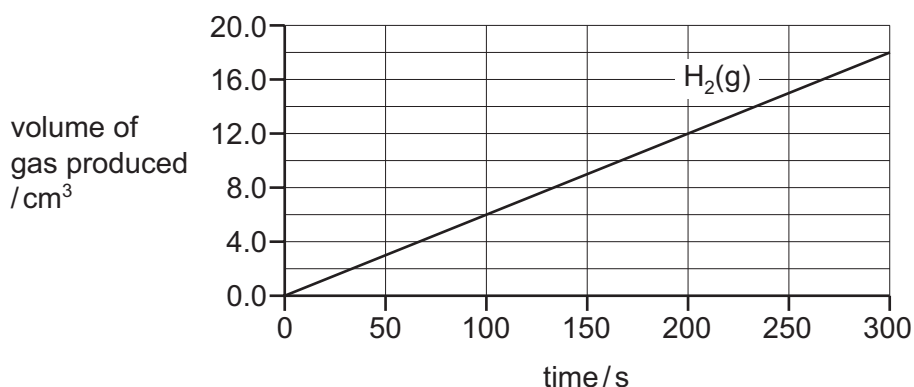
(iii) Use your answer to (ii) and the half-equation for the production of $\text{H}_2(\text{g})$ to calculate a numerical value for the Faraday constant (the charge of 1 mole of electrons).



..... C mol^{-1} [1]

- (e) (i) The graph below shows the relationship between volume of $\text{H}_2(\text{g})$ produced at the cathode and time, in a similar experiment.

Draw a line on the graph to show the relationship between volume of $\text{O}_2(\text{g})$ produced at the anode and time in this experiment.



[1]

- (ii) Suggest why the volume of $\text{O}_2(\text{g})$ measured in this experiment might be **less** than that shown by your drawn line.

Assume that no gas is lost from leaks.

.....
 [1]

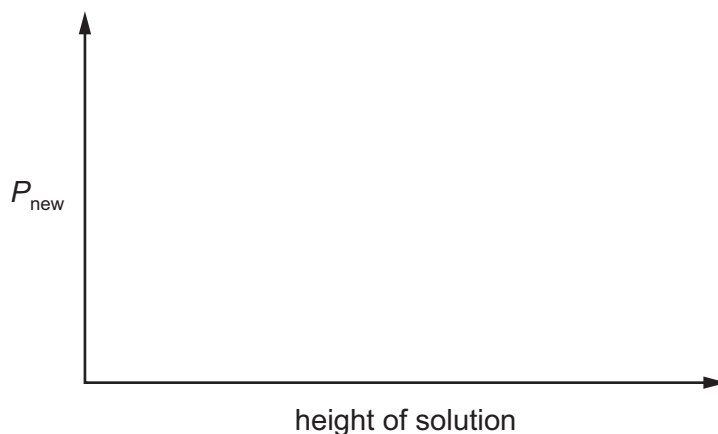
- (f) In these experiments, the pressure of the gas inside the burette is assumed to be atmospheric pressure, P_{atm} .

However, the presence of water vapour and the mass of the solution in the burette change the pressure of the gas to P_{new} .

The expression below shows the relationship between P_{new} and P_{atm} .

$$P_{\text{new}} = P_{\text{atm}} - 2.81 - (9.81 \times \text{height of solution in burette})$$

- (i) Use the expression to sketch a graph on the axes below to show the relationship between P_{new} and the height of solution in the burette.



[1]

- (ii) State how P_{new} changes the value of the Faraday constant calculated at P_{atm} in (d)(iii).

Explain your answer.

.....
 [1]

- (g) A student's teacher suggested it would be cheaper to use copper rather than platinum electrodes in the electrolysis of dilute sulfuric acid.

half-equation	E°/V
$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g})$	0.00
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}(\text{l})$	+1.23

Using the information in the table, suggest what effect, if any, the use of copper electrodes would have on the volume of gas produced at **each** electrode. Explain your answer.

cathode

.....

.....

anode

.....

.....

[3]

[Total: 16]

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NAME

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CANDIDATE
NUMBER

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CHEMISTRY

9701/52

Paper 5 Planning, Analysis and Evaluation

October/November 2017

1 hour 15 minutes

Candidates answer on the Question Paper.

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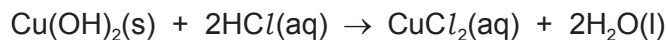
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- 1 Verdigris is a green pigment that contains both copper(II) carbonate, CuCO_3 , and copper(II) hydroxide, Cu(OH)_2 , in varying amounts.

Both copper compounds react with dilute hydrochloric acid.



- (a) You are to plan an experiment to determine the percentage of **copper(II) carbonate** in a sample of verdigris. Your method should involve the reaction of verdigris with excess dilute hydrochloric acid.

You are provided with the following materials.

- 0.5 g of verdigris
- 10.0 mol dm^{-3} hydrochloric acid, $\text{HCl}(\text{aq})$
- commonly available laboratory reagents and equipment

You may assume that any other material present in verdigris is unaffected by heating and is not acidic or basic.

- (i) Explain why a titration would **not** be a suitable method to determine the percentage of copper(II) carbonate in a sample of verdigris.

.....

 [1]

- (ii) The 10.0 mol dm^{-3} $\text{HCl}(\text{aq})$ is corrosive and too concentrated for use in the experiment.

Describe how you would accurately prepare 250 cm^3 of $0.500 \text{ mol dm}^{-3}$ hydrochloric acid from the 10.0 mol dm^{-3} $\text{HCl}(\text{aq})$ provided.

Include details of any apparatus, including their capacities in cm^3 , you would use.

.....

 [2]

- (iii) Identify a dependent variable that you could measure to determine the percentage of copper(II) carbonate in verdigris.

Your answer should be based on a difference that you can identify between the reactions of copper(II) carbonate and copper(II) hydroxide with excess dilute hydrochloric acid.

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

- (iv) Draw a diagram to show how you would set up apparatus and chemicals to measure the dependent variable identified in (iii).

Label your diagram.

[2]

- (v) Using the axes below, sketch a graph to show how the dependent variable you identified in (iii) would change during your experiment.

Extend the graph beyond the point at which the reaction is complete.

Label both axes.



[2]

- (vi) A student carries out this experiment once.

Describe how this **one** experiment should be carried out to ensure that the results are as accurate as possible.

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

- (vii) A student suspected that their 0.5 g sample of verdigris only contained CuCO_3 .

Calculate the minimum volume, in cm^3 , of $0.500 \text{ mol dm}^{-3} \text{ HCl(aq)}$ that would be needed for the complete reaction of the sample if the student was correct.

$[M_r: \text{CuCO}_3 = 123.5]$

volume of $0.500 \text{ mol dm}^{-3} \text{ HCl(aq)} = \dots\dots\dots \text{ cm}^3$ [2]

- (b) The following information gives some of the hazards associated with the chemicals used in the procedure.

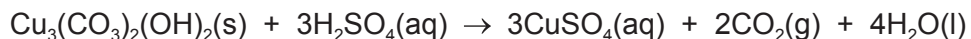
Copper(II) carbonate hydroxide	The solid is classified as health hazard and is harmful if swallowed. Dispose of by reacting no more than 60 g in 1 dm^3 of warm 1 mol dm^{-3} ethanoic acid before pouring down a foul-water drain.
Hydrochloric acid	Solutions equal to or more concentrated than 6.5 mol dm^{-3} are classified as corrosive ; solutions equal to or more concentrated than 2.7 mol dm^{-3} but less concentrated than 6.5 mol dm^{-3} are classified as moderate hazard and are irritant.

Describe **one** relevant precaution, other than eye protection and a lab coat, that should be taken to keep the risk associated with the chemicals used to a minimum. Explain your answer.

.....

 [1]

- (c) Azurite is a blue copper-containing mineral. The copper compound in azurite has the formula $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$. This copper compound reacts with sulfuric acid according to the reaction shown.



A student performed a series of titrations on 1.50 g samples of solid azurite using $0.400 \text{ mol dm}^{-3}$ sulfuric acid.

It can be assumed that any other material present in azurite does not react with sulfuric acid.

The titration data is given in the table.

experiment	rough	1	2
final reading / cm^3	25.50	24.05	32.70
initial reading / cm^3	0.00	0.15	8.30
titre / cm^3	25.50	23.90	24.40

The indicator for the titration was bromophenol blue.

The student concluded that 24.15 cm^3 of $0.400 \text{ mol dm}^{-3}$ sulfuric acid completely neutralised 1.50 g of azurite.

- (i) Using the student's value of 24.15 cm^3 , calculate the percentage by mass of $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$ in the sample of azurite.

Write your answer to **three significant figures**.

$[M_r: \text{Cu}_3(\text{CO}_3)_2(\text{OH})_2 = 344.5]$

percentage by mass of $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$ in the sample of azurite = ... % [3]

- (ii) Identify **two** possible problems with the student's titration **and** suggest improvements to it.

Problem 1

.....

Improvement 1

.....

Problem 2

.....

Improvement 2

.....

[3]

[Total: 18]

- 2 Activated charcoal is a form of carbon with a very high surface area. It can be used to remove impurities from mixtures. It does this by a process called *adsorption*, where particles of the impurity bond (adsorb) to the activated charcoal surface.

A student wanted to determine the ability of activated charcoal to adsorb a blue dye (the impurity) from aqueous solution.

The equation that links the mass of activated charcoal with the amount of blue dye adsorbed is shown.

$$\log\left(\frac{D}{m}\right) = A + b \log [X]$$

D = difference in concentration of dye (in g dm^{-3}) before and after adsorption

m = mass of activated charcoal (in g)

$[X]$ = final concentration of dye (in g dm^{-3}) after adsorption

A and b are constants

The student used the following procedure to investigate the ability of activated charcoal to adsorb a blue dye from an aqueous solution.

- Place a 50.0 cm^3 sample of a 25.00 g dm^{-3} solution of blue dye in a conical flask.
- Add a weighed mass of activated charcoal to the flask.
- Stir the contents of the flask for three minutes and then leave for one hour.
- Filter the mixture.
- Determine the final concentration of the blue dye, $[X]$, by colorimetry.
- Repeat the procedure using different masses of activated charcoal.

(a) The final concentrations of blue dye after carrying out the procedure, $[X]$, are shown in the table.

(i) Process the results to complete the table.

Record your data to **two** decimal places.

mass of activated charcoal, m / g	initial concentration of blue dye / g dm^{-3}	final concentration of blue dye, $[X]$ / g dm^{-3}	difference in concentration of blue dye, D / g dm^{-3}	$\frac{D}{m}$	$\log\left(\frac{D}{m}\right)$	$\log[X]$
0.20	25.00	0.96		120.20	2.08	
0.25	25.00	0.69		97.24	1.99	
0.30	25.00	0.60		81.33	1.91	
0.35	25.00	0.41		70.26	1.85	
0.40	25.00	0.33		61.68	1.79	
0.45	25.00	0.27		54.96	1.74	
0.50	25.00	0.23		49.54	1.69	
0.55	25.00	0.20		45.09	1.65	
0.60	25.00	0.17		41.38	1.62	

[3]

(ii) By considering the data in the first three columns, state the effect of increasing the mass of activated charcoal, m , on the amount of adsorption that occurs.

.....

.....

Explain this effect.

.....

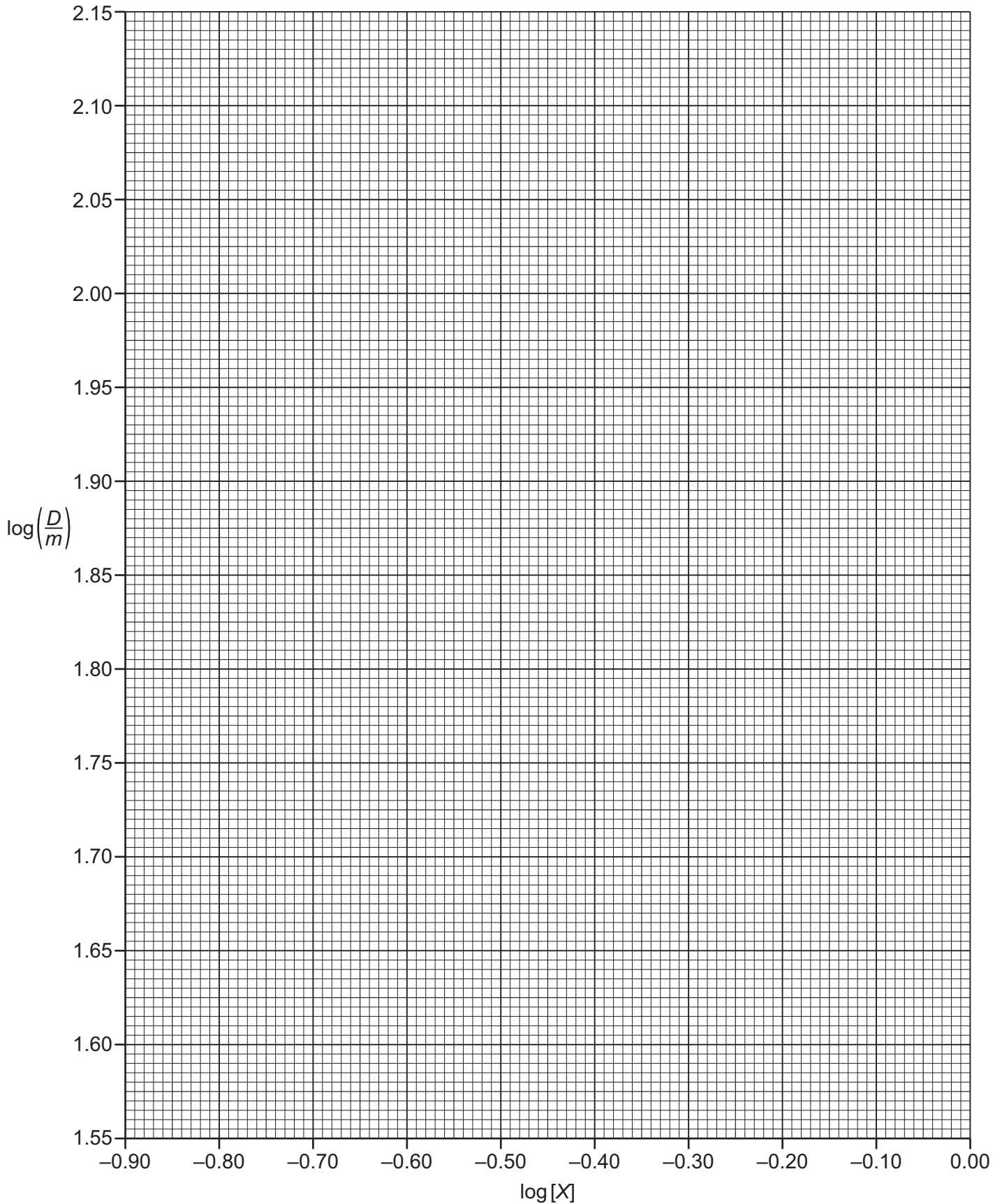
.....

.....

[2]

(b) Plot a graph on the grid to show the relationship between $\log\left(\frac{D}{m}\right)$ and $\log[X]$.

Use a cross (×) to plot each data point. Draw the straight line of best fit.



[2]

- (c) Circle the most anomalous point on the graph.

Suggest a reason why this anomaly may have occurred during the experimental procedure.

.....

.....

..... [2]

- (d) (i) Use the graph to determine the gradient of the best-fit line. State the co-ordinates of both points you used in your calculation.

Determine the value of the constant b .

co-ordinates 1 co-ordinates 2

gradient = ...

b = ... [2]

- (ii) Use the graph to determine a value for A .

A = ... [1]

[Total: 12]

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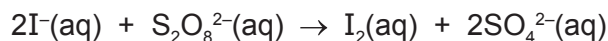
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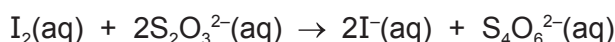
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- 1 Iodide ions, I^- , and persulfate ions, $\text{S}_2\text{O}_8^{2-}$, react according to the following equation.



The rate of reaction between these ions can be determined from the time it takes for a certain amount of iodine, $\text{I}_2(\text{aq})$, to be produced.

- A mixture of solutions is prepared, containing known volumes of
 - aqueous ammonium persulfate, $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{aq})$,
 - aqueous sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$,
 - starch indicator.
- A known volume of aqueous potassium iodide, $\text{KI}(\text{aq})$, is added to this mixture and a timer is started.
- After the reactants are mixed, they react slowly to produce iodine, $\text{I}_2(\text{aq})$.
- Any iodine initially produced is removed by a reaction with thiosulfate ions.



- Iodine, $\text{I}_2(\text{aq})$, is continuously removed until all of the thiosulfate ions have been used up.
- After that time any $\text{I}_2(\text{aq})$ that is produced turns the starch indicator blue.
- The time of the first appearance of the blue colour is recorded.
- This procedure is repeated with different volumes of reactants, keeping the total volume of the reaction mixture constant by adding the required volume of distilled water.

You are to plan a series of experiments to determine the effect of changing the concentration of iodide ions on the rate of reaction.

You are provided with the following materials.

solid ammonium persulfate, $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{s})$

0.20 mol dm^{-3} aqueous KI, a source of $\text{I}^-(\text{aq})$

$0.0050 \text{ mol dm}^{-3}$ aqueous $\text{Na}_2\text{S}_2\text{O}_3$, a source of $\text{S}_2\text{O}_3^{2-}(\text{aq})$

starch indicator

- (a) (i) Calculate the mass of $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{s})$ that would be required to prepare 250 cm^3 of a standard solution of concentration 1.00 mol dm^{-3} .

[A_r values: N, 14.0; H, 1.0; S, 32.1; O, 16.0]

mass of $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{s}) = \dots\dots\dots \text{ g [1]}$

- (ii) Describe how, after weighing the mass calculated in (i), you would prepare this standard solution for use in your experiment.

Give the name and capacity, in cm^3 , of any apparatus used.

.....

.....

.....

.....

..... [2]

- (iii) Explain how the use of starch solution improves the accuracy of the experiment.

.....

.....

..... [1]

- (b) A student planned five experiments to investigate the effect of iodide concentration, $[\text{I}^-]$, on the rate of reaction. The table shows the volumes used in experiment 1.

Complete the table for experiments 2 to 5.

experiment	volume of 1.00 mol dm^{-3} $(\text{NH}_4)_2\text{S}_2\text{O}_8(\text{aq})$ $/\text{cm}^3$	volume of 0.20 mol dm^{-3} $\text{KI}(\text{aq})$ $/\text{cm}^3$	volume of water $/\text{cm}^3$	volume of $0.0050 \text{ mol dm}^{-3}$ $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ $/\text{cm}^3$	volume of starch solution $/\text{cm}^3$
1	25.0	10.0	0.0	5.0	1.0
2				5.0	1.0
3				5.0	1.0
4				5.0	1.0
5				5.0	1.0

[3]

(c) In a different experiment, a student mixed the following solutions and measured the time taken for the reaction.

- 10.0 cm³ of 1.00 mol dm⁻³ (NH₄)₂S₂O₈(aq)
- 5.0 cm³ of 0.0050 mol dm⁻³ Na₂S₂O₃(aq)
- 5.0 cm³ of 0.20 mol dm⁻³ KI(aq)
- 1.0 cm³ of starch indicator

(i) The time taken for the blue colour to appear was 134 seconds (to the nearest second).

Calculate the rate of production of moles of I₂, in mol dm⁻³ s⁻¹.

rate of production of moles of I₂ = ... mol dm⁻³ s⁻¹ [3]

(ii) What should the student have done to make sure that the results were reliable?

.....
 [1]

(iii) The 5.0 cm³ of 0.0050 mol dm⁻³ Na₂S₂O₃(aq) was measured using a 50 cm³ burette which had graduations every 0.1 cm³.

Calculate the maximum percentage error in the measured volume of this solution.

percentage error = ... % [1]

(d) A second student tried to perform the same experiment but found that the reaction mixture turned blue immediately after KI(aq) was added.

State what error the student had made.

.....
 [1]

- (e) The following information gives some of the hazards associated with the chemicals used in the procedure.

Ammonium persulfate	Solid is oxidising and hazardous to the environment. Contact with combustible material may cause fire. It is classified as health hazard, is harmful if swallowed and is irritating to eyes, respiratory system and skin. Solutions equal to or more concentrated than 0.2mol dm^{-3} should be labelled health hazard and hazardous to the environment. Solutions equal to or more concentrated than 0.05mol dm^{-3} but less concentrated than 0.2mol dm^{-3} should be labelled health hazard.
Potassium iodide	All solutions are low hazard.
Sodium thiosulfate	All solutions are low hazard.

Describe **one** relevant precaution, other than eye protection and a lab coat, that should be taken to keep the risk associated with the chemicals used to a minimum. Explain your answer.

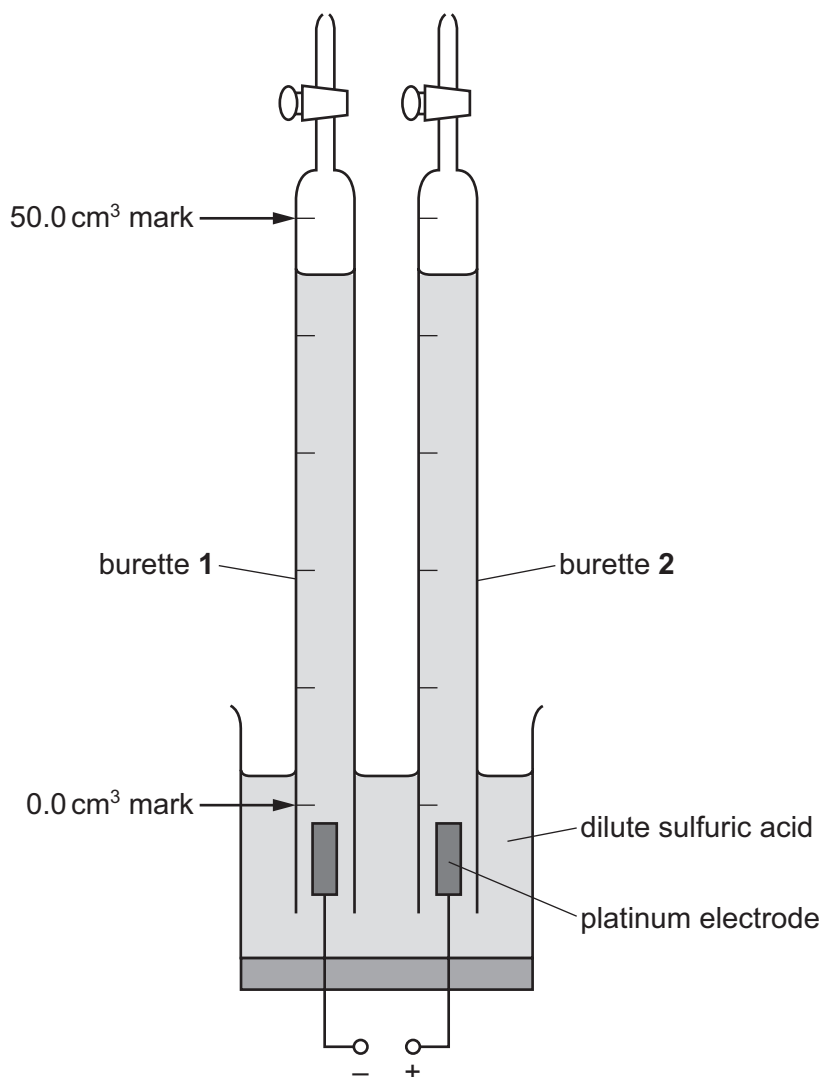
.....

.....

..... [1]

[Total: 14]

- 2 Dilute sulfuric acid, $\text{H}_2\text{SO}_4(\text{aq})$, can be electrolysed using platinum electrodes and a direct current. Hydrogen gas is produced at the cathode and oxygen gas is produced at the anode. The two gases are collected separately in burettes filled with dilute sulfuric acid placed over each electrode.



reaction at electrode in burette 1: $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$

reaction at electrode in burette 2: $\text{H}_2\text{O}(\text{l}) \rightarrow \frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$

The production of hydrogen gas over time can be measured, and the data used to determine the charge of one mole of electrons, known as the Faraday constant, F .

- (a) The volumes of hydrogen gas produced during the electrolysis process are recorded in the table.

Process the results to calculate the volume of hydrogen gas produced, in cm^3 , and the charge passed, in coulombs, C.

$$\text{charge (C)} = \text{current (A)} \times \text{time (s)}$$

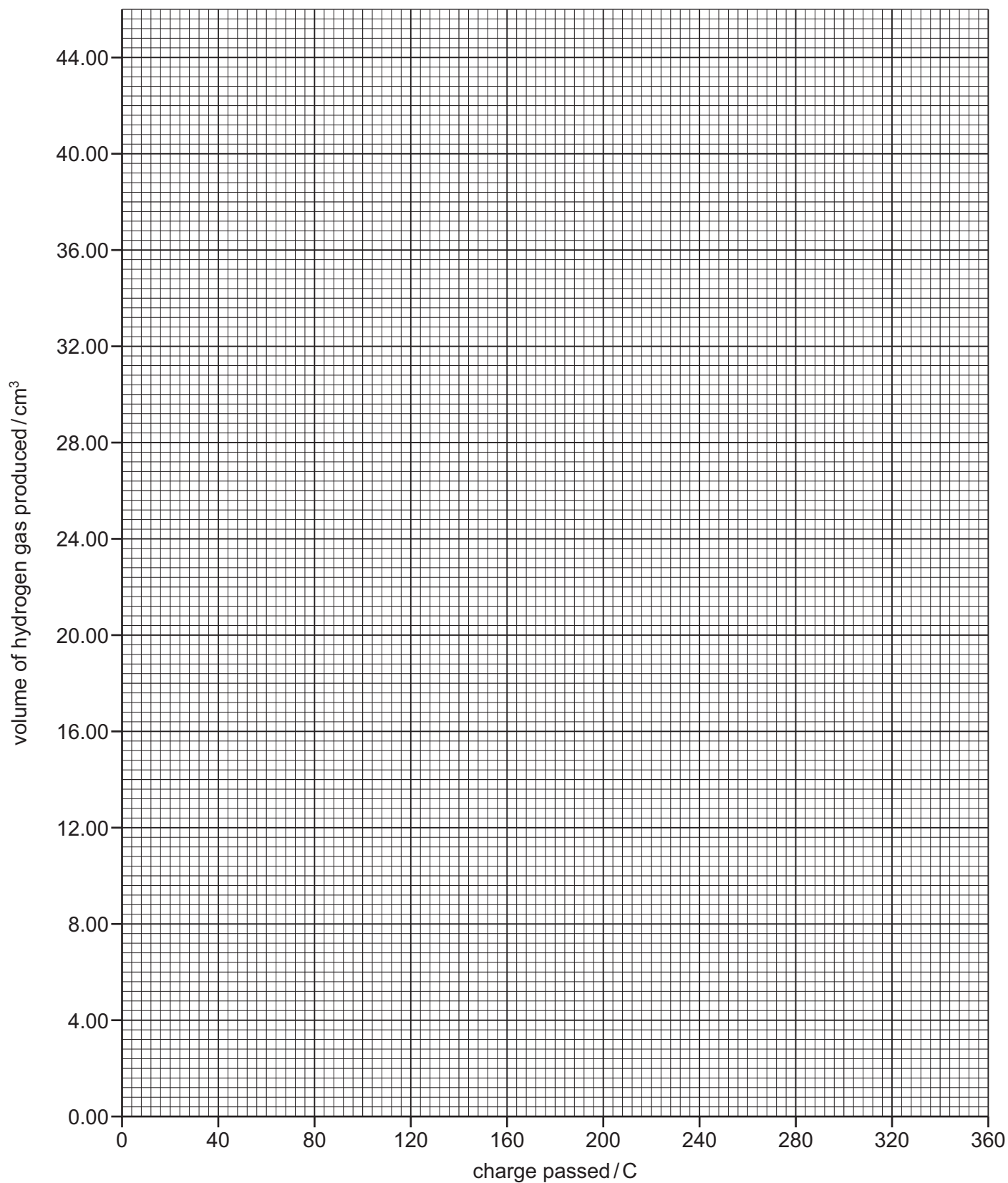
The current was kept constant at 0.80A.

time/s	reading on burette 1/ cm^3	volume of hydrogen gas produced/ cm^3	charge passed /C
0	46.20	0.00	
50	41.20		
100	36.20		
150	31.45		
200	25.80		
250	20.80		
300	16.40		
350	11.45		
400	6.80		
450	1.50		

[2]

- (b) Plot a graph on the grid to show the relationship between volume of hydrogen gas produced and charge passed.

Use a cross (×) to plot each data point. Draw the straight line of best fit.



[2]

(c) Do you think the results obtained in (a) are reliable? Explain your answer.

.....

 [1]

(d) (i) The gradient of the line of best fit gives the volume of hydrogen gas produced per coulomb.

Use the graph to determine the gradient of the line of best fit.

State the co-ordinates of both points you used in your calculation.

co-ordinates 1 co-ordinates 2

gradient = ... $\text{cm}^3 \text{C}^{-1}$
 [2]

(ii) Calculate the number of moles of hydrogen gas produced per coulomb.

If you were unable to obtain an answer for (d)(i), you may use the value $0.148 \text{ cm}^3 \text{C}^{-1}$, but this is not the correct answer.

[The molar volume of gas = 24.0 dm^3 at room temperature and pressure.]

..... mol C^{-1} [1]

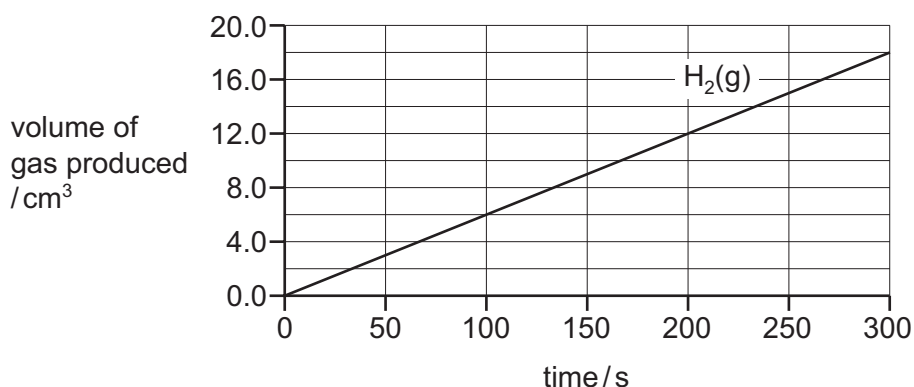
(iii) Use your answer to (ii) and the half-equation for the production of $\text{H}_2(\text{g})$ to calculate a numerical value for the Faraday constant (the charge of 1 mole of electrons).



..... C mol^{-1} [1]

- (e) (i) The graph below shows the relationship between volume of $\text{H}_2(\text{g})$ produced at the cathode and time, in a similar experiment.

Draw a line on the graph to show the relationship between volume of $\text{O}_2(\text{g})$ produced at the anode and time in this experiment.



[1]

- (ii) Suggest why the volume of $\text{O}_2(\text{g})$ measured in this experiment might be **less** than that shown by your drawn line.

Assume that no gas is lost from leaks.

.....
 [1]

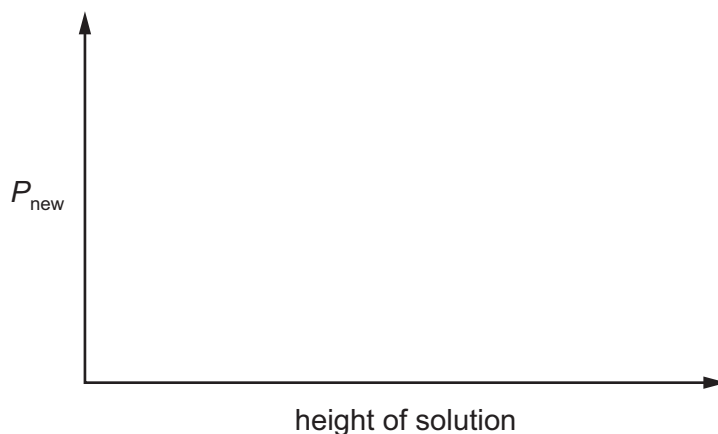
- (f) In these experiments, the pressure of the gas inside the burette is assumed to be atmospheric pressure, P_{atm} .

However, the presence of water vapour and the mass of the solution in the burette change the pressure of the gas to P_{new} .

The expression below shows the relationship between P_{new} and P_{atm} .

$$P_{\text{new}} = P_{\text{atm}} - 2.81 - (9.81 \times \text{height of solution in burette})$$

- (i) Use the expression to sketch a graph on the axes below to show the relationship between P_{new} and the height of solution in the burette.



[1]

- (ii) State how P_{new} changes the value of the Faraday constant calculated at P_{atm} in (d)(iii).

Explain your answer.

.....
 [1]

- (g) A student's teacher suggested it would be cheaper to use copper rather than platinum electrodes in the electrolysis of dilute sulfuric acid.

half-equation	E°/V
$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g})$	0.00
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}(\text{l})$	+1.23

Using the information in the table, suggest what effect, if any, the use of copper electrodes would have on the volume of gas produced at **each** electrode. Explain your answer.

cathode

.....

anode

.....

[3]

[Total: 16]

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