Cambridge Assessment International Education

Cambridge International AS & A Level

# The electrolysis of acidified water using a Hofmann voltameter – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

| Question | Year | Series | Paper number |
|---|---|---|---|
| 3 | 2018 | June | 41 |
| 3 | 2018 | June | 42 |
| 1 | 2018 | June | 51 |
| 2 | 2017 | November | 51 |

The mark scheme for each question is provided at the end of the document.

You can find the complete question papers and the complete mark schemes (with additional notes where available) on the School Support Hub at www.cambridgeinternational.org/support

3 **(a)** Complete the table, identifying the substance liberated at each electrode during electrolysis with inert electrodes.

| electrolyte | substance liberated at the anode | substance liberated at the cathode |
|---|---|---|
| $AgNO_3(aq)$ | | |
| concentrated $NaCl(aq)$ | | |
| $CuSO_4(aq)$ | | |

[3]

**(b)** Molten calcium iodide, $CaI_2$, is electrolysed in an inert atmosphere with inert electrodes.

**(i)** Write ionic equations for the reactions occurring at the electrodes.

- .............................................................................................................................
- .............................................................................................................................

[2]

**(ii)** The electrolysis of molten $CaI_2$ is a redox process.

Identify the ion that is oxidised and the ion that is reduced, explaining your answer by reference to oxidation numbers.

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

**(iii)** Describe **two** visual observations that would be made during this electrolysis.

1 .............................................................................................................................

2 .............................................................................................................................

[1]

**(c)** An oxide of iron dissolved in an inert solvent is electrolysed for 2.00 hours using a current of 0.800 A. The electrolysis products are iron and oxygen. The mass of iron produced is 1.11 g.

Calculate the oxidation number of Fe in the oxide of iron. Show **all** your working.

oxidation number of Fe = .............................. [3]

[Total: 11]

3 **(a)** Complete the table by predicting the identity of the substance liberated at each electrode during electrolysis with inert electrodes.

| electrolyte | substance liberated at the anode | substance liberated at the cathode |
|---|---|---|
| NaOH(aq) | | |
| dilute $CuCl_2$(aq) | | |
| concentrated $MgCl_2$(aq) | | |

[3]

**(b)** **(i)** The electrolysis of molten $ZnBr_2$ is a redox process.

Identify the ion that is oxidised and the ion that is reduced.

Use ionic half-equations to explain your answer.

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**(ii)** Describe **one** visual observation that would be made during this electrolysis.

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

**(c)** Dilute sulfuric acid is electrolysed for 50.0 minutes using inert electrodes and a current of 1.20 A. A different gas is collected above each electrode. The volumes of the two gases are measured under room conditions.

Calculate the maximum volume of gas that could be collected at the **cathode**.

volume = ............................. $cm^3$ [3]

[Total: 10]

1 The Faraday constant is the charge in coulombs, C, carried by 1 mole of electrons.

**(a)** A student plans an electrolysis experiment to determine the Faraday constant.

The student was supplied with the following.

- 1.0 $mol\,dm^{-3}$ copper(II) sulfate
- clean, dry copper foil electrodes, labelled 'anode' and 'cathode'
- balance
- stop-clock
- ammeter
- other equipment suitable for carrying out electrolysis

Draw a labelled diagram of the apparatus and chemicals the student should use in their electrolysis experiment. Include in your diagram the circuit connecting the anode and cathode.

[2]

**(b)** Two of the hazards of using copper(II) sulfate solution are given below.

For each hazard, state a precaution, other than eye protection and a lab coat, that the student should take when carrying out the experiment.

hazard: copper(II) sulfate solution causes skin irritation

precaution ..........................................................................................................................

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hazard: copper(II) sulfate solution is toxic to aquatic life

precaution ..........................................................................................................................

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

The student carried out the electrolysis for exactly 30 minutes with a current of 0.5A.

- After the electrolysis was finished, the student removed the electrodes.
- The electrodes were then carefully washed in water and then dipped in propanone.
- The electrodes were dried by allowing the propanone to evaporate.

**(c)** State the measurements the student would need to record to calculate the mass change of an electrode. Include the appropriate unit.

[1]

**(d)** Calculate the charge passed through the copper(II) sulfate solution during the electrolysis experiment using the formula shown.

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

charge passed = .............................. C [1]

**(e)** The mass change of the anode was –0.282 g.

Calculate the amount, in mol, of copper lost from the anode. Give your answer to 3 significant figures.
[$A_r$: Cu, 63.5]

moles of copper lost from the anode = .............................. mol [1]

**(f)** Use your answers to **(d)** and **(e)** to calculate the charge required to remove 1 mole of copper from the anode.

charge required to remove 1 mole of copper = .............................. C [1]

**(g)** The theoretical charge required to remove 1 mole of copper from the anode into solution as copper(II) ions is 193 000 C.
The Faraday constant is 96 500 C $mol^{-1}$.

Explain why the theoretical charge is twice the Faraday constant.

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

**(h)** A possible source of error is not drying the anode at the start of the experiment.

Explain the effect, if any, on the calculated value of the Faraday constant if the anode is wet at the beginning of the experiment but dry at the end.

effect ..............................................................................................................................

explanation ......................................................................................................................

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

**(i)** The student wanted to ensure that the anode was completely dry at the end of the experiment and decided to evaporate off the propanone using a blue Bunsen flame. The student noticed some blackening of the surface of the copper.

Suggest what caused this blackening.

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

**(j)** The student calculated the mass change of the anode and the cathode after the experiment was complete.

mass change of anode = –0.282 g        mass change of cathode = +0.217 g

Suggest **one** reason why the mass gained at the cathode is **not** the same as the mass lost at the anode. Assume the student has recorded the mass changes correctly.

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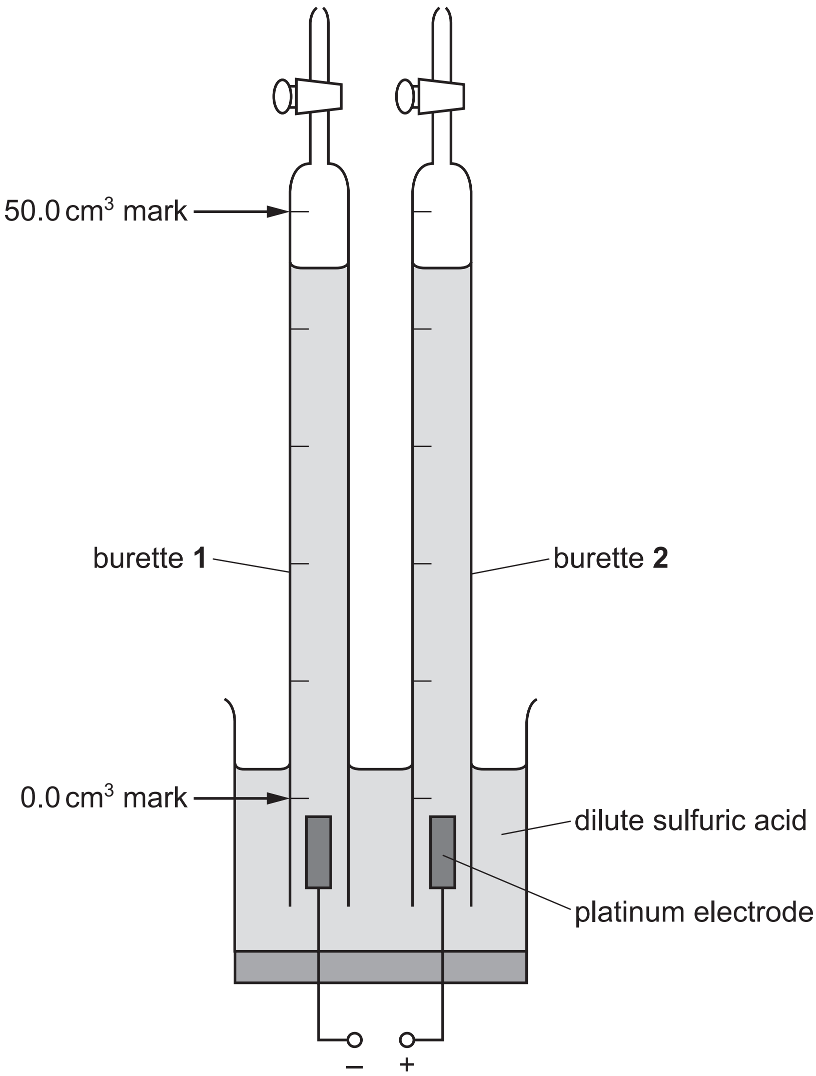
.............................................................................................................................................. [1]

[Total: 12]

**2** Dilute sulfuric acid, $H_2SO_4(aq)$, 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**: $2H^+(aq) + 2e^- \rightarrow H_2(g)$
reaction at electrode in burette **2**: $H_2O(l) \rightarrow \frac{1}{2}O_2(g) + 2H^+(aq) + 2e^-$

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.

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

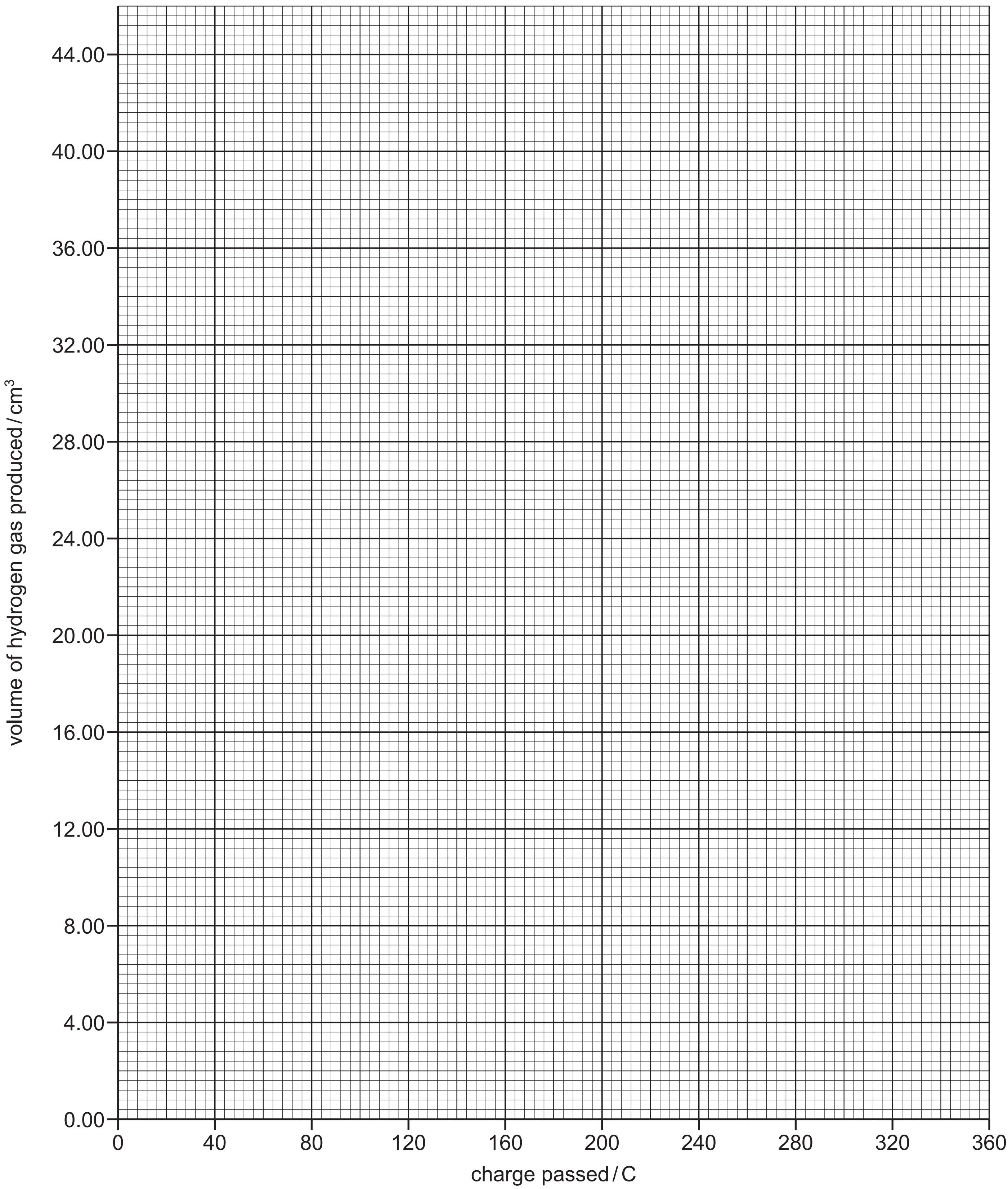
The current was kept constant at 0.80 A.

| 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.

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.................................................................................................................................... [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 = ............................. $cm^3\,C^{-1}$
[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 $cm^3\,C^{-1}$, 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]

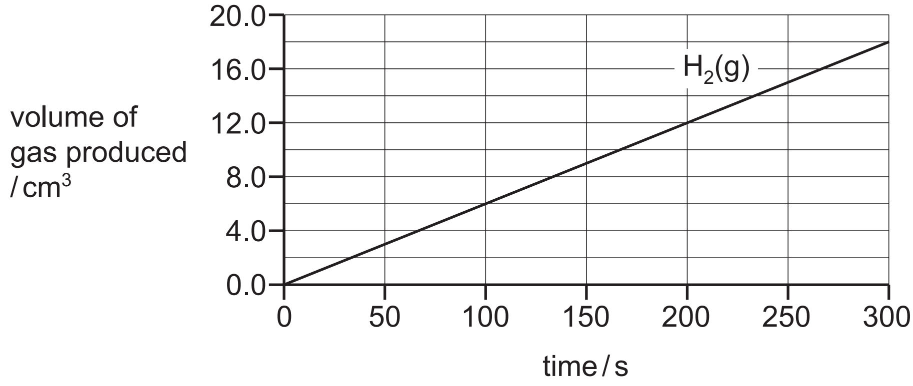
**(iii)** Use your answer to **(ii)** and the half-equation for the production of $H_2(g)$ to calculate a numerical value for the Faraday constant (the charge of 1 mole of electrons).

$$2H^+(aq) + 2e^- \rightarrow H_2(g)$$

............................. $C\,mol^{-1}$ [1]

**(e) (i)** The graph below shows the relationship between volume of $H_2(g)$ produced at the cathode and time, in a similar experiment.

Draw a line on the graph to show the relationship between volume of $O_2(g)$ produced at the anode and time in this experiment.




[1]

**(ii)** Suggest why the volume of $O_2(g)$ measured in this experiment might be **less** than that shown by your drawn line.

Assume that no gas is lost from leaks.

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

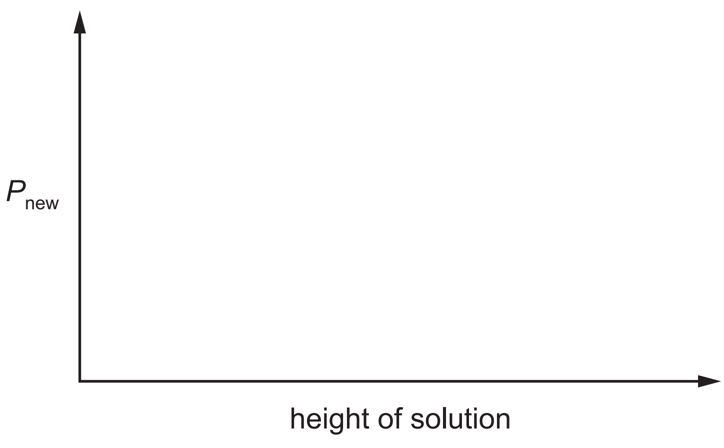
**(f)** In these experiments, the pressure of the gas inside the burette is assumed to be atmospheric pressure, $P_{atm}$.

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 $P_{atm}$.

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

**(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.

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............................................................................................................................. [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 | $E^{\ominus}$/V |
|---|---|
| $2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$ | 0.00 |
| $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$ | +0.34 |
| $\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O(l)$ | +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 .............................................................................................................................

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anode .............................................................................................................................

.............................................................................................................................

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[3]

[Total: 16]

| Question | Answer | Marks |
|---|---|---|
| 3(a) | <table><tr><td></td><td>anode</td><td>cathode</td></tr><tr><td>$AgNO_3$ (aq)</td><td>**oxygen / $O_2$**</td><td>**silver / Ag**</td></tr><tr><td>saturated $NaCl$ (aq)</td><td>**chlorine / $Cl_2$**</td><td>**hydrogen / $H_2$**</td></tr><tr><td>$CuSO_4$ (aq)</td><td>**oxygen / $O_2$**</td><td>**copper / Cu**</td></tr></table> | **3** |
| 3(b)(i) | $2I^- \rightarrow I_2 + 2e^-$ | **1** |
| | $Ca^{2+} + 2e^- \rightarrow Ca$ | **1** |
| 3(b)(ii) | • Ca / Calcium reduced and I / iodine oxidised<br>• Oxidation number of calcium decreases from 2 to 0<br>• Oxidation number of iodine increases from –1 to 0<br><br>2 points = 1 mark<br>3 points = 2 marks | **2** |
| 3(b)(iii) | • metal / grey / silvery<br>• purple AND vapour / gas / fumes<br>• amount of melt decreases<br><br>any 2 points for 1 mark | **1** |
| 3(c) | $2 \times 60 \times 60 \times 0.8 = 5760$ C<br>**AND**<br>5760 / 96500 = 0.060 (0.0597) F | **1** |
| | 1.11 / 55.8 = 0.020 (0.0199) mol of Fe | **1** |
| | 0.06 / 0.02 = 3 $\therefore$ $Fe^{3+}$ or +3 or 3 | **1** |

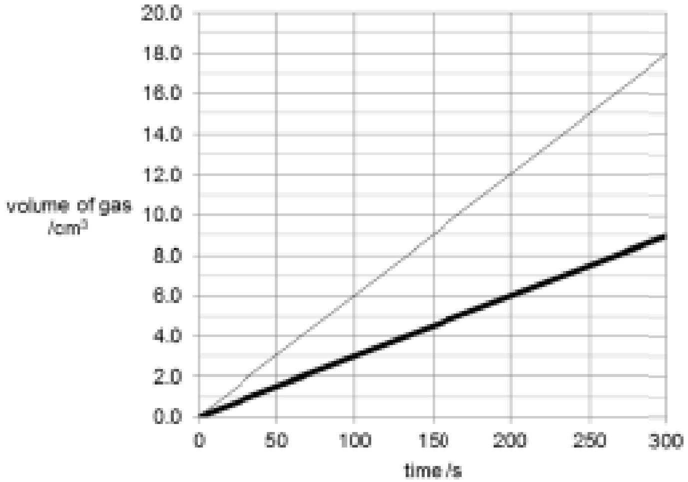
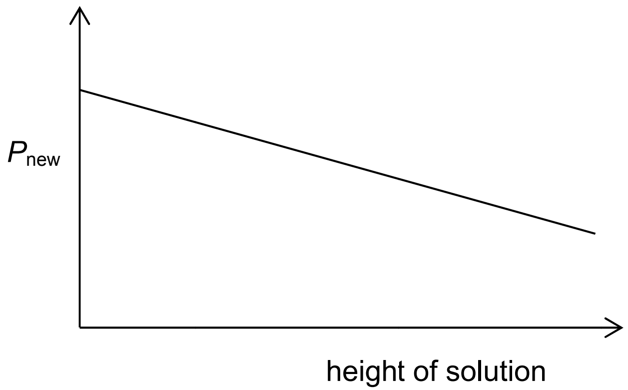
<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>3(a)</td><td><table><tr><td></td><td>anode</td><td>cathode</td></tr><tr><td>NaOH (aq)</td><td>oxygen / $O_2$</td><td>hydrogen / $H_2$</td></tr><tr><td>dilute $CuCl_2$ (aq)</td><td>oxygen / $O_2$</td><td>copper / Cu</td></tr><tr><td>conc $MgCl_2$ (aq)</td><td>chlorine / $Cl_2$</td><td>hydrogen / $H_2$</td></tr></table></td><td>3</td></tr>
<tr><td rowspan="3">3(b)(i)</td><td>$2Br^- \rightarrow Br_2 + 2e^-$ or $2Br^- - 2e^- \rightarrow Br_2$</td><td>1</td></tr>
<tr><td>$Zn^{2+} + 2e^- \rightarrow Zn$</td><td>1</td></tr>
<tr><td>Zinc / $Zn^{2+}$ reduced and $Br^-$ / bromide oxidised</td><td>1</td></tr>
<tr><td>3(b)(ii)</td><td>liquid / molten metal<br>or orange-<u>brown</u> / reddish <u>brown</u> vapour / gas (at anode)<br>or amount of melt / electrolyte decreases</td><td>1</td></tr>
<tr><td>3(c)</td><td>• 50 × 60 × 1.2 or 3600 C (calculation of number of Coulombs)<br>• 3600 / 96 500 or 0.0373 F (calculation of number of Faradays)<br>• 0.0373 F / 2 or 0.01865 / 0.0187 mol $H_2$ (use of stoichiometry)<br>• 0.01865 × 24 000 = 448–449 (Use of 24 000 & answer to 3sf)<br>2 points = 1 mark<br>3 points = 2 marks<br>4 points = 3 marks</td><td>3</td></tr>
</table>

| Question | Answer | Marks |
|---|---|---|
| 1(a) | Complete circuit with ammeter in series and DC power supply | **1** |
| | Anode, cathode and solution labelled | **1** |
| 1(b) | wear gloves | **1** |
| | do not dispose into the water waste / sink<br><br>**OR** do not put down drain / sewage<br><br>**OR** put in waste bottles | **1** |
| 1(c) | Mass (of electrode) before and after experiment **AND** mass unit | **1** |
| 1(d) | charge = 0.5 × 30 × 60 = 900 C | **1** |
| 1(e) | 0.282 / 63.5 = $4.44 \times 10^{-3}$ (mol) **OR** 0.00444 | **1** |
| 1(f) | (900 / $4.44 \times 10^{-3}$)= 202702.7027 C | **1** |
| 1(g) | 2 moles of electrons are **produced** / removed / released<br>(so 2 Faradays **OR** 2 × 96 500) | **1** |
| 1(h) | (Faraday) value is smaller<br>**AND** (apparent) mass / moles / amount is more (for same charge passed) | **1** |
| 1(i) | CuO is formed / oxidation of copper / carbon / soot is formed | **1** |
| 1(j) | Some copper falls off the electrode during electrolysis / falls to the bottom of the beaker<br>**OR** Some copper is lost during washing | **1** |

<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>2(a)</td><td>

| time / s | burette reading / $cm^3$ | volume (of hydrogen) / $cm^3$ | charge / C |
|---|---|---|---|
| 0 | 46.20 | 0.00 | 0 |
| 50 | 41.20 | 5.00 | 40 |
| 100 | 36.20 | 10.00 | 80 |
| 150 | 31.45 | 14.75 | 120 |
| 200 | 25.80 | 20.40 | 160 |
| 250 | 20.80 | 25.40 | 200 |
| 300 | 16.40 | 29.80 | 240 |
| 350 | 11.45 | 34.75 | 280 |
| 400 | 6.80 | 39.40 | 320 |
| 450 | 1.50 | 44.70 | 360 |

volumes of hydrogen correct to 2 d.p.<br>charge correct</td><td>2</td></tr>
<tr><td>2(b)</td><td>All ten points plotted correctly</td><td>1</td></tr>
<tr><td></td><td>Best-fit straight line drawn</td><td>1</td></tr>
<tr><td>2(c)</td><td>Yes, (the data is reliable because) most of the points are on the line OR only a few points are not on the line.</td><td>1</td></tr>
<tr><td>2(d)(i)</td><td>co-ordinates read and recorded correctly</td><td>1</td></tr>
<tr><td></td><td>gradient determined</td><td>1</td></tr>
<tr><td>2(d)(ii)</td><td>= (i) ÷ 24000</td><td>1</td></tr>
<tr><td>2(d)(iii)</td><td>= 1 ÷ (2 × (ii))</td><td>1</td></tr>
</table>

| Question | Answer | Marks |
|---|---|---|
| 2(e)(i) | <br>straight line from origin to (300, 9.0) | 1 |
| 2(e)(ii) | Oxygen is (slightly) soluble in water | 1 |
| 2(f)(i) | <br>straight line with negative gradient | 1 |
| 2(f)(ii) | Faraday constant will be <u>lower</u> (than calculated)<br>because the volume / $V_m$ larger | 1 |

| Question | Answer | Marks |
|---|---|---|
| 2(g) | No effect at cathode | **1** |
| | Less gas produced at anode | **1** |
| | Copper anode will dissolve / is (an) active (anode)<br>**OR** copper has lower / more negative $E^{\ominus}$ | **1** |