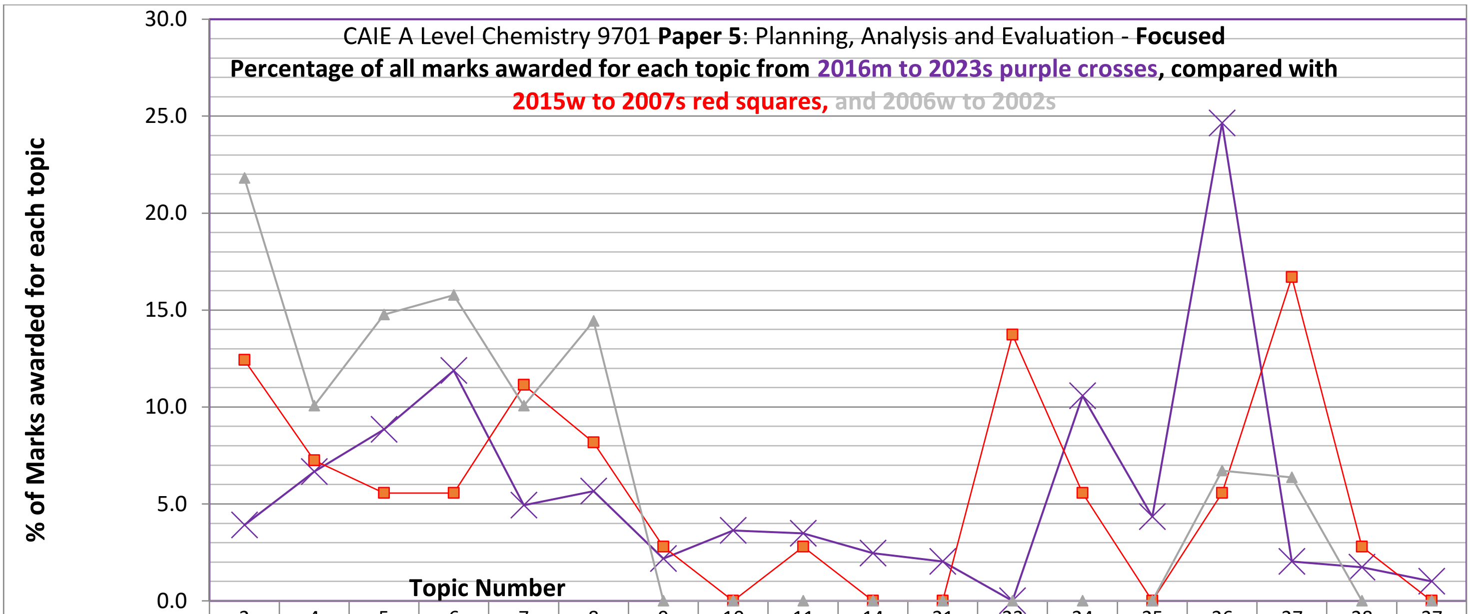
Name: Class: Date:

ALvl Chem 24 EQ P5 22w to 02s Paper 5 Electrochemistry 103marks

As you start and work through this worksheet you can tick off your progress to show yourself how much you have done, and what you need to do next. The first task is just to read the first question and should take you less than 3 minutes to complete.

Paper 5 **Topic 24**
Checklist Tick each task off as you go along

	RANK:	P5 Noob	P5 Novice	P5 Bronze	P5 Silver	P4 Gold	P5[1] Winner	P5 Hero	P5 Legend
	Marks	1 Q Started	1 Q done	10% of marks	25% of marks	40% of marks	50% of marks	75% of marks	100% of marks
Topic (marks)	103		15	10	26	41	52	77	103
Time @150s/mark (minutes)	258		37	26	64	103	129	193	258



	2	4	5	6	7	8	9	10	11	14	21	23	24	25	26	27	28	37
P5 16m-23s	3.9	6.7	8.8	11.9	4.9	5.7	2.2	3.6	3.5	2.5	2.0	0.0	10.6	4.3	24.6	2.0	1.7	1.0
P5 15w-07s	12.4	7.2	5.6	5.6	11.1	8.2	2.8	0.0	2.8	0.0	0.0	13.7	5.6	0.0	5.6	16.7	2.8	0.0
P5 06w-02s	21.8	10.1	14.8	15.8	10.1	14.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	6.4	0.0	0.0

What the most thoughtful students will get out of their extensive studying will be a capacity to do meaningful brain-based work even under stressful conditions, which is a part of the self-mastery skillset that will continue to deliver value for the whole of their lives. Outstanding grades will also happen, but the most important outcome from skillful action in study is being better at any important tasks even if circumstances are do not feel ideal.

Learning how to manage oneself so we can more reliably get ambitious and successful outcomes out of our challenges in a productive and positive way is one aspect of life’s most valuable pursuit summarised and inscribed on the Temple of Apollo at Delphi: “know thyself”.

1. To complete these questions, as important as your answer, is checking your answer against the mark scheme.
2. For each question, or page, convert your mark score into a percentage. This will allow you to see (and feel) your progress as you get more experience and understanding with each topic.
3. If you find you get a higher percentage answering short answer questions than multiple choice questions that often means you are using the marking scheme correctly; your correct answer might not be fully complete. The marks easiest to miss rely on providing more details fully described.

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[1] **DO NOT** work on these higher levels of completion unless you have also achieved at least a “**Gold**” (40%) in the same topic in **Paper 4**, which is **MOST** of your **A2 grade**.

Q# 72/ ALvl Chemistry/2019/w/TZ 1/ Paper 5/Q# 1/www.SmashingScience.org :o)

1 Yttrium barium copper oxide, $YBa_2Cu_3O_7$, is a crystalline compound.

You are to design an experiment in which $YBa_2Cu_3O_7$ is first synthesised and then analysed by titration.

(a) $YBa_2Cu_3O_7$ can be synthesised by reacting Y_2O_3, $BaCO_3$ and CuO using the following method.

- Place solid Y_2O_3, $BaCO_3$ and CuO together in a mortar and grind the mixture well with a pestle.
- Transfer the mixture to a porcelain crucible and place this in an oven set at 920 °C.
- Heat the mixture for 12 hours, then allow the crucible and its contents to cool slowly in the oven to below 100 °C before removing it.

The equation for the reaction is given.

$$Y_2O_3 + 4BaCO_3 + 6CuO + \tfrac{1}{2}O_2 \rightarrow 2YBa_2Cu_3O_7 + 4CO_2$$

(i) $YBa_2Cu_3O_7$ contains Y, Ba and Cu in the molar ratio of 1 : 2 : 3.

Calculate the minimum masses of $BaCO_3$ and CuO that are needed to react with 0.750 g of Y_2O_3, to give a Y : Ba : Cu ratio of 1 : 2 : 3.

[A_r: Y, 88.9; Ba, 137.3; Cu, 63.5; O, 16.0; C, 12.0]

mass of $BaCO_3$ = ... g

mass of CuO = ... g

[3]

(ii) State what should be done once the solid product has cooled to ensure that the highest possible yield of $YBa_2Cu_3O_7$ has been produced.

....

....

....

.... [1]

$YBa_2Cu_3O_7$ contains some copper ions in the unusual +3 oxidation state.

The proportion of Cu^{3+} in $YBa_2Cu_3O_7$ can be determined by titration.

- **Step 1**
  A sample of $YBa_2Cu_3O_7$ is reacted with an excess of concentrated aqueous HBr. Cu^{3+} ions are reduced to Cu^{2+} ions and Br_3^- ions are formed.

$$2Cu^{3+}(s) + 3Br^-(aq) \rightarrow 2Cu^{2+}(aq) + Br_3^-(aq)$$

- **Step 2**
  A solution of 1.0 mol dm^{-3} sodium citrate is added to the mixture from **Step 1**. The resulting mixture is then neutralised with a minimum volume of concentrated $NH_3(aq)$.

- **Step 3**
  Excess I^- is added which reacts with Br_3^- to form I_2.

$$Br_3^-(aq) + 2I^-(aq) \rightarrow 3Br^-(aq) + I_2(aq)$$

- **Step 4**
  The I_2 is titrated with a standard solution of $S_2O_3^{2-}$ and starch solution as an indicator.

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

The concentration of $I_2(aq)$ can therefore be determined and hence the concentration of $Br_3^-(aq)$. From this the amount of $Cu^{3+}(s)$ can be determined.

(b) The table gives some electrochemical data.

reduction process	E°/V
$I_2 + 2e^- \rightleftharpoons 2I^-$	+0.54
$Cu^{2+} + I^- + e^- \rightleftharpoons CuI$	+0.86
$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+1.23

Use these data and the information given above to answer the following questions.

(i) The citrate anion forms an insoluble complex with Cu^{2+} and so removes Cu^{2+} from solution.

Explain why this is necessary.

....

....

.... [1]

(ii) Explain why it is necessary to neutralise the mixture in **Step 2**.

....

.... [1]

(iii) When starch indicator is added in **Step 4**, the mixture turns blue-black due to the presence of I_2(aq). The end-point of the titration with $S_2O_3^{2-}$(aq) is a colourless solution.

The number of moles of $S_2O_3^{2-}$(aq) needed for complete reaction with I_2(aq) can be calculated from the mean titre value. Hence the moles of I_2(aq) can be determined.

State the expression for the moles of Cu^{3+} in the sample of $YBa_2Cu_3O_7$. Use A to represent the number of moles of I_2(aq) in **Step 4**.

moles Cu^{3+} = ... mol [1]

(c) **(i)** Calculate the mass of hydrated sodium citrate, $Na_3C_6H_5O_7{\bullet}2H_2O$, that would be required for the preparation of 250.0 cm³ of a solution of 1.0 mol dm^{-3} citrate ions, $C_6H_5O_7^{3-}$.

[M_r: $Na_3C_6H_5O_7{\bullet}2H_2O$, 294.0]

mass of $Na_3C_6H_5O_7{\bullet}2H_2O$ = ... g [1]

(ii) A student places the mass of $Na_3C_6H_5O_7{\bullet}2H_2O$ calculated in **(c)(i)** into a beaker.

Describe how the student can prepare exactly 250.0 cm³ of a solution of 1.0 mol dm^{-3} citrate ions from the sample in the beaker.

Give the name and capacity, in cm³, of any apparatus used.

....

....

....

....

.... [3]

(d) A different student records the following titration data in **Step 4**.

experiment	rough	1	2
final reading / cm³	21.20	24.60	47.75
initial reading / cm³	0.00	3.10	25.30
titre / cm³	21.20	21.50	22.45

Identify the problem with the student's titration method **and** suggest how it could be improved.

....

....

....

.... [2]

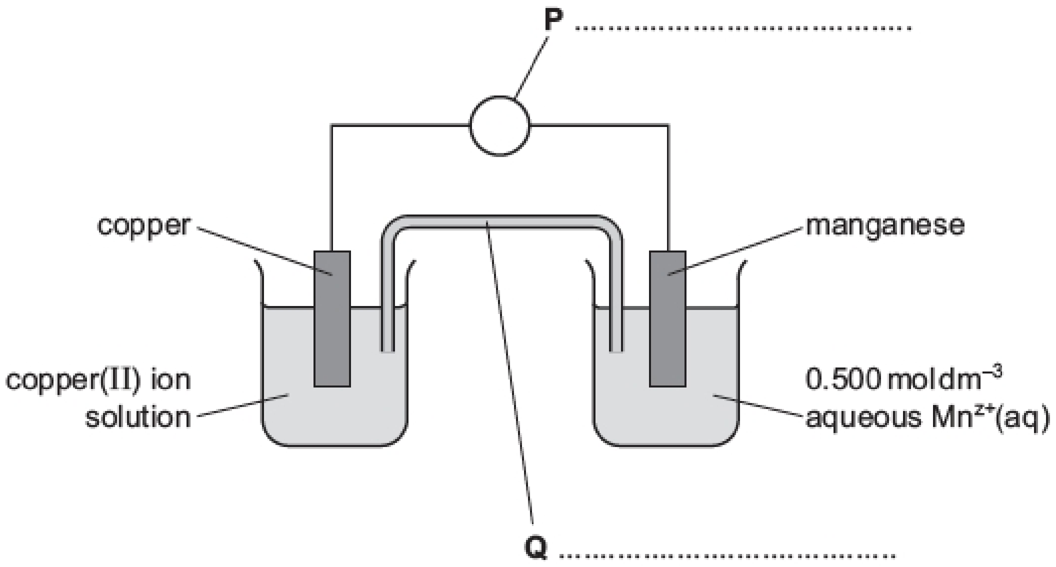
[Total: 13]

Q# 73/ ALvl Chemistry/2019/s/TZ 1/ Paper 5/Q# 1/www.SmashingScience.org :o)

1 A student investigates the charge (z+) carried by aqueous manganese ions, $Mn^{z+}(aq)$. The electrochemical cell shown is set up for this investigation with the following two half-cells:

- a standard copper(II) ion / copper half-cell ($E^\ominus = +0.340\,V$)
- a half-cell made from manganese and $0.500\,mol\,dm^{-3}$ $Mn^{z+}(aq)$.

(a) Label the items **P** and **Q** and state the concentration of the copper(II) ion solution in the copper half-cell.



concentration of the copper(II) ion solution in the copper half-cell = ...

[1]

(b) During the investigation the student plans to use solutions of $Mn^{z+}(aq)$ of lower concentration than $0.500\,mol\,dm^{-3}$.

(i) Calculate the volume of $0.500\,mol\,dm^{-3}$ $Mn^{z+}(aq)$ needed to prepare $100.0\,cm^3$ of $0.200\,mol\,dm^{-3}$ $Mn^{z+}(aq)$.

volume = ... cm^3 [1]

(ii) Describe how, using a 100 cm^3 volumetric flask, the student should prepare exactly 100.0 cm^3 of 0.200 mol dm^{-3} $Mn^{2+}(aq)$ using the volume of 0.500 mol dm^{-3} $Mn^{2+}(aq)$ calculated in **(b)(i)** and standard school or college apparatus.

[2]

The cell potential of the electrochemical cell in **(a)** is measured. The 0.500 mol dm^{-3} $Mn^{2+}(aq)$ is then replaced by the 0.200 mol dm^{-3} solution and the cell potential is measured again. This is repeated for other lower concentrations of $Mn^{2+}(aq)$. All measurements are made at 25 °C.

(iii) The results of the experiment are shown in the table.

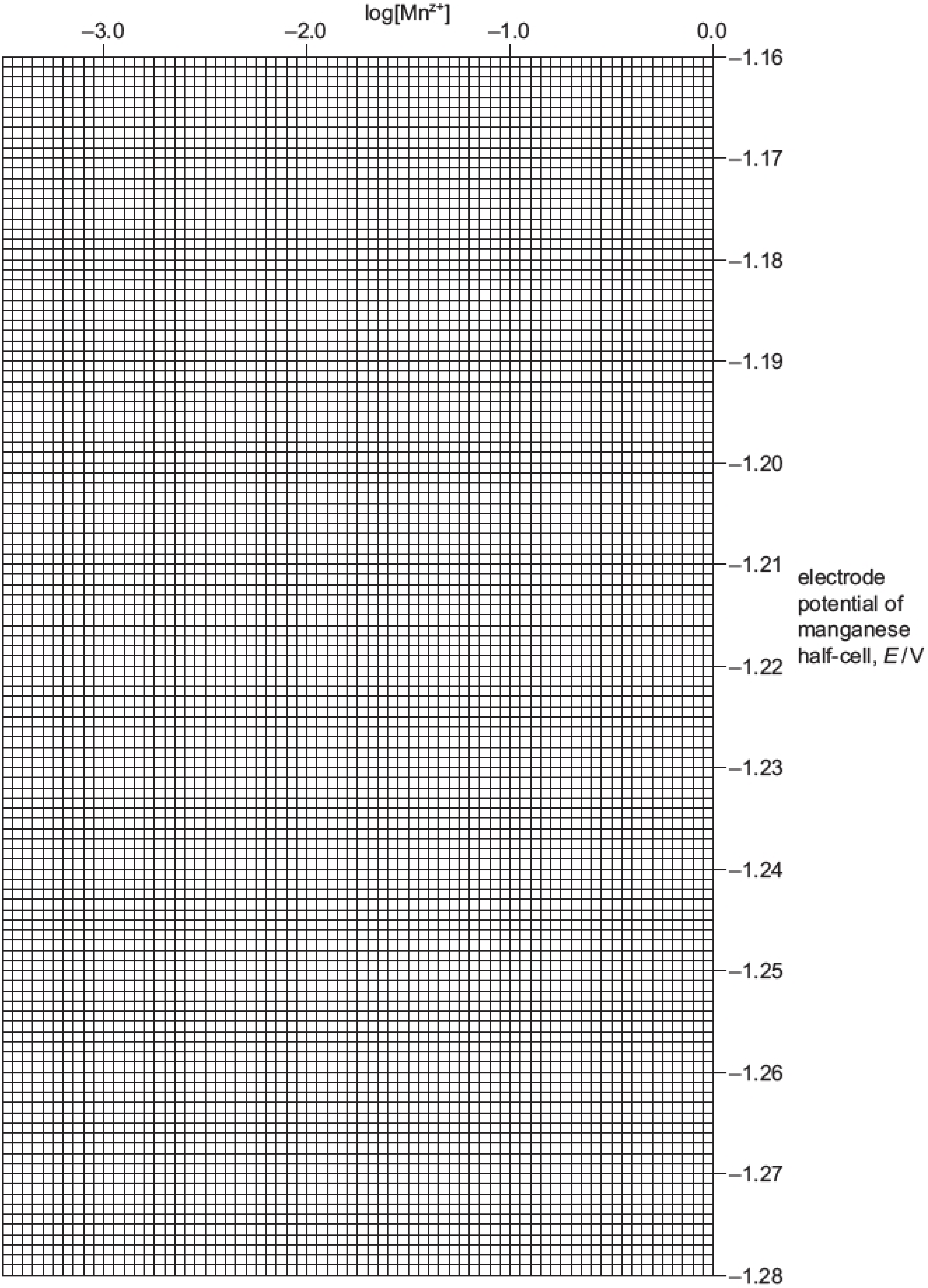
Complete column three of the table, calculating log[Mn^{2+}] to **two decimal places**. Complete column four of the table, calculating E, the electrode potential of each manganese half-cell, to **three decimal places**, using the equation shown.

$$E\text{(manganese half-cell)} = E_{cell} + 0.340\,V$$

[Mn^{2+}] / mol dm^{-3}	cell potential, E_{cell} / V	log[Mn^{2+}]	electrode potential of each manganese half-cell, E / V
5.0×10^{-1}	–1.529	–0.30	–1.189
2.0×10^{-1}	–1.541		
1.0×10^{-1}	–1.550		
7.5×10^{-2}	–1.553		
2.5×10^{-2}	–1.567		
8.0×10^{-3}	–1.582		
6.0×10^{-3}	–1.590		
4.0×10^{-3}	–1.591		
3.0×10^{-3}	–1.594		
5.0×10^{-4}	–1.617		

[2]

(c) Plot a graph of electrode potential of manganese half-cell (*y*-axis) against log[Mn^{2+}] (*x*-axis).
Use a cross (×) to plot each data point. Draw a line of best fit.



[2]

(d) **(i)** Circle the most anomalous point on your graph. [1]

(ii) The student is careful to ensure that all solutions used are at the same temperature in all experiments.

Suggest a possible explanation for the position of the anomalous point circled in **(d)(i)** relative to the line of best fit.

....

....

.... [1]

(e) Your graph is a plot of *E* against log[Mn^{z+}] and can be analysed using the Nernst equation at 25 °C.

$$E = E^{\ominus} + \frac{0.059}{z}\log[\mathrm{Mn}^{z+}]$$

z is the value of the charge carried by the manganese ion
E is the electrode potential / V
$E^{\ominus}$ is the standard electrode potential / V

Use the Nernst equation and your graph to find the standard electrode potential, $E^{\ominus}$, of the manganese half-cell.

$E^{\ominus}$ = ... V [1]

(f) **(i)** Determine the gradient of the graph.
State the co-ordinates of both points you used for your calculation.
Record the value of the gradient to **three significant figures**.

co-ordinates 1 .... co-ordinates 2 ....

gradient = ... [2]

(ii) Use your answer to **(f)(i)** and the Nernst equation to calculate the value of z to three significant figures and give the formula of the manganese ion.
Your calculation **must** show the use of the Nernst equation.

(If you were unable to calculate an answer to **(f)(i)** you may use the value 0.0197. This is **not** the correct value.)

z = ...

formula of manganese ion = ...
[2]

(g) Lowering [Mn^{z+}] causes the value of the electrode potential of the manganese half-cell to become more negative.

Suggest why this happens.

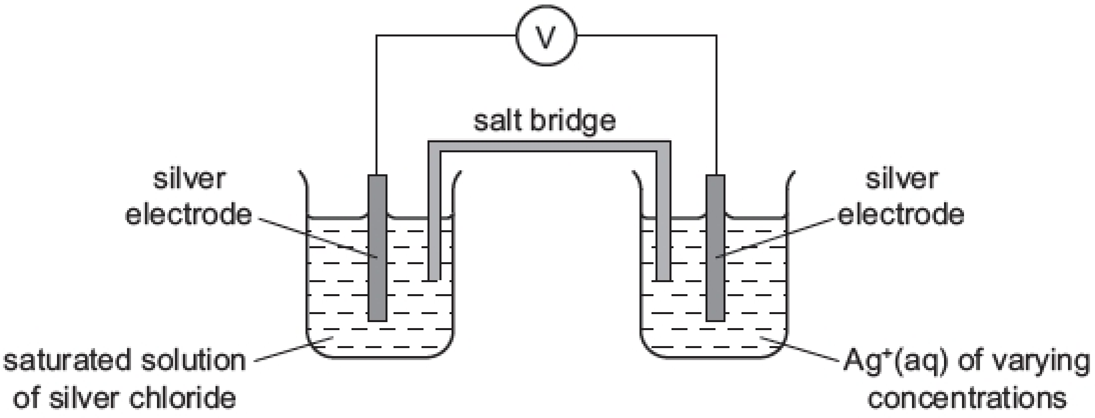
....

.... [1]

[Total: 16]

2 The solubility product, K_{sp}, of a sparingly soluble salt can be determined by measuring the cell potential of a cell known as a *concentration cell*. One of the half-cells uses a saturated solution of the salt as the electrolyte.

The K_{sp} of silver chloride, $AgCl$, can be measured using the apparatus shown.



The silver electrodes of the two half-cells were connected via a voltmeter, reading to three decimal places. This measured the cell potential of the concentration cell.

The half-cells were kept at a temperature of 40 °C. Under these conditions, the relationship between cell potential, E_{cell}, and $[Ag^+(aq)]$ is

$$16.1E_{cell} = \log C_{sat} - \log [Ag^+(aq)]$$

C_{sat} is the concentration of the saturated solution of silver chloride

(a) **(i)** The solutions in the half-cells need to be kept at 40 °C.

Explain how you would do this.

....

.... [1]

(ii) If the temperature was maintained at 40 °C, over time the reading on the voltmeter would change.

Suggest **one** reason why.

....

.... [1]

The cell potential was measured for various concentrations of $Ag^+(aq)$ and the results obtained are shown in the table.

(b) Complete the fourth and fifth columns of the table.

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

experiment	$[Ag^+(aq)]$ / mol dm^{-3}	E_{cell} / V	$-\log [Ag^+(aq)]$	$16.1E_{cell}$ / V
1	0.00100	–0.097		
2	0.00500	–0.140		
3	0.0100	–0.159		
4	0.0250	–0.171		
5	0.0500	–0.202		
6	0.100	–0.221		
7	0.200	–0.239		
8	0.500	–0.264		
9	1.50	–0.294		

[2]

(c) **(i)** On the grid on page 9, plot a graph of $16.1E_{cell}$ against $-\log [Ag^+(aq)]$.

Draw a line of best fit. [2]

(ii) Circle the single most anomalous point on the graph.

The temperature of the half-cells was maintained at 40 °C. Suggest what error in the experimental set-up may have caused the anomaly.

....

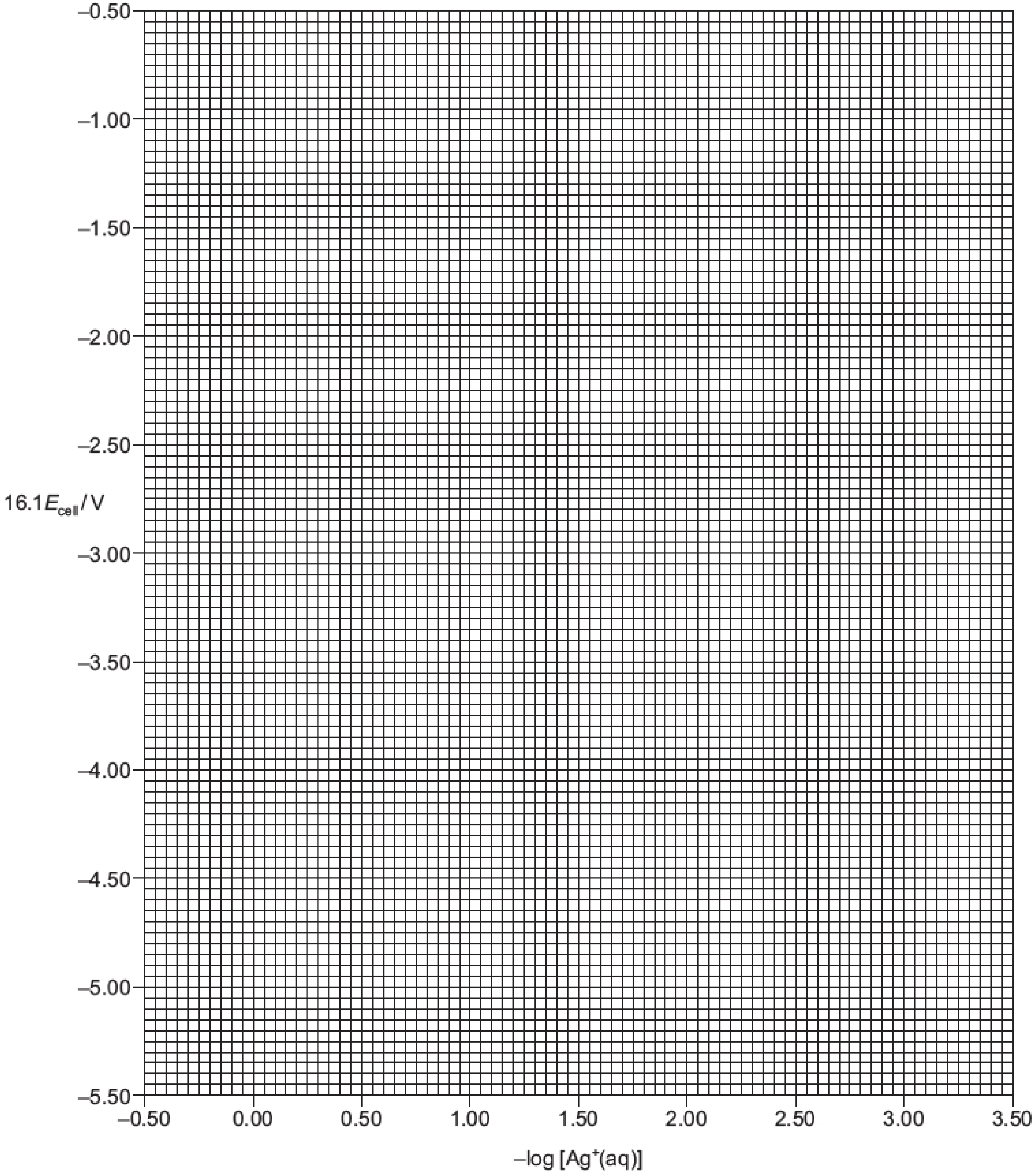
....

.... [2]

(iii) Use your graph and the equation to determine a value for $\log C_{sat}$.

$$16.1E_{cell} = \log C_{sat} - \log [Ag^+(aq)]$$

$\log C_{sat}$ = ... [1]


–0.50
–1.00
–1.50
–2.00
–2.50
16.1E_{cell} / V
–3.00
–3.50
–4.00
–4.50
–5.00
–5.50
–0.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
–log [Ag$^+$(aq)]

(d) To carry out these experiments, $Ag^+(aq)$ of concentration 2.0 mol dm^{-3} was prepared.

(i) For experiment 6, calculate the volume of 2.0 mol dm^{-3} $Ag^+(aq)$ needed to prepare exactly 250.0 cm^3 of $Ag^+(aq)$ in a 250.0 cm^3 volumetric flask.

volume = ... cm^3 [1]

(ii) Name a suitable piece of apparatus which could be used to measure the volume calculated in **(i)**.

....[1]

(e) **(i)** The relationship between the solubility product, K_{sp}, and the concentration of the saturated solution of silver chloride, C_{sat}, is shown.

$$K_{sp} = C_{sat}^2$$

Use this equation and your answer to **(c)(iii)** to calculate a value for K_{sp}.

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

(If you have no answer for **(c)(iii)**, use a value of –4.20 but this is **not** the true value.)

K_{sp} = ... [2]

(ii) The solubility of $AgCl$ increases with temperature.

Using the axes below, sketch a graph to show how the K_{sp} of $AgCl$ varies with temperature.

Label both axes.

[1]

(f) The salt bridge in a concentration cell commonly contains a solution of one of the following compounds.

potassium chloride   potassium nitrate   sodium chloride

Identify which, if any, of these compounds would **not** be suitable for use in the salt bridge in this experiment.

Explain your answer.

....

....

.... [2]

[Total: 16]

Q# 75/ ALvl Chemistry/2018/s/TZ 1/ Paper 5/Q# 1/www.SmashingScience.org :o)

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 ....

....

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.

charge (C) = current (A) × 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.

....

....

.... [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.

....

.... [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

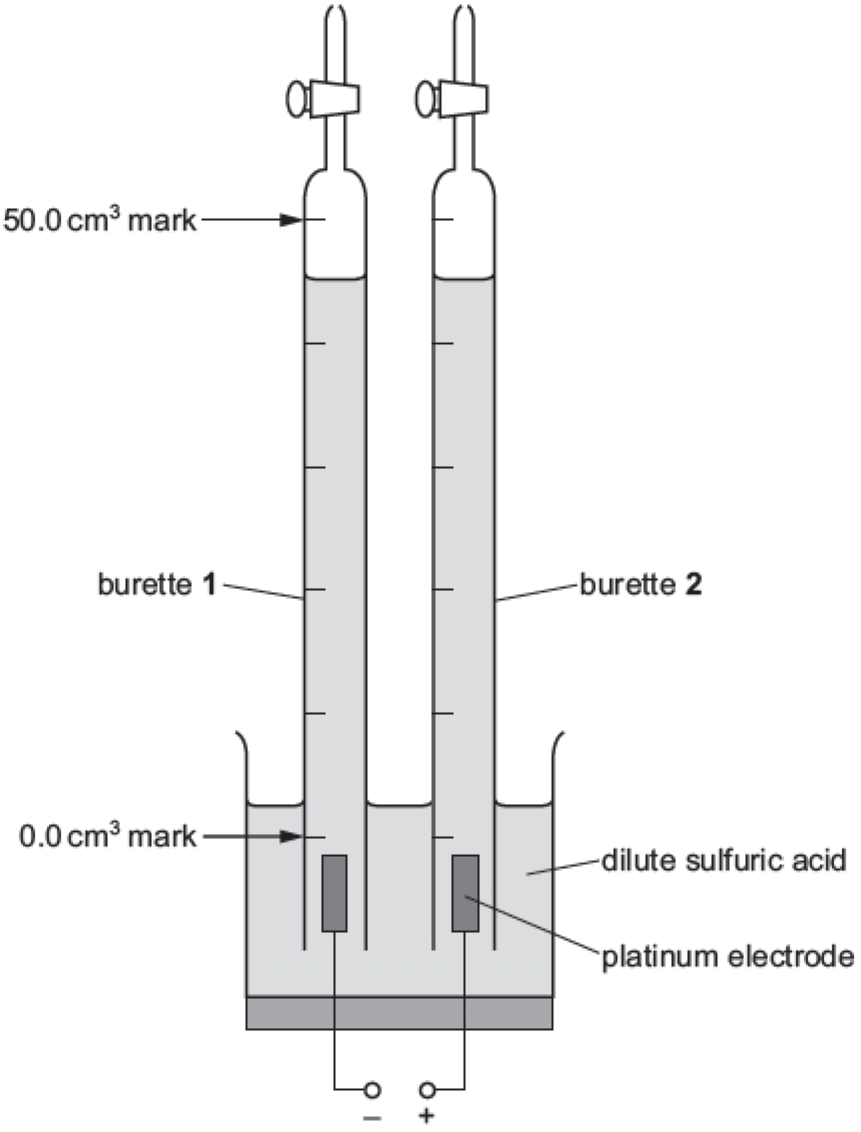
Suggest **one** reason why the mass gained at the cathode is **not** the same as the mass lost at the anode. Assume the student has recorded the mass changes correctly.

....

.... [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.

charge (C) = current (A) × time (s)

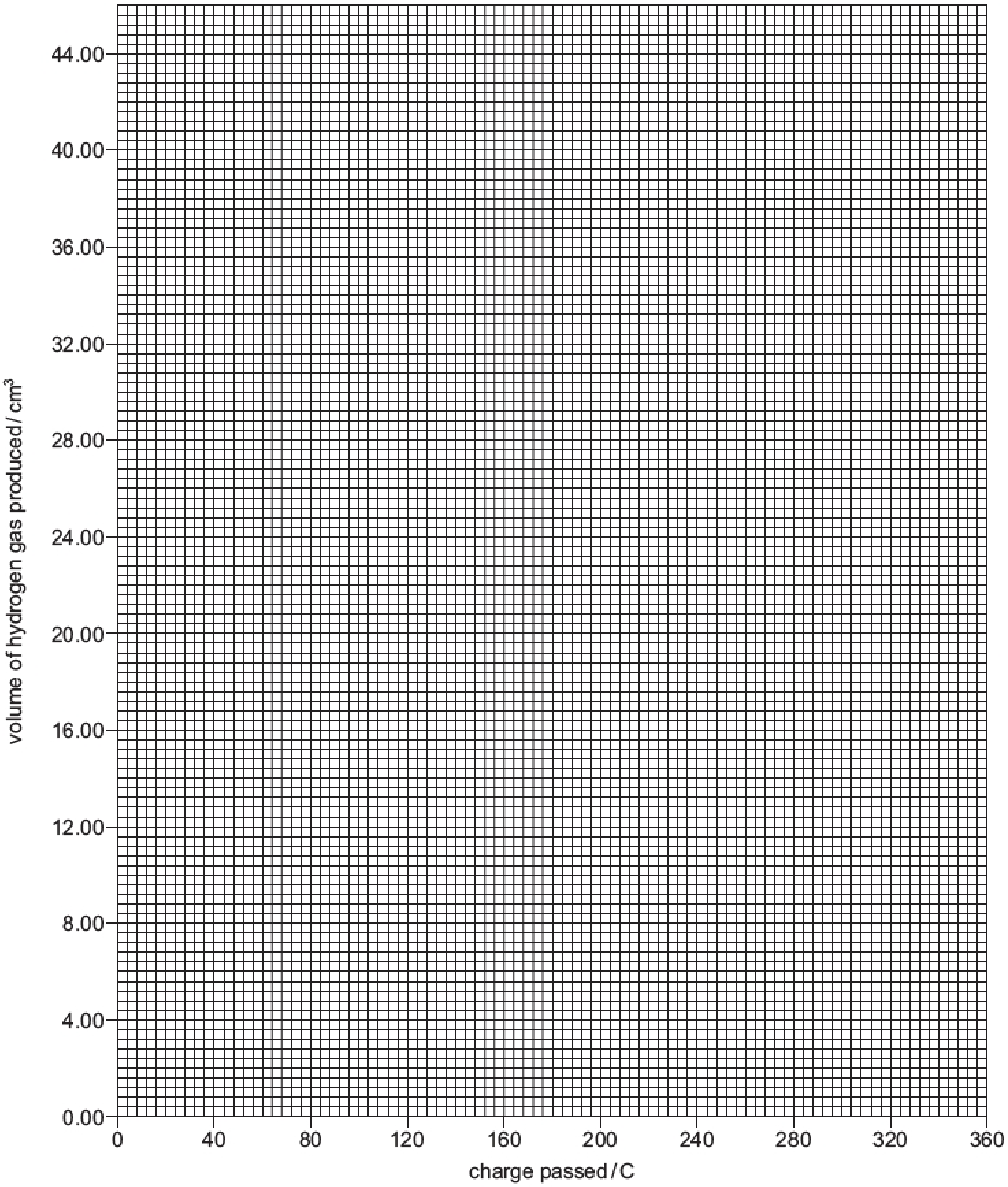
The current was kept constant at 0.80 A.

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

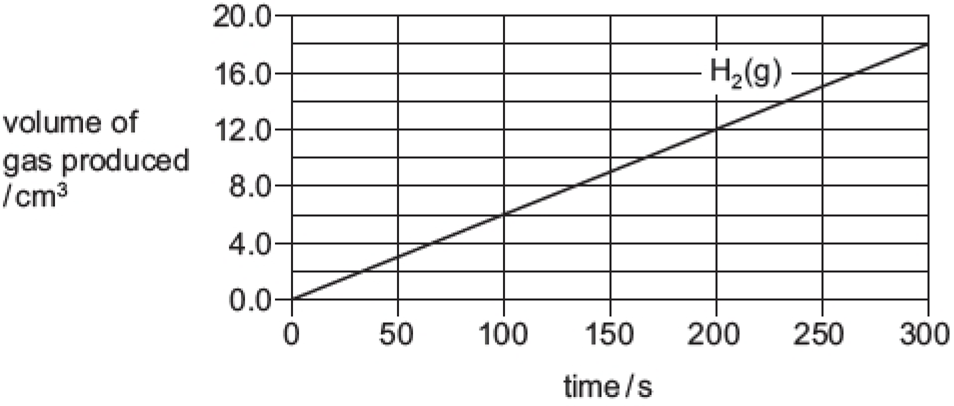
(iii) Use your answer to **(ii)** and the half-equation for the production of $H_2(g)$ to calculate a numerical value for the Faraday constant (the charge of 1 mole of electrons).

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

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

....

.... [1]

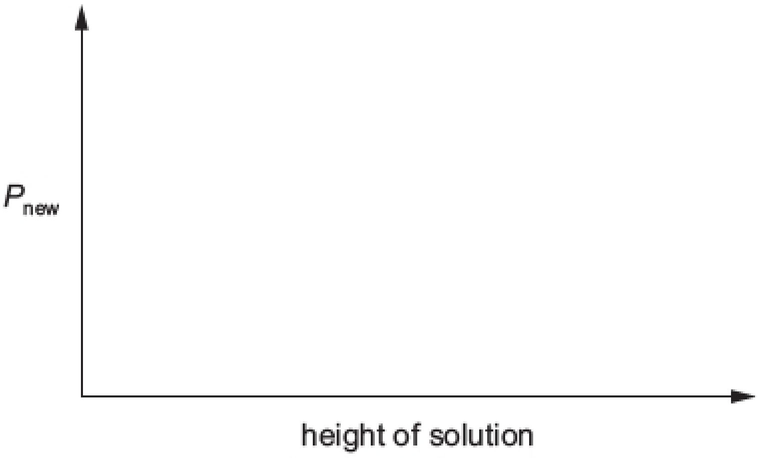
(f) In these experiments, the pressure of the gas inside the burette is assumed to be atmospheric pressure, P_{atm}.

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.

....

.... [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 ....

....

....

anode ....

....

....

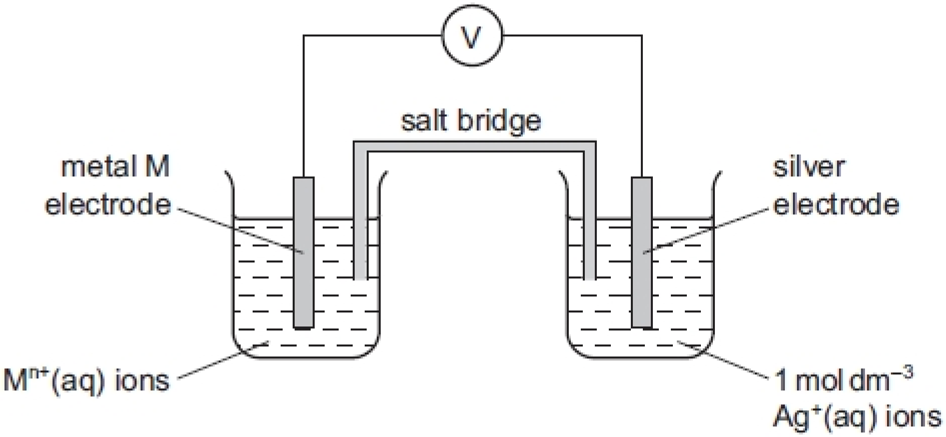
[3]

[Total: 16]

Q# 77/ ALvl Chemistry/2014/s/TZ 1/ Paper 5/Q# 2/www.SmashingScience.org :o)

2 An experiment was set up to investigate how the cell potential of a cell containing a metal, M, in contact with an aqueous solution of its ions, $M^{n+}(aq)$ (where n = 1, 2 or 3), changed as $M^{n+}(aq)$ was diluted.

Since a standard hydrogen half-cell was not available, a standard half-cell consisting of silver in contact with a 1 mol dm^{-3} solution of silver ions was used to connect to the half-cell with M in contact with $M^{n+}(aq)$.



The metal electrodes of the two half-cells were connected via a voltmeter, reading to two decimal places. This was used to measure the cell potential of the cell.

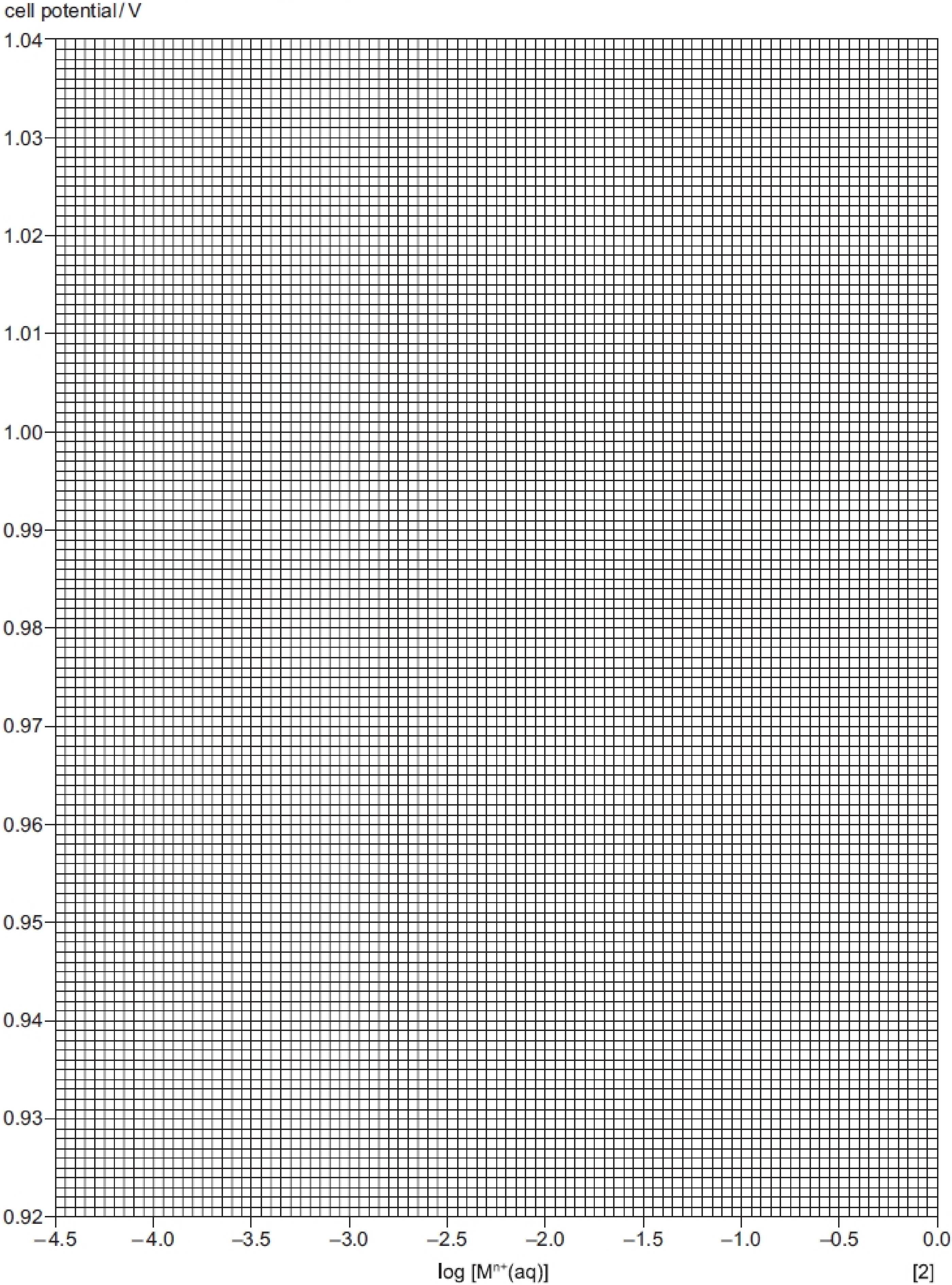
The cell potential was measured for various concentrations of $M^{n+}(aq)$ and the results obtained are shown in the table below.

(a) Complete the third column of the table below. Give each answer to two decimal places.

concentration of $M^{n+}(aq)$ / mol dm^{-3}	cell potential / V	log [$M^{n+}(aq)$]
5.00×10^{-1}	0.94	
1.00×10^{-1}	0.96	
4.00×10^{-2}	0.97	
1.00×10^{-2}	0.99	
5.00×10^{-3}	1.00	
2.00×10^{-3}	1.01	
8.00×10^{-4}	1.02	
2.00×10^{-4}	1.04	

[2]

(b) Plot a graph to show the relationship between log [$M^{n+}(aq)$] and the cell potential measured and draw the line of best fit.



[2]

(c) Are there any anomalous points on your graph? If so, circle those points. Give a reason for your answer.

[2]

(d) It is known that the cell potential of a cell, E, is related to the standard electrode potential, $E^{\ominus}$, by the equation:

$$E = E^{\ominus} - \frac{0.06 \log [\mathrm{M}^{n+}(aq)]}{n}$$

(i) Use your graph to determine the charge, n, of the M^{n+} ions. Draw appropriate lines on your graph to enable you to calculate its slope and show in the space below, how n was calculated.

[3]

(ii) Use your graph to determine the standard electrode potential, $E^{\ominus}$, of the cell.

[1]

(e) The standard electrode potential for silver is +0.80 V.
Calculate the standard electrode potential for the metal, M. Use the data given on page 12 to suggest the identity of M.

[1]

(f) Write an overall equation for the cell reaction which is taking place.

.... [1]

(g) The solutions contained in the two half-cells must be connected using a salt bridge.

(i) Why is a salt bridge necessary?

....

.... [1]

(ii) Which (if any) of the following salts would be suitable to use in the salt bridge:

potassium chloride, potassium nitrate, potassium sulfate?

If you consider any to be unsuitable, explain why.

....

....

.... [2]

[Total: 15]

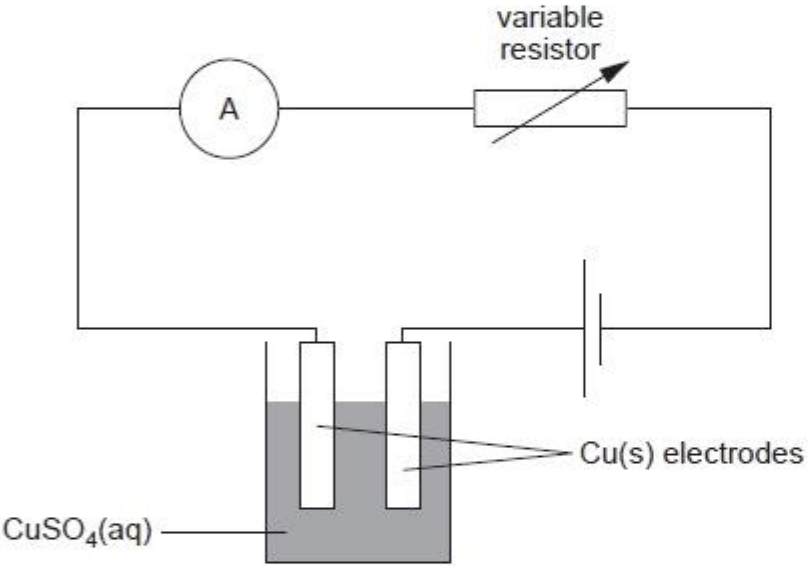
$E^\ominus$ in decreasing order of oxidising power

Electrode reaction	$E^\ominus$/V
$F_2 + 2e^- \rightleftharpoons 2F^-$	+2.87
$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	+2.01
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.77
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+1.52
$PbO_2 + 4H^+ + 2e^- \rightleftharpoons Pb^{2+} + 2H_2O$	+1.47
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1.33
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1.07
$NO_3^- + 2H^+ + e^- \rightleftharpoons NO_2 + H_2O$	+0.81
$Ag^+ + e^- \rightleftharpoons Ag$	+0.80
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$I_2 + 2e^- \rightleftharpoons 2I^-$	+0.54
$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.34
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2 + 2H_2O$	+0.17
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	+0.15
$S_4O_6^{2-} + 2e^- \rightleftharpoons 2S_2O_3^{2-}$	+0.09
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$Pb^{2+} + 2e^- \rightleftharpoons Pb$	–0.13
$Sn^{2+} + 2e^- \rightleftharpoons Sn$	–0.14
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	–0.44
$Zn^{2+} + 2e^- \rightleftharpoons Zn$	–0.76
$Mg^{2+} + 2e^- \rightleftharpoons Mg$	–2.38
$Ca^{2+} + 2e^- \rightleftharpoons Ca$	–2.87
$K^+ + e^- \rightleftharpoons K$	–2.92

2 A student reads about the electrolysis of aqueous copper(II) sulphate and makes the following notes.

- reaction at the cathode $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$
- reaction at the anode $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$
- 1 mol of Cu(s) is deposited on the cathode by 2 mol of electrons.
- The Faraday constant is the charge in coulombs, C, on 1 mol of electrons.
- The Faraday constant = 9.5×10^4 C mol^{-1}.

The student realises that a value for the Faraday constant can be determined experimentally using the following apparatus.



Method

- The cathode is cleaned and weighed before being placed in the copper(II) sulphate solution.
- The circuit is completed and the current set at 0.3 A by adjusting the variable resistor.
- The current is maintained at 0.3 A for exactly 40 minutes at which point the circuit is broken.
- The cathode is removed from the solution and carefully washed with distilled water to remove any copper(II) sulphate solution.
- Distilled water is removed from the cathode by rinsing it with propanone in which the water dissolves.
- The cathode is finally dried by allowing the propanone to evaporate from its surface.
- The cathode is reweighed and placed back in the solution.
- A constant current of 0.3 A is passed for a further 40 minutes when the rinsing, drying and weighing are repeated.
- This procedure is repeated a further 8 times.

The results of the experiment are recorded below.

A	B	C	D	E	F
time /minutes	mass of cathode /g				
0	115.74				
40	115.97				
80	116.22				
120	116.46				
160	116.70				
200	116.94				
240	117.19				
280	117.49				
320	117.67				
360	117.92				
400	118.14				

(a) Use the additional columns of the table to record the charge passed and the mass of copper deposited on the cathode.

[charge in coulombs = time in seconds × current in amps; 1 minute = 60 seconds]

You may use some or all of the columns. Label the columns you use, including the units and an equation to show how the value is calculated. [2]

(b) Present the data calculated in **(a)** in graphical form. Draw the line of best-fit.

[4]

(c) Indicate clearly one anomalous point on the graph that you did not use when drawing the line of best-fit. By reference to the instructions for the experiment suggest an explanation for the anomaly.

....

....

....

....

.... [2]

(d) The balance used by the student weighed to 2 decimal places. By reference to the results of the experiment explain why it would have been more appropriate to use an analytical balance weighing to 4 decimal places.

....

....

....

....

.... [1]

(e) Draw construction lines on the graph to derive relevant values and use them to calculate a numerical value for the Faraday constant.

reaction at the cathode $Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$

[A_r: Cu; 63.5]

The value of the Faraday constant determined in this experiment is

.... C mol^{-1}. [2]

(f) By considering the data you have processed and the graph you have drawn, decide if the experimental procedure described is suitable for the determination of the Faraday constant. Explain your reasoning.

....

....

....

....

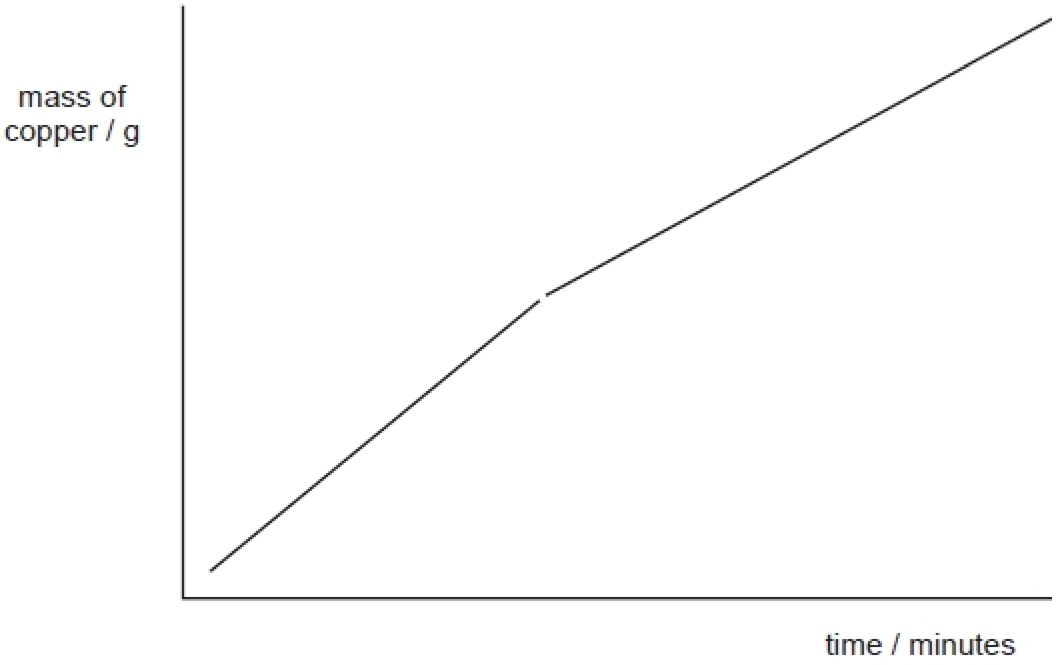
.... [2]

(g) What other measurements could be made during the course of the experiment to provide alternative data to confirm the determined value of the Faraday constant?

....

.... [1]

(h) Another student, performing the same experiment, plotted the mass of copper deposited against time, and obtained the results below.



Making reference to the experimental method, suggest an explanation for the shape of this graph.

....

.... [1]

[Total: 15]

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GENERIC MARKING PRINCIPLE 5: Marks should be awarded using the full range of marks defined in the mark scheme for the question (however; the use of the full mark range may be limited according to the quality of the candidate responses seen).
GENERIC MARKING PRINCIPLE 6: Marks awarded are based solely on the requirements as defined in the mark scheme. Marks should not be awarded with grade thresholds or grade descriptors in mind.

1(a)(i)	**M1:** moles of Y_2O_3 = 0.750 ÷ (2 × 88.9 + 3 × 16.0) = 0.750 ÷ 225.8 = 3.32 × 10^{-3} (mol) 3.3215235 × 10^{-3} **M2:** mass of $BaCO_3$ = 4 × 3.32 × 10^{-3} × (137.3 + 12.0 + 3 × 16.0) = 4 × 3.32 × 10^{-3} × 197.3 = 2.62 (g) 2.6213463 **M3:** mass of CuO = 6 × 3.32 × 10^{-3} × (63.5 + 16.0) = 6 × 3.32 × 10^{-3} × 79.5 = 1.58 (g) 1.5813667	3
1(a)(ii)	**heat solid again** (and allow to cool) **AND** (to) constant mass	1
1(b)(i)	(Prevents) reaction of Cu^{2+} with I^- OR (prevents) formation of CuI / Cu^+ / copper(I) OR (prevents) oxidation of I^- (to I_2) by Cu^{2+}	1
1(b)(ii)	I^- is oxidised (to I_2) in acidic solution	1
1(b)(iii)	2A	1
1(c)(i)	1.0 × 250.0 / 1000 × 294.0 = 73.5 (g)	1
1(c)(ii)	**M1:** Dissolve / make a solution in (beaker) in (small volume of distilled water) **M2: Add / transfer solution to a** 250 cm³ volumetric flask **M3:** Make to mark of (volumetric) flask with distilled water and the washings	3
1(d)	**M1:** titres are not concordant **M2:** repeat titration **until concordant titres are obtained** OR improved valid experimental technique	2

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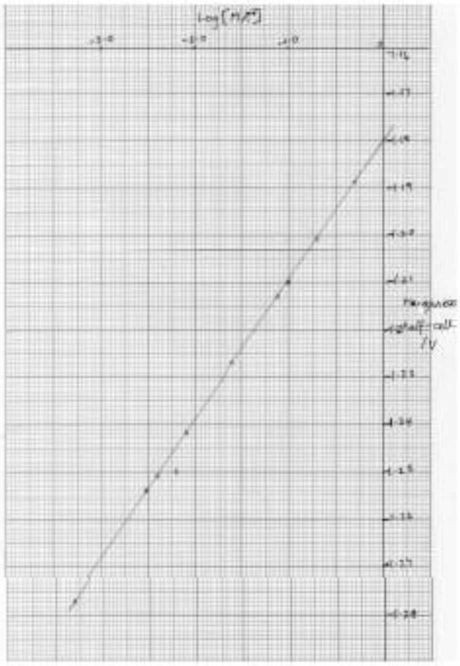
GENERIC MARKING PRINCIPLE 5: Marks should be awarded using the full range of marks defined in the mark scheme for the question (however; the use of the full mark range may be limited according to the quality of the candidate responses seen).
GENERIC MARKING PRINCIPLE 6: Marks awarded are based solely on the requirements as defined in the mark scheme. Marks should not be awarded with grade thresholds or grade descriptors in mind.

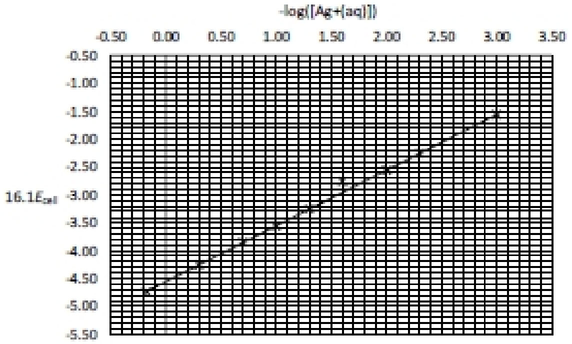
1(a)	P = Voltmeter Q = Salt bridge Conc = 1(.00) mol dm⁻³	1
1(b)(i)	100 / 1000 □ 0.200 = 0.020 moles Volume of 0.500 mol dm^{-3} = 0.020/0.500 = 40(.0) cm³	1
1(b)(ii)	M1 Transfer 40.0 cm³ of 0.500 mol dm^{-3} solution into a (100.0 cm³) volumetric flask using a burette	1
	M2 Make up to the **mark / line** with distilled water. (Stopper and shake).	1

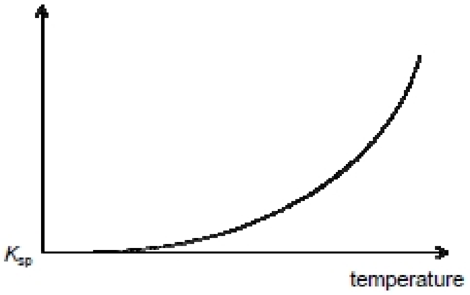
1(b)(iii)	See table below. **1 mark for each correct column**	**2**

$[Mn^{2+}]$ / mol dm^{-3}	Cell Potential / V	Log $[Mn^{2+}]$	Electrode potential (manganese half-cell), E / V
5.0 □ 10^{-1}	+1.529	–0.30	–1.189
2.0 □ 10^{-1}	+1.541	–0.70	–1.201
1.0 □ 10^{-1}	+1.550	–1.00	–1.210
7.5 □ 10^{-2}	+1.553	–1.12	–1.213
2.5 □ 10^{-2}	+1.567	–1.60	–1.227
8.0 □ 10^{-3}	+1.582	–2.10	–1.242
6.0 □ 10^{-3}	+1.590	–2.22	–1.250
4.0 □ 10^{-3}	+1.591	–2.40	–1.251
3.0 □ 10^{-3}	+1.594	–2.52	–1.254
5.0 □ 10^{-4}	+1.617	–3.30	–1.277

1(c)	**M1** Correctly plotted data points	**1**
	M2 Accurate line of best fit 	**1**
1(d)(i)	Ring around point at –2.22, –1.250	**1**
1(d)(ii)	(The point is below the line) The solution is more dilute than it should be.	**1**
1(e)	–1.18v	**1**
1(f)(i)	**M1** Points read from the graph	**1**
	M2 Gradient calculated correctly	**1**
1(f)(ii)	**M1** Gradient = 0.059 / z z = 0.059 / gradient 0.059 / 0.0293 = 2.01	**1**
	M2 Mn^{2+}	**1**
1(g)	The equilibrium between the metal and its ions moves to produce more Mn^{2+} or electrons / more reaction $Mn \rightarrow Mn^{2+} + 2e^-$ / the tendency to ionise / oxidise increases.	**1**

<table>
<tr><td>2(a)(i)</td><td>Temperature / thermostatically controlled water bath</td><td>1</td></tr>
<tr><td>2(a)(ii)</td><td>water may evaporate / [Ag$^+$] will change</td><td>1</td></tr>
<tr><td>2(b)</td><td>
<table>
<tr><th>–log [Ag$^+$(aq)]</th><th>16.1E_{cell} / V</th></tr>
<tr><td>3.00</td><td>–1.56</td></tr>
<tr><td>2.30</td><td>–2.25</td></tr>
<tr><td>2.00</td><td>–2.56</td></tr>
<tr><td>1.60</td><td>–2.75</td></tr>
<tr><td>1.30</td><td>–3.25</td></tr>
<tr><td>1.00</td><td>–3.56</td></tr>
<tr><td>0.70</td><td>–3.85</td></tr>
<tr><td>0.30</td><td>–4.25</td></tr>
<tr><td>–0.18</td><td>–4.73</td></tr>
</table>

M1 log [Ag$^+$] data correct to 2dp
M2 16.1E_{cell} data correct to 2dp</td><td>2</td></tr>
<tr><td>2(c)(i)</td><td>

M1 All nine points plotted correctly
M2 Best-fit straight line drawn</td><td>2</td></tr>
<tr><td>2(c)(ii)</td><td>**M1** Point at (1.60,–2.75) circled
M2 Not concentrated enough / more dilute / less than 0.025 moldm^{-3}</td><td>2</td></tr>
<tr><td>2(c)(iii)</td><td>intercept at –log [Ag$^+$(aq)] = 0 read and recorded correctly</td><td>1</td></tr>
<tr><td>2(d)(i)</td><td>12.5 / 12.50 cm^3</td><td>1</td></tr>
<tr><td>2(d)(ii)</td><td>burette</td><td>1</td></tr>
<tr><td>2(e)(i)</td><td>**M1** $K_{sp} = (2.82 \square 10^{-5})^2 = 7.95 \square 10^{-10}$
M2 3sf</td><td>2</td></tr>
<tr><td>2(e)(ii)</td><td>

Temperature labelled on the *x*-axis and K_{sp} on the *y*-axis AND (curved) line upwards</td><td>1</td></tr>
</table>

2(f)	**M1** Potassium chloride AND / OR sodium chloride **M2** Chloride ions would form a precipitate with Ag^+ ions / reduce $[Ag^+]$ concentration	1

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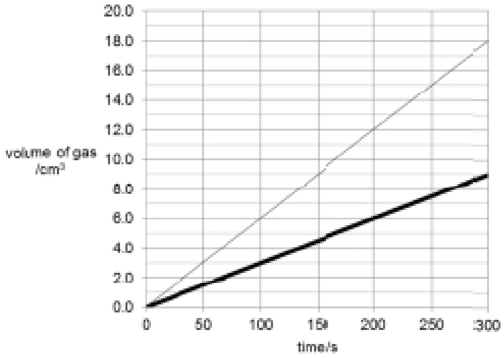
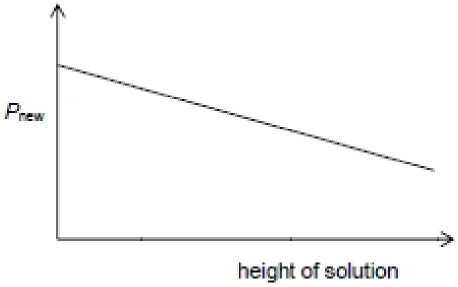
1(a)	Complete circuit with ammeter in series and DC power supply	1
	Anode, cathode and solution labelled	1
1(b)	wear gloves	1
	do not dispose into the water waste / sink OR do not put down drain / sewage OR put in waste bottles	1
1(c)	Mass (of electrode) before and after experiment AND mass unit	1
1(d)	charge = $0.5 \times 30 \times 60 = 900$ 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 (so 2 Faradays OR $2 \times 96\,500$)	1
1(h)	(Faraday) value is smaller 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 OR Some copper is lost during washing	1

Q# 76/ ALvl Chemistry/2017/w/TZ 1/ Paper 5/Q# 2/www.SmashingScience.org :o)

<table>
<tr><td>2(a)</td><td>
<table>
<tr><th>time / s</th><th>burette reading / cm³</th><th>volume (of hydrogen) / cm³</th><th>charge / C</th></tr>
<tr><td>0</td><td>46.20</td><td>0.00</td><td>0</td></tr>
<tr><td>50</td><td>41.20</td><td>5.00</td><td>40</td></tr>
<tr><td>100</td><td>36.20</td><td>10.00</td><td>80</td></tr>
<tr><td>150</td><td>31.45</td><td>14.75</td><td>120</td></tr>
<tr><td>200</td><td>25.80</td><td>20.40</td><td>160</td></tr>
<tr><td>250</td><td>20.80</td><td>25.40</td><td>200</td></tr>
<tr><td>300</td><td>16.40</td><td>29.80</td><td>240</td></tr>
<tr><td>350</td><td>11.45</td><td>34.75</td><td>280</td></tr>
<tr><td>400</td><td>6.80</td><td>39.40</td><td>320</td></tr>
<tr><td>450</td><td>1.50</td><td>44.70</td><td>360</td></tr>
</table>
volumes of hydrogen correct to 2 d.p.
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>

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

2(g)	No effect at cathode	1
	Less gas produced at anode	1
	Copper anode will dissolve / is (an) active (anode) OR copper has lower / more negative $E^{\ominus}$	1

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2 (a)	$[M^{n+}(aq)]$ / mol dm^{-3}	EMF / V	$\log[M^{n+}(aq)]$	
	5.00×10^{-1}	0.94	–0.30	
	1.00×10^{-1}	0.96	–1.00	
	4.00×10^{-2}	0.97	–1.40	
	1.00×10^{-2}	0.99	–2.00	
	5.00×10^{-3}	1.00	–2.30	
	2.00×10^{-3}	1.01	–2.70	
	8.00×10^{-4}	1.02	–3.10	
	2.00×10^{-4}	1.04	–3.70	
	Correctly calculated values			[1]
	All data to 2 decimal places			[1]
(b)	All 8 points present and plotted correctly			[1]
	Best fit continuous straight line			[1]

(c)	There are no anomalous points Variations in points due to rounding. **OR** Variations arise from being to just 2dp.	**[1]** **[1]**
(d) (i)	Appropriately drawn lines on graph Calculates correctly gradient of the graph Uses –0.06 / n = gradient to calculate n = 2 Correct working must be shown	**[1]** **[1]** **[1]**
(ii)	Extrapolates graph to obtain intercept on *y*-axis **and** deduces $E^\ominus$ for the cell to a minimum of 2 dp e.g. (+)0.93(V) **OR** Calculates a value for $E^\ominus$ using the electrode potential expression and candidate's final value for n calculated in **(d)(i)** or candidate's gradient and a data point on the candidate's line.	**[1]**
(e)	$E^\ominus$ for M, (0.80 – 0.93) = –0.13 **AND** Metal is Pb (allow Sn on –0.14) allow ecf from **(d)(ii)**	**[1]**
(f)	$2Ag^+ + Pb \rightarrow 2Ag + Pb^{2+}$	**[1]**
(g) (i)	To allow movement of ions **OR** to maintain charge / ion <u>balance</u>	**[1]**
(ii)	If lead given in **(e)** then only potassium nitrate is suitable If potassium chloride given as unsuitable, then accept precipitations with silver **OR** lead (ions) If potassium sulfate given as unsuitable, then accept precipitations with lead (ions) **ONLY** If tin given in **(e)** potassium sulfate or potassium nitrate are suitable precipitation would occur just with potassium chloride with silver (ions) **ONLY**	**[1]** **[1]**

Q# 78/ ALvl Chemistry/2008/w/TZ 1/ Paper 5/Q# 2/www.SmashingScience.org :o)

Question	Sections	Statement	Indicative material	Mark
2 (a)	ACE Data	D1	Labels additional columns: the charge passed through the electrolysis cell and the mass of copper deposited on the cathode. (Accept either a correct name or the correct equation.)	[1]
		D2	Appropriate units, however, must be given (accept 'Q' instead of charge). Must have two derived columns. Correct subtractions for the mass of copper deposited. (Allow 2 errors and 0 for 0.00, all data to 2 dp. If only the various intermediate masses are recorded, this second mark is not to be awarded.)	[1]
(b)	ACE Data	D3	A. Plots mass of copper deposited (*y*-axis) against charge passed (*x*-axis) with correct unambiguous labels and units. (Any other plot can access marks B, C and D)	[1]
		D3	B. Suitable scales selected – data to be plotted over more than half of each axis. This mark stands separate from A.	[1]
		D3	C. Line of best-fit drawn – passing through origin or through an intercept of 115.74. (Some part of the line drawn must cut/touch the origin or the 115.74 intercept.)	[1]
		D3	D. Check that all the points are on or **very close** to the line except the 1.75/5040 point whose plotting accuracy must be checked. If they are, award the mark. At least nine points must have been plotted. (For very unusual graphs, check the plotting of the first three points from the table.) The 'best' straight line is between the origin and the last point (2.40/7200). ***Do not penalise the same unit error twice.***	[1]
			Plots of (i) mass difference vs time (ii) mass of cathode vs charge (iii) mass of cathode vs time can access the marks in **2**(**c**), **2**(**d**), **2**(**e**) and **2**(**f**).	
(c)	ACE Evaluation	E1	Identifies the single point that does not lie on the line of best-fit (1.75 g Cu at 5040 coulomb) (either by giving the figures here or by suitably marking the graph). If there is another more anomalous point due to erroneous plotting accept this point instead.) (If time has been plotted, allow this also if correctly dealt with.)	[1]
		E2	Suggests an appropriate reason. (Mass of copper is too high – **has some residual liquid on the copper)**. The comment must relate to the position of the selected point. If no point is identified there is no second mark.	[1]

A	B	C	D	E
time /minutes	mass of cathode /g	mass of copper deposited (B -115.74) /g	time (A × 60) /seconds or /s	charge (D × 0.3) or (18A) /C
0	115.74	0.00	0.00	0.00
40	115.97	0.23	2400	720
80	116.22	0.48	4800	1440
120	116.46	0.72	7200	2160
160	116.70	0.96	9600	2880
200	116.94	1.20	12000	3600
240	117.19	1.45	14400	4320
280	117.49	1.75	16800	5040
320	117.67	1.93	19200	5760
360	117.92	2.18	21600	6480
400	118.14	2.40	24000	7200

Question	Sections	Statement	Indicative material	Mark
(d)	ACE Evaluation	E5	% error is decreased for the small masses involved.	[1]
(e)	ACE Data	D2	Enough construction lines on the graph to lead to the correct readings of the mass of copper and the charge.	[1]
		D2	Calculation of the correct answer (to 2 s.f. [however, allow the candidate to give the answer to no more than 5 s.f.]) corresponding to the readings from the graph. The reading should be within 50C and 0.01g of the Examiners values. (An answer must be given – the correct value is about 9.5×10^4 C mol^{-1}.)	[1]
(f)	ACE Conclusions	C1	Refers to **straight line** through origin (or 115.74) or few points off the line as supporting evidence.	[1]
		C1	If the candidate's answer is 9.5×10^4 to 2 sf allow the mark for comments referring to 'close agreement' with the real/given value etc. (must be comparative)	[1]
(g)	ACE Conclusions	C3	Candidate realised that the (loss in) mass of the anode could also have been measured and recorded. (Ignore all other suggestions.)	[1]
(h)	ACE Evaluation	E1	Any comment should refer to a decrease in the current or an increased resistance in the circuit.	[1]
				[Total: 15]