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NUMBER

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CHEMISTRY

9701/51

Paper 5 Planning, Analysis and Evaluation

October/November 2018

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.

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Answer **all** questions.

Electronic calculators may be used.

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Use of a Data Booklet is unnecessary.

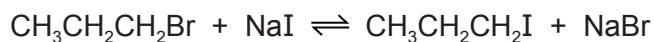
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- 1 The Finkelstein reaction is a nucleophilic substitution reaction in which a halogen atom in a halogenoalkane is replaced by another halogen atom. The reaction is carried out using dry propanone as a solvent.

One example of the Finkelstein reaction is given.



- (a) (i) Explain why it is important for **dry** propanone to be used as a solvent for this reaction.

.....

 [1]

- (ii) The solubilities of NaBr and NaI in propanone are shown.

compound	solubility at 25 °C in g / 100 g of propanone
NaBr	0.00841
NaI	39.9

Use this information to explain why, although the reaction between $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ and NaI is reversible, the reaction produces a very high yield.

.....

 [2]

(b) Some safety information for the organic compounds used in this reaction is shown.

- 1-bromopropane is **highly flammable** and **moderate health hazard**. It is irritating to eyes, the respiratory system and skin.
- 1-iodopropane is **flammable** and **moderate health hazard**. It is irritating to eyes, the respiratory system and skin.
- Propanone is **highly flammable** and **moderate health hazard**. It is irritating to eyes, and may cause dizziness and drowsiness.

Identify **two** different precautions, other than using protective equipment such as gloves, a lab coat or eye protection, that should be taken when carrying out this experiment. Explain each answer.

1 precaution

.....

explanation

.....

2 precaution

.....

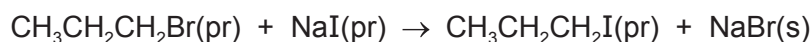
explanation

.....

[2]

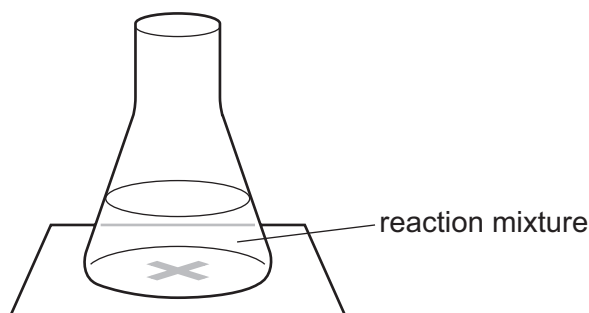
- (c) A student plans an experiment to show that the rate of the reaction is proportional to the concentration of NaI.

Propanone is used as the solvent in this reaction.



(pr) = substance is dissolved in propanone

The student plans to record the time it takes for the solid formed to obscure a cross on a piece of paper below the conical flask, as shown.



To carry out this experiment, the following materials are available.

- $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}(\text{l})$
- $\text{NaI}(\text{s})$
- dry propanone, $\text{CH}_3\text{COCH}_3(\text{l})$
- usual laboratory apparatus

- (i) Calculate the masses of $\text{NaI}(\text{s})$ and $\text{CH}_3\text{COCH}_3(\text{l})$ that would be needed to make 150 cm^3 of 0.50 mol dm^{-3} $\text{NaI}(\text{pr})$. Assume 150 cm^3 of propanone are required. Give your answers to **one decimal place**.

The density of $\text{CH}_3\text{COCH}_3(\text{l})$ is 0.79 g cm^{-3} .

[A_r : Na, 23.0; I, 126.9]

mass of $\text{NaI}(\text{s}) = \dots\dots\dots\text{ g}$

mass of $\text{CH}_3\text{COCH}_3(\text{l}) = \dots\dots\dots\text{ g}$
[2]

(ii) Part of the table the student used to record data is given.

Complete the table with appropriate volumes that the student could have used in four further experiments.

volume of 0.50 mol dm^{-3} $\text{NaI}(\text{pr})/\text{cm}^3$	volume of $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}(\text{l})$ $/\text{cm}^3$	volume of $\text{CH}_3\text{COCH}_3(\text{l})$ $/\text{cm}^3$	total volume $/\text{cm}^3$	time $/\text{s}$
10.0	2.0	30.0	42.0	

[2]

(iii) The student uses the same experimental set-up each time.

In this experiment, identify the dependent variable.

..... [1]

(iv) Write an expression to show how the student could calculate the rate of the reaction.

[1]

(v) Identify the major source of inaccuracy of measurement in this reaction.

Suggest an improvement to the experiment to make it more accurate.

inaccuracy

.....

improvement

.....

[2]

(d) The reaction between $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ and NaI proceeds via an $\text{S}_{\text{N}}2$ mechanism.

The student repeated the experiment in (c) using an isomer of $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ that reacts via both $\text{S}_{\text{N}}1$ and $\text{S}_{\text{N}}2$ mechanisms.

State and explain whether the student will be able to show that the rate of this reaction is proportional to the concentration of NaI .

.....

.....

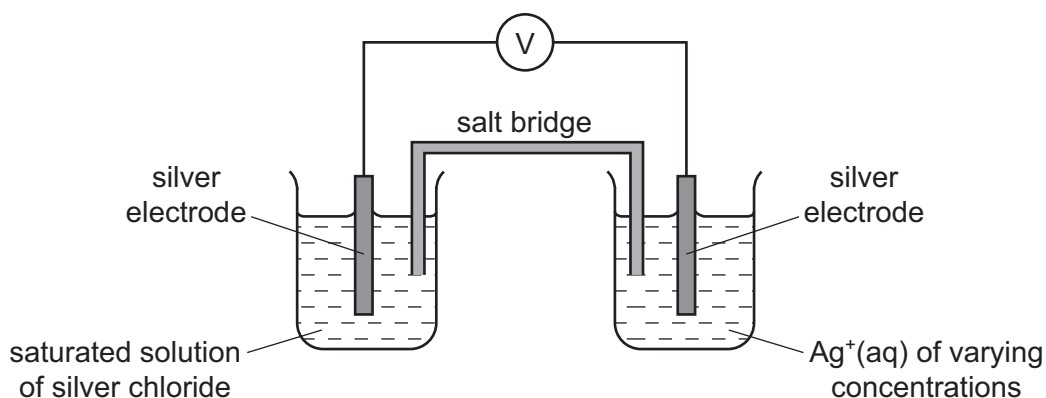
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..... [1]

[Total: 14]

- 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 $40^\circ C$. 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 $40^\circ C$.

Explain how you would do this.

.....
 [1]

- (ii) If the temperature was maintained at $40^\circ C$, over time the reading on the voltmeter would change.

Suggest **one** reason why.

.....
 [1]

The cell potential was measured for various concentrations of $\text{Ag}^+(\text{aq})$ 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	$[\text{Ag}^+(\text{aq})]$ / mol dm^{-3}	E_{cell}/V	$-\log [\text{Ag}^+(\text{aq})]$	$16.1E_{\text{cell}}/\text{V}$
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 $16.1E_{\text{cell}}$ against $-\log [\text{Ag}^+(\text{aq})]$.

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.

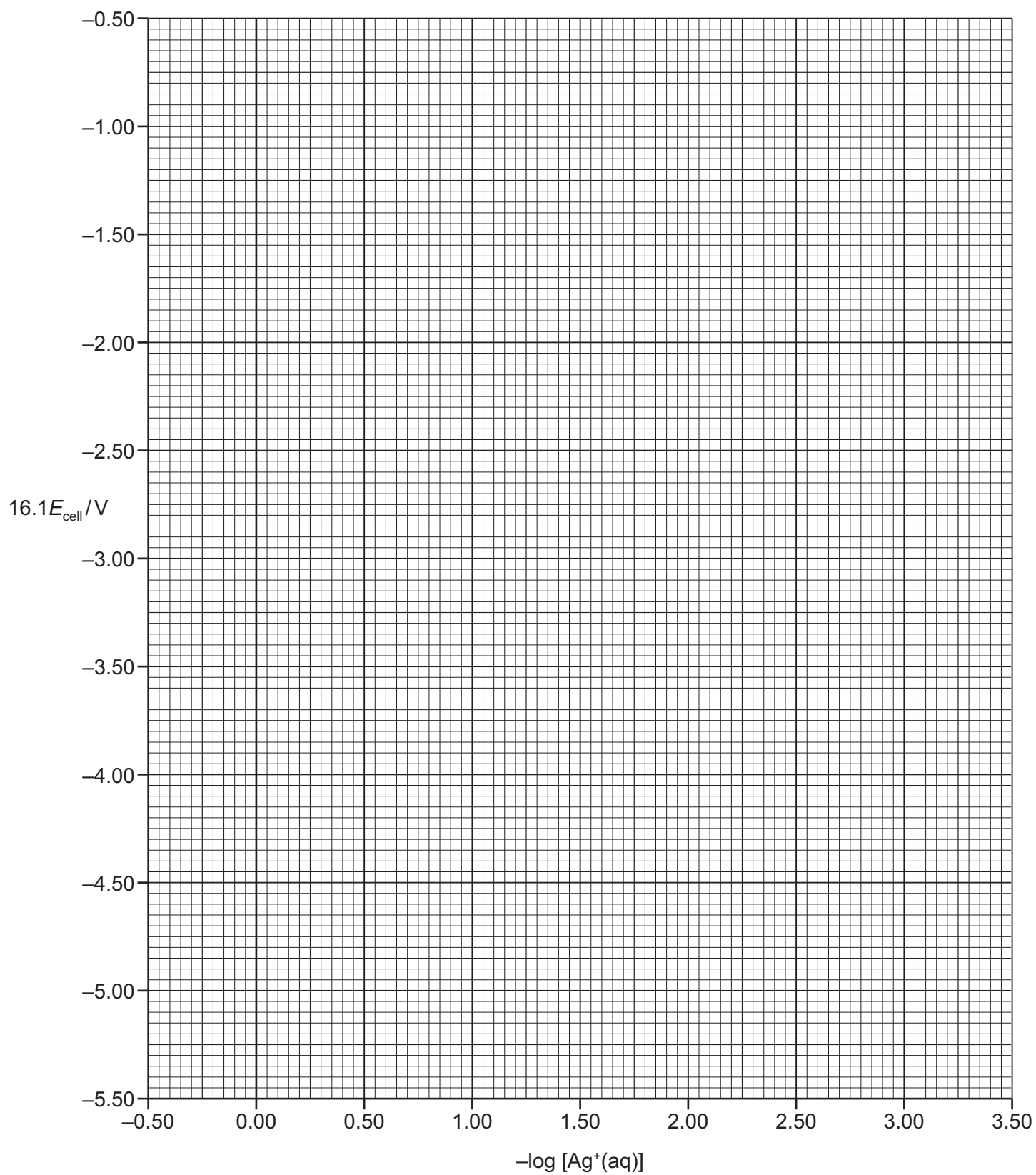
.....

 [2]

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

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

$$\log C_{\text{sat}} = \dots\dots\dots [1]$$



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

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

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

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.)

$K_{\text{sp}} =$ [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]

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9701/52

October/November 2018

1 hour 15 minutes

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- 1 A sample of waste water contains calcium ions, copper(II) ions and lead(II) ions.

You are to plan an experimental procedure to separate the metal ions in the waste water sample by forming precipitates of the metal ions.

The table shows the numerical values of the solubility products, K_{sp} , of some compounds. For example, the solubility product of calcium chloride, $K_{sp} = [Ca^{2+}][Cl^-]^2 = 2 \times 10^{-1} \text{ mol}^3 \text{ dm}^{-9}$. The smaller the solubility product, the easier it is for a precipitate to form.

	K_{sp} values		
	Cl^-	CO_3^{2-}	S^{2-}
Ca^{2+}	2×10^{-1}	5×10^{-9}	3×10^{-10}
Cu^{2+}	1×10^{-1}	3×10^{-10}	6×10^{-36}
Pb^{2+}	2×10^{-5}	7×10^{-14}	3×10^{-28}

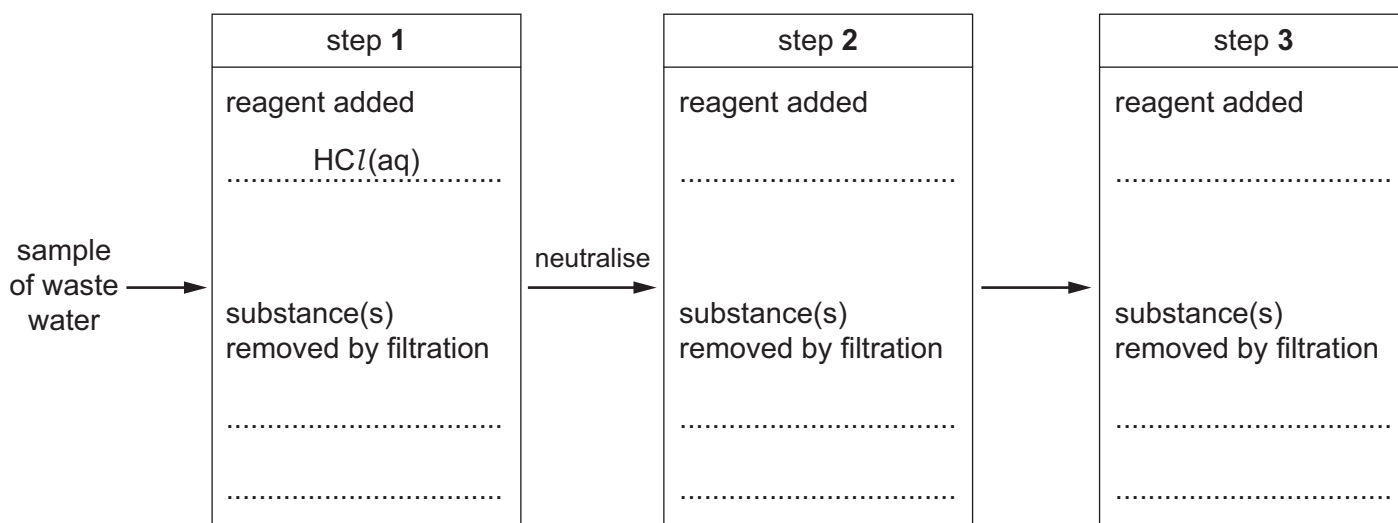
You are provided with

- a sample of waste water containing $Ca^{2+}(aq)$, $Cu^{2+}(aq)$ and $Pb^{2+}(aq)$,
- $HCl(aq)$,
- $(NH_4)_2CO_3(aq)$,
- $(NH_4)_2S(aq)$.

No other reagents should be used. Standard laboratory equipment is available.

- (a) The flowchart below is provided to plan the order of steps for the separation by filtration of the precipitates from the sample of waste water.

Complete the flowchart. For each step state the reagent added and the substance(s) removed by filtration.



[3]

- (b) After the substances formed in each step in (a) have been removed by filtration, a further drop of the reagent used for that step is added to the waste water sample.

Suggest why this is necessary.

.....
 [1]

- (c) Between steps 1 and 2, the waste water sample is neutralised. This is so that steps 2 and 3 will work.

Suggest a reagent that should be added to neutralise the waste water sample. State how you could test that the waste water sample had been neutralised.

reagent
 test

 [2]

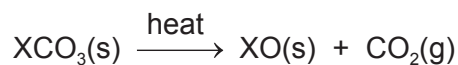
A student completes the reactions in (a) with a sample of waste water and obtains one of the precipitates produced, XCO_3 .

- (d) The student plans to calculate the concentration of X^{2+} ions present in this sample of waste water by measuring the mass loss on heating the freshly filtered sample of $\text{XCO}_3(\text{s})$.
- (i) Draw and label a diagram of the experimental set-up the student should use.
 Your diagram should show how loss of solid during heating would be prevented.

[2]

The student weighs the XCO_3 precipitate and records its mass. The student then heats the precipitate strongly for five minutes and weighs it again. The student records the difference in mass and from this calculates $[\text{X}^{2+}]$.

The precipitate thermally decomposes according to the following equation.



- (ii) Identify **two** problems with this method. Explain the effect that each problem has on the calculated concentration of X^{2+} .

problem 1

effect 1

.....

problem 2

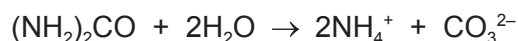
effect 2

.....

[4]

[Total: 12]

- 2 The hydrolysis of urea, $(\text{NH}_2)_2\text{CO}$, $M_r = 60$, is shown by the equation. The reaction is catalysed by the enzyme urease, when present in low concentrations.



The formation of the NH_4^+ and CO_3^{2-} ions increases the conductivity of the solution. The increase in conductivity over time can be measured and the rate of hydrolysis can be determined from this.

A student plans to carry out this reaction using a 50 cm^3 sample of $5.00 \times 10^{-3}\text{ mol dm}^{-3}$ urea solution.

- (a) The $5.00 \times 10^{-3}\text{ mol dm}^{-3}$ urea solution cannot be accurately prepared by dissolving urea in 50.0 cm^3 of water. A more concentrated solution is first prepared. This is then diluted to make the solution of the required concentration.

- (i) Suggest why diluting a more concentrated solution is a more accurate method of preparing this solution than by dissolving urea in 50.0 cm^3 of water.

.....

 [1]

- (ii) Describe how you would accurately prepare exactly 100 cm^3 of $5.00 \times 10^{-3}\text{ mol dm}^{-3}$ urea solution, starting with 3.00 g of solid urea. Your method should use more than one volumetric flask, including one of capacity 1000 cm^3 , and other suitable equipment.

.....

 [3]

- (b) A student added a small amount of urease to a 50.0 cm^3 sample of the solution made in (a)(ii). The conductivity of the solution was measured. The student obtained the results shown in the table. The student forgot to record the conductivity at 150 s. Conductivity is measured in $\mu\text{S cm}^{-1}$.

time, t /s	conductivity / $\mu\text{S cm}^{-1}$
0	0
30	55
60	110
90	160
120	215
150	—
180	320
210	375
240	425
270	480
300	530

- (i) Plot a graph on the grid to show the relationship between time t and conductivity.

Use a cross ($\times$) to plot each data point. Draw the straight line of best fit. [2]

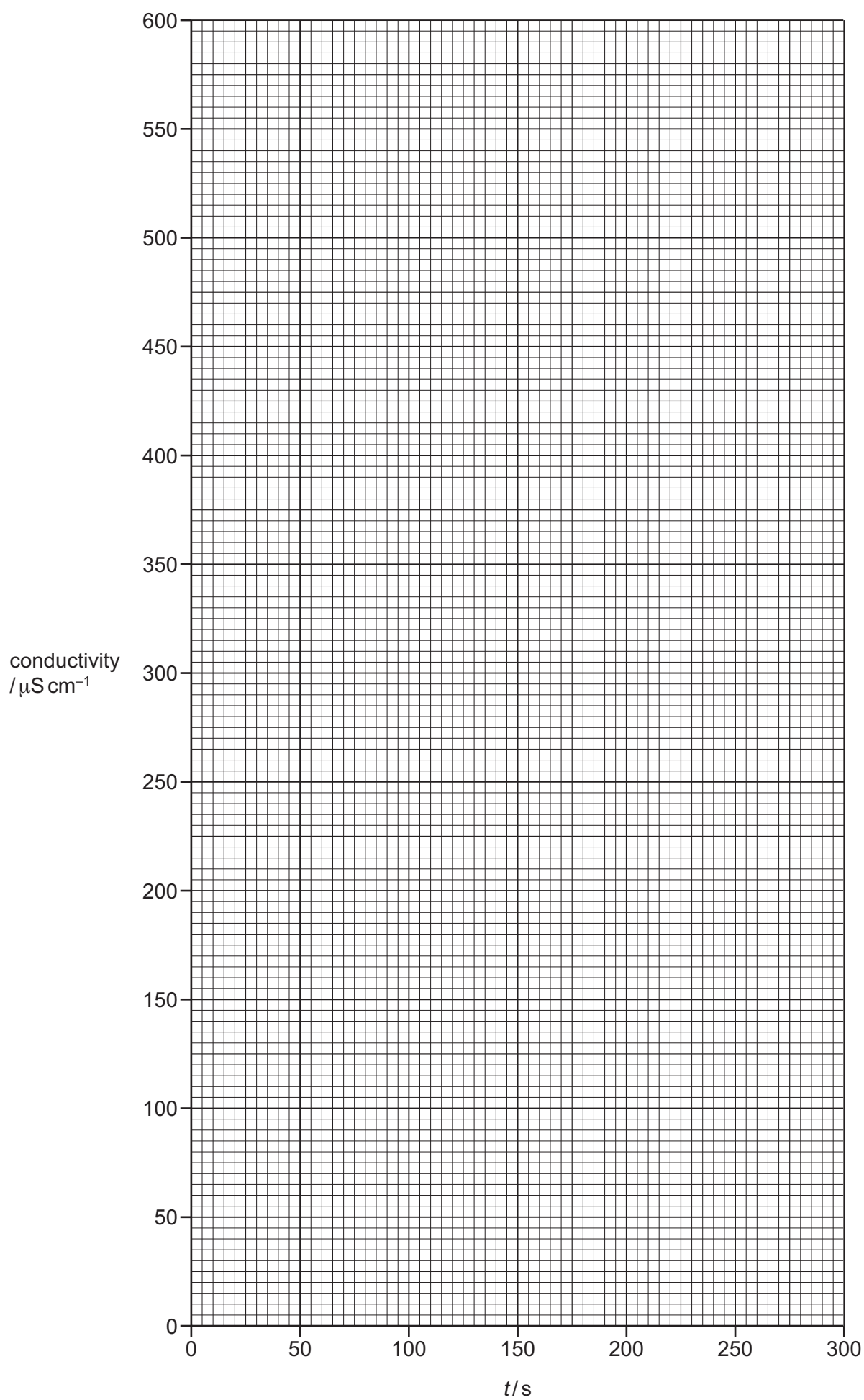
- (ii) Use the graph to determine the gradient of the best-fit line. State the co-ordinates of both points you used in your calculation.
Give your answer to **three significant figures**.

co-ordinates 1 co-ordinates 2

gradient = ... $\mu\text{S cm}^{-1} \text{ s}^{-1}$ [2]

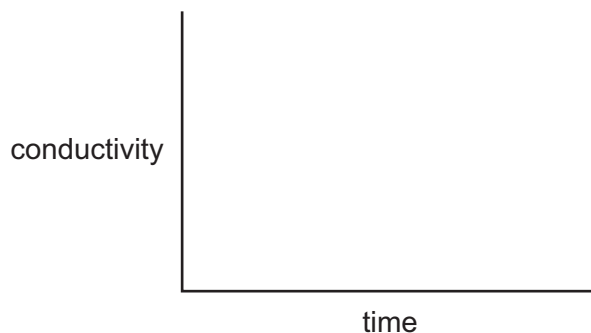
- (iii) Use your graph to determine the conductivity of the solution at $t = 150\text{ s}$.

conductivity at 150 s = ... $\mu\text{S cm}^{-1}$ [1]



- (c) In another experiment, a student added a small amount of urease to 50.0 cm³ samples of urea of various concentrations and measured their conductivity until hydrolysis was complete.
- (i) Sketch a graph on the axes below to show the variation in conductivity in **one** such experiment.

Explain the shape of your graph as hydrolysis reaches completion.



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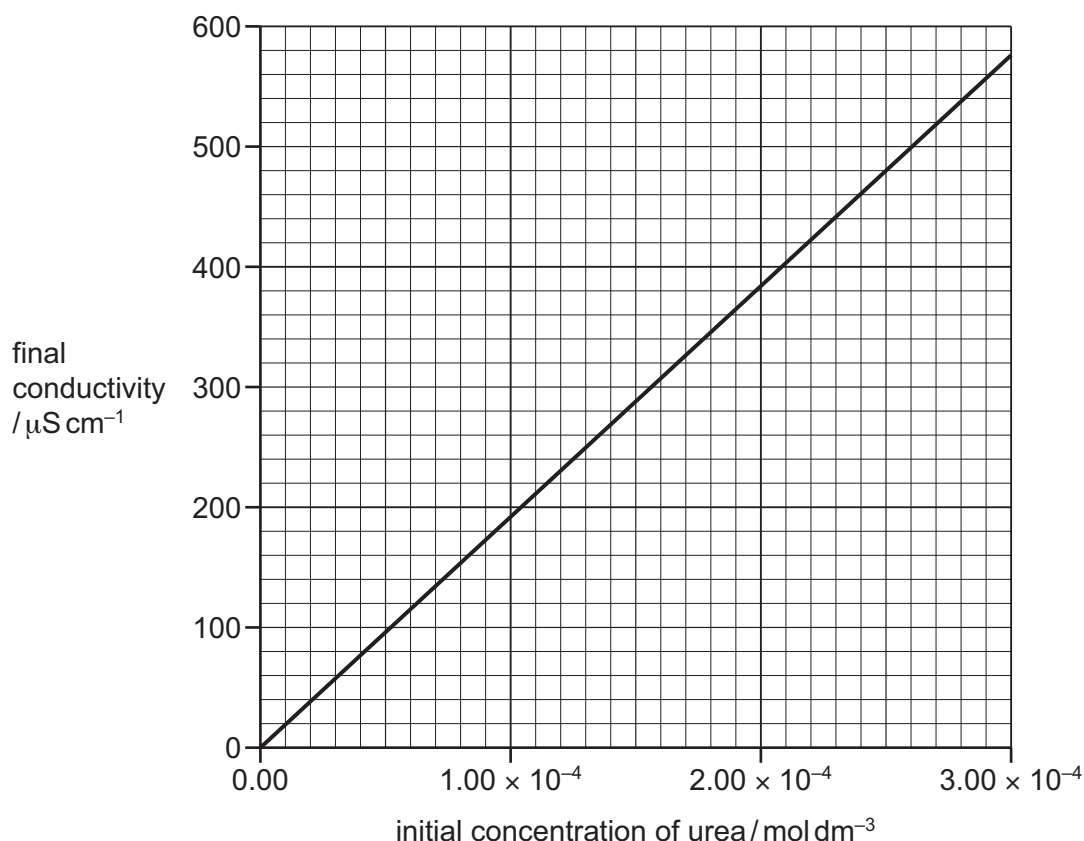
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[2]

From their results, the student plotted the calibration graph, shown below, of final conductivity of solution against initial concentration of urea.



You are going to determine the average rate of hydrolysis over the first 150 s of the experiment in **(b)**.

- (ii)** Use the calibration graph to determine the initial concentration of urea that would give the same final conductivity as your answer to **(b)(iii)**.
(If you were unable to obtain an answer to **(b)(iii)** you should use the value of $350 \mu\text{S cm}^{-1}$. This is not the correct value.)

initial concentration of urea = ... mol dm⁻³ [1]

- (iii)** Use your answer to **(c)(ii)** to calculate the average rate of hydrolysis of urea during the first 150 s. Determine the units of the rate of hydrolysis.

rate of hydrolysis = ... units = ... [2]

(d) The student repeats the experiment in (b) using a different low concentration of urea solution.

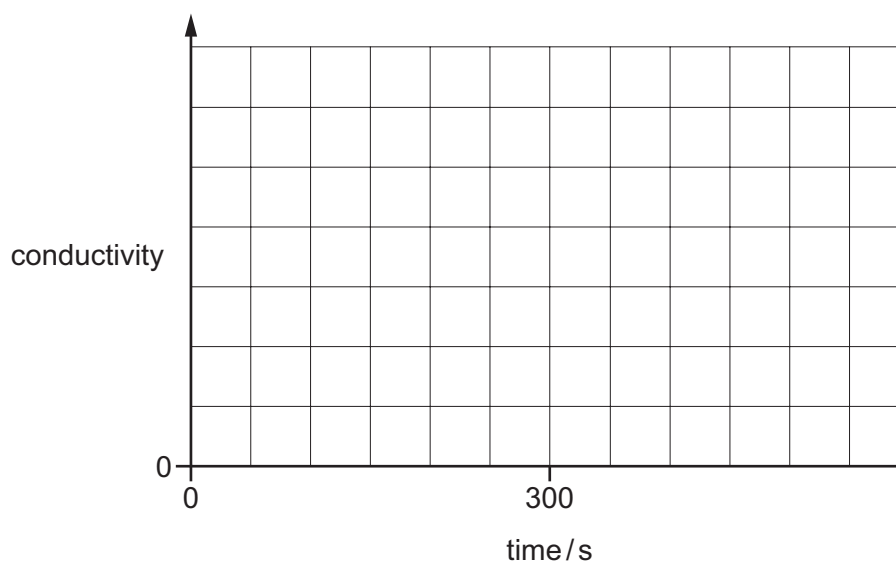
The student measures the conductivity of the solution for 300 s.

At 300 s, the student adds 1.0 cm^3 of 0.05 mol dm^{-3} aqueous silver nitrate, $\text{AgNO}_3(\text{aq})$. The measured conductivity of the solution immediately increases.

$\text{AgNO}_3(\text{aq})$ is known to prevent the enzyme urease from hydrolysing urea.

Using the axes below, sketch a graph to show how the conductivity of the solution changes during this experiment.

Extend the graph beyond the point at which $\text{AgNO}_3(\text{aq})$ is added at 300 s.



[3]

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

silver nitrate	Solutions equal to or more concentrated than 0.18 mol dm^{-3} are classified as corrosive and hazardous for the aquatic environment ; solutions equal to or more concentrated than 0.06 mol dm^{-3} but less concentrated than 0.18 mol dm^{-3} are classified as moderate hazard and hazardous for the aquatic environment ; solutions less concentrated than 0.06 mol dm^{-3} are classified as hazardous for the aquatic environment .
urea	All solutions are low hazard.
urease	Concentrated solutions may produce allergic reactions. They can cause asthma and irritate the eyes, nose and skin. Dilute 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.

precaution

.....

explanation

.....

[1]

[Total: 18]

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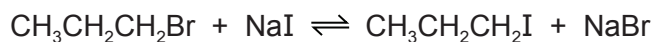
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One example of the Finkelstein reaction is given.



- (a) (i) Explain why it is important for **dry** propanone to be used as a solvent for this reaction.

.....

 [1]

- (ii) The solubilities of NaBr and NaI in propanone are shown.

compound	solubility at 25 °C in g / 100 g of propanone
NaBr	0.00841
NaI	39.9

Use this information to explain why, although the reaction between $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ and NaI is reversible, the reaction produces a very high yield.

.....

 [2]

(b) Some safety information for the organic compounds used in this reaction is shown.

- 1-bromopropane is **highly flammable** and **moderate health hazard**. It is irritating to eyes, the respiratory system and skin.
- 1-iodopropane is **flammable** and **moderate health hazard**. It is irritating to eyes, the respiratory system and skin.
- Propanone is **highly flammable** and **moderate health hazard**. It is irritating to eyes, and may cause dizziness and drowsiness.

Identify **two** different precautions, other than using protective equipment such as gloves, a lab coat or eye protection, that should be taken when carrying out this experiment. Explain each answer.

1 precaution

.....

explanation

.....

2 precaution

.....

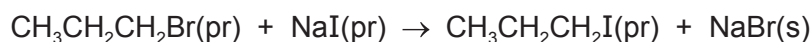
explanation

.....

[2]

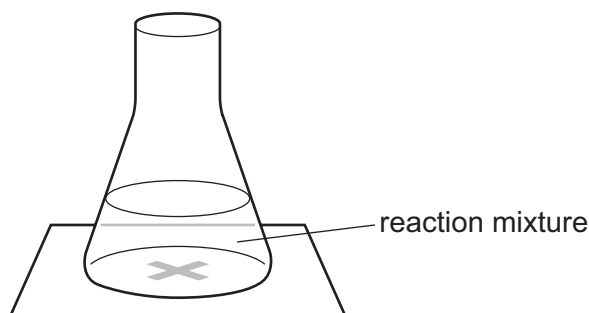
- (c) A student plans an experiment to show that the rate of the reaction is proportional to the concentration of NaI.

Propanone is used as the solvent in this reaction.



(pr) = substance is dissolved in propanone

The student plans to record the time it takes for the solid formed to obscure a cross on a piece of paper below the conical flask, as shown.



To carry out this experiment, the following materials are available.

- $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}(\text{l})$
- $\text{NaI}(\text{s})$
- dry propanone, $\text{CH}_3\text{COCH}_3(\text{l})$
- usual laboratory apparatus

- (i) Calculate the masses of $\text{NaI}(\text{s})$ and $\text{CH}_3\text{COCH}_3(\text{l})$ that would be needed to make 150 cm^3 of 0.50 mol dm^{-3} $\text{NaI}(\text{pr})$. Assume 150 cm^3 of propanone are required. Give your answers to **one decimal place**.

The density of $\text{CH}_3\text{COCH}_3(\text{l})$ is 0.79 g cm^{-3} .

[A_r : Na, 23.0; I, 126.9]

mass of $\text{NaI}(\text{s}) = \dots\dots\dots \text{ g}$

mass of $\text{CH}_3\text{COCH}_3(\text{l}) = \dots\dots\dots \text{ g}$
[2]

(ii) Part of the table the student used to record data is given.

Complete the table with appropriate volumes that the student could have used in four further experiments.

volume of 0.50 mol dm^{-3} $\text{NaI}(\text{pr})/\text{cm}^3$	volume of $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}(\text{l})$ $/\text{cm}^3$	volume of $\text{CH}_3\text{COCH}_3(\text{l})$ $/\text{cm}^3$	total volume $/\text{cm}^3$	time $/\text{s}$
10.0	2.0	30.0	42.0	

[2]

(iii) The student uses the same experimental set-up each time.

In this experiment, identify the dependent variable.

..... [1]

(iv) Write an expression to show how the student could calculate the rate of the reaction.

[1]

(v) Identify the major source of inaccuracy of measurement in this reaction.

Suggest an improvement to the experiment to make it more accurate.

inaccuracy

.....

improvement

.....

[2]

(d) The reaction between $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ and NaI proceeds via an $\text{S}_{\text{N}}2$ mechanism.

The student repeated the experiment in (c) using an isomer of $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ that reacts via both $\text{S}_{\text{N}}1$ and $\text{S}_{\text{N}}2$ mechanisms.

State and explain whether the student will be able to show that the rate of this reaction is proportional to the concentration of NaI .

.....

.....

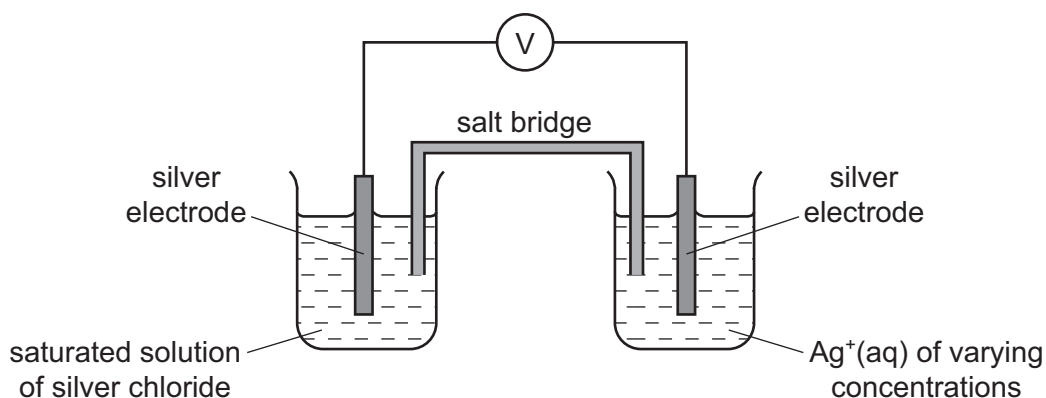
.....

..... [1]

[Total: 14]

- 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 $40^\circ C$. 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 $40^\circ C$.

Explain how you would do this.

.....
 [1]

- (ii) If the temperature was maintained at $40^\circ C$, over time the reading on the voltmeter would change.

Suggest **one** reason why.

.....
 [1]

The cell potential was measured for various concentrations of $\text{Ag}^+(\text{aq})$ 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	$[\text{Ag}^+(\text{aq})]$ / mol dm^{-3}	E_{cell}/V	$-\log [\text{Ag}^+(\text{aq})]$	$16.1E_{\text{cell}}/\text{V}$
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 $16.1E_{\text{cell}}$ against $-\log [\text{Ag}^+(\text{aq})]$.

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.

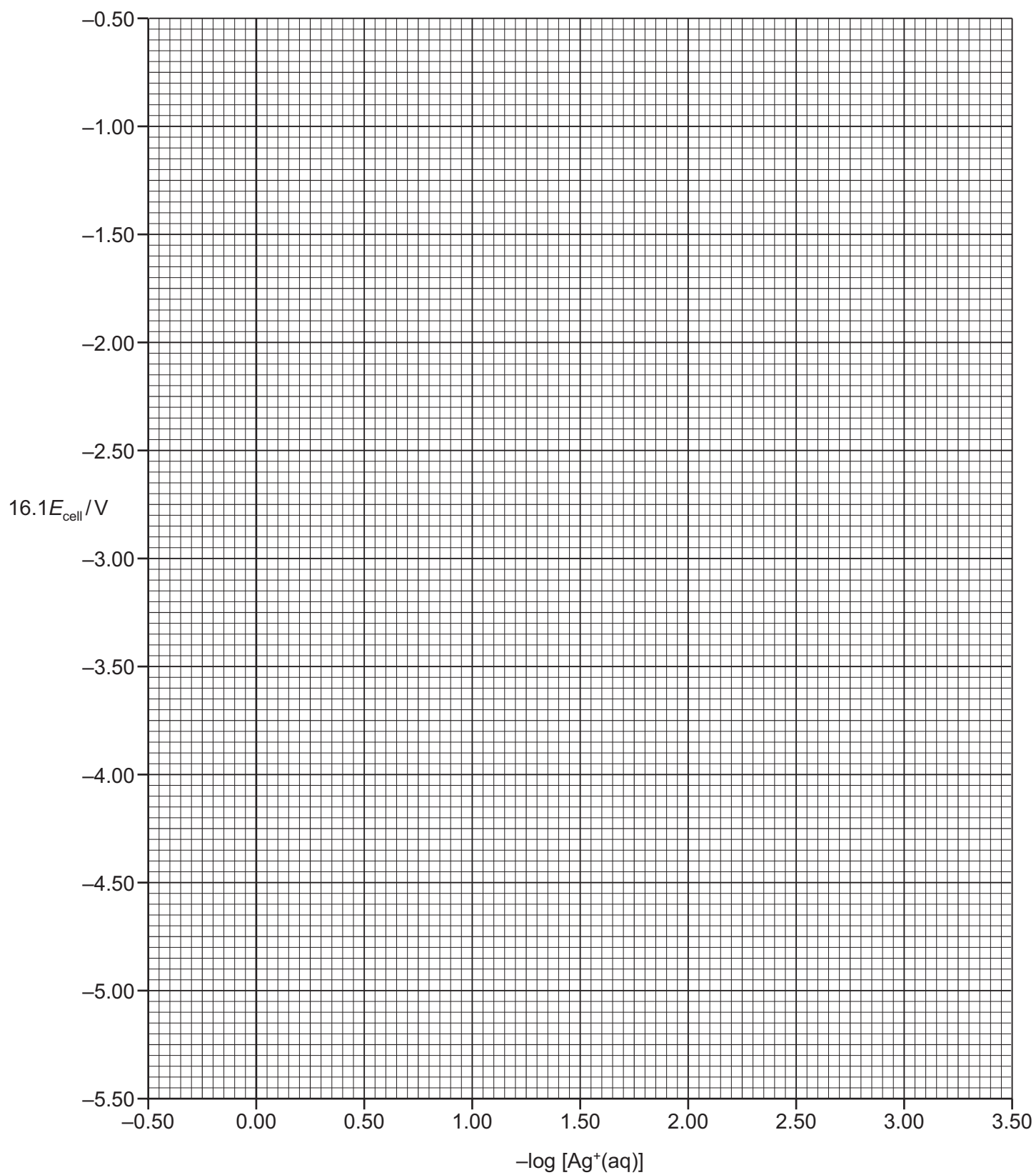
.....

 [2]

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

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

$$\log C_{\text{sat}} = \dots\dots\dots [1]$$



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

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

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

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.)

$K_{\text{sp}} = \dots\dots\dots$ [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]

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