SL Paper 3

Rhodium and palladium are often used together in catalytic converters. Rhodium is a good reduction catalyst whereas palladium is a good oxidation catalyst.

a. In a catalytic converter, carbon monoxide is converted to carbon dioxide. Outline the process for this conversion referring to the metal used. [3]

b.i. Nickel is also used as a catalyst. It is processed from an ore until nickel(II) chloride solution is obtained. Identify **one** metal, using sections 24 and 25 of the data booklet, which will not react with water and can be used to extract nickel from the solution. [1]

b.ii. Deduce the redox equation for the reaction of nickel(II) chloride solution with the metal identified in (b)(i). [1]

c. Another method of obtaining nickel is by electrolysis of a nickel(II) chloride solution. Calculate the mass of nickel, in g, obtained by passing a current of 2.50 A through the solution for exactly 1 hour. Charge (Q) = current (I) × time (t). [2]

Markscheme

a. carbon monoxide/CO adsorbs onto palladium/Pd

bonds stretched/weakened/broken
OR
«new» bonds formed
OR
activation energy/E_a «barrier» lowered «in both forward and reverse reactions»

products/CO_2 desorb «from catalyst surface»

[3 marks]

b.i. Fe/iron

OR

Zn/zinc

OR

Co/cobalt

OR

Cd/cadmium

OR

Cr/chromium

Accept "Mn/manganese".

[1 mark]

b.ii. $Ni^{2+}(aq) + Fe(s) \rightarrow Ni(s) + Fe^{2+}(aq)$

OR

$Ni^{2+}(aq) + Zn(s) \rightarrow Ni(s) + Zn^{2+}(aq)$

OR

$Ni^{2+}(aq) + Co(s) \rightarrow Ni(s) + Co^{2+}(aq)$

OR

$Ni^{2+}(aq) + Cd(s) \rightarrow Ni(s) + Cd^{2+}(aq)$

OR

$Ni^{2+}(aq) + Cr(s) \rightarrow Ni(s) + Cr^{2+}(aq)$

Accept "$3Ni^{2+}(aq) + 2Cr(s) \rightarrow 3Ni(s) + 2Cr^{3+}(aq)$".

*Do **not** penalize similar equations involving formation of $Fe^{3+}(aq)$, $Mn^{2+}(aq)$ **OR** $Co^{3+}(aq)$.*

Ignore Cl^- ions.

Accept correctly balanced non-ionic equations eg, "$NiCl_2(aq) + Zn(s) \rightarrow Ni(s) + ZnCl_2(aq)$" etc.

Do not allow ECF from (b)(i).

[2 mark]

c. $n(\mathrm{e^-})$ «$= \frac{2.50 \text{ A} \times 3600 \text{ s}}{96500 \text{ C mol}^{-1}}$» = 0.09326 «mol»

OR

$n(\mathrm{Ni})$ «$= \frac{0.09326 \text{ mol}}{2}$» = 0.04663 «mol»

$m(\mathrm{Ni})$ «= 0.04663 mol x 58.69 g mol^{-1}» = 2.74 «g»

*Award **[2]** for correct final answer.*

[2 marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

Water purity is often assessed by reference to its oxygen content.

The Winkler method uses redox reactions to find the concentration of oxygen in water. 100 cm^3 of water was taken from a river and analysed using this method. The reactions taking place are summarized below.

$$\text{Step 1} \quad 2Mn^{2+}(aq) + 4OH^-(aq) + O_2(aq) \rightarrow 2MnO_2(s) + 2H_2O(l)$$
$$\text{Step 2} \quad MnO_2(s) + 2I^-(aq) + 4H^+(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2H_2O(l)$$
$$\text{Step 3} \quad 2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$

a. Outline the meaning of the term *biochemical oxygen demand* (BOD). [2]

c.i. State what happened to the O_2 in step 1 in terms of electrons. [1]

c.ii. State the change in oxidation number for manganese in step 2. [1]

c.iii. 0.0002 moles of I^- were formed in step 3. Calculate the amount, in moles, of oxygen, O_2, dissolved in water. [1]

Markscheme

a. amount of oxygen needed to decompose organic matter;

in a specified time/five days / at a specified temp/ 20 °C;

Second mark can only be awarded if reasonable attempt made to define BOD.

c.i. gained electrons;

c.ii. +4 to +2 / decrease by 2;

c.iii. $0.00005/5 \times 10^{-5}$ (moles);

Examiners report

a. In part (a) the term *biochemical oxygen demand (BOD)* was not well known. Very few candidates could explain that it is related to the level of organic waste in the water measured at a specific temperature for a specific time period.

c.i. Many candidates understood that oxygen gained electrons.

c.ii. Many candidates understood that the oxidation number of manganese dropped from +4 to +2.

c.iii. Many candidates understood that oxygen gained electrons in (c) (i) and that the oxidation number of manganese dropped from +4 to +2 in (ii). However, they struggled to calculate the moles of dissolved oxygen.

Rechargeable nickel-cadmium batteries are used in portable electrical equipment and emergency lighting.

The **discharge** process can be summarized by the equation below.

$$2NiO(OH)(s) + Cd(s) + 2H_2O(l) \rightleftharpoons 2Ni(OH)_2(s) + Cd(OH)_2(s)$$

a. State the change in oxidation number of the cadmium and deduce if it is acting as the positive or negative electrode during the discharge process. [2]

b. Identify a physical property of $Cd(OH)_2$ which allows this process to be reversed and the battery recharged. [1]

Markscheme

a. $0 \rightarrow +2$ / increase by 2;

negative;

*If decrease by 2, positive, award **[1]**. If decrease by 2, negative, award **[0]**.*

b. insoluble (Cd^{2+} ions do not escape into solution);

Do not accept solid.

Examiners report

a. Most candidates were able to identify the change of oxidation number of cadmium but very few identified the insolubility of cadmium hydroxide as the physical property which allows the process to be reversed.

b. Most candidates were able to identify the change of oxidation number of cadmium but very few identified the insolubility of cadmium hydroxide as the physical property which allows the process to be reversed.

The biochemical oxygen demand (BOD) is a measure of water pollution.

State what is meant by the term *biochemical oxygen demand* (BOD).

Markscheme

amount of oxygen needed to decompose organic matter (in water sample);

in a specified time/five days / at a specified temperature/ 20 °C;

Examiners report

Most candidates knew the meaning of BOD.

Depressants can have different effects depending on their doses.

A breathalyser containing crystals of potassium dichromate(VI) can be used by the police to detect whether a driver has consumed alcohol.

b.i. State the chemical formula for potassium dichromate(VI). [1]

b.ii. Describe the colour change observed during its reaction with ethanol. [1]

b.iii. State the oxidation number of chromium in the product. [1]

b.iv. Deduce the **full** balanced chemical equation for the redox reaction of ethanol with acidified potassium dichromate(VI). [2]

b.v. State the name of the organic product formed. [1]

c. An intoximeter is used to determine an accurate value for the concentration of ethanol in the breath. Explain **one** technique used for the detection of ethanol in an intoximeter. [3]

Markscheme

b.i. $K_2Cr_2O_7$;

b.ii. orange to green;

Allow yellow instead of orange.

b.iii. +3/III;

Do not allow incorrect notation such as 3+ or 3.

b.iv. $3CH_3CH_2OH + 2Cr_2O_7^{2-} + 16H^+ \rightarrow 3CH_3CO_2H + 4Cr^{3+} + 11H_2O$

correct formulas of CH_3CH_2OH and $Cr_2O_7^{2-}/K_2Cr_2O_7$ as reactants **and**

CH_3CO_2H/CH_3COOH and Cr^{3+} as products;

full balanced chemical equation;

M2 can only be scored if M1 is correct.

Allow full balanced chemical equation to produce ethanal,

$3CH_3CH_2OH + Cr_2O_7^{2-} + 8H^+ \rightarrow 3CH_3CHO + 2Cr^{3+} + 7H_2O$.

Accept full or condensed structural formulas.

b.v. ethanoic acid;

Allow acetic acid.

Allow ethanal/acetaldehyde.

c. infrared (spectroscopy)/IR;

CH characteristic band (at $2950\ cm^{-1}$) for ethanol / C–H bonds in ethanol absorb at certain frequency/wavelength;

Do not award M2 for CH characteristic band if however wavenumber range/value is given for OH (eg, 3200–3600 cm^{-1} or value in between or even 2500–3300 cm^{-1}).

area under peak used to measure concentration (of ethanol);

Accept "size of" instead of "area under".

Do not accept "height" instead of "area under".

OR

fuel cell;

ethanol converts/oxidized to CO_2 and H_2O;

(energy released converted to) voltage/potential difference (which is) proportional to/can be used to measure concentration (of ethanol);

Allow potential instead of potential difference.

Examiners report

b.i. Only about half the candidates gave the correct formula for potassium dichromate(VI).

b.ii. Most candidates knew the colour change.

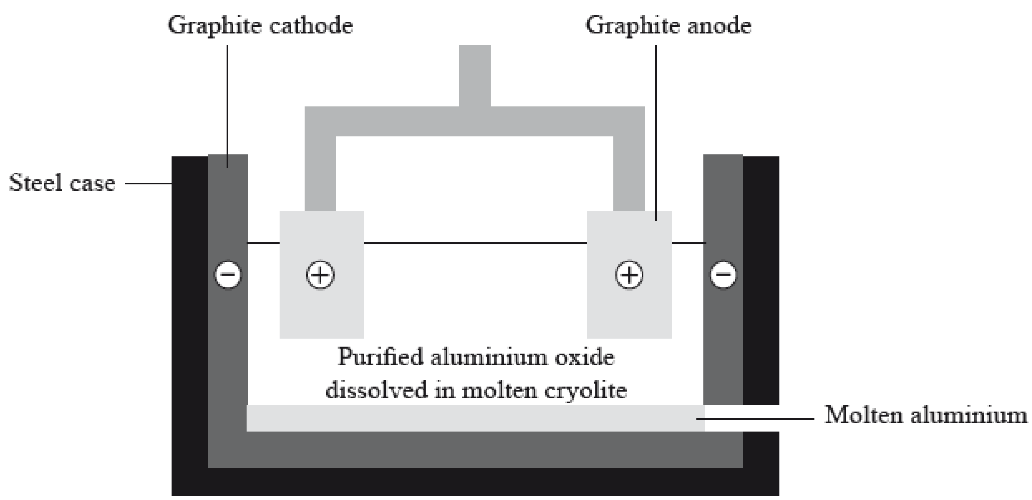
b.iii. The oxidation number was often given using incorrect notation (3+ or 3) failing to score the mark.

b.iv. The redox equation was challenge except for the strongest candidates.

b.v. About half the candidates gave the correct product for the oxidation of ethanol.

c. Part (c) was poorly answered. About half of the candidates scored one mark for recognizing that the intoximeter used IR radiation. Few candidates gained a second mark for recognizing that the absorption by C-H bonds is used to determine ethanol concentration. It was rare to see an answer mentioning the area under the peak or using the fuel cell in the intoximeter.

Aluminium is chemically reactive so it has to be extracted by the electrolysis of aluminium oxide dissolved in molten cryolite.



a. Deduce an equation for the discharge of the ions at each electrode. [2]

Positive electrode (anode):

Negative electrode (cathode):

b. (i) Outline why aluminium is alloyed with copper and magnesium when used to construct aircraft bodies. [2]

(ii) State **two** properties of aluminium that make it suitable for use in overhead power cables.

Markscheme

a. *Positive electrode (anode):*

$2O^{2-} \rightarrow O_2(g) + 4e^- / O^{2-} \rightarrow \frac{1}{2}O_2(g) + 2e^- / 2O^{2-} - 4e^- \rightarrow O_2(g) /$

$O^{2-} - 2e^- \rightarrow \frac{1}{2}O_2(g)$;

Allow $C(s) + 2O^{2-} \rightarrow CO_2(g) + 4e^-$.

Negative electrode (cathode):

$Al^{3+} + 3e^- \rightarrow Al(l)$;

Accept e instead of e^-.

Ignore state symbols.

If correct equations shown at wrong electrodes, award ***[1 max]****.*

b. (i) harder/stronger (than pure aluminium);

(ii) *Award* ***[1]*** *for any two of*:

good conductor of electricity;

resists corrosion;

Do not allow rusting.

low density;

Do not allow lighter/light mass/light weight.

ductile;

Do not allow malleable.

Examiners report

a. In (a), most were able to write the correct half-equation for the cathode though incorrect states were commonly seen, e.g. (aq). The anode half-equation was not well known.

b. Both parts of (b) were well done. In (ii), incorrect answers included malleability and light mass.

Ethanol is a depressant that is widely consumed in many societies. When consumed excessively it has a major impact on families and society as a whole. Other depressants such as diazepam (Valium®) may be prescribed by a doctor.

One problem associated with ethanol consumption is an increased risk of traffic accidents. Police in many countries use a breathalyser to test drivers. The breathalyser contains potassium dichromate(VI).

b.i. Describe the colour change of potassium dichromate(VI) when it reacts with ethanol. [1]

b.ii. State with a reason whether chromium in potassium dichromate(VI) is oxidised or reduced by ethanol. [1]

Markscheme

b.i. orange to green;

b.ii. reduced because oxidation number of Cr decreases / Cr gains electrons;

Explanation needed for mark.

Examiners report

b.i. [N/A]

b.ii. Candidates frequently confused oxidation and reduction or failed to provide a reason as to whether the chromium was oxidised or reduced by ethanol. This highlighted, again, the need for candidates to answer all parts of the question.

Dissolved oxygen is used up when organic matter is decomposed aerobically in water.

The Winkler method, which is based on redox reactions, can be used to determine the concentration of dissolved oxygen in water.

A $200\ \mathrm{cm^3}$ sample of water was taken from a river and analysed using this method.

The redox reactions are shown below.

Step 1 $\mathrm{2Mn^{2+}(aq) + 4OH^-(aq) + O_2(aq) \rightarrow 2MnO_2(s) + 2H_2O(l)}$

Step 2 $\mathrm{MnO_2(s) + 2I^-(aq) + 4H^+(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2H_2O(l)}$

Step 3 $\mathrm{2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)}$

(i) $1.50 \times 10^{-4}\ \mathrm{mol}$ of $\mathrm{I^-(aq)}$ was formed in step 3. Determine the amount, in mol, of oxygen, $\mathrm{O_2(aq)}$, dissolved in the water.

(ii) Determine the solubility, in $\mathrm{g\,dm^{-3}}$, of the oxygen in the water.

Markscheme

(i) $\left(\frac{1.50\times10^{-4}}{4} =\right)\ 3.75 \times 10^{-5}\ (\mathrm{mol})$;

(ii) $\left(\frac{3.75\times10^{-5}\times1000\times32.00}{200} =\right)\ 6.00 \times 10^{-3}\ (\mathrm{g\,dm^{-3}})$;

Examiners report

Candidates performed poorly on this question and were not able to gain the mark for part (a). Many did not apply the terms oxidation and reduction correctly and some did not distinguish between the two terms, only one of the two terms was explained. Some incorrectly stated hydrogen used in anaerobic respiration instead of oxygen being absent. Several also missed reference to organic material. Several candidates were able to perform the calculations, for part (b), correctly; some used incorrect value for $\mathrm{I^-}$ moles (2 instead of 4) in part (ii) and did not gain the mark.

In order to provide safe drinking water, a water supply is often treated with disinfectants, which aim to inactivate disease-causing bacteria in the water.

To compare the effectiveness of different disinfectants, a **CT value** is used as a measure of the dosage of disinfectant needed to achieve a certain level of inactivation of specific bacteria.

$$\text{CT value (mg min dm}^{-3}\text{)} = \text{C (mg dm}^{-3}\text{) concentration of disinfectant} \times \text{T (min) contact time with water}$$

a. The table below compares the CT values of different disinfectants necessary to achieve 99% inactivation of two types of bacteria, listed as **A** and **B**. [4]

Disinfectant	**CT value / mg min dm^{-3} for 99 % inactivation of bacteria**	
	Bacterium A	**Bacterium B**
Hypochlorous acid, $HOCl$	4×10^{-2}	8×10^{-2}
Hypochlorite ion, OCl^{-}	9.2×10^{-1}	3.3
Chlorine dioxide, ClO_2	1.8×10^{-1}	1.3×10^{-1}
Monochloramine, NH_2Cl	64	94

(i) Deduce the oxidation state of chlorine in the following disinfectants.

$HOCl$:

. . . .

ClO_2:

. . . .

(ii) From the data on CT values, justify the statement that bacterium **B** is generally more resistant to disinfection than bacterium **A**.

(iii) CT values can be used to determine whether a particular treatment process is adequate. Calculate the CT value, in mg min dm^{-3}, when 1.50×10^{-5} g dm^{-3} of chlorine dioxide is added to a water supply with a contact time of 9.82 minutes.

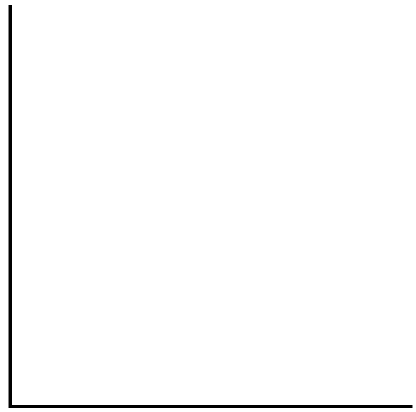
(iv) From your answer to (a) (iii) and the data in the table, comment on whether this treatment will be sufficient to inactivate 99% of bacterium **A**.

b. CT values are influenced by temperature and by pH. The table below shows the CT values for chlorine needed to achieve 99% inactivation of a specific bacterium at stated values of pH and temperature. [4]

pH	**Temperature / °C**				
	0.5	**5.0**	**10.0**	**15.0**	**20.0**
6.0	97	69	52	35	26
7.0	137	97	73	49	37
8.0	197	140	105	70	53
9.0	281	201	151	101	75

(i) With reference to the temperature data in the table, suggest why it may be more difficult to treat water effectively with chlorine in cold climates.

(ii) Sketch a graph on the axes below to show how the CT value (at any temperature) varies with pH.



(iii) Comment on the relative CT values at pH 6.0 and pH 9.0 at each temperature.

(iv) Chlorine reacts with water as follows:

$$Cl_2\ (g) + H_2O\ (l) \rightleftharpoons HOCl\ (aq) + HCl\ (aq)$$

$$HOCl\ (aq) \rightleftharpoons OCl^-\ (aq) + H^+\ (aq)$$

Predict how the concentrations of each of the species HOCl (aq) and OCl^- (aq) will change if the pH of the disinfected water increases.

HOCl (aq):

. . . .

OCl^- (aq):

. . . .

c. Despite widespread improvements in the provision of safe drinking water, the sale of bottled water has increased dramatically in recent years. [1]

State one problem caused by this trend.

Markscheme

a. i

HOCl: +1
AND
ClO_2: +4

*Accept "I" and "IV" but **not** "1+/1" and "4+/4" notations.*

ii

«most» CT values are higher for «bacterium» B
OR
«generally» higher dosage needed for «bacterium» B

Accept converse arguments. Accept "concentration" for "dosage"

iii

«CT = $1.50 \times 10^{-5} \times 10^{3}$ mg dm^{-3} × 9.82 min =» 1.47×10^{-1} «mg min dm^{-3}»

iv

lower than CT value/minimum dosage/1.8×10^{-1} «mg min dm^{-3}»
AND
no/insufficient

Accept "concentration" for "dosage".

b. i

higher CT value at lower temperature
OR
higher dosage «of chlorine» needed at low temperature

Accept "effectiveness decreases at lower temperature".
Accept "concentration" for "dosage".
Accept converse arguments.

ii

labeled axes (*y*: CT and *x*: pH)
AND
curve with increasing gradient

*Do **not** accept axes the wrong way round.*
Accept a linear sketch.

iii

values at pH 9.0 approximately 3 times values at pH 6.0
OR
increase in CT values in same ratio

The exact ratio is 2.9 times
*Do **not** accept just "increase in value".*

iv

[HOCl] decreases ***AND*** [OCl^-] increases

c. plastic disposal/pollution

OR

plastic bottles use up petroleum/non-renewable raw material

OR

chemicals in plastic bottle can contaminate water

OR

«prolonged» storage in plastic can cause contamination of water

OR

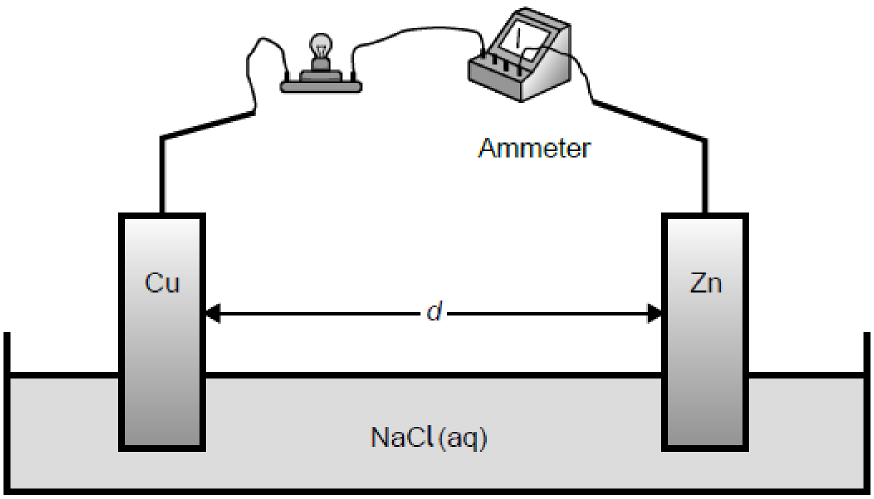
plastic water bottles sometimes reused without proper hygiene considerations

Accept other valid answers.
Accept economic considerations such as "greater production costs", "greater transport costs" or "bottled water more expensive than tap water"

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

A student set up a simple voltaic cell consisting of a copper electrode and a zinc electrode dipped in sodium chloride solution.



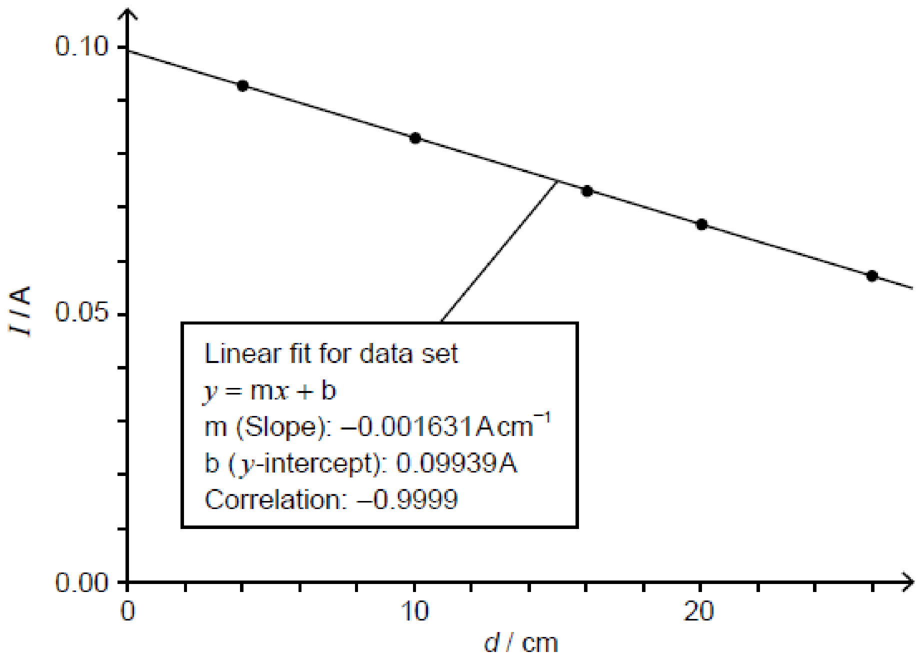
The student gradually increased the distance, *d*, between the electrodes to study the effect on the initial current, *I*, passing through the light bulb.

The student hypothesized that the initial current would be inversely proportional to the distance between the electrodes.

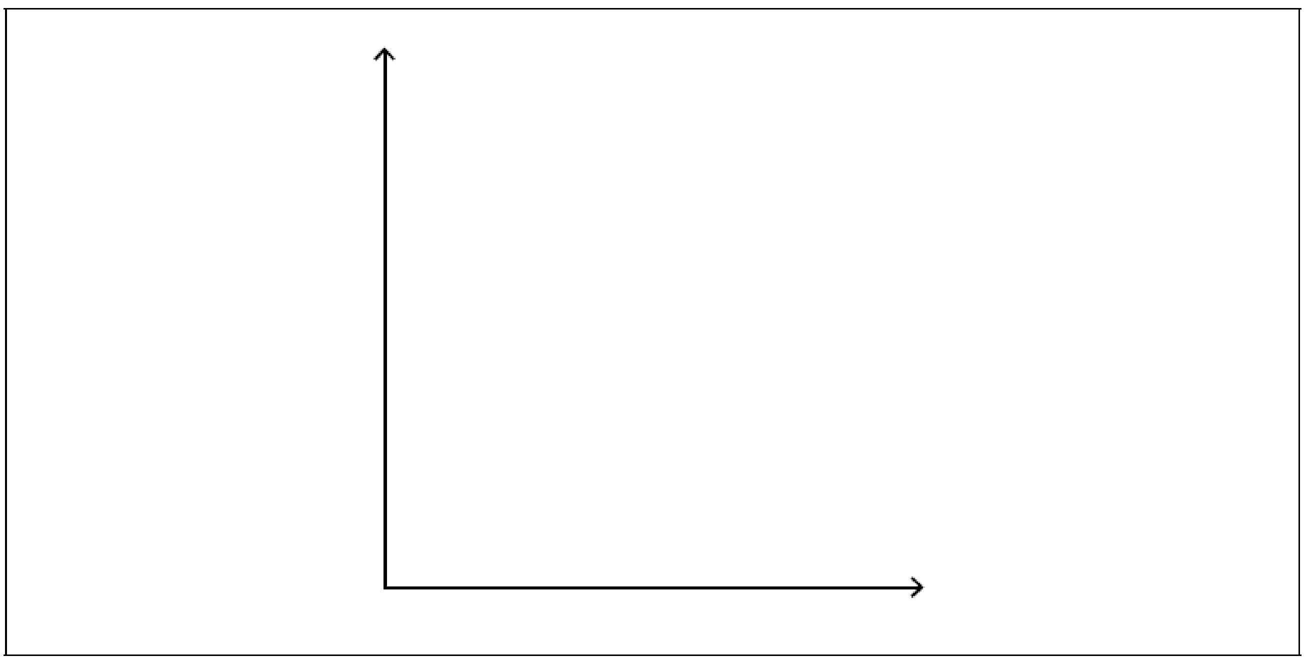
The following data was collected over five trials.

d **/ ±0.1 cm**	**Average *I* / ±0.04 A**
4.0	0.093
10.0	0.083
16.0	0.073
20.0	0.067
26.0	0.057

The data did not support the student's hypothesis. He investigated other possible relationships by plotting a graph of the average current against the distance between the electrodes. He obtained the following best-fit line with a correlation coefficient (r) of −0.9999.



a. Sketch a graph that would support the student's hypothesis. [1]

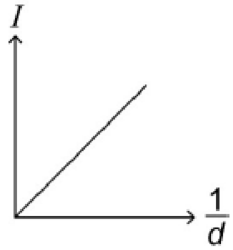


b.i. Suggest what the correlation coefficient of –0.9999 indicates. [1]

b.ii. State the equation of the straight line obtained using the data. [1]

b.iii. Outline how current flows in the sodium chloride solution. [1]

Markscheme

a. 

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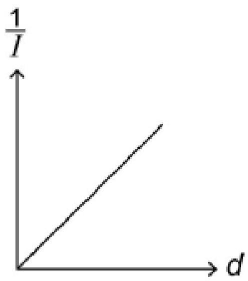

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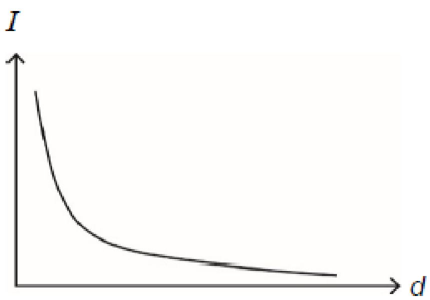

Correct labels of axes required for mark.

Accept d^{-1} instead of $\frac{1}{d}$.

Accept I^{-1} instead of $\frac{1}{I}$.

Plot of I vs d should not be linear.

b.i. negative correlation

OR

model/prediction matches results

OR

99% of variance accounted for

b.ii $I = -0.001631\,d + 0.09939$

OR

$y = -0.001631\,x + 0.09939$

Accept correctly rounded values for m and b in equation.

*Do **not** accept "y = mx + b".*

b.iii. ions move «across electrolyte»

Examiners report

a. [N/A]

b.i. [N/A]

[N/A]

b.iii. [N/A]