HL Paper 1

What is the standard half-cell potential of copper if the “zero potential reference electrode” is changed from the standard hydrogen electrode to a standard zinc electrode?

	$E^{\ominus}$ / V with respect to the standard hydrogen electrode
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34

A. –1.1

B. –0.34

C. +0.34

D. +1.1

Markscheme

D

Examiners report

[N/A]

Four electrolytic cells are constructed. Which cell would produce the greatest mass of metal at the negative electrode (cathode)?

	Electrolyte	Current / A	Time / s
A.	1.0 mol dm^{-3} $CuSO_4(aq)$	1.0	500
B.	1.0 mol dm^{-3} $AgNO_3(aq)$	2.0	250
C.	1.0 mol dm^{-3} $CuSO_4(aq)$	1.0	750
D.	1.0 mol dm^{-3} $AgNO_3(aq)$	1.5	250

Markscheme

B

Examiners report

[N/A]

What are the major products of electrolysing concentrated aqueous potassium iodide, KI(aq)?

	Negative electrode (cathode)	Positive electrode (anode)
A.	potassium	iodine
B.	hydrogen	iodine
C.	hydrogen	oxygen
D.	potassium	oxygen

Markscheme

B

Examiners report

[N/A]

Which signs for both E^{θ}_{cell} and ΔG^{θ} result in a spontaneous redox reaction occurring under standard conditions?

	$E^{\ominus}_{cell}$	$\Delta G^{\ominus}$
A.	+	+
B.	–	+
C.	–	–
D.	+	–

Markscheme

D

Examiners report

[N/A]

Which compound forms both hydrogen and oxygen at the electrodes when a concentrated aqueous solution is electrolyzed?

A. KI
B. NaCl
C. H_2SO_4
D. $AgNO_3$

Markscheme

C

Examiners report

[N/A]

An aqueous solution of a metal salt is electrolysed. Which factor will have no effect on the mass of the metal deposited on the negative electrode (cathode), if all other variables remain constant?

A. Size of metal ion

B. Relative atomic mass of metal

C. Current

D. Charge on metal ion

Markscheme

A

Examiners report

Four respondents stated in their G2 forms that they teach that time, current and charge will affect the mass of metal deposited during electrolysis, but nothing about size of the metal ion or the relative atomic mass of the metal. Although charge is important when considering the deposition of Na, Mg and Al when the same amount of current for the same amount of time is used, the relative atomic mass becomes important when considering the deposition of metal with ions of the same charge, Na and K for example.

This proved to be one of the fifth most difficult question in the paper with 37.54% choosing the correct answer A and 36.8% opting for answer B. The discrimination factor in this question was 0.41.

Consider these standard electrode potentials.

$$\mathrm{Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)} \quad E^\ominus = -2.36\ \mathrm{V}$$
$$\mathrm{Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)} \quad E^\ominus = -0.76\ \mathrm{V}$$

What is the cell potential for the voltaic cell produced when the two half-cells are connected?

A. –1.60 V

B. +1.60 V

C. –3.12 V

D. +3.12 V

Markscheme

B

Examiners report

[N/A]

Which are necessary conditions for the standard hydrogen electrode to have an $E^{\ominus}$ of exactly zero?

I. Temperature = 298 K

II. $[\mathrm{H}^+] = 1\ \mathrm{mol\,dm^{-3}}$

III. $[\mathrm{H_2}] = 1\ \mathrm{mol\,dm^{-3}}$

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Markscheme

A

Examiners report

[N/A]

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z mol of copper is deposited from $CuSO_4$ (aq) by a current, *I,* in time *t.* What is the amount of silver, in mol, deposited by electrolysis from $AgNO_3$ (aq) by a current, $\frac{I}{2}$, in time 2*t*?

A. $\frac{z}{4}$

B. $\frac{z}{2}$

C. *z*

D. 2*z*

Markscheme

D

Examiners report

[N/A]

A number of molten metal chlorides are electrolysed, using the same current for the same length of time. Which metal will be produced in the greatest amount, in mol?

A. Mg

B. Al

C. K

D. Ca

Markscheme

C

Examiners report

[N/A]

The standard electrode potentials of some half-reactions are given below.

$\mathrm{Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)} \quad E^\ominus = +0.15\ \mathrm{V}$

$\frac{1}{2}\mathrm{I_2(s) + e^- \rightleftharpoons I^-(aq)} \quad E^\ominus = +0.54\ \mathrm{V}$

$\mathrm{Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)} \quad E^\ominus = +0.77\ \mathrm{V}$

Which of the following reactions will occur spontaneously?

A. Iodine reduces $\mathrm{Fe^{3+}}$ to $\mathrm{Fe^{2+}}$

B. Iodine reduces $\mathrm{Sn^{4+}}$to $\mathrm{Sn^{2+}}$

C. Iodine oxidizes $\mathrm{Fe^{2+}}$to $\mathrm{Fe^{3+}}$

D. Iodine oxidizes $\mathrm{Sn^{2+}}$ to $\mathrm{Sn^{4+}}$

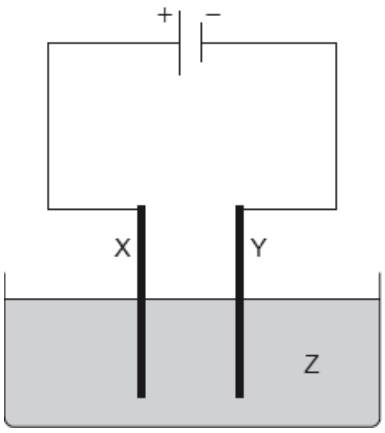
Markscheme

D

Examiners report

Two respondents stated in their G2 forms that the question was tricky and may have confused the candidates as they should apply the difference between Iodine and Iodide. If at Higher level candidates are not able to recognize that the symbol of Iodine is I2 and that of the Iodide ion is I- there is a severe problem in the candidates' basic preparation in Chemistry. Indeed, 33.08% of the candidates chose A as the correct answer thinking Iodine is I-, with only 32.05% choosing the correct answer D. This proved to be the third most difficult question in the paper with a discrimination index of 0.38.

Which combination would electroplate an object with copper?



	X	Z	Y
A.	object	$CuSO_4(aq)$	copper
B.	copper	$CuSO_4(aq)$	object
C.	object	$H_2SO_4(aq)$	copper
D.	copper	$H_2O(l)$	object

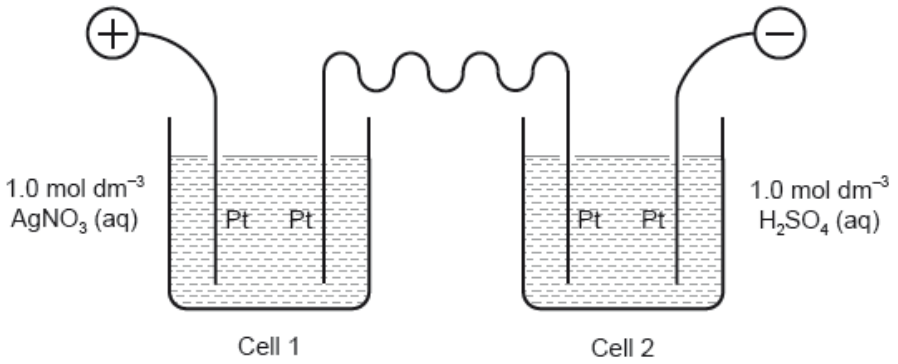
Markscheme

B

Examiners report

[N/A]

Two cells undergoing electrolysis are connected in series.



If x g of silver are deposited in cell 1, what volume of oxygen, in dm^3 at STP, is given off in cell 2?

A_r(Ag) = 108; Molar volume of an ideal gas at STP = 22.7 dm^3 mol^{-1}

A. $\frac{x}{108} \times \frac{1}{4} \times 22.7$

B. $\frac{x}{108} \times 4 \times 22.7$

C. $\frac{x}{108} \times \frac{1}{2} \times 22.7$

D. $\frac{x}{108} \times 2 \times 22.7$

Markscheme

A

Examiners report

[N/A]

The standard electrode potentials for two metals are given below.

$$\mathrm{Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)} \quad E^\ominus = -1.66\ \mathrm{V}$$
$$\mathrm{Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)} \quad E^\ominus = -0.23\ \mathrm{V}$$

What is the equation and cell potential for the spontaneous reaction that occurs?

A. $\mathrm{2Al^{3+}(aq) + 3Ni(s) \rightarrow 2Al(s) + 3Ni^{2+}(aq)} \quad E^\ominus = 1.89\ \mathrm{V}$

B. $\mathrm{2Al(s) + 3Ni^{2+}(aq) \rightarrow 2Al^{3+}(aq) + 3Ni(s)} \quad E^\ominus = 1.89\ \mathrm{V}$

C. $\mathrm{2Al^{3+}(aq) + 3Ni(s) \rightarrow 2Al(s) + 3Ni^{2+}(aq)} \quad E^\ominus = 1.43\ \mathrm{V}$

D. $\mathrm{2Al(s) + 3Ni^{2+}(aq) \rightarrow 2Al^{3+}(aq) + 3Ni(s)} \quad E^\ominus = 1.43\ \mathrm{V}$

Markscheme

D

Examiners report

[N/A]

Consider the following standard electrode potentials.

$\mathrm{Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)} \quad E^\ominus = -0.14\ \mathrm{V}$

$\mathrm{H^+(aq) + e^- \rightleftharpoons \frac{1}{2}H_2(g)} \quad E^\ominus = 0.00\ \mathrm{V}$

$\mathrm{Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)} \quad E^\ominus = +0.77\ \mathrm{V}$

Which species will reduce H^+(aq) to H_2 (g) under standard conditions?

A. Fe^{2+}(aq)

B. Sn^{2+}(aq)

C. Sn(s)

D. Fe^{3+}(aq)

Markscheme

C

Examiners report

60.56% gave the correct answer with the others fairly evenly spread over the three distractors.

What happens during the electrolysis of concentrated aqueous potassium chloride?

I. Reduction takes place at the negative electrode (cathode).

II. Hydrogen gas is evolved at the negative electrode (cathode).

III. The pH of the electrolyte increases.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Markscheme

D

Examiners report

There were four comments on this question, more than the others and, indeed, it was the second most difficult question (just under 46% correct).

This was a tough but fair question. Students have studied the electrolysis of aqueous sodium chloride (19.2.1) so would be expected to transfer that understanding to aqueous potassium chloride. Chlorine gas is produced at the anode but much of this will bubble away as a gas rather than cause acidity to neutralize the hydroxide ions forming around the cathode.

The standard electrode potentials for three reactions involving copper and copper ions are:

$$Cu^{2+}(aq) + e^- \rightleftharpoons Cu^+(aq) \quad E^\ominus = +0.15\ V$$

$$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s) \quad E^\ominus = +0.34\ V$$

$$Cu^+(aq) + e^- \rightleftharpoons Cu(s) \quad E^\ominus = +0.52\ V$$

Which statement is correct?

A. Cu^{2+} ions are a better oxidizing agent than Cu^+ ions.

B. Copper metal is a better reducing agent than Cu^+ ions.

C. Cu^+ ions will spontaneously form copper metal and Cu^{2+} ions in solution.

D. Copper metal can be spontaneously oxidized by Cu^{2+} ions to form Cu^+ ions.

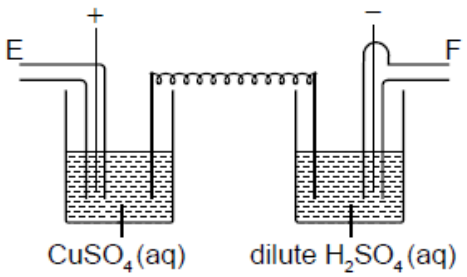
Markscheme

C

Examiners report

Candidates found this question tough – but it was fair, the data was set out in the conventional way and all candidates had to do was to apply the rules they had learnt and the understanding gained. Only 24% gave the correct answer whilst most (36%) chose B.

What are the relative volumes of gas given off at E and F during electrolysis of the two cells in series? Assume all electrodes are inert.



A. 1:1

B. 1:2

C. 2:1

D. 5:2

Markscheme

B

Examiners report

[N/A]

Two half-cells are connected via a salt bridge to make a voltaic cell. Which statement about this cell is correct?

A. Oxidation occurs at the positive electrode (cathode).

B. It is also known as an electrolytic cell.

C. Ions flow through the salt bridge.

D. It requires a power supply to operate.

Markscheme

C

Examiners report

[N/A]

Which signs are correct for a spontaneous redox reaction?

	Standard electrode potential, $E^{\ominus}$	Standard free energy change, $\Delta G^{\ominus}$
A.	+	−
B.	−	+
C.	−	−
D.	+	+

Markscheme

A

Examiners report

[N/A]

An iron rod is electroplated with silver. Which is a correct condition for this process?

A. The silver electrode is the positive electrode.

B. The iron rod is the positive electrode.

C. The electrolyte is iron(II) sulfate.

D. Oxidation occurs at the negative electrode.

Markscheme

A

Examiners report

[N/A]

What is the cell potential, in V, of the reaction below?

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

$\frac{1}{2}S_4O_6^{2-}(aq) + e^- \rightleftharpoons S_2O_3^{2-}(aq) \quad E^\Theta = +0.09\ V$

$I_2(aq) + 2e^- \rightleftharpoons 2I^-(aq) \quad E^\Theta = +0.54\ V$

A. $+0.63$

B. $+0.45$

C. -0.45

D. -0.63

Markscheme

B

Examiners report

[N/A]

What are the products when an aqueous solution of copper(II) sulfate is electrolysed using inert graphite electrodes?

	Cathode (negative electrode)	Anode (positive electrode)
A.	Cu(s)	$H_2(g)$
B.	$O_2(g)$	Cu(s)
C.	Cu(s)	$O_2(g)$
D.	$H_2(g)$	$O_2(g)$

Markscheme

C

Examiners report

[N/A]

What is the cell potential, in V, for the reaction that occurs when the following two half-cells are connected?

$$\mathrm{Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)} \qquad E^\ominus = -0.44\ \mathrm{V}$$
$$\mathrm{Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)} \qquad E^\ominus = +1.33\ \mathrm{V}$$

A. +0.01

B. +0.89

C. +1.77

D. +2.65

Markscheme

C

Examiners report

[N/A]

In the electrolysis of aqueous potassium nitrate, $KNO_3(aq)$, using inert electrodes, 0.1 mol of a gas was formed at the cathode (negative electrode).

Which is correct?

	Gaseous product at anode (positive electrode)	Amount of product at anode / mol
A.	hydrogen	0.05
B.	oxygen	0.05
C.	hydrogen	0.2
D.	oxygen	0.2

Markscheme

B

Examiners report

[N/A]

Consider the standard electrode potentials:

$$\mathrm{Fe}^{2+}(\mathrm{aq}) + 2\mathrm{e}^- \rightleftharpoons \mathrm{Fe(s)}\ E^\ominus = -0.45\ \mathrm{V}$$

$$\frac{1}{2}\mathrm{Cl_2(g)} + \mathrm{e}^- \rightleftharpoons \mathrm{Cl}^-(\mathrm{aq})\ E^\ominus = \ +1.36\ \mathrm{V}$$

What is the standard cell potential, in V, for the reaction?

$$\mathrm{Cl_2(g)} + \mathrm{Fe(s)} \rightarrow 2\mathrm{Cl}^-(\mathrm{aq}) + \mathrm{Fe}^{2+}(\mathrm{aq})$$

A. $+0.91$

B. $+1.81$

C. $+2.27$

D. $+3.17$

Markscheme

B

Examiners report

[N/A]

Which statement is correct for electroplating an object with gold?

A. The object must be the negative electrode (cathode).

B. The negative electrode (cathode) must be gold.

C. The object must be the positive electrode (anode).

D. The gold electrode must be pure.

Markscheme

A

Examiners report

[N/A]

Consider the following standard electrode potentials:

$$\mathrm{Sn}^{4+}(\mathrm{aq}) + 2\mathrm{e}^- \rightleftharpoons \mathrm{Sn}^{2+}(\mathrm{aq}) \quad E^\ominus = +0.13\ \mathrm{V}$$
$$\mathrm{Pb}^{2+}(\mathrm{aq}) + 2\mathrm{e}^- \rightleftharpoons \mathrm{Pb(s)} \quad E^\ominus = -0.13\ \mathrm{V}$$

What is the value of the cell potential, in V, for the spontaneous reaction that occurs when the two half-cells are connected together?

A. -0.26

B. 0.00

C. $+0.13$

D. $+0.26$

Markscheme

D

Examiners report

One respondent stated that it would have been better if the electrode potential half equations had equilibrium signs as in the Data Booklet. It is true that they could have been represented in this way (though not necessarily). This certainly did not have an impact on the question itself. 74.77% of candidates got the correct answer D.

The same quantity of electricity is passed through separate dilute aqueous solutions of sulfuric acid and copper(II) sulfate using platinum electrodes under the same conditions. Which statement is correct?

A. The same volume of oxygen is obtained in both cases.

B. The same volume of hydrogen is obtained in both cases.

C. The amount of copper deposited at the negative electrode in the copper(II) sulfate solution is half the amount of hydrogen gas formed at the negative electrode in the sulfuric acid solution.

D. The pH of both solutions increases as the electrolysis proceeds.

Markscheme

A

Examiners report

The most popular, but wrong, answer was C (42%) showing that candidates had not appreciated the formation of $\mathrm{H_2}$. Many gave answer B but candidates should know that copper is deposited from aqueous solution. It is true that this question requires a lot of thought and it turned out to be the fourth most difficult question on the paper.

Which statement is correct for the overall reaction in a voltaic cell?

$2AgNO_3(aq) + Ni(s) \rightarrow 2Ag(s) + Ni(NO_3)_2(aq) \qquad E^{\theta} = +1.06\ V$

A. Electrons flow from Ag electrode to Ni electrode.

B. Ni is oxidized to Ni^{2+} at the cathode (negative electrode).

C. Ag^{+} is reduced to Ag at the anode (positive electrode).

D. Ag has a more positive standard electrode potential value than Ni.

Markscheme

D

Examiners report

[N/A]

Two electrolytic cells are connected **in series** and the same current passes through each cell. The first cell contains silver electrodes in silver nitrate solution. The second cell contains copper electrodes in copper(II) sulfate solution. In one experiment 1.00 g of silver is deposited in the first cell. What mass of copper, in g, is deposited in the second cell?

A. $\frac{1.00}{107.87}$

B. $\frac{1.00}{63.55}$

C. $\frac{1.00}{107.87} \times \frac{63.55}{2}$

D. $\frac{1.00}{107.87} \times 63.55$

Markscheme

C

Examiners report

One respondent stated that mentioning the fact that the same current passes through each cell may have been better than using the term in series.

This is a fair point. The question overall was reasonably challenging with 53.53% of candidates getting the correct answer, C.

Which components are used to make the standard hydrogen electrode?

A. $\mathrm{H_2(g)}, \mathrm{H^+(aq)}, \mathrm{Pt(s)}$

B. $\mathrm{H_2(g)}, \mathrm{H^+(aq)}, \mathrm{Ni(s)}$

C. $\mathrm{H_2(g)}, \mathrm{HO^-(aq)}, \mathrm{Pt(s)}$

D. $\mathrm{H_2(g)}, \mathrm{HO^-(aq)}, \mathrm{Ni(s)}$

Markscheme

A

Examiners report

[N/A]

A voltaic cell is made by connecting two half-cells represented by the half-equations below.

$$\mathrm{Mn^{2+}(aq) + 2e^- \rightarrow Mn(s)} \quad E^\ominus = -1.19\ \mathrm{V}$$
$$\mathrm{Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)} \quad E^\ominus = -0.13\ \mathrm{V}$$

Which statement is correct about this voltaic cell?

A. Mn is oxidized and the voltage of the cell is 1.06 V.

B. Pb is oxidized and the voltage of the cell is 1.06 V.

C. Mn is oxidized and the voltage of the cell is 1.32 V.

D. Pb is oxidized and the voltage of the cell is 1.32 V.

Markscheme

A

Examiners report

[N/A]

The overall equation of a voltaic cell is:

$$\mathrm{Ni(s) + 2Ag^+(aq) \rightleftharpoons Ni^{2+}(aq) + 2Ag(s)} \quad E^\ominus = 1.06\ \mathrm{V}$$

The standard electrode potential for $\mathrm{Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)}$, is $-0.26\ \mathrm{V}$. What is the standard electrode potential for the silver half-cell, $\mathrm{Ag^+(aq) + e^- \rightleftharpoons Ag(s)}$, in V?

A. -1.32

B. -0.80

C. $+0.80$

D. $+1.32$

Markscheme

C

Examiners report

[N/A]

The same quantity of electricity was passed through separate molten samples of sodium bromide, NaBr, and magnesium chloride, $\mathrm{MgCl_2}$. Which statement is true about the amounts, in mol, that are formed?

A. The amount of Mg formed is equal to the amount of Na formed.

B. The amount of Mg formed is equal to the amount of $\mathrm{Cl_2}$ formed.

C. The amount of Mg formed is twice the amount of $\mathrm{Cl_2}$ formed.

D. The amount of Mg formed is twice the

Markscheme

B

Examiners report

[N/A]

What does **not** affect the mass of products formed in electrolysis of an aqueous solution?

A. Current

B. Duration of electrolysis

C. Initial mass of cathode

D. Charge on the ions

Markscheme

C

Examiners report

[N/A]

Consider the following two standard electrode potentials at 298 K.

$$\mathrm{Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)} \quad E^\ominus = -0.14\ \mathrm{V}$$

$$\mathrm{Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)} \quad E^\ominus = +0.77\ \mathrm{V}$$

What is the equation and cell potential for the spontaneous reaction that occurs?

A. $2Fe^{2+}(aq) + Sn^{2+}(aq) \rightarrow 2Fe^{3+}(aq) + Sn(s) \quad E^{\Theta} = -0.91\ V$

B. $2Fe^{3+}(aq) + Sn(s) \rightarrow 2Fe^{2+}(aq) + Sn^{2+}(aq) \quad E^{\Theta} = +0.91\ V$

C. $2Fe^{2+}(aq) + Sn^{2+}(aq) \rightarrow 2Fe^{3+}(aq) + Sn(s) \quad E^{\Theta} = +0.91\ V$

D. $2Fe^{3+}(aq) + Sn(s) \rightarrow 2Fe^{2+}(aq) + Sn^{2+}(aq) \quad E^{\Theta} = +1.68\ V$

Markscheme

B

Examiners report

[N/A]

For the electrolysis of aqueous copper(II) sulfate, which of the following statements is correct?

A. Cu and O_2 are produced in a mol ratio of 1:1

B. H_2 and O_2 are produced in a mol ratio of 1:1

C. Cu and O_2 are produced in a mol ratio of 2:1

D. H_2 and O_2 are produced in a mol ratio of 2:1

Markscheme

C

Examiners report

There were three G2 comments on this particular question, all of which suggested that the question was ambiguous as the nature of the electrodes was not stated for the electrolysis of aqueous copper(II) sulphate. Also noting the fact that candidates do not have access to a Data Booklet for P1. As regards the first point, it is a valid comment that the nature of electrodes could have been specified in the question itself.

However, on close examination of each of the first choices, it should be obvious to the candidate that inert electrodes were used as O_2 is given as a product in all four cases. This would not be the case if copper electrodes were used. As regards the second point, it is also a fair comment that in the case of the electrolysis of aqueous copper(II) sulfate, candidates can work out the specific products using the standard electrode potentials from Table 14. of the Data Booklet. However, to do so, this would have made this question a clear Objective 3 type question which is outside the realm of P1. This was discussed at length at GA and it was felt that, realistically, candidates should have seen this electrolysis in the laboratory and, hence, as regards this particular electrolysis process candidates should have been able to determine the correct mol ratio of 2:1 for Cu:O_2 . Although the question was, in fact, the hardest question on the entire paper, 43% of candidates did get the correct answer, C. Yet again this should emphasise the inherent importance of laboratory work as an integral part of the overall IB Diploma Chemistry programme.

What are the products of electrolysis when concentrated calcium bromide solution is electrolysed using graphite electrodes?

	Product at cathode (negative electrode)	Product at anode (positive electrode)
A.	hydrogen	bromine
B.	calcium	oxygen
C.	calcium	bromine
D.	hydrogen	oxygen

Markscheme

A

Examiners report

[N/A]