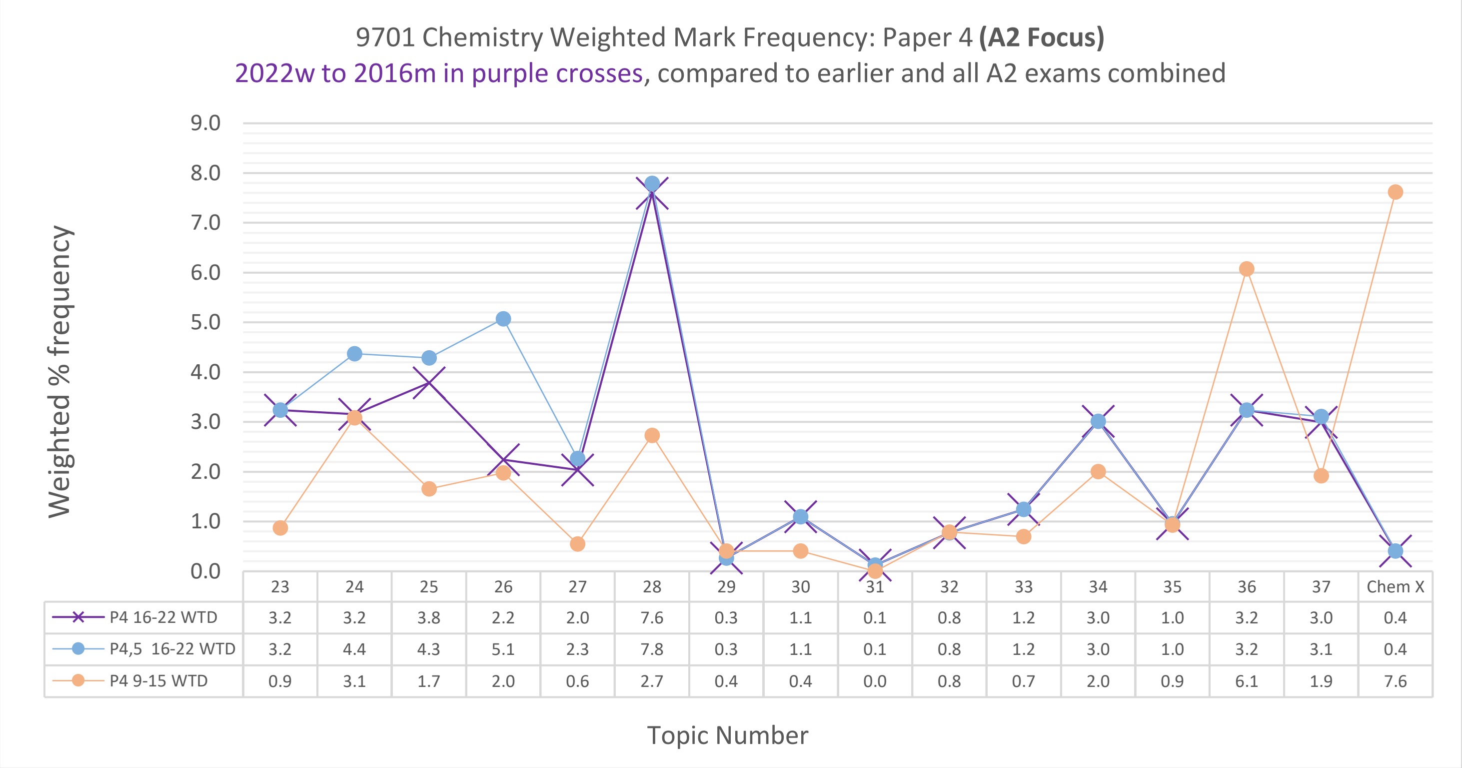
Name: Class: Date:

A Level Chem 24 EQ 22m to 09w **Paper 4** Electrochemistry 261marks

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 4 Topic Checklist Tick each task off as you go along	RANK: Marks	P4 Noob 1 Q Started	P4 Novice 1 Q done	P4 Bronze 10% of marks	P4 Silver 25% of marks	P4 Gold 40% of marks	**P4[1] Winner** 50% of marks	**P4 Hero** 75% of marks	**P4 Legend** 100% of marks
Topic 24 (marks)	261		8	26	65	104	131	196	261
Time - 72 seconds per mark (minutes)	318		9	32	79	127	159	238	318


9701 Chemistry Weighted Mark Frequency: Paper 4 **(A2 Focus)**
2022w to 2016m in purple crosses, compared to earlier and all A2 exams combined

	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	Chem X
P4 16-22 WTD	3.2	3.2	3.8	2.2	2.0	7.6	0.3	1.1	0.1	0.8	1.2	3.0	1.0	3.2	3.0	0.4
P4,5 16-22 WTD	3.2	4.4	4.3	5.1	2.3	7.8	0.3	1.1	0.1	0.8	1.2	3.0	1.0	3.2	3.1	0.4
P4 9-15 WTD	0.9	3.1	1.7	2.0	0.6	2.7	0.4	0.4	0.0	0.8	0.7	2.0	0.9	6.1	1.9	7.6

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 "Silver" (25%) in the same topic in Paper 5, if it exists.

24 Electrochemistry

24.1 Electrolysis

Learning outcomes

Candidates should be able to:

1. predict the identities of substances liberated during electrolysis from the state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration
2. state and apply the relationship $F = Le$ between the Faraday constant, F, the Avogadro constant, L, and the charge on the electron, e
3. calculate:
   - (a) the quantity of charge passed during electrolysis, using $Q = It$
   - (b) the mass and/or volume of substance liberated during electrolysis
4. describe the determination of a value of the Avogadro constant by an electrolytic method

24.2 Standard electrode potentials $E^{\ominus}$; standard cell potentials $E^{\ominus}_{cell}$ and the Nernst equation

Learning outcomes

Candidates should be able to:

1. define the terms:
   - (a) standard electrode (reduction) potential
   - (b) standard cell potential
2. describe the standard hydrogen electrode
3. describe methods used to measure the standard electrode potentials of:
   - (a) metals or non-metals in contact with their ions in aqueous solution
   - (b) ions of the same element in different oxidation states
4. calculate a standard cell potential by combining two standard electrode potentials
5. use standard cell potentials to:
   - (a) deduce the polarity of each electrode and hence explain/deduce the direction of electron flow in the external circuit of a simple cell
   - (b) predict the feasibility of a reaction
6. deduce from $E^{\ominus}$ values the relative reactivity of elements, compounds and ions as oxidising agents or as reducing agents
7. construct redox equations using the relevant half-equations

24.2 Standard electrode potentials $E^{\ominus}$; standard cell potentials $E^{\ominus}_{cell}$ and the Nernst equation (continued)

Learning outcomes

Candidates should be able to:

8. predict qualitatively how the value of an electrode potential, E, varies with the concentrations of the aqueous ions
9. use the Nernst equation, e.g. $E = E^{\ominus} + (0.059/z) \log \frac{[\text{oxidised species}]}{[\text{reduced species}]}$

   to predict quantitatively how the value of an electrode potential varies with the concentrations of the aqueous ions; examples include $Cu^{2+}(aq) + 2e^{-} \rightleftharpoons Cu(s)$, $Fe^{3+}(aq) + e^{-} \rightleftharpoons Fe^{2+}(aq)$
10. understand and use the equation $\Delta G^{\ominus} = -nE^{\ominus}_{cell}F$

Q# 1/ ALvl Chemistry/2022/m/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 Titanium is a transition element in Period 4. It is commonly found as TiO_2 in minerals.

(c) Acidified $Ti^{3+}(aq)$ reacts with oxygen dissolved in water as shown.

$$4Ti^{3+} + O_2 + 2H_2O \rightarrow 4TiO^{2+} + 4H^+ \qquad \Delta G^{\circ} = -436.1\,kJ\,mol^{-1}$$

The standard reduction potential, E°, of $O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$ is +1.23 V.

(i) Calculate the standard reduction potential, E°, in V, of the $TiO^{2+}(aq)/Ti^{3+}(aq)$ half-cell.
Show your working.

E° = ... V [3]

Q# 2/ ALvl Chemistry/2022/m/TZ 1/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 Silicon is the second most abundant element by mass in the Earth's crust.

(c) Silicon can also be produced by electrolysis of SiO_2 dissolved in molten $CaCl_2$.
The relevant half-equation for the cathode is shown.

$$SiO_2 + 4e^- \rightarrow Si + 2O^{2-}$$

Calculate the time, in seconds, required to produce 1.00 g of Si by this electrolysis, using a current of 6.00 A.
Assume no other substances are produced at the cathode.

time = ... s [2]

[Total: 9]

Q# 3/ ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

(b) **(i)** Define the term *standard cell potential*, E°_{cell}.

....

....

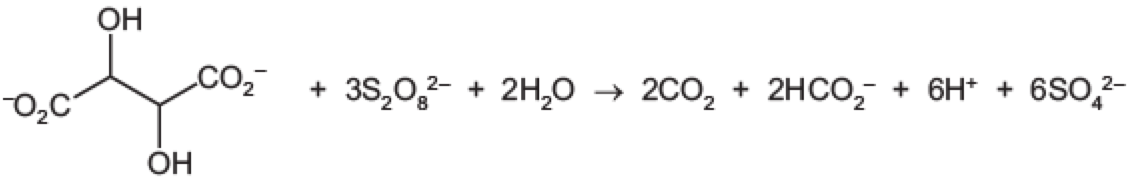
.... [2]

(ii) Draw a fully labelled diagram of the apparatus that can be used to measure the cell potential of a cell composed of a Cu(II)/Cu electrode and an Fe(III)/Fe(II) electrode. Include all necessary reactants.

[3]

(d) When aqueous solutions of $S_2O_8^{2-}$ and tartrate ions are mixed the reaction proceeds very slowly. However, this reaction proceeds quickly in the presence of an Fe^{3+}(aq) catalyst.
The overall equation for this reaction is shown.

tartrate ions



$$+ 3S_2O_8^{2-} + 2H_2O \rightarrow 2CO_2 + 2HCO_2^- + 6H^+ + 6SO_4^{2-}$$

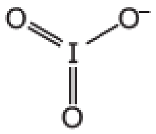
(ii) Use the overall equation to deduce the half-equation for the oxidation of tartrate ions, $C_4H_4O_6^{2-}$, to carbon dioxide, CO_2, and methanoate ions, HCO_2^-.

$C_4H_4O_6^{2-}$ + ... $\rightleftharpoons$ .... [1]

Q# 4/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 Iodates are compounds that contain the IO_3^- anion.

(a) The IO_3^- anion is shown.



(c) The decomposition of hydrogen peroxide, H_2O_2, is catalysed by acidified IO_3^-.

H_2O_2 reduces acidified IO_3^- as shown.

$$5H_2O_2 + 2H^+ + 2IO_3^- \rightarrow I_2 + 5O_2 + 6H_2O$$

This reaction is followed by the oxidation of I_2 by H_2O_2.

half-equation	$E^\ominus$/V
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.77
$IO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}I_2 + 3H_2O$	+1.19
$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	+0.68

(i) Use the data to show that the separate reactions of H_2O_2 with IO_3^- and with I_2 are both feasible under standard conditions.

In your answer, give the equation for the reaction of H_2O_2 with I_2.

....

....

....

....

....

.... [3]

(ii) Write the overall equation for the decomposition of H_2O_2 catalysed by acidified IO_3^-.

.... [1]

Q# 5/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 **(a)** Iron(II) compounds are generally only stable in neutral, non-oxidising conditions.

It is difficult to determine the lattice energy of FeO experimentally.

(b) Heating of FeO results in the formation of Fe_3O_4, as shown.

reaction 1 $4FeO \rightarrow Fe + Fe_3O_4$

Each formula unit of Fe_3O_4 contains one Fe^{2+} and two Fe^{3+} ions.

(i) Show how reaction 1 can be described as a disproportionation reaction.

....

....

.... [1]

Fe_3O_4(l) can be electrolysed using inert electrodes to form Fe.

(ii) Write the half-equation for the reaction that occurs at the anode during the electrolysis of Fe_3O_4(l).

.... [1]

(iii) Calculate the maximum mass of iron metal formed when Fe_3O_4(l) is electrolysed for six hours using a current of 50 A.

Assume the one Fe^{2+} and two Fe^{3+} ions are discharged at the same rate.

mass of iron = ... g [3]

(c) $LiFePO_4$ can be used in lithium-ion rechargeable batteries.

When the cell is charging, lithium reacts with a graphite electrode to form LiC_6.

When the cell is discharging, the half-equations for the two processes that occur are as follows.

anode half-equation $LiC_6 \rightarrow 6C + Li^+ + e^-$

cathode half-equation $Li^+ + FePO_4 + e^- \rightarrow LiFePO_4$

(i) State one possible advantage of developing cells such as lithium-ion rechargeable batteries.

.... [1]

(ii) Use the cathode half-equation to determine the change, if any, in oxidation states of lithium and iron at the **cathode** during discharging.

metal	change in oxidation state during discharging	
	from	to
lithium		
iron		

[1]

(iii) Write the equation for the overall reaction that occurs when this cell is discharging.

.... [1]

Q# 6/ ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 **(a)** Identify the substances liberated at the anode and at the cathode during the electrolysis of aqueous sodium sulfate, $Na_2SO_4(aq)$.

anode ....

cathode ....
[1]

(b) When molten sodium chloride is electrolysed, chlorine is liberated at the anode and sodium is liberated at the cathode.

A sample of molten sodium chloride is electrolysed for 1.50 hours using a current of 4.50A.

Calculate the volume of chlorine and the mass of sodium that are liberated under room conditions.

volume of chlorine = ... dm^3

mass of sodium = ... g
[4]

(c) The equation representing the standard electrode potential, $E^\ominus$, for the reduction of $MnO_4^-(aq)$ to $Mn^{2+}(aq)$ in acid solution is given.

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l) \qquad E^\ominus = +1.52\,V$$

(i) Draw a diagram of the apparatus that would be used to measure the $E^\ominus$ value of this half-cell. Your diagram should be fully labelled to identify all apparatus, substances and conditions.

[4]

(ii) Use the *Data Booklet* to identify a substance that could be used to oxidise Mn^{2+} ions to MnO_4^- ions under standard conditions.

Write an equation for the reaction.

....

....

.... [2]

[Total: 11]

Q# 7/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 9 /www.SmashingScience.org :o)

9 **(a)** Manganese(IV) oxide, MnO_2, catalyses the decomposition of hydrogen peroxide, H_2O_2, as shown.

$$2H_2O_2(aq) \xrightarrow{MnO_2} 2H_2O(l) + O_2(g)$$

The mechanism involves the formation of the intermediate species, Mn^{2+}, in the first step which is subsequently used up in the second step.

State and use relevant electrode potentials, $E^⦵$, to construct **two** equations to show how MnO_2 can catalyse this reaction.

....

....

....

....

....

equation 1 ....

equation 2 ....

[3]

Q# 8/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 The overall reaction for photosynthesis is shown.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Water is oxidised in this process according to the following half-equation.

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \qquad \text{half-equation 1}$$

(a) **(i)** Use these equations to deduce the half-equation for the reduction of carbon dioxide in this process.

[2]

(ii) Draw a fully labelled diagram of the apparatus that should be used to measure the standard electrode potential, $E^\ominus$, of $O_2(g)$ in half-equation 1 under standard conditions. Include all necessary chemicals.

[4]

(iii) For the cell drawn in **(a)(ii)**, use the *Data Booklet* to calculate the $E^\ominus_{cell}$ and deduce which electrode is positive.

$E^\ominus_{cell}$ = ... V

identity of the positive electrode = ...

[1]

Q# 9/ ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 Gold is an unreactive metal that can only be oxidised under specific conditions.

(a) The standard electrode potential, $E^\ominus$, of $Au^{3+}(aq)/Au(s)$ is +1.50 V.

(i) Define the term *standard electrode potential*.

....

....

.... [2]

(ii) Draw a fully labelled diagram of the apparatus that should be used to measure the standard cell potential, $E^{\ominus}_{\text{cell}}$, of Au^{3+}(aq)/Au(s) and HNO_3(aq)/NO(g).

Include all necessary chemicals.

[4]

Some relevant half-equations and their standard electrode potentials are given.

	half-equation	$E^{\ominus}$/V
1	$Au^{3+}(aq) + 3e^- \rightleftharpoons Au(s)$	+1.50
2	$[AuCl_4]^-(aq) + 3e^- \rightleftharpoons Au(s) + 4Cl^-(aq)$	+1.00
3	$NO_3^-(aq) + 4H^+(aq) + 3e^- \rightleftharpoons NO(g) + 2H_2O(l)$	+0.96

(iii) Write an ionic equation to show the spontaneous reaction that occurs when an electric current is drawn from the cell in **(a)(ii)**.

.... [1]

(iv) Calculate the $E^\ominus_{cell}$ of the reaction in **(a)(iii)**.

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

(v) Gold can be oxidised by a mixture of concentrated hydrochloric acid and concentrated nitric acid, known as *aqua regia*. Concentrated hydrochloric acid is 12 mol dm^{-3}. Concentrated nitric acid is 16 mol dm^{-3}.

Explain why *aqua regia* is able to dissolve gold.

In your answer, state and explain what effect the use of concentrated hydrochloric acid and concentrated nitric acid have on the *E* values of half-equations 2 and 3.

....

....

....

....

....

.... [3]

Q# 10/ ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 **(a)** Group 2 metals form stable carbonates and sulfates.

(b) Aluminium is extracted from Al_2O_3 by electrolysis. Al_2O_3 is dissolved in cryolite in this process.

(i) The half-equation for the reaction at the anode is shown.

$$O^{2-} + C \rightarrow CO + 2e^-$$

Use this half-equation to write the ionic equation for the electrolysis of Al_2O_3.

.... [1]

(ii) Aluminium oxide is electrolysed for 3.0 hours using carbon electrodes and a current of 3.5×10^5 A.

Calculate the mass of aluminium that is formed.

mass of aluminium = ... g [3]

Q# 11/ ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1 An electrochemical cell is constructed using two half-cells.

- an Sn^{4+}/Sn^{2+} half-cell
- an Al^{3+}/Al half-cell

(a) State the material used for the electrode in each half-cell.

- Sn^{4+}/Sn^{2+} half-cell ....
- Al^{3+}/Al half-cell .... [1]

(b) The cell is operated at 298 K.

The Al^{3+}/Al half-cell has standard concentrations.

The Sn^{4+}/Sn^{2+} half-cell has $[Sn^{4+}] = 0.300\,mol\,dm^{-3}$ and $[Sn^{2+}] = 0.150\,mol\,dm^{-3}$.

(i) Use the Nernst equation to calculate the electrode potential, E, of the Sn^{4+}/Sn^{2+} half-cell under these conditions.

E = ... V [2]

(ii) Calculate the E_{cell} under these conditions.

E_{cell} = ... V [1]

(iii) Write an equation for the overall cell reaction that occurs.

.... [2]

(c) Aluminium is produced industrially by electrolysis of a melt containing large amounts of Al^{3+} ions.

Calculate the mass of aluminium that is obtained when a current of 300 000 A is passed for 24 hours. Give your answer to **three** significant figures.

mass = ... units = ...

[4]

(d) Explain why chromium metal cannot be obtained by the electrolysis of dilute aqueous chromium(II) sulfate. Your answer should include data from the *Data Booklet*.

....

....

....

.... [2]

Q# 12/ ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 Chlorate(V) ions are powerful oxidising agents.

(a) The reduction of chlorate(V) ions, ClO_3^-, with SO_2 forms chlorine dioxide, ClO_2, and sulfate ions, SO_4^{2-}, as the only products.

Construct an equation for this reaction.

.... [1]

(b) **(i)** Chlorine dioxide, ClO_2, disproportionates with hydroxide ions, $OH^-(aq)$, to form a mixture of ClO_2^- and ClO_3^- ions.

$$2ClO_2 + 2OH^- \rightarrow ClO_2^- + ClO_3^- + H_2O$$

Explain, using this reaction as an example, what is meant by *disproportionation*.

....

.... [1]

(ii) Deduce the ionic half-equations for the reaction in **(b)(i)**.

....

.... [2]

(c) A lithium-iodine electrochemical cell can be used to generate electricity for a heart pacemaker. The cell consists of a lithium electrode and an inert electrode immersed in body fluids. When current flows lithium is oxidised and iodine is reduced.

(i) Use the *Data Booklet* to write half-equations for the reactions taking place at the two electrodes. Hence write the overall equation for when a current flows.

- ....
- ....

overall equation ....

[2]

(ii) Use the *Data Booklet* to calculate the $E^\ominus_{cell}$ for this cell.

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

(iii) A current of 2.5×10^{-5} A is drawn from this cell.

Calculate the time taken for 0.10 g of lithium electrode to be used up. Assume the current remains constant throughout this period.

time = ... s [3]

Q# 13/ ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 8 /www.SmashingScience.org :o)

(e) In a methanol-oxygen fuel cell, $CH_3OH(l)$ and $O_2(g)$ are in contact with two inert electrodes immersed in an acidic solution.

The half-equation for the reaction at the methanol electrode is shown.

$$CH_3OH + H_2O \rightleftharpoons CO_2 + 6H^+ + 6e^- \qquad E^{\ominus} = -0.02\,V$$

(i) Use the *Data Booklet* to write an equation for the overall cell reaction.

....

....

.... [1]

(ii) Use $E^{\ominus}$ values to calculate the $E^{\ominus}_{cell}$ for this reaction.

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

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

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

[3]

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

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

- ....
- ....

[2]

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

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

....

....

.... [2]

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

1 ....

2 ....

[1]

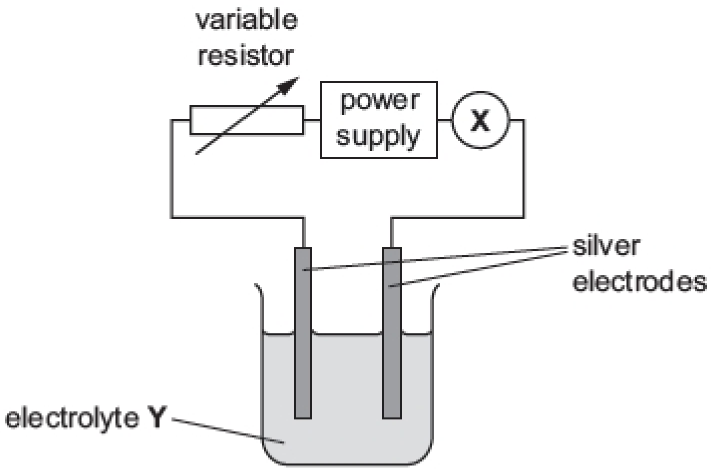
(c) An oxide of iron dissolved in an inert solvent is electrolysed for 2.00 hours using a current of 0.800A. The electrolysis products are iron and oxygen. The mass of iron produced is 1.11 g.

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

oxidation number of Fe = ... [3]

Q# 15/ ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 6 /www.SmashingScience.org :o)

6 The apparatus shows a cell which can be used to determine a value of the Avogadro constant, L.



(a) **(i)** Name component **X**.

.... [1]

(ii) Suggest a suitable electrolyte **Y**.

.... [1]

(b) In an experiment, a current of 0.200A was passed through the cell for 40.0 minutes. The mass of the silver cathode increased by 0.500g.

The charge on the electron is -1.60×10^{-19}C.

Calculate the:

- number of moles of silver deposited on the cathode
- number of coulombs of charge passed
- number of electrons passed
- number of electrons needed to deposit 1mol of silver at the cathode.

[3]

[Total: 5]

2 **(a)** Describe the trend in the reactivity of the halogens Cl_2, Br_2 and I_2 as oxidising agents. Explain this trend using values of $E^{\ominus}$ (X_2/X^-) from the *Data Booklet*.

....

....

....

....

.... [2]

(b) **(i)** Write an equation for the reaction between chlorine and water.

.... [1]

(ii) Use standard electrode potential, $E^{\ominus}$, data from the *Data Booklet* to calculate the $E^{\ominus}_{\text{cell}}$ for the following reaction.

$$Cl_2 + 2OH^- \rightleftharpoons Cl^- + ClO^- + H_2O$$

$E^{\ominus}_{\text{cell}}$ = ... V [2]

(iii) The [OH^-] was increased and the E_{cell} was measured.

Indicate how the value of the E_{cell} measured would compare to the $E^{\ominus}_{\text{cell}}$ calculated in **(ii)** by placing **one** tick (✓) in the table.

E_{cell} becomes less positive than $E^{\ominus}_{\text{cell}}$.	
E_{cell} stays the same as $E^{\ominus}_{\text{cell}}$.	
E_{cell} becomes more positive than $E^{\ominus}_{\text{cell}}$.	

Explain your answer.

....

....

....

[2]

(c) A half-equation involving bromate(V) ions, BrO_3^-, and bromide ions is shown.

$$BrO_3^-(aq) + 3H_2O(l) + 6e^- \rightleftharpoons Br^-(aq) + 6OH^-(aq) \qquad E^\ominus = +0.58\,V$$

(i) An alkaline solution of chlorate(I), ClO^-, can be used to oxidise bromide ions to bromate(V) ions.

Use the *Data Booklet* and the half-equation shown to write an equation for this reaction.

.... [1]

(ii) Calculate the $E^\ominus_{cell}$ for the reaction in **(i)**.

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

(iii) When a concentrated solution of bromic(V) acid, $HBrO_3$, is warmed, it decomposes to form bromine, oxygen and water only.

Write an equation for this reaction. The use of oxidation numbers may be helpful.

.... [1]

[Total: 10]

Q# 17/ ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 **(a)** Define the term *standard cell potential*.

....

....

.... [2]

(b) **(i)** Draw a fully labelled diagram of the experimental set-up you could use to measure the standard electrode potential of the $Pb^{2+}(aq)/Pb(s)$ electrode. Include the necessary chemicals.

[4]

(ii) The $E^\ominus$ for a $Pb^{2+}(aq)/Pb(s)$ electrode is –0.13 V.

Suggest how the E for this electrode would differ from its $E^\ominus$ value if the concentration of $Pb^{2+}(aq)$ ions is reduced. Indicate this by placing a tick (✓) in the appropriate box in the table.

more negative	no change	less negative

Explain your answer.

....

....

.... [2]

(c) Car batteries are made up of rechargeable lead-acid cells. Each cell consists of a negative electrode made of Pb metal and a positive electrode made of PbO_2. The electrolyte is $H_2SO_4(aq)$.

When a lead-acid cell is in use, Pb^{2+} ions are precipitated out as $PbSO_4(s)$ at the negative electrode.

$$Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$$

(i) Calculate the mass of Pb that is converted to $PbSO_4$ when a current of 0.40 A is delivered by the cell for 80 minutes.

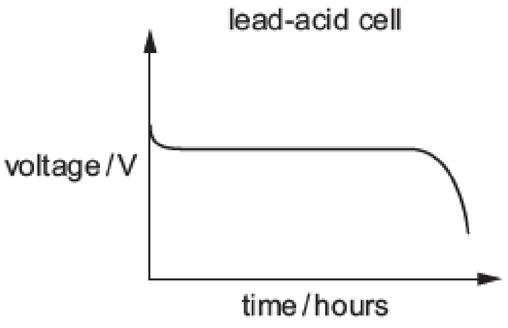
mass of Pb = ... g [2]

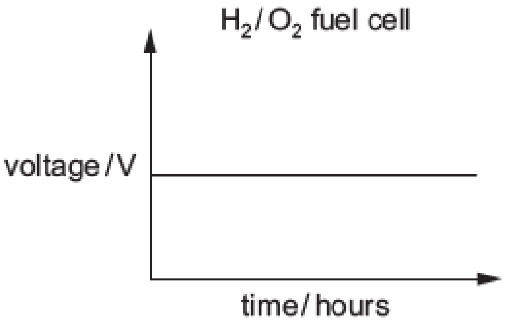
(ii) Complete the half-equation for the reaction taking place at the positive electrode.

$PbO_2(s) + SO_4^{2-}(aq) +$ .... + ... $\rightarrow PbSO_4(s) +$ ....

[1]

(d) The diagrams show how the voltage across two different cells changes with time when each cell is used to provide an electric current.





Suggest a reason why

- the voltage of the lead-acid cell changes after several hours,

....

....

- the voltage of the fuel cell remains constant.

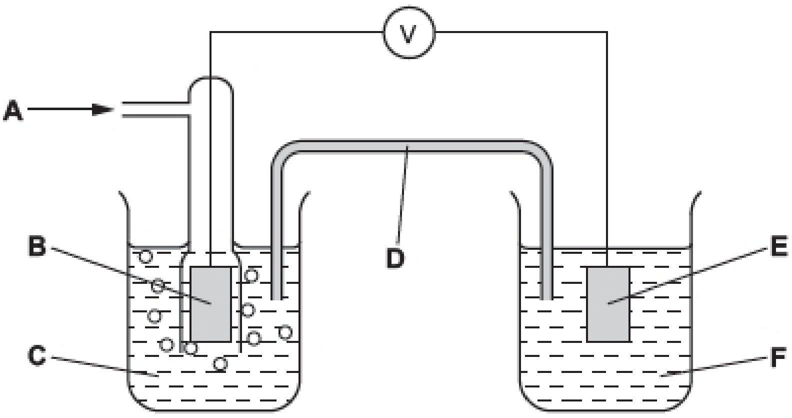
....

....

[2]

Q# 18/ ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 **(a)** The diagram shows the apparatus used to measure the standard electrode potential, $E^{\ominus}$, of $Fe^{3+}(aq)/Fe^{2+}(aq)$.



(i) Identify what the letters **A** to **F** represent.

A .... **D** ....

B .... **E** ....

C .... **F** ....

[3]

(ii) Label the diagram to show

- which is the positive electrode,
- the direction of electron flow in the external circuit.

Use the *Data Booklet* to help you.

[1]

(b) In another experiment, an $Fe^{3+}(aq)/Fe^{2+}(aq)$ half-cell was connected to a $Cu^{2+}(aq)/Cu(s)$ half-cell.

Determine the standard cell potential, $E^{\ominus}_{cell}$, when these two half-cells are connected by a wire and the circuit is completed.
Use the *Data Booklet* to help you.

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

(c) **(i)** The $E^{\ominus}$ of $Ni^{2+}(aq)/Ni(s)$ is –0.25 V.

State and explain how the electrode potential changes if the concentration of $Ni^{2+}(aq)$ is decreased.

....

....

.... [1]

(ii) The $E^{\ominus}$ of $Cr^{3+}(aq)/Cr^{2+}(aq)$ is –0.41 V.

Calculate the electrode potential when $[Cr^{3+}(aq)]$ is 0.60 mol dm^{-3} and $[Cr^{2+}(aq)]$ is 0.15 mol dm^{-3}. Use the Nernst equation.

$$E = E^{\ominus} + \frac{0.059}{z} \log \frac{[\text{oxidised species}]}{[\text{reduced species}]}$$

E = ... V [2]

Q# 19/ ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 4 /www.SmashingScience.org :o)

4 **(a)** Cobalt is a transition element that forms complex ions with oxidation states +2 and +3.

(c) Define the term *standard electrode potential*.

....

....

.... [2]

(d) An electrochemical cell was set up to measure the standard electrode potential, $E^{\ominus}_{cell}$, of a cell made of a Co^{2+}/Co half-cell and a Fe^{3+}/Fe^{2+} half-cell.

(i) Complete the table with the substance used to make the electrode in each of these half-cells.

half-cell	electrode
Co^{2+}/Co	
Fe^{3+}/Fe^{2+}	

[1]

(ii) Write the equation for the overall cell reaction.

.... [1]

(iii) Use the *Data Booklet* to calculate the $E^{\ominus}_{cell}$.

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

(e) The electrochemical cell in **(d)** was set up again but this time the concentration of $Co^{2+}(aq)$ was $0.050\,mol\,dm^{-3}$.

The Nernst equation can be used to calculate the value of an electrode potential at different concentrations.

$$E = E^{\ominus} + (0.059/z)\log[Co^{2+}(aq)] \qquad \text{Nernst equation}$$

(i) Use the *Data Booklet* and the Nernst equation to calculate the value of *E* for the Co^{2+}/Co half-cell in this experiment.

E for Co^{2+}/Co = ... V [1]

(ii) Suggest how this change will affect the overall cell potential, E_{cell}, compared to $E^\ominus_{cell}$ in **(d)(iii)**.
Circle your answer.

less positive   no change   more positive

[1]

(f) Iron(III) ions can oxidise vanadium metal.

Construct an equation for the reaction of an excess of iron(III) ions with vanadium metal.
Use of the *Data Booklet* will be helpful.

.... [2]

Q# 20/ ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 4 /www.SmashingScience.org :o)

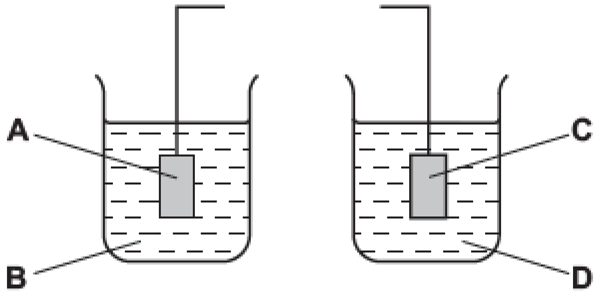
4 (a) (i) Define the term *standard cell potential*, $E^\ominus_{cell}$.

....

....

.... [1]

The following incomplete diagram shows the apparatus that can be used to measure the $E^\ominus_{cell}$ for a cell composed of the Fe^{3+}/Fe^{2+} and Ag^{+}/Ag half-cells.



(ii) Complete the diagram, labelling the components you add. [1]

(iii) Identify the components **A**-**D**.

A ....

B ....

C ....

D ....

[3]

(b) (i) Use $E^\ominus$ values to write an equation for the cell reaction that takes place if the two electrodes in **(a)** are connected by a wire and the circuit is completed.

....

.... [1]

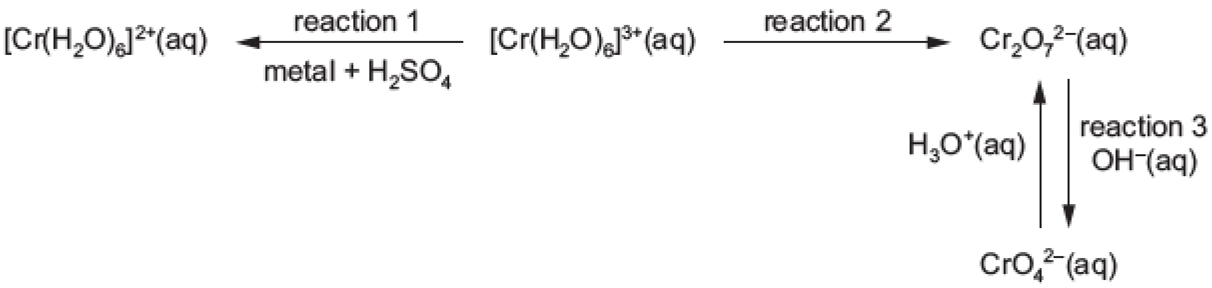
(ii) Another electrochemical cell was set up using 0.31 mol dm^{-3} $Ag^+(aq)$ instead of the standard Ag solution.

Use the Nernst equation, $E = E^\ominus + 0.059\log[Ag^+(aq)]$, and the relevant $E^\ominus$ values to calculate the new E_{cell} in this experiment.

E_{cell} = ... V [2]

Q# 21/ ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 5 /www.SmashingScience.org :o)

5 Some reactions of chromium ions are shown below.



(a) **(i)** Use the *Data Booklet* to suggest a suitable metal to carry out reaction 1.

.... [1]

(ii) Use $E^\ominus$ values to explain your answer to **(i)** by calculating the $E^\ominus_{cell}$.

....

....

.... [2]

(b) A student suggested that reaction 2 could be carried out using acidified hydrogen peroxide solution.

Use the *Data Booklet* to show whether or not this reaction is feasible.

....

....

.... [2]

(c) Explain using oxidation numbers whether or not reaction 3 is a redox reaction.

....

....

.... [2]

(d) The student used an acidified solution of $Cr_2O_7^{2-}(aq)$ to electroplate a steel box with chromium metal.

Calculate how long it would take for a current of 0.125A to deposit 0.0312g of chromium metal.

time = ... [3]

[Total: 10]

Q# 22/ ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 5 /www.SmashingScience.org :o)

5 **X** is a metallic element.

(a) **(i)** Draw a fully labelled diagram to show how the standard electrode potential, $E^\ominus$, of $\mathbf{X}^{2+}(aq)/\mathbf{X}(s)$ could be measured.

[4]

(ii) What are the conditions needed for the value measured to be a **standard** electrode potential?

.... [1]

(iii) State the charge carriers that transfer current through

the solutions, ... the wire. .... [1]

(b) An electrochemical cell was set up consisting of an **X**$^{2+}$(aq)/**X**(s) half-cell ($E^\ominus = -0.40\,V$) and an Ag^+(aq)/Ag(s) half-cell ($E^\ominus = +0.80\,V$).

(i) Write an equation for the reaction that would take place if the electrodes of this cell were connected by a wire.

.... [1]

When the current was allowed to pass for a period of time,

- the Ag electrode gained 1.30 g in mass,
- the electrode made of metal **X** lost 0.67 g in mass.

(ii) Calculate the A_r of metal **X**; hence suggest an identity for **X**.
Show all your working. Use of the *Data Booklet* is relevant to this question.

A_r = ...

X is ....

[4]

[Total: 11]

Q# 23/ ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 5 /www.SmashingScience.org :o)

(e) **(i)** State the relationship between the Faraday constant and the Avogadro constant.

.... [1]

(ii) When a current of 1.2A was passed through dilute sulfuric acid for 30 minutes, it was found that 130 cm^3 of oxygen, measured at 25 °C and 1 atm, was collected at the anode. The following reaction takes place.

$$2H_2O(l) \rightarrow 4H^+(aq) + O_2(g) + 4e^-$$

Use these data and data from the *Data Booklet* to calculate a value for the Avogadro constant, *L*, by calculating

- the number of moles of oxygen produced,
- the number of moles of electrons needed for this,
- the number of coulombs passed,
- the number of electrons passed,
- the number of electrons in one mole of electrons (*L*).

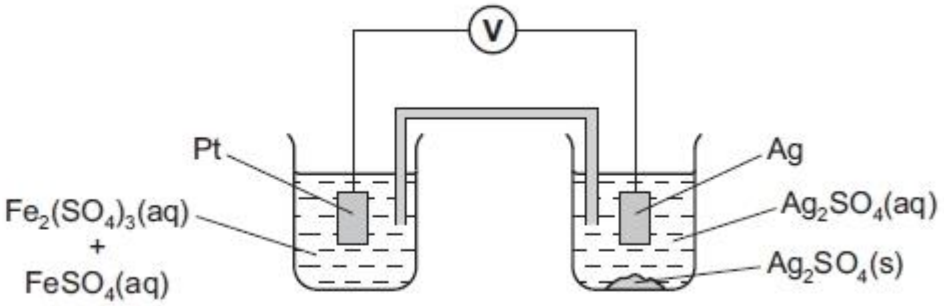
L = ... mol^{-1}
[4]

[Total: 15]

Q# 24/ ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 4 /www.SmashingScience.org :o)

4 **(a)** Silver sulfate, Ag_2SO_4, is sparingly soluble in water. The concentration of its saturated solution is $2.5 \times 10^{-2}\,mol\,dm^{-3}$ at 298 K.

(c) An electrochemical cell is set up as follows.



(i) Use the *Data Booklet* to calculate the value of $E^{\ominus}_{cell}$ under standard conditions, stating which electrode is the positive one.

$E^{\ominus}_{cell}$ = ... positive electrode: .... [1]

(ii) How would the actual E_{cell} of the above cell compare to the $E^{\ominus}_{cell}$ under standard conditions? Explain your answer.

....

.... [1]

(iii) How would the E_{cell} of the above cell change, if at all, if a few cm^3 of concentrated $Na_2SO_4(aq)$ were added to

- the beaker containing $Fe^{3+}(aq) + Fe^{2+}(aq)$,

....

- the beaker containing $Ag_2SO_4(aq)$?

....

[2]

(iv) Explain any changes in E_{cell} you have stated in **(iii)**.

....

.... [1]

Q# 25/ ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(c) **(i)** Use $E^{\ominus}$ values from the *Data Booklet* to predict the relative oxidising abilities of fluorine and chlorine.

....

....

.... [2]

(ii) Predict the *type of reaction* that would occur between the interhalogen compound chlorine fluoride, ClF, and potassium bromide solution.

.... [1]

(iii) Construct an equation for this reaction.

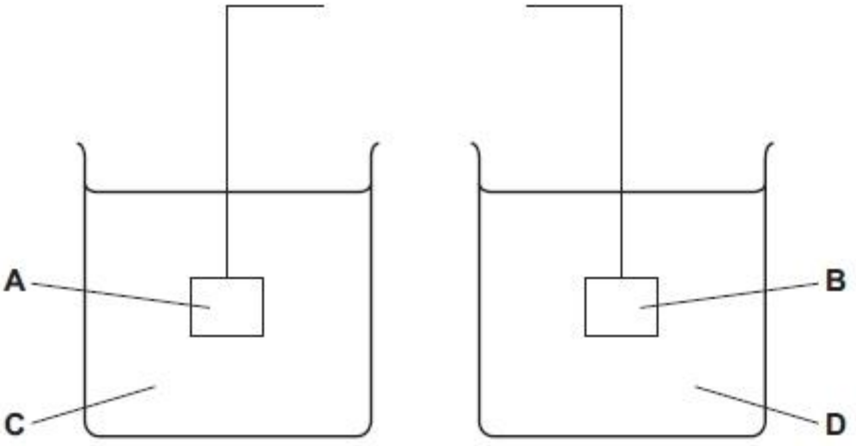
.... [1]

[Total: 8]

Q# 26/ ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(b) The following diagram shows the apparatus used to measure the standard electrode potential, $E^{\ominus}$, of a cell composed of a Cu(II)/Cu electrode and an Fe(II)/Fe electrode.

(i) Finish the diagram by adding components to show the complete circuit. Label the components you add.



(ii) In the spaces below, identify or describe what the four letters **A**-**D** represent.

A ....

B ....

C ....

D ....

(iii) Use the *Data Booklet* to calculate the $E^{\ominus}$ for this cell.

....

(iv) Predict how the size of the overall cell potential would change, if at all, as the concentration of solution **C** is increased.
Explain your reasoning.

....

....

....

[8]

Section A

Answer **all** the questions in the spaces provided.

1 **(a)** What is meant by the term *standard electrode potential*, SEP?

....

.... [2]

(b) Draw a fully labelled diagram of the apparatus you could use to measure the SEP of the Fe^{3+}/Fe^{2+} electrode.

[5]

(c) The reaction between Fe^{3+} ions and I^- ions is an equilibrium reaction.

$$2Fe^{3+}(aq) + 2I^-(aq) \rightleftharpoons 2Fe^{2+}(aq) + I_2(aq)$$

(i) Use the *Data Booklet* to calculate the $E^{\ominus}_{cell}$ for this reaction.

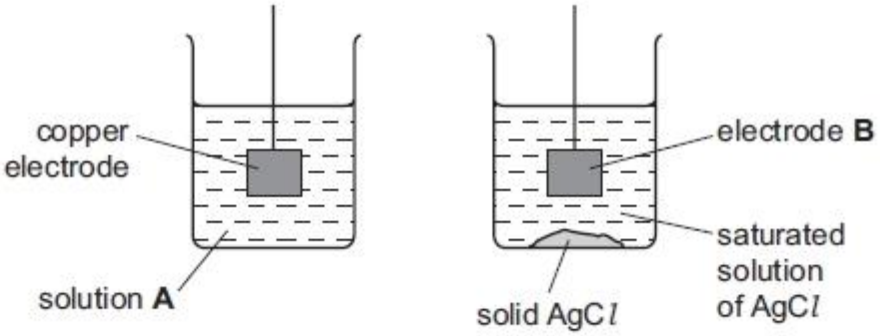
....

(ii) Hence state, with a reason, whether there will be more products or more reactants at equilibrium.

....

.... [2]

2 **(a)** The diagram below shows an incomplete experimental set-up needed to measure the E_{cell} of a cell composed of the standard Cu^{2+}/Cu electrode and an Ag^+/Ag electrode.



(i) State the chemical composition of

solution **A**, ...

electrode **B**. ....

(ii) Complete the diagram to show the whole experimental set-up.

[4]

(b) The above cell is not under standard conditions, because the $[Ag^+]$ in a saturated solution of AgC*l* is much less than $1.0\,mol\,dm^{-3}$. The $E_{electrode}$ is related to $[Ag^+]$ by the following equation.

equation 1 $$E_{electrode} = E^{\ominus}_{electrode} + 0.06 \log[Ag^+]$$

(i) Use the *Data Booklet* to calculate the $E^{\ominus}_{cell}$ if the cell was operating under standard conditions.

$E^{\ominus}_{cell}$ = ... V

In the above experiment, the E_{cell} was measured at +0.17V.

(ii) Calculate the value of $E_{electrode}$ for the Ag^+/Ag electrode in this experiment.

....

(iii) Use equation 1 to calculate $[Ag^+]$ in the saturated solution.

$[Ag^+]$ = ... $mol\,dm^{-3}$

[3]

(c) **(i)** Write an expression for K_{sp} of silver sulfate, Ag_2SO_4, including units.

K_{sp} = ... units ....

Using a similar experimental set-up to that illustrated opposite, it is found that $[Ag^+]$ in a saturated solution of Ag_2SO_4 is $1.6 \times 10^{-2}\,mol\,dm^{-3}$.

(ii) Calculate the value of K_{sp} of silver sulfate.

K_{sp} = ...

[3]

Q# 29/ ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(b) Iron(III) chloride, $FeCl_3$, is used to dissolve unwanted copper from printed circuit boards (PCBs) by the following reaction.

$$2FeCl_3(aq) + Cu(s) \rightarrow 2FeCl_2(aq) + CuCl_2(aq)$$

A solution in which $[Fe^{3+}(aq)]$ was originally equal to $1.50\,mol\,dm^{-3}$ was re-used several times to dissolve copper from the PCBs, and was then titrated as follows.

A $2.50\,cm^3$ sample of the partially-used-up solution was acidified and titrated with $0.0200\,mol\,dm^{-3}$ $KMnO_4$.
This oxidised any $FeCl_2$ in the solution back to $FeCl_3$.
It was found that $15.0\,cm^3$ of $KMnO_4(aq)$ was required to reach the end point.

(i) Construct an ionic equation for the reaction between Fe^{2+} and MnO_4^- in acid solution.

....

(ii) State here the $Fe^{2+} : MnO_4^-$ ratio from your equation in **(i)**. ....

(iii) Calculate the number of moles of MnO_4^- used in the titration.

(iv) Calculate the number of moles of Fe^{2+} in $2.50\,cm^3$ of the partially-used-up solution.

(v) Calculate the $[Fe^{2+}]$ in the partially-used-up solution.

(vi) Calculate the mass of copper that could still be dissolved by 100 cm^3 of the partially-used-up solution.

mass of copper = ... g

[6]

(d) Calcium forms three calcium silicides, Ca_2Si, CaSi and $CaSi_2$. The first of these reacts with water as follows.

$$.........Ca_2Si + ...H_2O \rightarrow ....Ca(OH)_2 + ...SiO_2 + ...H_2$$

(i) Balance this equation. You may find the use of oxidation numbers helpful.

(ii) During this reaction, state

which element(s) have been oxidised, ...

which element(s) have been reduced. ....

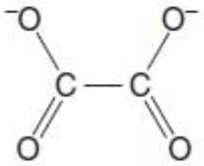
[2]

[Total: 14]

Q# 30/ ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

(c) Heating a solution containing potassium ethanedioate, iron(II) ethanedioate and hydrogen peroxide produces the light green complex $K_3Fe(C_2O_4)_3$, which contains the ion $[Fe(C_2O_4)_3]^{3-}$.

The structure of the ethanedioate ion is as follows.



(i) Calculate the oxidation number of carbon in this ion. .... [1]

(iv) In sunlight the complex decomposes into potassium ethanedioate, iron(II) ethanedioate and carbon dioxide.

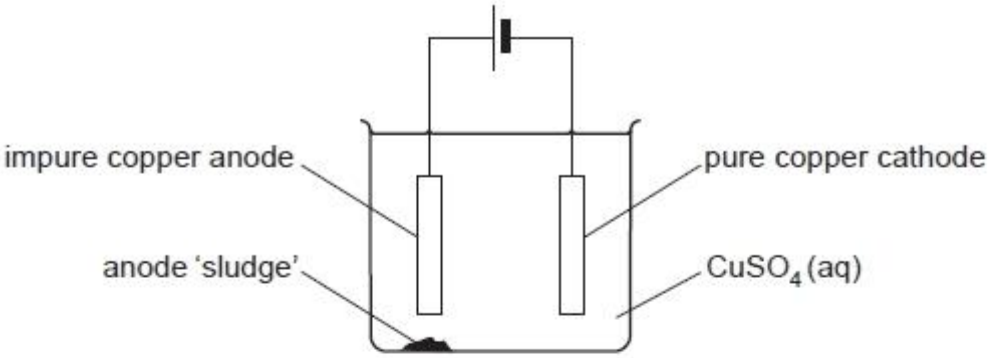
Use oxidation numbers to help you balance the following equation for this decomposition.

$$K_3Fe(C_2O_4)_3 \rightarrow ....K_2C_2O_4 + ...FeC_2O_4 + ...CO_2$$

[2]

[Total: 14]

3 The electrolytic purification of copper can be carried out in an apparatus similar to the one shown below.



The impure copper anode contains small quantities of metallic nickel, zinc and silver, together with inert oxides and carbon resulting from the initial reduction of the copper ore with coke. The copper goes into solution at the anode, but the silver remains as the metal and falls to the bottom as part of the anode 'sludge'. The zinc also dissolves.

(a) **(i)** Write a half equation including state symbols for the reaction of copper at the anode.

....

(ii) Use data from the *Data Booklet* to explain why silver remains as the metal.

....

(iii) Use data from the *Data Booklet* to predict what happens to the nickel at the anode.

....

....

(iv) Write a half equation including state symbols for the main reaction at the cathode.

....

(v) Use data from the *Data Booklet* to explain why zinc is not deposited on the cathode.

....

....

(vi) Suggest why the blue colour of the electrolyte slowly fades as the electrolysis proceeds.

....

....

[7]

(b) Most of the current passed through the cell is used to dissolve the copper at the anode and precipitate pure copper onto the cathode. However, a small proportion of it is 'wasted' in dissolving the impurities at the anode which then remain in solution.
When a current of 20.0 A was passed through the cell for 10.0 hours, it was found that 225 g of pure copper was deposited on the cathode.

(i) Calculate the following, using appropriate data from the *Data Booklet*.

- number of moles of copper produced at the cathode

- number of moles of electrons needed to produce this copper

- number of moles of electrons that passed through the cell

(ii) Hence calculate the percentage of the current through the cell that has been 'wasted' in dissolving the impurities at the anode.

[4]

(c) Nickel often occurs in ores along with iron. After the initial reduction of the ore with coke, a nickel-iron alloy is formed.
Use data from the *Data Booklet* to explain why nickel can be purified by a similar electrolysis technique to that used for copper, using an impure nickel anode, a pure nickel cathode, and nickel sulfate as the electrolyte. Explain what would happen to the iron during this process.

....

....

....

....[2]

[Total: 13]

Q# 32/ ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(b) When sulfur is heated under pressure with chlorine, the major product is SCl_2 (Cl-S-Cl).

$$S_8(g) + 8Cl_2(g) \rightarrow 8SCl_2(g)$$

(c) Under suitable conditions, SCl_2 reacts with water to produce a yellow precipitate of sulfur and a solution **A**. Solution **A** contains a mixture of $SO_2(aq)$ and compound **B**.

(i) What is the oxidation number of sulfur in SCl_2?..

(ii) Work out how the oxidation number of sulfur changes during the reaction of SCl_2 with water.

....

....

(iii) Suggest the identity of compound **B**. ....

(iv) Construct an equation for the reaction between SCl_2 and water.

....

(v) What would you observe when each of the following reagents is added to separate samples of solution **A**?

$AgNO_3(aq)$..

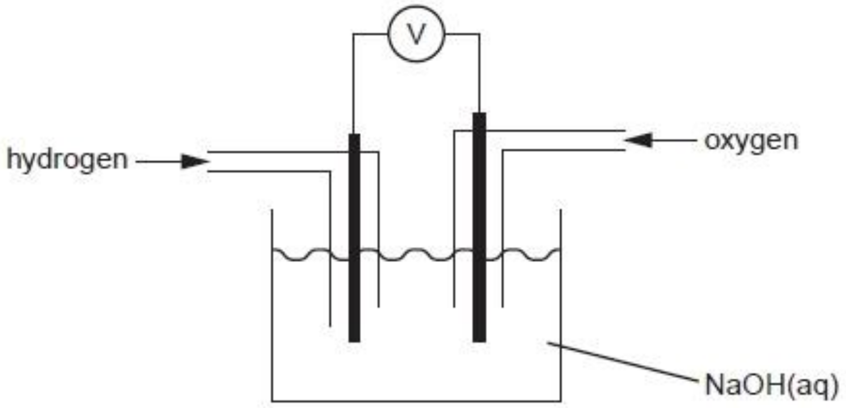
$K_2Cr_2O_7(aq)$ ....

[7]

Q# 33/ ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 5 /www.SmashingScience.org :o)

5 Although standard electrode potentials are measured for solutions where the concentrations of ions are 1.0 mol dm^{-3}, cells used as sources of battery power tend to operate with more concentrated solutions. This question concerns the electrode reactions involved in the hydrogen-oxygen fuel cell and the lead-acid car battery.

(a) In the hydrogen-oxygen fuel cell, $H_2(g)$ and $O_2(g)$ are fed onto two inert electrodes dipping into NaOH(aq).



The following reactions take place.

left hand electrode (cathode): $H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(l) + 2e^-$

right hand electrode (anode): $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

(i) Use the *Data Booklet* to calculate $E^{\ominus}_{cell}$ for this reaction.

....

(ii) Construct an equation for the overall reaction.

....

(iii) By using **one** of the phrases *more positive*, *more negative* or *no change*, deduce the effect of increasing [$OH^-(aq)$] on the electrode potential of

- the left hand electrode ....
- the right hand electrode ....

(iv) Hence deduce whether the overall E_{cell} is likely to *increase*, *decrease* or *remain the same*, when [$OH^-(aq)$] increases. Explain your answer.

....

....

(v) Suggest **one** other reason why a high [NaOH(aq)] is used in the fuel cell.

....

[6]

(b) In the cells of a lead-acid car battery the following reactions take place.

cathode: $Pb(s) \rightarrow Pb^{2+}(aq) + 2e^-$

anode: $PbO_2(s) + 4H^+(aq) + 2e^- \rightarrow Pb^{2+}(aq) + 2H_2O(l)$

(i) Use the *Data Booklet* to calculate $E^{\ominus}_{cell}$ for this reaction.

....

(ii) Construct an equation for the overall reaction.

....

The electrolyte in a lead-acid cell is $H_2SO_4(aq)$. Most of the $Pb^{2+}(aq)$ ions that are produced at the electrodes are precipitated as the highly insoluble $PbSO_4(s)$.

(iii) Construct an equation for the overall cell reaction in the presence of H_2SO_4.

....

(iv) By considering the effect of decreasing [$Pb^{2+}(aq)$] on the electrode potentials of the cathode and the anode, deduce the effect of the presence of $H_2SO_4(aq)$ in the electrolyte on the overall E_{cell}.
State whether the E_{cell} will *increase*, *decrease* or *remain the same*.

Overall E_{cell} will ....

Explain your answer.

....

....

[5]

Q# 34/ ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(d) Tin forms an oxide, **A**, that contains the metal in both oxidation states II and IV. The formula of **A** can be found by the following method.

- A sample of **A** was dissolved in $H_2SO_4(aq)$, producing solution **B**, which was a mixture of tin(II) sulfate and tin(IV) sulfate.
- A 25.0 cm^3 sample of solution **B** was titrated with 0.0200 mol dm^{-3} $KMnO_4$. 13.5 cm^3 of $KMnO_4$ was required to reach the end-point.
- Another 25.0 cm^3 sample of solution **B** was stirred with an excess of powdered zinc. This converted all the tin into tin(II). The excess of zinc powder was filtered off and the filtrate was titrated with 0.0200 mol dm^{-3} $KMnO_4$, as before. This time 20.3 cm^3 of $KMnO_4$ was required to reach the end-point.

The equation for the reaction occurring during the titration is as follows.

$$2MnO_4^- + 16H^+ + 5Sn^{2+} \longrightarrow 2Mn^{2+} + 8H_2O + 5Sn^{4+}$$

(i) Write a balanced equation for the reaction between Zn and Sn^{4+}.

....

(ii) Use the *Data Booklet* to calculate the $E^{\ominus}$ values for the reactions between

- Zn and Sn^{4+}, ...
- MnO_4^- and Sn^{2+}. ....

(iii) Use the results of the two titrations to calculate

- the number of moles of Sn^{2+} in the first titration sample,

....

....

- the number of moles of Sn^{2+} in the second titration sample.

....

....

(iv) Use the results of your calculation in **(iii)** to deduce the Sn^{2+}/Sn^{4+} ratio in the oxide **A**, and hence suggest the formula of **A**.

[8]

(e) A major use of tin is to make 'tin plate', which is composed of thin sheets of mild steel electroplated with tin, for use in the manufacture of food and drinks cans. A tin coating of 1.0×10^{-5} m thickness is often used.

(i) Calculate the volume of tin needed to coat a sheet of steel 1.0 m × 1.0 m to this thickness, on one side only.

(ii) Calculate the number of moles of tin that this volume represents.
[The density of tin is 7.3 g cm^{-3}.]

(iii) The solution used for electroplating contains Sn^{2+} ions. Calculate the quantity of electricity in coulombs needed to deposit the amount of tin you calculated in **(ii)**.

[4]

Mark Scheme A Level Chem 24 EQ 22m to 09w **Paper 4** Electrochemistry 261marks

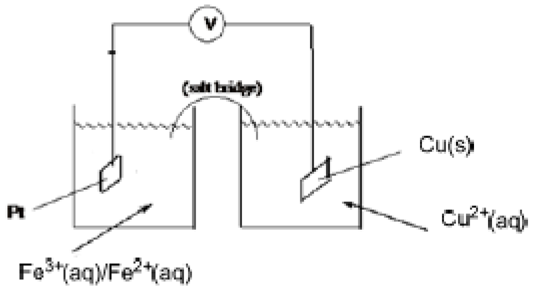
Q# 1/ ALvl Chemistry/2022/m/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(c)(i)	M1: $\Delta G = -nE^{\ominus}_{cell}F$ AND n = 4 M2: ∴ $E^{\ominus}_{cell} = -436100 / -4(96500) = 1.13$ V ecf M3: $E^{\ominus}_{cell} = E^{\ominus}(O_2,4H^+\vert H_2O) - E^{\ominus}(TiO^{2+}\vert Ti^{3+}) = 1.23 - E^{\ominus}(TiO^{2+}\vert Ti^{3+})$ ∴ $E^{\ominus}(TiO^{2+}\vert Ti^{3+}) = (+)0.1$ (V) ecf	3

Q# 2/ ALvl Chemistry/2022/m/TZ 1/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(c)	M1: 1.00 g Si is 1/28.1 = 0.0356 mol ∴ moles of e^- needed = 4 × mol Si = 0.142 faraday (3 sf) M2: $Q = It$ ∴ t = M1 × 96500 ÷ 6 = 2289 (s) ecf	2

Q# 3/ ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(b)(i)	**M1:** emf / potential difference / difference in electrode potential between two half-cells / two electrodes (in a cell) **M2:** (all solutions being) 1 mol dm^{-3} **AND either** 1 atm **OR** 298 K	**2**
3(b)(ii)	salt bridge, voltmeter, Cu(s), $Cu^{2+}(aq)$, Pt(s), Fe^{2+} and $Fe^{3+}(aq)$ two for one mark, four for two marks, six for three marks 	3
3(d)(ii)	$C_4H_4O_6^{2-} + 2H_2O \rightleftharpoons 2CO_2 + 2HCO_2^- + 6H^+ + 6e^-$	1

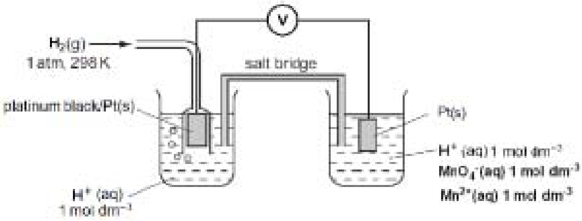
Q# 4/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(c)(i)	**M1:** $E^\ominus_{cell}$ for $IO_3^- / H_2O_2 = -0.68 + 1.19 = +0.51$ (∴ feasible) **M2:** $E^\ominus_{cell}$ for $H_2O_2 / I_2 = +1.77 - 1.19 = +0.58$ (∴ feasible) **M3:** $5H_2O_2 + I_2 \rightarrow 4H_2O + 2IO_3^- + 2H^+$	3
3(c)(ii)	$2H_2O_2 \rightarrow 2H_2O + O_2$	1

Q# 5/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(b)(i)	• Fe^{2+} *reduced* to Fe **OR** oxid no. Fe +2 → 0 • Fe^{2+} *oxidised* to Fe^{3+} (in Fe_3O_4) **OR** oxid no. Fe +2 → +3 **BOTH bullets required**	1
2(b)(ii)	$2O^{2-} \rightarrow O_2 + 4e^-$	1
2(b)(iii)	**M1:** coulombs and correct use of ÷ 96500 **M2:** correct use of 3 and 8 **M3:** correct use of 55.8 and answer **M1:** $Q = It = 50 \times 6 \times 60^2$ **OR** 1.08×10^6 C **AND** no. of faraday = $1.08 \times 10^6 \div 96500$ **OR** 11.2 / 11.19 mol e^- **M2:** $Fe^{2+} + 2Fe^{3+} + 8e^- \rightarrow 3Fe$ ∴ moles of Fe = 3 / 8 × M1 = 4.20 mol Fe ecf **M3:** mass of Fe = 55.8 × M2 = 234.2 g ecf 3sf min	3
2(c)(i)	Any one of: small size / compact, low mass, high voltage **OWTTE**	1
2(c)(ii)	Li from +1 to +1 Fe from +3 to +2	1
2(c)(iii)	$LiC_6 + FePO_4 \rightarrow LiFePO_4 + 6C$	1

Q# 6/ ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)	(anode =) oxygen / O_2 **AND** (cathode =) hydrogen/H_2 **BOTH [1]**	1
3(b)	**M1:** Q = 1.5 × 60 × 60 × 4.5 = 24300 (C) [1] **M2:** no. of F / moles of e^- = 24300 / 96500 = 0.25(1813) [1] ecf **M3:** volume of Cl_2 = 24 × 0.252 / 2 = **3.02** dm^3 [1] ecf min 2sf **M4:** mass of Na = 0.252 × 23 = **5.79** (5.7917) g Na [1] ecf min 2sf	4
3(c)(i)	 • MnO_4^-, H^+, Mn^{2+} in same beaker **AND** H^+ in other beaker • both electrodes Pt(s) (**ALLOW** graphite) • one solute clearly identified as 1M / 1 mol dm^{-3} • 298 K OR 1 atm • voltmeter / potentiometer labelled (or circled V) • salt bridge labelled (must touch the solution) • a good delivery system for H_2(g) • H_2(g) mark as two correct points = 1 mark [4]	4

3(c)(ii)	F_2 OR $S_2O_8^{2-}$ OR H_2O_2 OR HOC*l* OR Co^{3+} OR Pb^{4+} [1] $2Mn^{2+} + 8H_2O + 5F_2 \rightarrow 2MnO_4^- + 16H^+ + 10F^-$ [1] OR $2Mn^{2+} + 5S_2O_8^{2-} + 8H_2O \rightarrow 2MnO_4^- + 16H^+ + 10SO_4^{2-}$ OR $Mn^{2+} + 4H_2O + 5Co^{3+} \rightarrow MnO_4^- + 8H^+ + 5Co^{2+}$ OR $2Mn^{2+} + 8H_2O + 5Pb^{4+} \rightarrow 2MnO_4^- + 16H^+ + 5Pb^{2+}$ OR $2Mn^{2+} + 5H_2O_2 \rightarrow 2MnO_4^- + 6H^+ + 2H_2O$ OR $2Mn^{2+} + 10HOCl \rightarrow 2MnO_4^- + 6H^+ + 5Cl_2 + 2H_2O$	2

Q# 7/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 9 /www.SmashingScience.org :o)

9(a)	**M1** data seen H_2O_2/H_2O +1.77V and MnO_2/Mn^{2+} +1.23 V and O_2/H_2O_2 +0.68 V OR E_{cell}= 0.55 V (first step) **and** 0.54 V (second step) **M2** $MnO_2 + H_2O_2 + 2H^+ \rightarrow Mn^{2+} + O_2 + 2H_2O$ **M3** $Mn^{2+} + H_2O_2 \rightarrow MnO_2 + 2H^+$	3

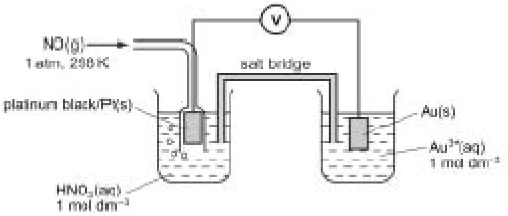
Q# 8/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)(i)	$6CO_2 + 24H^+ + 24e^- \rightarrow C_6H_{12}O_6 + 6H_2O$ **ALLOW** $6CO_2 + 12H^+ + 12e^- \rightarrow C_6H_{12}O_6 + 3O_2$ for both marks **ALLOW** one mark for an unbalanced equation showing the correct species of either equation	2

3(a)(ii)	salt bridge (indicated)	voltmeter / V labelled	4
	O_2 good delivery system	H_2 good delivery system	
	Pt electrode	H^+ / HCl / H_2SO_4 solution labelled (at least once)	
	1 atm	1 mol dm^{-3} quoted	
	Every two correct responses = 1 mark		
3(a)(iii)	E°_{cell} = (+) 1.23 V **AND** positive electrode = O_2 half-cell identified		1

Q# 9/ ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)(i)	Mark as • ✓✓ • voltage of an electrode / half-cell • compared / connected to (S)HE / hydrogen half-cell / electrode • under standard conditions / 1 mol dm^{-3}, 1 atm, 298 K	2

3(a)(ii)	 Mark as • ✓ • ✓ • ✓ • ✓ • HNO_3(aq) and Au^{3+}(aq) • Au(s) and Pt(s) electrode • voltmeter (or circled V) • salt bridge labelled • NO (g) • a good delivery system for NO • 1M / 1 mol dm^{-3} • 298 K **AND** 1 atm	**4**
3(a)(iii)	$Au^{3+} + NO + 2H_2O \rightarrow Au + NO_3^- + 4H^+$	**1**
3(a)(iv)	+1.50 – 0.96 = + 0.54 (V)	**1**
3(a)(v)	**M1 M2** any two [1] all four [2] • adding conc HNO_3 shifts equilibrium 3 to the right • *E* for (half-equation 3) increases / more positive • adding conc HC*l* shift equilibrium 2 to the left • *E* for (half-equation 2) decreases / less positive **M3** *E*(3) becomes greater than *E*(2)	**3**

Q# 10/ ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(b)(i)	$2Al^{3+} + 3O^{2-} + 3C \rightarrow 2Al + 3CO$	**1**
2(b)(ii)	**M1** $Q = It$ = $3.5 \times 10^5 \times 3 \times 60^2 = 3.78 \times 10^9$ C **M2** no. of mol e^- = $3.78 \times 10^9 / 96500 = 3.92 \times 10^4$ **M3** mass A*l* = $27 \times 3.92 \times 10^4 / 3 = 3.5(3) \times 10^5$ g	**3**

Q# 11/ ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1(a)	Platinum / Pt Aluminium / A*l* **BOTH**	**1**
1(b)(i)	**M1:** use of or quoting a valid Nernst equation $E = E^\circ + 0.0590 / z \log [ox] / [red]$ *OR* $E = 0.15 + (0.0590 / 2)\log 2$ **M2:** *E* = (+)**0.16** (0.159) V minimum 2 sig. fig. correct answer scores 2 marks	**2**
1(b)(ii)	$E_{cell} = 0.16 - (-1.66) =$ **+1.82 V** minimum 3 sig. fig.	**1**
1(b)(iii)	$2Al + 3Sn^{4+} \rightarrow 2Al^{3+} + 3Sn^{2+}$ **M1:** species **M2:** balancing	**2**
1(c)	**M1:** number of C (= 300 000 × 60 × 60 × 24) = 2.59×10^{10} (C) **M2:** number of F(= $2.592 \times 10^{10} / 9.65 \times 10^4$) = 2.69×10^5 (moles of electrons) **M3:** moles of A*l* (= $2.69 \times 10^5 / 3$) = 8.95×10^4 **M4:** mass of A*l* (= $8.95 \times 10^4 \times 27$) = **2420 kg** correct answer scores 4 marks	**4**
1(d)	**M1:** ($Cr^{2+} + 2e^- \rightleftharpoons Cr$) $E^\circ = -0.91$ and ($2H^+ + 2e^- \rightleftharpoons H_2$) $E^\circ = 0.00$ seen **M2:** hydrogen formed instead / hydrogen (ions) easier to reduce / hydrogen has more positive E°	**2**

Q# 12/ ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)	$2ClO_3^- + SO_2 \rightarrow 2ClO_2 + SO_4^{2-}$	1
3(b)(i)	Cl in ClO_2 gets both oxidised and reduced or Cl goes from +4 → +5 and +4 → +3	1
3(b)(ii)	**M1** $ClO_2 + 2OH^- \rightarrow ClO_3^- + H_2O + e^-$ **M2** $ClO_2 + e^- \rightarrow ClO_2^-$	2
3(c)(i)	**M1** $Li \rightarrow Li^+ + e^-$ and $I_2 + 2e^- \rightarrow 2I^-$ **M2** $2Li + I_2 \rightarrow 2Li^+ + 2I^-$	2
3(c)(ii)	E°_{cell} = 0.54 –(–3.04) = **+3.58 V** [1]	1
3(c)(iii)	**M1** amount of Li = 0.10 / 6.9 = 1.45 × 10^{-2} mol [1] **M2** Q needed = 96500 × 1.45 × 10^{-2} = 1399 (1398.55) C [1] ecf **M3** t = 1399 / (2.5 × 10^{-5}) = **5.6 × 10^7 s** [1] ecf 2sf min	3

Q# 13/ ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 8 /www.SmashingScience.org :o)

8(e)(i)	$2CH_3OH + 3O_2 \rightleftharpoons 2CO_2 + 4H_2O$ OR $2CH_3OH + 3O_2 \rightleftharpoons 2CO_2 + 4H^+ + 4OH^-$	1
8(e)(ii)	E°_{cell} = 1.23 – 0.02 = **1.21** V	1

Q# 14/ ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

<table>
<tr><td>3(a)</td><td><table><tr><td></td><td>anode</td><td>cathode</td></tr><tr><td>$AgNO_3$ (aq)</td><td>**oxygen / O_2**</td><td>**silver / Ag**</td></tr><tr><td>saturated NaCl (aq)</td><td>**chlorine / Cl_2**</td><td>**hydrogen / H_2**</td></tr><tr><td>$CuSO_4$ (aq)</td><td>**oxygen / O_2**</td><td>**copper / Cu**</td></tr></table></td><td>3</td></tr>
<tr><td rowspan="2">3(b)(i)</td><td>$2I^- \rightarrow I_2 + 2e^-$</td><td>1</td></tr>
<tr><td>$Ca^{2+} + 2e^- \rightarrow Ca$</td><td>1</td></tr>
<tr><td>3(b)(ii)</td><td>• Ca / Calcium reduced and I / iodine oxidised
• Oxidation number of calcium decreases from 2 to 0
• Oxidation number of iodine increases from –1 to 0

2 points = 1 mark
3 points = 2 marks</td><td>2</td></tr>
<tr><td>3(b)(iii)</td><td>• metal / grey / silvery
• purple AND vapour / gas / fumes
• amount of melt decreases

any 2 points for 1 mark</td><td>1</td></tr>
<tr><td rowspan="3">3(c)</td><td>2 × 60 × 60 × 0.8 = 5760 C
AND
5760 / 96500 = 0.060 (0.0597) F</td><td>1</td></tr>
<tr><td>1.11 / 55.8 = 0.020 (0.0199) mol of Fe</td><td>1</td></tr>
<tr><td>0.06 / 0.02 = 3 ∴ Fe^{3+} or +3 or 3</td><td>1</td></tr>
</table>

Q# 15/ ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 6 /www.SmashingScience.org :o)

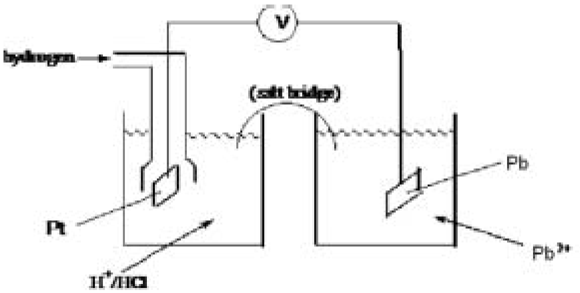
6(a)(i)	**X** is an ammeter	1
6(a)(ii)	**Y** is $AgNO_3$ *or* AgF *or* $AgClO_4$	1
6(b)	n(Ag) = 0.500 / 107.9 = 4.6(34) × 10^{-3} n(C) = 0.200 × 40 × 60 = 480 C n(e^-) = 480/1.60 × 10^{-19} = 3(.00) × 10^{21} n(e^-)/n(Ag) = 3.00 × 10^{21} / 4.634 × 10^{-3} = 6.474 × 10^{23} (**6.5 × 10^{23}**)	3

Q# 16/ ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2 /www.SmashingScience.org :o)

2(a)	the E° for X_2 / X^- becomes less positive / decrease down the group so the halogens are less reactive (as oxidants) down the group	2
2(b)(i)	$Cl_2 + H_2O \longrightarrow HCl + HClO$	1
2(b)(ii)	Cl_2/Cl^- = +1.36 V and $ClO^- / (Cl^- + OH^-)$ = +0.89 V so E°_{cell} = 1.36 – 0.89 = (+) 0.47 V	2

2(b)(iii)	box three ticked Le Chatelier argument, more OH^- / increase reactant concentration so equilibrium shifts right *or* an argument based on the half cell with OH^-	2
2(c)(i)	$Br^- + 3ClO^- \longrightarrow BrO_3^- + 3Cl^-$	1
2(c)(ii)	$E^\ominus_{cell} = 0.89 - 0.58 = +0.31$ V	1
2(c)(iii)	$4HBrO_3 \longrightarrow 2Br_2 + 5O_2 + 2H_2O$	1

Q# 17/ ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)	the potential **difference** between two half-cells / two electrodes (in a cell)	1
	under standard conditions of 1 atm., 298 K, (all) solutions being 1 mol dm^{-3}	1
3(b)(i)	 8 marking points, any 2 points for each mark H_2 / hydrogen correct delivery system for H_2 Pb^{2+} (aq) Pb electrode Pt electrode H^+(aq) solution salt bridge voltmeter / V labelled	4
3(b)(ii)	more negative	1
	shifts Pb^{2+} (+ $2e^-$) ⇋ Pb equilibrium / reaction to the left	1

3(c)(i)	Q = 0.4 × 80 × 60 = **1920** C **and** use of 96500 / 193000 Moles of Pb = 1920 / 193000 = 9.95×10^{-3} Mass of Pb = 207.2 × 9.95×10^{-3} = **2.1 g** OR Q = 0.4 × 80 × 60 = **1920** C **and** use of 1.6×10^{-19} / 1.2×10^{22} atoms Pb = 6×10^{21}; moles of Pb = $6 \times 10^{21} / 6 \times 10^{23}$ = 0.01 Mass of Pb = 207.2 × 0.01 = **2.1** g	2
3(c)(ii)	$PbO_2(s) + SO_4^{2-}(aq) + 4H^+ + 2e^- \rightarrow PbSO_4(s) + 2H_2O$	1
3(d)	reagents / PbO_2 / H_2SO_4 **and** used up / concentration decreases	1
	as fuel / hydrogen is being continuously supplied / fuel has not run out	1

Q# 18/ ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3 /www.SmashingScience.org :o)

3(a)(i)	**A** – H_2, 1 atm **B** – platinum **C** – 1 mol dm^{-3} H^+ / HCl etc. **D** – salt bridge / KNO_3 etc. **E** – platinum **F** – 1 mol dm^{-3} Fe^{2+} **AND** 1 mol dm^{-3} Fe^{3+}	3
3(a)(ii)	positive electrode is (Pt) on RHS **AND** electrons flow clockwise	1
3(b)	cell potential is 0.77 – 0.34 =(+) 0.43 (V)	1
3(c)(i)	electrode potential would become more negative as equilibrium shifts to left / explanation in terms of the Nernst equation	1
3(c)(ii)	$E = -0.41 + (0.059/1)\log[Cr^{3+}]/[Cr^{2+}]$ $= -0.41 + 0.059 \log 4.0$	1
	$= -0.37$ (V)	1

Q# 19/ ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 4 /www.SmashingScience.org :o)

<table>
<tr><td>4(c)</td><td>(emf / potential / E) of an electrode OR a half-cell compared to / connected to (S)HE which can be called a “hydrogen half-cell”

at concentration of 1 mol dm^{-3} and pressure of 1 atm (or in Pa) OR 298 K</td><td>1

1

2</td></tr>
<tr><td>4(d)(i)</td><td><table><tr><td>half-cell</td><td>electrode</td></tr><tr><td>Co^{2+} / Co</td><td>Co / cobalt</td></tr><tr><td>Fe^{3+} / Fe^{2+}</td><td>Pt / carbon / graphite</td></tr></table></td><td>1
1</td></tr>
<tr><td>4(d)(ii)</td><td>$Co + 2Fe^{3+} \rightarrow Co^{2+} + 2Fe^{2+}$</td><td>1
1</td></tr>
<tr><td>4(d)(iii)</td><td>$E^{\ominus}_{cell} = 0.77 - (-0.28) = (+ \text{or} -)1.05$ (V)</td><td>1
1</td></tr>
<tr><td>4(e)(i)</td><td>$E_{electrode} = -0.28 + (0.059/2)\log[0.05] = $ −0.32 / −0.318 (V)</td><td>1
1</td></tr>
<tr><td>4(e)(ii)</td><td>more positive</td><td>1
1</td></tr>
<tr><td>4(f)</td><td>$4Fe^{3+} + V + H_2O \rightarrow VO^{2+} + 4Fe^{2+} + 2H^+$

VO^{2+}
correct equation</td><td>1
1</td></tr>
<tr><td></td><td></td><td>2</td></tr>
</table>

Q# 20/ ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 4 /www.SmashingScience.org :o)

4 (a) (i)	SCP is the EMF / potential of a cell composed of two electrodes (OR half cells) under standard conditions (OR at 289K OR 1 moldm^{-3})	[1]
(ii)	voltmeter and salt bridge	[1]
(iii)	**A** is Ag **B** is Ag^+(aq) or $AgNO_3$(aq) **C** is Pt **D** is Fe^{2+}(aq) and Fe^{3+}(aq) (combination of **A** and **B** can be reversed with combination of **C** and **D**)	[3]
(b) (i)	$Ag^+ + Fe^{2+} \longrightarrow Ag + Fe^{3+}$	[1]
(ii)	$E = E^{\ominus} + 0.059\log[Ag^+] = 0.80 - 0.03 = 0.77$ V so $E_{cell} = 0.77 - 0.77 = 0.0$ V	[1] [1]
		[Total: 8]

Q# 21/ ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 5 /www.SmashingScience.org :o)

5 (a) (i)	any metal with an $E^{\ominus}$ value more negative than −0.41 V, e.g. Fe, Mn, Zn, Mg, Cr, Al **R:** Li / Na / K / Ca / Ba	**1**
(ii)	**M1**: value of E_{cell} correctly calculated (with correct sign) for metal named in **(i)** **M2**: $E^{\ominus}_{cell}$ is positive **and** so reaction is feasible	**1** **1**
(b)	**M1**: $(Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O)$ $E^{\ominus} = +1.33$ V $(H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O)$ $E^{\ominus} = +1.77$ V $E^{\ominus}_{cell} = 0.44$ (V) **M2**: $E^{\ominus}_{cell}$ (0.44 V) is positive (so the reaction is feasible) / $E^{\ominus}(Cr_2O_7^{2-} / Cr^{3+})$ is less positive than $E^{\ominus}(H_2O_2 / H_2O)$	**1** **1**

(c)	**M1**: $Cr_2O_7^{2-}$: ox.no Cr = +6 because –2 = 2 × ox.no(Cr) + (7 × –2) CrO_4^{2-}: ox.no Cr = +6 because –2 = ox.no(Cr) + (4 × –2) **M2**: no change in oxidation number, so reaction is not redox	1 1
(d)	**M1**: no. moles Cr deposited = 0.0312 / 52 = 6.0 × 10^{-4} moles **M2**: deduction that 6 moles of e^- needed per mole of Cr / reaction is $Cr_2O_7^{2-}$ + $14H^+$ + $12e^-$ → 2Cr + $7H_2O$ **M3**: no. moles of e^- = 6 × 6.0 × 10^{-4} = (0.125 × t) / 96 500 so t = (6 × 6.0 × 10^{-4} × 96 500) / (0.125 × 60) = 46.3 min / 0.772 h / 2780 s	1 1 1

Q# 22/ ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 5 /www.SmashingScience.org :o)

5 (a) (i)	M1: salt bridge **and** voltmeter / M2: method of H_2 gas delivery M3: X **and** Pt electrode labelled M4: solution H^+ / HC*l*(aq) / H_2SO_4 **and** X^{2+} labelled	**4**
(ii)	25°C / 298 K **and** 1 atm / 101 kPa pressure **and** 1 mol dm^{-3} (solution)	**1**
(iii)	solution – ions ***or*** H^+ and X^{2+} **and** wires – electrons / e^-	**1**
(b) (i)	X + $2Ag^+$ → 2Ag + X^{2+}	**1**
(ii)	moles Ag = 1.30 / 107.9 = 0.0120 1 moles of X react with 2 moles Ag^+ moles of X lost = 0.012 × 0.5 = 0.00602 A_r of X = 0.67/0.006 = 111–112 **and** X = Cd	**4**
		<u>11</u>

Q# 23/ ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 5 /www.SmashingScience.org :o)

(e) (i)	F = Le	**1**
(ii)	moles of $O_2(g)$ = 130/24000 = 5.417 x 10^{-3} mol moles of electrons needed = 4 x 5.417 x 10^{-3} ***or*** 2.17 x 10^{-2} mol no. of coulombs passed = 1.2 x 30 x 60 ***or*** 2160 C no. of electrons passed = 2160 / 1.6 x 10^{-19} ***or*** 1.35 x 10^{22} no. of electrons per mole = 1.35 x 10^{22} / 2.17 x 10^{-2} = **6.2 x 10^{23}** (mol^{-1})	**1** **1** **1** **1**
		[Total: 15]

Q# 24/ ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 4 /www.SmashingScience.org :o)

(c) (i)	$E^{\ominus}_{cell}$ (= 0.80 – 0.77 =) (+)**0.03V and** Ag^+/Ag ***or*** Ag/silver ***or*** right	**1**
(ii)	E_{cell} would be less positive/more negative because the [Ag^+(aq)] (in the Ag electrode) is less than 1.0 mol dm^{-3}	**1**
(iii)	• no change	**1**
	• more negative/less positive	**1**
(iv)	the [Ag^+(aq)] will decrease $E_{electrode}$ becomes less positive ***or*** due to the common ion effect	**1**

Q# 25/ ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(c) (i)	$E^\ominus$ values: $F_2/F^- = 2.87V$ and $Cl_2/Cl^- = 1.36V$ fluorine (has the more positive $E^\ominus$ so) is more oxidising	1 1
(ii)	redox	1
(iii)	$ClF + 2KBr \longrightarrow KCl + KF + Br_2$	1

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(b) **(i)** components to be added: voltmeter *or* **V** [1]
salt bridge [must be labelled] [1]

(ii) M1: **A** and **B** copper (metal) or Cu **and** iron (metal) or Fe [1]
M2: either **C** or **D** as 1 mol dm^{-3} / 1 M [1]
M3 **C** and **D** Cu^{2+} or $CuSO_4$ or $CuCl_2$ or $Cu(NO_3)_2$ etc. **and** Fe^{2+} or $FeSO_4$ etc. [1]

(iii) $E^\ominus_{cell} = 0.34 + 0.44 = \mathbf{0.78}$ (V) [1]

(iv) if **C** is Fe^{2+}; (as [**C**] increases), the *E* of the Fe^{2+}/Fe increases / becomes more positive / less negative [1]

so the overall cell potential / E_{cell} would **decrease / become less positive / more negative** [1]

or

if **C** is Cu^{2+}; (as [**C**] increases), the E of the Cu^{2+}/Cu increases / becomes more positive / less negative [1]

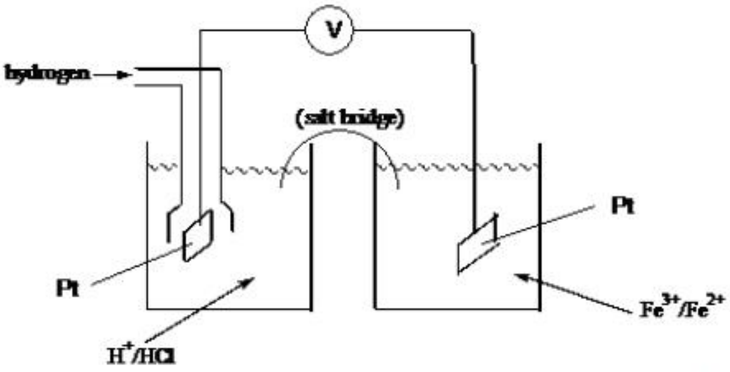
so the overall cell potential / E_{cell} would **increase / become more positive / less negative** [1]

Q# 27/ ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

1 **(a)** The potential of an **electrode** compared to that of a standard hydrogen electrode (SHE)
or
the EMF of a **cell** composed of the test electrode and the SHE [1]

all measurement concentrations of 1 mol dm^{-3} **and** 298 K / 1 atm pressure [1]
[2]

(b)



H_2 and good delivery system [1]
Fe^{2+}/Fe^{3+} solution labelled [1]
platinum electrodes (both) [1]
salt bridge and voltmeter [1]
H^+ *or* HCl *or* H_2SO_4 [1]
(acid is not sufficient)
[5]

(c) (i) $E^\ominus = 0.77 - 0.54 = 0.23$ (V) [1]

(ii) Since $E^\ominus$ is positive/ $E^\ominus > 0$

So more products / the equilibrium will be over to the right / forward reaction is favoured ecf from **(c)(i)** [1]

Q# 28/ ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 2 /www.SmashingScience.org :o)

2 (a) (i) **A** = $CuSO_4$ [1]
B = silver [1]

(ii) salt bridge [1]
voltmeter [1]

[4]

(b) (i) 0.80 – 0.34 = **(+) 0.46 V** [1]

(ii) If $E_{cell} = 0.17$, this is 0.29 V less than the standard $E^\ominus$,
so $E_{Ag\ electrode}$ must = 0.80 – 0.29 = **0.51 V** [1]

(iii) $0.51 = 0.80 + 0.06\log[Ag^+]$, so $[Ag^+] = 10^{(-0.29/0.06)}$ = $\underline{\mathbf{1.47 \times 10^{-5}}}$ $mol\,dm^{-3}$ ecf from **(ii)** [1]

[3]

(c) (i) $K_{sp} = [Ag^+]^2[SO_4^{2-}]$ [1]
units = mol^3dm^{-9} ecf on K_{sp} [1]

(ii) $[SO_4^{2-}] = [Ag^+]/2$ $K_{sp} = (1.6 \times 10^{-2})^2 \times 0.8 \times 10^{-2}$ = $\underline{\mathbf{2.05 \times 10^{-6}}}$ (mol^3dm^{-9}) [1]

[3]

Q# 29/ ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(b) (i) $MnO_4^- + 8H^+ + 5Fe^{2+} \longrightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$ [1]

(ii) 5 : 1

(iii) $n(MnO_4^-) = 0.02 \times 15/1000 = 3 \times 10^{-4}$ (mol) [1]

(iv) $n(Fe^{2+}) = 5 \times 3 \times 10^{-4} = 1.5 \times 10^{-3}$ (mol) ecf from **(i)** or **(ii)** [1]

(v) $[Fe^{2+}] = 1.5 \times 10^{-3} \times 1000/2.5 =$ **0.6** ($mol\,dm^{-3}$) ecf from **(iv)** [1]

(vi) In the original solution, there was 0.15 mol of Fe^{3+} in 100 cm^3.
In the partially-used solution, there is 0.06 mol of Fe^{2+} in 100 cm^3.

So remaining Fe^{3+} = 0.15 – 0.06 = 0.09 mol. ecf from **(v)** [1]

This can react with 0.045 mol of Cu, which = 0.045 × 63.5 = **2.86 g** of copper. ecf [1]

[6]

(d) (i) $Ca_2Si + 6H_2O \longrightarrow 2Ca(OH)_2 + SiO_2 + 4H_2$ [1]

(ii) silcon has been oxidised **AND** hydrogen has been reduced [1]

[2]

Q# 30/ ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

(c) (i) O.N.(carbon) = +3 $(4 \times (-2) + 2x = -2$, thus $2x = +6)$ [1]

(iv) $\underline{2}\ K_3Fe(C_2O_4)_3 \rightarrow \underline{3}\ K_2C_2O_4 + \underline{2}\ FeC_2O_4 + \underline{2}\ CO_2$ [2]
Or $K_3Fe(C_2O_4)_3 \rightarrow \underline{3/2}\ K_2C_2O_4 + FeC_2O_4 + CO_2$

[max 5]

[Total: 14]

Q# 31/ ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 3 /www.SmashingScience.org :o)

3 (a) (i) $Cu(s) - 2e^- \rightarrow Cu^{2+}(aq)$ allow electrons on RHS (1)

(ii) E° for Ag^+/Ag is +0.80V which is more positive than +0.34V for Cu^{2+}/Cu, (1)
so it's less easily oxidised (owtte) (1)

(iii) E° for Ni^{2+} is –0.25V, (1)
Ni is readily oxidised and goes into solution as $Ni^{2+}(aq)$ (1) [Mark **(ii)** and **(iii)** to max 3]

(iv) $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ (1)

(v) E° for Zn^{2+}/Zn is negative / = –0.76V, so Zn^{2+} is not easily reduced. (1)

(vi) The blue colour fades because $Cu^{2+}(aq)$ is being replaced by $Zn^{2+}(aq)$ *or* $Ni^{2+}(aq)$ *or* $[Cu^{2+}]$ decreases (1) **[7]**

(b) amount of copper = 225/63.5 = **3.54**(3) mol (1)
amount of electrons needed = 2 × 3.54 = **7.08/9** (7.087) mol (1)

no. of coulombs = 20 × 10 × 60 × 60 = 7.2×10^5 C
no. of moles of electrons = $7.2 \times 10^5 / 9.65 \times 10^4$ = **7.46** mol (1)

percentage "wasted" = 100 × (7.461 – 7.087)/7.461 = 5.01 (**5.0**)% (accept 4.98–5.10) (1)
[4]

(c) E° data: Ni^{2+}/Ni = –0.25V
Fe^{2+}/Fe = –0.44V (1)

Because the Fe potential is more negative than the Ni potential, the iron will dissolve (1) **[2]**

[Total: 13]

Q# 32/ ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(c) (i) +2 (1)

(ii) (half) the sulfur goes up by +2, (1)
(the other half) goes down by –2 (1)

(iii) HCl (can be read into **(iv)**) (1)

(iv) $2SCl_2 + 2H_2O \rightarrow S + SO_2 + 4HCl$ (1)

(v) $(+ AgNO_3)$ white ppt. (1)
$(+ K_2Cr_2O_7)$ solution turns green (1) [7]

[Total: 11]

Q# 33/ ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 5 /www.SmashingScience.org :o)

5 (a) (i) E° = 0.40 – (–0.83) = 1.23V (1)

(ii) $2H_2 + O_2 \longrightarrow 2H_2O$ (1)

(iii) LH electrode will become more negative (1)
RH electrode will also become more negative / less positive (1)

(iv) no change ecf from **(iii)** (1)

(v) increased conductance *or* lower cell resistance *or* increased rate of reaction (1) [6]

(b) (i) E° = 1.47 – (–0.13) = 1.60V (1)
(ii) $PbO_2 + Pb + 4H^+ \longrightarrow 2Pb^{2+} + 2H_2O$ (1)

(iii) $PbO_2 + Pb + 4H^+ + 2SO_4^{2-} \longrightarrow 2PbSO_4(s) + 2H_2O$ (1)

(iv) E°_{cell} will increase (1)

as $[Pb^{2+}]$ decreases, $E_{electrode}(PbO_2)$ will become more positive, but $E_{electrode}(Pb)$ will become more negative (1) [5]

[Total: 11]

Q# 34/ ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 1 /www.SmashingScience.org :o)

(d) (i) $Zn + Sn^{4+} \longrightarrow Zn^{2+} + Sn^{2+}$ [1]

(ii) $E^\theta = 0.15 - (-0.76) = \mathbf{0.91}$ V [1]
$E^\theta = 1.52 - 0.15 = \mathbf{1.37}$ V [1]

(iii) $n(Sn^{2+}) = 0.02 \times 13.5/1000 \times 5/2 = \mathbf{6.75 \times 10^{-4}}$ mol use of the 5/2 ratio [1]
correct rest of working [1]
$n(Sn^{2+}) = 0.02 \times 20.3/1000 \times 5/2 = \mathbf{1.02 \times 10^{-3}}$ mol [1]

(iv) $n(Sn^{4+}) = 1.02 \times 10^{-3} - 6.75 \times 10^{-4} = 3.45 \times 10^{-4}$ mol [1]
∴ ratio = 6.75/3.45 = 1.96:1 ≈ **2:1**
∴ formula is $2SnO + SnO_2 \Rightarrow \mathbf{Sn_3O_4}$ *(cond^l on calculation, but allow ecf)* [1]
[8]

(e) (i) volume = $1 \times 1 \times 1 \times 10^{-5} = 1 \times 10^{-5}$ m³ *or* **10** cm³ [1]

(ii) mass = vol × density = 10 × 7.3 = **73** g ecf [1]
moles = mass/A_r = 73/119 = **0.61** mol ecf [1]

(iii) Q = nFz = $0.61 \times 9.65 \times 10^4 \times 2 = \mathbf{1.18\ (1.2) \times 10^5}$ coulombs ecf [1]
[4]

[Total: 19]