**Q1.**

1 (a) What do you understand by the term *standard electrode potential*?

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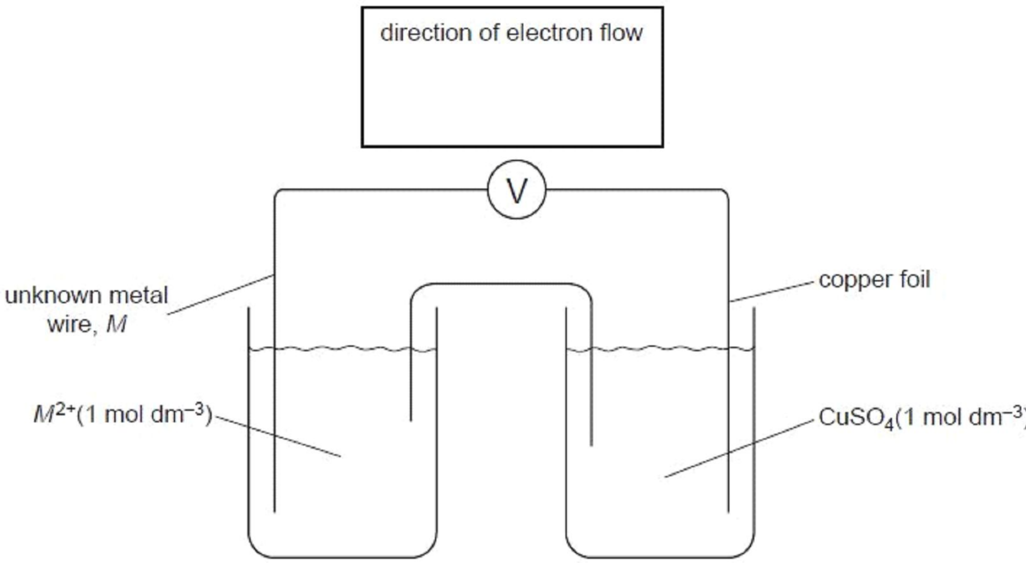
.........................................................................................................................................[2]

(b) The following cell was set up between a copper electrode and an unknown metal electrode $M^{2+}$(aq) / $M$(s). The standard cell potential was found to be 0.76 V, and the copper foil was the positive electrode.




(i) Use the *Data Booklet* to calculate the standard electrode potential of the $M^{2+}$(aq) / $M$(s) system.

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(ii) Draw an arrow over the voltmeter symbol in the above diagram to show the direction of electron flow through the voltmeter.

(iii) Predict the outcomes of the following situations. Describe what you might see and write ionic equations for any reactions that occur.

I A rod of metal $M$ is dipped into a solution of 1 mol $dm^{-3}$ $CuSO_4$.

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**Q2.**

II Dilute sulphuric acid is added to a beaker containing a powdered sample of metal *M*.

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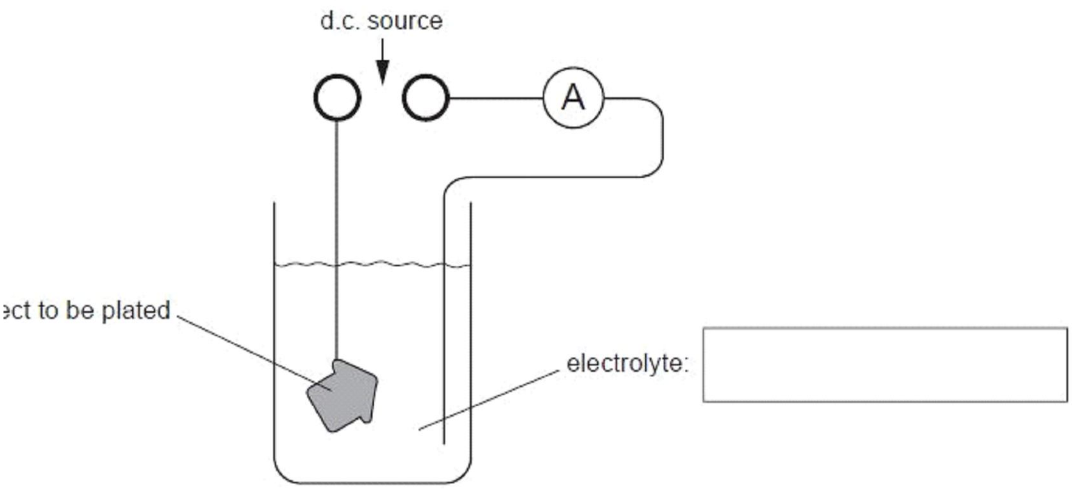
[6]

**(c)** Because of its increased scarcity, cheaper copper ornaments are no longer made from the solid metal, but from iron that has been copper plated.

**(i)** Complete the following diagram showing the set-up for a copper electroplating process. Show clearly the polarity (+/–) of the power source, and suggest a suitable electrolyte.

**(i)** Complete the following diagram showing the set-up for a copper electroplating process. Show clearly the polarity (+/–) of the power source, and suggest a suitable electrolyte.




**(ii)** A current of 0.500 A is passed through the electroplating cell. Calculate the time required to deposit a mass of 0.500 g of copper on to the ornament.

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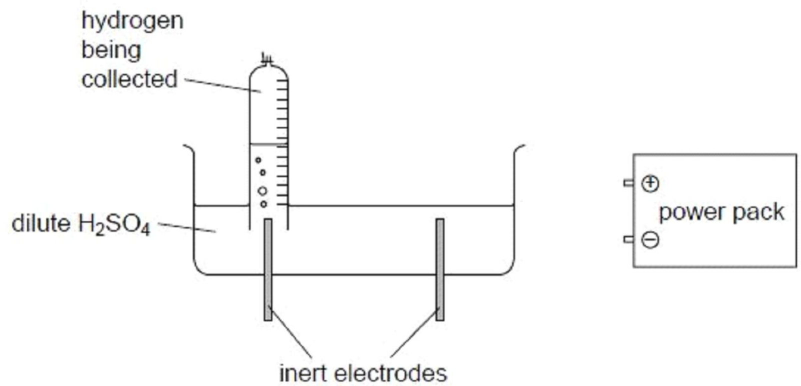
[5]

[Total : 13]

**Q2.**

**1** A student decided to determine the value of the Faraday constant by an electrolysis experiment. The following incomplete diagram shows the apparatus that was used.




**(a)** **(i)** Apart from connecting wires, what **two** additional pieces of equipment are needed for this experiment?

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**(ii)** Complete the diagram, showing additional equipment connected in the circuit, and showing the powerpack connected to the correct electrodes.

**(iii)** List the measurements the student would need to make in order to use the results to calculate a value for the Faraday constant.

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[7]

**(b)** **(i)** Using an equation, state the relationship between the Faraday constant, $F$, the Avogadro constant, $L$, and the charge on the electron, $e$.

.............................................................................................................................

**(ii)** The value the student obtained was: 1 Faraday = $9.63 \times 10^4$ Coulombs

Use this value and your equation in **(b)(i)** to calculate the Avogadro constant (take the charge on the electron to be $1.60 \times 10^{-19}$ Coulombs)

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[2]

[Total: 9]

**Q3.**

1 Zinc chloride is one of the most important compounds of zinc. It is used in dry cell batteries, as a flux for soldering and tinning, as a corrosion inhibitor in cooling towers and in the manufacture of rayon.

**(a)** Draw a **fully labelled** diagram to show how you could use a standard hydrogen electrode to measure the standard electrode potential, $E^\ominus$, of zinc.

[6]

**(b)** The electrolysis of zinc chloride can give different electrode products, depending on the conditions used.
Suggest the products formed at each electrode in the following cases. One space has been filled in for you.

| conditions | product at anode | product at cathode |
|---|---|---|
| $ZnCl_2$(l) | ***chlorine*** | |
| $ZnCl_2$(concentrated aqueous) | | |
| $ZnCl_2$(dilute aqueous) | | |

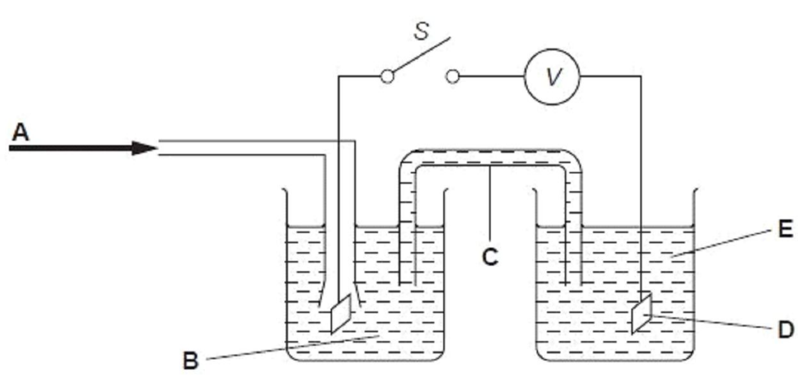
[3]

## Q4.

1 Chlorine gas and iron(II) ions react together in aqueous solution as follows.

$$Cl_2 + 2Fe^{2+} \rightarrow 2Cl^- + 2Fe^{3+}$$

**(a)** The following diagram shows the apparatus needed to measure the $E^\ominus_{cell}$ for the above reaction.



**(i)** In the spaces below, identify what the five letters **A** – **E** in the above diagram represent.

**A** ....................................................

**B** ....................................................

**C** ....................................................

**D** ....................................................

**E** ....................................................

**(ii)** Use the *Data Booklet* to calculate the $E^{\ominus}_{cell}$ for this reaction, and hence decide which direction (left to right, or right to left) electrons would flow through the voltmeter *V* when switch *S* is closed.

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

direction of electron flow ....................................................

[7]

**(b)** Iron(III) chloride readily dissolves in water.

$$FeCl_3(s) \rightarrow Fe^{3+}(aq) + 3Cl^-(aq)$$

**(i)** Use the following data to calculate the standard enthalpy change for this process.

| species | $\Delta H^{\ominus}_f$ / kJ mol$^{-1}$ |
|---|---|
| $FeCl_3(s)$ | –399.5 |
| $Fe^{3+}(aq)$ | –48.5 |
| $Cl^-(aq)$ | –167.2 |

$\Delta H^{\ominus}$ = ........................................ kJ mol$^{-1}$

**(ii)** A solution of iron(III) chloride is used to dissolve unwanted copper from printed circuit boards.

When a copper-coated printed circuit board is immersed in $FeCl_3(aq)$, the solution turns pale blue.

Suggest an equation for the reaction between copper and iron(III) chloride and use the Data Booklet to calculate the $E^\ominus$ for the reaction.

equation ..........................................................................................................

$E^\ominus$ = ..................................................... V

**[4]**

[Total: 11]

**Q5.**

**2** **(a)** Describe the observations you would make when concentrated sulfuric acid is added to separate portions of $NaCl(s)$ and $NaBr(s)$. Write an equation for **each** reaction that occurs.

*For Examiner's Use*

$NaCl(s)$: observation ..........................................................................................

..........................................................................................................

equation

$NaBr(s)$: observation ..........................................................................................

..........................................................................................................

equation

[4]

**(b)** By quoting relevant $E^\ominus$ data from the *Data Booklet*, explain how the observations you have described above relate to the relative oxidising power of the elements.

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.......................................................................................................... [2]

**(c)** By referring to relevant $E^\ominus$ data choose a suitable reagent to convert $Br_2$ into $Br^-$. Write an equation and calculate the $E^\ominus$ for the reaction.

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.................................................................................................................................. [3]

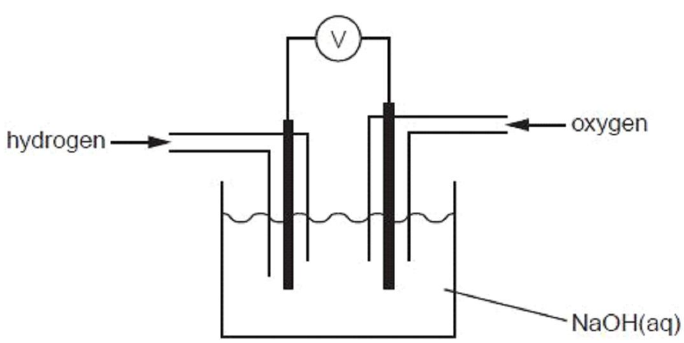
[Total: 9]

## Q6.

**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.

*For Examiner's Use*

**(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.

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**(ii)** Construct an equation for the overall reaction.

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**(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.

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**(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.

*For Examiner Use*

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

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

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

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**(ii)** Construct an equation for the overall reaction.

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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 $H_2SO_4$.

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**(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]

[Total: 11]

**Q7.**

**8** The design and development of batteries has been a major research area in recent years.

*For Examiner's Use*

**(a)** Lead-acid batteries, used in cars, are made up of a number of rechargeable cells in series, and were first developed in 1860. They have the disadvantage of a relatively high mass compared to the energy stored. During discharge, the electrode reactions in the cells of these batteries are as follows.

**I** $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$

**II** $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$

State which of these reactions occurs at the positive electrode in a lead-acid cell during discharge, explaining your answer.

..........................................................................................................................................

..........................................................................................................................................[1]

**(b)** Use the *Data Booklet* and the equations **I** and **II** above to calculate the voltage produced by a lead-acid cell under standard conditions.

[2]

**(c)** Nickel-metal hydride batteries were developed in the 1980s and have become increasingly common particularly for small devices such as mobile phones and digital cameras that need near-constant sources of electrical energy. These cells use nickel oxohydroxide (NiO(OH)) as one electrode and a hydrogen-absorbing alloy such as $LiNi_5$ as the other electrode.

One reaction that takes place in these batteries is

$$NiO(OH) + H_2O + e^- \rightleftharpoons Ni(OH)_2 + OH^-$$

**(i)** State the oxidation state of nickel in NiO(OH). ......................

**(ii)** Suggest a likely advantage of these batteries compared with lead-acid batteries.

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..........................................................................................................................................

[2]

**(d)** Hydrogen fuel cells have been suggested as the next major advance in electrically powered vehicles. In these fuel cells hydrogen is oxidized to produce water, using a catalyst and inert electrodes.

*For Examiner's Use*

**(i)** Suggest a material for the electrodes.

..........................................................................

**(ii)** Use your knowledge of hydrogen to suggest a disadvantage of these fuel cells in powering vehicles.

..........................................................................................................................................

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[2]

**(e)** Many of the world's countries are developing ways of recycling materials which are valuable or which require large amounts of energy to produce.

For each of the following recyclable materials, state whether recycling of this material is important in saving energy or in saving resources. Use your knowledge of chemistry to explain each choice.

glass ..............................................................................................................

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steel ..............................................................................................................

..............................................................................................................

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plastics ..............................................................................................................

..............................................................................................................

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[3]

[Total: 10]

**Q8.**

3 **(a)** State the relationship between the Faraday constant, *F*, the charge on the electron, *e*, and the Avogadro number, *L*.

For Examiner's Use

.......................................................................................................................................[1]

**(b)** If the charge on the electron, the $A_r$ and the valency of copper are known, the value of the Avogadro number can be determined experimentally. This is done by passing a known current for a known time through a copper electrolysis cell, and weighing the mass of copper deposited onto the cathode.

**(i)** Draw a diagram of suitable apparatus for carrying out this experiment.
Label the following: power supply (with + and – terminals); anode; cathode; and ammeter.
State the composition of the electrolyte.

The following are the results obtained from one such experiment.

| | | |
|---|---|---|
| current passed through the cell | = | 0.500 A |
| time current was passed through cell | = | 30.0 min |
| initial mass of copper cathode | = | 52.243 g |
| final mass of copper cathode | = | 52.542 g |

**(ii)** Use these data and relevant information from the *Data Booklet* to calculate a value of *L* to **3 significant figures**.

*L* = ...............................................

[9]

(c) Use relevant information from the *Data Booklet* to identify the substances formed at the anode and at the cathode when aqueous solutions of the following compounds are electrolysed.

For Examiner's Use

| compound | product at anode | product at cathode |
|---|---|---|
| AgF | | |
| $FeSO_4$ | | |
| $MgBr_2$ | | |

[5]

[Total: 15]

**Q9.**

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]

**Q10.**

F
Exan
U

2 **(a)** **(i)** With the aid of a fully-labelled diagram, describe the standard hydrogen electrode.

**(ii)** Use the *Data Booklet* to calculate the standard cell potential for the reaction between $Cr^{2+}$ ions and $Cr_2O_7^{2-}$ ions in acid solution, and construct a balanced equation for the reaction.

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

equation ..........................................................................................................

**(iii)** Describe what you would see if a blue solution of $Cr^{2+}$ ions was added to an acidified solution of $Cr_2O_7^{2-}$ ions until reaction was complete.

..........................................................................................................

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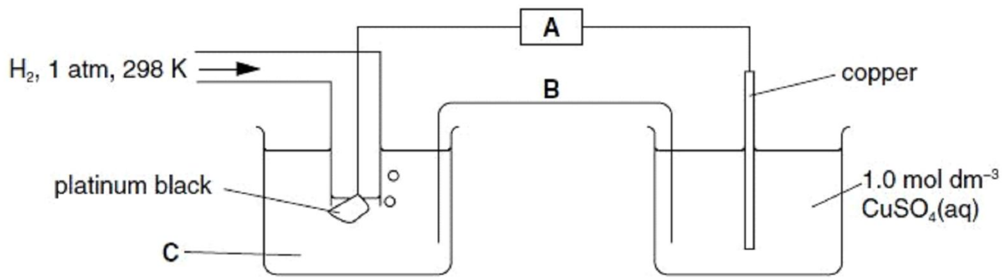
[8]

**Q11.**

1 (a) The following diagram shows the apparatus needed to measure the standard electrode potential of copper. In the spaces below, identify or describe what the three letters **A**–**C** represent.




**A** ..........................................................................................................

**B** ..........................................................................................................

**C** ..........................................................................................................

[3]

(b) A student wishes to measure the standard electrode potential of the $Fe^{3+}/Fe^{2+}$ electrode. In the space below, draw and label the set-up for the right-hand beaker that would replace the one shown in the diagram above.

[2]

(c) Predict how the *E* of the $Fe^{3+}/Fe^{2+}$ electrode would vary as

(i) the $[Fe^{3+}]$ is increased,

..........................................................................................................

(ii) the $[Fe^{2+}]$ is increased.

..........................................................................................................

[1]

(d) An aqueous solution of iron(III) chloride is used to dissolve the excess of copper metal from printed-circuit boards.

Use the half-equations and $E^{\ominus}$ values in the *Data Booklet* to

(i) write an equation for this reaction,

..............................................................................................................................

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

..............................................................................................................................

[2]

(e) The solution resulting from dissolving the copper from a small printed-circuit board was acidified and titrated with 0.0200 mol dm$^{-3}$ $KMnO_4$. A volume of 75.0 cm$^3$ was required for the end point.

The equation for the titration reaction is as follows.

$$5Fe^{2+} + MnO_4^- + 8H^+ \longrightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

Calculate

(i) the number of moles of $Fe^{2+}$ in the solution,

(ii) the mass of copper that had dissolved from the printed-circuit board.

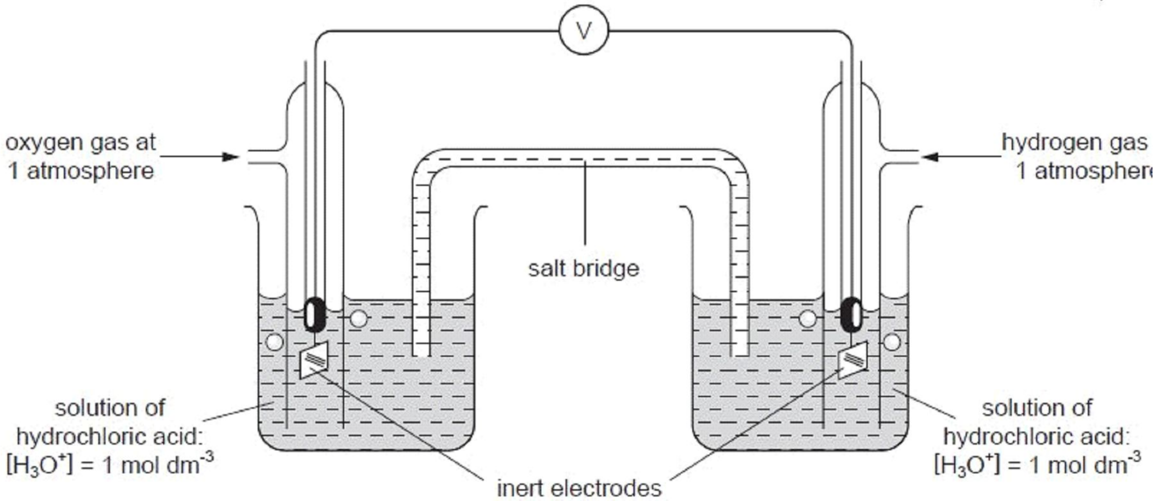
[4]

[Total: 12]

**Q12.**

Use

**2** The diagram shows a laboratory illustration of a simple hydrogen-oxygen fuel cell.




**(a)** Write the half equation for the reaction occurring at the left hand (oxygen) electrode when the cell operates.

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.......................................................................................................................... [1]

**(b)** State the polarity (+ or –) of the left hand (oxygen) electrode. ...................................... [1]

**(c)** Use the *Data Booklet* to calculate the voltage produced by this cell.

.......................................................................................................................... [1]

**(d)** Only a very small current can be drawn from this laboratory cell. Suggest **one** way in which it could be modified to enable a larger current to be drawn from it.

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.......................................................................................................................... [1]

**(e)** A fuel cell in an orbiting satellite is required to produce a current of 0.010 A for 400 days. Calculate the mass of hydrogen that will be needed.

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.......................................................................................................................... [3]

**(f)** State **one** advantage, and **one** disadvantage of using fuel cells to power road vehicles compared to hydrocarbon fuels such as petrol.

advantage: ..........................................................................................................

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disadvantage: ..........................................................................................................

.......................................................................................................... [2]

[Total: 9]

**Q13.**

Use

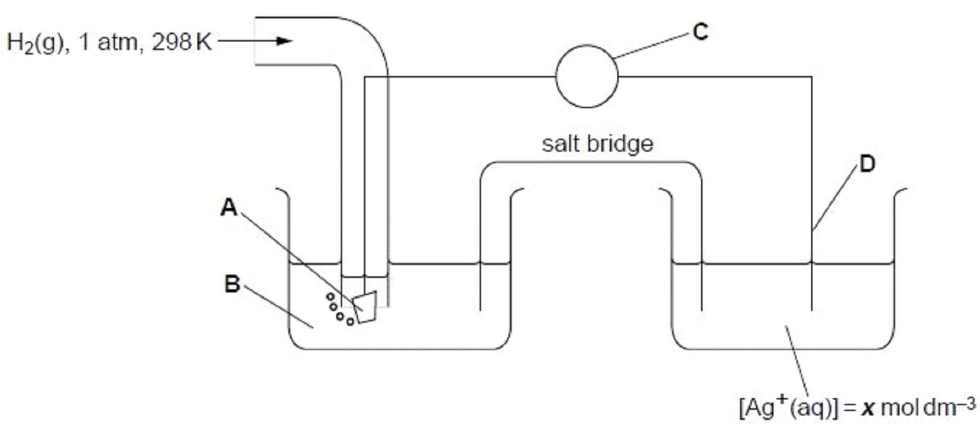
1 Silver bromide, AgBr, is widely used in photography. In a photographic film, AgBr crystals are precipitated into a gelatine base as 'grains' of diameter about $1 \times 10^{-6}$ m.

**(a)** Calculate the approximate number of silver ions contained in a grain of AgBr of mass $2.5 \times 10^{-12}$ g.

..........................................................................................................

.......................................................................................................... [2]

**(b)** AgBr is only sparingly soluble in water. The $[Ag^+]$ in a saturated solution of AgBr can be estimated by measuring the $E_{cell}$ of the following cell.



(i) In the spaces below, identify what the four letters **A** – **D** in the above diagram represent.

**A** ............................................ **C** ............................................

**B** ............................................ **D** ............................................

(ii) Predict how the potential of the right hand electrode might vary as $[Ag^{+}]$ is decreased.

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In its saturated solution, $[AgBr(aq)] = 7.1 \times 10^{-7}\,mol\,dm^{-3}$.

(iii) Write an expression for the solubility product of AgBr, and calculate its value, including units.

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[7]

**Q14.**

2 (a) What do you understand by the term *standard electrode potential*?

..........................................................................................................

.......................................................................................................... [2]

(b) By reference to relevant $E^{\ominus}$ data in the *Data Booklet*, explain how the halogen/halide electrode potentials relate to the relative reactivity of the halogens as oxidising agents.

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..........................................................................................................

.......................................................................................................... [2]

(c) Use data from the *Data Booklet* to construct redox equations, and calculate the standard cell potentials, for the reactions between

(i) Acidified $H_2O_2(aq)$ and KI(aq),

..........................................................................................................

(ii) $Cl_2(aq)$ + $SO_2(aq)$.

..................................................................................................................................
[4]

(d) Use data from the *Data Booklet* to predict the likely product of the reaction between $I_2(aq)$ and tin metal, writing a balanced equation for the reaction.

.................................................................................................................................. [2]

[Total: 10]

**Q15.**

3 The following account describes the preparation of Péligot's salt, named after the 19th century French chemist who first made it.

Place 6.0 g of potassium dichromate(VI) in a 100 $cm^3$ beaker and add 8.0 g of concentrated hydrochloric acid and 1.0 $cm^3$ water. Warm the mixture gently; if carefully done the dichromate(VI) will dissolve without the evolution of chlorine. On cooling the beaker in an ice bath the solution will deposit long orange-red crystals of Péligot's salt.

An analysis of Péligot's salt showed that it contained the following percentages by mass:
K, 22.4%; Cr, 29.8%; C*l*, 20.3%; O, 27.5%.

(a) Calculate the empirical formula of Péligot's salt.

[2]

(b) Suggest a balanced equation for the formation of Péligot's salt.

..................................................................................................................................[1]

**(c)** The instructions suggest that strong heating might cause chlorine to be evolved.

**(i)** What *type of reaction* would produce chlorine in this system?

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**(ii)** Use the *Data Booklet* to identify relevant half equations and $E^{\ominus}$ values for the production of chlorine from the reaction between $K_2Cr_2O_7$ and $HCl$.

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Use these equations to write the overall full ionic equation for this reaction.

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**(iii)** The use of **dilute** $HCl(aq)$ does not result in the production of chlorine. Suggest why this is so.

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**(iv)** Use the *Data Booklet* to suggest a reason why it is **not** possible to prepare the bromine analogue of Péligot's salt by using HBr(aq) instead of $HCl(aq)$.

..........................................................................................................................

[6]

[Total: 9]

**Q16.**

Use

5 Potassium manganate(VII) can be used to estimate the percentage of hydrogen peroxide in household bleach. The following unbalanced equation represents the reaction between them.

$$\ldots\ldots\ MnO_4^- + \ldots\ldots\ H_2O_2 + \ldots\ldots\ H^+ \longrightarrow \ldots\ldots\ Mn^{2+} + \ldots\ldots\ H_2O + \ldots\ldots\ O_2$$

**(a)** Balance this equation by putting the appropriate numbers in the spaces above. [1]

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

.......................................................................................................................... [1]

**(c)** When 0.020 mol dm$^{-3}$ $KMnO_4$(aq) was added from a burette into an acidified 25.0 cm$^3$ sample of $H_2O_2$, 15.0 cm$^3$ of $KMnO_4$ was required to reach the end-point.

**(i)** Describe what you would see during this titration, and also at the end-point.

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**(ii)** Calculate the concentration of $H_2O_2$ in the sample.

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[4]

[Total: 6]

# Q17.

1 **(a)** The Group IV oxides $CO_2$ and $SiO_2$ differ widely in their physical properties. Describe these differences and explain them in terms of their structure and bonding.

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.......................................................................................................................... [3]

**(b)** What are the properties of a *ceramic* material? Why is silicon(IV) oxide very suitable as a component of ceramics?

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.......................................................................................................................... [2]

**(c)** Lead(II) oxide reacts with both acids and bases.

**(i)** What is the name given to oxides that have this property?

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**(ii)** Write a balanced equation for the reaction between PbO and NaOH.

..........................................................................................................................

[2]

**(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.

*For Examiner Use*

- 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,

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

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**(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**.

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[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 $1.0 \times 10^{-5}$ 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.

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

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**(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)**.

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[4]

[Total: 19]

Exa

## Q18.

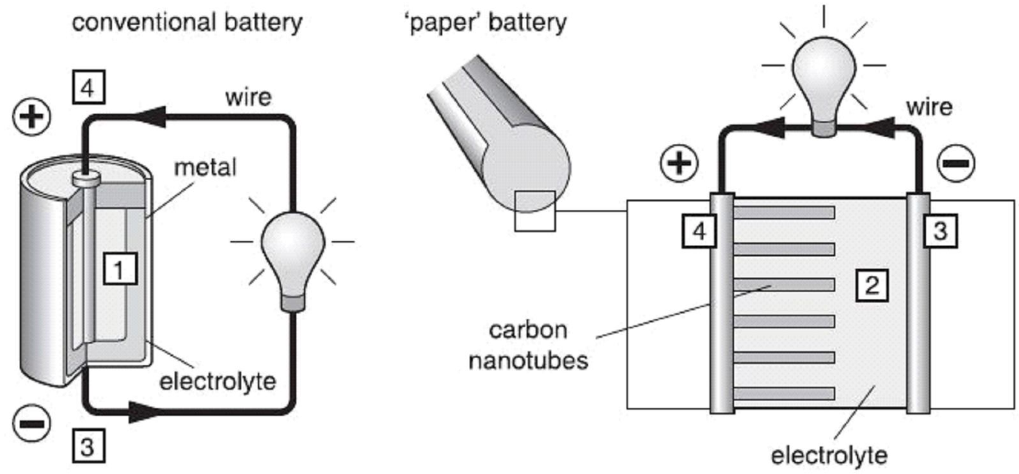
**8** A new method of making very light, flexible batteries using nanotechnology was announced in August 2007. Read the passage and answer the questions related to it.

*For Examiner's Use*

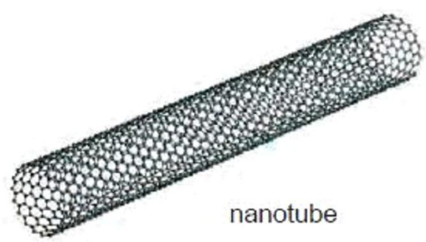
*Researchers have developed a new energy-storage device that could easily be mistaken for a simple sheet of black paper. The nano-engineered battery is lightweight, ultra-thin and completely flexible. It is geared towards meeting the difficult design and energy requirements of tomorrow's gadgets, such as implantable medical devices and even vehicles.*

*Researchers soaked 'paper' in an ionic liquid electrolyte which carries the charge. They then treated it with aligned carbon nanotubes, which give the device its black colour.*

*The nanotubes act as electrodes and allow the storage devices to conduct electricity. The device, engineered to function as both a battery and a supercapacitor, can provide the long, steady power output comparable to a conventional battery, as well as a supercapacitor's quick burst of high energy. The device can be rolled, twisted, folded, or cut into shapes with no loss of strength or efficiency. The 'paper' batteries can also be stacked, like a pile of printer paper, to boost the total power output.*




1. *Conventional batteries produce electrons through a chemical reaction between electrolyte and metal.*
2. *Chemical reaction in the 'paper' battery is between electrolyte and carbon nanotubes.*
3. *Electrons collect on the negative terminal of a battery.*
4. *Electrons must flow from the negative terminal, through the external circuit to the positive terminal for the chemical reaction to continue.*



**(a)** From your knowledge of the different structures of carbon, suggest which of these is used to make nanotubes.

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**(b)** Suggest a property of this structure that makes it suitable for making nanotubes.

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**(c)** Carbon in its bulk form is brittle like most non-metallic solids. Suggest why the energy storage device described can be rolled into a cylinder.

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**(d)** Name an example of an 'ionic *liquid* electrolyte' (not a solution).

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[Total: 4]

## Q19.

1 **(a)** Write a balanced equation for the reaction of each of the following chlorides with water.

phosphorus(V) chloride ..............................................................................................

silicon(IV) chloride ..............................................................................................

[2]

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

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

Use data from the *Data Booklet* to calculate the enthalpy change, $\Delta H$, for this reaction. The eight sulfur atoms in the $S_8$ molecule are all joined in a single ring by single bonds.

$\Delta H$ = ..........................................kJ $mol^{-1}$

[2]

**(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.

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

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

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**(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) .........................................................................................................

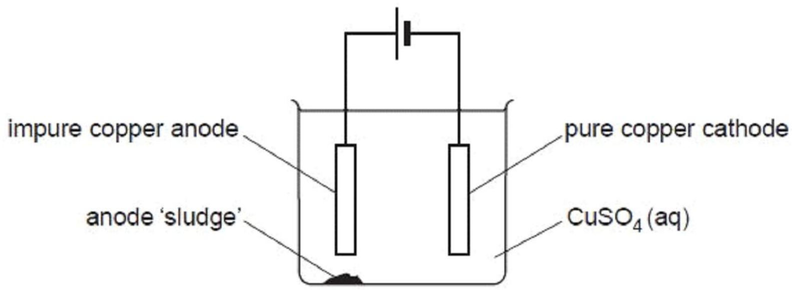
[7]

[Total: 11]

**Q20.**

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

For Examiner's Use




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.

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

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

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

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

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

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[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.

*For Examiner's Use*

**(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.

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[Total: 13]

**Q21.**

**9** A possible source of energy for the road vehicles of the future is hydrogen. One of the problems still to be solved is the storage of the hydrogen in the vehicle. A conventional tank holding liquid hydrogen would have to be pressurised and refrigerated. In a crash, this type of tank could break resulting in the rapid release of hydrogen and an explosion.

*For Examiner's Use*

One alternative is to use a fuel tank packed with carbon nanotubes. The hydrogen in the tank would be adsorbed onto the surface of the nanotubes at a pressure of no more than a few atmospheres.

**(a)** **(i)** What is the approximate width of a carbon nanotube?

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**(ii)** In what structural form is the carbon in a nanotube?

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**(iii)** What forces could be responsible for holding the hydrogen on the surface of the nanotubes? Explain your answer.

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[4]

**(b)** The hydrogen atoms in a fuel tank packed with nanotubes are closer together than in liquid hydrogen. Suggest **one** advantage of this.

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**(c)** When a nanotube-packed fuel tank is full of hydrogen there is a steady pressure of hydrogen in the tank. While hydrogen gas is being removed from the fuel tank to power the car, the pressure in the fuel tank drops very little for some time. State Le Chatelier's principle, and suggest how it explains this observation.

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..........................................................................................................................[4]

[Total: 9]

**Q22.**

**5** Chlorine is manufactured by the electrolysis of brine, $NaCl(aq)$. At the cathode, $H_2(g)$ and $OH^-(aq)$ are produced, but the product at the anode depends on the $[NaCl(aq)]$ in the solution. Either $O_2(g)$ or $Cl_2(g)$ is produced.

For Examiner's Use

**(a)** The equation for the cathode reaction is $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$.

Starting from **neutral** $NaCl(aq)$, write equations for the production at the anode of

**(i)** $O_2(g)$, ..........................................................................................................

**(ii)** $Cl_2(g)$. .......................................................................................................... [2]

**(b)** For electrolysis to occur, the voltage applied to the cell must be at least as large as the $E^{\ominus}_{cell}$, as calculated from standard electrode potentials.
Use the *Data Booklet* to calculate $E^{\ominus}_{cell}$ for the production at the anode of

**(i)** $O_2(g)$, ..........................................................................................................

**(ii)** $Cl_2(g)$. .......................................................................................................... [2]

**(c)** **(i)** By using **one** of the phrases *more positive*, *less positive* or *no change*, use the equations you wrote in **(a)** to deduce the effect of increasing $[Cl^-(aq)]$ on

- the $E_{anode}$ for the production of $O_2(g)$, ..........................................................
- the $E_{anode}$ for the production of $Cl_2(g)$. ..........................................................

**(ii)** Hence explain why the $Cl_2(g) : O_2(g)$ ratio increases as $[NaCl(aq)]$ increases.

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.......................................................................................................... [3]

**(d)** Sodium chlorate(V) is prepared commercially by electrolysing $NaCl(aq)$ in a cell which allows the cathode and anode electrolytes to mix.
The cathode reaction is the same as that described in **(a)**.
The equation for the anode reaction is

$$Cl^-(aq) + 6OH^-(aq) - 6e^- \rightarrow ClO_3^-(aq) + 3H_2O(l)$$

**(i)** Construct an ionic equation for the overall reaction.

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**(ii)** Calculate the mass of $NaClO_3$ that is produced when a current of 250 A is passed through the cell for 60 minutes.

For Examiner's Use

mass of $NaClO_3$ = .............................................g [4]

[Total: 11]

## Q23.

1 **(a)** Write down what you would see, and write equations for the reactions that occur, when silicon(IV) chloride and phosphorus(V) chloride are separately mixed with water.

silicon(IV) chloride

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phosphorus(V) chloride

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[4]

**(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.

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**(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.

For Examiner's Use

**(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]

**(c)** When $SiCl_4$ vapour is passed over Si at red heat, $Si_2Cl_6$ is formed. $Si_2Cl_6$ contains a Si-Si bond.

The reaction of $Si_2Cl_6$ and $Cl_2$ re-forms $SiCl_4$.

$$Si_2Cl_6(g) + Cl_2(g) \rightarrow 2SiCl_4(g)$$

Use bond energy data from the *Data Booklet* to calculate $\Delta H^\ominus$ for this reaction.

$\Delta H^{\ominus}$ = ............................ kJ mol$^{-1}$
[2]

**(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, ..............................................................

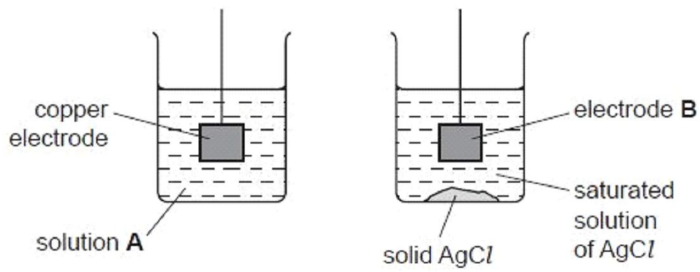
which element(s) have been reduced. ..............................................................
[2]

[Total: 14]

**Q24.**

For Examiner's Use

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 AgCl is much less than 1.0 mol dm$^{-3}$. The $E_{electrode}$ is related to $[Ag^{+}]$ by the following equation.

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

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

$E^{\circ}_{cell}$ = ........................... 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.

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**(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]

**(d)** Describe how the colours of the silver halides, and their relative solubilities in $NH_3(aq)$, can be used to distinguish between solutions of the halide ions $Cl^-$, $Br^-$ and $I^-$.

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.................................................................................................................................. [4]

**(e)** Describe and explain the trend in the solubilities of the sulfates of the elements in Group II.

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.................................................................................................................................. [4]

[Total: 18]

## Q25.

1 **(a)** Write down what you would see, and write equations for the reactions that occur, when magnesium chloride, aluminium chloride and silicon tetrachloride are separately mixed with water.

magnesium chloride

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aluminium chloride

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silicon tetrachloride

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[5]

**(b)** Sodium chloride is traditionally added to a particular meat product. In response to the evidence that sodium chloride can lead to high blood pressure, the manufacturers have replaced the sodium chloride with a mixture of sodium and potassium chlorides. 100 g of the meat product usually contains about 2 g of the chloride mixture.
A particular meat product contains 1.10 g of sodium chloride and 0.90 g potassium chloride in 100 g.

**(i)** Calculate the number of moles of chloride ions in 100 g of this meat product.

The amount of chloride in the meat product can be found by titration with silver nitrate solution.

**(ii)** Write the ionic equation, including state symbols, for the reaction between aqueous sodium chloride and aqueous silver nitrate.

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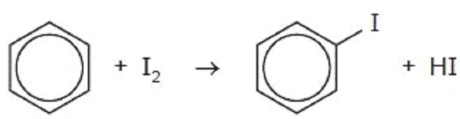
**(iii)** Calculate the volume of 0.0200 mol dm$^{-3}$ silver nitrate solution that would be required if this titration were carried out on 100 g of the particular meat product described above.

[5]

**(c)** The iodination of benzene requires the presence of nitric acid.

**(i)** Using bond enthalpies from the *Data Booklet*, calculate the enthalpy change for the following reaction.



**(ii)** Nitric acid reacts with hydrogen iodide according to the following unbalanced equation.

........HI + ........ $HNO_3$ → ........ $I_2$ + ........ $N_2O_3$ + ........ $H_2O$

Balance this equation, and describe how the oxidation numbers of nitrogen and iodine have changed during the reaction.

nitrogen ..........................................................................................................

iodine ..........................................................................................................

[4]

[Total: 14]

**Q26.**

**1** **(a)** Phosphorus and sulfur are two non-metallic elements on the right hand side of the Periodic Table.
For each of these elements describe the observations you would make when it burns in air, and write a balanced equation for the reaction.

**phosphorus**

observation ..........................................................................................................

equation ..............................................................................................................

**sulfur**

observation ..........................................................................................................

equation ..............................................................................................................

[4]

**(b)** White phosphorus, $P_4$, is produced commercially by heating calcium phosphate(V) rock with a mixture of silica, $SiO_2$, and coke in an electric furnace at 1400 °C. Calcium silicate, $CaSiO_3$, and carbon monoxide are the other products.

**(i)** Balance the following equation which represents the overall process.

$$\_\_\_ Ca_3(PO_4)_2 + \_\_\_ SiO_2 + \_\_\_ C \rightarrow \_\_\_ P_4 + \_\_\_ CaSiO_3 + \_\_\_ CO$$

When heated to 400 °C in the absence of air, white phosphorus is changed into the red form of the element. The following table lists some of the properties of the two forms, which are known as allotropes.

| allotrope | electrical conductivity | melting point / °C | solubility in water | solubility in benzene |
|---|---|---|---|---|
| white | none | 44 | insoluble | soluble |
| red | none | 500 | insoluble | insoluble |

**(ii)** Suggest the type of structure and bonding in each allotrope.

| allotrope | type of structure | type of bonding |
|---|---|---|
| white | | |
| red | | |

**(iii)** In both allotropes, phosphorus has a valency of 3. Suggest by means of diagrams how the phosphorus atoms might be joined together in each allotrope.

*For Examiner's Use*

| white phosphorus | red phosphorus |
|---|---|

[7]

[Total: 11]

## Q27.

**3** **(a)** State and explain the variation in the oxidation numbers of the chlorides of the elements Na, Mg, Al and Si.

*For Examiner's Use*

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..........................................................................................................................................[2]

**(b)** Describe the reaction of phosphorus(V) chloride with water, and write an equation for the reaction.

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**(c)** When microwave radiation is passed through phosphorus(III) chloride, $PCl_3$, at low pressure, a new chloride of phosphorus, **B**, is formed.
**B** contains 69.6% by mass of chlorine and 30.4% by mass of phosphorus, and its $M_r$ is approximately 200.

**(i)** Calculate the empirical and molecular formulae of **B**.

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**(ii)** Assuming phosphorus and chlorine show their typical valencies, draw the displayed formula of **B**, showing all bonds and lone pairs.

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**(iii)** Calculate the oxidation number of phosphorus in **B**.

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**(iv)** One mole of **B** reacts with four moles of water.
Suggest the structure of the phosphorus-containing product of this reaction.

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[6]

[Total: 10]

## Q28.

**4** The combustion of fuels in motor vehicles, trains, aeroplanes and power stations produces the pollutant gas $NO_2$.

*For Examiner's Use*

**(a)** Write an equation to show how $NO_2$ is formed in these situations.

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**(b)** **(i)** How is the $NO_2$ removed from the exhaust gases of motor vehicles?

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**(ii)** Write an equation for this process.

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[2]

**(c)** Suggest whether the production of the pollutant $NO_2$ would be reduced if fossil fuels were replaced by hydrogen as a fuel for combustion. Explain your answer.

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.......................................................................................................................[1]

**(d)** In the atmosphere, $NO_2$ acts as a catalyst for the oxidation of $SO_2$ to $SO_3$.

$$SO_2(g) + \tfrac{1}{2} O_2(g) \xrightarrow{NO_2} SO_3(g)$$

**(i)** What is the environmental significance of this reaction?

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The oxidation takes place in two steps. The initial reaction is that between $NO_2$ and $SO_2$.

*reaction 1* $NO_2(g) + SO_2(g) \rightleftharpoons NO(g) + SO_3(g)$ $\Delta H = -168\,kJ\,mol^{-1}$

**(ii)** Write an equation to show how the $NO_2$ is regenerated in the second step of the oxidation.

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**(iii)** Write an expression for the equilibrium constant, $K_p$ for *reaction 1*, stating its units.

$K_p$ =

units ..............................................

**(iv)** If equal amounts of $NO_2(g)$ and $SO_2(g)$ are allowed to react at room temperature, it is found that 99.8% of the gases have been converted into products at equilibrium. Calculate a value for $K_p$.

$K_p$ = ..............................................

(v) The temperature of the atmosphere decreases with height. How will this affect the position of the equilibrium in *reaction 1*? Explain your answer.

For Examiner's Use

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[7]

[Total: 11]

## Q29.

4 (a) Describe and explain the trend in the volatilities of the halogens $Cl_2$, $Br_2$ and $I_2$.

For Examiner's Use

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.............................................................................................................................. [3]

(b) For each of the following pairs of compounds, predict which compound has the higher boiling point, and explain the reasons behind your choice.
Use diagrams in your answers where appropriate.

(i) $H_2O$ and $H_2S$

**(ii)** $CH_3-CH_2-CH_3$ and $CH_3-O-CH_3$

[4]

**(c)** Briefly explain the shape of the $SF_6$ molecule, drawing a diagram to illustrate your answer.

[2]

[Total: 9]