SECTION A: MULTIPLE-CHOICE QUESTIONS

Instructions for Section A

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.
Choose the response that is **correct** or that **best answers** the question.
A correct answer scores 1, an incorrect answer scores 0.
Marks will **not** be deducted for incorrect answers.
No mark will be given if more than one answer is completed for any question.

Question 1

A calorimeter is calibrated chemically by measuring the temperature change caused by the combustion of precisely 1.131 g of benzoic acid. The enthalpy of combustion of benzoic acid is given by the thermochemical equation below.

$$2C_6H_5COOH(s) + 15O_2(g) \rightarrow 14CO_2(g) + 6H_2O(l) \quad \Delta H = -6454 \text{ kJ mol}^{-1}$$

If the temperature increases by 30.94°C, the calibration factor of the calorimeter (in J °C^{-1}) is

A. 208.5
B. 966.9
C. 1934
D. 3868

Questions 2 and 3 refer to the following information.

The industrial production of chemical R proceeds via the reaction represented by the equation below.

$$2P(g) + 4Q(g) \rightleftharpoons R(g) + 2S(g)$$

Question 2

Which of the following statements concerning the rate of this reaction is correct?

A. The rate of formation of R is one quarter the rate of the disappearance of Q.
B. The rate of disappearance of Q is one half of the rate of disappearance of P.
C. The rate of formation of S is double the rate of disappearance of Q.
D. The rate of disappearance of P is unrelated to the rate of appearance of S.

Question 3

A catalyst is used in the production of R.

Which of the following shows the effect of the catalyst on the rate of reaction, and on the amount of R produced?

	Rate of formation of R(g)	Amount of R(g) formed
A.	increases	no change
B.	increases	decreases
C.	increases	increases
D.	no change	increases

Question 4

Consider the following thermochemical equations.

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H = -393.5 \text{ kJ mol}^{-1}$$
$$S(s) + O_2(g) \rightarrow SO_2(g) \qquad \Delta H = -296.1 \text{ kJ mol}^{-1}$$
$$CS_2(l) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g) \qquad \Delta H = -1072 \text{ kJ mol}^{-1}$$

The enthalpy of reaction (in kJ mol^{-1}) for $C(s) + 2S(s) \rightarrow CS_2(l)$ is

A. –1762
B. –873.3
C. +86.3
D. +382.4

Question 5

Hydrogen sulfide (H_2S) is a weak, diprotic acid with ionisation constants $K_{a1} = 10^{-7}$ and $K_{a2} = 10^{-13}$. The following equilibria exist in a 0.10 M hydrogen sulfide solution.

$$H_2O(l) + H_2S(aq) \rightarrow H_3O^+(aq) + HS^-(aq)$$

$$H_2O(l) + HS^-(aq) \rightarrow H_3O^+(aq) + S^{2-}(aq)$$

Which species is present in the highest concentration in 0.10 M hydrogen sulfide solution?

A. $H_2S(aq)$
B. $H_3O^+(aq)$
C. $HS^-(aq)$
D. $S^{2-}(aq)$

Question 6

Sulfuryl chloride is formed when a mixture of sulfur dioxide and chlorine gas is heated according to the equation below.

$$SO_2(g) + Cl_2(g) \rightleftharpoons SO_2Cl_2(g) \quad \Delta H < 0$$

An appropriate procedure to increase the yield of SO_2Cl_2 would be to

A. increase the volume of the container.
B. increase the gas pressure by adding argon gas.
C. increase the temperature.
D. use an excess of SO_2 in the reaction mixture.

Question 7

Which of the following correctly states the energy changes occurring when chemical bonds are formed and broken?

A. Energy is released when bonds are formed and when they are broken.
B. Energy is absorbed when bonds are formed and when they are broken.
C. Energy is absorbed when bonds are formed and released when they are broken.
D. Energy is released when bonds are formed and absorbed when they are broken.

Question 8

Ammonium perchlorate (NH_4ClO_4) is used as the oxidising agent in solid fuel rocket boosters, as employed on the Discovery space shuttle. Its combustion generates temperatures in excess of 5800°C and lifts the space shuttle 45 km into the atmosphere in less than two minutes. An equation for this reaction is shown below.

$$3Al(s) + 3NH_4ClO_4(s) \rightarrow Al_2O_3(l) + 3NO(g) + 6H_2O(g) + AlCl_3(s) \quad \Delta H = -2667 \text{ kJ mol}^{-1}$$

The amount of energy (in MJ) generated by the combustion of 500 kg of ammonium perchlorate with excess aluminium powder is

A. 3.78
B. 3780
C. 1.13×10^4
D. 3.40×10^4

Question 9

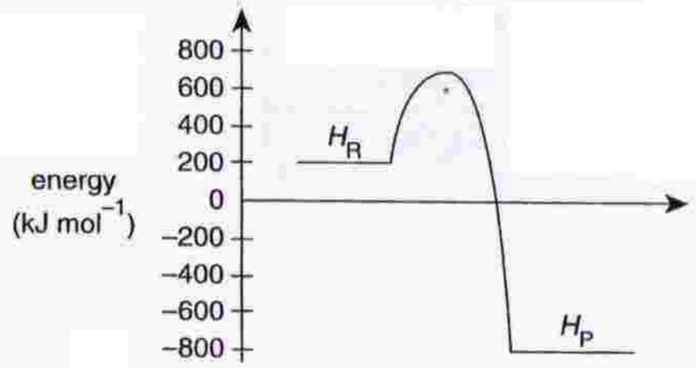
Which of the following shows acids arranged in order of increasing strength?

A. lactic acid < propanoic acid < hypochlorous acid
B. lactic acid < hypochlorous acid < propanoic acid
C. hypochlorous acid < propanoic acid < lactic acid
D. propanoic acid < lactic acid < hypochlorous acid

Questions 10 and 11 refer to the following information.

The diagram below represents the heat change for the reaction

$$2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)$$



Question 10

The enthalpy of reaction (ΔH in kJ mol^{-1}) for the reaction $4H_2S(g) + 6O_2(g) \rightarrow 4H_2O(l) + 4SO_2(g)$ is

A. –2000
B. –1600
C. –1000
D. +600

Question 11

If a catalyst was used in this reaction, the activation energy (E_A in kJ mol^{-1}) for the reaction $2SO_2(g) + 2H_2O(l) \rightarrow 2H_2S(g) + 3O_2(g)$ could be

A. 500
B. 800
C. 1200
D. 1500

Question 12

An amount of energy E (in kJ) was added to a mass m (in g) of a substance of specific heat capacity c (in J g^{-1} K^{-1}).

The increase in temperature (in °C) of the mass is given by the expression

A. $\frac{E}{m \times c} - 273$
B. $\frac{E}{m \times c}$
C. $\frac{1000E}{m \times c} - 273$
D. $\frac{1000E}{m \times c}$

Question 13

Passage of 0.10 faradays of electricity through an aqueous tin chloride solution deposited 5.94 g of tin at one electrode.

The oxidation number of tin in the chloride salt was likely to be

A. +1
B. +2
C. +3
D. +4

Question 14

80.0 mL of 0.150 M $Ba(OH)_2$ solution is added to 120 mL of 0.250 M HNO_3 solution.

The pH of the resulting mixture is closest to

A. 1.05
B. 1.13
C. 1.52
D. 12.5

Question 15

Consider the reaction shown in the equation below.

$$A + 2B \rightleftharpoons C \quad K = 0.318$$

Given that [A] = 0.532 M and [C] = 0.0914 M at equilibrium, the concentration of species B at equilibrium is

A. 0.234 M
B. 0.540 M
C. 0.735 M
D. 4.28 M

Questions 16 and 17 refer to the following information

The methylammonium ion ($CH_3NH_3^+$) is the weak acid conjugate of methylamine and reacts with water according to the equation below.

$$CH_3NH_3^+ + H_2O(l) \rightleftharpoons CH_3NH_2(aq) + H_3O^+(aq) \quad K_a = 2.7 \times 10^{-11}\ M$$

Question 16

The pH of a 0.050 M solution of methylammonium is

A. 4.6
B. 5.9
C. 9.3
D. 12

Question 17

A small amount of 4 M hydrochloric acid is added to a solution of the methylammonium ion so as to increase the concentration of $H_3O^+(aq)$ ions.

After a period of time, when equilibrium is re-established,

A. the concentration of methylammonium ions will have decreased.
B. the pH will have increased.
C. the value of the fraction $\frac{[CH_3NH_2][H_3O^+]}{[CH_3NH_3^+]}$ will have increased.
D. the value of the fraction $\frac{[CH_3NH_2][H_3O^+]}{[CH_3NH_3^+]}$ will not have changed.

Question 18

In many industrial processes there is a conflict between the temperature required to achieve the maximum yield and the temperature desired to obtain the fastest rate of reaction. Consider the reactions below.

I $2P(g) + 3Q(g) \rightleftharpoons 2R(g) \quad \Delta H > 0$

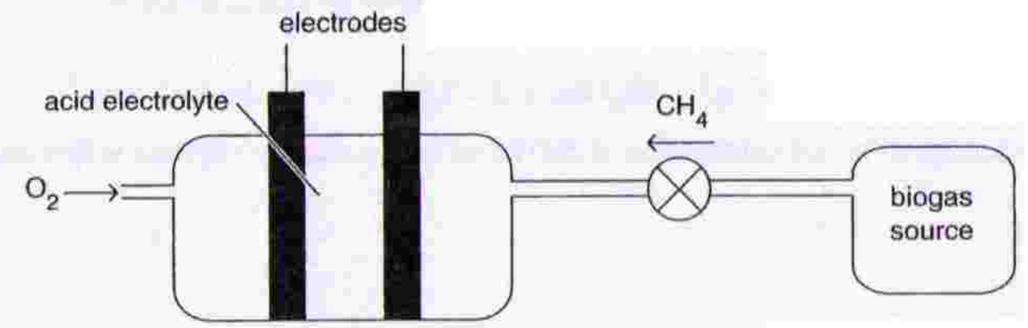
II $P(g) + 2Q(g) \rightleftharpoons 3R(g) \quad \Delta H < 0$

For which of these reactions would this conflict arise?

A. I only
B. II only
C. both I and II
D. neither I nor II

Questions 19 and 20 refer to the following information.

The diagram below shows a laboratory model of a fuel cell designed to produce electricity using the methane found in biogas.



Question 19

The source of the methane in the biogas is the

A. anaerobic breakdown of organic matter by a variety of microorganisms.
B. aerobic breakdown of organic matter by a variety of microorganisms.
C. yeast-catalysed anaerobic breakdown of glucose.
D. yeast-catalysed aerobic breakdown of glucose.

Question 20

In this fuel cell, the reductant and the half equation for the reaction occurring at the cathode are

	Reductant	Cathode reaction
A.	oxygen	$CH_4(g) + 2H_2O(l) \rightarrow CO_2(g) + 8H^+(aq) + 8e$
B.	methane	$CH_4(g) + 2H_2O(l) \rightarrow CO_2(g) + 8H^+(aq) + 8e$
C.	oxygen	$O_2(g) + 4H^+(aq) + 4e \rightarrow 2H_2O(l)$
D.	methane	$O_2(g) + 4H^+(aq) + 4e \rightarrow 2H_2O(l)$

SECTION B: SHORT-ANSWER QUESTIONS

Instructions for Section B

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

To obtain full marks for your responses you should

- give simplified answers with an appropriate number of significant figures to all numerical questions; unsimplified answers will not be given full marks.
- show all working in your answers to numerical questions. No credit will be given for an incorrect answer unless it is accompanied by details of the working.
- make sure chemical equations are balanced and that the formulas for individual substances include an indication of state, for example $H_2(g)$; NaCl(s).

Question 1

When excess calcium carbonate pieces are added to dilute hydrochloric acid, a reaction occurs according to the equation shown below.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

a. Describe one way in which the rate of this reaction could be studied.

1 mark

b. On the axes provided below, sketch a graph to show the expected results of the rate investigation outlined in part **a**.

2 marks

c. How would the total volume of carbon dioxide gas produced in this reaction change (increase, decrease or remain the same) if a greater mass of calcium carbonate was used? Explain your choice.

2 marks

Total 5 marks

Question 2

a. 2.00 mol of nitrosyl bromide ($NOBr_2$) is introduced into a 5.00 L evacuated vessel at a temperature of 350 K. The gas decomposes and reaches equilibrium according to the equation below.

$$2NOBr_2(g) \rightleftharpoons 2NO(g) + Br_2(g) \quad \Delta H < 0$$

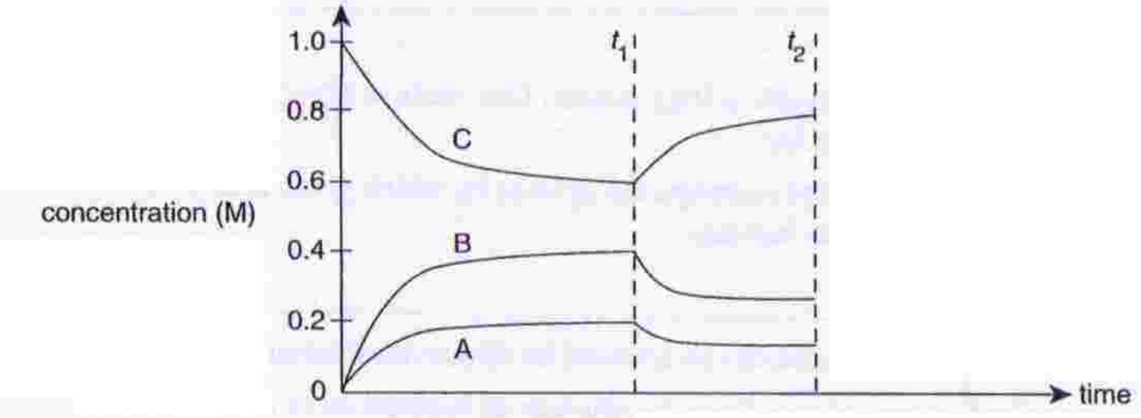
At equilibrium, 1.528 mol of $NOBr_2$ remained.

i. Calculate the concentrations of the three gases in the container once equilibrium had been established.

ii. Calculate the equilibrium constant for the reaction at this temperature.

2 + 1 = 3 marks

b. In a second experiment, a quantity of $NOBr_2$ was introduced into a vessel and allowed to reach equilibrium at constant temperature. A graph showing the changes in concentrations of the three gases over a period of time is shown below.



i. Identify gas B as shown on the graph above.

ii. At time t_1 the temperature in the reaction vessel was changed.

Was the temperature increased or decreased? Explain your answer in terms of Le Chatelier's Principle.

iii. At time t_2 a small quantity of chemical B was added while the temperature remained constant. On the same set of axes draw what changes would occur in the concentrations of gases A, B and C as the reaction proceeds to a new equilibrium position.

1 + 2 + 2 = 5 marks

Total 8 marks

Question 3

a. With the increasing need to find renewable energy sources, scientists have been investigating the use of chemicals in 'heat banks' rather than traditional brick or stone walls. A heat bank is a device that absorbs passive solar radiation and releases it into the home when the sun goes down, thus helping to keep a home cool during the day and warm at night. One such chemical is sodium sulfate decahydrate, $Na_2SO_4.10H_2O$, also known as Glauber's Salt. The chemical is placed into sealed sleeves and these are placed into the ceiling space of houses. When the temperature reaches 32°C the salt dissolves in its own water of hydration and absorbs thermal energy according to the equation below.

$$Na_2SO_4.10H_2O(s) \rightleftharpoons Na_2SO_4(aq) \quad \Delta H = +78.2 \text{ kJ mol}^{-1}$$

i. Calculate the amount of heat energy that would be absorbed by 25.0 kg of Glauber's Salt as it changes from a solid to a solution at 32°C.

ii. Determine the increase in temperature that would be experienced by 25.0 kg of water if it was to absorb the same amount of heat energy, given that the specific heat capacity of water is $4.18 \text{ J °C}^{-1} \text{ g}^{-1}$.

2 + 1 = 3 marks

b. Solar energy is a promising renewable energy source. One method of capturing solar energy is through its use in producing biomass.

i. Write a balanced equation to represent the process by which green plants convert solar energy into the chemical energy in biomass.

ii. The energy stored in biomass can be released by direct combustion.

State **one** disadvantage of this direct combustion of biomass as an energy source.

iii. Alternatively, the energy stored in biomass can be released through conversion of biomass to bioethanol.

State **one** way in which bioethanol may be used as an energy source

1 + 1 + 1 = 3 marks

c. Solar energy can also be directly converted to electricity by photovoltaic cells.

State **one** disadvantage of using photovoltaic cells.

1 mark

d. For each of the following energy sources, state **one** reason why it is not widely used at present.

i. nuclear fusion

ii. geothermal energy

1 + 1 = 2 marks

e. The headline of an article describing the gopher tree reads 'Fuel does grow on trees!'. The gopher tree contains one third hydrocarbons in its sap, and it has been suggested that this hydrocarbon mixture could be used as an alternative energy source.

i. Suggest **one** advantage of this potential energy source.

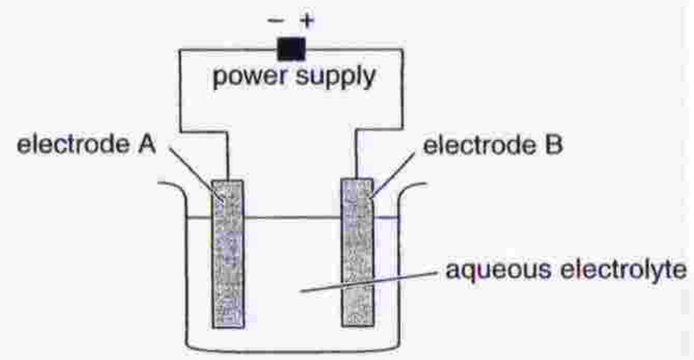
ii. Suggest **one** disadvantage of this potential energy source.

1 + 1 = 2 marks
Total 11 marks

Question 4

Three experiments were conducted to investigate electrolytic cell reactions.

a. In experiment 1, the apparatus shown below was used.



After current had passed through the cell for some time, a reddish brown liquid was formed at electrode B, while a metal was found deposited on electrode A.

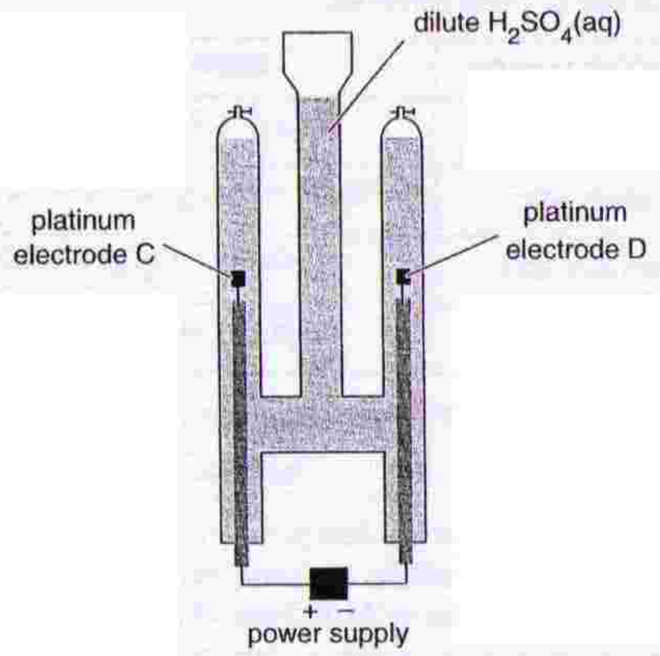
i. Suggest the probable formula of the reddish brown liquid.

ii. Explain why the deposited metal could not be magnesium.

iii. Suggest a possible electrolyte for this cell which is consistent with the observations made.

1 + 2 + 1 = 4 marks

b. In experiment 2, the apparatus shown below was used with a dilute sulfuric acid solution as the electrolyte. A steady current of 0.060 amperes was maintained during the experiment.

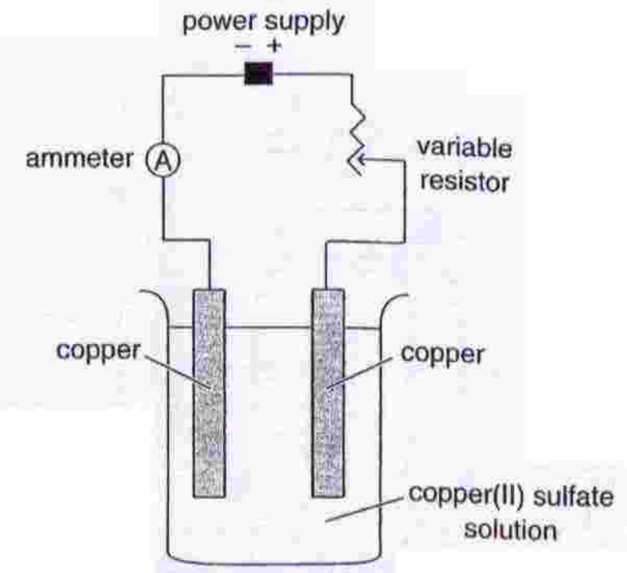


i. Write a half equation for the gas-producing reaction expected at electrode C.

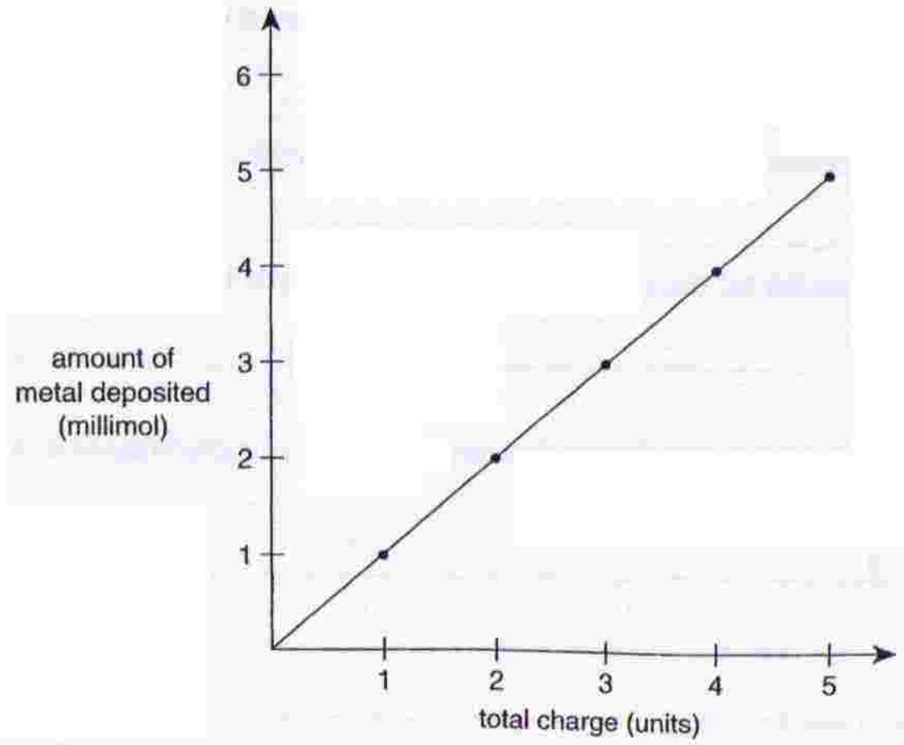
ii. Determine the minimum amount of time needed to collect 25.0 mL of gas at electrode C, assuming standard laboratory conditions are used.

1 + 3 = 4 marks

c. In experiment 3, the apparatus shown below was used with a dilute copper(II) sulfate solution as the electrolyte.



A measured current was passed through the cell for a fixed time, and the mass of copper deposited at one electrode was determined and recorded. The experiment was repeated several times to obtain the results shown in the graph below.



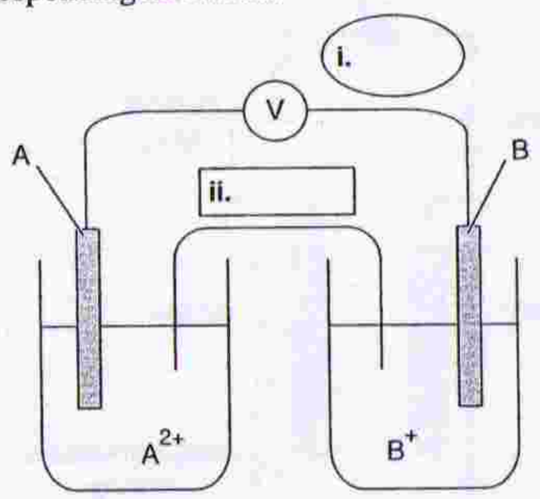
On the axes shown above, draw the results expected if the experiment was repeated using the same apparatus, but replacing the copper(II) sulfate electrolyte with a silver nitrate solution, and replacing the copper electrodes with silver electrodes.

2 marks

Total 10 marks

Question 5

A galvanic cell was set up as shown in the diagram below. Each half cell consisted of a strip of metal immersed in a solution of the corresponding metal ion.



After some time the two electrodes were removed from the cell, carefully dried and weighed. Electrode A had decreased in mass by 0.34 g, while electrode B had increased in mass by 1.3 g.

a. Complete the labelling of the diagram by showing the direction of

i. electron movement (place an arrow in the oval pointing in the appropriate direction).

ii. cation movement in the salt bridge (place an arrow in the rectangle pointing in the appropriate direction).

1 + 1 = 2 marks

b. i. Write a half equation for the reaction occurring at electrode A.

_____

ii. Write a half equation for the reaction occurring at electrode B.

_____

1 + 1 = 2 marks

c. i. Using the results of the experiment, determine the ratio of molar masses of metals A and B. Express this ratio as M(A):M(B).

_____

_____

_____

_____

_____

_____

ii. Given that metals A and B are both transition metals, use the electrochemical series and the Periodic Table in the Data Booklet to suggest a possible identity for each of metals A and B.

_____

_____

2 + 2 = 4 marks
Total 8 marks

Question 6

A significant reaction from each of four industrial production processes is listed below. Answer the following questions by referring to one of these reactions.

Industrial production process	Significant reaction
production of ammonia	$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
production of nitric acid	$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$
production of sulfuric acid	$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
production of ethene	$C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g)$

Circle the name of the industrial production process that you have chosen.

ammonia nitric acid sulfuric acid ethane

a. i. For the significant chemical reaction relevant to your chosen industrial process, circle the relevant term (high or low) to indicate the temperature and pressure conditions that would theoretically be used to maximise the yield and rate of reaction.

	Temperature		Pressure	
Yield	high	low	high	low
Rate	high	low	high	low

ii. In practice, the conditions given in part **i** may not necessarily be employed.

State the approximate conditions (temperature and pressure) actually used in industry for the chosen reaction.

_____

_____

iii. Explain any differences between the conditions listed in parts **i** and **ii**.

_____

_____

_____

2 + 2 + 2 = 6 marks

b. i. State **one** way in which waste materials from the chosen production process are managed so as to restrict their adverse effects on the environment.

_____

ii. State **one** safety consideration that needs to be taken into account in the chosen production process.

_____

1 + 1 = 2 marks
Total 8 marks

END OF QUESTION AND ANSWER BOOKLET

