Section A

Answer **all** questions.

1 Table 1.1 shows a list of substances.

Table 1.1

ammonium carbonate	barium chloride	copper(II) sulfate
potassium oxide	silicon dioxide	silver chloride
sulfur dioxide	zinc carbonate	zinc sulfate

Use the list of substances to answer the following questions.
Each substance can be used once, more than once, or not at all.

(a) Which substance(s) can be prepared by the reaction of a metal with a dilute acid?

.... [1]

(b) Which substance(s) will turn moist blue litmus paper red?

.... [1]

(c) Which substance(s) can be prepared by precipitation?

.... [1]

(d) Which substance(s) can react with both acids and alkalis to form gaseous products?

.... [1]

[Total: 4]

2 Separate beams of protons, neutrons and electrons are passed through an apparatus shown in Fig 2.1. The apparatus contains a positively-charged plate and a negatively-charged plate, which sets up an electric field.

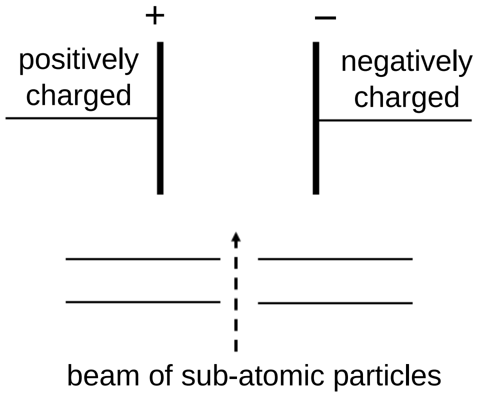

Fig 2.1

Sub-atomic particles behave differently in the apparatus depending on their masses and charges.

(a) **(i)** Draw an arrow to indicate the path of the particle which will be deflected the most by the electric field, and label the name of the particle. [1]

(ii) Explain your answer.

……………………………………………………………………………………………...

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

(b) **(i)** In nuclear reactions, protons or neutrons are accelerated to high speeds and fired as 'nuclear bullets' at the nucleus of an atom of an element.

Suggest why protons are less effective 'nuclear bullets' than neutrons.

……………………………………………………………………………………………...

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

(ii) When neutrons are fired at nucleus of atoms, the neutrons may become part of the nucleus of those atoms.

Explain the effect of the presence of an extra neutron on the chemical properties of the new atoms formed.

……………………………………………………………………………………………...

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

[Total: 4]

3 Boron trifluoride, BF_3 is often used as a versatile building block for other boron compounds.

Fig 3.1 shows the bonding in a boron trifluoride molecule, showing only outer electrons.

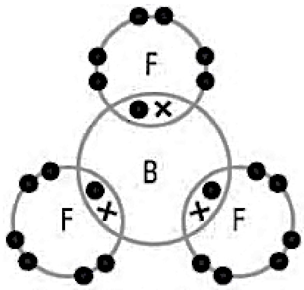

Fig 3.1

(a) Give a reason why the bonding in BF_3 is typical and one reason why it is not typical of similarly bonded compounds.

………………………………………………………………………………………………….

………………………………………………………………………………………………….

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

(b) Boron trifluoride can react with caesium fluoride to form caesium tetrafluoroborate.

$$BF_3 + CsF \rightarrow CsBF_4$$

Caesium tetrafluoroborate consists of caesium cations and tetrafluoroborate anions. Tetrafluoroborate ion has a chemical formula BF_4^- and is formed when the fluoride ion from caesium fluoride **donates a pair of electrons** to the outermost electron shell of the central boron atom.

Draw a 'dot-and-cross' diagram to show the arrangement of electrons in a tetrafluoroborate ion.

Show outer electrons only.

[2]

(c) Boron trifluoride and caesium tetrafluoroborate both contain boron and fluorine atoms but have vastly different physical properties.

Boron trifluoride has a boiling point of −100.3 °C.
Caesium tetrafluoroborate has a melting point of 555 °C.

Explain, in terms of bonding and structure, why boron trifluoride and caesium tetrafluoroborate exist as different states at room temperature and pressure.

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…………………………………………………………………………………………………

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………………………………………………………………………………………………… [3]

[Total: 7]

4 Titration experiments are commonly used to determine the concentration of chemical species in samples.

(a) A student conducted a titration experiment to investigate the percentage purity of a sample.

Substance **Q** is impure calcium carbonate.

50.00 cm^3 of 0.200 mol/dm^3 sulfuric acid was first added to a sample of **Q**. It is assumed that the impurities in **Q** do not react with acid. The excess sulfuric acid that did not react with **Q** was titrated with 0.320 mol/dm^3 of dilute potassium hydroxide. The average volume of potassium hydroxide required for the titration was 25.00 cm^3.

Given that 0.835 g of substance **Q** was used in the experiment, calculate the percentage purity of Substance **Q**.

percentage purity of Q = …………………% [4]

(b) The pH and electrical conductivity of the reaction mixture will change during titration experiments.

In a separate experiment, dilute sodium hydroxide was slowly added from a burette to 24 cm^3 of 0.100 mol/dm^3 nitric acid. The graph in Fig 4.1 shows the pH changes during this titration experiment.

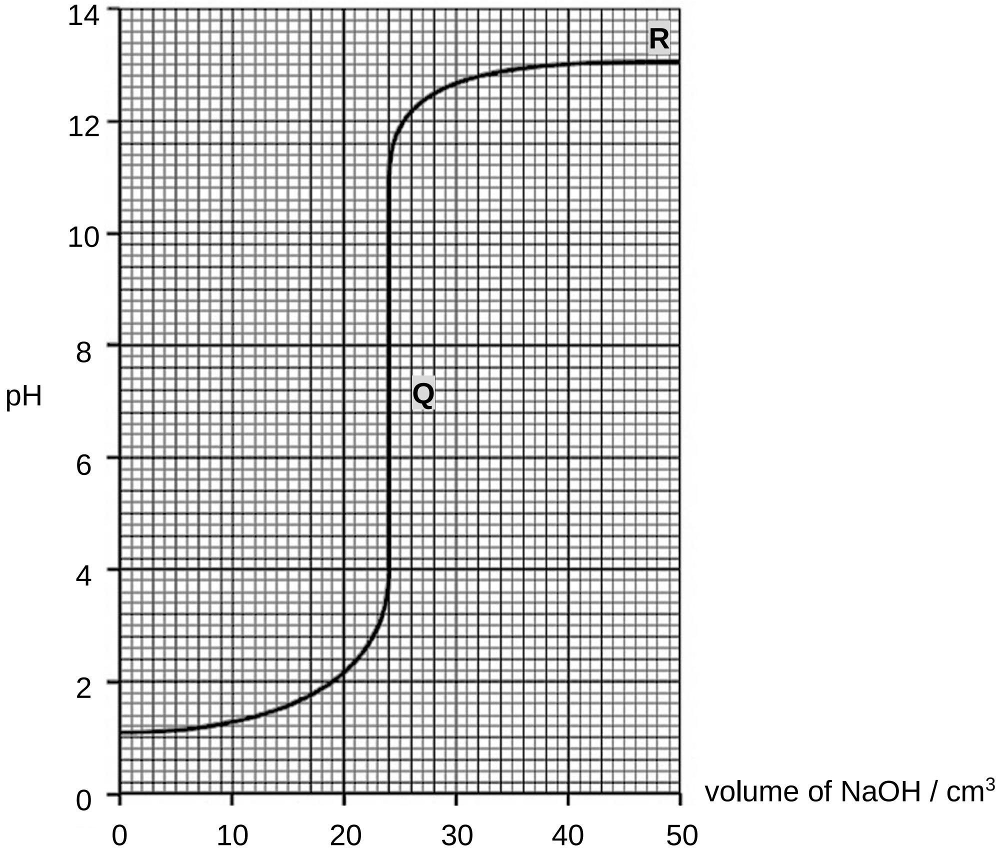


Fig 4.1

The electrical conductivity of the reaction mixture was also measured.

(i) The electrical conductivity of the reaction mixture increases from **Q** to **R**. Explain this observation.

…………………………………………………………………………………………..

…………………………………………………………………………………………..

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

(ii) The experiment is repeated using 24 cm^3 of 0.100 mol/dm^3 ethanoic acid.

Given that the pH value of the ethanoic acid is 4, draw a graph on Fig 4.1 to show the results you would expect to obtain. [1]

(iii) Nitric acid and ethanoic acid used in the titration experiments have the same concentration.

Explain why they have different pH values.

…………………………………………………………………………………………..

…………………………………………………………………………………………..

…………………………………………………………………………………………..

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

[Total: 8]

5 Some chemical reactions consist of multiple steps, with each step typically involving one or two reactants. One example of a multistep chemical reaction is the iodine clock reaction.

The reaction uses peroxodisulfate ions, $S_2O_8^{2-}$ to oxidise iodide ions to iodine in two separate steps. A small amount of iron(II) ions is also added to the reaction mixture during the reaction.

In the first step, iron(II) ions react with peroxodisulfate ions to form iron(III) and sulfate ions.

$$2Fe^{2+}\,(aq) + S_2O_8^{2-}\,(aq) \rightarrow 2Fe^{3+}\,(aq) + 2SO_4^{2-}\,(aq)$$

The iron(III) ions further react with iodide ions to form iodine.

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

A brown solution is obtained at the end of the iodine clock reaction.

(a) Explain the role of iron(II) ions in the iodine clock reaction.

………………………………………………………………………………………………….

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

(b) **(i)** Describe how iron(II) ions could be removed completely from aqueous iodine at the end of the experiment.

……………………………………………………………………………………………..

……………………………………………………………………………………………..

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

(ii) A few drops of potassium astatide was added to the solution after the Fe^{2+} ions were removed at the end of the experiment.

State the expected observations and explain your answer.

……………………………………………………………………………………………..

……………………………………………………………………………………………..

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

[Total: 5]

6 The chemical reactivity of four metals, **W**, **X**, **Y** and **Z** was investigated in a series of experiments.

In the first experiment, small pieces of different metals were added to different solutions of metal ions in water. The results are summarised in Table 6.1.

Table 6.1

	W	**X**	**Y**	**Z**
W^{3+}		reaction occurs	reaction occurs	no reaction
X^{2+}	no reaction		reaction occurs	no reaction
Y^{+}	no reaction	no reaction		no reaction
Z^{2+}	reaction occurs	reaction occurs	reaction occurs	

(a) **(i)** Place the four metals in order of increasing chemical reactivity, with the **least** reactive metal first.

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

(ii) Write a balanced chemical equation, with state symbols, for the reaction between metal **X** and the nitrate of **W**.

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

(b) In the second experiment, it was found that the oxide of metal **X** can be reduced by heating with carbon, but not by hydrogen.
Suggest the identity of metal **X**.

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

(c) In the third experiment, metal **W**, **X** and **Z** were heated in steam for a fixed amount of time.

(i) Given that copper is found between **W** and **Z** in the reactivity series, describe and explain the difference in volumes of gas collected for the reactions in the third experiment, during the first two minutes.

…………………………………………………………………………………………..

…………………………………………………………………………………………..

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

(ii) Name a suitable drying agent for the gas produced in the reaction between the metals and steam.

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

(d) Metal **V** is in the same group as metal **Y** but is more reactive than **Y**.
Suggest the position of metal **V** relative to **Y** in the Periodic Table.
Explain your reasoning.

…………………………………………………………………………………………….

…………………………………………………………………………………………….

…………………………………………………………………………………………….

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

[Total: 8]

7 Nearly all petrol and diesel vehicles have some kind of catalytic converter fitted to the exhaust to reduce the amount of polluting substances emitted into the atmosphere.

Fig 7.1 shows one design of a catalytic converter.

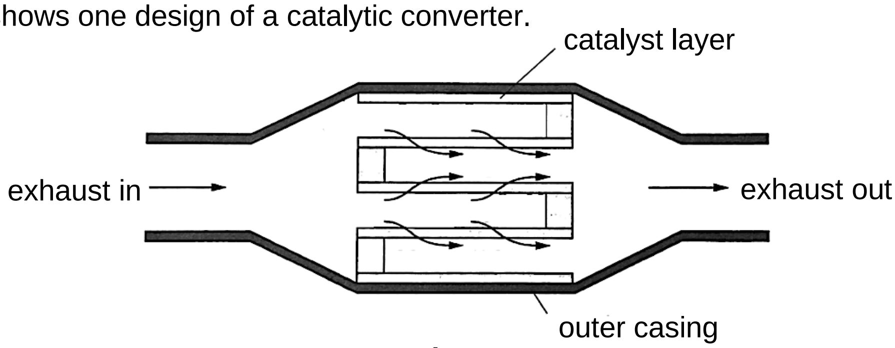


Fig 7.1

Oxides of nitrogen, carbon monoxide and unburnt hydrocarbons are pollutants that enter the catalytic converter.

(a) **(i)** Explain how these pollutants are converted into less harmful substances.

……………………………………………………………………………………………..

……………………………………………………………………………………………..

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

(ii) Suggest one reason why the catalytic converter is less effective at removing oxides of nitrogen when the temperature of the car engine is high.

……………………………………………………………………………………………..

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

(b) Diesel engines may also be fitted with a second catalytic converter to remove the remaining oxides of nitrogen. This second converter uses ammonia.

One possible reaction is shown by the following chemical equation.

$$8NH_3 + 6NO_2 \rightarrow 7N_2 + 2H_2O$$

Explain, in terms of oxidation states, whether the reaction is a redox reaction.

…………………………………………………………………………………………….

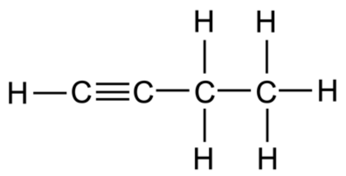
…………………………………………………………………………………………….

…………………………………………………………………………………………….

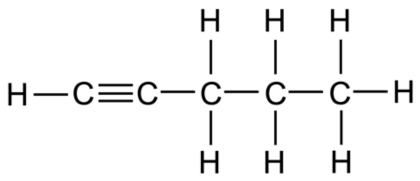
……………………………………………………………………………………………. [2]

[Total: 5]

8 Alkynes are a homologous series of hydrocarbons.
The structural formulae of two members of this series are shown.



butyne



pentyne

(a) Given that the members of a homologous series have the same general molecular formula, deduce the molecular formula of the first member of the alkyne series.

molecular formula: …………………………… [1]

(b) Alkynes react in a similar way to alkenes.

(i) Write a balanced chemical equation for the reaction that occurs when butyne is burnt in oxygen.

……………………………………………………………………………….. [1]

(ii) Describe a simple test that can be used to distinguish between butyne and butane.

………………………………………………………………………………..

……………………………………………………………………………….. [1]

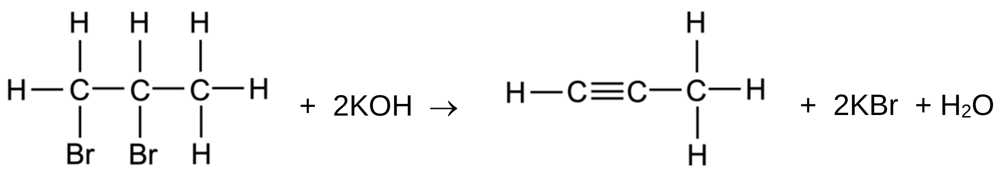
(iii) State the type of reaction that occurs when butyne reacts with steam and draw the structural formula of a possible product formed.

type of reaction ……………………………………………

structural formula of product:

[2]

(c) Alkynes can be prepared by reacting with dibromoalkane with potassium hydroxide solution. An equation for the reaction is shown in Fig 8.1.

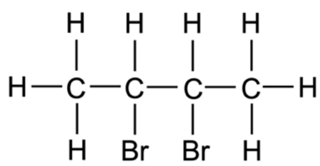


dibromoalkane

propyne

Fig 8.1

Another bromoalkene shown below also reacts with potassium hydroxide solution.



Draw the structural formulae of the alkyne formed.

[1]

(d) Predict whether the dibromoalkane shown in Fig 8.2 forms an alkyne when it is added to potassium hydroxide solution.

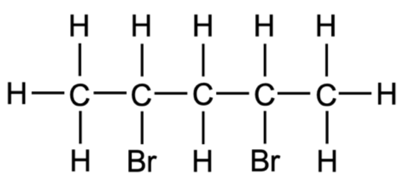


Fig 8.2

Explain your answer.

....

.... [1]

(e) PHBV, or poly(3-hydroxybutyrate-*co*-3-hydroxyvalerate) is a biodegradable and non-toxic plastic commonly used in food packaging. The structure of this polymer is shown in Fig 8.3.

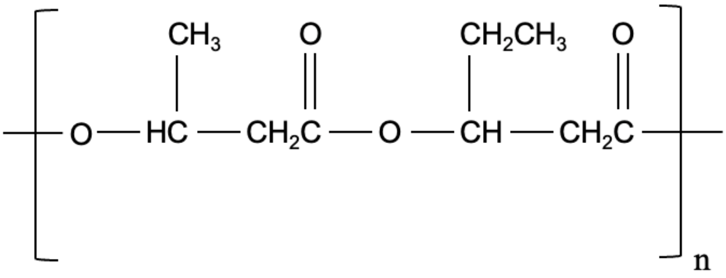


Fig 8.3

Draw the structural formulae of the two monomers used to make PHBV.

[2]

[Total: 9]

9 Steel is an alloy made up of iron and carbon. Two electrolysis experiments were carried out with steel electrodes.

In experiment 1, aqueous silver nitrate is electrolysed with platinum and steel electrodes.

In experiment 2, aqueous silver nitrate is electrolysed with silver and steel electrodes.

Fig 9.1 shows the appearance of the experimental set-ups before electrolysis.

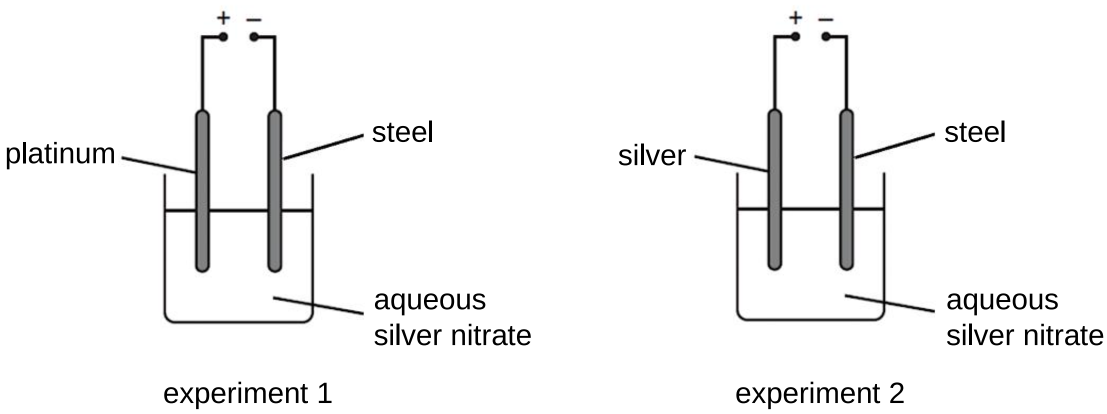


Fig 9.1

(a) Explain the observations at the end of experiment 1 and 2.

Your answer should:

- describe the expected observations in each experiment,
- explain why each change occurs,
- give half-equations for each change,
- explain why the run time for experiment 1 is shorter than in experiment 2.

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....

....

....

....

....

.... [6]

(b) Experiment 3 was conducted by modifying the electrolysis set-up in experiment 2.

In experiment 3, the battery was removed and replaced by a voltmeter.

Describe and explain the experimental observations at the steel electrode of experiment 3.

…………………………………………………………………………………………….

…………………………………………………………………………………………….

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

[Total: 8]

10 Enthalpy Change

Energy changes occur in chemical reactions as bonds are broken and new bonds are formed. Enthalpy change (ΔH) measures the difference in energy content of the reactants and products, and indicates the amount of heat absorbed or released in the chemical reaction. The sign and magnitude of enthalpy change allows chemists to plan their reactions and helps industries determine the efficiency of their processes.

The enthalpy changes accompanying chemical processes can be expressed in different ways, depending on the nature of the reaction:

Enthalpy change of reaction (ΔH_r) is defined as the amount of energy change when the molar quantities of reactants specified in the balanced chemical equation react to form products.

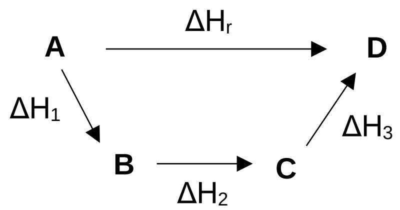
Enthalpy change of combustion (ΔH_c) of a substance is defined as the amount of energy released when one mole of the substance is completely burnt in oxygen.

Hess' Law

In 1840, a chemist Germain Hess introduced **Hess' law**, which states that the enthalpy change of a reaction depends only on the initial and final states of the system and is independent of the pathway taken.

This means that the energy change of a chemical reaction is the same regardless of whether the reaction takes place in one step or several steps. The Hess' law enables chemists to determine the enthalpy change of a reaction indirectly through the alternative pathways through which the reactants of the reaction can be converted to its products.

Hess' law can be illustrated in Fig 10.1. The enthalpy change of reaction (ΔH_r), to convert reactant **A** to product **D** can be found by adding the enthalpy changes of alternative pathways, where **A** is converted to **B**, then **C**, and finally **D**.



By Hess' Law, $\Delta H_r = \Delta H_1 + \Delta H_2 + \Delta H_3$

Fig 10.1

For instance, Hess' law can be used to calculate the enthalpy change of reaction between carbon and steam to form carbon dioxide and hydrogen gas. Fig 10.2 shows an energy cycle with the alternative reaction pathways.

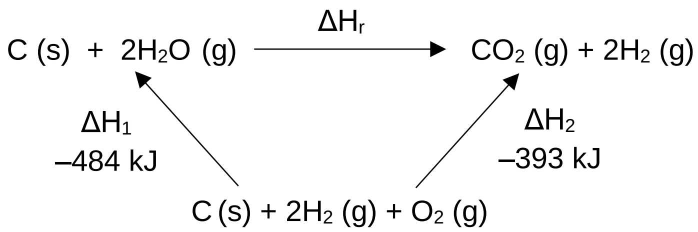


Fig 10.2

By Hess' law

$$\Delta H_1 + \Delta H_r = \Delta H_2 \quad \text{(clockwise = anticlockwise)}$$

rearranging the equation,

$$\begin{aligned}\Delta H_r &= \Delta H_2 - \Delta H_1 \\ &= -393 - (-484) \\ &= 91 \text{ kJ}\end{aligned}$$

Formation of Methane

Methane can be formed from its constitutent elements.

$$C\ (s) + 2H_2\ (g) \rightarrow CH_4\ (g)$$

The enthalpy change of formation of methane from its elements can be calculated using Hess' law. Table 10.1 shows the enthalpy changes of combustion of the respective reactants and products.

Table 10.1

reaction	ΔH_c / kJ/mol
$H_2\ (g) + \frac{1}{2}O_2\ (g) \rightarrow H_2O\ (l)$	–286
$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$	–393
$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (l)$	–890

Bomb Calorimeter

The enthalpy change of some reactions can also be determined experimentally using a bomb calorimeter by measuring the heat evolved or absorbed. Fig 10.3 shows a bomb calorimeter, inside a controlled temperature jacket, which is used to find accurate values of enthalpy changes of combustion for substances.

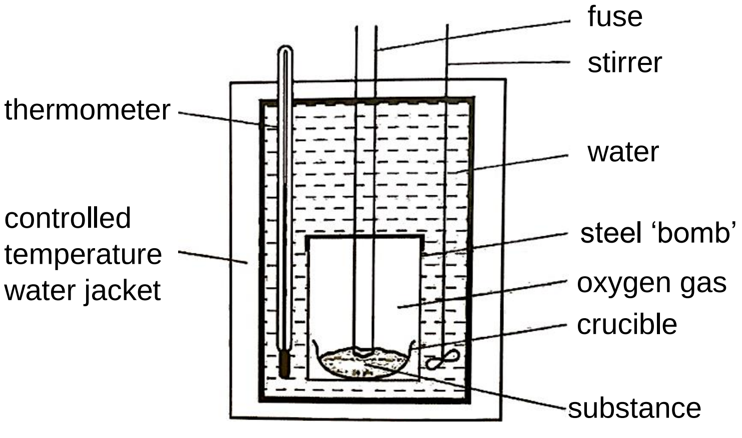


Fig 10.3

A known quantity of substance is placed in the crucible in the 'bomb', which is a strong steel container. The bomb is filled with oxygen gas at high pressure and then immersed into a container filled with water, inside a controlled temperature water jacket. The substance is ignited using a fuse and the maximum temperature rise of the water inside the calorimeter is measured.

Equal number of moles of three samples were burnt in the bomb calorimeter separately and the maximum temperature rise of the water inside the calorimeter is recorded in Table 10.2.

Table 10.2

sample	initial temperature / ºC	highest temperature / ºC
1	25.0	37.0
2	25.0	33.0
3	25.0	49.0

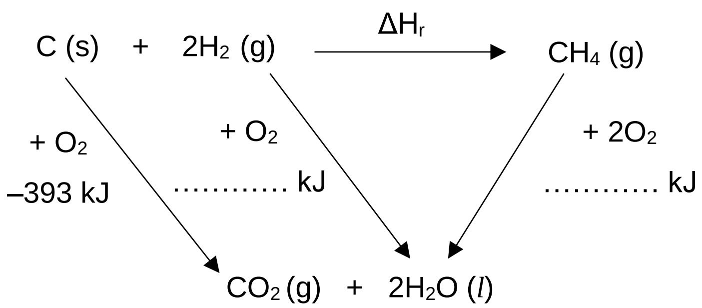
The samples are (not necessarily in this order) methane, ethanol and butanol. The change in temperature within the calorimeter is then proportional to the energy change of combustion of substance.

The reference value for the enthalpy change of combustion of ethanol is –1335 kJ/mol.

(a) Using information from the article, draw an energy profile diagram for the formation of carbon dioxide and hydrogen from carbon and steam.
Label the diagram clearly.

[2]

(b) **(i)** Using Table 10.1, complete the energy cycle for the formation of methane.



[2]

(ii) Hence, calculate the enthalpy change of reaction for the formation of methane.

enthalpy change of reaction for formation of methane = ……………….. kJ [2]

(c) **(i)** Identify the samples which corresponds to the following substances.

substance	sample
methane	
ethanol	
butanol	

[1]

(ii) Using information from Table 10.2 and the bonds present in the three substances, explain your answer in part **(c)(i)**.

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

……………………………………………………………………………………… [3]

(iii) Deduce the enthalpy change of combustion of butanol.

……………………… kJ [1]

(d) After the third sample was burnt, there was a coating of black powder on the surface of the crucible in the bomb calorimeter.

Suggest the reason for the production of black powder during the reaction.

……………………………………………………………………………………………….

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

[Total: 12]

End of Section A

Section B
Answer **one** question from this section.

11 Four experiments, **A**, **B**, **C** and **D** were carried out to investigate the reaction of unknown metal **X** with nitric acid under different conditions.

0.468 g of metal **X** was used in each experiment, while the volume and concentration of nitric acid were varied. Some of the experimental conditions are shown in Table 11.1.

Table 11.1

experiment	concentration of acid / mol/dm^3	volume of acid /cm^3	particle size of metal
	0.25	20	large
	0.40	30	large
C			
	0.50	20	small

In one of the experiments, metal **X** and nitric acid were added in stoichiometric amounts (i.e. there is no excess of either reactant). In the remaining three experiments, metal **X** was added in excess. The volume of gas collected till the end of experiment was recorded and presented in Fig 11.1.

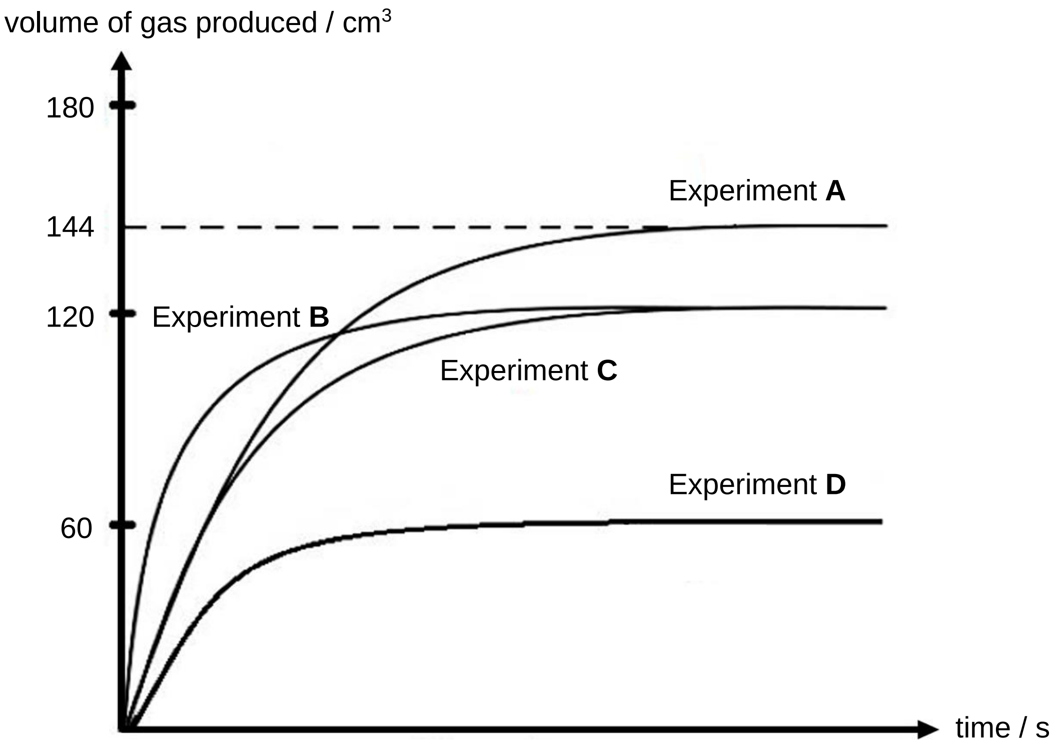


Fig 11.1

(a) Using Fig 11.1, complete Table 11.1 with the correct experimental conditions. [3]

(b) Metal **X** has a valency of 1.

With the information provided, identify metal **X**. Show your calculations clearly.

Metal **X** is .... [2]

(c) Experiment **E** is conducted with the following conditions.

experiment	concentration of acid / mol/dm^3	volume of acid /cm^3	particle size of metal
E	0.40	12.5	small

On Fig 11.1, draw a graph to show the results you would expect to obtain. [1]
Label this graph as Experiment **E**.

(d) Experiment **A** is repeated at a lower temperature.

Explain, in terms of collision theory, the effect of conducting the experiment at a lower temperature on the initial rate of reaction.

....

....

....

....

.... [3]

(e) Suggest if there will be a difference in volume of gas produced if metal **X** is changed to silver. Explain your answer.

....

.... [1]

[Total: 10]

12 Chlorine dioxide, ClO_2 can react with hydroxide ions in an aqueous solution.

$$2ClO_2\,(aq) + 2OH^-\,(aq) \rightarrow ClO_3^-\,(aq) + ClO_2^-\,(aq) + H_2O\,(l)$$

Chlorine dioxide is a yellow liquid and its colour will gradually 'disappear' as the reaction proceeds. The rate of reaction can be determined using the experimental set-up shown in Fig 12.1, by measuring the time taken for the colour to disappear and for the black cross to be seen clearly.

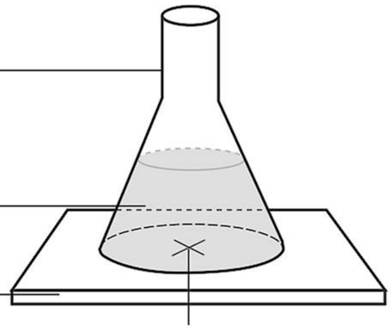


Fig 12.1

Five experiments were conducted with different concentrations of solutions of chlorine dioxide and hydroxide ions. The experimental conditions and initial rate of disappearance of chlorine dioxide are recorded in Table 12.1.

Table 12.1

experiment	concentration of ClO_2 / mol/dm^3	concentration of OH^- / mol/dm^3	initial rate of disappearance of ClO_2 / mol/dm^{3}s
1	0.020	0.015	0.00358
2	0.040	0.015	0.01432
3	0.020	0.030	0.00716
4	0.040	0.045	0.04296
5	0.080	0.015	0.05728

The higher the initial rate of disappearance of chlorine dioxide, the faster the rate of reaction.

(a) Does the increase in concentration of each reactant have an *equal* effect on the rate of reaction?

Explain your answer using Table 12.1, stating the experimental data clearly.

....

....

....

.... [3]

(b) Predict the initial rate of disappearance of chlorine dioxide if the experiment was conducted with 0.060 mol/dm^3 of aqueous chlorine dioxide and 0.075 mol/dm^3 of aqueous sodium hydroxide.

initial rate of disappearance of ClO_2 = ……………………... mol/dm^{3}s [1]

(c) Experiment 1 was repeated with the addition of an catalyst.
Explain, the effect of a catalyst on the initial rate of reaction.

……………………………………………………………………………………………….

……………………………………………………………………………………………….

……………………………………………………………………………………………….

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

(d) Calculate the mass of water produced from the reaction in experiment 3 if 50 cm^3 of each solution was used. Show your calculations clearly.

mass of water produced = …………………………… g [3]

[Total: 10]

End of Section B

End of Paper

Setter: Ms Jasmine Liew