Class	Adm No

Candidate Name: ____________________

H

millennia institute

2024 Preliminary Exams
Pre-University 2

H1 CHEMISTRY **8873/02**

Paper 2 Structured Questions **9 Sep 2024**

2 hours

Candidates answer on the Question paper.

Additional materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Do not turn over this question paper until you are told to do so
Write your name, class and admission number on all the work you hand in.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Section A
Answer **all** the questions.

Section B
Answer **one** question.

The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

Question	Section A					Section B		Total
	1	2	3	4	5	6	7	
Marks	11	18	16	6	9	20	20	**80**

Section A

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

For Examiners' Use

1 Silicon compounds are used in the production of glass, ceramics, and refractory materials. Silicon dioxide is a major component of glass and is used in a wide range of applications, including construction, optics, and consumer products.

(a) A sample of silicon contains three isotopes, as shown in Table 1.1.

Table 1.1

Isotope	Percentage abundance / %
^{28}Si	92.23
^{29}Si	4.67
^{30}Si	3.1

(i) Define the term *relative atomic mass of silicon*.

....[1]

Weighted average mass of a silicon atom compared to 1/12 the mass of a ^{12}C atom.

(ii) Calculate the relative atomic mass of silicon from this sample, giving your answer in **two** decimal places.

[1]

Relative atomic mass of silicon = [(92.23 x 28) + (4.67 x 29) + (3.1 x 30)] / 100
= 28.11

(b) **(i)** State the full electronic configuration of silicon.

Si : ....[1]

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$

(ii) With reference to the Data Booklet, compare the values of second and third ionisation energies of silicon. Explain why these two energies are different and include an equation representing the third ionisation energy of silicon in your answer.

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....[3]

$Si^{2+}(g) \rightarrow Si^{3+}(g) + e^-$
2nd IE of Si: 1580 kJ mol^{-1}
3rd IE of Si: 3230 kJ mol^{-1}

The third IE of Si is larger than its second ionisation energy because the remaining electrons are closer to, and less shielded from the nucleus.

(c) Describe the reaction, if any, of silicon dioxide with water. Include the approximate pH value of any resulting solution.

....[1]

SiO_2 does not react with water and thus the pH remains at 7.

(d) Silicon dioxide can react with carbon under high temperature to form silicon carbide, SiC. Silicon carbide has a high melting point of 2730 °C. It is very hard and can be used as a semiconductor material.

(i) Suggest the type of structure and bonding of SiC.

Structure : ....

Bonding : .... [1]

Structure: giant covalent
Bonding: strong covalent bonds between atoms

(ii) Another method to produce silicon carbide uses silane, SiH_4, and methane gas.

$$SiH_4 + CH_4 \rightarrow SiC + 4H_2$$

Draw the 'dot-and-cross' diagram of silane. State and explain the shape and bond angle around the silicon atom in silane.

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....[3]

Shape: Tetrahedral
Bond angle: 109.5°

According to Valence Shell Electron Pair Repulsion (VSEPR) theory, SiH_4 has 4 bond pairs around silicon atom. Having a tetrahedral shape is to minimise bond pair bond pair repulsion.

[Total: 11]

For Examiners' Use

2 **(a)** Silver can exist in the form of nanoparticles. The properties of silver nanoparticles make them valuable in a wide range of fields, from healthcare to materials science.

(i) Define the term *nanoparticle*.

....

....[1]

Nanoparticles are defined as particles with all three dimensions on the nanoscale of 1 to 100 nm.

(ii) Suggest why silver nanoparticles are more effective catalysts compared to a single 1 cm^3 block of silver metal.

....

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....[2]

Silver nanoparticles provide larger surface area to volume ratio compared to a block of silver metal, resulting in higher frequency of effective collisions and increases rate of reaction.

(iii) Suggest how silver nanoparticles may have an effect on human health.

....

....[1]

Silver nanoparticles may be ingested / inhaled / absorbed into the body through skin, leading to adverse effect on human health.

(iv) Silver can be synthesised in the form of nanoparticles, while graphene can be synthesised as a nanomaterial.

Describe the structure of graphene and use it to explain why graphene has a high tensile strength.

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....[2]

Graphene is a single layer of carbon atoms covalently bonded together to form a giant covalent structure. Each C atom is attached to 3 other C atoms by a network of strong covalent bonds, resulting in high tensile strength.

(b) Silver bromide is a sparingly soluble salt that can dissolve in concentrated ammonia. When ammonia is added to silver bromide, a diamminesilver(I) complex ion, $[Ag(NH_3)_2]^+$, is formed.

$$AgBr(s) + 2NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^+(aq) + Br^-(aq) \quad K_c = 8.5 \times 10^{-6}$$

(i) Write the expression for the equilibrium constant for the above reaction, including its units.

[2]

$K_c = \frac{[[Ag(NH_3)_2]^+][Br^-]}{[NH_3]^2}$ no units

(ii) In an experiment, solid silver bromide was added to aqueous ammonia. Given that the equilibrium concentration of NH_3 is 0.50 mol dm^{-3}, calculate the equilibrium concentration of $[Ag(NH_3)_2]^+$.

[2]

$8.5 \times 10^{-6} = x^2 / (0.50)^2$

$x = 0.00146$ mol dm^{-3}

(iii) Explain the effect of adding excess concentrated ammonia on

I the position of equilibrium

II K_c

I ....

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II ....

.... [3]

I When excess concentrated ammonia is added, by Le Chatelier's Principle, position of equilibrium of reaction shifts to the right to decrease the concentration of ammonia.

II K_c remains constant as it is only affected by temperature.

(iv) Predict the sign for the enthalpy change when one mole of AgBr is dissolved in water. Explain your answer.

....

....[2]

Positive. Since AgBr is sparingly soluble, energy released during the formation of ion-dipole interactions with water is insufficient to overcome the energy absorbed to break the strong electrostatic forces of attraction between Ag^{+} and Br^{-} ions.

(c) Table 2.1 contains the values of lattice energies of AgBr and MgO.

Table 2.1

Compound	Theoretical value / kJ mol^{-1}	Experimental value / kJ mol^{-1}
AgBr	905	795
MgO	3795	3791

(i) Explain why the lattice energy of MgO is considerably larger in magnitude than AgBr.

....

....[2]

Both Mg^{2+} and O^{2-} have **higher charge** than Ag^{+} and Br^{-}.

Both Mg^{2+} and O^{2-} have **smaller sizes** than Ag^{+} and Br^{-}.

Since $|\Delta H_{\text{latt}}| \propto \left|\frac{q_+ q_-}{r_+ + r_-}\right|$, hence MgO has a lattice energy that is larger in magnitude than AgBr.

(ii) There is close agreement between the experimental and theoretical values of lattice energy for MgO but not for AgBr. Suggest a reason for this.

....

....[1]

Due to the larger electron cloud size of Br^{-} compared to O^{2-}, Br^{-} is more polarisable.

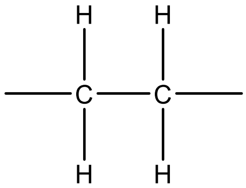
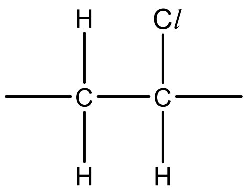
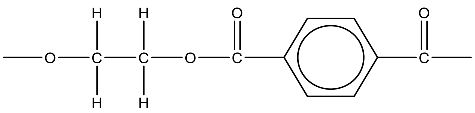
Hence, AgBr has a larger degree of covalent character, resulting in a larger difference between experimental and theoretical lattice energy.

[Total: 18]

For Examiners' Use

3 Polymers are used in a wide range of applications across industries due to their diverse properties. The properties related to the different polymers are shown in Table 3.1.

Table 3.1

polymer	structure of repeat unit of polymer	chemical reactivity	strength	rigidity
high density poly(ethene) (HDPE)		Low	High	Moderate
Kevlar®	**Structure W**	Very low	Very High	High
poly(chloroethene) (PVC)		Moderate	High	High
poly(ethene) terephthalate (PET)		Moderate	High	Moderate

(a) State the type of reaction when PVC reacts with aqueous NaOH and write an equation for the reaction.

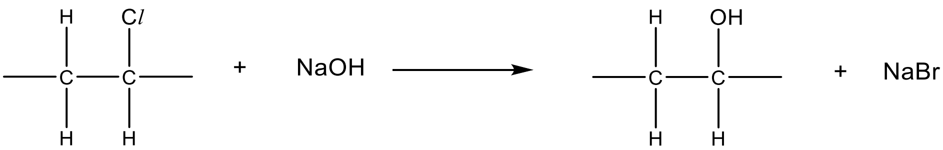
Type of reaction: ....

Equation:

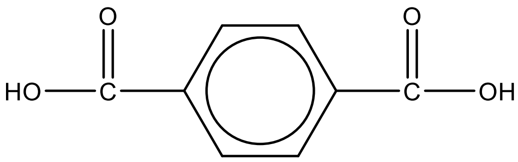
[2]

Type of reaction: hydrolysis / substitution

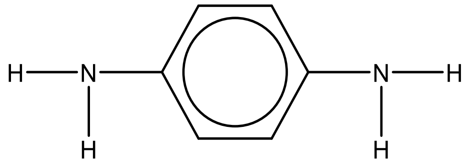
Equation:



(b) The following structures are the monomer units of Kevlar®.



terephthalic acid



p-phenylenediamine

(i) Explain, in terms of structure and bonding, the differences in melting point between the two monomer units of Kevlar®.

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....[2]

Both monomer units have simple molecular structure with hydrogen bonding between molecules.

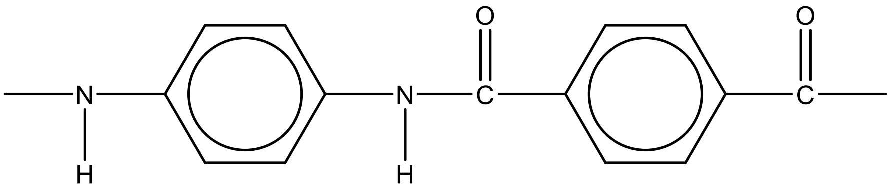
Since O is more electronegative than N, the hydrogen bond formed between terephthalic acid molecules is stronger than that between p-phenylenediamine molecules.

or terephthalic acid has a larger electron cloud size hence has stronger instantaneous dipole-induced dipole interactions.

Hence, more energy is needed to overcome the stronger interactions between terephthalic acid molecules, leading to a higher boiling point for terephthalic acid.

(ii) Draw one repeat unit of Kevlar®, structure **W**.

[1]



Ans:

(iii) Identify the type of polymerisation in the formation of Kevlar® and provide two reasons to explain your answer.

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....[3]

Condensation polymerisation
Reason 1: amide linkages in Kevlar® is formed when 2 different monomers were reacted to form a long chain polymer molecule.
Reason 2: a small molecule of H_2O is eliminated for every amide linkage formed during the reaction.

(c) Suggest which polymer can be chosen to make plastic hose. Explain your choice by considering each of the properties listed in the table.

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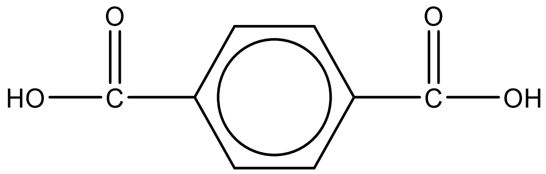
....[4]

HDPE
Low chemical reactivity so that it is resistant to a wide range of chemicals.
High strength so that the hose is resistant to bursting and capable of withstanding higher pressure.
Although Kevlar also has low chemical reactivity and high strength, HDPE has lower rigidity compared to Kevlar, hence allowing the water hose to be flexible and easy to handle;

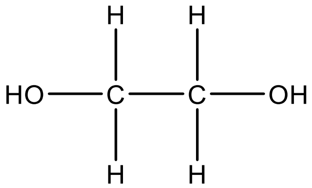
(d) **(i)** One of the monomer units of PET is terephthalic acid.



terephthalic acid

Draw the structure of the other monomer.

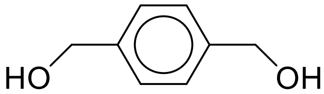
[1]

Ans: 

(ii) Terephthalic acid can be synthesised from 1,4-benzenedimethanol via oxidation.

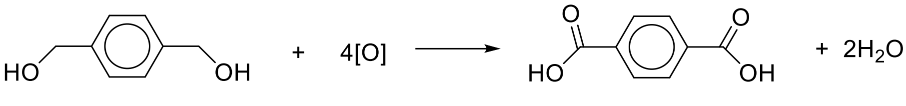
Write an equation for the synthesis of terephthalic acid from 1,4-benzenedimethanol.

You may represent the oxidising agent with [O].



1,4-benzenedimethanol

[1]

Ans: 

(iii) In a reaction, the oxidation of 3.8 g of 1,4-benzenedimethanol yielded 3.4 g of terephthalic acid. Determine the percentage yield in this reaction.
[M_r of 1,4-benzenedimethanol = 138; M_r of terephthalic acid = 166]

[2]

Amount of methylbenzoic acid = 3.8 / 138 = 0.02754 mol

Theoretical amount of terephthalic acid = 0.02754 mol

Mass of terephthalic acid = 0.02754 x 166 = 4.571 g

% yield = 3.4 / 4.571 x 100% = 74.4%

[Total: 16]

For Examiners' Use

4 The reaction between hydrogen peroxide and acidified potassium iodide solution can be represented by the following equation.

$$H_2O_2 + 2I^- + 2H^+ \rightarrow I_2 + 2H_2O$$

(a) Identify the species which is being oxidised and the species that is being reduced. Explain your answers in terms of oxidation numbers.

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....[2]

H_2O_2 is being reduced as the oxidation number of O in H_2O_2 increases from -1 to -2 in H_2O.
I^- is being oxidised as the oxidation number of I increases from -1 to 0 in I_2.

(b) A chemist performs a series of experiments to investigate the effect of changes in concentration on the rate of reaction. The reaction is completed when a deep blue colour solution is obtained. The data obtained for each experiment is given in table 4.1.

Table 4.1

Experiment number	Volume of 0.10 mol dm^3 H_2O_2 / cm^3	Volume of 1.00 mol dm^{-3} KI / cm^3	Volume of 1.00 mol dm^3 HC*l* / cm^3	Volume of water / cm^3	Time for the appearance of deep blue colour / s
1	10.0	15.0	20.0	55.0	20
2	10.0	10.0	20.0	60.0	30
3	40.0	15.0	20.0	35.0	5

(i) State the simple relationship between the time taken for the deep blue colour to appear and the initial rate of reaction.

....

....[1]

The initial rate is inversely proportional to the time taken.

(ii) Deduce the order of reaction with respect to $[I^-]$ and $[H_2O_2]$.

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....[2]

When volume of I^- increased by 1.5 times from experiment 2 to experiment 1, time decreases by 1.5 times. Since rate is inversely proportional to time, rate increases by 1.5 times. Hence order of reaction with respect to $[I^-]$ is 1.

When volume of H_2O_2 increased by 4 times from experiment 1 to experiment 3, time decreases by 4 times, rate increases by 4 times. Hence order of reaction with respect to $[H_2O_2]$ is 1.

(iii) Hence, write the rate equation.

....[1]

rate = k $[I^-]$ $[H_2O_2]$

[Total: 6]

5 3-chloropropanoic acid, $ClCH_2CH_2COOH$, is a weak monobasic acid.

(a) **(i)** Define the term *weak acid*.

....[1]

Weak acids undergo partial dissociation into H^+ ions in the presence of water.

(ii) Given that the pH of a 0.0125 mol dm^{-3} of 3-chloropropanoic acid is 2.38, show that it is a weak acid.

[1]

If 3-chloropropanoic acid is a strong acid,
pH of solution = -log (0.0125) = 1.90
Since pH of the solution is greater than 1.90, 3-chloropropanoic acid is a weak acid.

(b) 3.25 g of 3-chloropropanoic acid is dissolved in water and the volume made up to 250 cm^3 in a volumetric flask. During titration, it was found that 25.0 cm^3 of the acid required 20.00 cm^3 of NaOH(aq) for complete reaction.

(i) Write a balanced equation for the reaction.

....[1]

$ClCH_2CH_2COOH + NaOH \rightarrow ClCH_2CH_2COO^-Na^+ + H_2O$

(ii) Calculate the concentration of NaOH used in the titration.

[2]

Amount of 3-chloropropanoic acid in 250 cm^3 solution = 3.25 / 108.5 = 0.0300 mol
Amount of 3-chloropropanoic acid in 25 cm^3 solution = 0.00300 mol
Since mol ratio of 3-chloropropanoic acid : NaOH =1:1,
Concentration of NaOH required = 0.00300 / (20/1000) = 0.150 mol dm^{-3}

(iii) Suggest a suitable indicator for the titration of 3-chloropropanoic acid with sodium hydroxide.

....[1]

Phenolphthalein

(iv) Before the end-point was reached, there was a mixture of 3-chloropropanoic acid and its salt in the solution. By means of ionic equations, explain how this mixture behaves as a buffer.

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....[3]

$ClCH_2CH_2COO^- + H^+ \rightarrow ClCH_2CH_2COOH$

When small amount of HC*l* is added, the added H^+ is removed as 3-chloropropanoic acid. $[H^+]$ is slightly changed and pH of the solution remains fairly constant.

$ClCH_2CH_2COOH + OH^- \rightarrow ClCH_2CH_2COO^- + H_2O$

When small amount of HC*l* is added, the added OH^- is removed as 3-chloropropanoate. $[OH^-]$ is slightly changed and pH of the solution remains fairly constant.

[Total: 9]

Section B

Answer **one** question in this section in the spaces provided.

For Examiners' Use

6 (a) Propyne is a weak acid. It can react with an aldehyde in the presence of a trace amount of strong base, $NaNH_2$.

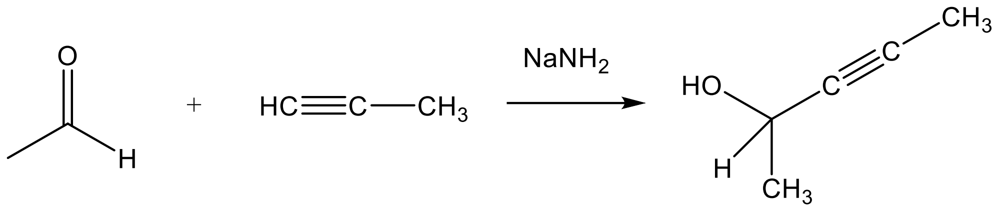


Fig. 6.1

(i) State the number of σ and π bonds present in propyne.

s bonds: .... p bonds: .... [1]

6 σ and 2 π

(ii) The first step of the reaction involves propyne reacting with $NaNH_2$ which produces ammonia as one of the products.
Suggest an equation for the reaction between propyne and $NaNH_2$.

....[1]

$NaNH_2 + CH_3C{\equiv}CH \rightarrow CH_3C{\equiv}C^- \, Na^+ + NH_3$

(b) Fig 6.2 shows the synthesis of compounds **A** and **B** from the product shown in Fig 6.1.

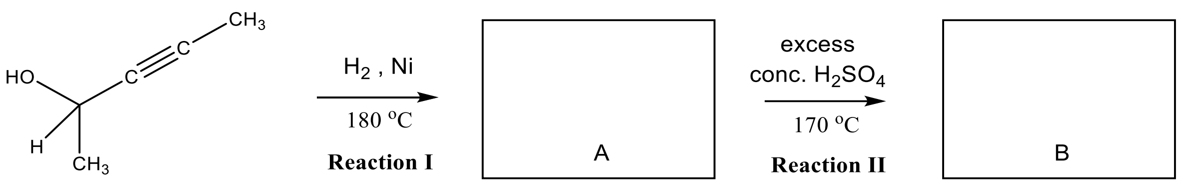
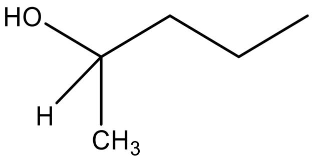


Fig 6.2

(i) Given that the molecular formula of compound **A** is $C_5H_{12}O$, draw the structure of compound **A**.

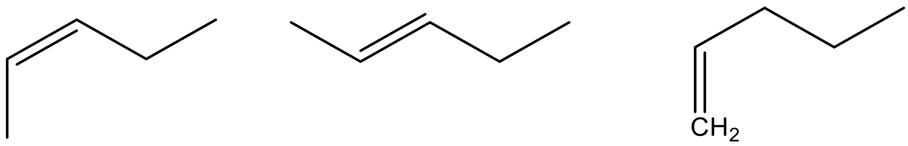
[1]

Ans: 

(ii) Reaction **II** produces three compounds that are isomers of each other.

Draw all three isomers.

[3]

Ans: 

(iii) 0.70 g of compound **A** is formed from **Reaction I**.

Calculate the volume of hydrogen gas, measured at room temperature and pressure, needed for the reaction.

[2]

Amount of product A = 0.7 / 88 = 0.007955 mol

Amount of H_2 gas = 0.007955 x 2 = 0.01591 mol ;
Vol of H_2 gas at r.t.p. = 0.01591 x 24 = 0.382 dm^3 ;

(c) **(i)** Define the term *bond energy*.

....[1]

Bond energy is the energy required to break 1 mole of covalent bonds between two atoms in the gas phase.

(ii) By using appropriate bond energy values from the Data Booklet, calculate a value for the standard enthalpy change of the reaction in Fig 6.1.

[2]

Bonds broken	No. of moles	Bond energy / kJ mol^{-1}
C=O	1	740
C–H	1	410

Bonds formed	No. of moles	Bond energy / kJ mol^{-1}
O–H	1	460
C–O	1	360
C–C	1	350

$\Delta H_{reaction}$ = (740 + 410) – (460 + 360 + 350) = - 20.0 kJ mol^{-1}

(iii) The actual $\Delta H_{reaction}$ of the reaction in Fig 6.1 is -136 kJ mol^{-1}. Suggest a reason for the discrepancy between the actual value and that calculated in **c(ii)**.

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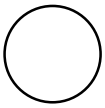
……………………………………………………………………………………………...[1]

Bond energies quoted in the data booklet are average values from many different molecules. They are not actual bond energy values specific to the molecule. / Bond energies refer to gas phase molecules but the molecules shown in Fig. 6.1 are not in gas phase.

(d) **(i)** Draw and label the shape of the **occupied** orbital in the valence shell of Na atom.

[1]

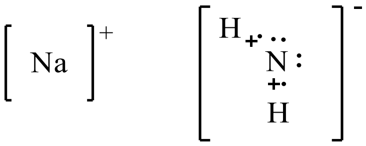


3s orbital

(ii) Draw the 'dot-and-cross' diagram of $NaNH_2$.

[1]

Ans:



(iii) State and explain the trend observed for the ionic radii of Group 1 metals.

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....[2]

Down group 1 metals, the number of principal quantum shells increases. Although nuclear charge and shielding effect increases down the group, the distance of valence electrons from the nucleus increases and electrostatic attraction on the electron from the nucleus is weaker. Hence, ionic radii increase down group 1 metal cations.

(e) Describe the reactions, if any, of $NaCl$ with water and $MgCl_2$ with water. State and explain the approximate pH of any solution formed. Write balanced equations for any reactions taking place.

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....[4]

NaC*l* dissolves readily in water. It does not undergo hydrolysis due to the low charge density of Na^{+}. Hence, pH of resulting solution = 7

Mg^{2+} has a higher charge density (due to small ionic radius and high charge) than Na^{+} thus has higher polarising power. Hence, $MgCl_2$ undergoes hydration and partial hydrolysis, producing a slightly acidic solution.

pH of resulting solution = 6.5

$MgCl_2 + 6H_2O \rightarrow [Mg(H_2O)_6]^{2+} + 2Cl^-$ (hydration)
$[Mg(H_2O)_6]^{2+} + H_2O \rightleftharpoons [Mg(H_2O)_5OH]^{+} + H_3O^{+}$ hydrolysis

[Total: 20]

7 **(a)** **X** and **Y** are two elements in Period 3 of the Periodic Table.

X is a hard, dark grey solid with a melting point above room temperature. When **X** is heated in oxygen, **X**O_2, with a melting point of 1414 °C, is formed.

Y is a solid that can exist as several different allotropes, most of which contains **Y**$_8$ molecules. **Y** forms a gaseous oxide, **Y**O_3, which dissolves in water to form a solution that reacts with sodium hydroxide.

(i) Deduce the identities of **X** and **Y**.

....[2]

X: silicon
Y: sulfur

(ii) State and explain the difference in electronegativity of the elements **X** and **Y**.

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....[3]

Across the period, electronegativity generally increases. Nuclear charge increases as proton number increases. Negligible increase in the screening effect as electrons are added to the same quantum shell. Hence, the ability of nucleus to attract bonding electrons to itself, and electronegativity of Y is higher than X.

(b) **(i)** Magnesium is also an element in Period 3. Using the energy cycle in Fig 7.1, identify the two enthalpy changes, ΔH_1 and ΔH_2 and calculate the enthalpy change of reaction.

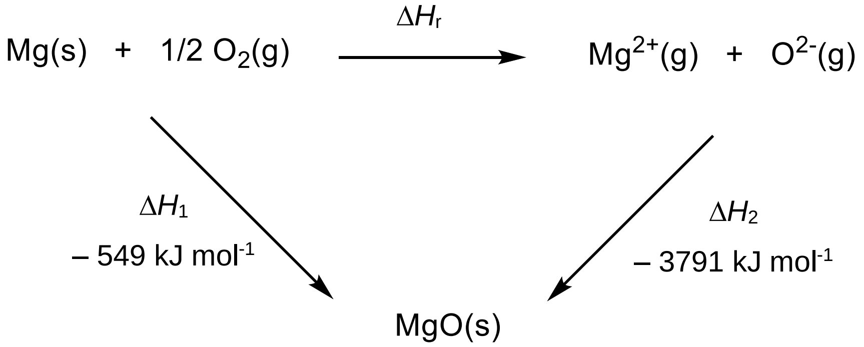

Fig 7.1

[3]

ΔH_1 is standard enthalpy change of formation of MgO(s)
ΔH_2 is lattice energy of MgO(s).

$\Delta H_r = -549 - (-3791) = +3242 \text{ kJ mol}^{-1}$

(ii) Draw two simple diagrams to show how a water molecule can be attracted to a magnesium cation, and to an oxide anion. Label each diagram to show the type of interaction involved. Hence, explain why magnesium oxide is soluble in water.

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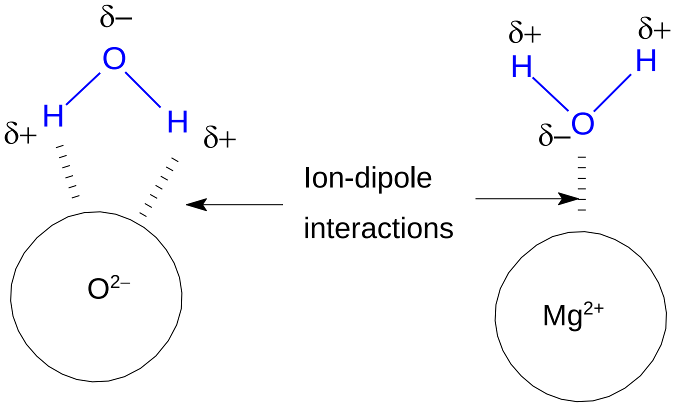
....[4]



Energy released from the formation of ion-dipole interactions between Mg^{2+} and O^{2-} ions with water molecules is sufficient to overcome the energy required to break the strong electrostatic forces of attraction between Mg^{2+} and O^{2-}.

(c) Magnesium plays a critical role in muscle function, particularly in the process of muscle contraction and relaxation. ATPase is one of the enzymes used to increase the rate of hydrolysis of adenosine triphosphate (ATP) into adenosine diphosphate (ADP). This process provides energy needed for muscle contraction.

For Examiners' Use

(i) Explain why ATPase can be described as a *biological catalyst*.

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....[2]

ATPase allows certain reactants to bind specifically to it for the conversion into products in a biological reaction. It is regenerated / remained chemically unchanged at the end of the reaction

(ii) The rate of reaction is increased with the use of ATPase.

Using a labelled Boltzmann distribution diagram, explain why the rate of reaction increases with the use of ATPase.

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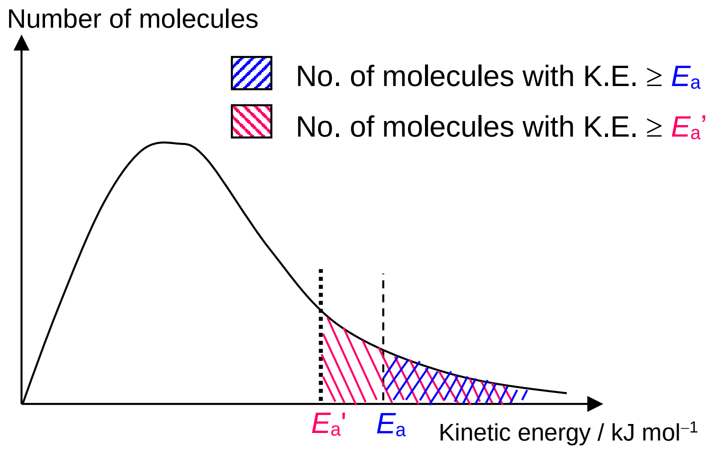
....[3]

ATPase provides an alternative reaction mechanism of lower activation energy E_a' than that of the uncatalysed reaction.

Thus, the number of particles having kinetic energy ≥ E_a' increases.

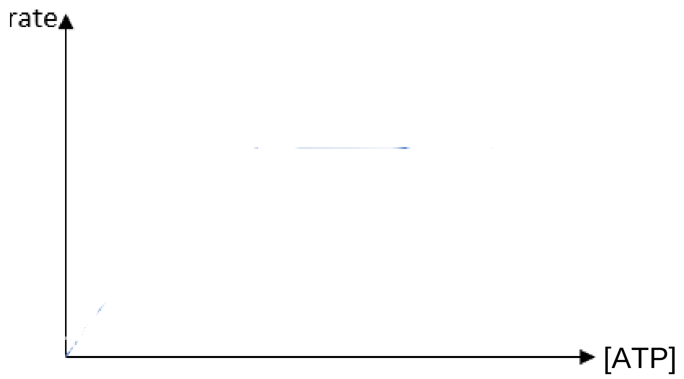
Therefore, frequency of effective collisions between particles increases and hence the reaction rate increases.



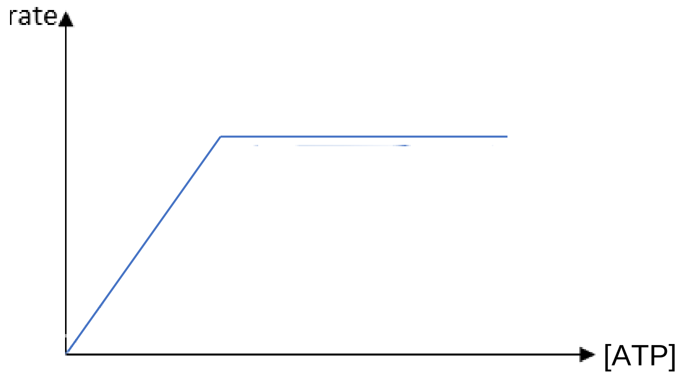
[1] for correct shape, correct axis, correct shaded areas, correct legend.

(iii) At low concentration of ATP, the reaction is first order with respect to [ATP]. However, as the concentration of ATP becomes higher, the active sites of the ATPase becomes fully occupied and the reaction becomes zero order with respect to [ATP].

Using the axes below, sketch a graph showing how the rate of this ATPase catalysed reaction varies with the concentration of ATP.



[2]



(d) Graphene could be used in electrical devices such as transistors as it has good electrical conductivity. Explain why it is a good electrical conductor.

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....[1]

Each carbon atom has one p electron that is delocalised that hence graphene is able to conduct electricity.

[Total: 20]

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