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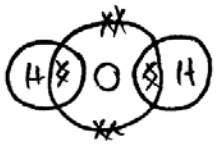
## PART I

Answer **ALL** questions. Write your answers in the spaces provided.

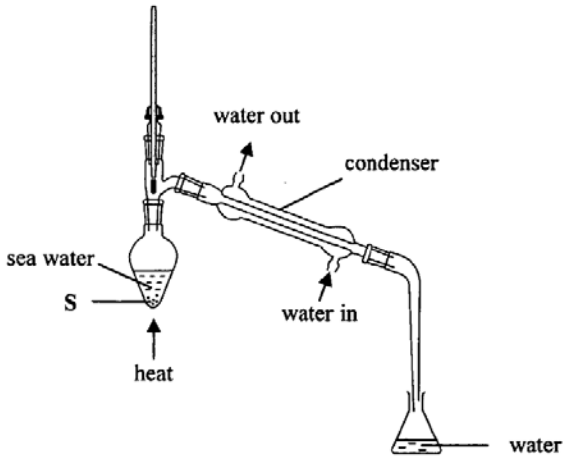
1. Water is the most abundant compound on the Earth's surface. It is very important to life on Earth.

(a) Draw the electron diagram for a water molecule, showing *electrons in the outermost shells* only.




(1 mark)

(b) Nearly 98% of the water on Earth is sea water, which is not fit for human consumption. The diagram below shows the set-up used in a simple distillation experiment for obtaining water from sea water.




(i) Outline the underlying principle of this simple distillation experiment.

Water can be obtained from sea water by distillation because water and the minerals like sodium chloride that are present in the sea water have different boiling point as they have different structure and different bonding to hold them together. As the boiling point of water is lower it boils at lower temperature and can be separated from the sea water.

(ii) Insoluble solid S was placed into the flask before heating. Why?

This is to ensure uniform heating and prevent bumping to occur. Otherwise, some sea water that are not yet vaporized may splurt into the condenser and enter the conical flask.

(3 marks)

Answers written in the margins will not be marked.

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1. (c) Explain, from molecular level, why the density of ice is lower than that of water.

Due to the presence of hydrogen bond between water molecules, in ice, each water molecule forms four hydrogen bonds with other water molecules. The tetrahedral arrangement repeats over and over again and results in a regular open network structure. This structure causes the density of ice to be lower than that of water.

(3 marks)

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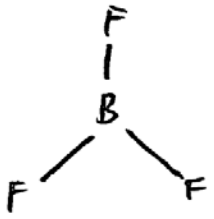
2. Both $BF_3$ and $NH_3$ exist as simple molecules.

(a) For each of these molecules, draw its three-dimensional structure.

$BF_3$




$NH_3$


(2 marks)

(b) For each of these molecules, explain whether or not it is polar.

$BF_3$ is non-polar because it has three polar B–F bonds in trigonal planar in shape and which the dipole moment can cancel out each other.

$NH_3$ is polar because it has three polar N–H bonds in trigonal pyramidal in shape and which the dipole moment cannot cancel out each other.

(2 marks)

(c) $BF_3$ reacts with $NH_3$ to give $F_3BNH_3$. Describe the bond formation between $BF_3$ and $NH_3$.

This is a dative covalent bond. $NH_3$ and $BF_3$ forms a covalent bond by the sharing of electrons and both electrons of the shared pair is contributed by $NH_3$.

(2 marks)

Answers written in the margins will not be marked.

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Answers written in the margins will not be marked.

3. Compound **W** contains carbon, hydrogen and oxygen only. The relative molecular mass of **W** is 88.0. Complete combustion of 1.32 g of **W** gives 2.64 g of carbon dioxide and 1.08 g of water.

(a) Deduce the molecular formula of **W**.
(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0)

Mass of carbon present $= 2.64 \times \frac{12.0}{12.0+16.0\times2} = 0.72\ g$

Mass of hydrogen present $= 1.08 \times \frac{1.0\times2}{1.0\times2+16.0} = 0.12\ g$

Mass of oxygen present $= 1.32 - 0.72 - 0.12 = 0.48\ g$

| | C | H | O |
|---|---|---|---|
| Mass | 0.72 | 0.12 | 0.48 |
| Mole | 0.06 | 0.12 | 0.03 |
| Relative mole ratio | 2 | 4 | 1 |

The empirical formula of W is $C_2H_4O$.

Let the molecular formula of W be $(C_2H_4O)_n$.

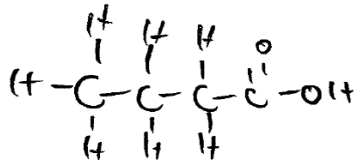
$n \times (12.0\times2 + 1.0\times4 + 16.0) = 88.0$

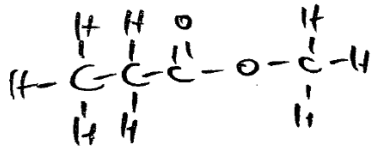
$n = 2$

The molecular formula of W is $C_4H_8O_2$.

(3 marks)

(b) Given that **W** has only one functional group, draw TWO possible structures of **W**.





(2 marks)

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Answers written in the margins will not be marked.

4. The structure of a dibasic acid with chemical formula $H_2C_2O_4$ is shown below:

(a) Give the systematic name of this dibasic acid.

Ethanedioic acid

(1 mark)

(b) A student expected a 0.0500 mol $dm^{-3}$ standard $H_2C_2O_4(aq)$ to have a pH of 1.0. However, the pH of the solution, when measured with a calibrated pH meter, was found to be greater than 1. Explain this observation with the aid of a chemical equation.

This is because this acid is a weak acid which only slightly ionizes in water to form $H^+(aq)$ ions. Therefore, the actual concentration of $H^+(aq)$ ions is lower that the student expected and the pH of the acid is greater.

$$H_2C_2O_4(aq) \rightleftharpoons 2H^+(aq) + C_2O_4^{2-}(aq)$$

(2 marks)

(c) Solid sodium hydroxide is available in school laboratories. However, standard NaOH(aq) CANNOT be directly prepared by weighing NaOH(s) and then dissolving it in water. Explain why.

This is because in order to prepare standard solution of NaOH(aq), the solid sodium hydroxide should be highly pure. But the sodium hydroxide in school laboratories may not be pure enough.

(1 mark)

(d) In a titration experiment, 25.00 $cm^3$ of a 0.0500 mol $dm^{-3}$ standard $H_2C_2O_4(aq)$ and a few drops of phenolphthalein indicator were placed in a conical flask. NaOH(aq) of unknown concentration was then added from a burette into the flask. 17.20 $cm^3$ of the NaOH(aq) was required to reach the titration end point.

(i) State the colour change at the titration end point.

The reaction mixture changes from colourless to pink.



Answers written in the margins will not be marked.

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4. (d) (ii) From the titration results, calculate the concentration of the NaOH(aq), in mol $dm^{-3}$.

$2NaOH(aq) + H_2C_2O_4(aq) \longrightarrow Na_2C_2O_4(aq) + 2H_2O(l)$

No. of mole of $H_2C_2O_4(aq)$ used $= 0.0500 \times \frac{25.00}{1000}$

$= 1.25 \times 10^{-3}$ mol

No. of mole of $NaOH(aq)$ reacted $= 2.5 \times 10^{-3}$ mol

Concentration of $NaOH(aq) = \frac{2.5 \times 10^{-3}}{\frac{17.20}{1000}}$

$= 0.145$ mol $dm^{-3}$ (corr. to 3 sig. figs)

(3 marks)

(e) The following were considered as INAPPROPRIATE practices when carrying out the experiment in (d). For each of them, explain why it would lead to inaccurate titration results:

(i) rinsing the conical flask with the standard $H_2C_2O_4(aq)$ before transferring 25.00 $cm^3$ of the acid solution to it

As some of the $H_2C_2O_4(aq)$ is left on the conical flask after rinsing, the actual amount of $H_2C_2O_4(aq)$ used would thus be greater than expected.

(ii) carrying out the titration with the filter funnel remained on top of the burette after using it to fill the burette with the NaOH(aq)

Some of the $NaOH(aq)$ that are remained on the filter funnel may flow down into the burette after some time, affecting the reading of volume of $NaOH(aq)$ used. The reading may be smaller than the actual amount of $NaOH(aq)$ used.

(2 marks)



Answers written in the margins will not be marked.

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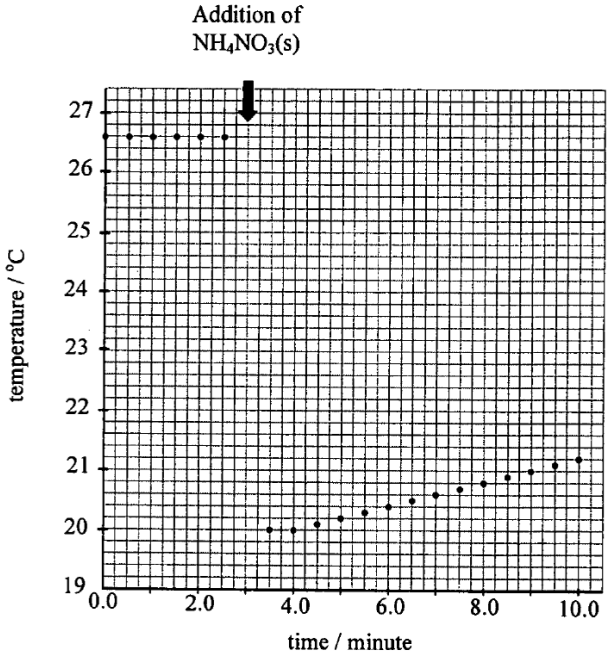
5. The following experiment was carried out to determine the enthalpy change of solution of ammonium nitrate:

$$NH_4NO_3(s) \xrightarrow{H_2O(l)} NH_4NO_3(aq)$$

A certain volume of water was placed in an expanded polystyrene cup. The temperature of the water in the cup was measured with a thermometer at half-minute intervals. Right at the third minute, 2.0 g of $NH_4NO_3(s)$ was added to the cup. The solution in the cup was then stirred thoroughly and its temperature was measured for an additional 7 minutes.

The recordings of temperature are shown in the graph below:




(a) (i) From the graph, estimate the greatest temperature drop of the solution in the cup.

Greatest temperature drop = 26.6 °C − 20 °C
= 6.6 °C

(ii) The mass of the $NH_4NO_3(aq)$ obtained was found to be 21.8 g. Calculate the enthalpy change of solution of ammonium nitrate, in kJ $mol^{-1}$, under the experimental conditions. (Assume that the heat capacity of the expanded polystyrene cup is negligible, and the specific heat capacity of the $NH_4NO_3(aq)$ obtained is 4.3 J $g^{-1}$ $K^{-1}$.)

Energy change = 21.8 × 4.3 × [(20 + 273) − (26.6 + 273)]
= −0.619 kJ (corr. to 3 s.f.)

No. of mole of $NH_4NO_3(s)$ used = 0.025 mol

Answers written in the margins will not be marked.

5. Enthalpy change of solution of ammonium nitrate
= +24.7 kJ mol$^{-1}$ (corr. to 3 sig. fig.)

(4 marks)

(b) Suggest ONE way of keeping $NH_4NO_3(s)$ dry during storage.

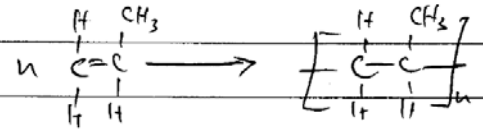
To put $NH_4NO_3(s)$ in a desiccator where drying agent like calcium chloride would absorb moisture from air.

(1 mark)

*6. Briefly describe how polypropene can be produced from naphtha.

(4 marks)

First, the monomer propene can be produced from naphtha through cracking.
Then, polypropene can be produced from additional polymerization in which the monomer propene is joined together repeatedly to form an large polymer molecule. In the process, a catalyst of $TiCl_4$ etc may be used.



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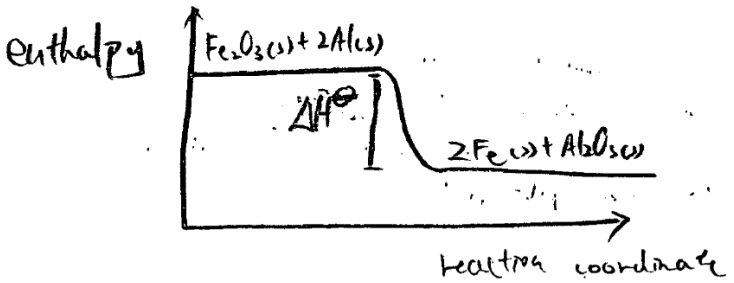
7. Thermite reactions broadly refer to exothermic oxidation-reduction reactions between a metal powder and a metal oxide. One example is the reaction of finely divided iron(III) oxide with aluminium powder. This reaction results in a very high temperature, and is commonly used in the welding of rail tracks for trains. At this very high temperature, the molten iron formed joins the rail tracks together.

(a) (i) Complete and balance the chemical equation for the following thermite reaction.

$$1\ Fe_2O_3(s) + 2\ Al(s) \longrightarrow 2\ Fe(s) + Al_2O_3(s)$$

(ii) Sketch a labelled enthalpy level diagram for this reaction.




(2 marks)

(b) Copper powder CANNOT be used to replace aluminium powder in carrying out the thermite reaction with iron(III) oxide. Explain why.

This is because copper is less reactive than iron and iron loses its outermost shell electrons to form cations more readily. Therefore, copper cannot displace iron from its oxide.

(1 mark)

(c) The extraction of iron from its ores also involves the reduction of iron oxides.

(i) Suggest why aluminium is NOT used as the reducing agent in iron extraction.

This is because aluminium is even more expensive than iron. Therefore, it would not be used in the extraction of iron.

(ii) Suggest ONE reducing agent commonly used in iron extraction.

Carbon.

(2 marks)

Answers written in the margins will not be marked.

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Answers written in the margins will not be marked.

8. Both caesium (Cs) and sodium (Na) are elements in Group I of the Periodic Table. Caesium reacts with chlorine to form caesium chloride.

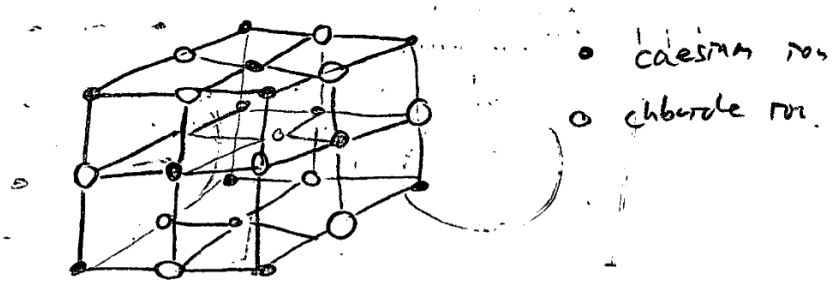
(a) Write the chemical equation for the reaction of caesium with chlorine.

$2Cs(s) + Cl_2(g) \longrightarrow 2CsCl(s)$

(1 mark)

(b) Solid caesium chloride has a giant ionic structure.

(i) Draw a diagram to show the structure of caesium chloride.




(ii) Explain why solid caesium chloride is brittle.

This is because caesium chloride has a giant ionic structure and the oppositely charged ions are held together by strong ionic bond. As the oppositely charged ions are not mobile in the structure, when a force is applied to the solid, it would break as the structure has collapsed.

(3 marks)

(c) Predict, with ONE reason, whether sodium or caesium is more reactive towards chlorine.

Caesium is more reactive towards chlorine because caesium can form chloride directly by reacting with chlorine but sodium cannot.

(1 mark)

Answers written in the margins will not be marked.

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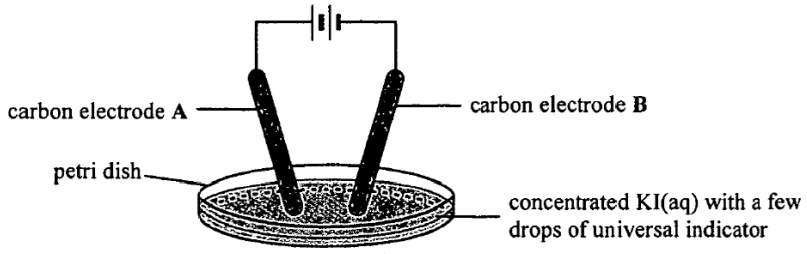
Answers written in the margins will not be marked.

9. The diagram below shows the set-up used in an investigation on the electrolysis of concentrated potassium iodide solution:




(a) State and explain the expected observation around carbon electrode **A** during the electrolysis.

The solution around carbon electrode A would turn brown during electrolysis. This is because the concentration of $I^-_{(aq)}$ ion is much higher than that of $OH^-_{(aq)}$ ion while they are not too far away in the Electrochemical series. Therefore, under the concentration effect, $I^-_{(aq)}$ ions are preferentially discharged to form $I_{2(aq)}$ which is brown in colour.

$2I^-_{(aq)} \rightarrow I_{2(aq)} + 2e^-$

(2 marks)

(b) The solution near carbon electrode **B** gradually turned blue.

(i) Explain this observation.

At carbon electrode B, $H^+_{(aq)}$ ion is preferentially discharged as it is stronger oxidizing agent than $K^+_{(aq)}$ ion. This leaves an excess of $OH^-_{(aq)}$ ions around carbon electrode B and make the solution there slightly alkaline. Therefore, the universal indicator solution changes from yellow to blue.

(ii) Would there be any change in observation if carbon electrode **B** is replaced by a copper electrode in the investigation ? Explain.

There would be no change in observation because $H^+_{(aq)}$ ion would still be preferentially discharged as it is stronger oxidizing agent than $K^+_{(aq)}$ ion.

(3 marks)

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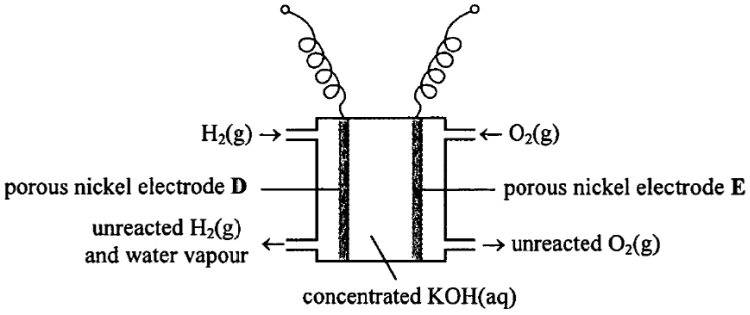
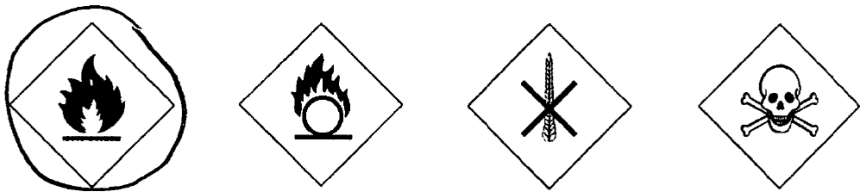
Answers written in the margins will not be marked.

10. The diagram below shows the structure of a hydrogen-oxygen fuel cell using concentrated potassium hydroxide solution as the electrolyte.




(a) An oxygen cylinder can be used to provide oxygen for the above fuel cell. From the hazard warning labels shown below, circle the label that should be displayed on the oxygen cylinder.



(1 mark)

(b) Write the half equation for the change occurring at each of the following electrodes when this fuel cell is producing a current.

electrode **D**

$H_{2(g)} + 2OH^-_{(aq)} \rightarrow 2H_2O_{(l)} + 2e^-$

electrode **E**

$O_{2(g)} + 2H_2O_{(l)} + 4e^- \rightarrow 4OH^-_{(aq)}$

(2 marks)

(c) Some people have the view that cars powered by hydrogen-oxygen fuel cells are more environmentally friendly than those powered by petrol.

Comment on this view from each of the following aspects:

(i) source of fuel

This view is not agreed as hydrogen gas is produced from industrial process like electrolysis of brine which consumes electricity as well and air pollutants is produced during the electricity production process.

(ii) the car emissions

This view is agreed as the products formed from the energy production process of fuel cell is water which will not cause pollution problem.

(2 marks)

Answers written in the margins will not be marked.

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## PART II

Answer **ALL** questions. Write your answers in the spaces provided.

11. Safety airbags are important devices installed in vehicles. During a serious car crash, the chemicals in the airbag immediately react to release a large amount of gas. An airbag hence inflates instantly, protecting the passenger. The main chemicals in safety airbags are sodium azide ($NaN_3$) and potassium nitrate ($KNO_3$). The equations below show the reactions involved when an airbag is inflated:

$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$

$10Na(s) + 2KNO_3(s) \rightarrow K_2O(s) + 5Na_2O(s) + N_2(g)$

(a) Explain why the $NaN_3(s)$ and $KNO_3(s)$ used in the airbags are in the form of fine powder.

This increases their surface area so as to increase the reaction rate so that the airbag can inflate faster.

(1 mark)

(b) An airbag contains 100.0 g of $NaN_3(s)$ and 200.0 g of $KNO_3(s)$. Calculate the theoretical volume, measured at room temperature and pressure, of the gas produced when the bag is inflated.
(Formula masses: $NaN_3$ = 65.0, $KNO_3$ = 101.1;
molar volume of gas at room temperature and pressure = 24 $dm^3$)

No. of mole of $NaN_3(s)$ present = 1.54 mol
No. of mole of $N_2(g)$ produced from $NaN_3(s)$ = 2.31 mol
Volume of $N_2(g)$ produced = 55.4 $dm^3$
No. of mole of $KNO_3(s)$ present = 1.98 mol
No. of mole of $N_2(g)$ produced from $KNO_3(s)$ = 0.989 mol
Volume of $N_2(g)$ produced = 23.7 $dm^3$

∴ Theoretical volume of gas produced
= 79.1 $dm^3$

(3 marks)

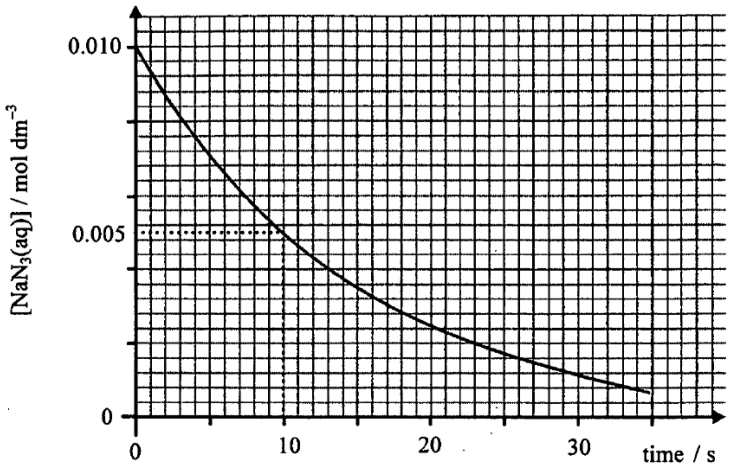
(c) The main function of $NaN_3(s)$ is to produce $N_2(g)$ for inflating the airbags. Suggest why it is necessary to include $KNO_3(s)$ in the airbags.

This is to consume the Na(s) which is produced from the reaction of $NaN_3(s)$ so as to reduce the production of metals which may pollute the environment

(1 mark)

Answers written in the margins will not be marked.

11. (d) Sodium azide is a toxic chemical. Thus any $NaN_3$ waste remained during the manufacture of safety airbags needs special treatment before disposal. The treatment involves first dissolving $NaN_3$ in water, and then reacting the solution formed with excess nitrous acid, $HNO_2(aq)$. The graph below shows the variation of the concentration of $NaN_3(aq)$ in the reaction mixture with time in one such process:




(i) Calculate the average rate of consumption of $NaN_3(aq)$ in the first 10 seconds.

Average rate of consumption

$= \frac{0.010 - 0.005}{10}$

$= 5 \times 10^{-4}$ mol $dm^{-3}$ $s^{-1}$.

(ii) Suggest how the instantaneous rate of consumption of $NaN_3(aq)$ at the 10th second can be determined from the graph.

It can be determined by finding the slope of tangent to the curve on the graph at the 10th second. The slope represents the rate of consumption of $NaN_3(aq)$ at the 10th second. (2 marks)

Answers written in the margins will not be marked.

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12. At 250°C, the equilibrium constant $K_c$ for the following reaction is 25 $mol^{-1}dm^3$.

$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$

A 10.0 $dm^3$ sealed container, which is maintained at 250°C, initially contains 0.50 mol of $PCl_3(g)$, 0.20 mol of $Cl_2(g)$ and 0.40 mol of $PCl_5(g)$.

(a) For this system under the initial conditions, calculate its reaction quotient. Predict and explain, under the initial conditions, whether the forward reaction rate or the backward reaction rate would be greater.

$$\text{Reaction quotient} = \frac{[PCl_5(g)]}{[PCl_3(g)][Cl_2(g)]}$$

$$= 40 \ mol^{-1} dm^3$$

As the reaction quotient is greater than the equilibrium constant, the equilibrium position would shift to the reactant side and the rate of backward reaction would be greater.

(2 marks)

(b) Calculate the concentration of $Cl_2(g)$ when the system attains equilibrium at 250°C.

Let $x$ mol $dm^{-3}$ be the change in concentration of $Cl_2(g)$.

| Concentration | $PCl_3(g)$ | + $Cl_2(g)$ | $\rightleftharpoons$ $PCl_5(g)$ |
|---|---|---|---|
| Initial | 0.05 | 0.02 | 0.04 |
| Change | $-x$ | $-x$ | $+x$ |
| Equilibrium | $0.05-x$ | $0.02-x$ | $0.04+x$ |

$$K_c = \frac{[PCl_5(g)]_{eqm}}{[PCl_3(g)]_{eqm}[Cl_2(g)]_{eqm}}$$

$$25 = \frac{0.04+x}{(0.05-x)(0.02-x)}$$

$$0.025 - 1.75x + 25x^2 = 0.04 + x$$

$$25x^2 - 2.75x - 0.015 = 0$$

$x = 0.115$ (rejected) or $x = -5.121 \times 10^{-3}$

So, the equilibrium concentration of $Cl_2(g)$ is 0.0252 mol $dm^{-3}$.

(2 marks)

Answers written in the margins will not be marked.

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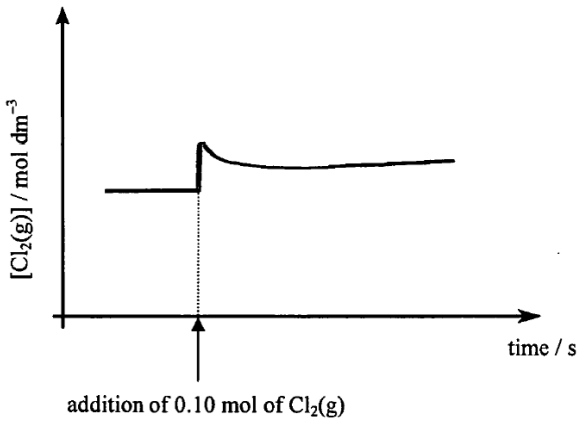
12. (c) 0.10 mol of $Cl_2(g)$ is added to the equilibrium mixture in (b). Sketch, in the graph below, the variation of the concentration of $Cl_2(g)$ with time until a new equilibrium is attained. (Assume that the temperature of the system remains at 250°C throughout the whole process.)




(1 mark)

*13. Lithium, beryllium, carbon (graphite) and nitrogen are elements of the second period of the Periodic Table. Arrange them in increasing order of melting point, and explain the order in terms of structure and bonding.

(5 marks)

Nitrogen < Lithium < beryllium < Carbon (graphite)

Nitrogen has simple molecular structure. The molecules of nitrogen are held together by weak van der Waals' forces, less energy is required to separate the nitrogen molecules during melting.

Lithium and beryllium has giant metallic structure and their atoms are held together by strong metallic bond. As the metallic bonds do not have to be substantially broken down during the melting process, the melting point of Lithium and beryllium may not be very high. As the number of delocalized electrons in beryllium is more than that in lithium, beryllium has stronger metallic bond and higher melting point than lithium.

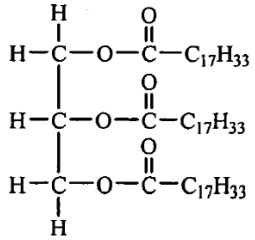
Graphite has giant covalent structure. The carbon atoms are held together by strong covalent bond. A large amount of energy is required to break the strong covalent bonds during the melting process.

Answers written in the margins will not be marked.

Answers written in the margins will not be marked.

Answers written in the margins will not be marked.

14. An unsaturated fat **F** is a component of a vegetable oil. The structure of **F** is shown below:



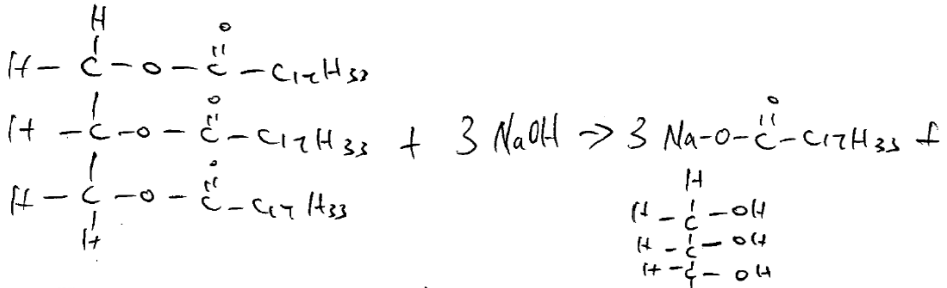
(a) State the reagents needed for converting **F** to a saturated fat.

Hydrogen gas and nickel metal catalyst.

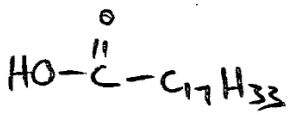
(1 mark)

(b) Vegetable oils can be used to make soap.

(i) Write the chemical equation involved for the formation of soap from **F**.



(ii) In the presence of an acid, the soap formed in (i) can react with methanol to give compound **G**, which can be used as a biodiesel. Draw the structure of **G**.



(2 marks)

(c) With reference to their relative molecular masses and physical properties, explain why **G** can be used as a fuel for cars, but **F** cannot.

This is because the molecular mass of F is much larger than that of G and G has less carbon atoms and can be burnt more completely. Moreover, F is likely to be solid at room temperature and pressure due to its large molecular size and strong van der Waals' forces between the molecules. Therefore, F cannot be used as a fuel. (2 marks)

Answers written in the margins will not be marked.

15. Consider the conversions of organic compounds shown below:

$$\underset{\textbf{X}}{CH_3CH_2COCH_2CH_3} \xrightarrow{\textbf{R}} \underset{\textbf{Y}}{CH_3CH_2CH(OH)CH_2CH_3} \xrightarrow{\text{dehydrating agent}} \underset{\textbf{Z}}{\text{a mixture of alkenes}}$$

(a) Suggest a chemical test to distinguish between **X** and **Y**.

We can use 2,4-dinitrophenylhydrazine to distinguish between X and Y. Only X would give red precipitate of 2,4-dinitrophenylhydrazone.

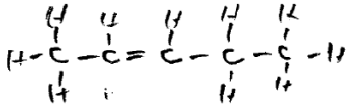
(2 marks)

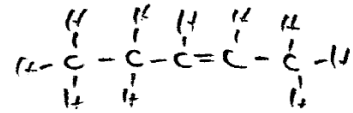
(b) Suggest what reagent **R** might be.

It may be lithium aluminium hydride in dry ether solvent.

(1 mark)

(c) The mixture **Z** contains two alkenes with the same structural formula. Draw the respective structures of these two alkenes, and state their isomeric relationship.

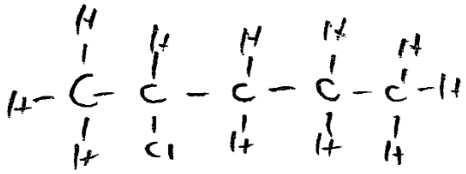




They are structural isomers which shows position isomerism with different position of functional group.

(2 marks)

(d) The alkenes in (c) can react with HCl to form an optically active chloroalkane. Write the structural formula of this chloroalkane.



(1 mark)

**END OF SECTION B**

**END OF PAPER**

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(a)(i)(1) The y-axis represents the number of molecules and the x-axis represents the kinetic energy of the molecules

(2) As shown from the above graph, as the temperature increases, the Maxwell-Boltzmann distribution curve would shift to the right. Therefore, the number of molecules having kinetic energy greater than or equal to the activation energy increases. Thus increases the chance of effective collision and hence the reaction rate would increase.

Moreover, as temperature increases, the kinetic energy of molecules increases. As they move faster, they have higher chance to collide with each other. This increases the chance of effective collision and hence the reaction rate higher.

(ii) $k = Ae^{-\frac{E_A}{RT}}$

$\log k = \log A - \frac{E_A}{2.3RT}$

Slope of the straight line $= \frac{-4.1-(-5.7)}{2.8-2.57} = -\frac{40}{23}$

$-\frac{E_A}{2.3R} = -\frac{40}{23}$

$E_A = 0.03324 \text{ kJ mol}^{-1}$

∴ The activation energy of the reaction is $0.03324 \text{ kJ mol}^{-1}$.

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(b)(i) A catalyst increases the rate of a chemical reaction by providing an alternative pathway with lower activation energy for the chemical reaction to proceed.

(ii) Concentrated sulphuric acid. This is because concentrated sulphuric acid has dehydrating property, thus it would remove water from the equilibrium system, driving the equilibrium position to the product side and increase the yield of eugenol benzoate.

(iii) Using homogeneous catalyst does not need the separation of the solid catalyst through physical method like filtration. The product can be used directly.
Heterogeneous catalyst can be easily separated out through physical method like filtration. Therefore, it can be recused.

(c)(i) In the electrolytic cells, chloride ions are preferentially discharged at the anode. This is because the concentration of $Cl^-_{(aq)}$ ion in brine is much higher than that of $OH^-_{(aq)}$ ions while they are not too far away in the Electrochemical ~~force~~ series. Therefore, under the concentration effect, $Cl^-_{(aq)}$ ions are preferentially discharged to form $Cl_{2(g)}$.

$$2Cl^-_{(aq)} \rightarrow Cl_{2(g)} + 2e^-$$

At the cathode, $H^+_{(aq)}$ ions are preferentially discharged

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as it is stronger oxidizing agent than $Na^+_{(aq)}$ ions in the brine and hydrogen gas is produced. This leaves the $Na^+_{(aq)}$ ions and $OH^-_{(aq)}$ ions in the electrolytic cells to form $NaOH_{(aq)}$.

(ii) Atom economy $= \frac{44.6985}{76} \times 100\%$

$= 58.8\%$

(iii) Method 2 is greener than Method 1 as it has higher atom economy.

Moreover, Method 2 does not use $NaOH_{(aq)}$ which is corrosive in the synthesis. The synthesis in method 2 is safer.

(iv) A reaction with high atom economy not always has a high percentage yield.

Percentage yield is affected by other factors, like in an equilibrium system, the percentage yield of a product is affected by the operating temperature and pressure.

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(a) ~~Hex-1-ene can be obtained from a mixture of hex-1-ene, octane and water by fractional distillation~~

Water can first be removed from the mixture of hex-1-ene, octane and water by liquid-liquid extraction using a separating funnel as hex-1-ene and octane are immiscible with water. Hex-1-ene and octane being less dense than water forms the upper layer and water forms the lower layer in the separating funnel.

Octane can then be removed from the mixture of hex-1-ene and octane by fractional distillation using a fractionating column as they have a difference of about 60°C in their boiling point. As hex-1-ene has lower boiling point than octane, hex-1-ene will be separated out as the distillate ~~at~~ in the distillation.

(b)(i) A suitable indicator should be present to show colour change in order to show the end point of the titration.

(ii) This is to prevent the $SO_2(aq)$ from being oxidized by atmospheric oxygen.

(iii) It changes from blue to colourless.

(iv) No. of mole of $I_2(aq)$ used = $4.326 \times 10^{-5}$ mol

No. of mole of $SO_2(aq)$ present = $4.326 \times 10^{-5}$ mol.

Mass of $SO_2(aq)$ present = 2.77 mg (corr. to 3 s.f.)

Concentration of $SO_2$ = 111 mg $dm^{-3}$ (corr. to 3 s.f.)

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(v) ~~Yes, the total concentration of $SO_2$ in a sample of red wine can be determined in this experiment as~~
No, this is because the colour of red wine may affect us to determine the end point of the titration through ~~observing~~ observing the colour change.

(c) (i) Rf value $= \frac{2.3}{2.3+1.9+2.9} = 0.324$ (correct to 3 sig. fig.)

(ii) The first-collected coloured fraction would be β-carotene as it travels faster ~~than~~ than lycopene under the same stationary phase and mobile phase.

(iii) Colourimetry can be used to determine the concentration of lycopene using a colourimeter.
This is because the intensity of reddish orange colour of the lycopene fraction is directly proportional to the concentration of lycopene. The light absorbance of the lycopene fraction could be measured.

(iv) According to the infra-red spectrum, lycopene has an absorption peak at around 1610 $cm^{-1}$, indicating that lycopene has carbon-carbon double bond.
Lycopene also has absorption peak at around 2850 $cm^{-1}$ and 2900 $cm^{-1}$, indicating that lycopene has C-H bond.

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Therefore, structure D may be the structure of lycopene as it only has C-H bond and C=C bond in its structure.

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**Comments**

The candidate's answers show a clear understanding of the chemical concepts and principles covered in the curriculum. He/she demonstrates very good problem-solving skills in answering questions involving unfamiliar situations (e.g. the organic structure determination in Paper 2 Q.3(c)). The questions involving chemical calculations (e.g. Paper 1 Qs. 3, 4 and 12; Paper 2 Q.3(b)) are well answered. He/she can effectively communicate ideas using scientific terminology, appropriate diagrams and chemical equations. His/her presentation of ideas in the essay questions (Paper 1 Qs.6 and 13) demonstrates proficiency in the language used and a smooth flow of ideas.

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