# ANDERSON SERANGOON JUNIOR COLLEGE

## 2025 JC 2 PRELIMINARY EXAMINATION

**NAME:**____________________________ (        ) **CLASS:** 25 / _____

**CHEMISTRY** **9729/02**

Paper 2 Structured Questions **27 August 2025**

**2 hours**

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

**READ THESE INSTRUCTIONS FIRST**

Write your name, class and register 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.

Answer **all** questions in the spaces provided on the Question Paper.
The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

The number of marks is given in brackets [ ] at the end of each question or part question.

| For Examiner's Use | | |
|---|---|---|
| Paper 2 | 1 | /8 |
| | 2 | /16 |
| | 3 | /25 |
| | 4 | /14 |
| | 5 | /12 |
| Total | | / 75 |

This document consists of **22** printed pages and **2** blank pages.

Answer **all** the questions.

**1** **(a)** Mild steel is an alloy that contains iron and carbon. A sample of mild steel was analysed, and four different types of atoms were identified; **A**, **B**, **C** and **D**. Table 1.1 shows information about the four types of atoms found in the sample.

**Table 1.1**

| atom | relative mass | relative % abundance |
|---|---|---|
| **A** | 12.00 | 0.238 |
| **B** | 13.00 | 0.012 |
| **C** | 53.94 | 5.79 |
| **D** | 55.93 | 93.96 |

**(i)** Calculate the relative atomic mass of carbon in this sample to four significant figures. Show your working.

[1]

**(ii)** In an experimental set-up, beams of particles travelling at the same speed from different sources are subjected to an electric field as shown in Fig. 1.1. A beam of protons with an angle of deflection of 60° has already been drawn.

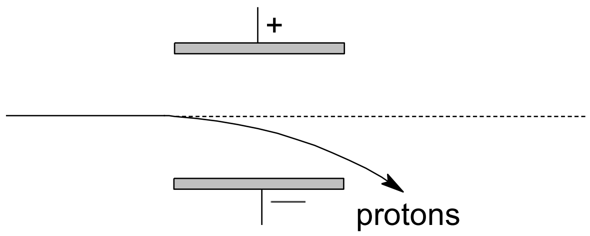


**Fig. 1.1**

Under identical conditions, beams of particles $^{12}C^{2+}$ and $^{56}Fe^{2+}$ were subjected to the same electric field.

Calculate the angle of deflection of $^{12}C^{2+}$ and $^{56}Fe^{2+}$particles under the electric field and sketch the beams of $^{12}C^{2+}$ and $^{56}Fe^{2+}$ on Fig. 1.1. Label the beams clearly.

[2]

**(b)** The compound $C_6H_6$ has many possible structural isomers. Three suggested structures of $C_6H_6$ are shown in Fig. 1.2.

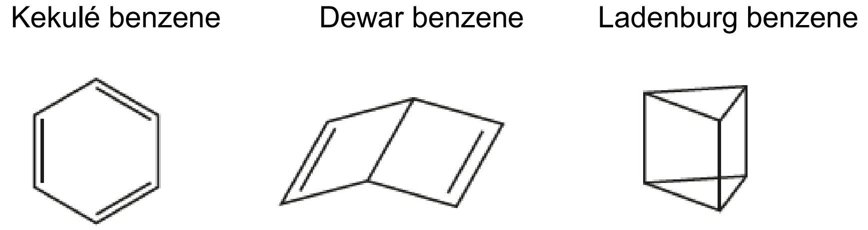


**Fig. 1.2**

**(i)** Using Fig. 1.2, complete Table 1.2 to predict the number of carbon atoms that have sp, $sp^2$ and $sp^3$ hybridisation in Kekulé benzene, Dewar benzene and Ladenburg benzene.

**Table 1.2**

| $C_6H_6$ structure | sp hybridised | $sp^2$ hybridised | $sp^3$ hybridised |
|---|---|---|---|
| Kekulé benzene | | | |
| Dewar benzene | | | |
| Ladenburg benzene | | | |

[2]

**(ii)** Dewar benzene contains both σ bonds and π bonds.
By reference to the hybridisation of the carbon atoms and orbital overlap, describe the covalent bonding in Dewar benzene.

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**(iii)** Suggest why Dewar benzene and Ladenburg benzene are unstable isomers of $C_6H_6$.

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[Total: 8]

**2** Aluminum is the most abundant metal in the earth's crust and has been produced commercially since 1888. It is now the second most used metal in the world after iron.

Approximately 75% of aluminum ever produced is still in use today, as it can be recycled endlessly without compromising any of its unique properties or quality.

**(a)** Aluminum objects that have had the aluminum oxide layer removed may be anodised.

**(i)** Complete Table 2.1 to show the relevant half-equations, during the anodisation of an aluminum object.

**Table 2.1**

| | half-equation |
|---|---|
| anode | ….. A*l* + …... $H_2O$ → ….. $Al_2O_3$ + ….. $H^+$ + …...e |
| cathode | |

[2]

**(ii)** During the anodisation of an aluminum object, 3.50 g of a protective layer aluminum oxide is formed in 2 hours.

Calculate the value of the current used.

[2]

**(b)** Fig. 2.1 shows an **incomplete** energy cycle involving aluminium oxide, $Al_2O_3$.

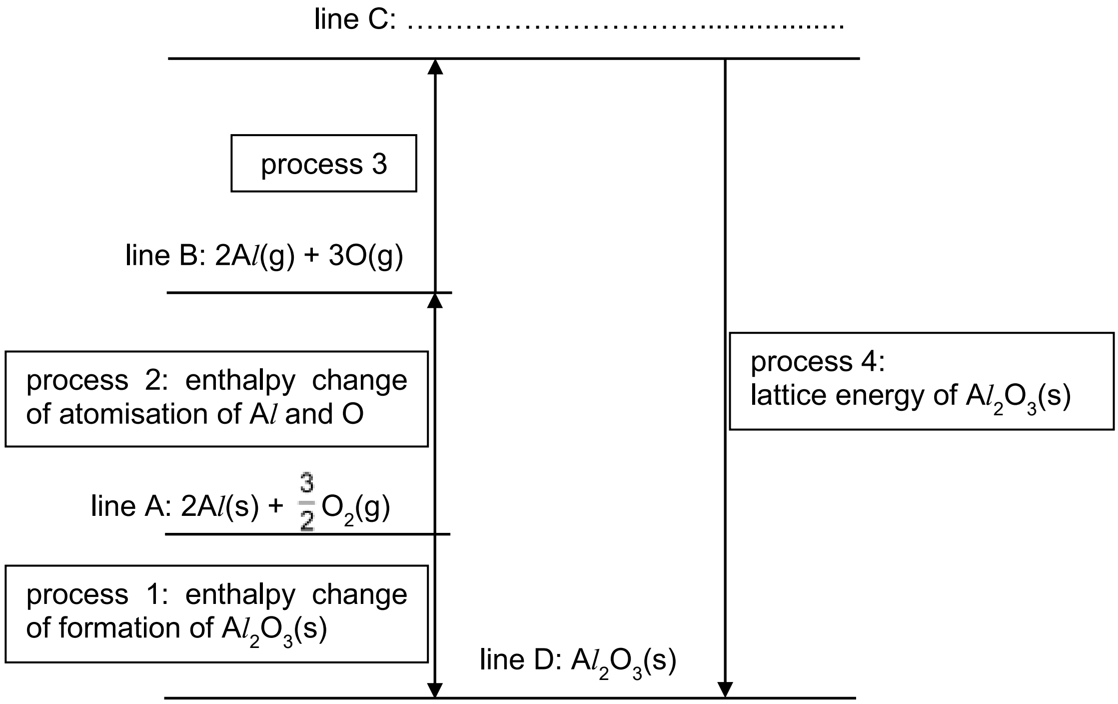


**Fig. 2.1**

**(i)** Complete line C. Include state symbols. [1]

**(ii)** Using Fig 2.1, the data in Table 2.2, together with data from the *Data Booklet*, to calculate the lattice energy of $Al_2O_3$(s).

**Table 2.2**

| | $\Delta H^\ominus$ / kJ mol$^{-1}$ |
|---|---|
| 1st electron affinity of oxygen, $O(g) + e^- \rightarrow O^-(g)$ | –141 |
| 2nd electron affinity of oxygen, $O^-(g) + e^- \rightarrow O^{2-}(g)$ | +790 |
| standard enthalpy change of atomisation of A*l*(s) | +326 |
| standard enthalpy change of formation of $Al_2O_3$(s) | –1676 |

[2]

**(iii)** Explain why the first electron affinity of oxygen is exothermic, but the second electron affinity is endothermic.

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**(c)** When aluminum reacts with dry chlorine, aluminum chloride, $AlCl_3$, is formed.

**(i)** $AlCl_3$ can undergo dimerisation to form $Al_2Cl_6$.

With the aid of a diagram, name the type of bond formed during dimerisation and explain why this bond is formed.

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**(ii)** When $AlCl_3$ is dissolved in water, a solution of pH 3.0 is formed.

Explain with the aid of a balanced equation why the solution has a pH of 3.0.

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**(iii)** $AlCl_3$ can be used as a catalyst in the reaction of methylbenzene with chloroethane to form 4-ethylmethylbenzene.

Describe the mechanism of this reaction.

[3]

[Total: 16]

**3** **(a)** The acid strength of a carboxylic acid is measured by its p$K_a$ value.
Table 3.1 shows p$K_a$ of ethanoic acid, chloroethanoic acid and fluoroethanoic acid.

**Table 3.1**

| carboxylic acid | p$K_a$ |
|---|---|
| ethanoic acid, $CH_3CO_2H$ | 4.76 |
| chloroethanoic acid, $ClCH_2CO_2H$ | 2.87 |
| fluoroethanoic acid, $FCH_2COOH$ | 2.60 |

**(i)** Explain the difference in p$K_a$ values for ethanoic acid, chloroethanoic acid and fluoroethanoic acid.

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**(ii)** Calculate the $\frac{[\text{anion}]}{[\text{acid}]}$ ratio for each of the following acids when it is placed in a buffer solution kept at pH 3.8. Give your answer to **three** significant figures.

| For $CH_3CO_2H$: | For $ClCH_2CO_2H$: |
|---|---|
| | |

[1]

**(iii)** Hence, using your answer from **(a)(ii)**, explain if ethanoic acid or chloroethanoic acid, and its conjugate base forms a more effective buffer in removing the small amount of $H^+$ added at pH 3.8.

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**(b)** Both ethanoic acid, $CH_3COOH$, and lactic acid, $CH_3CH(OH)CO_2H$, can be synthesised from ethanol, $CH_3CH_2OH$, in the laboratory via different routes, as shown in Fig. 3.1.

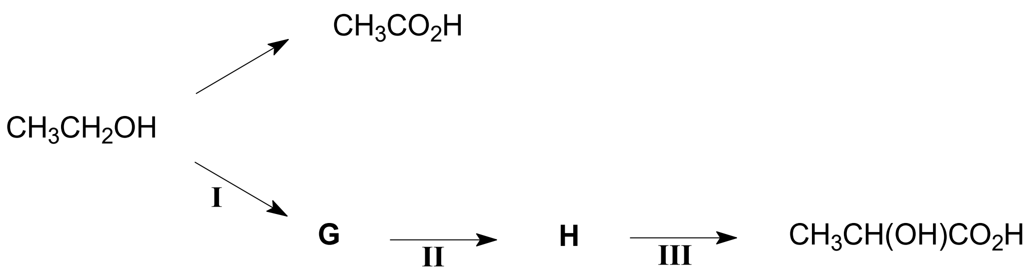


**Fig. 3.1**

**(i)** Suggest structures for compounds **G** and **H**.

**G** **H**

[2]

**(ii)** Suggest reagents and conditions for each of the steps **I** and **II**.

step **I** ……………………………………………………………………………

step **II** ……………………………………………………………………………
[2]

**(iii)** It is found that lactic acid synthesised in the lab do not rotate plane polarised light while naturally occurring lactic acid found in goat milk exhibits optical activity. Explain why such observation is made.

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**(c)** Lactic acid reacts in the presence of hot, concentrated sulfuric acid to form two different compounds, **J** and **K**.

- **J** has a molecular mass 72.0 g mol$^{-1}$
- **K** is a cyclic compound and has a molecular formula $C_6H_8O_4$.

Draw the skeletal formula of **J** and **K**.

| **J** | **K** |
| --- | --- |

[2]

**(d)** Table 3.2 shows the solubility of various calcium salts in water.

**Table 3.2**

| calcium salt | solubility / mol dm$^{-3}$ | colour |
|---|---|---|
| $CaC_2O_4$ | 4.8 x $10^{-5}$ | white |
| $Ca_3(PO_4)_2$ | 1.6 x $10^{-7}$ | white |
| $CaCrO_4$ | 2.7 x $10^{-2}$ | bright yellow |

**(i)** Write an expression for the solubility product of $Ca_3(PO_4)_2$.

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

**(ii)** Calculate the solubility product, $K_{sp}$, for $Ca_3(PO_4)_2$, giving its units.

[1]

**(iii)** Describe what you would observe if equal volumes of saturated solutions of $CaC_2O_4$ and $CaCrO_4$ were mixed. Explain your answer using calculations.

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**(e)** An iodometric titration can be used to determine the percentage purity of calcium oxalate crystals, $CaC_2O_4$.

A 3.20 g impure sample of $CaC_2O_4$ is shaken with 100.0 $cm^3$ of 0.10 mol $dm^{-3}$ aqueous acidified $MnO_4^-$ ions. One of the products of this reaction is $CO_2$.

The remaining $MnO_4^-$ is reacted with an excess of iodide solution to liberate $I_2$(aq).

$$2MnO_4^-(aq) + 10I^-(aq) + 16H^+(aq) \rightarrow 2Mn^{2+}(aq) + 5I_2(aq) + 8H_2O(l)$$

A 25.0 $cm^3$ aliquot requires 24.50 $cm^3$ of 0.2 mol $dm^{-3}$ $S_2O_3^{2-}$ for this titration.

$$2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$

**(i)** Construct an equation for the reaction between $MnO_4^-$ ions and $C_2O_4^{2-}$ ions.

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

**(ii)** Calculate the percentage purity of the sample of $CaC_2O_4$.

[3]

**(f)** The trend in the thermal stability of Group 2 oxalates, $MC_2O_4$, is similar to that of Group 2 carbonates.

Suggest if $MgC_2O_4$ or $CaC_2O_4$ undergoes thermal decomposition at a lower temperature. Explain your answer.

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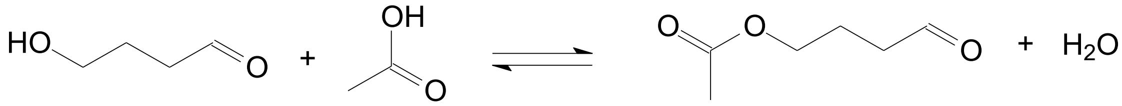
[Total: 25]

**4** **(a)** 4-hydroxybutanal can undergo an esterification reaction with a carboxylic acid. In a controlled experiment, 4-hydroxybutanal and ethanoic acid were heated under reflux with a small amount of concentrated sulfuric acid as a catalyst.




The following information was recorded from the experiment at 298 K.

- initial amount of 4-hydroxybutanal: 0.500 mol
- initial amount of ethanoic acid: 0.400 mol
- total volume of solution: 2.00 dm³
- at equilibrium, 60% of 4-hydroxybutanal has reacted

**(i)** Write the expression for the equilibrium constant, $K_c$, for this reaction. Use your expression to calculate the value of $K_c$ for this reaction.

[3]

**(ii)** Aqueous potassium hydroxide was added to the equilibrium mixture at 298 K.

Suggest how the position of equilibrium might change and if the $K_c$ will be affected.

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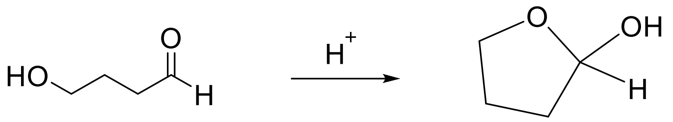
**(b)** 4-hydroxybutanal can form a cyclic hemiacetal in the presence of an acid catalyst as shown in Fig. 4.1.

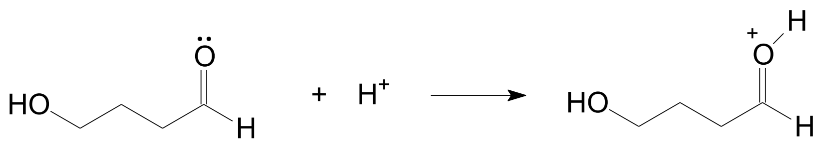
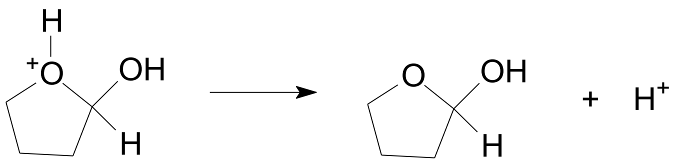



4-hydroxybutanal | cyclic hemiacetal

**Fig. 4.1**

**(i)** The mechanism for the reaction in Fig. 4.1 is shown in Table 4.1.
Draw **four** curly arrows to complete the mechanism shown in Table 4.1.

**Table 4.1**

| | |
|---|---|
| Step 1:<br>The aldehyde is protonated by the acid catalyst to form a non-cyclic intermediate. |  |
| Step 2:<br>Nucleophilic attack by the alcohol to form a cyclic intermediate. |  |
| Step 3:<br>Deprotonation of the cyclic intermediate to form the product. |  |

[2]

**(ii)** The reaction to form cyclic hemiacetal is completed when all the 4-hydroxybutanal is used up. Describe a chemical test to check the completion of the reaction.

Include the reagents and conditions for the test. Explain how the observations will be used to determine if the reaction has been completed.

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**(c)** Koch reaction uses carbon monoxide to manufacture tertiary carboxylic acids as shown in Fig. 4.2.

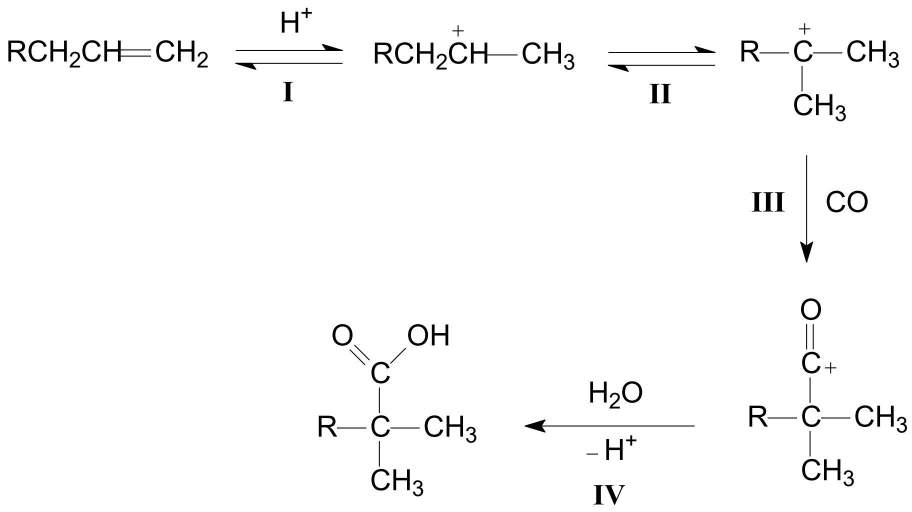


**Fig. 4.2**

**(i)** Step **II** is known as a rearrangement reaction. With reference to the stability of the species involved, suggest a reason why such a reaction occurs.

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**(ii)** Draw the "dot–and–cross" diagram for carbon monoxide, CO.

[1]

**(iii)** Hence, state the role of carbon monoxide, CO, in the mechanism of step **III**.

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

**(iv)** Acidic hydrolysis of an ester can be explained in terms of nucleophilic acyl substitution.

Besides electronic effect, suggest another reason why esters synthesised from tertiary carboxylic acids are stable when heated in the presence of acids.

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[Total: 14]

**5** **(a)** Volatile Organic Compounds (VOCs) are a group of organic chemicals that easily vaporise at room temperature. They are released by a wide range of products and processes, both indoors and outdoors.

Some VOCs can contribute to the formation of secondary pollutants like ozone and have adverse health effects. They are usually released from sources like vehicle exhaust, paint and solvents.

In the presence of sunlight, photochemical reaction is triggered between nitrogen oxides (NO and $NO_2$) and VOCs. The five stages of the reaction between formaldehyde, one of the common VOCs, with NO in the presence of sunlight leading to the formation of ozone, $O_3$, are described in Table 5.1.

**Table 5.1**

| stage | description of stage | equation |
|---|---|---|
| 1 | *photolysis of formaldehyde | $HCHO \rightarrow \bullet H + \bullet CHO$ |
| 2 | oxidation of formyl radical | $\bullet CHO + O_2 \rightarrow CO + \bullet HO_2$ |
| 3 | oxidation of NO(g) | $\bullet HO_2 + NO \rightarrow NO_2 + \bullet OH$ |
| 4 | photolysis of $NO_2$(g) | |
| 5 | formation of $O_3$(g) | |

* photolysis is the decomposition of a molecule by the action of light.

After stage 3, $NO_2$ is photolysed by sunlight to generate NO and O atoms. The O atom formed then reacts with the oxygen gas in the air to form ozone.

**(i)** Explain why the hydrogen atom produced in step 1 is described as a *free radical*.

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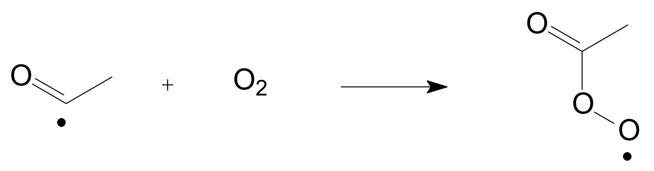
**(ii)** Complete Table 5.1 by adding the two equations to represent stages 4 and 5. [1]

**(iii)** Propanone, $CH_3COCH_3$, undergoes a similar reaction to that shown for stage 1 to 3 in Table 5.1.

Complete Table 5.2 by adding the equations to represent stage 1 and 3.

**Table 5.2**

| stage | description of stage | equation |
|---|---|---|
| 1 | photolysis of $CH_3COCH_3$ to generate two radicals, $CH_3CO\bullet$ being one of them | |
| 2 | oxidation of $CH_3CO\bullet$ radical to form peroxyacetyl radical |  |
| 3 | oxidation of NO(g) by peroxyacetyl radical to form brown gas | |

[2]

**(b)** In recent years, there is an increasing concern about the post renovation air quality in buildings. In 2018, the death of a flat-dweller in Beijing has been attributed to formaldehyde, a carcinogenic substance widely used in wood products due to its strong adhesive, preservative and binding properties. Similarly, homeowners in Singapore have also been seeking help as they experienced stinging sensation in their nose and eyes due to VOCs released from furniture in their newly-renovated houses.

The air quality of a newly renovated office with limited ventilation was studied over the course of one week. Table 5.3 shows the average concentrations, in parts per billion (ppb), of selected VOCs detected.

**Table 5.3**

| VOCs detected in the air of the office | molar mass (g $mol^{-1}$) | concentration (ppb) |
|---|---|---|
| Formaldehyde, HCHO | 30.0 | 0.0692 |
| Toluene, $C_6H_5CH_3$ | 92.0 | 38.5 |
| Xylene $C_6H_4(CH_3)_2$ | 106.0 | 12.7 |

**(i)** State two basic assumptions of the kinetic theory as applied to an ideal gas.

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**(ii)** Explain, with reference to intermolecular forces, which VOC vapour in Table 5.3 will have the greatest deviation from ideal gas behaviour.

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**(iii)** The concentration of VOC in the air is often represented in parts per billion (ppb). 1ppb VOC means there should be 1 mole of VOC for every 1 000 000 000 moles of air.
Calculate the concentration, in mol $dm^{-3}$, of toluene in the sample of office air.

[Assume the sample of air is at room temperature and pressure conditions.]

[1]

**(iv)** The indoor air quality is often measured by TVOC (Total Volatile Organic Compounds) levels. It is calculated as the sum of the concentrations of all measured VOCs, expressed in ppb.

Using Table 5.3, determine the TVOC level of the office.

[1]

**(v)** The World Health Organisation (WHO) recommends a target level of under 50 ppb for TVOC.

Explain if the TVOC level of the office is of concern and suggest a measure that can be taken to keep TVOC low in indoor spaces.

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[Total: 12]

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