TAMPINES MERIDIAN JUNIOR COLLEGE

JC2 PRELIMINARY EXAMINATION

CANDIDATE NAME **SUGGESTED ANSWERS**

CIVICS GROUP

H1 CHEMISTRY **8873/02**

Paper 2 Structured Questions **12 September 2024**

2 hours

Candidates answer on the Question Paper.

Additional materials: *Data Booklet*

READ THESE INSTRUCTIONS FIRST

Write your name and civics group in the spaces provided at the top of this page.
Write in dark blue or black pen on both sides of the paper.
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.

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

Examiner's Use		
Paper 1	**MCQ**	**/ 30**
Paper 2	**Section A**	
	Q1	**/ 9**
	Q2	**/ 6**
	Q3	**/ 14**
	Q4	**/ 8**
	Q5	**/ 10**
	Q6	**/ 13**
	Section B	
	Q7	**/ 20**
	Q8	**/ 20**
		/ 80
Total		**/ 100**
Grade		

Section A

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

1 **(a)** Aluminium and boron are two elements of Group 13.

(i) Complete the electronic configuration for Al and Al^{3+}.

Al: $1s^2$ **$2s^2 2p^6 3s^2 3p^1$** .....

Al^{3+}: $1s^2$ **$2s^2 2p^6$** ..... **[1] for both** [1]

(ii) Atoms of elements are made up of the three subatomic particles: protons, electrons and neutrons, in varying numbers.

Complete Table 1.1 for each subatomic particle of an atom of $^{26}_{13}Al$.

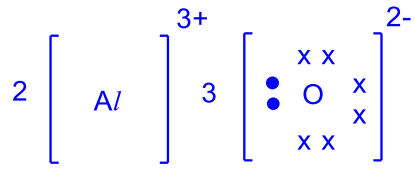
Table 1.1

atom	number of protons	number of neutrons	number of unpaired electrons
$^{26}_{13}Al$	**13**	**13**	**1**

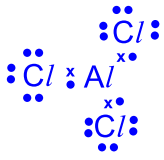
[1] for all three entries [1]

(b) The compounds of aluminium and boron have many uses. Aluminium oxide, Al_2O_3, is commonly used as a refractory material for lining furnaces while aluminium chloride, $AlCl_3$, is an antiperspirant agent. Boron trichloride, BCl_3, is used in the refining process of aluminium.

(i) Draw the dot-and-cross diagrams for Al_2O_3 and $AlCl_3$.



[1]



[1]

[2]

(ii) Briefly describe the bonding in $AlCl_3$ in terms of the overlap of orbitals.

There are 3 single Al–Cl covalent bonds where the orbitals **overlap head-on** to form (σ) bonds. **[1]** [1]

(iii) With reference to the Valence Shell Electron Pair Repulsion Theory, explain the shape and bond angle with respect to the B atom in BCl_3.

There are **3 bond pairs and 0 lone pairs around B** atom. To minimise repulsion and maximise stability, it is **trigonal planar [1]**.

There are **equal bond pair – bond pair repulsions**, **bond angle is 120°**. **[1]**

[2]

(c) Table 1.2 shows the melting points of two different boron compounds, BCl_3 and $NaBH_4$.

Table 1.2

compound	melting point / °C
BCl_3	– 107
$NaBH_4$	400

With reference to structure and bonding, explain the difference in melting points of the two compounds.

$NaBH_4$ has a **giant ionic lattice** structure, while BCl_3 is **simple molecular**. **More energy** is required to overcome the **stronger electrostatic attraction between oppositely charged ions** in $NaBH_4$ than the **weaker instantaneous dipole – induced dipole attractions between BCl_3 molecules**, hence $NaBH_4$ has a higher melting point than BCl_3. **[2]**

[2]

[Total: 9]

2 This question is about ionisation energies of elements.

(a) **(i)** Define the term *first ionisation energy*.

The first ionisation energy is the **energy required** to **remove one mole of electrons** from **one mole of gaseous atoms** to **form one mole of singly-charged gaseous cations**. **[1]** [1]

(ii) Explain the general trend in first ionisation energy of elements down a Group in the Periodic Table.

First ionisation energy **decreases** down the Group as the number of protons increases, hence **nuclear charge increases**.

However, the **number of electron shells and shielding effect also increases**.

Hence, the valence electrons experience **weaker electrostatic forces of attraction** to the **nucleus**. **Less energy** is required to remove the valence electron. [2]

[2]

(b) The first six ionisation energies for an unknown element **X** is given in Table 2.1.

Table 2.1

	1st	2nd	3rd	4th	5th	6th
ionisation energy of **X** / kJ mol^{-1}	1050	1900	2910	4960	6270	21300

(i) Deduce the Group number of element **X,** giving your reasoning.

The **first big jump** in ionisation energy takes place **between the 5th and 6th electron**. This means that the **6th electron is from an inner quantum shell**. **[1]**

Hence there are **5 valence electrons** and thus element **X** is in **Group 15**. **[1]**

[2]

(ii) The graph in Fig. 2.1 shows a sketch of the first ionisation energies of six consecutive elements within Periods 2 and Period 3.

The letters do not represent the symbols of elements.

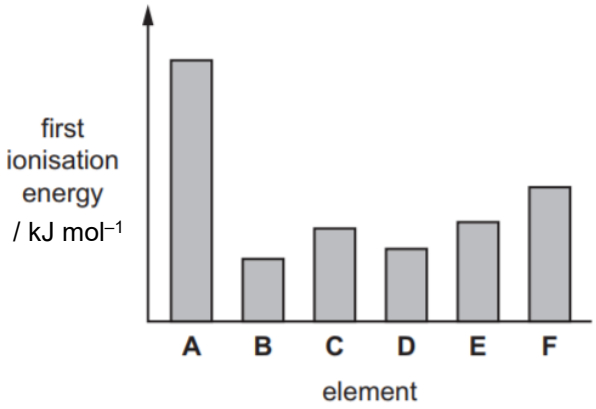


Fig. 2.1

Identify the alphabet letter in Fig. 2.1 that belongs to element **X**.

X corresponds to letter **F**. **[1]** ..... [1]

[Total: 6]

3 **(a)** Ethanoic acid is a weak acid.

$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$

A sample of ethanoic acid can be mixed with aqueous sodium ethanoate to make a buffer solution.

(i) Define the term *pH*.

It is defined as the **negative logarithm to base 10 of the concentration of H^+** in solution in mol dm^{-3} *OR* **$pH = -\log_{10}[H^+]$ [1]** [1]

(ii) Explain with aid of equations, how the sample mixture of ethanoic acid and sodium ethanoate behaves as a buffer.

When **small amount of acid, H^+**, is added, **$CH_3COO^- + H^+ \rightarrow CH_3COOH$ [1]**

The **added H^+ is removed as CH_3COOH**, $[H^+]$ is slightly changed hence **pH remains fairly constant**.

When a **small amount of base, OH^-** is added, **$CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$ [1]**

The added OH^- is removed as CH_3COOH and H_2O, $[OH^-]$ is slightly changed hence **pH remains fairly constant**. **[1]** [3]

(iii) The sample of ethanoic acid with a pH value of 3.0 has a molar concentration of 0.0750 mol dm^{-3}.

The degree of dissociation, α, is the percentage of acid molecules that dissociate into ions:

$$\alpha = \frac{[\text{acid}]_{\text{dissociated}}}{[\text{acid}]_{\text{initial}}} \times 100\%$$

Using this information, determine α for the sample of ethanoic acid.

$pH = -\log_{10}[H^+] \Rightarrow [H^+] = 10^{-3.0} =$ **1.00×10^{-3} mol dm^{-3} [1]**

$$\alpha = \frac{[HA]_{\text{dissociated}}}{[HA]_{\text{initial}}} = \frac{[H^+]_{\text{eqm}}}{[HA]_{\text{initial}}} \times 100\%$$

$\alpha = (1.00 \times 10^{-3}) \div 0.0750 \times 100\% =$ **1.33% [1]**

α = ...% [2]

(b) A student determines the concentration of ethanoic acid in a sample of vinegar by titrating it with aqueous sodium hydroxide.

$$CH_3COOH + NaOH \longrightarrow CH_3COO^-Na^+ + H_2O$$

A 10.0 cm^3 portion of the sample of vinegar is transferred into a 250 cm^3 volumetric flask.

The solution is made up to 250 cm^3 with deionised water.

Several 25.0 cm^3 portions of this diluted vinegar are titrated against 0.0220 mol dm^{-3} sodium hydroxide, using thymolphthalein indicator. The mean volume of aqueous sodium hydroxide added is 21.10 cm^3.

(i) Calculate the concentration, in mol dm^{-3}, of ethanoic acid in the original sample of vinegar.

Amount of NaOH = (21.10/1000) × 0.0220 = 4.642×10^{-4} mol

Since NaOH ≡ CH_3COOH

Amount of CH_3COOH **in 25 cm^3** portion = 4.642×10^{-4} mol

Amount of CH_3COOH **in 250 cm^3** solution = 4.642×10^{-3} mol **[1]**

Amount of CH_3COOH **in 10 cm^3** vinegar sample = 4.642×10^{-3} mol

Concentration of CH_3COOH in 10 cm^3 vinegar sample = 4.642×10^{-3} / (10/1000)

= **0.464 mol dm^{-3}** **[1]**

[2]

(ii) The minimum legal acidity level of vinegar in most countries is 4% by mass. Below this level, it cannot be sold as vinegar.

Calculate the percentage by mass of ethanoic acid in the original sample of vinegar and state whether the vinegar meets the minimum legal acidity level.

Assume the density of vinegar to be 1 g cm^{-3}.

Mass of CH_3COOH in 10 cm^3 vinegar sample = $4.642 \times 10^{-3} \times 60$ = **0.2785 g [1]**

Since density of vinegar = 1 g cm^{-3}
10 cm^3 of vinegar = 10 g of vinegar

Hence, % mass = (0.2785 / 10) × 100% = 2.79%

Since **2.79% < 4%**, **does not meet** the minimum acidity level. **[1]**

[2]

(c) Ethanoic acid can be reduced to form ethanol, C_2H_5OH, which is useful as fuel.
A direct-ethanol fuel cell (DEFC) is a type of fuel cell that uses ethanol as a fuel source.

The redox reaction in DEFC involves the oxidation of ethanol to carbon dioxide and the reduction of oxygen to water.

(i) Determine the average oxidation number of carbon in ethanol and the oxidation number of carbon in carbon dioxide.

Average oxidation number of C in C_2H_5OH = $\frac{-3-1}{2}$ = **−2**
Oxidation number of C in CO_2 = **+4** **[1] for both**

[1]

(ii) Construct the half-equations for the redox reaction in the DEFC.

Oxidation: $C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 12H^+ + 12e$ [1]

Reduction: $3O_2 + 12H^+ + 12e \rightarrow 6H_2O$ [1] [2]

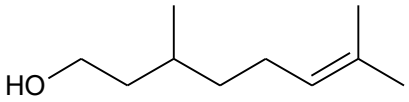
(iii) Hence, or otherwise, write the overall equation for the redox reaction in the DEFC.

$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ [1] [1]

[Total: 14]

4 Organic compounds can have a vast variety of uses and can be found naturally or man-made.

(a) Citronellol has a distinct smell found in perfumes and in some natural insect repellents.



citronellol

Deduce the molecular formula of citronellol.

$C_{10}H_{20}O$ [1]

..... [1]

(b) Fig. 4.1 shows reactions of citronellol.

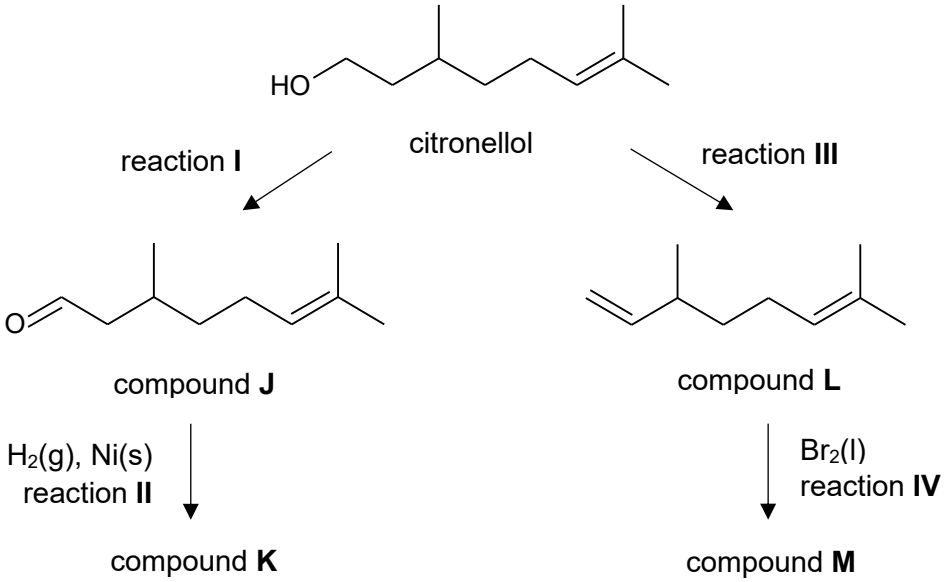
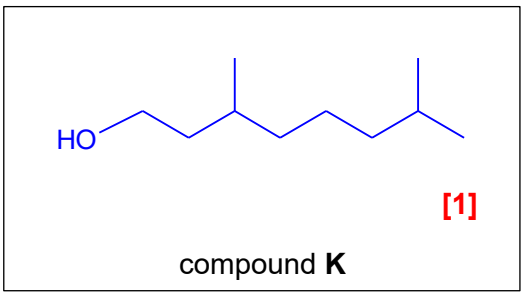
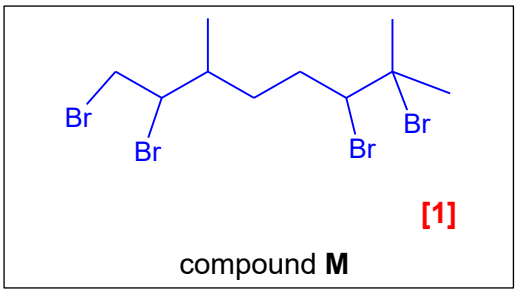


Fig. 4.1

(i) Give the **skeletal** formulae for compounds **K** and **M**.





[2]

(ii) Suggest the reagents and conditions for reactions **I** and **III**.

for reaction **I** acidified $K_2Cr_2O_7$ heat with immediate distillation [1]

for reaction **III** excess concentrated H_2SO_4, heat [1]
OR excess conc H_3PO_4, heat *OR* Al_2O_3, heat

[2]

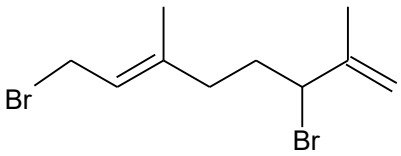
(iii) State the type of reaction occurring in reaction **III**.

type of reaction **Elimination [1]** ..... [1]

(iv) Suggest the IUPAC name for compound **L**.

3,7-dimethylocta-1,6-diene [1] ..... [1]

(v) Compound **M** can be converted into compound **N** which displays cis-trans isomerism.



compound **N**

Explain why compound **N** can exhibit cis-trans isomerism while citronellol cannot.

Compound **N** has a **C=C** double bond that **has restricted rotation** and there are ..... **two different substituents attached to each C of the C=C** (compared with ..... [1] citronellol where the C=C bond has a C atom with two same groups attached.) **[1]**

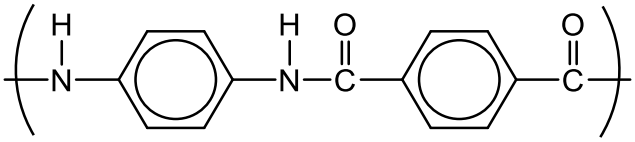
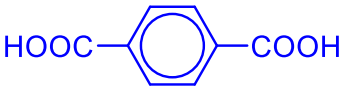
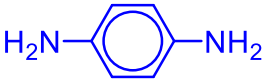
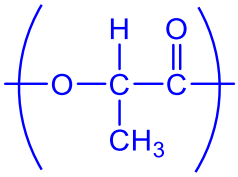
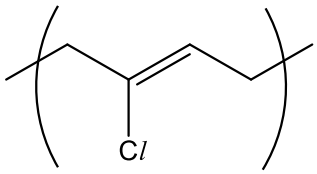
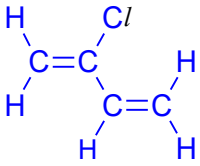
[Total: 8]

5 Many organic molecules are widely used in creating polymers.

(a) *Kevlar*, polylactic acid (PLA) and neoprene are some examples.

(i) Complete the boxes in Table 5.1.

Table 5.1

polymer	structure of repeat unit of polymer	structural formula of monomer(s)
Kevlar		 **[1]**  **[1]**
PLA	 **[1]**	$HOCH(CH_3)CO_2H$ lactic acid
neoprene		 **[1]**

[4]

(ii) Suggest **two** properties why *Kevlar* is suitable to be used in the manufacture of bulletproof vests, racing tires and racing sails.

High tensile strength / light weight / flexible / heat-resistant

(any two of the above – [1])

[1]

(b) PLA is a thermoplastic and used as medical implants in biomedical applications, food packaging and single-use cups.

(i) State the type of polymerisation used to form PLA.

type for polymerisation **Condensation [1]** ..... [1]

(ii) PLA can be used as biomedical implants are intended to be absorbed into the body within two years as they form lactic acid which is non-toxic to the body. Explain why PLA can be broken down in the body.

Ester functional group can be hydrolysed [1] to form smaller monomers which are non-toxic. ..... [1]

(iii) Explain, in terms of structure and bonding, the difference in how a thermoplastic polymer behaves when heated compared to a thermosetting polymer.

- Thermoplastic polymer chains are **closely packed** in space and have **weak van der Waals' forces of attractions between the various chains.**
- Thermosetting polymers are polymers with **cross–linking between individual polymer chains**. The monomer units are linked together to form a three dimensional network where the polymers are expected to be quite **hard, rigid and brittle**.
- These cross–links make the chains much **stronger than in thermoplastics**.
- **Thermoplastics soften when heated and harden again on cooling**. Such materials can be **melted or moulded or reshaped** into various useful products such as food packaging.
- On the other hand, **thermosets do not soften when heated**. **[3]** ..... [3]

[Total: 10]

6 Sulfur trioxide and ammonia are manufactured industrially in processes that involve adjusting conditions to their respective reaction equilibria to optimise production yields.

(a) The Contact process is used to prepare sulfur trioxide from sulfur dioxide and oxygen. The process is a reversible reaction and is performed in a closed system to achieve dynamic equilibrium.

equilibrium 1 $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H < 0$

(i) Define what is meant by *dynamic equilibrium*.

Dynamic equilibrium is where the **rate of forward reaction is equal** to the **rate of reverse reaction**, with the **substances still reacting together** although the **concentrations of reactants and products** remain **constant / the same**. **[1]** [1]

(ii) Write the expression for the equilibrium constant, K_c, of the reaction, stating its units.

$K_c = \dfrac{[SO_3]^2}{[SO_2]^2[O_2]}$ **[1]**

units **mol^{-1} dm^3 [1]**

[2]

(iii) At a certain temperature, 3.00 mol of SO_2 and 2.00 mol of O_2 were added into a reaction chamber of 2.00 dm^3. At equilibrium, the O_2 concentration was found to be 0.30 mol dm^{-3}.

Calculate a value for the equilibrium constant K_c at this temperature.

equilibrium 1	$2SO_2$	O_2	⇌	$2SO_3$
Initial concentration / mol dm^{-3}	3.00 ÷ 2.00 = 1.50	2.00 ÷ 2.00 = 1.00		0
Change concentration / mol dm^{-3}	–0.70 × 2 = –1.40	–0.70		+0.70 × 2 = +1.40
Equilibrium concentration / mol dm^{-3}	**0.10**	0.30		**1.40**

[1]

$K_c = \dfrac{(1.40)^2}{(0.10)^2 \times 0.30}$

= **653** (mol^{-1} dm^3) **[1]**

[2]

(iv) Explain how the following changes would affect the position of equilibrium 1 in the Contact process:

- compression of the container volume,

  Compressing the container will lead to an **increase in total pressure**. **[1]**

  By Le Chatelier's Principle, the **equilibrium position will shift towards the right to decrease the total pressure**. **[1]** [2]

- increase in temperature.

  By Le Chatelier's Principle, an **increase in temperature will favour the endothermic reaction, which is the reverse reaction**. **[1]** Hence the **equilibrium position will shift towards the left to absorb heat**. **[1]** [2]

(b) The Haber process is used to produce ammonia as shown:

equilibrium 2 $\quad N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H < 0$

Fig. 6.1 shows the relationship between temperature, pressure (p) and the percentage of gases converted. A conversion of 100% means the limiting reagent is fully depleted.

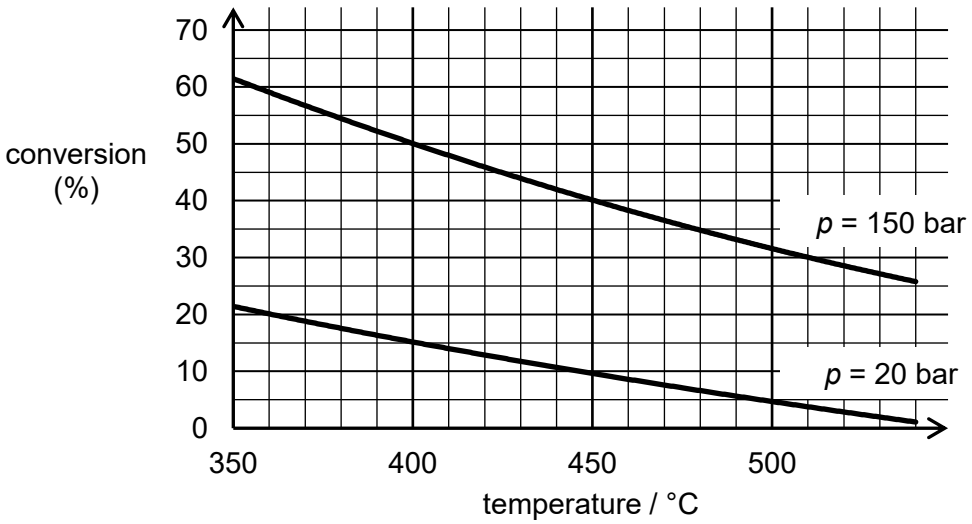


Fig. 6.1

(i) Using Fig. 6.1, estimate the expected percentage conversion of reactants into products at a temperature of 400 °C and pressure of 20 bar. Give your answer to two significant figures.

15% [1] [1]

(ii) Hence, calculate the amount of ammonia gas that will be present at equilibrium when excess nitrogen gas is mixed with 2.00 mol of hydrogen gas at 400 °C and 20 bar.

equilibrium 2	N_2	$3H_2$	⬚	$2NH_3$
Initial amount / mol	1.00	2.00		0
Change in amount / mol	$-0.30 \times \frac{1}{3}$ = –0.10	–15% × 2.00 = **–0.30** **[1]**		$+0.30 \times \frac{2}{3}$ = +0.20
Equilibrium amount / mol	0.90	1.70		**0.20** **[1]**

[2]

(iii) Estimate the pressure needed to achieve 30% conversion at a temperature of 450 °C. State any assumption made.

Assuming the **relationship between pressure and conversion percentage is** ……

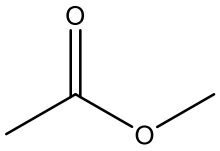
linear / directly proportional, at 450 °C, pressure ≈ **100 bar** **[1]** …… [1]

[Total: 13]

Section B

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

7 **(a)** The skeletal structure of the ester methyl ethanoate, $C_3H_6O_2$, is shown below.



(i) Define the *standard enthalpy change of formation* of methyl ethanoate.

Energy change when **1 mole** of **methyl ethanoate** is formed from its **constituent elements** (of **carbon, hydrogen and oxygen**) under **standard conditions** (**298K, 1 bar**). **[1]** [1]

(ii) Use data from Table 7.1 and the energy cycle to calculate the standard enthalpy change of formation of methyl ethanoate, $\Delta H_f^{\ominus}$.

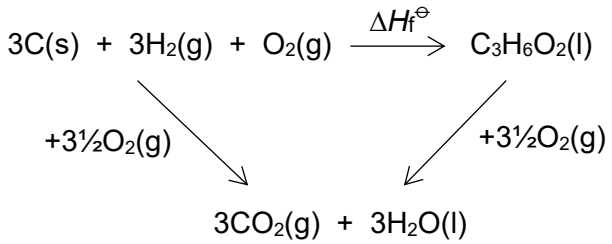


Table 7.1

substance	standard enthalpy change of combustion, $\Delta H_c^{\ominus}$ / kJ mol^{-1}
C(s)	–394
$H_2(g)$	–286
$C_3H_6O_2(l)$	–1592

$\Delta H_f^{\ominus} + \Delta H_c^{\ominus}(C_3H_6O_2) = \mathbf{3}\Delta H_c^{\ominus}(C) + \mathbf{3}\Delta H_c^{\ominus}(H_2)$

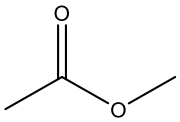
$\Rightarrow \Delta H_f^{\ominus} = \mathbf{3}\Delta H_c^{\ominus}(C) + \mathbf{3}\Delta H_c^{\ominus}(H_2) - \Delta H_c^{\ominus}(C_3H_6O_2)$

$= \mathbf{3}(-394) + \mathbf{3}(-286) - (-1592)$ **[1]**

$=$ **–448 kJ mol^{-1}** **[1]**

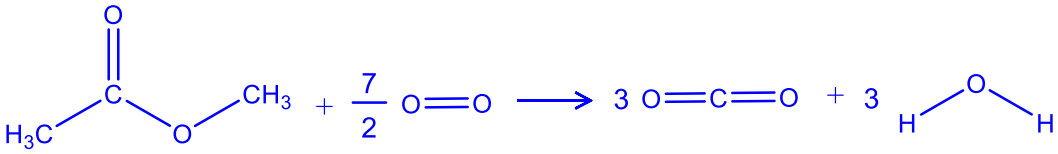
[2]

(iii) The complete combustion of methyl ethanoate is shown below.



(l) + $\frac{7}{2}O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(l)$

With the aid of appropriate bond energies from the *Data Booklet*, calculate another value for the standard enthalpy change of combustion of methyl ethanoate.



$\Delta H_c^{\ominus}(C_3H_6O_2) = \Sigma BE_{rxt} - \Sigma BE_{pdt}$

$= \{[6BE(C–H) + BE(C–C) + 2BE(C–O) + BE(C=O)] + [\frac{7}{2}BE(O=O)]\}$
$\quad – \{6BE(C=O \text{ of } CO_2) + 6BE(O–H)\}$

$= \{(6 \times 410) + 350 + (2 \times 360) + 740 + (\frac{7}{2} \times 496)\}$ **[1]**
$\quad – \{(6 \times 805) + (6 \times 460)\}$ **[1]**

$= \underline{\mathbf{-1584\ kJ\ mol^{-1}}}$ **[1]**

[3]

(iv) The enthalpy change of combustion of methyl ethanoate determined in **(a)(iii)** differs from that listed in Table 7.1. Suggest a reason why this is so.

Some of bond energies used are **average values** **[1]**

…… [1]

(b) Hydrogen peroxide decomposes very slowly to form water and oxygen gas as shown in the equation below.

equation 1 $\quad H_2O_2(aq) \longrightarrow H_2O(l) + \frac{1}{2}O_2(g) \qquad \Delta H_{decomp}$

The enthalpy change of decomposition, ΔH_{decomp}, is exothermic. Iron(III) nitrate, $Fe(NO_3)_3$, is an effective catalyst in this reaction. A student used the apparatus shown in Fig. 7.1 to carry out an experiment to determine ΔH_{decomp}.

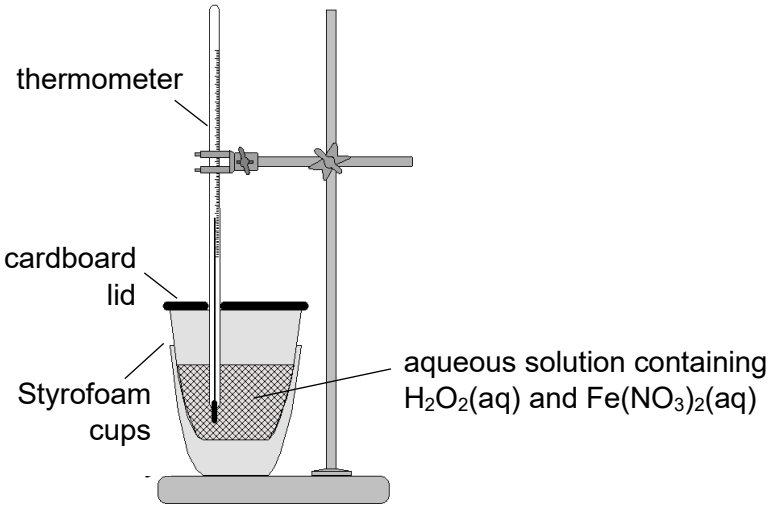


Fig. 7.1

- 50.0 cm^3 of 0.850 mol dm^{-3} aqueous H_2O_2 was placed in Styrofoam cup, which was in turn placed into another cup.
- At fixed time intervals, the temperature of the solution was measured.
- At time t = 4.0 min, 50.0 cm^3 of aqueous $Fe(NO_3)_3$ was added to the H_2O_2.
- The reaction was monitored with temperature taken at fixed time intervals.
- A consistent fall in temperature indicated that the reaction had finished.
- The results are shown in Fig. 7.2.

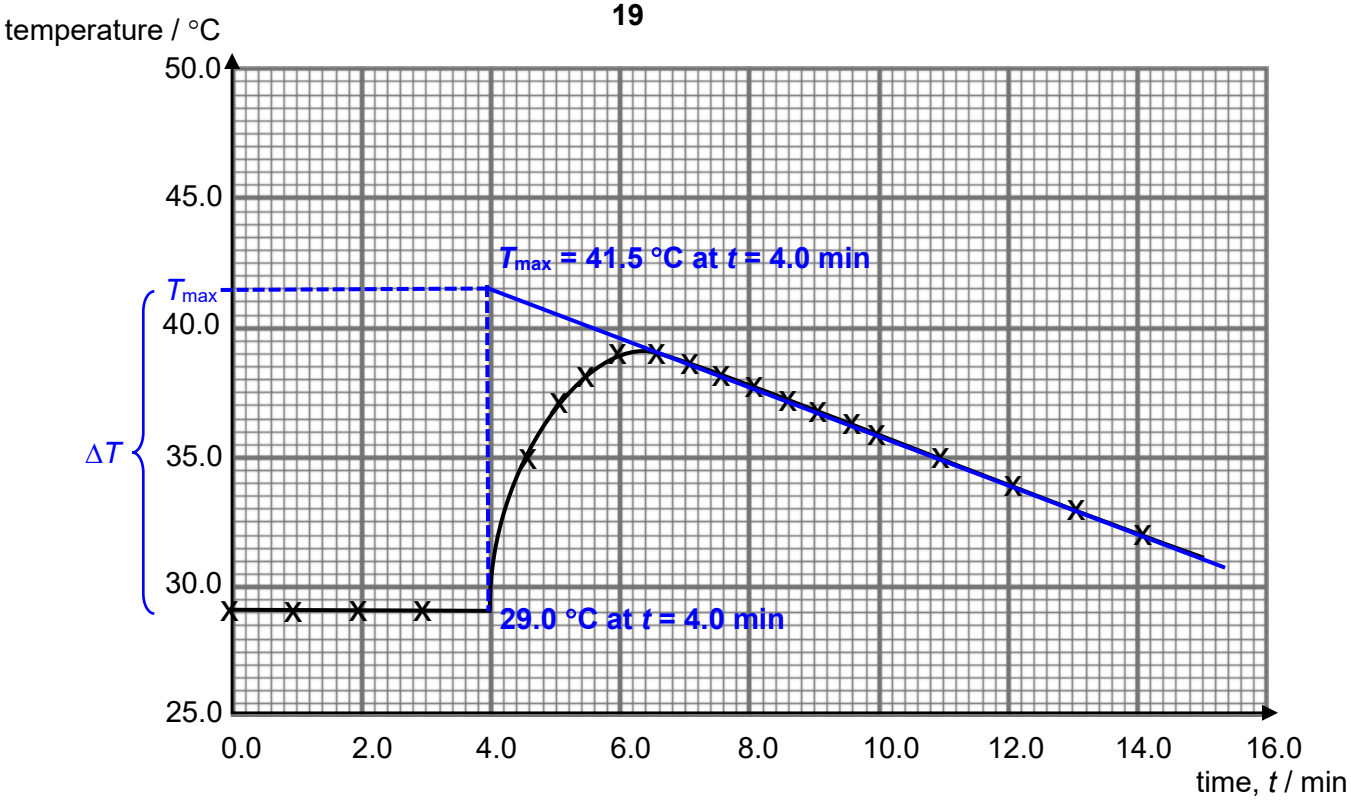


Fig. 7.2

(i) On the grid in Fig. 7.2, taking into account the portion of the graph after the reaction had finished, extrapolate (extend) the line back to t = 4.0 min.

Determine a value for the maximum theoretical temperature, T_{max}, and the temperature change for the experiment, ΔT, at t = 4.0 min.

T_{max} = **41.5 °C**

ΔT = 41.5 (T_{max}) – 29.0 **[1]** = **+ 12.5 °C**

[1] for extrapolated line from t = 7.0 min to t = 4.0 min

[2]

(ii) Hence, calculate the enthalpy change for the decomposition, ΔH_{decomp}, for the reaction shown in equation 1.

The specific heat capacity of the aqueous solution is 4.18 J g^{-1} K^{-1}.
Assume the density of the aqueous solution to be 1 g cm^{-3}.

$q_{soln} = mc\Delta T$

$q_{rxn} = q_{soln} = mc\Delta T$
$= (50+50)(4.18)(12.5) =$ **5225** J **[1]**

Amount of H_2O_2 used = $0.850 \times \frac{50}{1000}$
= **0.0425** mol **[1]**

$\Delta H_{decomp} = -\frac{5225 \div 1000}{0.0425}$ = **–123 kJ mol^{-1}** (3 s. f.) **[1]**

[3]

(iii) Suggest **one** feature of the experimental set-up in Fig. 7.1 that minimises heat loss.

Lid / **double Styrofoam cups provided insultation** to minimise heat loss. **[1]**

..... [1]

(c) The chlorides of elements in the third period of the Periodic Table show variations in different properties.

(i) Sketch the general trend of melting point of the chlorides in Fig. 7.3.

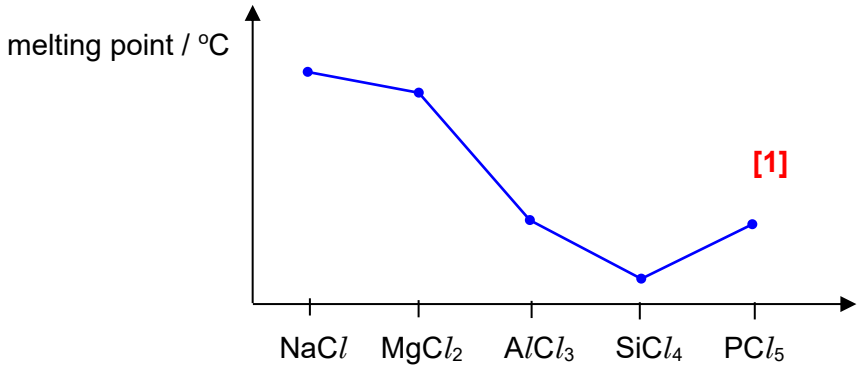


Fig. 7.3

[1]

(ii) With the aid of chemical equations, describe and explain what happens when samples of NaC*l*, A*l*C*l*$_3$ and PC*l*$_5$ are each added separately to water. In each case, state the likely pH of the resulting solution.

NaC*l* **dissolves readily** (with **no hydrolysis**) to form a **neutral** solution, pH = **7**

A*l*C*l*$_3$ **dissolves readily** to form a **weak acidic** solution via **dissolution** and **hydrolysis**, pH = **3**

$AlCl_3(s) \rightarrow Al^{3+}(aq) + 3Cl^-(aq)$

$[Al(H_2O)_6]^{3+}(aq) \rightleftharpoons [Al(H_2O)_5(OH)]^{2+}(aq) + H^+(aq)$

PC*l*$_5$ **readily reacts** with water / **readily hydrolyses** to form **strongly acidic** solution (as the HC*l* produced fully dissociates in water), pH = **2**

$PCl_5(s) + 4H_2O(l) \rightarrow H_3PO_4(aq) + 5HCl(g)$

[4]

..... [4]

(iii) Describe the thermal decomposition of the hydrogen halides HBr and HI, and explain the difference in their thermal stabilities.

HBr **decomposes slightly upon strong heating** to give **reddish brown Br_2** while HI **decomposes readily upon heating** to give **purple fumes of I_2**. **[1]**

HBr is more thermally stable than HI as the **H−Br bond strength is greater than that of H–I** due to **greater orbital overlap**, hence **less energy** is required to break the bond in order to decompose. **[1]**

..... [2]

[Total: 20]

8 Nitric oxide, NO, and ozone, O_3, are pollutants commonly associated with car engine exhaust.

(a) NO and O_3 react according to the following equation.

$$NO(g) + O_3(g) \longrightarrow NO_2(g) + O_2(g) \qquad \Delta H < 0$$

An experiment was conducted in a container with constant volume to monitor the concentration of NO over time. O_3 was used in excess. Fig. 8.1 shows the graph obtained.

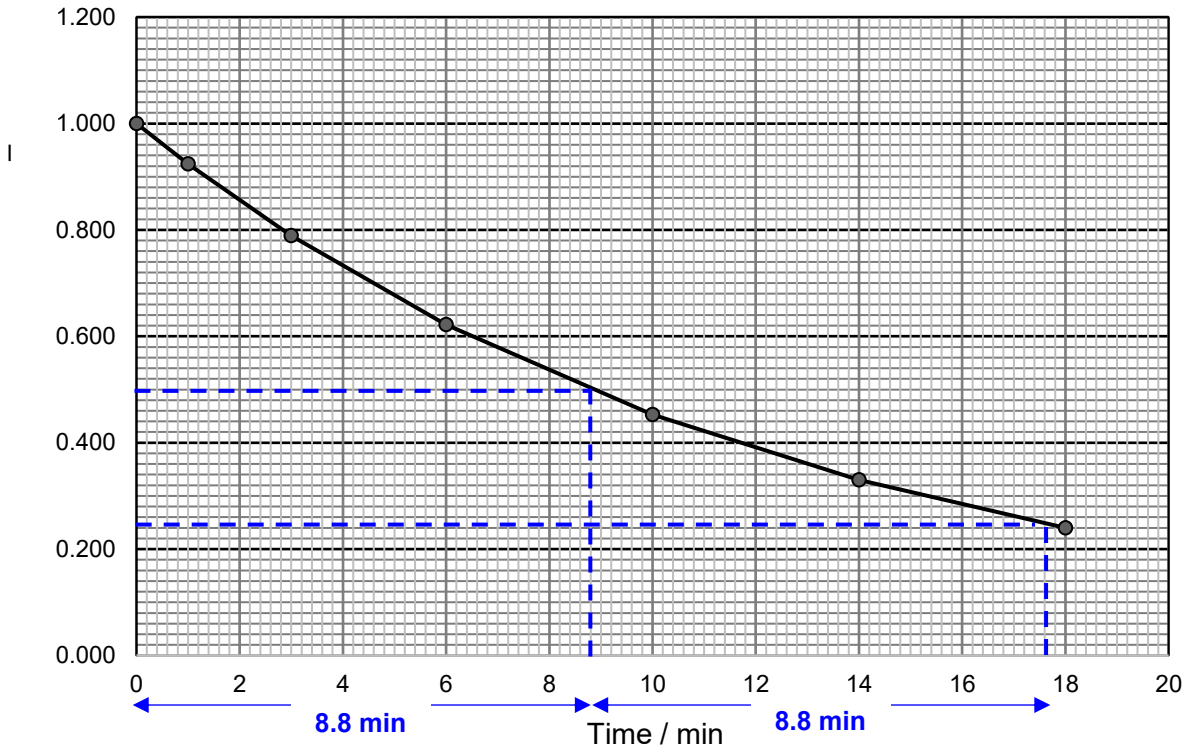


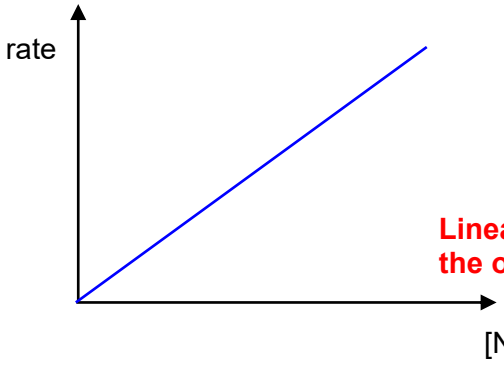
Fig. 8.1

(i) Using the data in Fig. 8.1, show that the order of reaction with respect to NO is one.

Half-life is **constant** at **8.8 min** **[1] with construction lines shown on graph**

[1]

(ii) Sketch a graph of the rate of reaction versus [NO] using the axes given below.



Linear line passing through the origin [1]

[1]

(iii) Another set of experiments were conducted to determine the order of reaction with respect to O_3.

Using the data in Table 8.1, determine the order of reaction with respect to O_3.

Table 8.1

expt	[NO] / mol dm^{-3}	[O_3] / mol dm^{-3}	relative rate
1	0.5	0.6	0.5
2	1.0	0.6	1.0
3	2.0	1.8	6.0

Comparing Expt 2 and 3,

When **[NO] × 2 and [O_3] × 3, rate × 6**, hence **order of reaction w.r.t. O_3** is **1** **[1]**

[1]

(iv) Hence, write a rate equation for the reaction between NO and O_3.

Rate = k[NO][O_3] **[1]** ..... [1]

(v) Suggest how the half-life of the graph in Fig. 8.1 will change when

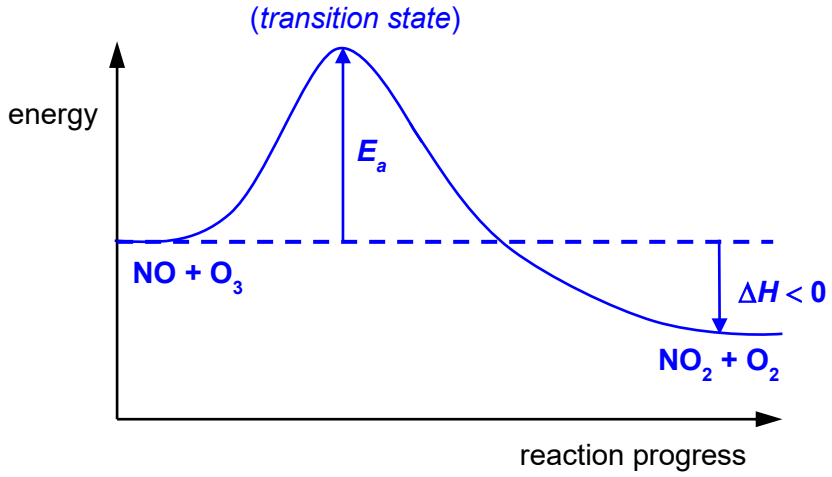
- [NO] is doubled,

  There will be **no change** to the half-life. **[1]** ..... [1]

- [O_3] is doubled.

  Half-life will be **halved**. **[1]** ..... [1]

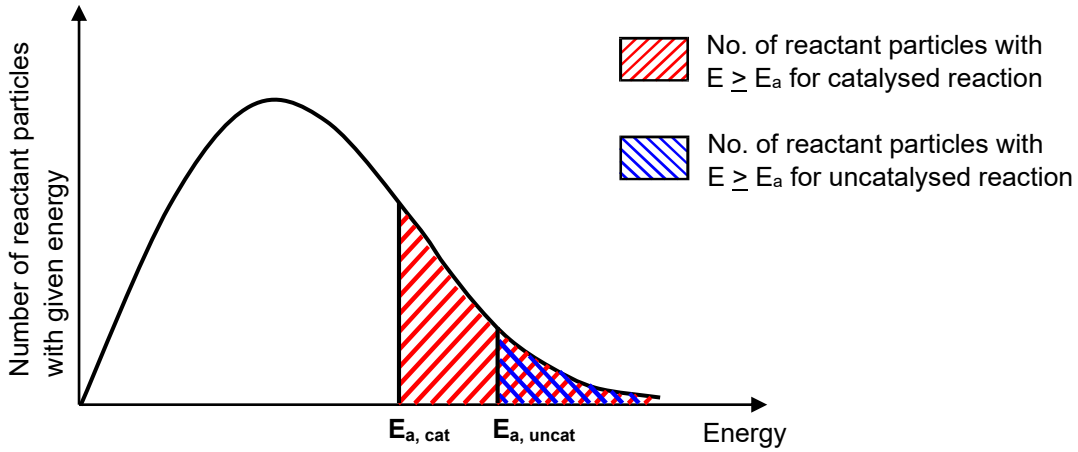
(vi) Assuming a one-step reaction, complete the reaction pathway diagram for the reaction between NO with O_3. Label clearly the activation energy, E_a, the enthalpy change of reaction, ΔH, the reactants, and the products.



[2]

[2]

(vii) When a catalyst is used, the reaction rate increases. With the aid of a labelled diagram, explain this in terms of the Boltzmann distribution.



The area under the curve is proportional to number of reactant particles.

A catalyst **provides an alternative reaction pathway of lower activation energy**.

When a **catalyst is used**, **number of reactant particles with energy ≥ E_a increases**,

the **frequency of effective collisions increases**,

resulting in **larger rate constant, k**, and hence rate of reaction increases. [3]

[3]

(b) In recent years, rhodium nanoparticles have replaced the finely divided metals that were used as heterogeneous catalysts in catalytic converters to remove NO and CO from car exhaust gases.

(i) Define the term *nanoparticles*.

Nanoparticles are particles with **all dimensions between 1–100 nm** **[1]** on the nanoscale. [1]

(ii) Suggest a health reason why the exhaust gases must be removed before releasing into the environment.

NO causes **respiratory issues** in human beings **[1]** *OR*

CO can **kill human beings by preventing the intake of O_2 gas**. [1]

(iii) Write a balanced equation for the reaction between NO and CO, producing two harmless gases.

$2CO(g) + 2NO(g) \rightarrow N_2(g) + 2CO_2(g)$ **[1]** [1]

(iv) Describe the mechanism for heterogenous catalysis.

Adsorption

- Reactant molecules are **adsorbed onto the nanoparticle catalyst surface** through the formation of **temporary bonds**.

Activation

- This adsorption increases the surface concentration of the reactants and **weakens the covalent bonds** within the reactant molecules, thereby **lowering the activation energy**.
- Reactant molecules are **brought closer together** and reaction can take place between the reactants molecules more easily.

Desorption

- Products **diffuse away formed from the surface** of the catalyst. [3]

[3]

(v) State a feature of rhodium nanoparticles which could explain why it can replace finely divided metals as a more efficient catalyst.

The **larger surface area to volume ratio** **[1]** of the rhodium nanoparticles promotes the adsorption stage as more of the metal surface is exposed to reactants. [1]

(vi) The use of nanoparticle catalytic convertors has also made them more cost efficient. Suggest a reason why this is so.

Less metal is needed in the manufacture. **[1]**

[1]

(vii) Disposal of a catalytic convertor releases nanoparticles into the air. Give an example of how this can cause a potential health hazard to the human body.

Nanoparticles **in the blood stream** may be able to **cross the blood-brain barrier** and hence **affect brain cells**. **[1]** [1]

[Total: 20]