Anderson Junior College
H2 Chemistry 9729

2017 JC1 Promo Paper 2 Suggested Solutions

Section A

1 (a) (i) $C_4H_{10}O(l) + 6O_2(g) \longrightarrow 4CO_2(g) + 5H_2O(l)$ [1]

Balanced equation with state symbols

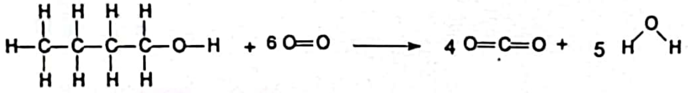
(ii) Heat absorbed by water = 100 x **4.18** x (76.7 – 25.0)
= 21610.6 J

Heat released from combustion = **(100/60)** x 21610.6 = 36017.7 J [1]

n($C_4H_{10}O$) burned = 1.00/74.0 = 0.01351 mol

$\Delta H_c(C_4H_{10}O)$ = – 36017.7/ 0.01351
= <u>– 267000 J mol⁻¹</u> OR <u>– 2670 kJ mol⁻¹</u> [1]

(iii)



$CH_3CH_2CH_2CH_2OH + 6\,O{=}O \longrightarrow 4\,O{=}C{=}O + 5\,H_2O$

ΔH_c = [9(410) + 3(350) + 360 + 460 + 6(496)] – [(4 x 2)(805) + (5 x 2)(460)] [1]
= 8536 – 11040
= <u>– 2504 kJ mol⁻¹</u> [1]

(iv) The bond energies in the *Data Booklet* are <u>average values</u>. [1]

OR

In their standard states at 298 K, <u>$C_4H_{10}O$ and H_2O are liquids</u> whereas the ΔH_r° calculated in **(iii)** is based on reactions in the <u>gaseous phase</u>.

(b) (i) $\Delta G_r^\circ = -RT \ln K_p$

$\Delta G_r^\circ = -8.31 \times 298 \times \ln(1.15 \times 10^{21})$
= <u>–120000 J mol⁻¹</u> OR <u>–120 kJ mol⁻¹</u> [1]

(ii) $\Delta G_r^\circ = \Delta H_r^\circ - T\Delta S_r^\circ$

$\Delta H_r^\circ = \Delta G_r^\circ + T\Delta S_r^\circ$
= –120 + 298(–175.9 x 10⁻³) = <u>–172 kJ mol⁻¹</u> [1]

(iii)
- (ΔH is negative; ΔS is negative, hence $-T\Delta S$ is positive)
- Decreasing the temperature causes <u>$-T\Delta S$ to become less positive</u> [1]
- <u>ΔG becomes more negative</u> and hence the reaction becomes <u>more feasible</u> [1]

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2 (a) (i) *order of reaction with respect to*

- *hydrogen ions:* <u>0</u>

Comparing Expt 1 and 3,
when [H⁺] increases 1.2 times, rate remains constant
⇒ reaction is **zero order** with respect to H⁺.

Correct answer + working/explanation [1]

- cyanide ions: <u>1</u>

Comparing Expt 2 and 3,
when **[CN⁻]** increases 1.2 times, rate also increases 1.2 times
⇒ reaction is **first order** with respect to CN⁻.

Correct answer + working/explanation [1]

- propanone: <u>1</u>

Either
Comparing Expt 1 and 4,

$$\frac{1.00}{0.833} = \frac{k(0.060)(0.02)^x}{k(0.040)(0.025)^x}$$

$1.2 = 1.5\,(0.8)^x$
$0.8 = (0.8)^x$
$x = 1$

OR
Comparing Expt 2 and 4,

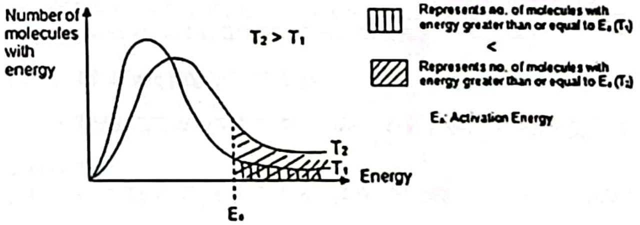
$$\frac{0.833}{0.833} = \frac{k(0.050)(0.020)^x}{k(0.040)(0.025)^x}$$

$1 = \frac{5}{4}(\frac{4}{5})^x$
$x = 1$

Correct answer + working/explanation [1]

(ii) rate = $k\,[(CH_3)_2CO][CN^-]$ OR rate = k [propanone][CN^-] [1]

(b)



Correct axes and graph shapes (labelled T_1 and T_2), show $T_2 > T_1$
Correctly shaded larger area for graph at T_2 and legend shown [1]

- When temperature increases, the <u>average kinetic energy of the reactant molecules increases</u>.
- As shown on the diagram, the <u>number of reactant molecules with energy greater or equal to the activation energy</u> will <u>increase</u>. [1]
- This results in an <u>increase</u> in the <u>frequency of effective collisions</u>. [1]
- Hence, the <u>rate</u> of reaction <u>increases</u>.

(c) (i) x = <u>120°</u> (accept <120°), y = <u>109.5°</u> [1]

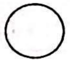
(ii) • 2–hydroxy–2–methylpropanenitrile has one more bonding pair of electrons (from 3 in propanone to 4 bonding pairs of electrons in 2–hydroxy–2–methylpropanenitrile) [1]

- ➢ To minimise repulsion, the bonding pairs of electrons are arranged as far apart as possible (in a tetrahedral shape) [1]
- ➢ smaller bond angle

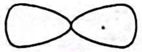
3 (a) (i) $_{24}Cr$: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$ [1]

(ii) [1]

s orbital



p orbital



(iii)

	protons	neutrons	electrons	
^{50}Cr	24	26	24	[1]
$^{52}Cr^{3+}$	24	28	21	[1]

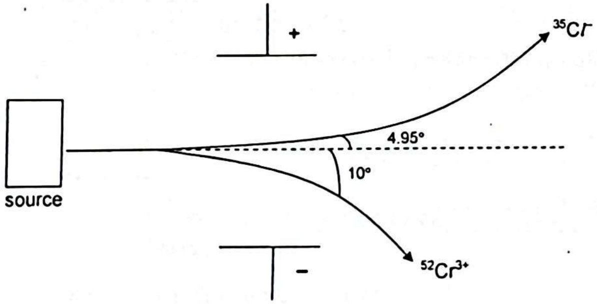
(b) (i) Since angle of deflection ∝ z/m

z/m for $^{52}Cr^{3+}$ = 3/52 = 0.05769

z/m for $^{35}Cr^-$ = 1/35 = 0.02857

∴ angle of deflection for $^{35}Cr^-$ = (0.02857 / 0.05769) x 10° = **4.95°** [1]

(ii) [1]



[1]: correct direction and relative magnitude of angle of deflection (ecf)

(c) (i) Down the group, first ionisation energy decreases. [1]

Down the group, the (nuclear charge increases) but the number of electron shells also increases. [1]

Valence electrons are further away from the nucleus and experience less (electrostatic) attraction by the nucleus.

Hence, less energy is required to remove the valence electrons. [1]

(ii) Across the period, ionisation energies generally increase. [1]

Nuclear charge increases (as the number of protons increases). Screening effect remains relatively constant, as the number of inner shells remains the same. [1]

Thus, the attraction of positively charged nucleus for the negatively charged valence electrons increases.

Hence, energy required to remove the valence electrons increases.

Award [1] for commenting on 'attraction between nucleus and valence electrons' and 'energy required' in EITHER part **(i)** OR **(ii)**

4 (a) (i) The volume of gas molecules is negligible compared to the volume of the container. [1]

Intermolecular forces of attraction between gas molecules are negligible. [1]

(ii) Low pressure and high temperature [1]

At low pressure, the gas molecules are far apart.
The volume of the gas molecules therefore becomes insignificant compared to the volume of the container OR the intermolecular forces of attraction are negligible. [1]

At high temperature, the gas molecules move faster (higher K.E.) and the intermolecular forces of attraction become negligible. [1]

(b) (i)

$$p = \frac{nRT}{(V - nb)} - \frac{n^2 a}{V^2}$$

$$= \frac{(1)(8.31)(298)}{(0.25 \times 10^{-3} - 4.27 \times 10^{-5})} - \frac{(1)^2 (0.364)}{(0.25 \times 10^{-3})^2}$$

= **6.12×10^6 Pa** [1]

(ii) Using the ideal gas equation,

$p = nRT/V = 1 \times 8.31 \times 298 / 0.25 \times 10^{-3}$

= **9.91×10^6 Pa** [1]

(iii) The actual pressure exerted is lower than the pressure calculated from the ideal gas equation as significant / strong intermolecular forces of attraction (instantaneous dipole–induced permanent dipole) exist between CO_2 molecules. [1]

(c) (i)

	C	H
% by mass	85.7	14.3
A_r	12.0	1.0
no. of moles	7.1416	14.3
simplest whole no. ratio	1	2

Empirical formula of A: CH_2 [1]

$$\underset{10\ cm^3}{C_xH_y} + \underset{45\ cm^3}{(x + y/4)\,O_2} \longrightarrow \underset{30\ cm^3}{xCO_2} + (y/2)\,H_2O$$

Volume of CO_2 produced = 65 – 35 = $\underline{30\ cm^3}$
Volume of O_2 reacted = 80 – 35 = $\underline{45\ cm^3}$ } [1]

$$\frac{n(A)}{n(CO_2)} = \frac{1}{x} = \frac{10}{30}$$

x = 3

$$\frac{n(A)}{n(O_2)} = \frac{1}{3 + \frac{y}{4}} = \frac{10}{45}$$

y = 6

Molecular formula of A: $\underline{C_3H_6}$. [1]

5 (a) (i) $Na_2CO_3 + 2HCl \longrightarrow 2NaCl + H_2O + CO_2$ [1]

(ii) $n(Na_2CO_3)$ in 25.0 cm^3 = ½ x 35.80 x 10^{-3} x 0.100 [1]
= $\underline{1.79 \times 10^{-3}\ mol}$

$n(Na_2CO_3)$ in 250 cm^3 = 1.79 x 10^{-3} x 250/25.0 [1]
= $\underline{1.79 \times 10^{-2}\ mol}$

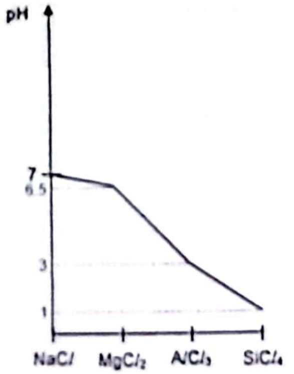
(iii) mass of Na_2CO_3 in 5.13 g washing soda crystals = 1.79 x 10^{-2} x 106.0
= 1.897 g
= $\underline{1.90\ g}$ [1]

(iv) $$\frac{106}{106 + 18x} \times 5.13 = 1.897$$

Solving for x,

$x = \underline{10}$ [1]

(b) (i) [1]



pH values not required

(ii) NaCl <u>does not hydrolyse</u> in water due to the <u>low charge density (or polarising power) of Na^+</u> ion. [2]

<u>$MgCl_2$</u> undergoes <u>slight hydrolysis</u> as <u>Mg^{2+}</u> ion has <u>higher charge density</u>.

<u>Explanation (not required)</u>
Mg^{2+} slightly polarises/distorts the electron cloud of water molecule. The weakened O–H bond is easily broken to release a proton and thus the resulting solution is slightly acidic.

$MgCl_2(s) + 6H_2O(l) \rightarrow [Mg(H_2O)_6]^{2+}(aq) + 2Cl^-(aq)$ not required

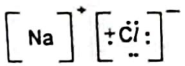
$[Mg(H_2O)_6]^{2+}(aq) + H_2O(l) \rightleftharpoons [Mg(H_2O)_5(OH)]^+(aq) + H_3O^+(aq)$

state symbols not required

[1] <u>compare</u> charge density or polarising power of Na^+ and Mg^{2+}
[1] <u>compare</u> extent of hydrolysis + equation for $MgCl_2$

Section B

6 (a) [1]



(b) (i) Energy cycle

$$\begin{tikzcd}
NaCl(s) \arrow[rr, "\Delta H_{sol}"] & & NaCl(aq) \\
& Na(s) + \frac{1}{2}Cl_2(g) \arrow[ul, "-414"] \arrow[ur, "-409"'] &
\end{tikzcd}$$

$\Delta H_{sol} = (-409) - (-414) = \underline{+5 \text{ kJ mol}^{-1}}$ [1]

Formula

$\Delta H_{sol} = \Delta H_r = \Delta H_f\,[NaCl(aq)] - \Delta H_f\,[NaCl(s)]$
$= (-409) - (-414) = +5 \text{ kJ mol}^{-1}$

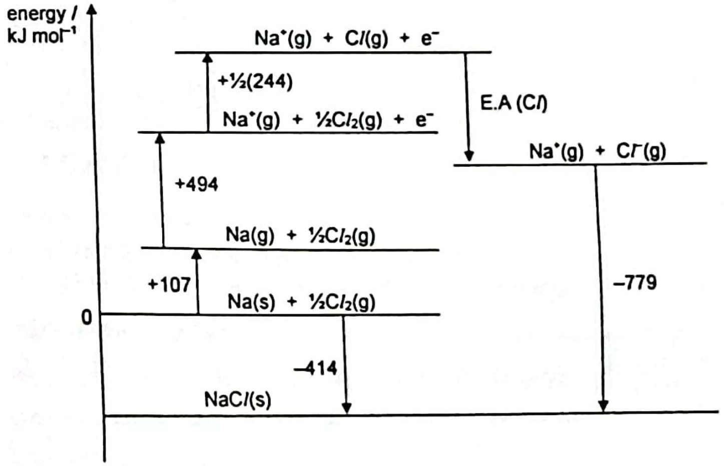
$L.E\ (NaCl) = \Delta H_{hyd}(Na^+) + \Delta H_{hyd}(Cl^-) - \Delta H_{sol}$
$= (-390) + (-384) - (+5)$
$= \underline{-779 \text{ kJ mol}^{-1}}$ [1]

(b) (ii) Energy cycle [3]

$$\begin{tikzcd}
Na(s) \arrow[d, "+107"'] & + & \frac{1}{2}Cl_2(g) \arrow[d, "+\frac{1}{2}(244)"] \arrow[r, "-414"] & NaCl(s) \\
Na(g) \arrow[d, "+494"'] & + & Cl(g) \arrow[d, "E.A\ (Cl)"] & \\
Na^+(g) & + & Cl^-(g) \arrow[uur, "-779"'] &
\end{tikzcd}$$

By Hess' Law,
$-414 = +107 + \frac{1}{2}(244) + 494 + E.A\ (Cl) - 779$
$E.A\ (Cl) = -414 - 107 - \frac{1}{2}(244) - 494 + 779$
$= \underline{-358 \text{ kJ mol}^{-1}}$

Energy level diagram



By Hess' Law,
$E.A\ (Cl) = -494 - 122 - 107 - 414 - (-779) = \underline{-358 \text{ kJ mol}^{-1}}$

[2]: correctly constructed and labelled Born–Haber cycle (energy cycle or energy level diagram)
[1]: correct final answer
[−1]: if state symbols are omitted and/or enthalpy changes not labelled
[−1]: if any equations in the Born–Haber cycle are not balanced

(c) Numerical magnitudes of L.E decreases. [1]

Ionic radius of Group 1 ions increases / inter–ionic distance increases down the group. Thus, electrostatic forces of attraction between the cation and anion will be weaker. [1]

(d) **(i)** $K_p = \frac{(p_{NO})^2(p_{O_2})}{(p_{NO_2})^2}$ [1]

(ii) Let the initial pressure of NO_2 be x. [2]

	$2NO_2$ (g)	$\rightleftharpoons$ 2NO (g)	+ O_2 (g)
Initial	x	0	0
Change	–0.45 x	+0.45 x	+0.225 x
Equilibrium	0.55 x	0.45 x	0.225 x

$$K_p = \frac{(p_{NO})^2(p_{O_2})}{(p_{NO_2})^2} = \frac{(0.45x)^2(0.225x)}{(0.55x)^2} = 36.9$$

$0.1506\,x = 36.9$
$x = 245$

Partial pressure of NO_2 at eqm = 0.55 x = 0.55 (245) = **135 kPa**

[1]: correct substitution of partial pressures into K_p expression
[1]: correct partial pressure of NO_2 (ignore units)

(iii) When the volume of the vessel is decreased, the pressure is increased. [1]

When pressure is increased, the equilibrium position shifts to the left to reduce the pressure by producing less gaseous molecules. [1]

(iv) ΔH is positive / The reaction is endothermic. [1]

Since K_p increases as the temperature rises, the forward reaction is favoured and the equilibrium position shifts to the right to remove the extra heat. Therefore, it is concluded that the forward reaction is endothermic. [1]

(e) Magnesium oxide dissolves sparingly in water to give a white suspension of $Mg(OH)_2$. pH = 8. [1]

$MgO(s) + H_2O(l) \rightleftharpoons Mg(OH)_2(s)$ [1]

Aluminium oxide is insoluble in water. pH = 7. [1]

Phosphorus(V) oxide reacts readily in water to produce a strongly acidic solution. pH = 1. [1]

$P_4O_{10}(s) + 6H_2O(l) \longrightarrow 4H_3PO_4(aq)$ [1]

7 **(a)** **(i)** Refer to graph on the last page.

- Correct axes and appropriate scales (no odd scales)
- Graph occupies at least half the grid } [1]
- Check following 3 points correctly plotted [1]

Time / min	$[Br_2(aq)] \times 10^{-3}$ / mol dm^{-3}
2	6.50
6	2.85
10	1.25

- construction lines
- indicate at least 2 t½ values on graph or answer script
- conclude that $t_{1/2}$ is constant } [1]

(ii) rate = k [Br_2] [methanoic acid]

$$k = \frac{\text{mol dm}^{-3}\text{ min}^{-1}}{(\text{mol dm}^{-3})^2} = \text{mol}^{-1}\text{ dm}^{3}\text{ min}^{-1}$$

- Correct final answer and working [1]

(iii)
$[Br_2]$: 0.010 mol dm^{-3} $\xrightarrow{t_{½}}$ 0.005 mol dm^{-3}

When [methanoic acid] doubles, rate doubles.
Time taken for [Br_2] to decrease to 0.005 mol dm^{-3} = ½ (t½) } explanation
= ½ (3.3 min)
= 1.65 min
Alternative answer
Since [bromine(aq)] remains the sa Time / min oic acid] is doubled,
⇒ twice the amount of acid is reacting with the same amount of Br_2(aq)
⇒ [Br_2] decreases twice as fast } explanation
Time taken for [Br_2] to decrease to 0.005 mol dm^{-3} = ½ (t½)
= ½ (3.3 min)
= 1.65 min

- Correct explanation (accept pseudo–first order method or any other correct explanation) [1]
- Correct final answer (allow ecf) [1]

(b) **(i)** **I** More energy is required to break stronger hydrogen bonds between $CH_2(OH)CH_2OH$ molecules compared to (weaker) permanent dipole–permanent dipole forces of attraction between CH_3CH_2CHO molecules. [3]

II More energy required to break more extensive hydrogen bonds between $CH_2(OH)CH_2OH$ molecules compared to less extensive hydrogen bonds between CH_3COOH molecules.

[1] x 2: correctly identify type of IMF for each part
[1]: correctly compare strength and energy

(ii) CH_3COOH molecules are held in a simple molecular structure. Lower amount of energy is required to overcome weaker hydrogen bonds between CH_3COOH molecules.

On the other hand, larger amount of energy is required to break the strong electrostatic forces of attraction between oppositely charged CH_3COO^- and Na^+ ions in a giant ionic structure. [1]

Hence, $CH_3COO^-Na^+$ has a higher melting point. [1]

(c) **(i)** $2HX \longrightarrow H_2 + X_2$ [1]

Do not accept '$2HCl \longrightarrow H_2 + Cl_2$'

(ii) Down Group 17, the H–X bond energy decreases OR The H–X bond becomes weaker and is more easily broken. [1]

HC*l* is stable to heat and hence do not decompose.
HBr decomposes slightly on heating, brown fumes of Br_2 observed.
HI decomposes easily, gives out dense purple fumes of I_2 on gentle heating. [1]

Description of trend for all 3 HX must be given including observation of colours

(d) **(i)**

	$2SO_2(g)$	+	$O_2(g)$	$\rightleftharpoons$	$2SO_3(g)$
Initial / mol	4		2		0
Change / mol	–3.92		–3.92 / 2 = –1.96		+3.92
Equilibrium / mol	0.02 x 4 = 0.08		0.04		3.92
Equilibrium / mol dm^{-3}	0.08 / 10.0 = 8 x 10^{-3}		0.04 / 10.0 = 4 x 10^{-3}		3.92 / 10.0 = 0.392

$[SO_2]_{eqm}$ = 8.00 x 10^{-3} mol dm^{-3} [1]
$[O_2]_{eqm}$ = 4.00 x 10^{-3} mol dm^{-3} [1]
$[SO_3]_{eqm}$ = 0.392 mol dm^{-3} [1]

(ii)

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(0.392)^2}{(8\times10^{-3})^2(4\times10^{-3})} = \underline{6.00 \times 10^5 \text{ mol}^{-1}\text{ dm}^3}$$ [1]

(ignore wrong units)

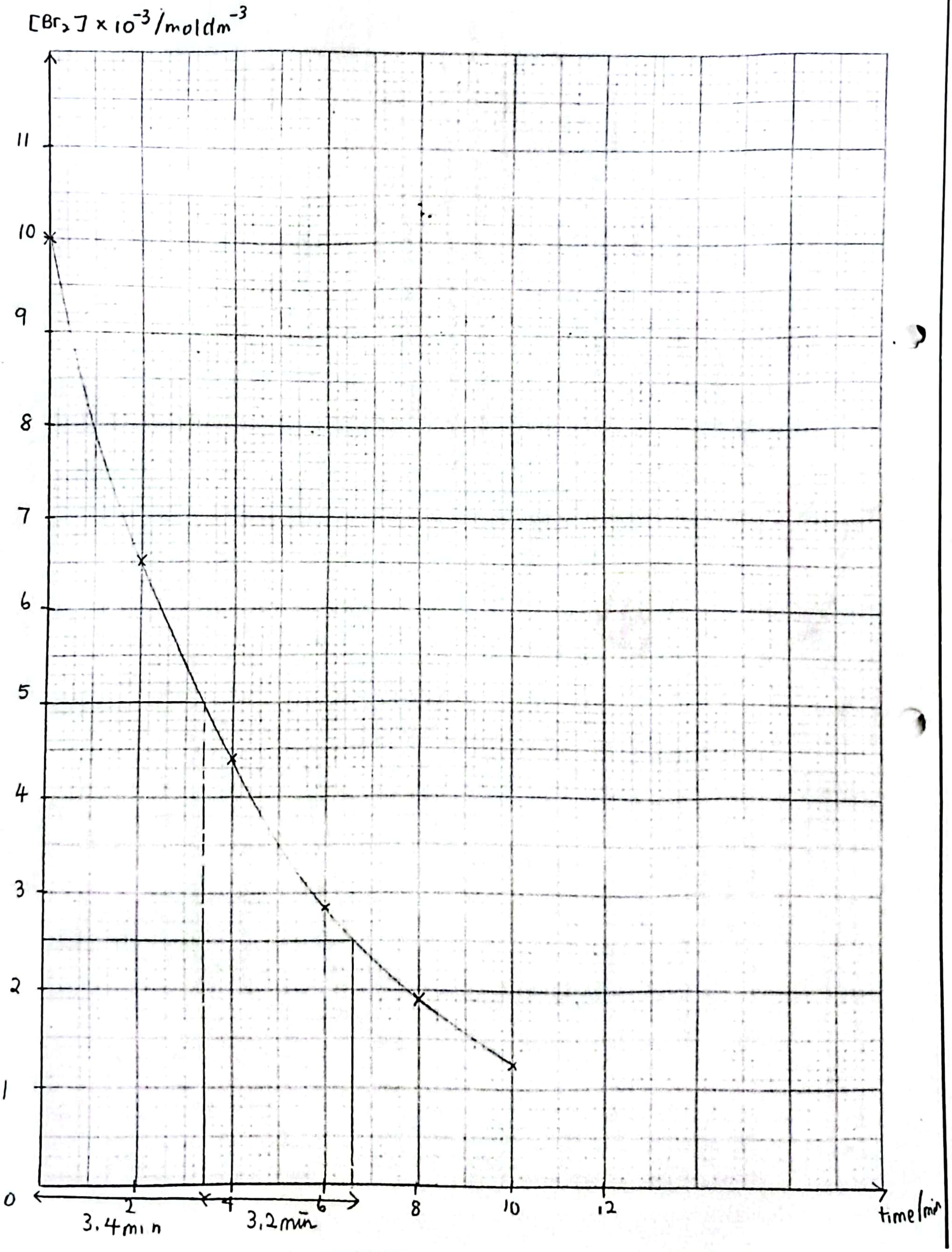
(iii) The percentage of unconverted SO_2 at equilibrium would

I: decrease

When excess of oxygen is added, the concentration of O_2 increases (number of moles of O_2 gas increases). The position of equilibrium will shift to the right to remove O_2. [1]

II: remain unchanged

The position of equilibrium remains unchanged. A catalyst increases the rate of both forward and backward reactions by the same extent. [1]


[Br₂] × 10⁻³/moldm⁻³
11
10
9
8
7
6
5
4
3
2
1
0
2
4
6
8
10
12
time/min
3.4 min
3.2 min