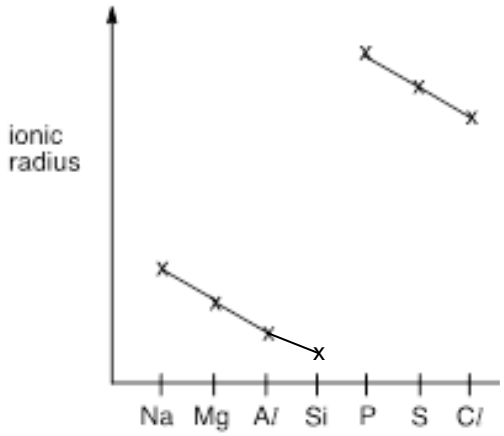
HWA CHONG INSTITUTION
2025 C2 H2 CHEMISTRY PRELIMINARY EXAMINATION
MARK SCHEME

Paper 2

1 (a)



Na^+, Mg^{2+}, Al^{3+} and Si^{4+} are isoelectronic (or have the same number of electrons) and P^{3-}, S^{2-} and Cl^- are isoelectronic, hence **shielding effect** is the **same**. Across each series, number of protons and thus **nuclear charge** increases**. [1]**

Thus, **effective nuclear charge** increases, attraction of the nucleus on the **valence/outermost** electrons become stronger (*or* outermost electrons pulled closer to the nucleus), and ionic radius decreases.

There is a sharp increase in radius from Si^{4+} to P^{3-}, as anions have one more **quantum/electron shell** than cations. **[1]**

(b) $P_4O_{10(s)} + 6H_2O_{(l)} \rightarrow 4H_3PO_{4(aq)}$ **[0.5]**

pH of resulting mixture is 2 (*accept 1 – 3*). **[0.5]**

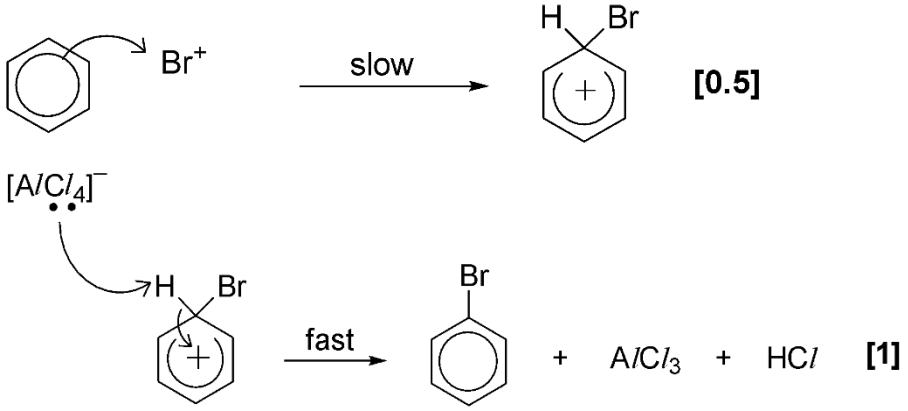
(c) Al_2O_3 is amphoteric. **[0.5]**

$Al_2O_{3\,(s)} + 3H_2SO_{4(aq)} \rightarrow Al_2(SO_4)_{3(aq)} + 3H_2O_{(l)}$ **[0.5]**

$Al_2O_{3\,(s)} + 2NaOH_{(aq)} + 3H_2O_{(l)} \rightarrow 2Na[Al(OH)_4]_{(aq)}$ **[1]**

(d) (i) A Lewis acid is a species that accepts an **electron pair**. **[1]**

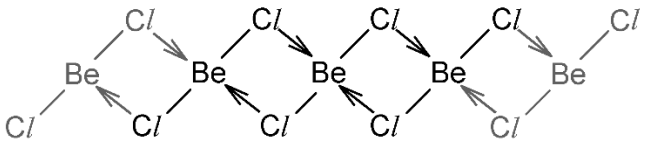
(ii) $AlCl_3 + BrCl \longrightarrow Br^+ + [AlCl_4]^-$ **[0.5]**



[0.5]

[1]

(iii)



[1]

2 (a) (i) The heat evolved when 1 mole of water is formed from an acid-base reaction at 298 K and 1 bar. **[1]**

(ii) q = mcΔT = [(25+45) × 1.00](4.18)(30.5 – 27.8) = 733.6 J **[1]**

no. of moles of H_2O = no. of moles of LiOH (limiting reagent)
= 25/1000 × 0.5 = 0.0125 mol

$\Delta H^{\ominus}_{neut} = -\frac{q}{n_{H2O}} = -\frac{733.6}{0.0125}$ = –58688 J mol^{-1} = **–58.7** kJ mol^{-1} (3 s.f.) **[1]**

(b) (i)

$$2HCl(aq) + 2LiOH(s) + CO_2(g) \xrightarrow{\Delta H^{\ominus}_2} Li_2CO_3(s) + H_2O(l) + 2HCl(aq)$$

$$2HCl(aq) + 2Li^+(aq) + 2OH^-(aq) + CO_2(g) \longrightarrow 2LiCl(aq) + CO_2(g) + 2H_2O(l)$$

2(–21) ; –29.0 ; 2(–58.7)

[2]

$\Delta H^{\ominus}_2$ = 2(–21) + 2(–58.7) + 29.0 = –130.4 kJ mol^{-1} = –130 kJ mol^{-1} (3 s.f.) **[1]**

If used suggested value in question ($\Delta H^{\ominus}_{neut} = -48.2$ kJ mol^{-1})

$\Delta H^{\ominus}_2$ = 2(–21) + 2(–48.2) + 29.0 = –109.4 = –109 kJ mol^{-1} **[1]**

(ii) Since the no. of moles of gas decreases from 1 to 0 in this reaction, the entropy change of reaction is negative. **[1]**

ΔG = ΔH – TΔS
When temperature increases, –TΔS becomes more positive. Since ΔH is negative, ΔG becomes less negative, and reaction is less spontaneous. **[1]**

(iii) Volume of CO_2 exhaled per crewmember per day
= 25 × 15 × 60 × 24 = 540000 cm^3/CM-d = 540 dm^3/CM-d **[1]**

Mass of CO_2 exhaled = 1.98 × 540 = 1069.2 g/CM-d = **1.07** kg/CM-d **[1]**

(iv) No. of moles of CO_2 /CM-d = 1069.2 / (12+16+16) = 24.3 mol
No. of moles of LiOH/ CM-d = 24.3 × **2** = **48.6 mol [0.5]**
Mass of LiOH /CM-d = 48.6 × (6.9+16+1) = 1161.54 g = 1.16 kg **[0.5]**
Mass of LiOH brought on trip = 250 × 5.2 = 1300 kg **[0.5]**
No. of days = 1300 / (**8** × 1.16) =139.9 = 139 days **[0.5]**

Alternative method:
Total no. of moles of LiOH supplied = 5.2 × 1000 (6.9+16+1) = 54393 mol
Total no. of moles of CO_2 can be absorbed = 54393/2 = 27196.5 mol
Total mass of CO_2 that can be absorbed = 27196.2 × (12+16+16) = 1196600 g
= 1196.6 kg
Max no. of days = 1196.6/(1.07 × 8) = 139.8 = 139 days

(v) For the same number of moles, the mass of LiOH is smallest hence it is easier to transport in a space craft. **[1]**

(c) (i) $Li_2CO_3(s) \rightarrow Li_2O(s) + CO_2(g)$ **[1]**

Li^+ is a cation with small ionic radius and high charge density **[1]**, it polarises the electron cloud of carbonate to a large extent, hence weakening the C-O bonds **[1]**. Hence less energy is needed to break the C-O bonds and it decomposes easily when heated.

(ii)

ion	Li^+	Na^+	Mg^{2+}	Ca^{2+}
ionic radius / nm	0.06	0.095	0.065	0.099
$\frac{q^+}{r^+}$	16.7	10.5	30.7	20.2

Marking points **[2]**
- quote **ionic** radius for all 4 ions
- suggest a temperature **between 635 and 851** (excluding the two numbers)
- correct explanation in terms of charges and ionic radii: calculate $\frac{q^+}{r^+}$ and conclude that charge density of Li^+ is between those of Na^+ and Ca^{2+}

3 (a) (i) 50%. The optically inactive mixture of **P** contains equal proportions of two enantiomers **[0.5]**. Enzyme amidase has specific activity and only one enantiomer can bind to the active sites of the enzyme **[0.5]**.

(ii) Amidase is a biological catalyst which is regenerated during the reaction / remains chemically unchanged / not used up / lower E_a **[0.5]**. Hence, its concentration stays constant **[0.5]**.
H_2O is a solvent and is present in large excess **[0.5]**. Hence, its concentration can be treated as a constant (or differs very slightly or pseudo-zeroth order) **[0.5]**.

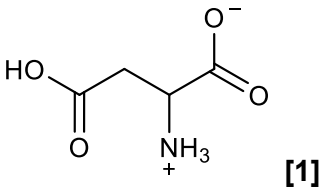
(iii) At lower concentrations of P
From experiments 1 and 2 (*accept* if compare expt 2 and 3), when [**P**] doubles from 0.50 to 1.00 mmol dm^{-3}, the initial rate doubles from 1.25 to 2.50 × 10^{-4} mol dm^{-3} s^{-1}.**[1]** Reaction is first order with respect to [**P**]. **[0.5]**

At higher concentrations of P
From experiments 5 to 6, when [**P**] doubles from 8.00 to 16.00 mmol dm^{-3}, the initial rate remains constant at 8.00 × 10^{-4} mol dm^{-3} s^{-1}.**[1]** Reaction is zeroth order with respect to [**P**]. **[0.5]**
or
From experiments 4 to 5, when [**P**] doubles from 4.00 to 8.00 mmol dm^{-3}, the initial rate remains almost constant at 7.50 × 10^{-4} mol dm^{-3} s^{-1} (*accept* increases slightly). Reaction is zeroth order with respect to [**P**].

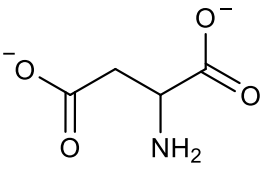
(iii) At low [**P**], rate of reaction increases **proportionally** with increasing [**P**] (or follow first order kinetics) **[0.5]** as [amidase] is greater than [**P**] / [**P**] is the limiting factor (*accept* there are many active sites available on the enzyme amidase / binds->reaction->released / form enzyme-substrate complex). **[0.5]**

At high [**P**], rate of reaction remains constant with increasing [**P**] (or follow zeroth order kinetics) **[0.5]** as the active sites on the enzyme amidase are saturated (*accept* all active sites are filled) with **P** molecules. **[0.5]**

(b)

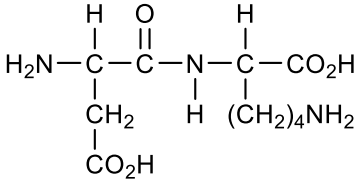


pH 3 **[1]**



pH 14 **[1]**

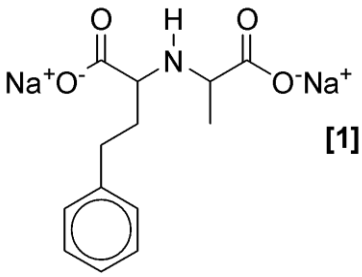
(c)



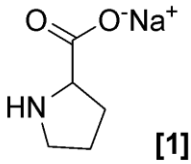
[1]

(d)

[1]



[1]



[1]

4 (a) (i) disproportionation **[1]**

(ii) **3** Cl_2 + **6** NaOH → **5** NaCl + **1** $NaClO_3$ + **3** H_2O **[1]**

(b) (i) $E^{\ominus}(Cl_2/Cl^-)$ = +1.36 V, $E^{\ominus}(O_2/H_2O)$ = +1.23 V **[1]**

Since $E^{\ominus}(O_2/H_2O)$ is less positive than $E^{\ominus}(Cl_2/Cl^-)$ **[1]**, H_2O will be selectively oxidised.

(ii) The high concentration of Cl^- (5.0 mol dm^{-3}) **[0.5]** causes the position of equilibrium $Cl_2 + 2e^- \rightleftharpoons 2Cl^-$ to shift to the left. **[0.5]** This causes $E(Cl_2/Cl^-)$ to become less positive than +1.23 V, resulting in the selective oxidation of Cl^- over H_2O. **[1]**

(c) total charge passed = 5000 × 60 × 60 = 18 000 000 C **[0.5]**

actual charge to produce Cl_2 = 18 000 000 × 0.88 = 15 840 000 C **[0.5]**

$$\text{amount of } e^- = \frac{15\,840\,000}{96500} = 164.145 \text{ mol } \textbf{[0.5]}$$

$$\text{amount of } Cl_2(g) = \frac{164.145}{2} = 82.07 \text{ mol } \textbf{[0.5]}$$

$$\text{volume} = \frac{(82.07)(8.31)(70 + 273)}{10^5} = 2.34 \text{ m}^3$$

(d) **(i)** $NaHg + H_2O \rightarrow NaOH + \frac{1}{2}H_2 + Hg$ **[1]**

(ii) It can be used in fuel cells / to hydrogenate alkenes / in the Haber Process. **[1]**

(e) **(i)** The electronegativity of an atom is a measure of its ability to attract the electrons in a covalent bond to itself. **[1]**

(ii)

chemical bond	explanation
ionic	There is a transfer of electrons from the less electronegative Na to more electronegative Hg to form Na^+ and Hg-rich polyanions like Hg_4^{4-} and Hg_2^{2-}.
metallic	Electrons are lost from low electronegativity Na atoms to form a sea of delocalised electrons.

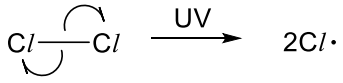
[1] each correct explanation

5 **(a)** The order of thermal stability is: H−C*l* > H−Br > H−I **[0.5].** Down the group, atomic radius (or size of halogen atom) increases, hence orbital overlap (with H atom) is less effective **[0.5]**, resulting in a longer/weaker H–X bond **[0.5]** (*accept* if quoted BE values from *Data Booklet*), hence less energy is needed to break the H–X bond.

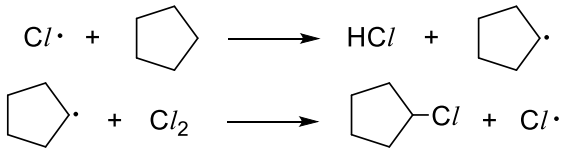
HC*l* does not decompose even on strong heating. **[0.5]**
HBr yields reddish-brown (accept "brown") fumes of Br_2 under strong heating. **[0.5]**
HI gives violet fumes of I_2 when red-hot rod is plunged into jar of HI. **[0.5]**

(b) Free radical substitution **[0.5]**
Correct stages labelled: initiation + propagation + termination **[0.5]**

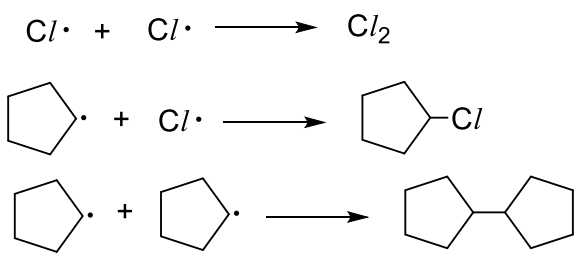
initiation



propagation

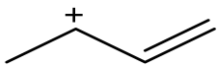
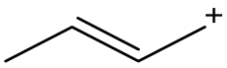


termination



Total 6 equations for 2 marks:

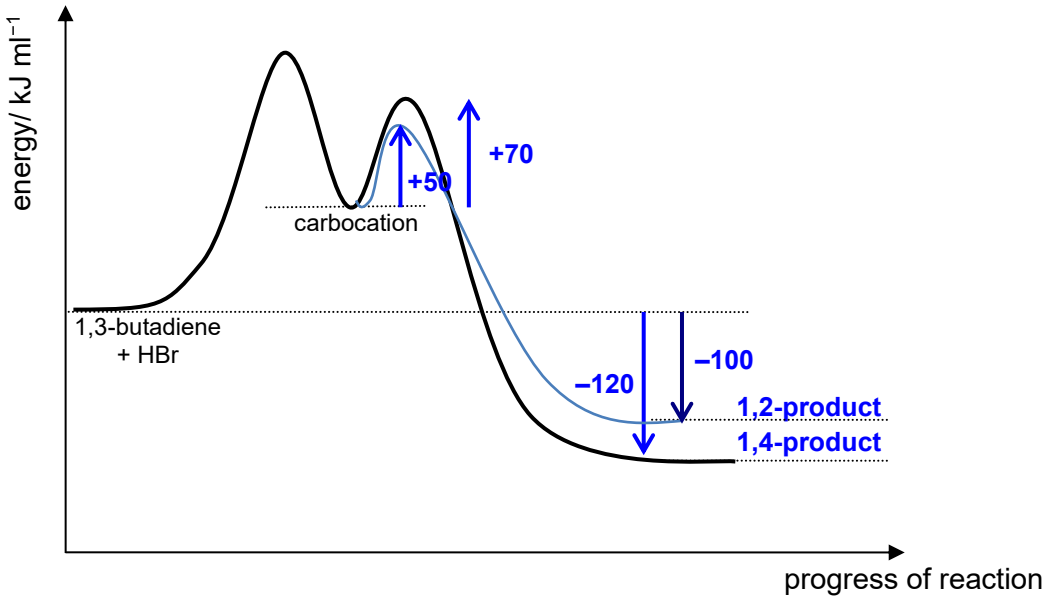
(c) (i)

carbocation structure that forms 1,2-product	carbocation structure that forms 1,4-product
	

The continuous overlap of p orbitals **[0.5]**, causes the delocalisation of π electrons. Hence the positive charge can be delocalised to C4. **[0.5]**

(ii) The bulky I atom on the carbocation on C-1 causes steric hindrance for the attack of Br^- on C-2, hence reducing the % of 1,2-product. **[1]**

(iii)



[2]

(iv) At low temperatures, a greater proportion of the reacting particles would possess sufficient (kinetic) energy to overcome E_{a1} which is lower compared to E_{a2}. Hence the 1,2-product dominates. **[1]**

At high temperatures, the particles have sufficient energy to overcome both E_a and hence the more stable 1,4-product dominates. **[1]**

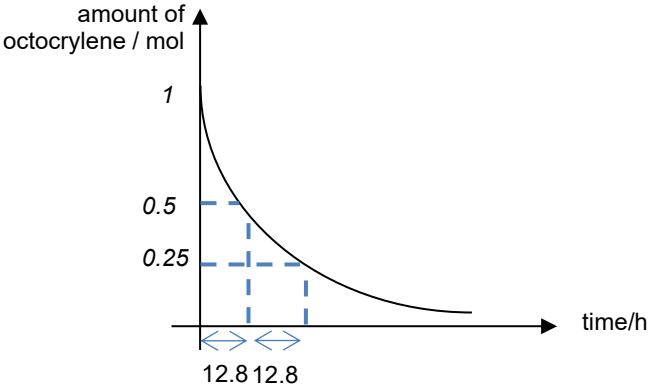
(d) (i) Ti^{4+} and Zn^{2+} have electronic configurations d^0 and d^{10} (or fully-filled and empty d subshell) **[0.5]** respectively, hence no d-d transition can occur. **[0.5]**

(iii) **X** is the best as octocrylene covers UVB (280–320) while avobenzone covers UVA (310–400) **[1]** (or it contains both octocrylene and avobenzone which together covers the whole range of UVA and UVB).

(e) (i) The half-life, $t_{½}$, of a reaction is the time taken for the concentration of a reactant to decrease to half its initial value. **[1]**

(ii) t = 12.8 × 3 = 38.4 hours **[1]**

(iii)



[1]