

# HWA CHONG INSTITUTION 2019 C2 H2 CHEMISTRY PRELIMINARY EXAM SUGGESTED SOLUTIONS



## Paper 3

- **1 (a) (i)**  $MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$  [1]
  - (ii) L.E  $\alpha \frac{q_+q_-}{r_++r_-}$  [1]

Both MgCO<sub>3</sub> and MgO have the <u>same charges and cationic radius [0.5]</u> <u>Anionic radius for  $CO_3^{2-}$  is bigger than  $O^{2-}$  [0.5] Magnitude of L.E. of MgCO<sub>3</sub> is smaller than that of MgO.</u>

(iii)  $\Delta S$  is positive as gaseous CO<sub>2</sub> is evolved [1]. Hence,  $-T\Delta S$  term is negative.

 $\Delta G = \Delta H - T \Delta S$ 

Since the decomposition of MgCO<sub>3</sub> is endothermic,  $\Delta H$  is positive. So for the decomposition to be spontaneous, for  $\Delta G$  to be negative, the decomposition should take place at high temperature [1].

(iv) MgCO<sub>3</sub> has the lower decomposition temperature. [0.5]

Both Mg<sup>2+</sup> and Ba<sup>2+</sup> have the same charge. The ionic radius of Mg<sup>2+</sup> is smaller than Ba<sup>2+</sup> (0.5). So Mg<sup>2+</sup> has a higher charge density (0.5) and a greater polarizing power and it can distort the electron cloud of the  $CO_3^{2-}$  to a greater extent (0.5 for either point), weakening the C-O covalent bonds in  $CO_3^{2-}$  to a greater extent (0.5), hence less energy is needed for decomposition (0.5).

(b) (i) Type of reaction (reaction 1): Nucleophilic Addition [1]

[1]

[1]

Type of reaction (reaction 2): Elimination/Dehydration [1]

(ii)  $H_{N}^{H}$  $H_{C}^{H}$  $H_{C}^{H}$  $H_{C}^{H}$ 

(iv)

(iii) The geometry about the center C is trigonal planar [1]. Hence, there is equal probability for the CN<sup>-</sup> ion to attack from either side of the plane [1], giving rise to an equimolar mixture of two stereoisomers.

2019 HCI C2 H2 Chemistry Preliminary Exam / Paper 3



- (b) constitutional/structural/functional group isomerism [1]
- (c) The LF molecule is polar and can form strong/favourable permanent-dipole permanent-dipole interactions/hydrogen bonding/ion-dipole interactions with water molecules. [1]
- (d) (i) When the onion is cooled, less LF will vaporise and come into contact with the eyes. [1]
  - (ii) Heating the onion can <u>denature the enzyme</u> *LF* synthase so that <u>LF will not be</u> formed. [1]
- (e) (i) condensation [1]
  - (ii)  $C_9H_{16}OS_3 + 17O_2 \rightarrow 9CO_2 + 8H_2O + 3SO_3$  [1]
  - (iii)  $n(\text{cepaene}) = 5 \times 10^{-3} / 236.3 = 2.116 \times 10^{-5} \text{ mol } [\frac{1}{2}]$   $n(O_2) = 2.116 \times 10^{-5} \times 17 = 3.597 \times 10^{-4} = 3.60 \times 10^{-4} \text{ mol } [\frac{1}{2}] \text{ ecf from ii}$ volume of O<sub>2</sub> mixture at r.t.p. = 3.597  $\times 10^{-4} \times 24000 = 8.63 \text{ cm}^3 [\frac{1}{2}]$ volume of mixture = 8.63  $\times 100/40 = 21.6 \text{ cm}^3 [1]$
  - (iv) Role of copper: reducing agent [1]  $Cu + \frac{1}{2}O_2 \rightarrow CuO$  [1]
  - (v) The blue crystals are CuSO<sub>4</sub> [1], which can be formed from the reaction of CuO with SO<sub>3</sub>. [1]

 $CuO + SO_3 \rightarrow CuSO_4$ 



(vi) Order of gases released: CO<sub>2</sub>, then SO<sub>2</sub>, then water. [1]

CO<sub>2</sub> is a non-polar molecule, hence intermolecular forces are the weakest – only dispersion forces, so it is released first at a lower temperature. followed by SO<sub>2</sub>.

 $SO_2$  is a polar molecule with *both* intermolecular permanent-dipole permanent-dipole interactions, which are stronger than dispersion forces, *and* dispersion forces, which are also stronger than those of  $CO_2$  due to  $SO_2$  having more electrons and the larger electron cloud size than  $CO_2$ .

Water has intermolecular hydrogen bonding, which are the strongest intermolecular forces, and most energy required to vapourise it, and hence it is released last.

[1] correct types of intermolecular forces for all 3 molecules[1] correct comparison of the strength of the 3 different intermolecular forces and relate to energy required to overcome the intermolecular forces for the gas to escape to the detector.

- 3 (a) Transition elements are d-block elements that form one or more stable ions with partially filled d-subshell. [1]
  - (b) (i) Precipitation occurs when I.P. = Ksp

For Cr<sup>3+</sup>: Ksp = [Cr<sup>3+</sup>][OH<sup>-</sup>]<sup>3</sup>

 $1.6 \times 10^{-20} = 1.23 \times 10^{-2} [OH^{-}]^{3}$ [OH^{-}] = 1.09 × 10^{-6} mol dm^{-3} [1]

For  $Co^{2+}$ : Ksp =  $[Co^{2+}][OH^{-}]^{2}$ 

 $5.92 \times 10^{-15} = 5.77 \times 10^{-3} [OH^{-}]^2$ [OH^-] = 1.01×10^{-6} mol dm<sup>-3</sup> [1]

Since the [OH<sup>-</sup>] required for IP = Ksp is similar for both precipitates to form, it does not allow for the separation of the two metal ions. **[1]** 

#### (ii) either

 $Cr(OH)_3$  is sparingly soluble and dissolves to give small concentrations of  $Cr^{3+}$  and  $OH^{-}$ .

 $Cr(OH)_3 \ll Cr^{3+} (aq) + 3OH^{-} (aq)$  (1) [1]

When excess OH<sup>-</sup> is added, complex formation takes place. Cr<sup>3+</sup> (aq) + 6OH<sup>-</sup> (aq)  $\ll$  [Cr(OH)<sub>6</sub>]<sup>3-</sup> [1] (accept if [Cr(OH)<sub>4</sub><sup>-</sup>]) The [Cr<sup>3+</sup>] falls shifting the position of equilibrium of (1) to the right, causing the precipitate to dissolve. [1]

or

 $[Cr(H_2O)_3(OH)_3]$  (s) + 3OH<sup>-</sup> (aq)  $\ll [Cr(OH)_6]^{3-}$  +3H<sub>2</sub>O (*l*) [2]

# ([1] for $[Cr(H_2O)_3(OH)_3]$ and $[Cr(OH)_6]^{3-}$ , [1] for balancing equation)

When the  $[OH^-]$  increases, position of equilibrium shifts forward to offset the increase in the  $[OH^-]$  concentration. This causes the solid to dissolve. [1]



The 5 *d* orbitals can be classified into two groups. The  $d_{x^2-y^2}$  and  $d_{z^2}$  have their lobes along the axis, while the  $d_{xz}$ ,  $d_{xy}$  and  $d_{yz}$  have lobes in between the axis. Since the ligands approach the central metal ion along the axis, **the repulsion** for the *d* and *d* are the *d* and *d* are the *d* and *d* are the *d* are *d* are the *d* 

felt by the  $d_{xz}$ ,  $d_{xy}$  and  $d_{yz}$  orbitals is less than for the  $d_{x^2 - y^2}$  and  $d_{z^2}$  orbitals. [1] As such the  $d_{xz}$ ,  $d_{xy}$  and  $d_{yz}$  orbitals are at the lower energy.

(ii) When an electron is promoted from the lower energy d-orbitals, energy is absorbed corresponding to a wavelength in the visible spectrum. [1]

The colour observed is the complement of the colours absorbed. [1]

- (iii) Ligand exchange reaction. [1]
- (iv) Identify the 1:4 ratio for Co<sup>2+</sup>: SCN<sup>-</sup> [1]

[Co(SCN)<sub>4</sub>]<sup>2-</sup> [1]

(d) (i) The energy levels of 3d and 4s electrons in cobalt are similar, hence once the 4s electrons are removed, some or all of the 3d electrons may also be removed without requiring much more energy. [1]

However in calcium, once the 4s electrons are removed, the subsequent removal of electrons must come from an inner quantum shell which requires too much energy. [1]

+0.40

(ii)  $[Co(NH_3)_6]^{3+} + e \ll [Co(NH_3)_6]^{2+}$  E  $O_2 + 2H_2O + 4e \ll 4OH^-$ 

## $E_{cell} = +0.40 - (+0.17) = +0.23V$ [1]

### (e) (i) AgCl [1]

The number of moles of free  $Cl^-$  ions/  $Cl^-$  counter ions are different in both the complexes. [1]

**S** has one  $Cl^-$  ion datively bonded to the  $Co^{3+}$  while **T** has two  $Cl^-$  ion datively bonded to the  $Co^{3+}$  central metal ion.

2 +

#### (ii) complex from S



[1] (mark for dative bonds and positive charge)

(iii) complex from T



[1] (as long as *trans* structure is shown, ignore dative bonds/charges etc.)

(f) Reactant molecules, CO and H<sub>2</sub>O are **adsorbed onto the active sites** of the catalyst surface by formation of weak attractive forces.

This brings the molecules closer together, weakens the C<sup>~</sup>O and O–H bond, orientating them in the right position for reaction, hence lowering the activation energy. ([2] for all 3 points, [1] for any 2 points)

Once the reaction has taken place, the aldehyde formed **desorbs and diffuses away** from the catalyst surface so that the **active sites are exposed** for further reaction.

[1] adsorb and desorb + active sites





### [1] deduct 0.5 for every mistake

 $E^{\odot}_{Zn2+/Zn} = -0.76 \text{ V}$  $E^{\odot}_{Cu2+/Cu} = +0.34 \text{ V}$  $E^{\odot}_{Ag+/Ag} = +0.80 \text{ V}$  (0.5 for these 3 values correctly quoted)

At the <u>anode</u>, Zn is oxidised to  $Zn^{2+}$  (can be described in equation form) as  $\underline{E}_{Zn2+/Zn}^{\oplus}$  is more negative than  $\underline{E}_{Cu2+/Cu}^{\oplus}$  and dissolves into the <u>electrolyte</u>. **[0.5]** 

Ag will not be oxidised as  $\underline{E}_{Ag+/Ag}^{\ominus}$  is more positive than  $\underline{E}_{Cu2+/Cu}^{\ominus}$ , [0.5] hence Ag drops off as anode sludge. [0.5] can be drawn in diagram

At the <u>cathode</u>, only  $Cu^{2+}$  is reduced as <u> $E^{\Theta}_{Cu2+/Cu}$  is more positive than  $E^{\Theta}_{Zn2+/Zn}$ . [0.5] Hence Cu is collected, whereas <u> $Zn^{2+}$  is not reduced/remains in solution</u>. [0.5]</u>





any 3 [1] any 2 [1/2] HO<sub>2</sub>C CO<sub>2</sub>H B is (not required to show cis or trans arrangement) [1] (e) dilute HCl, heat (i) [1] (accept NaOH(aq), heat followed by dilute aqueous acid e.g. HCl) (ii)  $\Delta H$  would be <u>similar</u> (or the same) as the <u>same bonds are broken and formed</u>. [1] (iii) Reaction 1 has a more negative / less positive  $\Delta G$  (from  $\Delta G = \Delta H - T\Delta S$ ). [1] ecf from (e)(ii) Hence, <u> $K_1$  is larger</u> than  $K_2$  (from  $\Delta G = -RTInK$ ). [1] ecf from  $\Delta G$ 

2019 HCI C2 H2 Chemistry Preliminary Exam / Paper 3