



**HWA CHONG INSTITUTION**  
**2024 C2 H2 CHEMISTRY PRELIMINARY EXAMINATION**  
**SUGGESTED SOLUTIONS**

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**Paper 1**

1	2	3	4	5	6	7	8	9	10
A	D	C	B	C	B	A	A	C	D
11	12	13	14	15	16	17	18	19	20
A	D	B	B	D	C	C	D	C	A
21	22	23	24	25	26	27	28	29	30
D	D	C	A	B	B	B	A	B	C

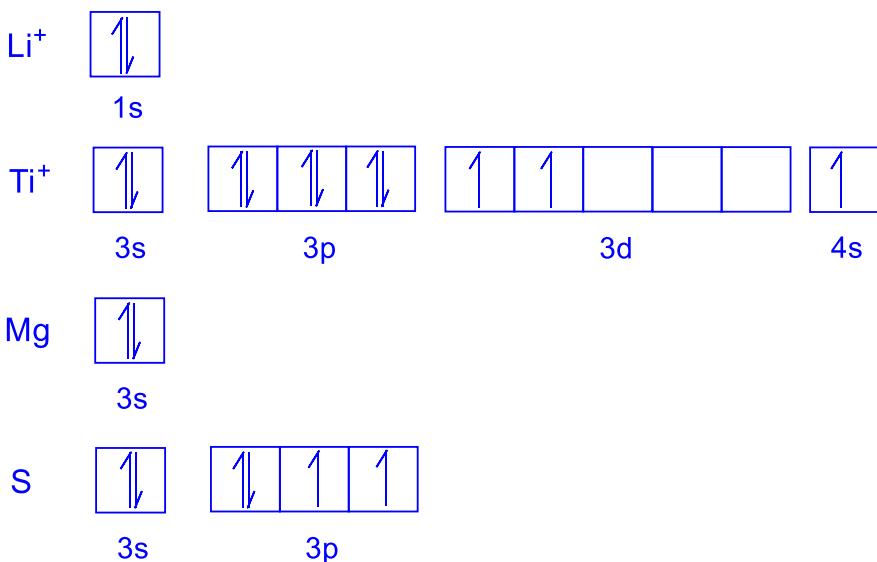
**Comments**

- 1 A  ${}^2\text{H}$  has 1 proton, 1 electron and 1 neutron.  
 ${}^{16}\text{O}$  has 8 protons, 8 electrons and 8 neutrons.

For  $\text{D}_3\text{O}^+$ ,  
Number of neutrons =  $1 + 1 + 1 + 8 = 11$

Since  $\text{D}_3\text{O}^+$  is cationic, it is short of 1 electron overall.  
Number of electrons =  $1 + 1 + 1 + 8 - 1 = 10$

- 2 D Here are the electron-in-box diagrams of the valence orbitals in each species.



Only sulfur has 2 unpaired electrons in its electronic configuration.

- 3 C Based on the number of bond pairs and lone pairs listed in the question, these are the corresponding geometries and bond angles:  
A: Bent,  $118^\circ$                       B: Bent,  $104.5^\circ$   
C: Trigonal pyramidal,  $107^\circ$               D: T-shaped:  $88^\circ$

- 4    **B** Since electrons are delocalised in the carbonate ion, there is partial double bond character, and the bond length is likely to be between a C–O bond and a C=O bond.

From *Data Booklet*, the average C–O bond energy is 360 kJ mol<sup>-1</sup> while the average C=O bond energy is 740 kJ mol<sup>-1</sup> thus it is likely that the C–O bond energy in carbonate is 485 kJ mol<sup>-1</sup>.

5    **C**

	bonding type	physical properties
1	giant covalent	high melting point, <del>conducts electricity when in solution but not when solid</del> does not conduct electricity in any state.
2	simple covalent	low melting point, does not conduct electricity in any state
3	metallic	variety of melting points, conducts electricity when solid and when molten
4	ionic	<del>low melting point</del> high melting point, <del>conducts</del> does not conduct electricity in any state.

- 6    **B** The ordinate (i.e. y-coordinate) is  $PV = nRT = mRT/M_r = \text{constant} / M_r$

Hence the y-value of the graph is inversely proportional to the molar mass of the gas. In order of increasing molar mass, the gases are helium ( $M_r = 4.0$ ), methane ( $M_r = 16.0$ ), nitrogen ( $M_r = 28.0$ ) and chlorine ( $M_r = 71.0$ ). Hence the graph for methane should be the second highest horizontal line (i.e. second largest y-value).

- 7    **A** The gas is compressed to a pressure 4 times its original. If the gas were an ideal gas, its new volume would be expected to be one-quarter of its original, i.e. 19.0 cm<sup>3</sup>. However, its new volume was 20.5 cm<sup>3</sup>, so the gas did not behave ideally. The gas could not have dimerised, as the number of moles of gas would have decreased and the final volume would have been smaller than 19.0 cm<sup>3</sup>.

Option **3** also does not explain the observation, as the presence of significant intermolecular forces of attraction would have also caused the actual volume to be smaller than 19.0 cm<sup>3</sup>.

- 8    **A** First, use the Data Booklet to find the first ionisation energies of the elements.

	1 <sup>st</sup> IE / KJ mol <sup>-1</sup>
Mg	736
Al	577
Si	786
P	1060

From this data, Al will be the leftmost on the x-axis while P will be the rightmost on the x-axis. Option **C** will be eliminated at this point. Options **A**, **B** and **D** are possible.

The melting point of Si will be the highest among the 4 while P has the lowest. Hence on the y-axis Si will be the highest point while P is the lowest point.

Only Option A fits both sets of data and is the correct answer.

FYI: Melting points of the following Period 3 elements are as follows.

	$mp / {}^\circ C$
Mg	659
Al	703
Si	1410
P	44

9 C No. of moles of  $FeC_2O_4 = 0.020 \times 0.020 = 0.000400$  mol

No. of moles of  $KMnO_4 = 0.015 \times 0.020 = 0.000300$  mol

No. of moles electrons transferred =  $0.000400 \times 3 = 0.00120$  mol

No. of moles of  $MnO_4^-$  : No. of moles of electrons =  $0.000300 : 0.00120 = 1:4$

Each mole of  $MnO_4^-$  takes in 4 moles of electrons.

Hence the oxidation number of Mn changes from +7 to +3.

- 10 D Options 1 and 2 allow us to determine the total number of moles of carbonates in the sample. Since the mass of the sample is known, we can then solve for the mole fraction of magnesium carbonate using the molar masses of the two carbonates.

For option 3,  $BaSO_4$  is collected as a precipitate, allowing us to determine the number of moles of barium carbonate. We can then calculate the mass of barium carbonate, mass of magnesium carbonate and number of moles of magnesium carbonate.

- 11 A The only enthalpy change that is always exothermic in the list provided is the lattice energy as it is a process that forms ionic bonds.

Bond breaking and ionisation energy are both endothermic processes.

As for electron affinity, 1<sup>st</sup> electron affinity to form monoanions are exothermic, but 2<sup>nd</sup> electron affinity and beyond are endothermic processes.

- 12 D  $[H^+]$  will remain constant as it is the catalyst. Hence methods that measure changes in  $[H^+]$  (options A, B and C) are not suitable for monitoring the reaction.

Experiments that use different  $[H^+]$  have to be set up in order to determine the order for  $H^+$  (option D).

- 13 B From the given data, the maximum volume of oxygen that can be collected at the end of the experiment =  $2.38 \times \frac{280}{1000} \times \frac{1}{2} \times 24 = 8.0 \text{ dm}^3$ . Option 1 is correct.

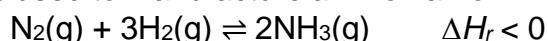
From the graph, first  $t_{1/2}$  is found from 0 to 4.0 dm<sup>3</sup> (50% of 8.0), which is 42 min. The second  $t_{1/2}$  is found from 4.0 dm<sup>3</sup> to 6.0 dm<sup>3</sup> (75% of 8.0), which is also 42 min. Hence the reaction is first order with respect to hydrogen peroxide and is also overall first order. The rate constant of an overall first order reaction is  $k = \frac{\ln 2}{t_{1/2}}$ . Hence the value of rate constant,  $k = \frac{\ln 2}{42} = 0.017$ .

For a first order reaction, rate =  $k[A]$ .

The units of rate constant =  $\frac{\text{mol dm}^{-3} \text{min}^{-1}}{\text{mol dm}^{-3}} = \text{min}^{-1}$  Option 2 is correct.

For a first order reaction, half-life is independent of initial concentration of hydrogen peroxide. Hence option C is wrong as it should have remained at 42 min.

- 14 B The Haber process is used to manufacture ammonia from nitrogen and hydrogen.



When temperature increases, the backward endothermic reaction will be favoured, leading to a decrease in yield. Hence A is wrong.

High pressure favours the forward reaction as it reduces the number of moles of gases. In addition, rate increases as the frequency of effective collisions increases. Thus B is correct.

The presence of a catalyst only affects the rate of reaction but not the position of equilibrium, so C is wrong.

The introduction of more nitrogen will favour the forward reaction, causing an increase in the yield. Hence D is wrong.

- 15 D A negative value for  $\Delta G^\circ$  represents a driving force in the forward direction, and position of equilibrium lies to the right.

A positive value for  $\Delta G^\circ$  represents a driving force in the reverse direction, and position of equilibrium lies to the left.

For point 4, the position of equilibrium lies to the right, which means that the concentration of H<sub>2</sub> should be higher than the concentration of CO.

- 16 C Option 1 is incorrect. If lead(II) nitrate is limiting, the mass of precipitate should remain constant beyond V.

Option 2 is correct. When more KI is added, a soluble lead iodide complex is formed. This decreases the concentration of Pb<sup>2+</sup>(aq) in solution, causing the position of equilibrium of  $\text{PbI}_2(\text{s}) \rightleftharpoons \text{Pb}^{2+}(\text{aq}) + 2\text{I}^-(\text{aq})$  to shift right, and mass of the precipitate will decrease.

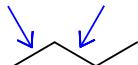
Option 3 is correct. The formula of the soluble lead complex is PbI<sub>4</sub><sup>2-</sup>.

17 C

start with 4C  
linear chain:

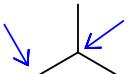


putting one -OH group on either  
of these two carbons gives 2 isomers



inserting one O atom at either  
of these positions gives 2 isomers

then branch  
the 4C chain:



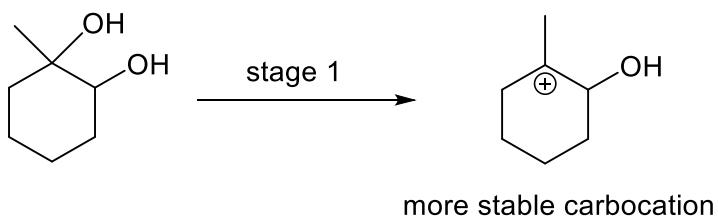
putting one -OH group on either  
of these two carbons gives 2 isomers



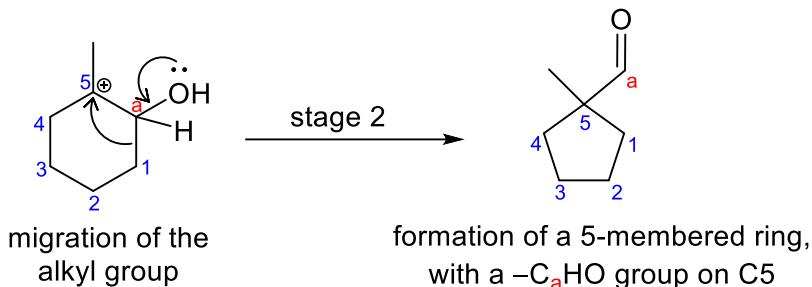
inserting one O atom at this  
position gives 1 isomers

Total = 7 constitutional isomers

18 D



more stable carbocation



migration of the  
alkyl group

formation of a 5-membered ring,  
with a -C<sub>a</sub>HO group on C5

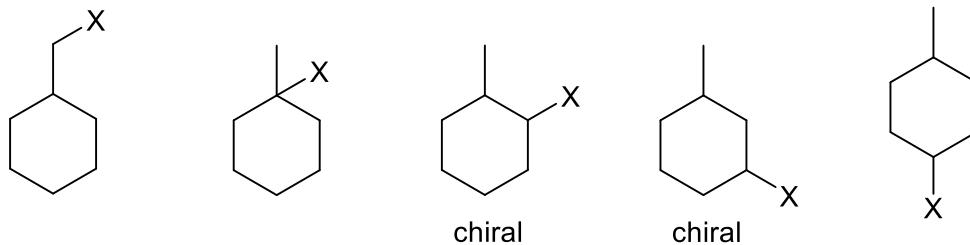
19 C

**A**

H<sub>•</sub> radicals are not produced in the propagation steps, so no H<sub>2</sub> can form in the termination step. Incorrect.

**B**

Incorrect. There are only five monosubstituted products as shown below.



chiral

chiral

**C**

Only two of the monosubstituted products above are chiral. Correct.

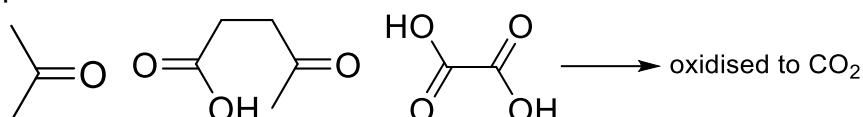
**D**

Z only has 9 carbon atoms. If two  $\text{C}_6\text{H}_5\cdot$  radicals combine,  $\text{C}_6\text{H}_5\text{C}_6\text{H}_5$  should be obtained instead.

- 20 A** The reaction between propene and aqueous bromine is an electrophilic addition. In the first (slow) step of the mechanism, the bromine electrophile adds to one of the C=C carbons, forming an intermediate carbocation. Hence options **C** and **D** are incorrect.

Comparing intermediates A and B, the former is favoured as it is a secondary carbocation, which is more stable than the latter, a primary carbocation. Carbocation A is attacked by a water molecule in the second step, leading eventually to the bromoalcohol major product.

- 21 D** Option **1** is correct as there is an aldehyde group in the citral molecule, which will give a silver mirror with Tollens' reagent (ammoniacal silver nitrate). Option **2** is correct as citral undergoes oxidation/oxidative cleavage to give the following products:



Option **3** is correct as all 5 carbons at a double bond are  $sp^2$ -hybridised, whereas all 5 other carbons are  $sp^3$ -hybridised.

- 22 D** Electrons are donated to an electrophile and not a nucleophile.

Electrons in the  $\pi$  electron cloud are donated to the electrophile, not from the  $\sigma$  bond.

When electrophilic substitution occurs, the hybridisation state of the carbon undergoing the reaction changes from  $sp^2$  in benzene, to  $sp^3$  in the intermediate, and back to  $sp^2$  again when the benzene ring is reformed.

<b>23 C</b>	<p><b>A</b> Alcohols do not react with KCN.</p> <p><b>B</b> Phenol's benzene ring is strongly activated by the <math>-OH</math> group and will undergo tri-substitution when concentrated nitric acid is used.</p> <p><b>C</b> The given bromoalkane does not have any <math>-CH</math> adjacent to the C–Br carbon, and hence cannot undergo elimination with ethanolic KOH. Nucleophilic substitution may occur using <math>OH^-</math> nucleophile to produce the alcohol shown.</p>
<b>D</b>	<p>Excess of the chloroalkane is needed for multiple substitution to give the quaternary ammonium salt. The reaction stops once all the chloroethane has reacted to give the secondary amine, as there is no more electron deficient carbon for the excess methylamine nucleophile to attack.</p> $CH_3CH_2Cl + CH_3NH_2 \rightarrow CH_3CH_2NHCH_3 + HCl$

**24 A** Alcohols with  $\text{CH}_3\text{CH}(\text{OH})-$  structure or ketones with  $\text{CH}_3\text{CO}-$  structure or ethanal ( $\text{CH}_3\text{CHO}$ ) give a positive iodoform test (yellow solid produced). Options B, C and D do not have any of these relevant structures, hence are incorrect. Although option C has the  $\text{CH}_3\text{CO}-$  structure, it is not a ketone but rather an ester, hence gives a negative iodoform test.

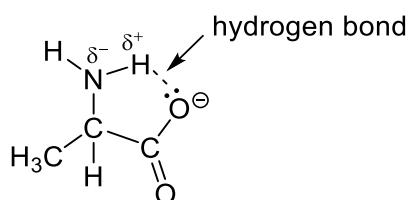
**25 B**  $\text{LiAlH}_4$  does not react with alkenes. It reduces carboxylic acid ( $\text{RCO}_2\text{H}$ ) to primary alcohol ( $\text{RCH}_2\text{OH}$ ), which is a gain of 2H and loss of 1O. It reduces aldehyde ( $\text{RCHO}$ ) to primary alcohol ( $\text{RCH}_2\text{OH}$ ) which is a gain of 2H. It also reduces ketone ( $\text{RCOR}$ ) to secondary alcohol ( $\text{RCH}(\text{OH})\text{R}$ ) which is a gain of 2H.

Hence X (a dicarboxylic acid), Y (a ketone) and Z (an aldehyde) will have 4, 2 and 2 hydrogen atoms incorporated respectively after reacting with  $\text{LiAlH}_4$ . Considering that X, Y and Z are present in 1:1:2 ratio, the average number of hydrogen atoms incorporated per molecule is  $(4+2+2+2)/4 = 2.50$ .

**26 B** The  $-\text{Cl}$  and  $-\text{NH}_2$  groups in I, II and III are all electron-withdrawing groups which help to disperse the negative charge on the carboxylate ion, thereby stabilising the corresponding conjugate bases formed. Hence, IV is the least acidic as its carboxylate ion is the least stable.

Students who choose options **A** or **C** wrongly thought that the  $-\text{NH}_2$  group in III is electron-donating. The lone pair on the nitrogen of this  $-\text{NH}_2$  group cannot be delocalised over to the  $-\text{CO}_2^-$  group in the conjugate base, as the  $-\text{NH}_2$  group is bonded to an  $\text{sp}^3$  carbon (which thus would not have any unhybridised p orbital for lone pair on the  $-\text{NH}_2$  nitrogen to be delocalised).

Comparing I, II and III, the  $-\text{NH}_2$  group is a stronger electron-withdrawing group than  $-\text{Cl}$  (as N is more electronegative than Cl). The carboxylate ion of III can also be stabilised via an internal hydrogen bond as shown below. III is hence the most acidic as its conjugate base is the most stable.



Comparing I and II, the electron-withdrawing  $-\text{Cl}$  disperses the negative charge on the carboxylate ion of I less effectively than that of II, as the electron-withdrawing effect weakens with distance. Conjugate base of I is less stable, so I is less acidic than II.

<b>27 B</b>	<b>A</b>	This pair of compounds do not have the same number of carbon atoms.
	<b>B</b>	The alcohol can undergo a reaction with alkaline aqueous iodine to form the same carboxylic acid as the nitrile. Note that the reaction with aqueous alkaline iodine is an oxidation reaction.

<b>C</b>	The alcohol is a tertiary alcohol that will not undergo oxidation to form a carboxylic acid.
<b>D</b>	Phenols are not able to undergo oxidation to form carboxylic acids.

- 28 A** The reaction between ethanoyl chloride and ethylamine leads to the formation of an amide. Option **1** describes one of the key bond formed and broken in the course of the reaction.

When ethanoyl chloride is replaced by ethanoic acid, an acid base reaction will take place instead of nucleophilic acyl substitution. So option **2** is incorrect.

The amide formed is neutral and the pH of the solution should therefore be 7. So option **3** is incorrect.

- 29 B** Cell potential =  $E^\ominus_{\text{Fe}^{3+}/\text{Fe}^{2+}} - E^\ominus_{\text{H}^+/\text{H}_2} = +0.77 - 0.00 = +0.77\text{V}$

When water is added into the  $\text{Fe}^{3+}/\text{Fe}^{2+}$  half-cell, both  $\text{Fe}^{3+}$  and  $\text{Fe}^{2+}$  will be diluted by the same extent. There is no change in the position of equilibrium for the half cell. Thus the cell potential will remain unchanged.

Should the pressure of  $\text{H}_2(\text{g})$  increase, the position of equilibrium for the hydrogen electrode will shift to favour the oxidation of  $\text{H}_2$ , making the  $E_{(\text{H}^+/\text{H}_2)}$  negative and thus the cell potential will be more positive.

When excess  $\text{CN}^-$  is added into the  $\text{Fe}^{3+}/\text{Fe}^{2+}$  half-cell, ligand exchange will occur and all the  $\text{Fe}^{3+}$  and  $\text{Fe}^{2+}$  will form their respective complex ions with  $\text{CN}^-$ . The new  $E$  is (close to)  $+0.36\text{V}$  leading to a lower cell potential.

- 30 C** Option **A** involves  $\text{SO}_4^{2-}$  ligands replacing  $\text{H}_2\text{O}$  ligands in  $[\text{Cr}(\text{H}_2\text{O})_6]^{2+}$ .

Option **B** involves  $\text{NH}_3$  ligands replacing  $\text{H}_2\text{O}$  ligands in  $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ , followed by oxidation.

Option **C** involves step-wise deprotonation of  $\text{H}_2\text{O}$  ligands due to high charge density of  $\text{Fe}^{3+}$  rather than ligand exchange.

Option **D** involves  $\text{Cl}^-$  ligands replacing  $\text{H}_2\text{O}$  ligands in  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ .