



HWA CHONG INSTITUTION
2022 C2 H2 CHEMISTRY PRELIMINARY EXAM
SUGGESTED SOLUTIONS (PAPER 1)

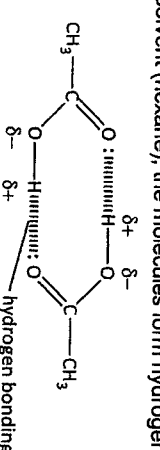
Paper 1

C	B	B	D	D	D	C	A	B	A
B	A	A	B	B	C	C	D	B	A
A	C	A	D	C	A	D	D	D	D

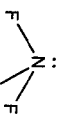
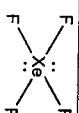
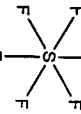
1 C Option D can be eliminated immediately as He contains 2 protons.

Option	No. of protons	No. of neutrons	No. of electrons
A	1	0	2
B	1	1	3
C	1	2	3

2 B The large drop in the graph suggests that A^+ ion (which has already lost its first electron) has electronic configuration of ns^2 and is a Group 2 element. Since the graph is showing consecutive elements in the Period Table, B is a Group 13 element.

Option	Explanation
A	Methanol forms favourable hydrogen bonding between its -OH group and that in water.
B	The hydrogen atom is not bonded to F, O or N atom, hence there is no intermolecular hydrogen bonding for HBr and HCl.
C	For 2-aminophenol, the -NH ₂ and the -OH groups are in close proximity which allows for intramolecular hydrogen bonding. Hence there is less extensive intermolecular hydrogen bonding for 2-aminophenol and less energy is required to overcome the intermolecular forces, leading to a lower boiling point.
D	When ethanoic acid, CH ₃ CO ₂ H ($M_r = 60$), is dissolved in a non-polar solvent (hexane), the molecules form hydrogen-bonded dimers.  hydrogen bonding

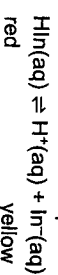
4 D

Option	Explanation
1	 about 107°
2	 about 104.5°
3	 90°

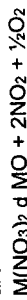
5 D Recall that real gases would deviate from ideal behaviour at high pressures and low temperatures.

Option	Explanation
A	HCl is a polar molecule, which will deviate less at higher temperature since the molecules have more kinetic energy to overcome the intermolecular permanent dipole-permanent dipole (pd-pd) interactions.
B	CH ₄ is a non-polar molecule with only weak intermolecular dispersion forces. CH ₄ will also deviate less at higher temperature since the molecules have more kinetic energy to overcome the intermolecular forces.
C	O ₂ is a non-polar molecule with only weak intermolecular dispersion forces, hence should deviate less from ideal behaviour than HCl.
D	HF is a polar molecule with stronger hydrogen bonding interactions than the permanent dipole-permanent dipole interactions of HCl. Hence HF deviates more from ideal behaviour than HCl at the same temperature of 300 K.

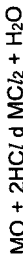
6 D An acid-base indicator is a weak aqueous acid whose acid form, HIn, is a different colour from its ionised form (or conjugate base form), In⁻. As such, it shows different colours in solutions of different pH.



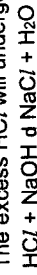
7 C When the metal nitrate decomposes, metal oxide, nitrogen dioxide and oxygen are formed.



The metal oxide then reacts with the added acid to form salt and water.



The excess HCl will undergo neutralisation with NaOH.



Amount of NaOH = $0.0780 \times 0.0216 = 0.001685 \text{ mol}$ = amount of excess HCl/

Amount of HCl used to dissolve residue = $0.0350 \times 0.080 = 0.00280 \text{ mol}$

Amount of HCl reacted with MO = $0.00280 - 0.001685 = 0.001115 \text{ mol}$

Amount of MO = $0.001115 / 2 = 0.0005575 \text{ mol}$ = Amount of $M(NO_3)_2$

M_r of $M(NO_3)_2 = 0.118 / 0.0005575 = 211.7$

A_r of M = $211.7 - 2(14 + 16 \times 3) = 87.7$

Checking the periodic table, M is Sr.

Statement	Explanation
1	Down the group, the size of electron cloud and hence polarisability of the halogen molecule increases. More energy is required to overcome stronger intermolecular dispersion forces. Hence, the volatility of halogens decreases down Group 17.
2	Large anions have high polarisability as their electron cloud is less attracted by the nucleus and can be more easily distorted by a cation. Hence, there is a higher degree of covalent character in the silver halide ionic compounds down Group 17.
3	As the atomic radius increases down the group, the bond length of H-X increases and thus bond strength decreases. Hence, the H-X bond energy decreases down Group 17 and less energy is required to break the bond and HX decomposes more readily.

9 B In the experiment with benzoic acid,

No. of moles of benzoic acid combusted = $0.986 / 122 = 0.008082$

$q = -\Delta H_c \times \text{no. of moles of benzoic acid} = 3054 \times 0.008082 = 24.68 \text{ kJ}$

Heat capacity of the bomb calorimeter = $24.68 / 2.14 \text{ kJ } ^\circ\text{C}^{-1}$

In the experiment with glycine,

No. of moles of glycine combusted = $0.483 / 75 = 0.00644$

$q = (24.68 / 2.14) \times 0.54 = 6.228 \text{ kJ}$

Enthalpy change of combustion of glycine = $-6.228 / 0.00644 = -967 \text{ kJ mol}^{-1}$

10 A This decomposition is endothermic since energy is required for breaking the covalent bonds in the OH^- anion.

ΔS is expected to be positive since there is formation of gaseous H_2O , thus statement 3 is wrong.

ΔG can be positive or negative depending on the temperature.

For reactions to be spontaneous, ΔG needs to be negative. As $\Delta G = \Delta H - T\Delta S$, T has to be high so that $|T\Delta S| > \Delta H$. Thus statement 2 is correct.

Similar to Group 2 carbonates, the thermal decomposition of Group 2 hydroxides is dependent on the charge density of the cation. Since Ba^{2+} is larger in cationic radius as compared to Mg^{2+} , the charge density of Ba^{2+} is smaller. Hence its polarising power is weaker and is less able to distort the electron cloud of the hydroxide ion, weakening the O-H covalent bond to a smaller extent. Thus, barium hydroxide will decompose at a higher temperature than magnesium hydroxide.

11 B Comparing the first two sets of experiments, when concentration of bromine doubles while the concentrations of other reactants remain unchanged, the rate of reaction remains the same. Hence, it should be zero order with respect to Br_2 .

Comparing the first and third sets of experiments, when concentration of H^+ doubles while the concentrations of other reactants remain unchanged, rate doubles. Hence it is first order with respect to H^+ .

Comparing the third and fourth sets of experiments, when the concentration of H^+ doubles and the concentration of propanone increases 4/3 times, the rate of reaction increases by $(2 \times 4/3)$ times. Hence it is first order with respect to propanone.

Option	Explanation
A	Rate equation should be rate = $k[CH_3COCH_3][H^+]$.
B	The rate constant value may be obtained by substituting the rate and concentrations from any set of experiments.
C	Rate constant is only affected by temperature or addition of catalyst.
D	Overall order is not 1. Hence half lives may not be the same across different experiments.

- 12 A Recall Haber process: $N_2(g) + 3H_2 \rightleftharpoons 2NH_3(g)$
The forward reaction is exothermic.

Option	Explanation
A	High temperature will favour the endothermic backward reaction. Hence the yield will decrease but the rate of the reaction will increase.
B	At lower temperature, K_p increases. There will be more NH_3 formed and less N_2 and H_2 present.
C	Higher pressure will favour the forward reaction to produce less number of gaseous molecules. Hence the yield will increase.
D	The presence of catalyst does not affect the yield.

- 13 A

	$CH_3CO_2H + CH_3CH_2OH$	\rightleftharpoons	$CH_3CO_2CH_2CH_3 + H_2O$
initial amvl/ mol	0.50		0.50
change/ mol	-x		-x
eqm amvl/ mol	0.50 - x		0.50 - x
			x
			x

$$K_c = (x/V)^2 / ((0.50 - x)/V)^2 = 4.0$$

Taking square root on both sides, $x = 0.33$

$$\text{Hence amount of } CH_3CO_2H = 0.50 - 0.33 = 0.17$$

- 14 B $pH = -\lg[H^+] = 7$

$$pK_w = -\lg[H^+][OH^-] = 14$$

$$pK_a = -\lg \frac{[H^+][O_2F^-]}{[H_2O]} = -\lg((10^{-7})^2 / (55.6)) = 15.7$$

- 15 B Recall that a buffer should be made up of a weak acid and its conjugate base or a weak base and its conjugate acid.

Option	Explanation
A	This mixture consists of $NaCl(aq)$ (a salt) and $HCl(aq)$ (a strong acid). Thus this is not a buffer solution.
B	$HCl + NH_3 \rightarrow NH_4Cl$ Since the same volume but a higher concentration of $NH_3(aq)$ is used, $NH_3(aq)$ is added in excess. The resulting mixture consists of NH_3 (a weak base) and NH_4Cl (its conjugate acid) which makes up a buffer solution.
C	H_2CO_3 is a dibasic acid. Twice the volume of $NaOH(aq)$ (a monoacidic strong base) is added to $H_2CO_3(aq)$ of the same concentration. Hence, H_2CO_3 and $NaOH$ are completely neutralised to give Na_2CO_3 and H_2O . This is not a buffer solution.
D	$CH_3CO_2H + NaOH \rightarrow CH_3CO_2Na + H_2O$

Since a larger volume of the same concentration of $NaOH(aq)$ is used, $NaOH(aq)$ is added in excess. The resulting mixture consists of a strong base and a salt and hence is not a buffer solution.

- 16 C $PbI_2(s) \rightleftharpoons Pb^{2+}(aq) + 2I^-(aq)$

Option	Explanation
A	As more I^- is added, the above equilibrium will shift to the left, causing the solubility of PbI_2 to decrease. This is the common ion effect.
B	When even more I^- is added, a soluble complex $[PbI_4]^{2-}$ is formed. The formation of this complex decreases the $[Pb^{2+}]$, causing the above equilibrium to shift to the right. This increases the solubility of PbI_2 .
C	At Q, the concentration of I^- is not necessarily twice that of Pb^{2+} as I^- is also contributed by the addition of KI .
D	K_{sp} is only dependent on temperature.

- 17 C The first step is a reduction reaction as there is a loss of oxygen, and hydrogen is added. The second step is a nucleophilic addition reaction, hence an addition reaction.

- 18 D This is a recall question on the reagents and conditions for mild oxidation of an alkene functional group, which requires basic or acidic conditions with cold temperature, and $KMnO_4$ as the oxidising agent. Option D is preferred over C due to the lower temperature used in D.

- 19 B Students should take note that bromine addition occurs on the alkene functional groups, and electrophilic substitution would occur on both the 2 and 4 positions respective to the $-OH$ group, except in options B and D, where one of the positions is blocked by a methyl group.

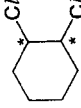
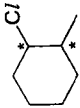
- 20 A

Option	Explanation
A	When $AlCl_3$ reacts as a Lewis acid catalyst, it takes in the electron rich atom. In option A, the $I-Cl$ would become an I^+ electrophile, hence the $-I$ would be substituted onto the benzene ring.
B	The oxidising agent should be potassium manganate(VII), not potassium dichromate.
C	Concentrated nitric and sulfuric acids should be used, not diluted.
D	Iron(III) bromide must be used under anhydrous conditions. In the presence of water, iron(III) bromide is hydrolysed and no longer able to accept the lone pair of electrons from bromine.

- 21 A

Any halogen directly bonded to a benzene ring would not be hydrolysed and remain bonded. The $C-F$ bond is also very strong hence alkyl fluorides do not undergo nucleophilic substitution. Option A would not generate any silver halide.

Option	Explanation
1	The carbon bonded to the Cl and CH ₃ groups is not chiral.
2	There are two chiral carbons present as indicated with asterisks. This compound exhibits stereoisomerism, and there are 4 stereoisomers in total.
3	There are two chiral carbons present as indicated with asterisks. This compound exhibits stereoisomerism, and there are 3 stereoisomers in total.



Option	Explanation
A	The aluminium hydride ion is negatively charged and would be attracted to the electron deficient carbonyl carbon. But it would be repelled and unable to react with the electron rich alkene functional group.
B	Ethene does not have any delocalised electrons.
C	Adsorption is related to heterogeneous catalysis, but lithium aluminium hydride is not a heterogeneous catalyst.
D	Alkene can be further reduced using hydrogenation reaction. This statement is false.

Option	Explanation
A	The ketone is the electrophile in this nucleophilic addition reaction.
B	The alkoxide intermediate acquires a proton in the second step of the mechanism, hence it should be a Bronsted acid-base reaction.
C	The shape with respect to the carbonyl carbon changes from trigonal planar to tetrahedral, hence the hybridisation should change from sp ² to sp ³ .
D	The reaction can proceed with just KCN without HCN. The nucleophile is the CN ⁻ ion. The proton in the second step of the mechanism is provided by the dilute sulfuric acid.

25 C The key phrases in the question are 'ester' and 'immediately' so students should be looking for an alcohol and an acid chloride pair. Option A will form an ester but not immediately. Option B will not give an ester. Option D will just result in an acid-base reaction.

26 A Options B and C (nitrogen compounds chapter), and D (alkyl halide chapter) will all result in products with amine functional groups. Option A is a base-catalysed hydrolysis but the nitrogen containing product is ammonia, not a compound with an amine functional group.

Option	Explanation
A	Changing the size of the metal electrode has no effect on the standard electrode potential, hence the reading on the voltmeter does not change.
B	Adding water dilutes the concentration of the Fe ²⁺ ions, the equilibrium Fe ²⁺ + 2e ⁻ ⇌ Fe favours the reverse reaction, and the electrode potential of Fe ²⁺ /Fe becomes more negative, so the voltmeter would register a more positive reading.
C	Adding aqueous AgNO ₃ decreases the concentration of Cl ⁻ ions due to precipitation of AgCl. The equilibrium Cl ₂ + 2e ⁻ ⇌ 2Cl ⁻ favours the forward reaction, making the electrode potential of Cl ₂ /Cl ⁻ more positive, causing the voltmeter reading to become more positive.
D	Decreasing the pressure of the chlorine gas would cause the equilibrium Cl ₂ + 2e ⁻ ⇌ 2Cl ⁻ to favour the reverse reaction, causing the electrode potential of Cl ₂ /Cl ⁻ to become less positive, resulting in a less positive voltmeter reading.

27 D At the cathode, reduction occurs. The species with the more positive reduction potential will be the one undergoing the reduction.

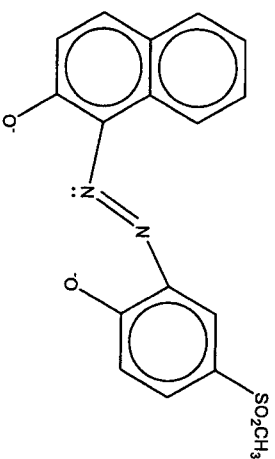
At the anode, oxidation occurs. The species with the less positive reduction potential will be the one undergoing the oxidation.

Option	Explanation
A	At the cathode, E°(Na ⁺ /Na) = -2.71V; E°(H ₂ O/H ₂) = -0.83V. Hence the reaction that occurs will be 2H ₂ O + 2e ⁻ → H ₂ + OH ⁻ . A gas is produced. At the anode, E°(Cl ₂ /Cl ⁻) = +1.36V; E°(O ₂ /H ₂ O) = +1.23V. Hence the reaction that occurs will be 2H ₂ O → O ₂ + 4H ⁺ + 4e ⁻ . A gas is produced.
B	For the cathode, it will be similar to that in Option A. At the anode however, due to the high concentration of Cl ⁻ , E°(Cl ₂ /Cl ⁻) is likely to be less positive than E°(O ₂ /H ₂ O). Hence, 2Cl ⁻ → Cl ₂ + 2e ⁻ . A gas is also produced.
C	At the cathode, E°(Cu ²⁺ /Cu) = +0.34V; E°(H ₂ O/H ₂) = -0.83V. Hence the reaction that occurs will be Cu ²⁺ + 2e ⁻ → Cu. No gas will be produced. At the anode, Cu is used. Hence the reaction that occurs will be Cu → Cu ²⁺ + 2e ⁻ . No gas will be produced too.
D	The cathode reaction will be similar to that in Option C. An inert electrode is used as the anode in this case. The reaction that occurs will be 2H ₂ O → O ₂ + 4H ⁺ + 4e ⁻ . A gas is produced.

28 D At the cathode, reduction occurs. The species with the more positive reduction potential will be the one undergoing the reduction.

At the anode, oxidation occurs. The species with the less positive reduction potential will be the one undergoing the oxidation.

29 C This is the ligand used which has a charge of 2-.



Since the complex has an overall charge of 0 and two such ligands are used, Cr must have an oxidation number of +4.

30 D $E^{\circ}(\text{VO}_3^-/\text{VO}_2^+) = +1.00\text{V}$

$E^{\circ}(\text{VO}_2^+/\text{V}^{3+}) = +0.34\text{V}$

$E^{\circ}(\text{V}^{3+}/\text{V}^{2+}) = -0.26\text{V}$

$E^{\circ}(\text{Zn}^{2+}/\text{Zn}) = -0.76\text{V}$

$E^{\circ}(\text{SO}_4^{2-}/\text{SO}_2) = +0.17\text{V}$

$E^{\circ}(\text{NO}_3^-/\text{NO}_2) = +0.81\text{V}$

For the solution to be green at the end of the reaction, the final oxidation state of vanadium-containing ion should be +3. For the species to be able to reduce the vanadium-containing ions, the reduction potential of the vanadium-containing ion should be more positive than that of the added reagent.

For zinc, $E^{\circ}(\text{VO}_3^-/\text{VO}_2^+)$, $E^{\circ}(\text{VO}_2^+/\text{V}^{3+})$ and $E^{\circ}(\text{V}^{3+}/\text{V}^{2+})$ are more positive than $E^{\circ}(\text{Zn}^{2+}/\text{Zn})$. Hence zinc is able to reduce the vanadium-containing ions to an oxidation state of +2, giving a violet solution at the end.

For sulfur dioxide, $E^{\circ}(\text{VO}_3^-/\text{VO}_2^+)$ and $E^{\circ}(\text{VO}_2^+/\text{V}^{3+})$ are more positive than $E^{\circ}(\text{SO}_4^{2-}/\text{SO}_2)$. Hence sulfur dioxide is able to reduce the vanadium-containing ions to an oxidation state of +3.

For nitrogen dioxide, only $E^{\circ}(\text{VO}_3^-/\text{VO}_2^+)$ is more positive than $E^{\circ}(\text{NO}_3^-/\text{NO}_2)$. Hence nitrogen dioxide is only able to reduce the vanadium-containing ions to an oxidation state of +4, giving a blue solution at the end.



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SUGGESTED SOLUTIONS (PAPER 2)

1 (a) (i) Hydrocarbons / Alkanes / Alkenes / Arenes [1]

1 (a) (ii) $N_2 + O_2 \rightarrow 2NO$ [0.5]
 $2NO + O_2 \rightarrow 2NO_2$ [0.5]

1 (a) (iii) Forms photochemical smog / leads to acid rain [1]

1 (b) (i) $pV = nRT$
 $n(\text{gas}) = \frac{pV}{RT}$
 $= \frac{(10 \times 10^5)(63.2 + 1000)}{(8.31)(900+273)}$
 $= 6.48 \text{ mol}$

[1] correct substitution and conversions
[1] answer (ecf)

1 (b) (ii) Amount of $SO_2 = 0.0183 + 64.1$
 $= 2.85 \times 10^{-4} \text{ mol}$

Number of SO_2 particles $= 2.85 \times 10^{-4} \times L$ (where L is Avogadro constant)
Number of particles in fuel exhaust $= 6.48 \times L$

Amount of SO_2 in ppm $= \frac{[(2.85 \times 10^{-4} \times L) + (6.48 \times L)] \times 1 \times 10^6}{6.48 \times L}$
 $= 44.1 \text{ ppm}$

The sample meets the sulfur emission standards

[1] Finding the number of SO_2 particles

[1] Calculating the concentration of SO_2 in ppm and correct conclusion (ecf given from part (b)(ii)). [-0.5] if comparison is correct but answer in ppm is absent)

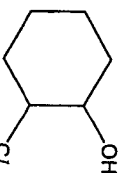
1 (c)

- SO_3 dissolves in water in a violent / very exothermic reaction
- forming a strongly acidic solution around pH 1
- $SO_3(l) + H_2O(l) \rightarrow H_2SO_4(aq)$
- Na_2O dissolves completely in water in a vigorous / exothermic reaction
- forming a strongly alkaline colourless solution around pH 13
- $Na_2O(s) + H_2O(l) \rightarrow 2Na^+(aq) + 2OH^-(aq)$
- Al_2O_3 is insoluble / has no reaction in water
- The resulting mixture is neutral / pH 7

8 points - [4]
5 to 7 points - [3]
4 points - [2]
2 to 3 points - [1]
1 point - [0.5]
[4] total

2 (a) (i)

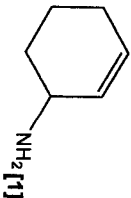
Intermediate A



Cl [1] step 1: $C_2(aq)$ [1], step 2: excess conc H_2SO_4 , heat OR concentrated H_3PO_4 , heat OR Al_2O_3 , heat [1]

WRONG INTERMEDIATE A LOSES MARKS FOR STEP 1 AND STEP 2.

Intermediate B



(a) (ii) The $-C^{\alpha}O_2H$ is nearer the electron withdrawing amine group, that better disperses the negative charge on the conjugate carboxylate ($-C^{\alpha}O_2^-$), stabilising this conjugate carboxylate more, this makes the $-C^{\alpha}O_2H$ group more acidic and hence is deprotonated first.

All 4 points below = [2]. 2 out of 4 points = [1]

- amine group (NH_2) is nearer $-C^{\alpha}O_2H$ than to $-C^{\beta}O_2H$ (compares distance)
- amine group is electron withdrawing
- negative charge on the conjugate base ($-C^{\alpha}O_2^-$) is better dispersed
- conjugate base of $-C^{\alpha}O_2H$ is more stable (than that of $-C^{\beta}O_2H$)

2 (a) (iii) Naturally occurring MSG consists of only 1 enantiomer. MSG synthesised in the laboratory will be a racemic mixture, the enantiomer produced in lab synthesis may interact with the taste bud differently.

[1] for realising the lab synthesis results in a racemic mixture, or at least acknowledge different ratios of enantiomers may be produced in lab synthesis vs the natural process.

2 (b) Relative mass of $NaCl$ = 183
Amount of Na^+ in 1 g of MSG = $1 \div 183 = 5.46 \times 10^{-3}$ mol [1]

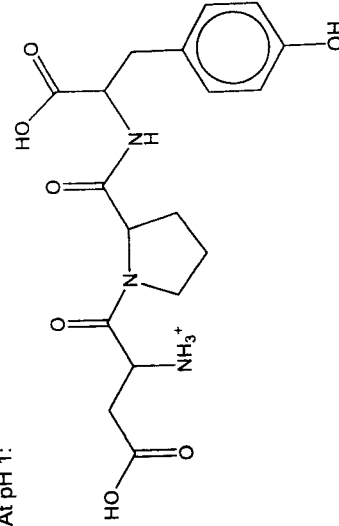
Relative mass of $NaCl$ = 58.5
Amount of Na^+ in 1 g of $NaCl$ = $1 \div 58.5 = 1.71 \times 10^{-2}$ mol [1]

There are less sodium ions in 1 g of MSG than in 1 g of table salt.

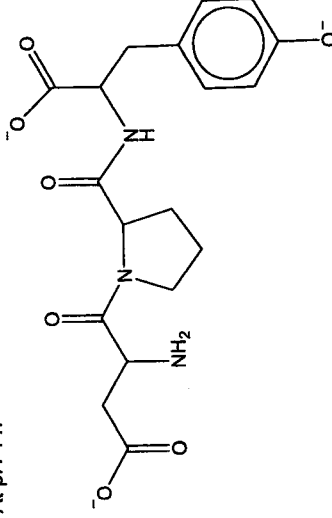
OR correct calculations of percentage by mass OR actual mass of Na^+ ions

3 (a) C [1]

3 (b) At pH 1:



At pH 14:



Any correct tripeptide drawn [1]

At pH 1: Protonation of correct functional group i.e. amine group [1]

At pH 14: Deprotonation of correct functional groups i.e. carboxylic acid and phenol groups [1]

3 (c) (i) The lone pairs on $N^{\delta+}$ and $N^{\delta-}$ can delocalise over the $C=N$ group, making the lone pair on both N atoms much less available for donation to H^+ . [1]

3 (c) (ii) Concentration of arginine = $0.100 \times 20 + 10 = 0.200$ mol dm^{-3} [1]

3 (c) (iii) $K_{a1} = x^2 / (0.200 - x) = 10^{-2.17}$

Assume that $x \ll 0.200$,

$$K_{a1} = x^2 / (0.200) = 10^{-2.17}$$

$$x = [H^+] = 0.03677 \text{ mol } dm^{-3}$$

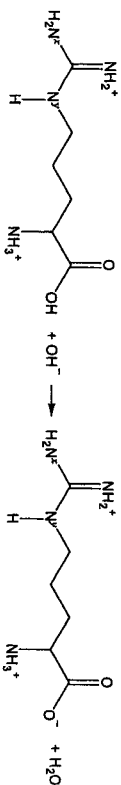
$$pH = -\lg 0.03677 = 1.43$$

Calculate $[H^+]$ correctly [1] allow ecf from (c)(ii)

Calculate pH correctly [1] allow ecf from $[H^+]$ calculated

3 (c) (iv) 2.17 [1]

3 (c) (v)



[11]

As there is a large reservoir of the acid and conjugate base, [1]

the addition of OH^- will only lead to a small change in the ratio of the [acid] : [conjugate base]. Since $[\text{H}^+] = K_a \times [\text{acid}]/[\text{conjugate base}]$ and K_a is constant, the pH change will be very gradual. [1]

3 (c) (vi) Put an X at the point when volume = 40 cm^3 [1]

4 (a) (i) A ligand is an ion or molecule with one or more lone pairs of electrons available for donation to the vacant orbitals of a metal atom or ion. [1]

4 (a) (ii) (i) Nickel(II) contains partially filled d-orbitals.

(ii) In the presence of ligands, the degenerate d-orbitals split into two distinct energy levels with an energy gap, ΔE .

(iii) When light shines on the solution, an electron from the lower energy level will absorb light of a specific wavelength and is promoted to a vacant orbital at a higher energy level.

(iv) The wavelength of light absorbed corresponds to the wavelengths of visible light.

(v) The complementary colours are seen, and so, the colour of each complex will be different.

(vi) When the ligands change from H_2O to NH_3 , the magnitude of the energy gap, ΔE , also changes, so the solution changes colour.

Explanation of the origin of colour (points (i) – (v) above)

5 points – [2]

3 to 4 points – [1]

1 to 2 points – [0]

[1] Explain why a colour change occurs during ligand exchange (point (vi) above)

4 (b) (i)

The entropy change is positive because there are more ways to distribute energy since there is an increase in the amount of aqueous species in the solution. The entropy change is large as the amount of products is significantly greater than the amount of reactants in this system.

[1] For explaining why the change in entropy is positive
[1] For explaining why the change in entropy is large

4 (b) (ii) $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

$$= -17.0 - 298(121/1000)$$

$$= -53.1 \text{ kJ mol}^{-1} \text{ [1]}$$

4 (b) (iii) ΔG° is a negative number, this shows that the position of equilibrium lies to the right i.e. it is product favoured. Thus, ethane-1,2-diamine binds preferentially with Ni^{2+} .

[1] Correct identification of position of equilibrium based on (b)(ii) (ecf)

[1] Correct identification of preferred ligand based on position of equilibrium (ecf)

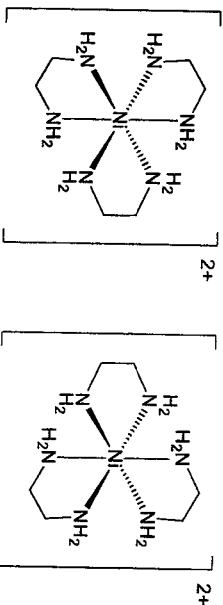
4 (b) (iv) The coordination of the first $-\text{NH}_2$ group is an intermolecular reaction, but the second coordinate bond is an intramolecular reaction, which occurs much more quickly than an intermolecular reaction. (or other words to that effect)

OR

The complexation of three bidentate ligands involve three sequential bimolecular reactions, which has a higher probability of occurring than the complexation of ammonia ligands, which will involves six sequential bimolecular reactions. Thus the rate of reaction involving an ligands is faster. (or other words to that effect)

[1] for a suitable explanation using Collision Theory

4 (c) (i)



[1] Correct drawing of $[\text{Ni}(\text{en})_3]^{2+}$

[1] Correct drawing of enantiomer

4 (c) (ii) $[\text{Ni}(\text{en})_3]^{2+}$ is chiral because its mirror image isomers are non-superimposable.

OR

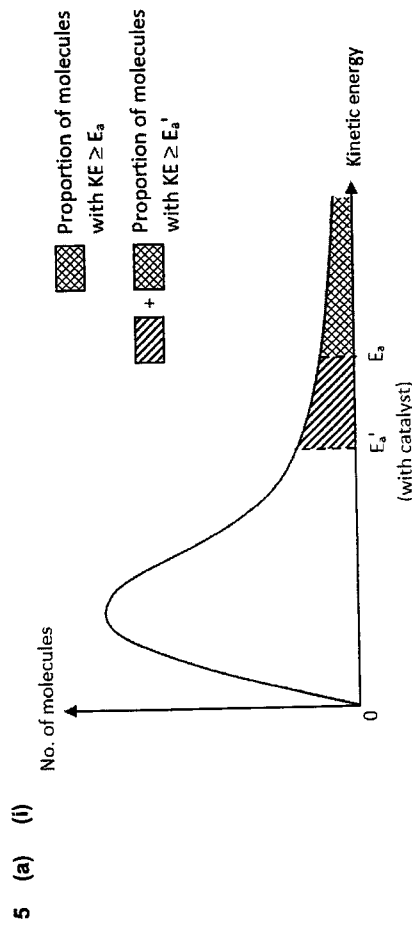
$[\text{Ni}(\text{en})_3]^{2+}$ is chiral because it has no internal plane of symmetry.

[1]

4 (c) (iii) The enantiomers have the same boiling point / melting point / colour / density / electrical conductivity.

The enantiomers rotate plane-polarised light in opposite directions.

- [1] Stating one similarity
[1] Stating one difference



[1] diagram (–½ m per mistake in axes labels, starting from origin, single curve)
A catalyst provides an alternative reaction pathway which requires a lower activation energy (E_a') than the uncatalysed reaction (E_a). [½]

As represented by the shaded areas in the Boltzmann diagram, there is an increase in the proportion/ fraction/ number of reactant particles that have kinetic energy greater than or equal to activation energy E_a' . [½]. This increases the frequency of effective collisions [½] and hence rate of reaction. As concentration of the reactants are unchanged when a catalyst is added, rate constant increases as well. [½]

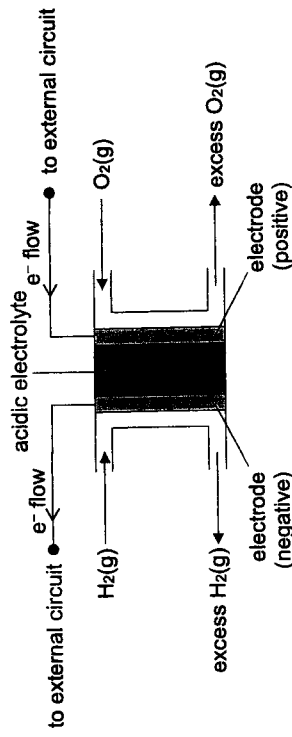
5 (a) (ii) [1] $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$

5 (a) (iii)

balanced equation for catalysed reaction	homogeneous catalysis	heterogeneous catalysis
$2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$ or $2H_2O_2 \rightarrow 2H_2O + O_2$	$2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$ [½]	$N_2 + 3H_2 \rightleftharpoons 2NH_3$ [½]
catalyst used	Fe^{2+} (or Fe^{3+}) [½]	Fe (or Fe_2O_3) [½]
reason why iron or its compound could act as this type of catalyst	Fe is able to exhibit variable oxidation states / relative ease of interconverting between different oxidation states [1]	Fe has partially filled 3d orbitals (to accept/donate electron pairs) for the adsorption of reactant molecules [1]

5 (b) (i) Standard electrode potential is the potential difference between a half-cell and a standard hydrogen electrode at standard conditions of 298 K, 1 bar for gases and 1 mol dm^{-3} for solutions. [1]

5 (b) (ii)



- [1] polarity of electrodes
[1] direction of e^- flow in the wires

5 (b) (iii) pathway 1: half-equation 3

pathway 2: half-equation 2 [1] for both correct

5 (b) (iv) [1] idea of stronger adsorption leads to weaker O–O bond

[1] hence greater tendency for O–O bond to be broken to give H_2O instead of H_2O_2

- 5 (c) (i) [1] $2\text{H}_2\text{O}(l) \rightarrow \text{O}_2(g) + 4\text{H}^+(aq) + 4e^-$ (0m if no state symbols)

$E^\ominus(\text{O}_2/\text{H}_2\text{O}) = +1.23\text{V}$ is less positive than $E^\ominus(\text{H}_2\text{O}_2/\text{H}_2\text{O}) = +1.77\text{V}$.
Hence, H_2O should be preferentially oxidised to O_2 , so this competing reaction is more likely to occur.

[1] quote standard reduction potentials
[1] compare standard reduction potentials + conclusion

- 5 (c) (ii) [1] $2\text{Ce}^{4+} + \text{H}_2\text{O}_2 \rightarrow 2\text{Ce}^{3+} + 2\text{H}^+ + \text{O}_2$

- 5 (c) (iii) $-179.5 \times 10^3 = -2 \times 96500 \times E^\ominus_{\text{cell}}$
 $E^\ominus_{\text{cell}} = +0.930\text{V}$ [1]

$E^\ominus_{\text{cell}} = E^\ominus(\text{Ce}^{4+}/\text{Ce}^{3+}) - E^\ominus(\text{O}_2/\text{H}_2\text{O}_2)$
 $E^\ominus(\text{Ce}^{4+}/\text{Ce}^{3+}) = 0.930 + (0.68) = +1.61\text{V}$ [1] ecf from calculated E^\ominus_{cell}

- 5 (c) (iv) $Q = 1.00 \times 10^{-4} \times 60 \times 60 = 0.360\text{C}$
 $n(\text{electrons}) \text{ transferred} = 0.360 \div 96500 = 3.7306 \times 10^{-6}\text{ mol}$ [1]

Theoretical $n(\text{H}_2\text{O}_2)$ formed = $3.7306 \times 10^{-6} \div 2 = 1.8653 \times 10^{-6} \approx 1.87 \times 10^{-6}\text{ mol}$
[1]

- 5 (c) (v) $[\text{Ce}^{4+}]$ after reaction in step 4 = $(1.00 \times 10^{-4}) \div 0.567 \times 0.200$
 $= 3.5273 \times 10^{-5}$
 $\approx 3.53 \times 10^{-5}\text{ mol dm}^{-3}$ [1]

- 5 (c) (vi) Initial $n(\text{Ce}^{4+}) = 100 \div 1000 \times 1.00 \times 10^{-4} = 1.00 \times 10^{-5}\text{ mol}$
Final $n(\text{Ce}^{4+}) = 200 \div 1000 \times 3.5273 \times 10^{-5} = 7.0547 \times 10^{-6}\text{ mol}$
[1] both steps, ecf final $n(\text{Ce}^{4+})$ based on calculated $[\text{Ce}^{4+}]$ in (c)(v)

Hence, $n(\text{Ce}^{4+})$ that reacted
 $= 1.00 \times 10^{-5} - 7.0547 \times 10^{-6}$
 $= 2.9453 \times 10^{-6}$
 $= 2.95 \times 10^{-6}\text{ mol}$ [1] ecf based on initial and final $n(\text{Ce}^{4+})$

- 5 (c) (vii) $n(\text{H}_2\text{O}_2)$ in 100 cm^3 electrolyte
 $= 2.9453 \times 10^{-6} \div 2$ (based on $n(\text{Ce}^{4+})$): $n(\text{H}_2\text{O}_2)$ in (c)(iii)
 $= 1.47265 \times 10^{-6}$
 $\approx 1.47 \times 10^{-6}\text{ mol}$ [1] sf, units assessed

FE = $(1.47265 \times 10^{-6}) \div (1.8653 \times 10^{-6}) \times 100\% = 78.9\%$ [1] ecf



HWA CHONG INSTITUTION
2022 C2 H2 CHEMISTRY PRELIMINARY EXAM
SUGGESTED SOLUTIONS (PAPER 3)

1 (a) (i) [1/2] working

[1/2] answer to nearest integer (n must be 65)

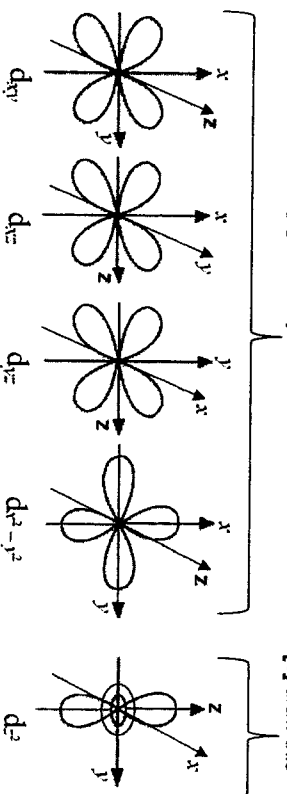
$$63 \times \frac{74.1}{100} + n \times \frac{25.9}{100} = 63.5$$

$$25.9n = 6350 - 4668.3$$

$$\therefore n = \frac{1681.7}{25.9} = 65$$

1 (a) (ii) [1] nucleon number is the total number of protons and neutrons in the nucleus of an atom

1 (a) (iii) [1] draw any one of these



[1] draw this

For each 1m: 1/2m for drawing the shape

1/2m for labelling x y z axes AND 'naming' that orbital

(students who drew, say, the d_{z^2} orbital but named it as $d_{x^2-y^2}$ are penalised)

1 (b) (i) [1/2]

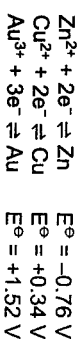
Zn oxidised to Zn^{2+}
AND justify in terms of $E^{\ominus}(Zn^{2+}/Zn)$ vs. $E^{\ominus}(Cu^{2+}/Cu)$ and $E^{\ominus}(Au^{3+}/Au)$

[1/2] Explain why Zn^{2+} is not reduced at the cathode
in terms of $E^{\ominus}(Zn^{2+}/Zn)$ vs. $E^{\ominus}(Cu^{2+}/Cu)$

[1/2] Au is collected as anode sludge / Au falls off the anode
(Reject 'Au remains on the anode' / 'remains as anode' / 'remains on the Shakkudo')

[1/2] Explain why Au is not oxidised in terms of $E^{\ominus}(Au^{3+}/Au)$ vs. $E^{\ominus}(Cu^{2+}/Cu)$

Sample write-up:



At the anode,

$E^{\ominus}(Zn^{2+}/Zn)$ is the least positive (or most negative), so Zn oxidises to Zn^{2+} (which enters the solution).

$E^{\ominus}(Au^{3+}/Au)$ is more positive than $E^{\ominus}(Cu^{2+}/Cu)$, therefore Au is not oxidised, Au sinks to the bottom of the container as anode sludge.

At the cathode,

$E^{\ominus}(Zn^{2+}/Zn)$ is less positive (or more negative) than $E^{\ominus}(Cu^{2+}/Cu)$, therefore Zn^{2+} is not reduced (but remains as Zn^{2+} in the solution).

1 (b) (ii) $Q = n(\text{electrons}) \times F = n(\text{electrons}) \times L \times e = It$

$$\frac{0.26}{63.5} \times 2 \times L \times 1.60 \times 10^{-19} = 1.10 \times 12 \times 60$$

$$L = 6.04 \times 10^{23}$$

[2] Any mistake loses 1m
No 1/2m for this part

1 (c) (i) [1] no electron-rich centres / no region of high electron density / no δ^+ carbon / non-polar C-C and C-H bonds

1 (c) (ii) [1/2]

difference in reaction condition: Benzene needs conc. H_2SO_4 as catalyst while propoxybenzene doesn't. (Reject discussion of temperature \therefore for benzene, even at higher temperature (55 $^{\circ}C$), the reaction still doesn't work if conc. H_2SO_4 catalyst isn't added. The question also never label the temperature for propoxybenzene's nitration, so students shouldn't be looking at temperature.)

[1/2] *difference in organic products:* Benzene only mono-nitration / mono-substitution or draw out the nitrobenzene, while propoxybenzene is tri-substituted.

[1/2] *regarding the lone pair on O:* Oxygen's lone pair delocalises over the benzene ring. (Reject: 'O is electron donating' / 'OCH₂CH₂CH₃ is electron donating' \therefore that could refer to an inductive effect.) (Reject: 'alkyl' group electron donating' – must discuss about the lone pair on O)

[1/2] *so what if that lone pair delocalises:* This increases electron density in the benzene ring, making it more reactive towards electrophile / more susceptible towards electrophilic substitution.

1 (d) [1] P: HOCH₂CH₂CHO

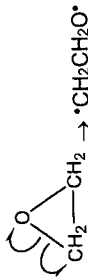
[1] R: HOCH₂CH₂CH₂OH

(allow ecf from P only if student's P can be reduced to student's R using the H_2/Pt)

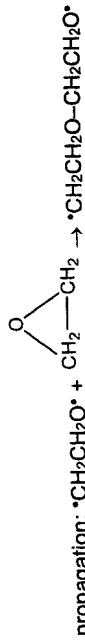
[1] Q: HOCH₂CO₂H

(all three structures must fit their given molecular formula)

1 (e)



initiation: $\text{CH}_2\text{-CH}_2 \rightarrow \cdot\text{CH}_2\text{CH}_2\text{O}\cdot$
 [1/2] two curly half-arrows 'fly out' from one C-O bond, 'fly to' the correct atoms
 [1/2] correct product radical, • at correct atoms



[1/2] correct radical reacts with epoxyethane
 [1/2] correct product radical, • at correct atoms

2 (a) (i) No. of moles of thiosulfate needed to react with 25 cm³ of solution = 12.0/1000 x 0.50 = 0.006

No. of moles of I₂ in 25 cm³ of solution = 0.006/2 = 0.003 mol [1]

No. of moles of I₂ formed from solid NaI = 0.003 x (100/25) = 0.012 mol

2I⁻ + 2e⁻ → I₂

No. of moles of electrons lost by iodide on reacting with conc H₂SO₄ = 0.012 x 2 = 0.024 mol

No. of moles of electrons gained per mole of sulfuric acid = 0.024 / 0.003 = 8 [1]

Oxidation state of sulfur product = +6 - 8 = -2 [1]

2 (a) (ii) $\text{Cl}_2 + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$ E° = +1.36 V or E° (Cl₂/Cl⁻) = +1.36 V
 $\text{I}_2 + 2\text{e}^- \rightleftharpoons 2\text{I}^-$ E° = +0.54 V or E° (I₂/I⁻) = +0.54 V
 [1] for quote E° and comment on more/less positive E°

Iodide is a stronger reducing agent than chloride due to less positive E° (I₂/I⁻).
 Iodide is more easily oxidised to iodine and is able to reduce sulfur atom from +6 to a product with a lower oxidation state or chloride is unable to reduce H₂SO₄. [1]

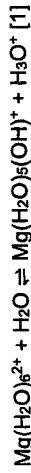
2 (b) (i) Strong ionic bonds in P require large amounts of energy to overcome, hence P has high melting point and exists as a solid. [1]

Weak dispersion forces between molecules of Q require lesser energy to overcome, hence Q has low melting point and exists as a liquid. [1]

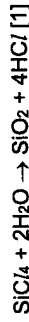
2 (b) (ii) P: MgCl₂ [1]

Q: SiCl₄ [1]

2 (b) (iii) P undergoes slight/partial hydrolysis in water [1/2]



Q undergoes complete hydrolysis in water [1/2]



2 (c) (i) $K_p = P_{\text{Cl}_2} P_{\text{PCl}_3} / P_{\text{PCl}_5}$ [1]

Initial pressure/kPa	PCl ₅ (g)	⇌	PCl ₃ (g)	+	Cl ₂ (g)
Change in pressure/kPa	84 - x		+x		+x
Eqm pressure/kPa	84		x		x

Total equilibrium pressure = (84 + 2x) kPa

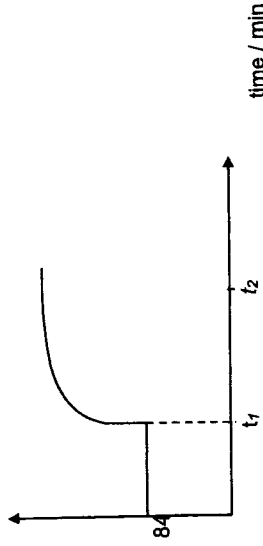
(84 + x) / (84 + 2x) = 0.70 [1] correctly set up initial P/total eqm P = 0.7

84 + x = 58.8 + 1.4x → x = 63 [1] find partial pressure of PCl₃ or Cl₂

$K_p = 63^2 / 84 = 47.3$ kPa or 47300 Pa [1]

*must use 84 as equilibrium pressure of PCl₅ is given in question.

2 (c) (iii) partial pressure of PCl₃ / kPa



[1] correct sketch at t₁ (sharp increase) + explain: volume reduced hence pressure increased

[1] correct sketch between t₁ and t₂ (increase at decreasing rate) + explain: POE shifts left to lower total pressure by forming fewer gaseous molecules

2 (d)

X undergoes oxidation / iodoform reaction with warm alkaline aqueous iodine I₃ → X contains CH₃CH(OH)- (structure must be drawn out, there is no name for this structure)

X undergoes (nucleophilic) substitution reaction with PCl₅ → X contains an alcohol group

Y is reduced by tin, conc HCl → Y contains nitrobenzene or Z contains phenylamine.

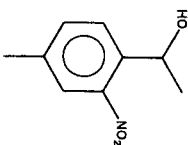
This is followed by an intramolecular nucleophilic substitution reaction between chloroalkane and phenylamine to form Z.

2 marks for any 4 underlined points from above.
1 mark for 2-3 underlined points from above.

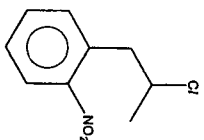
X:



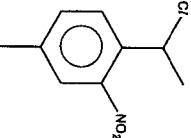
alternative structure:



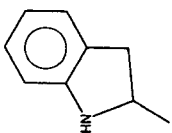
Y:



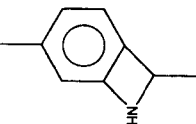
alternative structure:



Z:



alternative structure:



Z must be in 1,2 position otherwise no intramolecular reaction.

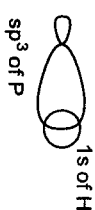
- 3 (a) (i) Nitrogen is in Period two of the Periodic Table whereas phosphorus is in Period three. Phosphorus has energetically accessible 3d subshells to accommodate beyond eight electrons in its valence shell. However, for nitrogen, the next available subshell beyond 2p is 3s, which is not energetically accessible. [1]

(credit is awarded for an idea of nitrogen being unable to "expand octet".)

- 3 (a) (ii) σ : 6
 π : 1

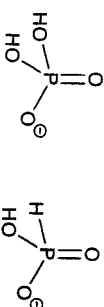
[1] for both

- 3 (a) (iii) For P-H: head-on overlap between the sp^3 orbital P and the 1s orbital of H to form an sp^3 -1s σ bond. [1]



[1] correct labels are required to score this credit.

- 3 (a) (iv) The structures of the conjugate base of H_3PO_4 and H_3PO_3 are shown below.



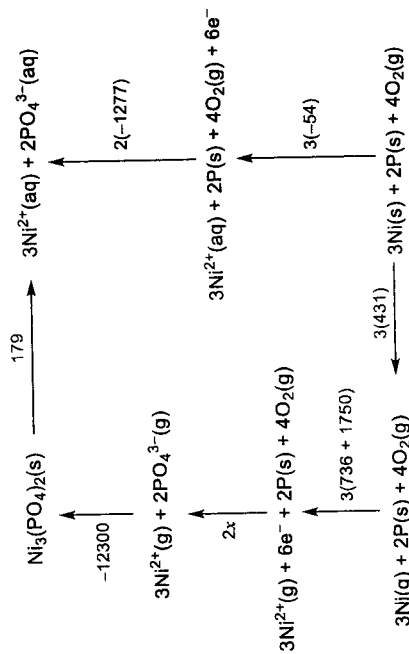
H_3PO_4 has a higher pK_a than H_3PO_3 , implying that the latter has a large K_a and thus H_3PO_3 ionises to a greater extent than H_3PO_4 . [0.5]

$H_2PO_4^-$ is therefore less stable than that of $H_2PO_3^-$ and because the former has 2 -OH groups and the latter has 1 -OH group [0.5], it can be inferred that the negative charge on O^- in $H_3PO_4^-$ is likely to be intensified by the presence of the extra -OH via an electron-donating effect. [0.5]

The lone pair of electrons on O^- in $H_2PO_3^-$ delocalises over $P=O$ to a greater extent than that in $H_2PO_4^-$ (due to the former having only 1 -OH group). [0.5]

3 (b)

Let the standard enthalpy change of formation of $\text{PO}_4^{3-}(\text{g})$ be x .



Credit is awarded based on the following correct enthalpic terms illustrated in the cycle (state symbols and molar ratios are included):

[1] ΔH_f for both $\text{PO}_4^{3-}(\text{aq})$ and $\text{Ni}^{2+}(\text{aq})$.

[1] First and second ionisation energies for $\text{Ni}(\text{g})$

[1] The rest of the enthalpic terms, i.e. $\Delta H_{\text{atom}} \text{Ni}_3(\text{PO}_4)_2(\text{s})$, $\Delta H_{\text{atom}} \text{Ni}(\text{s})$ and $\text{LE Ni}_3(\text{PO}_4)_2(\text{s})$

[1] **Close cycle** drawn and correct application of Hess' law (ecf allowed)

Using Hess' Law,

$$2x = -3(736 + 1750) - 3(431) + 3(-54) + 2(-1277) - 179 + 12300 = +654 \text{ kJ mol}^{-1}$$

$$x = +327 \text{ kJ mol}^{-1}$$

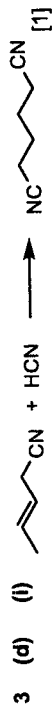
3 (c) (i)

The melting point of Ni is higher compared to that of Ca. As compared to Ca, more energy is required to overcome the stronger metallic bonds between the Ni^{2+} ions and the sea of delocalised electrons, since both 3d and 4s electrons are involved in the metallic bonding. [1]

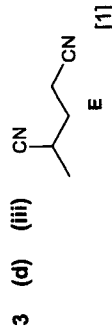
The density of Ni is higher compared to that of Ca, because Ni has a smaller atomic radius (or cationic radius) and a larger A_r than Ca. Since density is the mass per unit volume, assuming that the atoms are spherical in shape, Ni will have a higher density as compared to Ca. In addition, having a smaller atomic radius also means that its structure is more closely packed. [1]

3 (c) (ii)

CO undergoes a ligand exchange reaction and displaces O_2 from oxyhaemoglobin. CO binds more strongly / irreversibly (or CO is a stronger ligand) [1] to haemoglobin than O_2 thus preventing oxygen transport (in the blood/tissues etc.) [1]



3 (d) (ii) Ni is being oxidised from 0 to +2 [1] and HCN is being added to NiL_3 as $-\text{H}$ and $-\text{CN}$ ligands. [1]



3 (e) (i) HCN and alkene are in excess and the change in their concentration during the reaction is negligible/ their concentration appears to be unchanged. Hence both concentration terms can be subsumed into K . [1]

3 (e) (ii) From the graph, $m = \frac{1.10 - (-0.55)}{-0.78 - 0.04} = -2.01$

Order of reaction with respect to L is -2 . [1]

3 (e) (iii) When [L] doubles, rate will be reduced to a quarter of its original value. [1] (allow ecf)

4 (a) Because its molecules are non-polar, they can form dispersion forces with the non-polar molecules in skin and be absorbed. [1]

it has a simple molecular structure with only weak dispersion forces between its non-polar molecules, therefore little energy is required to overcome these forces, causing it to be easily vapourised. [1]

4 (b) (i) 2-chloro-6-methylheptane [1]

4 (b) (ii) The central Al atom in these molecules are only surrounded by six valence electrons, therefore it is electron-deficient / contains a vacant low-lying orbital that can accept an electron pair. [1]

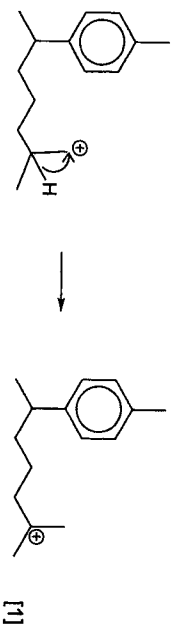
4 (b) (iii) constitutional / structural / positional isomers [1]

The $-\text{CH}_3$ group of methylbenzene is 2,4-directing and hence directs the electrophile to preferentially substitute on C2 or C4 instead of C3. [1]

4 (b) (iv) (limiting) Br₂, uv light [1]

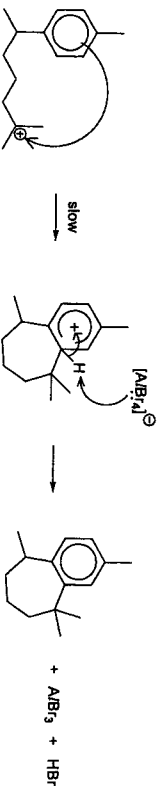
4 (b) (v) There are six equivalent H atoms on the terminal -CH₃ groups that can be substituted to produce R, therefore there is a high chance that the bromine radical will abstract one of those H atoms to produce the corresponding alkyl radical. [1]

4 (c) (i)



4 (c) (ii) The carbocation II has three electron-donating alkyl groups bonded to the positively charged carbon while carbocation I only has one. [1] Therefore, the positive charge in carbocation II is more dispersed, resulting in carbocation II being more stable. [1]

4 (c) (iii) electrophilic substitution [1]



4 (d) (i) hydrolysis [1]



OR

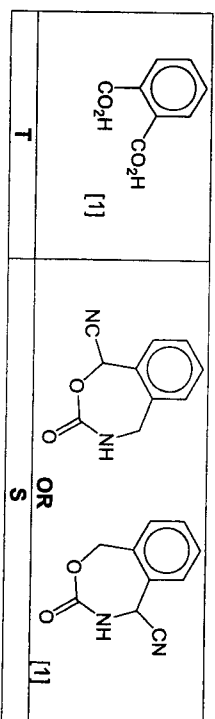


4 (d) (ii) The carbamate group contains an amide as well as an ester functional group, both of which are able to undergo hydrolysis. [1]

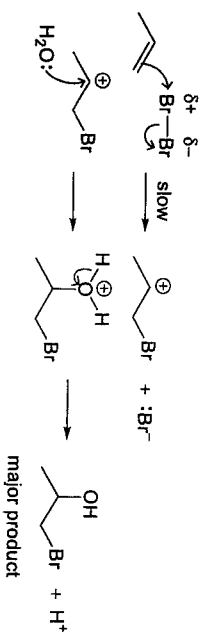
OR The carbamate C is very electron deficient and is able to attract the H₂O nucleophile.

4 (e) (i) nitrile [1]

4 (e) (ii)

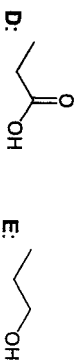


5 (a) (i)



[1] correct secondary carbocation and major product
[1] correct mechanism drawn

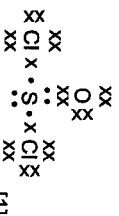
5 (a) (ii)



Step 1: aqueous I₂ in NaOH warm, followed by dilute H₂SO₄
Step 2: LiAlH₄ in dry ether
Step 3: excess concentrated H₂SO₄, heat

[3] for correct structures of D and E and reagents and conditions in each step.

5 (b) (i)



Shape: trigonal pyramidal, bond angle: 107° [1] for both correct

5 (b) (ii) pH of J is 0.5, H is 2.5 and G is 3.0. [1]

J undergoes hydrolysis in water to produce HCl, which is a strong acid. Therefore, it has the lowest pH. [1]

G and H are carboxylic acids, which are weak acids. The conjugate base of H is more stable than G due to presence of electronegative Cl atom, which withdraws electron density from the carboxylate ion, dispersing the negative charge, making H more acidic than G. [1]

J hydrolyses in water to produce Cl^- ion, forming AgCl white ppt. [1]

J undergoes hydrolysis more readily than **H** as the C-Cl carbon in **J** is much more electron deficient, having bonded to 2 highly electronegative atoms O and Cl, making it more susceptible to nucleophilic attack, than the C-Cl carbon in alkyl chloride **H**. [1]

5 (c) (i) $[\text{Cl}^-]$ in water sample = $0.0500 \times 21.60 / 25.0 = 0.0432 \text{ mol dm}^{-3}$ [1]

5 (c) (ii) $\text{IP} = (0.1 \times 0.05 / 25.1) (25 \times 0.0432 / 25.1) = 8.57 \times 10^{-6}$. [1]
Since $\text{IP} > K_{\text{sp}}$, precipitate will be formed. [1]

5 (c) (iii) $[\text{Ag}^+] = 10^{-4.87} = 1.349 \times 10^{-5} \text{ mol dm}^{-3}$
 $[\text{Cl}^-] = 1.80 \times 10^{-10} \div (1.349 \times 10^{-5}) = 1.33 \times 10^{-5} \text{ mol dm}^{-3}$ [1]

5 (c) (iv) Before point **E**, the Ag^+ added is used to precipitate AgCl continuously, hence the $[\text{Ag}^+]$ remains relatively the same, so pAg value decreases steadily. [1]

As it passes through point **E**, all AgCl ppt has been formed. Ag^+ added is not used to precipitate AgCl . $[\text{Ag}^+]$ increases quickly, causing pAg to decrease sharply. [1]

5 (c) (v) $\text{NH}_3(\text{aq})$ will form $[\text{Ag}(\text{NH}_3)_2]^+$ complex [1], consuming more Ag^+ , causing titre value to be larger, and hence larger calculated $[\text{Cl}^-]$. [1]



HWA CHONG INSTITUTION
2022 C2 H2 CHEMISTRY PRELIMINARY EXAM
SUGGESTED SOLUTIONS (PAPER 4)

1 (a) (i) 1m: Fill up Table 1.1

AND both ΔT correctly calculated
 AND all T & ΔT values to 1 d.p.

1m: student's $\frac{\Delta T_2}{\Delta T_1}$ within 1.8 – 2.2

(Typical result: $\Delta T_1 = 3.1^\circ\text{C}$ and $\Delta T_2 = 6.2^\circ\text{C}$, $\frac{\Delta T_2}{\Delta T_1} = 2.0$)

1 (a) (ii) 1m: Acid A is monobasic (not awarded if no explanation at all is given)

1m: Explanation based on comparison of ΔT for expt 1 vs. expt 2
 AND discussion of limiting/excess reactant and no. of moles of H_2O produced

Sample answer:

	$n(\text{OH}^-)$ /mol	$n(\text{A})$ /mol	$n(\text{H}^+)$ /mol	$n(\text{H}_2\text{O})$ formed /mol
If A monobasic	expt 1 0.06 (excess)	0.015	0.015 (limiting)	0.015
	expt 2 0.03 (stoch. amt)	0.03	0.03 (stoch. amt)	0.03
If A dibasic	expt 1 0.06 (excess)	0.015	0.03 (limiting)	0.03
	expt 2 0.03 (limiting)	0.03	0.06 (excess)	0.03

A is monobasic. The amount of water formed in experiment 2 is twice that in experiment 1. This means that twice the amount of heat is liberated; as total volume is the same in both experiments, this is reflected in ΔT for experiment 2 (6.2°C) being double that in experiment 1 (3.1°C). If A were dibasic, the amount of water formed in both experiments is the same, and the ΔT would be the same.

1 (a) (iii) 1m: Calculate heat change q (may use expt 1 or expt 2)

1m: Calculate ΔH_{neut} including – sign

Sample calculation:

$$\text{Heat change } q = 60 \times 1.00 \times 4.18 \times 6.2 = 1555 \text{ J}$$

$$n(\text{H}_2\text{O}) \text{ produced} = n(\text{NaOH}) \text{ reacted} = 1.50 \times \frac{20}{1000} = 0.03 \text{ mol}$$

$$\Delta H_{\text{neut}} = -\frac{1554.96}{0.03} = -51.8 \text{ kJ mol}^{-1}$$

1 (a) (iv) 1m: ΔT doubles

1m: So q doubles but will be divided by double the no. of moles of water produced, therefore no effect on ΔH_{neut}

1 (b) (i) 1m: 20.0 cm^3 FA 3 + 40.0 cm^3 FA 2, both volumes to 1 d.p.

AND ΔT correctly calculated
 AND student's ΔT within 4.5 – 5.5

(Typical result: $\Delta T_3 = 5.0^\circ\text{C}$)

1 (b) (ii) 1m: B is a weak base and compare ΔT for expt 3 (smaller) vs. expt 2

AND some energy is required to fully dissociate B (which was partially dissociated), resulting in less exothermic ΔH_{neut} , although same no. of moles of H_2O produced in expt 3 and expt 2.

2 (a) (i) 1m: Headers & units (for both time and titration recordings)

- Reject 'final volume' 'initial volume' 'amount'
- This mark is lost if final burette reading < initial or 50.00 used as initial

1m:

- transfer time in min & s to nearest whole number
- t_0 correctly calculated to 1 d.p.

1m:

- burette readings, volumes to nearest 0.05 cm^3 (2 d.p.)
- correct subtraction between final & initial burette readings

1m:

- transfer time for the first aliquot is within first 3 min of starting the reaction (accept up to 3min 59s = 3.9min)
- last aliquot not exceeding 25 min

1m: 5 sets of results

time	t_0 / min		Final Burette reading / cm^3	Initial Burette reading / cm^3	Vol of FA5 / cm^3
	min	s			
3	1	3.0	35.10	0.10	35.00
7	0	7.0	24.80	0.00	24.80
12	30	12.5	15.40	0.40	15.00
18	7	18.1	25.20	15.60	9.60
23	0	23.0	31.60	25.20	6.40

2 (a) (ii)

$$\text{gradient} = \frac{44.50 - 0}{0 - 14.5} = -3.0690 \approx -3.07 \text{ cm}^3 \text{ min}^{-1}$$

1m: Draw tangent at $t_d = 0.0$ min, tangent line must touch the curve at $t_d = 0.0$

1m: Read coordinates correctly ($\pm 1/2$ small square allowance)
AND Calculate gradient, include negative sign

2 (b) (ii) 1m:

$$\begin{aligned} \frac{-3.0690 \text{ cm}^3 \text{ MnO}_4^-}{1 \text{ min}} &= \frac{-3.0690}{1000} \text{ dm}^3 \times 0.0200 \text{ mol dm}^{-3} \\ &= -6.1379 \times 10^{-5} \\ &\approx -6.14 \times 10^{-5} \text{ mol min}^{-1} \end{aligned}$$

If absence of negative sign has already been penalised earlier, no further penalty here.

2 (b) (iii) $2\text{MnO}_4^- + 5\text{H}_2\text{O}_2 + 6\text{H}^+ \rightarrow \text{products}$

1m: $n(\text{H}_2\text{O}_2)$ decomposed per minute = $6.1379 \times 10^{-5} \times \frac{5}{2}$
 $= 1.5345 \times 10^{-4}$
 $\approx 1.53 \times 10^{-4} \text{ mol}$

1m:

$$\text{rate of change of } [\text{H}_2\text{O}_2] = \frac{-1.5345 \times 10^{-4}}{10/1000} = -0.0153 \text{ mol dm}^{-3} \text{ min}^{-1}$$

If absence of negative sign has already been penalised earlier, no further penalty here.

1m: sf for 1(a)(iii), 2(b) and units for 1(a)(iii)

2 (b) (iv)

Volume / cm^3	half-life / min
44.50 \rightarrow 22.25	8.0 - 0.0 = 8.0
22.25 \rightarrow 11.125	16.0 - 8.0 = 8.0

Agree. The half-lives are constant at 8.0 minutes. Since the $t_{1/2}$ are constant, it is a 1st order reaction with respect to H_2O_2 .

1m: Quote at least two half-life values or label on the graph

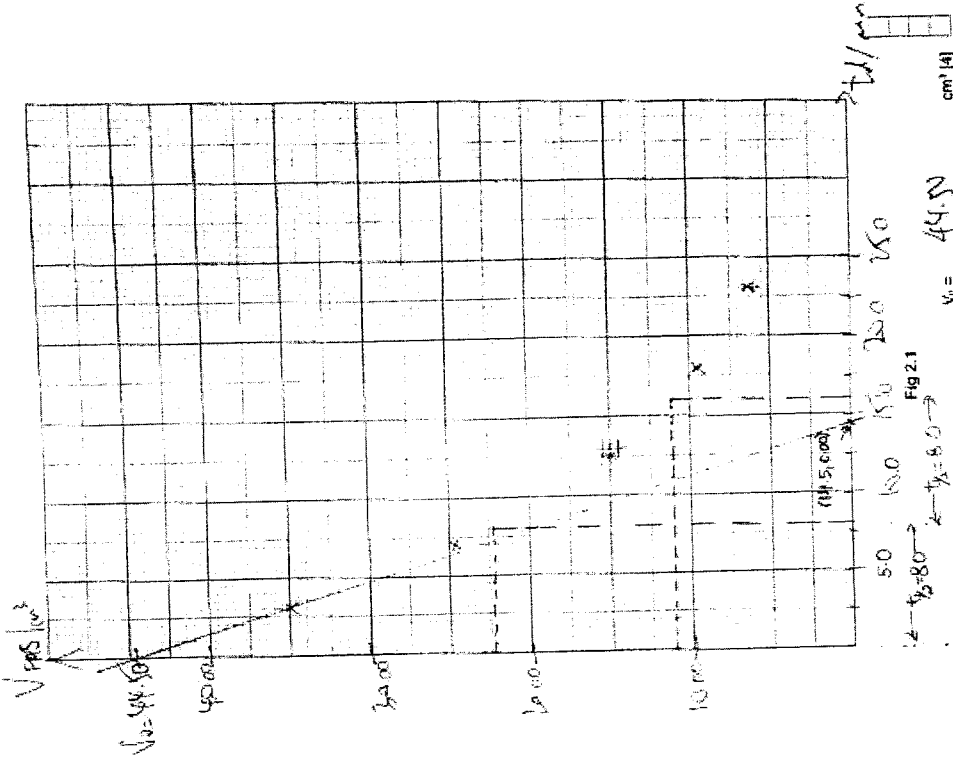
1m: Conclusion based on whether half-life is (approximately) constant or not

2 (c) (i) A brown solution was initially observed on adding orange $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$.

Then vigorous effervescence of a colourless gas which relights a glowing splint. The gas is O_2

An orange/yellow solution was observed at the end.

1/2 m for each underlined observation \Rightarrow 2m



1m:

- Label x & y axes including units
- Plotted points occupy at least 1/2 of graph grid in both x & y directions
- Reject awkward scale (e.g. 3:10)

1m: Plot all points ($\pm 1/2$ small square allowance)

1m: Draw best-fit smooth curve and extend it to $t_d = 0.0$ min

1m: Read V_0 correctly ($\pm 1/2$ small square allowance)

2 (c) (ii) 1m: Suggests $[\text{Fe}(\text{H}_2\text{O})_6(\text{O}_2\text{H})]^{2+}$ as the brown intermediate (accept $[\text{Fe}(\text{H}_2\text{O})_5\text{O}]^{3+}$) 1m: suggests orange/yellow $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ regenerated

2 (c) (iii) 1m: A brown intermediate was formed, showing that $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ participated in the catalysed pathway, as shown in step 1

1m: Vigorous effervescence of oxygen indicated an increase in the rate of reaction
1m: The catalyst was regenerated as seen by the return of the yellow/orange colour at the end and as shown in step 3

3 (a)

1. White solid dissolves to give a colourless solution.
2. Effervescence/bubbles of gas
3. Gas gives white ppt when bubbled through limewater. Gas is CO_2 .
4. Black residue
5. Colourless/pale pink/yellow filtrate
6. Filtrate gives off-white/light brown ppt with $\text{NaOH}(\text{aq})$
7. Ppt is insoluble in excess
8. Ppt rapidly turns brown on contact with air

1m for every two observations $\Rightarrow 4\text{m}$

3 (b) 1m: No more effervescence is observed when FA 8 is added.

3 (c) 1m: Oxidising agent, as ethanedioate/ethanedioic acid was oxidised to carbon dioxide.

3 (d) (i) 1m: Mn^{2+} , as off-white ppt rapidly turns brown on contact with air, insoluble in excess

3 (d) (ii) 1m: MnO_2

1m: FA 8 acted as an oxidising agent, so itself must have been reduced from a higher oxidation state of Mn to Mn^{2+} , and MnO_2 , the oxide with Mn in +4 oxidation state, has $M_r = 86.9$, which is less than 140.

4 (a) There are 10 marking points (M1 – M10)

No. of correct marking points	0–1	2–3	4–5	6–7	8–9	10
No. of marks scored	0	1	2	3	4	5

M1: Separate measuring cylinders (or burettes) to measure volume of each liquid (aqueous ethanoic acid, cyclohexane, deionised water).

M2: Shake the mixture in the separating funnel (or invert the separating funnel a few times to mix the liquids). Then leave the mixture to stand / to equilibrate / to separate into two layers.

M3: Mixture 1 contains 50 cm^3 aq. ethanoic acid and 50 cm^3 cyclohexane.

AND at least a total of four mixtures stating the volumes of aq. ethanoic acid, cyclohexane and deionised water.

(The top of pg 13 says 'Using the information given'. The bottom of pg 12 says 'using different volumes of aq. ethanoic acid, and adding water such that the total volume of the aq. and cyclohexane layers is kept constant'. So you should stick to 50 cm^3 cyclohexane for all mixtures.)

M4: Total volume of aq. layer and cyclohexane layer kept constant.
(M4 is lost if student mixed aq. ethanoic acid and water, never add cyclohexane / mixed water and cyclohexane, never add aq. ethanoic acid.)

M5: Turn the tap of the separating funnel to drain out most of the lower aqueous layer into a beaker.
(M5 is lost if student uses the wrong apparatus e.g. volumetric flask / conical flask to prepare the mixture. Please use separating funnel.)
(Some students poured aq. ethanoic acid/cyclohexane into a beaker/conical flask, then transferred the mixture into the separating funnel (instead of using the separating funnel directly). If you do this, some liquids will stay in the beaker/conical flask \Rightarrow loss of reagents \Rightarrow M5 lost.)

M6: Pipette out 10.0 cm^3 of the aqueous layer from the beaker (after M5).
(Reject use of dropping pipette here. The dropping pipette (it's actually just a plastic dropper) was used in Question 2 because the bubbling H_2O_2 makes it difficult to use a 10.0 cm^3 or 25.0 cm^3 glass pipette.)

M7: Place the 10.0 cm^3 aqueous aliquot into a conical flask.

M8: Add 2 or 3 drops of thymol blue to the aq. aliquot.

M9: Titrate the aq. aliquot with aq. NaOH from a burette.
AND record initial burette reading and final burette reading.

M10: Titrate until yellow turns green.
(The cyclohexane layer cannot be titrated with $\text{NaOH}(\text{aq})$. NaOH is an ionic compound, its OH^- ions have no favorable interactions with the non-polar cyclohexane molecules. So the OH^- ions will not 'enter' the organic solvent to react with the $\text{CH}_3\text{CO}_2\text{H}$ molecules.)

SAMPLE WRITE-UP:

The equilibrium mixtures to be prepared are stated below.

mixture	Volume /cm ³			Titration of 10.0 cm ³ aq. aliquot against NaOH(aq)		
	aq. ethanoic acid	deionised water	cyclohexane	Final burette reading /cm ³	Initial burette reading /cm ³	Volume of NaOH(aq) needed /cm ³
1	50	0	50			
2	40	10	50			
3	30	20	50			
4	20	30	50			
5	10	40	50			

- Use separate measuring cylinders to measure 50 cm³ of aq. ethanoic acid and 50 cm³ of cyclohexane. Add both liquids into the separating funnel.
- Stopper and shake the separating funnel to mix the liquids. Leave the separating funnel to stand for a few hours.
- Turn the tap of the separating funnel to drain out most of the lower aqueous layer into a beaker.
- Pipette 10.0 cm³ of the aqueous layer, from the beaker in step 3, into a conical flask. Add 2 or 3 drops of thymol blue indicator.
- Titrate the aqueous aliquot with (or against) the NaOH(aq) from a burette until the solution just changes from yellow to green. Record the initial and final burette readings.
- Repeat steps 1 to 2 to prepare the other four mixtures. Use a third measuring cylinder to measure the volume of deionised water. Then repeat steps 3 to 5 for the titration of the aqueous aliquot.

4 (b)

1m: n(NaOH) needed for titration

1m: [CH₃CO₂H] in aqueous layer

1m: subtraction working to obtain n(CH₃CO₂H) in cyclohexane layer including scale-up-working for n(CH₃CO₂H) in the aqueous layer

1m: [CH₃CO₂H] in cyclohexane layer

(equilibrium mixture 1: 50 cm³ aq. CH₃CO₂H + 50 cm³ cyclohexane)
(V cm³ NaOH(aq) needed for titration of 10.0 cm³ aq. layer)

$$n(\text{NaOH}) = \frac{V}{1000} \times 0.100 = a \text{ mol}$$

$$n(\text{CH}_3\text{CO}_2\text{H}) \text{ in } 10.0 \text{ cm}^3 \text{ aq. layer} = a \text{ mol}$$

$$[\text{CH}_3\text{CO}_2\text{H}] \text{ in aq. layer} = \frac{a}{10/1000} \text{ mol dm}^{-3}$$

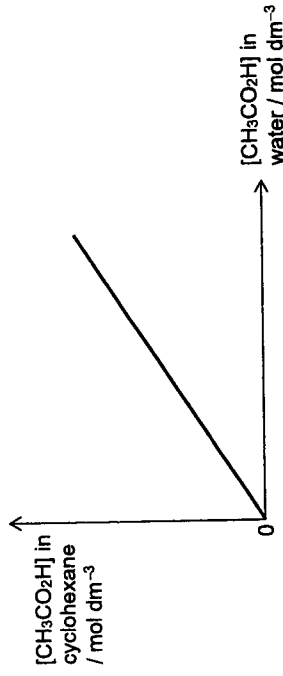
$$n(\text{CH}_3\text{CO}_2\text{H}) \text{ in } 50 \text{ cm}^3 \text{ aq. layer} = a \times \frac{50}{10} = b \text{ mol}$$

$$n(\text{CH}_3\text{CO}_2\text{H}) \text{ in the original } 50 \text{ cm}^3 \text{ aq. acid} = \frac{50}{1000} \times 0.250 = 0.0125 \text{ mol}$$

$$n(\text{CH}_3\text{CO}_2\text{H}) \text{ in cyclohexane layer} = 0.0125 - b \text{ mol}$$

$$[\text{CH}_3\text{CO}_2\text{H}] \text{ in cyclohexane layer} = \frac{0.0125 - b}{50/1000} \text{ mol dm}^{-3}$$

- 4 (c) (i)** 1m: draw a straight line, positive gradient, joins origin (steepness doesn't matter)



- 4 (c) (ii)** 1m: K = gradient of this line

4 (d)

1m: Ethanoic acid is a weak acid that ionises partially / dissociates partially in water to give CH₃CO₂⁻ and H⁺ ions.

(Reject 'hydrolyses' / 'hydrolysis')

or Ethanoic acid molecules may form dimers in the cyclohexane solvent. Therefore, the assumption is not entirely true.

NAME _____

CLASS 21S



JURONG PIONEER JUNIOR COLLEGE
JC2 PRELIMINARY EXAMINATION 2022

CHEMISTRY**9729/01****Higher 2****22 September 2022**

Paper 1 Multiple Choice

1 hour

Candidates answer on separate paper.

 Additional Materials: Multiple Choice Answer Sheet
 Data Booklet
READ THESE INSTRUCTIONS FIRST

Write in soft pencil.

Do not use staples, paper clips, glue or correction fluid.

Write your name, class and exam index number on the Answer Sheet in the spaces provided unless this has been done for you.

There are **thirty** questions on this paper. Answer **all** questions. For each question there are four possible answers **A, B, C or D**.Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet.**Read the instructions on the Answer Sheet very carefully.**

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.

Any rough working should be done in this booklet.

The use of an approved scientific calculator is expected, where appropriate.

This document consists of 13 printed pages.

Turn Over

2

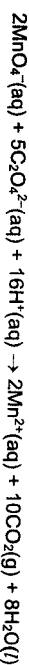
1 Use of the Data Booklet is relevant to this question.

The table shows the fourth, fifth, sixth, seventh, eighth and ninth ionisation energies of an element.

Which element has these ionisation energies values?

	4 th	5 th	6 th	7 th	8 th	9 th
Ionisation Energy / kJ mol ⁻¹	5900	7100	8700	11000	13500	42000

- A Si B P
 C Cl D Ar

2 Ethanedioate ions, C₂O₄²⁻, are oxidised by hot acidified, aqueous potassium manganate(VII) according to the following equation.What volume of 0.020 mol dm⁻³ potassium manganate(VII) is required to oxidise completely 1.0 x 10⁻³ mol of the salt K₂C₂O₄?

- A 20 cm³
 B 40 cm³
 C 50 cm³
 D 125 cm³

3 Propanone and dichloromethane are common organic solvents used in the laboratory. Propanone is soluble in water but dichloromethane is not.



propanone dichloromethane

Which of the following statements best accounts for this?

- A Propanone is a polar molecule but dichloromethane is non-polar.
 B A hydrogen bond forms between the hydrogen in propanone and the oxygen of a water molecule.
 C A hydrogen bond forms between the oxygen in propanone and the hydrogen of a water molecule.
 D Propanone has a smaller relative molecular mass than dichloromethane.

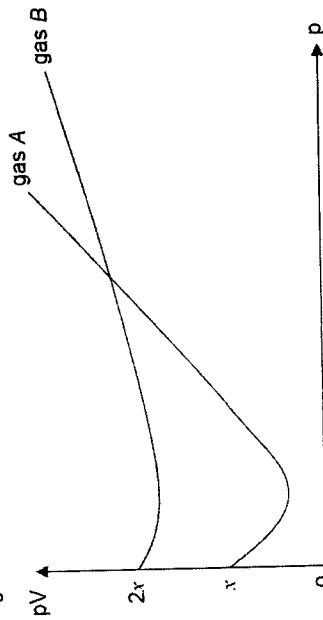
3

4 Nitrogen oxides (NO_x) can be formed from the reaction of nitrogen with oxygen in car engines. It can dissolve in water to form nitric acid which causes acid rain. Which of the following statements are correct?

- 1 N atom in NO_3^- is sp^2 hybridised.
- 2 NO and NO_2 contain an unpaired electron.
- 3 NO and NO_2 have no net dipole moment.

- A 1 only
- B 1 and 2
- C 2 and 3
- D 1, 2 and 3

5 The value of pV is plotted against p for 2 gases, A and B, where p is the pressure and V is the volume of the gas.



Which of the following could be identities of the gases?

- | | |
|-------------------------------------|------------------------------------|
| gas A | gas B |
| A 0.5 mol of CH_4 at 25 °C | 0.5 mol of CH_4 at 50 °C |
| B 0.5 mol of NH_3 at 25 °C | 0.5 mol of NH_3 at 323 °C |
| C 0.5 mol of CH_4 at 25 °C | 1 mol of NH_3 at 25 °C |
| D 1 mol of NH_3 at 25 °C | 0.5 mol of CH_4 at 25 °C |

4

6 Travellers to countries with cold climate may sometimes use heat packs to keep warm. One example is the sodium ethanoate heat pack. This consists of a supersaturated solution of sodium ethanoate and a small metal disc containing very small crystals of sodium ethanoate.

When the disc is broken, the small crystals of sodium ethanoate are released into the solution and act as nucleation sites to catalyse the crystallisation reaction of sodium ethanoate.

Which line gives the signs of ΔH , ΔS and ΔG for the overall process?

	ΔH	ΔS	ΔG
A	-	-	-
B	-	-	+
C	+	+	-
D	+	+	+

7 A student investigated the kinetics of the reaction between 1.00 mol dm^{-3} potassium iodide and 0.0500 mol dm^{-3} sodium peroxodisulfate.



The two reactants were mixed in the presence of a known amount of sodium thiosulfate and a few drops of starch. The time taken for an intense blue colour to be observed was recorded.

Experiment number	Volume used / cm^3			Time / s
	KI	$\text{Na}_2\text{S}_2\text{O}_8$	H_2O	
1	10.0	5.0	25.0	170
2	15.0	5.0	20.0	113
3	15.0	10.0	15.0	56.5
4	20.0	20.0	0.0	z

What is the value of z?

- A 11
- B 21
- C 85
- D 1360

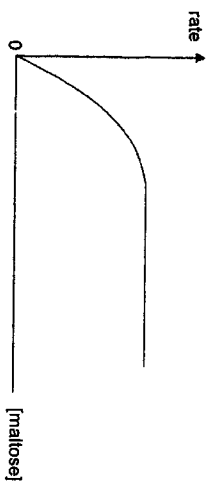
- 8 Gas A decomposes to two other gases, B and C, according to the equation:



Which of the following correctly describes what will happen if a proposed change is made to this system at equilibrium?

proposed change	value of K_c	position of equilibrium
A add inert solid	no change	shift left
B increase pressure	no change	shift right
C increase temperature	increase	shift right
D add catalyst	increase	no change

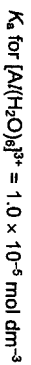
- 9 The graph shows the result of an investigation of the initial rate of hydrolysis of maltose by the enzyme amylase. In the experiments, the initial concentration of maltose was varied, but that of amylase was kept constant.



Which conclusions can be deduced from these results?

- When [maltose] is low, the rate is first order with respect to [maltose].
 - When [maltose] is high, the rate is independent of [maltose].
 - When [maltose] is high, the rate is independent of [amylase].
- A 1 only
 B 1 and 2 only
 C 2 and 3 only
 D 1, 2 and 3

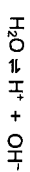
- 10 Aqueous solutions of aluminium salts are acidic. They contain $[Al(H_2O)_6]^{3+}$ ions.



What is the pH of $0.01 \text{ mol dm}^{-3} AlCl_3$?

- A 2.5 B 3.5 C 5.0 D 6.0

- 11 Pure water undergoes dissociation as shown in the equation below.

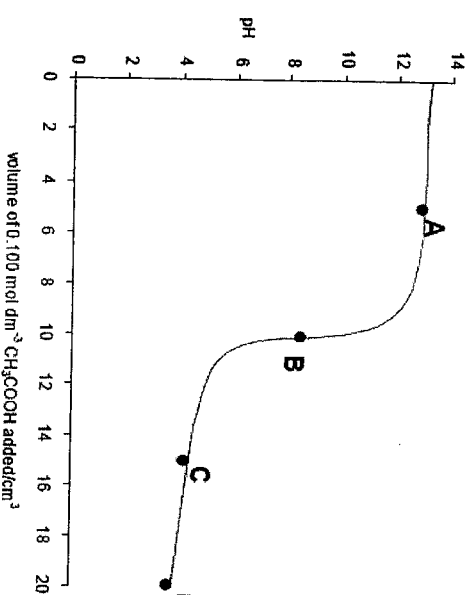


At $40^\circ C$, the $[H^+]$ is found to be $10^{-6.8} \text{ mol dm}^{-3}$.

Which of the following statements is **incorrect**?

- A The dissociation of water is an endothermic process.
 B Water is acidic at $40^\circ C$.
 C At $40^\circ C$, the value of pK_w is 13.6.
 D Both H^+ and OH^- ions are of the same concentration for pure water at $40^\circ C$.

- 12 The pH change when $0.100 \text{ mol dm}^{-3} CH_3CO_2H$ is added dropwise to 10.0 cm^3 of $0.100 \text{ mol dm}^{-3} KOH(aq)$ is given in the graph below.



At which point on the graph does $pH = pK_a$, where K_a is the acid dissociation constant of the weak acid?

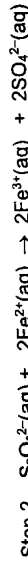
13 The use of Data Booklet is relevant to this question.

Peroxodisulfate ions convert iodide ions into iodine slowly.



The rate of the reaction can be increased by adding catalysts such as aqueous iron(III) ions.

A possible pathway of a catalyst reaction involves the following steps:

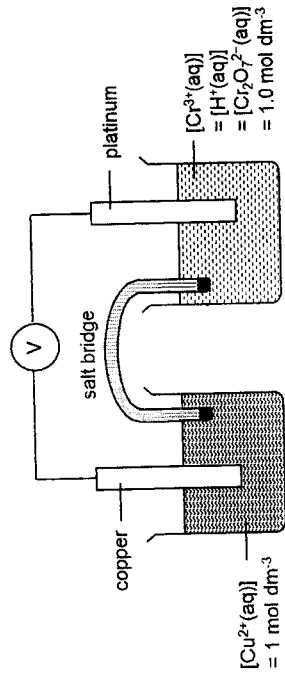


Which statement about the reaction is **incorrect**?

- A $S_2O_8^{2-}$ is a stronger oxidising agent than Fe^{3+} .
- B The reaction between $S_2O_8^{2-}$ and I^- is slow because the E°_{cell} value is small.
- C The E°_{cell} for step 2 is more positive than step 1.
- D Aqueous cobalt(II) ions can be used as a catalyst for this reaction.

14 Use of the Data Booklet is relevant to this question.

A cell is set up by connecting a Cu^{2+}/Cu half-cell and an acidified $Cr_2O_7^{2-}/Cr^{3+}$ half-cell under standard conditions.

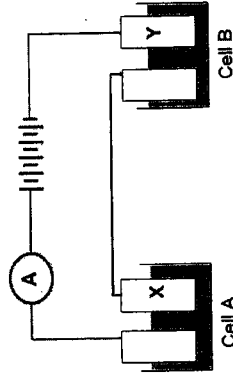


Which of the following correctly describes the effect on the e.m.f. of the cell when the respective change is made?

- | | |
|---|--------------------------|
| A using a larger copper electrode | effect on e.m.f. of cell |
| B addition of concentrated H_2SO_4 into reduction half-cell | Become more positive |
| C addition of dilute NaOH into oxidation half-cell | Become less positive |
| D addition of water into oxidation half-cell | Become more positive |

15 Use of the Data Booklet is relevant to this question.

A student carried out an experiment involving the electrolysis of aqueous copper(II) sulfate in cell A and aqueous chromium(III) sulfate in cell B.



Given that 6.35 g of copper was deposited at electrode X at the end of the experiment, what is the mass of chromium deposited at electrode Y?

- A 0.87 g
- B 1.74 g
- C 3.47 g
- D 10.4 g

16 The solubility product of a substance is S . If the concentration of the cation in a saturated solution is found to be $(\frac{9S}{4})^{\frac{1}{5}}$, what could be the substance?

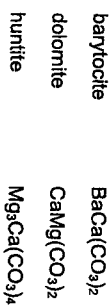
- A $CaCl_2$
- B $Ca_3(PO_4)_2$
- C $Al(OH)_3$
- D $Al_2(SO_4)_3$

17 Adding concentrated HCl to $CuSO_4(aq)$ causes the colour of the solution to change from blue to green.

Which of the following best explains this observation?

- 1 number of d-electrons in copper changes
- 2 energy gap between the d-orbitals changes
- 3 oxidation state of copper changes.
- A Only 1 is correct.
- B Only 2 is correct.
- C 1 and 2 are correct.
- D 1 and 3 are correct.

- 18 The three minerals below are obtained from mines around the world. Each one behaves as a mixture of two carbonate compounds. They can be used as fire retardants because they decompose in the heat, producing CO₂. This gas smothers the fire.



What is the order of effectiveness as fire retardant, from best to worst?

best → worst

- | | | |
|------------|-------------|-------------|
| A dolomite | barytoctite | huntite |
| B dolomite | huntite | barytoctite |
| C huntite | dolomite | barytoctite |
| D huntite | barytoctite | dolomite |

- 19 When aqueous potassium fluoride is added to an aqueous solution of iron(III) chloride, the yellow solution decolorises. No colour change is observed when aqueous ammonium thiocyanate is added to the resulting solution. However, when aqueous sodium cyanide is added, the colourless solution turns red.

complex	[Fe(H ₂ O) ₆] ³⁺	[Fe(H ₂ O) ₅ SCN] ²⁺	[Fe(H ₂ O) ₅ SCN] ²⁺	[Fe(CN) ₆] ³⁻
colour	yellow	colourless	blood red	red

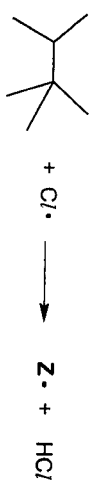
In which sequence are the ligands listed in order of increasing ligand strength?

- A F⁻ < SCN⁻ < CN⁻
 B SCN⁻ < F⁻ < CN⁻
 C F⁻ < CN⁻ < SCN⁻
 D CN⁻ < F⁻ < SCN⁻

- 20 What is the total number of different isomers that can be produced when 2-methylpentan-3-ol is heated with an excess of concentrated sulfuric acid?

- A 1
 B 2
 C 3
 D 4

- 21 Compound **W** undergoes free radical substitution with chlorine. The equation below represents one of the propagation steps, where the free radical **Z•** is formed by the loss of a hydrogen atom.

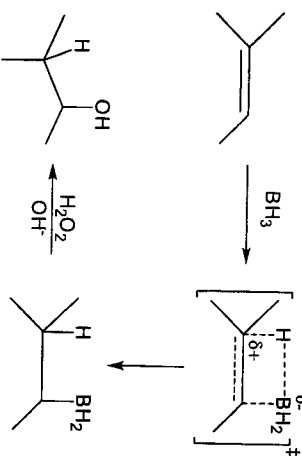


compound **W**

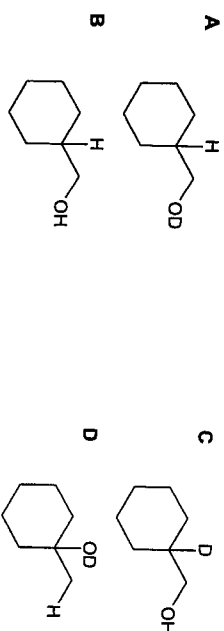
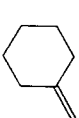
What is the total number of different mono-substituted radicals **Z•** that can be formed?

- A 2
 B 3
 C 4
 D 5

- 22 Hydroboration is a method of preparing alcohols from alkenes in an anti-Markovnikov manner. The reaction involves the formation of a four-membered cyclic transition state, where the partial positive charge is carried on the more highly substituted carbon. The alkylborane undergoes redox reaction with hydrogen peroxide to form an alcohol.

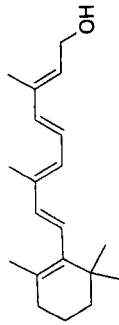


Which of the following will be obtained if the following compound **Y** is subjected to hydroboration using BD₃ followed by H₂O₂ and OH⁻? (D = ²H)



- 23 Vitamin A₁ is a fat-soluble vitamin that can be found in food. It is used as a supplement to treat and prevent vitamin A deficiency, and to reduce the risk of complications in measles patients.

The structure of Vitamin A₁ is given below:

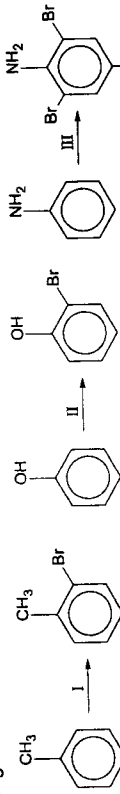


Which statements regarding Vitamin A₁ is/are correct?

- 1 When Vitamin A₁ is treated with cold alkaline KMnO₄, the product has a total of 2¹⁰ isomers.
- 2 3 different organic compounds are formed when Vitamin A₁ is treated with hot acidified KMnO₄.
- 3 2 mol of CO₂ gas is produced when Vitamin A₁ is treated with hot acidified KMnO₄.

- A Only 1
B Only 2
C 1 and 2
D 1, 2 and 3

- 24 Methylbenzene, phenol and phenylamine all undergo electrophilic substitution with suitable reagents.



Which of the following gives the correct reagent and condition for reactions I, II and III?

- | | I | II | III |
|---|-------------------------------------|-------------------------------------|-------------------------------------|
| A | Br ₂ , Fe | Br ₂ in CCl ₄ | Br ₂ (aq) |
| B | Br ₂ , FeBr ₃ | Br ₂ (aq) | Br ₂ in CCl ₄ |
| C | Br ₂ (aq) | Br ₂ in CCl ₄ | Br ₂ , Fe |
| D | Br ₂ in CCl ₄ | Br ₂ , FeBr ₃ | Br ₂ (aq) |

- 25 Putrescine is used in the production of Nylon-4,6. It can be synthesised from ethene by the following reactions.



Which of the following gives the correct reagents and conditions for steps I to III?

- | | I | II | III |
|---|----------------------------------|-----------------------|--------------------------------|
| A | Br ₂ | KCN in ethanol, heat | H ₂ , Ni, heat |
| B | Br ₂ | HCN, trace NaCN, cold | LiAlH ₄ , dry ether |
| C | cold, alkaline KMnO ₄ | KCN in ethanol, heat | LiAlH ₄ , dry ether |
| D | cold, alkaline KMnO ₄ | HCN, trace NaCN, cold | H ₂ , Ni, heat |

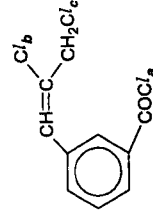
- 26 Compound P, C₃H₈O₂, is an alcohol containing two -OH groups per molecule. It can be oxidised in stages to compound Q, C₃H₆O₂, which reacts with 2,4-dinitrophenylhydrazine but not with Fehling's solution. Compound Q is then further oxidised to R, C₃H₄O₃ which reacts with aqueous sodium carbonate.

Which of the following about the properties of P, Q and R is correct?

contains at least one chiral centre gives positive iodoform test

- A P, Q and R P only
B Q only P and Q
C P only P, Q and R
D P and Q Q and R

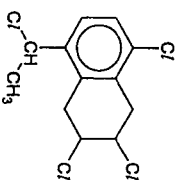
- 27 The diagram below shows an aromatic organic compound that contains 3 chlorine atoms labelled a, b, and c respectively.



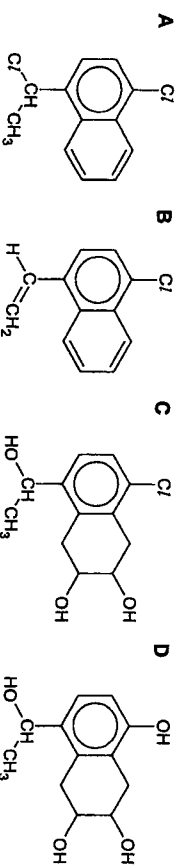
Which gives the correct order of the Cl atoms based on their decreasing ease of hydrolysis?

- A a, b, c
B a, c, b
C b, a, c
D b, c, a

- 28 Which of the following represents the structure of the organic product when compound Y is heated with ethanolic NaOH?



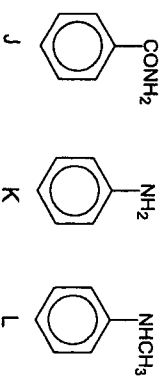
Compound Y



- 29 Which of the following will produce solutions of increasing pH when equimolar quantities of the organic compounds are separately dissolved in water?

- A ethanamide, ethanoic acid, ethanoyl chloride
 B ethanamide, ethanoyl chloride, ethanoic acid
 C ethanoic acid, ethanoyl chloride, ethanamide
 D ethanoyl chloride, ethanoic acid, ethanamide

- 30 The diagram below shows 3 common organic nitrogen compounds.



Which of the following shows the correct order of increasing basicity of these compounds?

- A J, K, L
 B J, L, K
 C K, L, J
 D K, J, L

End of paper

