HWA CHONG INSTITUTION
2022 C2 H2 CHEMISTRY PRELIMINARY EXAM
SUGGESTED SOLUTIONS (PAPER 2)

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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) $pV = nRT$

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

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

1 (b) (ii) Amount of $SO_2 = 0.0183 \div 64.1$
$= 2.85 \times 10^{-4}$ 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 $= [(2.85 \times 10^{-4} \times L) \div (6.48 \times L)] \times 1 \times 10^6$
$= 44.1$ 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)(i)**). (**[–0.5]** if comparison is correct but answer in ppm is absent)

1 (c)

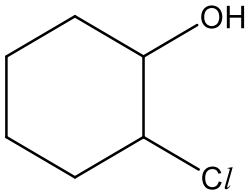
- SO_3 dissolves in water in a **violent / very exothermic** reaction
- forming a strongly acidic solution around **pH 1**
- $SO_3(l) + H_2O(l) \rightarrow H_2SO_4(aq)$

- 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

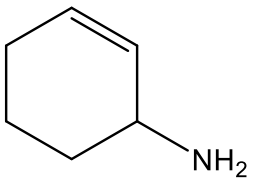
2 (a) (i) Intermediate **A**



[1], step 1: $Cl_2(aq)$ **[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**



[1]

2 (a) (ii) The $–C^yO_2H$ is nearer the electron withdrawing amine group, that better disperses the negative charge on the conjugate carboxylate ($–C^yO_2^–$), stabilising this conjugate carboxylate more, this makes the $–C^yO_2H$ 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 $–C^yO_2H$ than to $–C^xO_2H$ (compares distance)
- amine group is electron withdrawing
- negative charge on the conjugate base ($–C^yO_2^–$) is better dispersed
- conjugate base of $–C^yO_2H$ is more stable (than that of $–C^xO_2H$)

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 MSG = 183
Amount of Na^+ in 1 g of MSG = $1 \div 183 = 5.46 \times 10^{-3}$ mol **[1]**

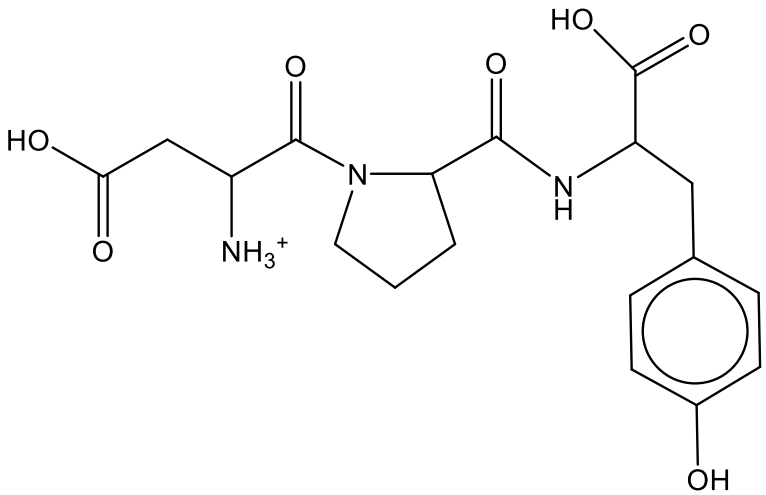
Relative mass of NaC*l* = 58.5
Amount of Na^+ in 1 g of NaC*l* = $1 \div 58.5 = 1.71 \times 10^{-2}$ mol **[1]**

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

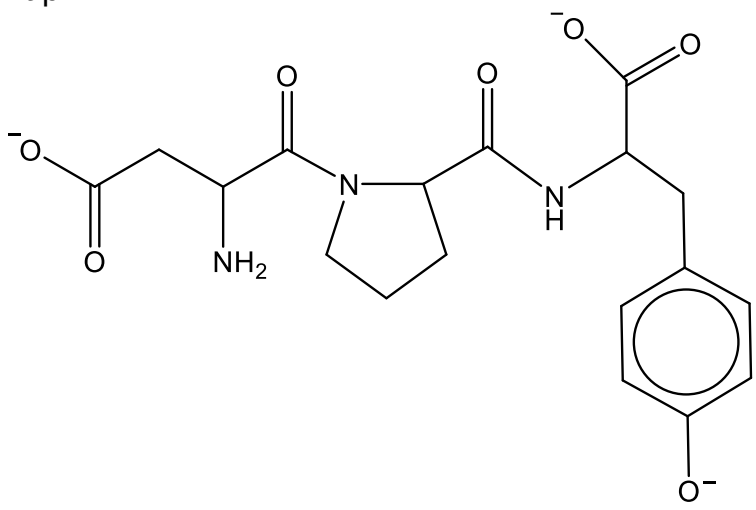
OR correct calculations of percentage by mass OR actual mass of Na^+ ions

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^x and N^y 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 = $0.100 \times 20 \div 10 = 0.200$ mol dm^{-3} **[1]**

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

Assume that x << 0.200,

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

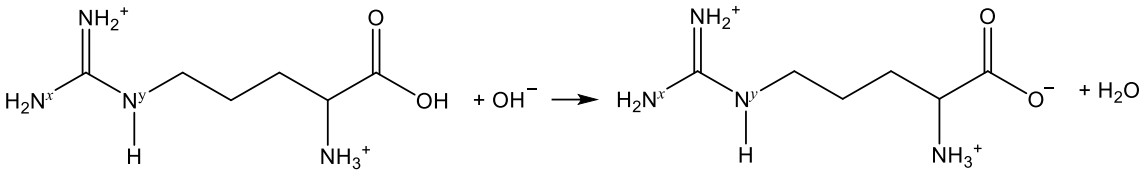
$x = [H^+] = 0.03677$ mol dm^{-3}

$pH = -\lg 0.03677 = 1.43$

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)



[1]

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 $[H^+] = K_a \times$ [acid]/[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 **<u>there are more ways to distribute energy</u>** since there is an increase in the amount of aqueous species in the solution. The entropy change is large as **<u>the amount of products is significantly greater than the amount of reactants</u>** 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) $\Delta G^{\ominus}_r = \Delta H^{\ominus}_r - T\Delta S^{\ominus}_r$
$= -17.0 - 298(121/1000)$
$= -53.1$ kJ mol^{-1} **[1]**

4 (b) (iii) $\Delta G^{\ominus}_r$ is a negative number, this shows that the **<u>position of equilibrium lies to the right</u>** i.e. it is product favoured. Thus, **<u>ethane-1,2-diamine binds preferentially</u>** 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)

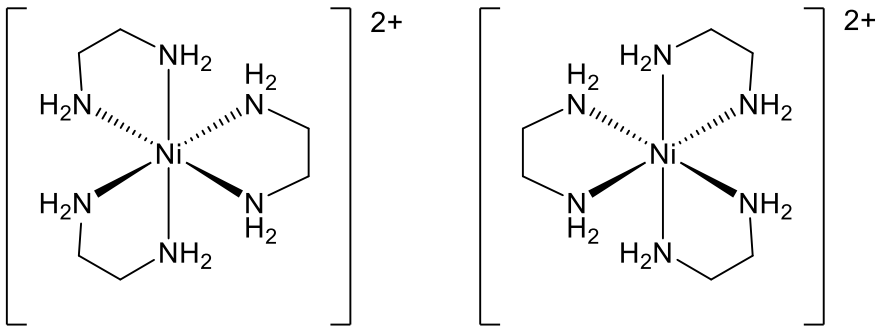
4 (b) (iv) The coordination of the first $-NH_2$ group is an intermolecular reaction, but **the second coordinate bond is an intramolecular reaction**, which occurs much more quickly than an intermolecular reaction. (or other words to that effect)

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 en ligands is faster. (or other words to that effect)

[1] for a suitable explanation using Collision Theory

4 (c) (i)



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

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

OR

$[Ni(en)_3]^{2+}$ is chiral because it has **<u>no internal plane of symmetry</u>**.

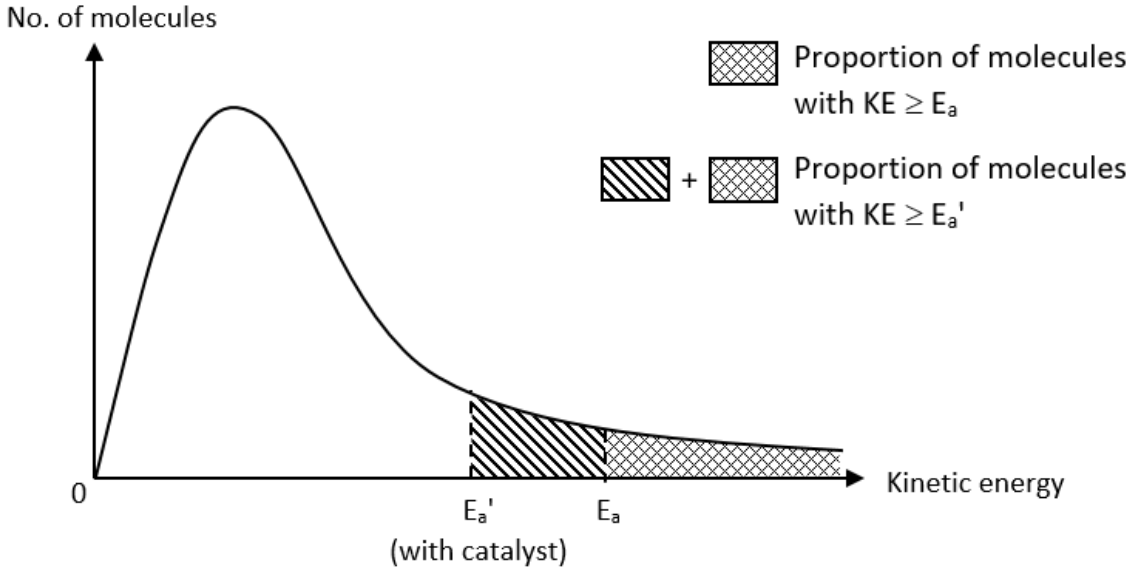
[1]

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

5 (a) (i)



[1] diagram (–½ m per mistake in axes labels, starting from origin, single curve)

A catalyst **provides an <u>alternative reaction pathway</u> which requires a <u>lower activation energy</u> (E_a') than the uncatalysed reaction (E_a). [½]**

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

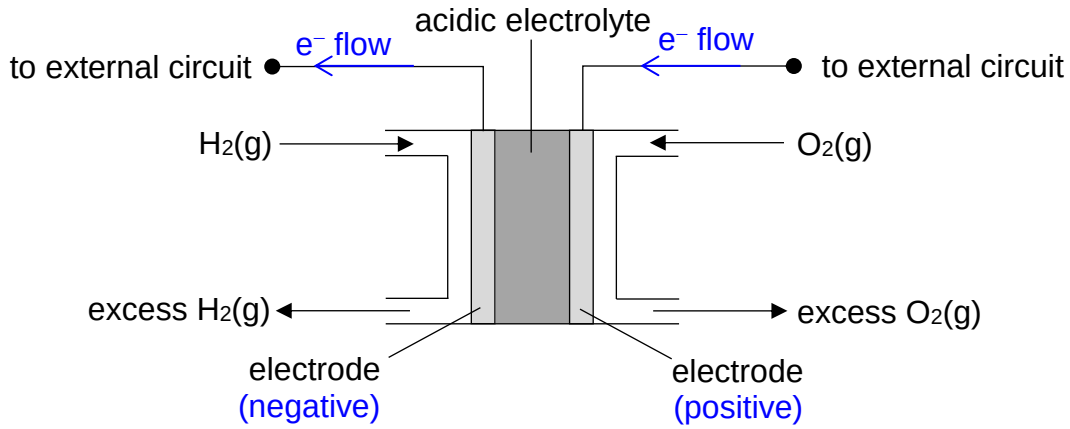
5 (a) (ii) [1] $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ 4s^2$

5 (a) (iii)

	homogeneous catalysis	heterogeneous catalysis
balanced equation for catalysed reaction	$2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$ or $2H_2O_2 \rightarrow 2H_2O + O_2$ **[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 <u>variable oxidation states</u> / relative ease of interconverting between different oxidation states **[1]**	Fe has <u>partially filled 3d orbitals</u> (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 <u>in the wires</u>

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]** $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$ (0m if no state symbols)

$E^\ominus(O_2/H_2O) = +1.23V$ is less positive than $E^\ominus(H_2O_2/H_2O) = +1.77V$.
Hence, H_2O should be preferentially oxidised to O_2, so this competing reaction is more likely to occur.

[1] quote standard <u>reduction</u> potentials
[1] compare standard reduction potentials + conclusion

5 (c) (ii) **[1]** $2Ce^{4+} + H_2O_2 \rightarrow 2Ce^{3+} + 2H^+ + O_2$

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

$E^\ominus_{cell} = E^\ominus(Ce^{4+}/Ce^{3+}) - E^\ominus(O_2/H_2O_2)$
$E^\ominus(Ce^{4+}/Ce^{3+}) = 0.930 + (0.68) = +1.61$ V **[1]** ecf from calculated $E^\ominus_{cell}$

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

Theoretical $n(H_2O_2)$ formed $= 3.7306 \times 10^{-6} \div 2 = 1.8653 \times 10^{-6} \approx 1.87 \times 10^{-6}$ mol **[1]**

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

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

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

5 (c) (vii) $n(H_2O_2)$ in 100 cm^3 electrolyte
$= 2.9453 \times 10^{-6} \div 2$ (based on $n(Ce^{4+})$: $n(H_2O_2)$ in **(c)(ii)**
$= 1.47265 \times 10^{-6}$
$\approx 1.47 \times 10^{-6}$ mol **[1]** sf, units assessed

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