2025 Y6 H2 Chemistry Preliminary Exams Paper 1 – Suggested Solutions

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Answer	A	D	C	C	B	D	C	B	B	A	D	B	A	A	C

Question	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Answer	C	B	C	B	D	B	D	B	C	A	C	D	A	D	A

MCQ worked solutions

Q1 **(Ans: A)**

The $^{37}Cl^+$ ion has 37 nucleons which comprise 17 protons and 20 neutrons.
It has one positive charge (having lost one electron) and hence it has a total of 16 electrons.

Q2 **(Ans: D)**

angle of deflection $\propto \left|\frac{q}{m}\right|$
For $^{17}O^+$, $\left|\frac{q}{m}\right| = \frac{1}{17}$ (= 0.0588)
For $[^{16}O^{18}O]^{2-}$, $\left|\frac{q}{m}\right| = \frac{2}{(16+18)} = \frac{1}{17}$ (= 0.0588)
Hence $[^{16}O^{18}O]^{2-}$ will be deflected to the same extent as $^{17}O^+$.
Option 1 is incorrect.

Option 2 is correct since positively charged species will deflect in an opposite direction to negatively charged species.

Each beam of charged particles will travel in a curved path, not a straight path.
Option 3 is incorrect.

Q3 **(Ans: C)**

The cis-isomer (Q) has a higher boiling point as it has a net dipole moment and has permanent dipole-permanent-dipole interactions, whereas the trans-isomer (P) is non-polar.

R has instantaneous dipole-induced dipole interactions, as well as the smallest electron cloud and hence has the weakest interactions amongst the three. Thus, it has the lowest boiling point.

Correct order of increasing boiling point: R < P < Q.

Q4 **(Ans: C)**

BeF_2 acts as a Lewis acid (as NH_3 donates its lone pair to Be to form $H_3N \rightarrow BeF_2$).
A is incorrect.

It is tetrahedral around the N atom in $BeF_2 \bullet NH_3$, hence the molecule is not planar.
B is incorrect.

In BeF_4^{2-}, two F^- ions form one co-ordinate bond each with BeF_2.
C is correct.

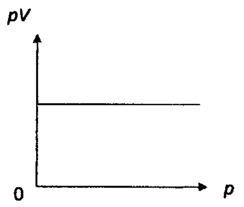
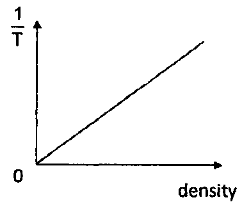
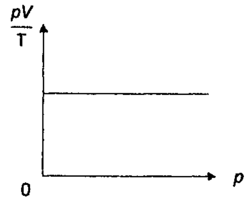
It is possible for the lone pair on F to form a hydrogen bond with the H in H_2O.
D is incorrect.

Q5 **(Ans: B)**

$pV = nRT$
$p = \frac{1}{V}(nRT)$

Since n, R and T are constants,
$p = \frac{1}{V}(k)$

Hence graph is $y = kx$ *(straight line that passes through origin)*

Option A	Option C	Option D
$pV = nRT$ Since n, R and T are constants, pV = constant at a particular T  	$pV = nRT$ $p = \frac{mass}{MV}RT$ $= density(\frac{RT}{M})$ $\frac{1}{T} = density(\frac{R}{Mp})$ Since R, M and p are constants, $\frac{1}{T}$ = density(k)  	$pV = nRT$ $\frac{pV}{T} = nR$ Since n and R are constants, $\frac{pV}{T}$ = constant at a particular n 

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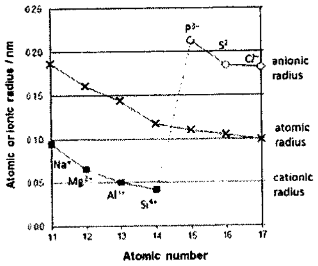
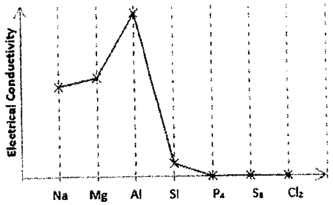
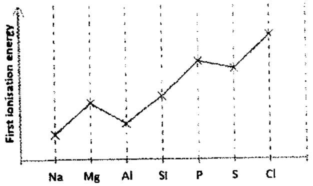
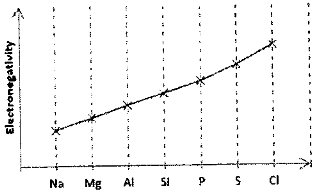
Q6 **(Ans: D)**

element	identity
X	Si
Y	Na
Z	P

<table>
<tr><td>✗</td><td>A</td><td>Y (Na) has a smaller atomic radius than Z (P)
 </td></tr>
<tr><td>✗</td><td>B</td><td>Y (Na) has a lower electrical conductivity than X (Si)
 </td></tr>
<tr><td>✗</td><td>C</td><td>X (Si) has a higher first ionisation energy than Z (P)
 </td></tr>
<tr><td>✓</td><td>D</td><td>X (Si) has a higher electronegativity value than Y (Na)
 </td></tr>
</table>

Q7 **(Ans: C)**

A	$E^\ominus$ value becomes more negative down the Group. $M^{2+}(aq) + 2e \rightleftharpoons M(s) \quad E^\ominus$ The tendency of backward reaction occurring increases, hence reducing power of metal increases.
B	The reactivity of Group 2 elements increases down the group as the ease of Group 2 elements losing electrons increases down the group.
C	Cationic radius increases down the Group, resulting in a lower charge density and weaker polarising power of the cations. Consequently, there is decreasing extent of distortion of the electron cloud of the CO_3^{2-} anion and hence decreasing extent of weakening of covalent bonds within the CO_3^{2-} anion. More heat energy is required to break the covalent bonds within the CO_3^{2-} anion, causing the decomposition temperature to increase. Hence, the thermal stability of the Group 2 carbonates increases.
D	As cationic radius increases down the Group, $\left\|\Delta H^\ominus_{hyd}[M^+(g)]\right\| \propto \left\|\frac{q_+}{r_+}\right\|$ the magnitude of the enthalpy of hydration of the metal ion decreases.

Q8 **(Ans: B)**

Let the nitrogen-containing compound be X. Since the mole ratio of NO_2 to HNO_3 is 3:2, the remaining N atom is in X. Hence, the redox equation involving only the N compounds is:

$$3\ NO_2 \rightarrow X + 2\ HNO_3$$

2 moles of NO_2 (where N has an oxidation state of +4) is oxidised to 2 moles of HNO_3 (where N has an oxidation state of +5) by the **loss of $2e^-$**.

Therefore, the remaining 1 mole of NO_2 **gains $2e^-$** when it is reduced to 1 mole of X. Thus, the oxidation of N in X is +2. Hence, X is NO.

Alternatively, the redox equation can be balanced by stoichiometry to deduce the identity of X.

Q9 **(Ans: B)**

$$A_r \text{ of Cr} = \frac{(4.3)(50) + (83.8)(52) + (9.5)(53) + (2.4)(54)}{(4.3 + 83.8 + 9.5 + 2.4)} = 52.06 = 52.1$$

Note that the sum of the relative abundances may not always add up 100. Hence, it's necessary to divide the numerator by the sum of the relative abundances given.

Q10 **(Ans: A)**

✓	1	Sublimation requires energy to overcome the attractive forces holding the particles together in a solid state to change into a gaseous state.
✗	2	The combustion of all fuels is always exothermic.
✗	3	The formation of ion-dipole interactions releases energy, making the process exothermic.

Q11 **(Ans: D)**

Theoretical lattice energy can be calculated using

$$|\text{lattice energy}| \propto \left|\frac{q_+q_-}{r_+ + r_-}\right|$$

which assumes a 100% ionic nature. The discrepancy between the experimental and theoretical lattice energies shows the presence of covalent character in the bonding in the silver halides, arises due to substantial polarisation of the anion by the cation. Since the anionic radius increases down the Group, the polarisability of the anion increases, causing a greater degree of covalency and hence greater deviation of the experimental from the theoretical value.

Q12 **(Ans: B)**

A possible method to solving this question without an energy cycle is to use the algebraic method (refer to section 4.7 of your lecture notes for Energetics Part 1).

	enthalpy change / kJ mol^{-1}
$\cancel{Ba(s)} + O_2(g) \longrightarrow \cancel{BaO_2(s)}$	s
$\cancel{BaO_2(s)} \longrightarrow \cancel{Ba^{2+}(g)} + O_2^{2-}(g)$	−q
$\cancel{Ba^{2+}(g)} + 2e^- \longrightarrow \cancel{Ba(g)}$	−p
$\cancel{Ba(g)} \longrightarrow \cancel{Ba(s)}$	−r
$O_2(g) + 2e^- \longrightarrow O_2^{2-}(g)$	s – q – p – r

Q13 **(Ans: A)**

Statement A is correct. Adding a catalyst to increase the rate of reaction increases the value of the rate constant (by decreasing the activation energy).

Statement B is incorrect. In autocatalytic reactions, the concentration of the catalyst increases as the products are formed, thus increasing the rate of reaction initially. However, as the concentration of the reactants decrease, the rate of reaction also decreases.

Statement C is incorrect. Heterogeneous catalysts are in a different phase from the reactant molecules.

Statement D is incorrect. In enzyme-catalysed reactions, increasing the concentration of the substrate increases the rate of the reaction until all the active sites are saturated, after which, the concentration of the substrate has no effect on the rate of the reaction.

Q14 **(Ans: A)**

At constant temperature, pressure is directly proportional to concentration,
since pV=nRT => $\frac{p}{RT} = \frac{n}{V}$ => $p \propto \frac{n}{V}$.

At very low pressures of A, the k_2[A] term in the denominator becomes negligible in comparison with the k_3 term.

$$\text{rate} = \frac{k_1k_3[A]^2}{k_3} = k_1[A]^2$$

Hence, the rate equation is second order with respect to A.

At very high pressures of A, the k_3 term in the denominator becomes negligible in comparison with the k_2[A] term.

$$\text{rate} = \frac{k_1k_3[A]^2}{k_2[A]} = \frac{k_1k_3}{k_2}[A]$$

Hence, the rate equation is first order with respect to A.

Q15 **(Ans: C)**

The end-point volume, V, is independent of temperature as it depends only on the concentrations of HA and NaOH.

The pH at $\frac{1}{2}V$ is equal to the pK_a of the weak acid, HA. As pK_a is affected by temperature, its value will decrease at a higher temperature (as the dissociation of the weak acid is endothermic). Hence, the pH at $\frac{1}{2}V$ also decreases.

Q16 **(Ans: C)**

When solid $CuSO_4$, which is soluble in water, is added to the saturated solution of $PbSO_4$, the increase in concentration of the common ion SO_4^{2-} causes the equilibrium position of the dissolution of $PbSO_4$ to shift left and the solubility of $PbSO_4$ decreases. Thus, $PbSO_4$ will precipitate in the mixture.

Q17 **(Ans: B)**

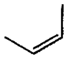
For step 1, using CH_3Cl, $AlCl_3$ catalyst will produce methylbenzene, whereas using conc. H_2SO_4, conc. HNO_3, heat will produce nitrobenzene. As the methyl group is 2-directing while the nitro group is 3-directing, the 2-directing methyl group is preferred as the subsequent group is added to the 2-position.

For step 2, nitration is done before the side-chain oxidation of the methyl group as it is directed to the 2-position relative to the methyl group. If the methyl group were oxidised to the carboxyl group, it will be 3-directing instead.

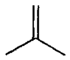
Hence, the set of reagents and conditions that will give the highest yield of the product is option B.

Q18 **(Ans: C)**

Other than chain isomers (straight-chain and branched), there are also functional group isomers (saturated cycloalkane and alkene), as well as stereoisomers (cis-trans).





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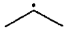
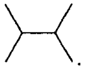
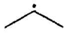
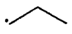
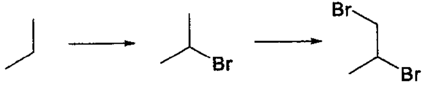
Q19 **(Ans: B)**

Option 1 cannot be formed from two  radicals. Instead, the correct structure is .

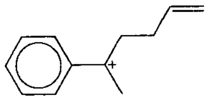
Option 2 cannot be formed from combining  and  radicals.

Option 3 is correct as it can be formed from multiple free-radical substitution steps.

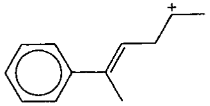


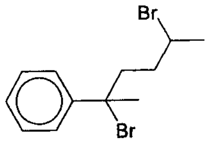
Q20 **(Ans: D)**

The tertiary carbocation is more stable than the secondary carbocation, which is more stable than the primary carbocation. Hence, the more stable intermediates of the reaction are



and

.

This in turn will give rise to the product .

Q21 **(Ans: B)**

Statement 1 is correct as rotation of plane-polarised light is due to the presence of chiral molecules and a sample that can rotate plane-polarised light is optically active.

Statement 2 is correct as a racemic mixture has equal proportions of both enantiomers, and the enantiomers are chiral molecules. However, a racemic mixture is not optically active as there is no net rotation of plane-polarised light.

Q22 **(Ans: D)**

Option D is correct as chlorine is more electronegative than bromine and the alcohol in option D has two chlorine atoms present. Both chlorine atoms can disperse the negative charge in the conjugate base of the alcohol to a greater extent and thus stabilising the conjugate base to a greater extent.

Q23 **(Ans: B)**

Option B is correct as R–X does not undergo nucleophilic substitution with aqueous NaOH as there is no heating. NaOH will undergo acid-base reaction with carboxylic acid functional group but not the alcohol functional group.

Q24 **(Ans: C)**

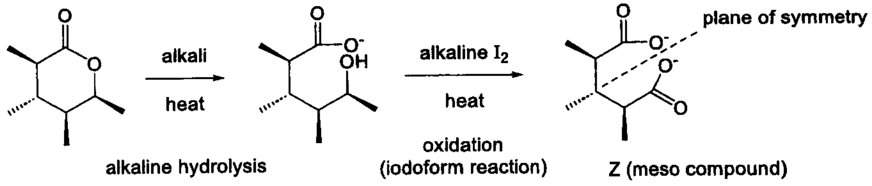
Option A is incorrect as the aldehyde functional group in both S and T will be oxidised by $K_2Cr_2O_7$ to form carboxylic acid.

Option B is incorrect as the aldehyde and ketone functional groups in both S and T will react with 2,4-DNPH.

Option C is correct as only the aliphatic aldehyde functional group in S can be oxidised by Fehling's reagent to give a brick red precipitate while the ketone and aromatic aldehyde functional groups in T do not.

Option D is incorrect as the aliphatic and aromatic aldehyde functional groups in both S and T respectively will react with Tollens' reagent to form silver mirror.

Q25 **(Ans: A)**



Option A is correct as Y first undergoes alkaline hydrolysis (due to the presence of alkali and heating) to give the carboxylate and alcohol functional group. The $-CH(OH)CH_3$ group then undergoes oxidation (iodoform reaction) to form Z which has chiral centres but also a plane of symmetry (meso compound).

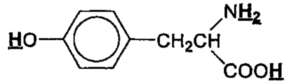
Option B is incorrect as there are four oxygen atoms in Z due to the subsequent oxidation (iodoform reaction).

Option C is incorrect as there is no –OH or –COOH group in Z to react with sodium metal to cause effervescence.

Option D is incorrect as there is no H atom which is directly bonded to highly electronegative O atom in Z.

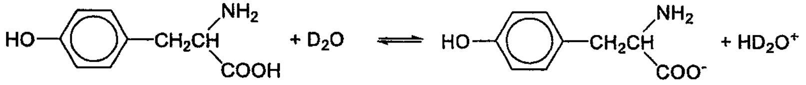
Q26 **(Ans: C)**

The H atoms in tyrosine which could be replaced by deuterium atoms are shown in bold and underlined.

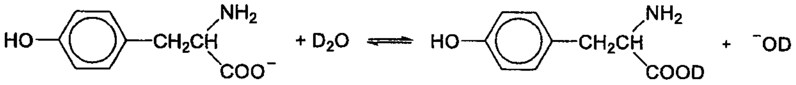


For phenol and –COOH
In D_2O solvent, the phenol and –COOH groups can lose H^+ to form the respective conjugate bases.

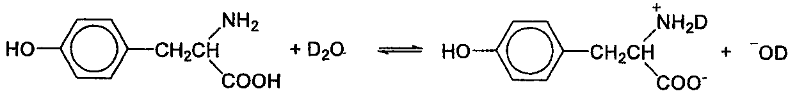
Using the COOH group as an example,



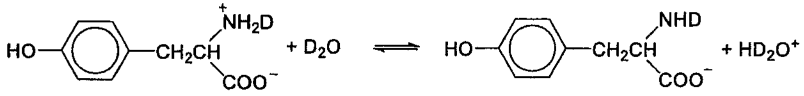
The carboxylate anion can then undergo base hydrolysis with D_2O to form RCOOD as the deuterated solvent is present in large excess.



For –NH₂
Similarly, in D_2O solvent, the $-NH_2$ group can undergo base hydrolysis to form a conjugate acid.



The conjugate acid can also undergo acid hydrolysis with the possibility of breaking the N–H bond instead of N–D bond, thus replacing the original H atom in $-NH_2$.



Since tyrosine is in dynamic equilibrium in D_2O, up to 2 H atoms in $-NH_2$ could be replaced.

Q27 **(Ans: D)**

Option A is incorrect. At standard conditions, the S.H.E. contains 1 bar of H_2 gas.

Option B is incorrect. As 1 mole of H_2SO_4 ionises to form 2 moles of H^+ ions, at standard conditions, the S.H.E. should have 0.5 mol dm^{-3} of H_2SO_4, which corresponds to 1 mol dm^{-3} of H^+.

Option C is incorrect. The conditions for s.t.p. are 273 K (20 °C) and 1 bar.

Option D is correct. At standard conditions, the S.H.E. is measured at 298 K or 25 °C.

Q28 **(Ans: A)**

Option A is correct. In the electrolyte, Cu^{2+} is reduced at the cathode while nickel is oxidised at the impure copper anode, forming Ni^{2+} ions. Thus, the concentration of Cu^{2+} ions decreases.

Option B is incorrect. Silver is collected at the bottom of the anode as anodic sludge, and is not oxidised.

Option C is incorrect. Since some nickel is oxidised at the anode before copper is oxidised, less copper is oxidised at the anode compared to the copper ions reduced at the cathode.

Option D is incorrect. Since copper is reduced from Cu^{2+} to Cu, the pure copper needs to be at the cathode where Cu is deposited.

Q29 **(Ans: D)**

Ti has an electronic configuration of [Ar] $3d^2\ 4s^2$.
Its possible oxidation states as a metal cation are: +1, +2, +3 and +4.

The oxidation state of Ti in the respective compounds is
(A) +2
(B) +3
(C) +3
(D) +6

Hence the compound in Option D is unlikely to exist.

Q30 **(Ans: A)**

Option A is correct. Fe has a higher melting point than Mg because Fe forms stronger metallic bonds (greater number of delocalised electrons).

Option B is incorrect. Fe has a higher density than Mg due to Fe having a smaller atomic radius (and hence more atoms per unit volume) and a larger atomic mass than Mg.

Option C is incorrect. While Fe has a higher first ionisation energy, the reason is because the increase in nuclear charge outweighs the increase in shielding effect.

Option D is incorrect. Fe has better electrical conductivity due to having more delocalised electrons because the 3d electrons are also delocalised in the metallic structure of iron.

BP-251

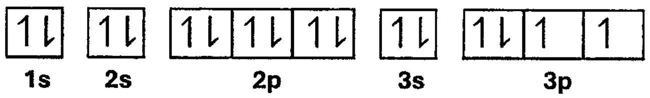
1(a) $B^{6+}(g) \longrightarrow B^{7+}(g) + e^-$

1(b) C

There is a large jump between the 8th and 9th ionisation energies.
This indicates that significantly more energy is needed to remove the 9th electron. Thus this 9th electron is located in an inner electron shell that is nearer to the nucleus, experiencing less shielding and is attracted more strongly by the nucleus.
Therefore, there are 8 valence electrons.
Hence **C** belongs to Group 18 of the Periodic Table and is a noble gas.

1(c)(i) Sulfur

1(c)(ii)



1(d) **D**$^+$: $1s^2 2s^2 2p^6 3s^2 3p^6$
C: $1s^2 2s^2 2p^6 3s^2 3p^6$

D$^+$ and **C** are isoelectronic species and hence their outermost electrons experience the same shielding effect.
However, **D**$^+$ has a larger nuclear charge than **C** and so there is stronger electrostatic attraction between the nucleus and the outermost electrons in **D**$^+$.

Hence the 2nd ionisation energy of **D** is more positive than the 1st ionisation energy of **C**.

1(e)(i) The electronegativity of an atom in a molecule is a relative measure of its ability to attract bonding electrons.

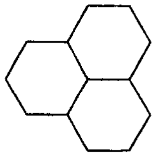
1(e)(ii) 2.5

1(f)(i) The B–H_a bond is longer.

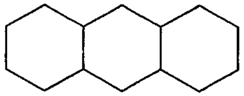
Since two electrons are shared between three atoms in B–H_a–B, there is an average of one shared electron per B–H_a bond, which is less than the two shared electrons per B–H_b bond. This decrease in electron density between the B and H_a atoms causes the B–H_a bond to be weaker and therefore longer.

1(f)(ii) 122°
Since the electron density of the B–H_b bond is greater than that of the B–H_a bond, the repulsion between two B–H_b bonds is greater than that of the repulsion between B–H_a and B–H_b, which is greater than that between two B–H_a bonds. Hence H_b–B–H_b bond angle is greater than 109.5°.

2(a)(i)



or



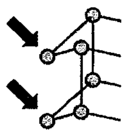
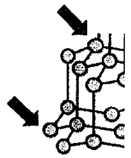
2(a)(ii) Each carbon atom has an unhybridised p orbital which overlaps side-on with the other p orbitals on adjacent carbon atoms. This continuous side-on overlap of the p-orbitals allows the π electrons to be delocalised and shared equally across all carbon atoms, resulting in all bond lengths to be equal.

2(a)(iii) sp^3
Each carbon atom has four bond pairs / regions of electron densities and no lone pairs and exhibits a tetrahedral molecular geometry (shape). Each bond pair must thus be located in an sp^3 hybrid orbital.

2(a)(iv) Allotrope **F** is a non-conductor of electricity while graphite is a conductor of electricity.

All four valence electrons on each C atom in allotrope **F** are used to form σ bonds, and no electrons are available for delocalisation / no mobile charge carrier to conduct electricity. In graphite, three of the valence electrons on each C atom are used to form σ bonds. The last electron on each C atom in graphite delocalises across the whole layer, acting as a mobile charge carrier. Hence, graphite is a conductor of electricity.

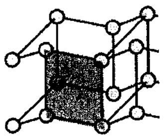
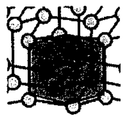
2(a)(v) The researcher is incorrect.
The two structures are different because

 **Fig. 2.1**	 **Fig. 2.2**
These two carbons point in the same direction.	These two carbons point in different / opposite directions.

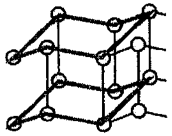
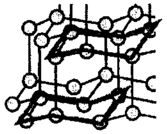
BP-253

BP~254

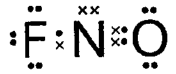
OR

 Fig. 2.1	 Fig. 2.2
There are "rectangular" faces. There are 4-carbon rings on the sides.	There are hexagonal faces. There are 6-carbon rings on the sides.

OR

 Fig. 2.1	 Fig. 2.2
Chair structures are stacked directly on top of each other.	Chair structures are staggered between the layers.

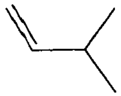
2(b)(i)

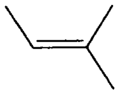


2(b)(ii) see-saw / distorted tetrahedral

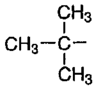
2(c)(i) ethanolic NaOH and heat

2(c)(ii)





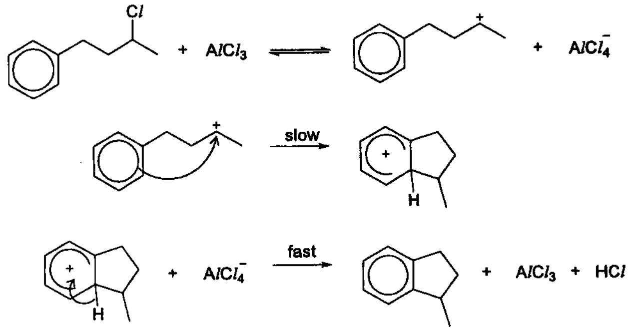
2(c)(iii) S_N1 does not occur because **N** is a 1° bromoalkane and the carbocation formed is not stable enough.



$CH_3-C(CH_3)_2-$

The bulky group hinders the backside attack by the OH^- nucleophile on the electron-deficient carbon and hence S_N2 does not occur.

3(a)(i) Electrophilic Substitution



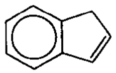
3(a)(ii) The delocalisation of the six π electrons in the ring structure of benzene causes resonance stabilisation. Addition reactions disrupt the delocalisation of the six π electrons in benzene while substitution reactions restores the resonance stabilisation after temporarily disrupting it.

3(a)(iii) $AlCl_3$ acts as a Lewis acid catalyst in the reaction.

3(a)(iv) With reference to the mechanism, the electrophile is planar about the positively charged carbon in the carbocation. Hence, the π electrons from the benzene ring will attack the positively charged carbon on either side of the plane with equal probability. Hence, a racemic mixture is formed, and the product is unable to rotate plane-polarised light.

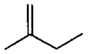
3(b)(i)

U:



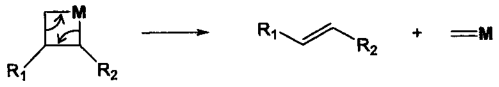
3(b)(ii)

V:

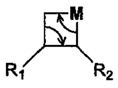


3(b)(iii) Free radical substitution reaction may result in produce multiple alternative monosubstituted products / major product is another monosubstituted product / multiple substitutions

3(c)



W

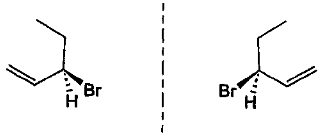
OR 

3(d) Test: To each compound in separate test-tubes, add H$_2$SO$_4$(aq), a few drops of KMnO$_4$ and heat in hot water bath

Observation(s):
For **X**, there is decolourisation of purple KMnO$_4$.
For **Y**, there is decolourisation of purple KMnO$_4$ and evolution of a colourless gas (CO$_2$) which gives a white precipitate with limewater.

3(e)(i) 3-bromopent-1-ene

3(e)(ii)



4(a)(i) In 1 m^3, mass of air is 1 kg.

mass of O$_3$ = $\frac{2 \times 10^{-5}}{100} \times 1$
$= 2 \times 10^{-7}$ kg
$= 2 \times 10^{-7} \times 10^{3} \times 10^{6}$
$= 200$ μg

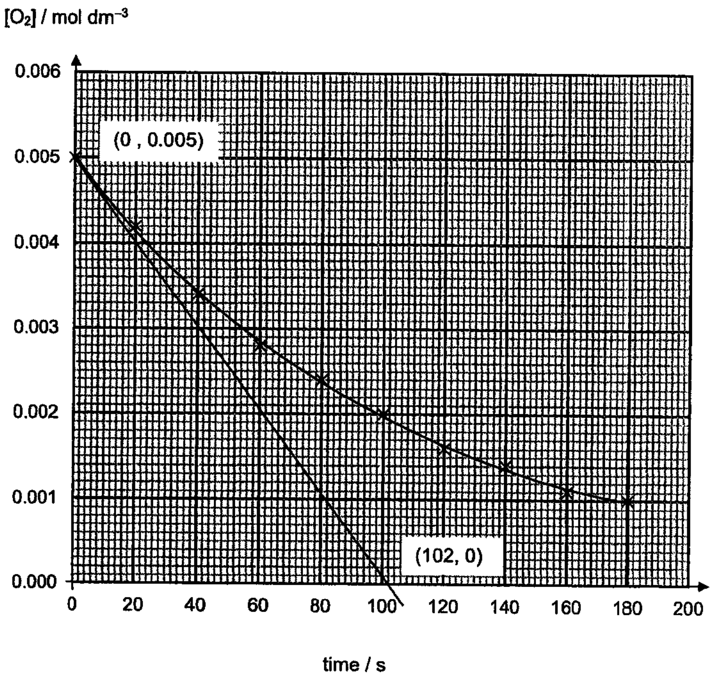
Hence, concentration of O$_3$ is 200 μg m^{-3}

4(a)(ii) PSI of O$_3$ = $\frac{200 - 100}{235 - 157}(200 - 157) + 100$
= 155 (3 s.f.)

4(b)(i) Vehicular emissions are a significant source of NO$_2$. When the lockdown measures were implemented, there were fewer vehicles on the road, and concentration of NO$_2$ decreased.

4(b)(ii) NO$_2$ is a radical and can react with O$_3$. During the Circuit Breaker, the concentration of NO$_2$ decreased, leading to less reaction with O$_3$. Therefore, the concentration of O$_3$ increased.

4(c)(i)



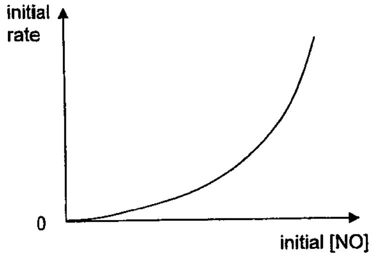
Draw a tangent at t = 0 s

Initial rate = −gradient
= −[(0.005 – 0) / (0 – 102)]
= 4.90 x 10^{-5} mol dm^{-3} s^{-1}
= z

BP-255

4(c)(ii) Comparing experiments 1 and 2, when $[O_2] \times 3$, initial rate x 3. $[O_2] \propto$ rate. Hence, reaction is first order with respect to O_2.

4(c)(iii)



4(c)(iv) rate = $k[NO]^2[O_2]$

4(c)(v) The half-life of a reaction is the time taken for the concentration of a reactant to decrease to half its initial value.

4(c)(vi) rate = $k[NO]^2[O_2]$

Using large excess of NO, reaction becomes pseudo first order.

rate = $k'[O_2]$ where $k' = k[NO]^2$

$t_{½} = \frac{\ln 2}{k'}$

$= \frac{\ln 2}{k[NO]^2}$

Since [NO] in experiment 3 is doubled that of experiment 1,

$t_{½}$ of experiment 3 = $\frac{74}{2^2}$ = 18.5 s

4(c)(vii) $N_2O_2 + O_2 \longrightarrow 2NO_2$

4(d)(i) Homogeneous catalysis

4(d)(ii)

$NO_2 + SO_2 \longrightarrow SO_3 + NO$ (I)

$NO + ½\,O_2 \longrightarrow NO_2$ (II)

4(e) $n(S_2O_3^{2-})$ reacted = $\frac{15.60}{1000} \times 4.00 \times 10^{-4}$

$= 6.24 \times 10^{-6}$ mol

$n(I_2)$ formed = $6.24 \times 10^{-6} / 2$

$= 3.12 \times 10^{-6}$ mol

$n(SO_2)$ in 1 m^3 sample of air = $3.12 \times 10^{-6} \times 5$

$= 1.56 \times 10^{-5}$ mol

mass in 1 m^3 sample of air = $1.56 \times 10^{-5} \times 64.1$

= 0.00099996 g

mass concentration of SO_2 = 0.00100 g m^{-3} (3 s.f.)

5(a) $Zn^{2+} + 4OH^- \longrightarrow [Zn(OH)_4]^{2-}$

5(b)(i) At high $[OH^-]$, $[Zn(OH)_4]^{2-}$ is produced, causing $[Zn^{2+}]$ to decrease. This causes the position of equilibrium of $Zn^{2+} + 2e^- \rightleftharpoons Zn$ to shift to the left. Hence, $E(Zn^{2+}/Zn)$ becomes more negative.

5(b)(ii)

$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$

$Zn^{2+} + 2e^- \rightleftharpoons Zn$

When $E_{(Zn^{2+}/Zn)} = -1.25$ V, $E(O_2/OH^-) = +0.34$ V

$E_{cell} = +0.34 - (-1.25) = +1.59$ V

$\Delta G = -nFE_{cell}$

$= -(4)(96500)(+1.59)$

$= -613740$ J mol^{-1}

$= -614$ kJ mol^{-1}

5(b)(iii) With a lower $[OH^-]$, $Zn(OH)_2$ is less able to dissolve to form $[Zn(OH)_4]^{2-}$. The insoluble $Zn(OH)_2$ forms a non-conducting layer on the electrode surface, preventing the electrode from coming into contact with the electrolyte. Hence, the electrode is not able to conduct electricity, and the oxidation of active zinc cannot occur.

5(c) Reactant molecules diffuse towards the catalyst surface and become adsorbed onto the active sites. This increases the concentration of reactants at the catalyst surface and weakens the covalent bonds within the molecules which lowers activation energy. Reactants molecules also come in close contact with orientation to react and form products. The product molecule desorbs and diffuse away from the catalyst surface.

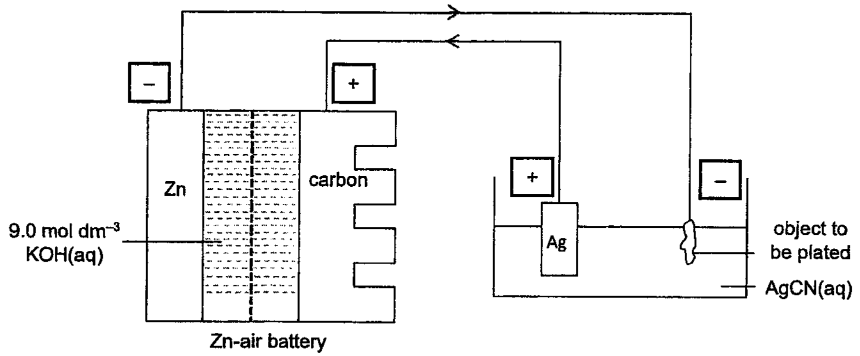
5(d)

- Use of air as reactants at the cathode means less harmful chemicals are used in the making of the cell.
- Rechargeable feature reduces the amount of chemicals wasted in production of batteries as compared to single-use batteries.
- Rechargeable batteries reduce electronic waste caused by the disposal of single-use batteries.
- Lower cost of purchasing batteries repeatedly.

5(e)(i) The amount of active zinc decreased.

5(e)(ii) $H_2(g)$

5(f)(i)



5(f)(ii) $Ag^+ + e^- \longrightarrow Ag$

amount of Ag = 1.75 / 107.9 = 0.01621 mol
amount of e$^-$ = <u>0.0162 mol</u>

5(f)(iii) $Zn \longrightarrow Zn^{2+} + 2e^-$

amount of Zn reacted = 0.01621 / 2 = 8.109 × 10^{-3} mol
mass of Zn lost = 8.109 × 10^{-3} × 65.4 = <u>0.530 g</u>

5(f)(iv) $Q = It = n_eF$

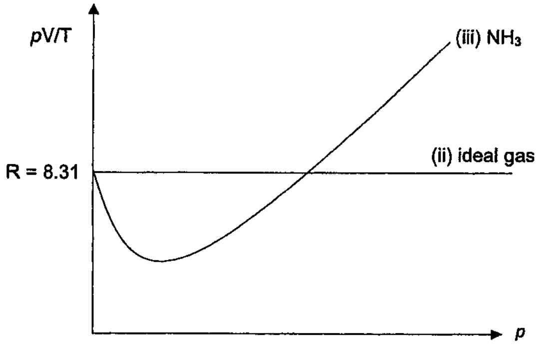
1.5*t* = 0.01621 × 96500
t = <u>1040 s</u> (or 17.4 min)

2025 Y6 H2 Chemistry Preliminary Exams Paper 3 – Suggested Solutions

Section A

1(a)(i)
- The gas particles have negligible volume or size of the gas particles is negligible compared to the volume of the container.
- The gas particles exert negligible attractive forces on one another.
- The collisions between the gas particles are perfectly elastic.

1(a)(ii)



1(a)(iii) At moderately high pressure, NH_3 molecules come closer together and the intermolecular attractive forces (hydrogen bonds) between NH_3 molecules become significant. This causes the gas to occupy a volume smaller than that of an ideal gas.

1(a)(iv) 27 °C = 300 K and 227 °C = 500 K

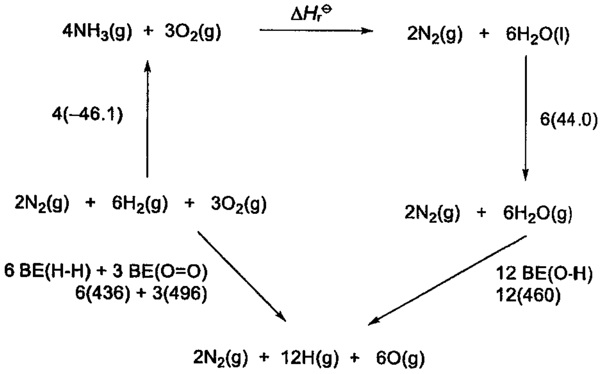
When compressed at constant T to half V,
Apply $p_1V_1 = p_2V_2$
$4.00 \times 5 = p_2 \times 2.5$
$p_2 = 8.00$ atm

When heated from 300 K to 500 K at constant V,
Apply $p_2/T_2 = p_3/T_3$
$8.00 / 300 = p_3 / 500$
$p_3 =$ **13.3 atm**

Alternative method using pV/T:
$p_1V_1/T_1 = p_2V_2/T_2$
$4.00 \times 5 / 300 = p_2 \times 2.5 / 500$
$p_2 =$ **13.3 atm**

1(b)(i) It is the energy released when 1 mol of ammonia gas is completely burnt in excess oxygen under standard conditions of 298 K and 1 bar.

1(b)(ii)



By Hess' law,

$$\Delta H_r^\ominus = -4(-46.1) + 6(436) + 3(496) - 12(460) - 6(44.0) = \mathbf{-1495.6\ kJ\ mol^{-1}}$$

Therefore,

$$\Delta H_c^\ominus \text{ of } NH_3(g) = -1495.6 / 4 = -373.9 = \mathbf{-374\ kJ\ mol^{-1}}$$

1(b)(iii) The reaction is accompanied by a decrease in number of gaseous particles, resulting in less disorder.

1(b)(iv) $\Delta G_r^\ominus = \Delta H_r^\ominus - T\Delta S_r^\ominus$
$\Delta G_r^\ominus = -1495.6 - 298(-583/1000) = -1322 =$ **-1320 kJ mol^{-1}**

Since $\Delta H_r^\ominus$ is negative and $\Delta S_r^\ominus$ is also negative, this means $\Delta G_r^\ominus$ is more negative as lower temperature where negative $\Delta H_r^\ominus$ term outweighs the positive $-T\Delta S_r^\ominus$ term. The reaction is spontaneous at low temperatures.

1(b)(v) At lower temperatures, particles have insufficient energy to overcome the high activation energy needed to break the strong N≡N and O=O bonds to form NO_x.
Or
The N≡N bond is very strong, forming NO_x from N_2 requires a lot of energy to break this bond, which is not favoured at low temperatures.

1(c)(i) Acid. NH_3 donates H^+ to H^- in NaH to form NH_2^- and H_2.
Or
Oxidising agent. NH_3 is reduced as the oxidation number of H decreases from +1 in NH_3 to 0 in H_2.

1(c)(ii) Reducing agent. NH_3 is oxidised as oxidation number of N increases from –3 in NH_3 to –2 in N_2H_4.

BP-260

1(c)(iii) Nucleophile. Electron pair on N is donated to the electron deficient carbon in C–Br.

2(a)(i) $K_p = \dfrac{{P_{NH_3}}^2}{{P_{H_2}}^3 P_{N_2}}$ unit: atm^{-2}

Since the initial molar ratio and change in molar ratio of H_2 and N_2 are in the ratio of 3:1, the equilibrium amount molar ratio will also be 3:1.

Thus,

$P_{H_2} = \frac{3}{4} \times (200 - 35) = 123.75$ atm

$P_{N_2} = \frac{1}{4} \times (200 - 35) = 41.25$ atm

$$K_p = \frac{{P_{NH_3}}^2}{{P_{H_2}}^3 P_{N_2}} = \frac{(35)^2}{(123.75)^3\,(41.25)} = 1.57 \times 10^{-5}\ \text{atm}^{-2}$$

2(a)(ii) As temperature increases, K_p decreases. This shows that the equilibrium position shifts left with increasing temperature to absorb heat energy. Hence, the backward reaction is endothermic and the forward reaction has a negative enthalpy change (i.e. exothermic).

2(a)(iii) When small amount of inert gas is added into the reaction vessel under constant temperature and pressure, total volume of the gaseous system is increased (as the system must expand to keep its total pressure constant). Concentrations (or partial pressures) of the reactants and products are decreased. The system counteract the change shifting the position of equilibrium so as to re-establish the equilibrium, hence, the equilibrium position will shift to the left, i.e. the side involving greater number of moles of gas.

2(a)(iv) Iron has partially filled 3d subshell for the ready exchange of electrons to and from reactant molecules, facilitating the formation of weak bonds with the reactant molecules.

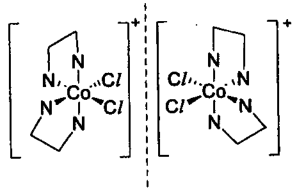
2(a)(v) Since the forward reaction is exothermic, a lower temperature would result in a higher yield of ammonia. However, the rate of production is too slow at low temperature, hence a moderately high temperature of 450 °C is used to ensure a reasonable rate of production and yield.

The forward reaction takes place with a reduction in the number of gaseous particles and a high pressure will favour the desired reaction (increase yield). However, too high a pressure increases cost of production / increases safety concerns. Thus, a moderate pressure of 200 atm is used.

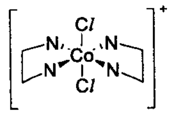
Iron catalyst is added to increase the rate of reaction and reduce the time taken to reach equilibrium.

2(b)(i) A ligand is a chemical species which can form a dative/co-ordinate bond simultaneously with the central metal ion (or atom) through lone pair of electrons.

2(b)(ii) Isomers A and B:



Isomer C that does not rotate plane polarised light:

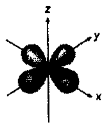


2(c)(i) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7$

2(c)(ii) In the presence of ligands causes the splitting of the five 3d orbitals in Co^{2+} into two sets of slightly different energy levels. Since the 3d subshell in Co^{2+} is partially filled, electrons from the lower-energy d orbitals can absorb energy corresponding to certain wavelengths from the visible spectrum and get promoted to the higher-energy d orbitals (d-d transitions). The colour observed is the complement of the colour absorbed.

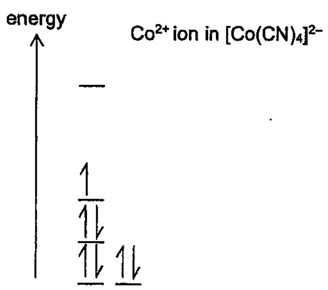
2(c)(iii) Due to the large energy gap between the d-orbitals, it is energetically more favourable for electrons to pair up in d-orbitals in the lower energy level despite inter-electronic repulsion.

2(c)(iv)



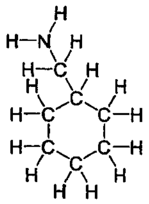
$d_{x^2-y^2}$

2(c)(v)



3(a)(i) LiA*l*H₄ in dry ether

3(a)(ii)

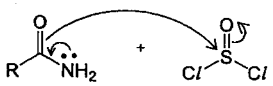


3(b)(i) nucleophilic addition

3(b)(ii) *cis-trans* isomerism

3(b)(iii) +3

3(c)(i)

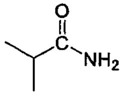


3(c)(ii) SO_2 and Cl^-

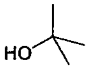
3(d)(i) The orbital containing the lone pair of electrons on the nitrogen atom overlaps with the π electron cloud of the adjacent C=O bond and the lone pair of electrons is delocalised. Hence, this lone pair of electrons on the nitrogen is not available for donation/coordination to an electron-deficient species.

3(d)(ii)

P:



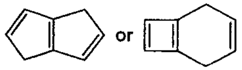
Q:



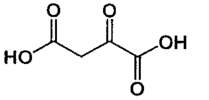
3(e)(i)

Evidence	Deduction
T decolourises Br_2(aq).	**T** undergoes electrophilic addition reaction **T** contains C=C bond(s)
T, C_8H_8, is reacts with hot, acidified $KMnO_4$, to form **U**, $C_4H_4O_6$ as the only carbon-containing product.	**T** undergoes strong oxidation/oxidation cleavage **U** contains either ketone and/or carboxylic acids functional groups. Since no CO_2 is formed and T has 8 C while U has 4 C, 1 mole of T formed 2 mole U
U forms an orange ppt with 2,4-DNPH.	**U** undergoes condensation reaction. **U** contains ketone functional group(s).
1 mol of **U** reacts with excess Na_2CO_3(aq) to form 1 mole of CO_2 gas.	**U** undergoes acid-base reaction. **U** contains 2 carboxylic acid functional group(s).

T:



U:



3(e)(ii)

Section B

4(a)(i) Down group 17, the electron clouds of the halogens become larger and more polarisable. Hence, more energy is required to overcome the increasing strength of the instantaneous dipole-induced dipole interactions between the halogen molecules down the group, leading to decreasing volatility.

4(a)(ii) **Cl_2(aq) + NaBr(aq)**

$Cl_2(aq) + 2Br^-(aq) \rightarrow Br_2(aq) + 2Cl^-(aq)$

- Orange colour due to production of Br_2(aq) is observed.

I_2(aq) + NaCl(aq)

No reaction occurs.

- Brown colour due to unreacted I_2(aq) is observed.

Br_2(aq) + NaI(aq)

$Br_2(aq) + 2I^-(aq) \rightarrow I_2(aq) + 2Br^-(aq)$

- Brown colour due to production of I_2(aq) is observed.

BP~262

4(b)(i) Hydrogen chloride is thermally stable (does not decompose). Hydrogen bromide and hydrogen iodide thermally decompose to give <u>hydrogen gas</u> and their <u>respective halogens</u> as shown in the following equation.

$$2HX \rightleftharpoons H_2 + X_2 \text{ (where X = Br and I)}$$

Since the bond energy decreases from H–C*l* to H–Br to H–I, the <u>bond strength decreases</u> in the same order. Thus, the <u>thermal stability of the hydrogen halides decreases</u> from HC*l* to HBr to HI.

4(b)(ii) There is <u>steric strain</u> in the nitrogen triiodide molecule due to the 3 large iodine atoms bonded to a small nitrogen atom. The instability of the molecule results in a very <u>small activation energy</u>.
OR
<u>N–I bond is weak</u>, leading to <u>small activation energy</u>.

4(c)(i) <u>Addition of NH_3</u>

$AgBr(s) \rightleftharpoons Ag^+(aq) + Br^-(aq)$ Eqm 1
$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^+(aq)$ Eqm 2

Upon addition of NH_3, the <u>$[Ag(NH_3)_2]^+$</u> complex is formed (according to equilibrium 2) which causes <u>$[Ag^+]$ to decrease</u>. This momentarily causes the ionic product of AgBr to fall below its K_{sp}, which in turn <u>causes the position of equilibrium 1 to shift to the right</u> to increase $[Ag^+(aq)]$, causing AgBr(s) to dissolve, <u>increasing the solubility</u> of AgBr.

4(c)(ii) $[CrO_4^{2-}]$ in mixture $= \dfrac{\frac{1}{1000} \times 0.01}{\frac{25+1+26}{1000}} = 1.923 \times 10^{-4}$ mol dm^{-3}

Ag_2CrO_4 is just about to precipitate, thus $[Ag^+]^2[CrO_4^{2-}] = K_{sp}$

$[Ag^+]$ required to precipitate $CrO_4^{2-} = \sqrt{\dfrac{1.1 \times 10^{-12}}{0.0001923}} = \underline{7.56 \times 10^{-5} \text{ mol dm}^{-3}}$

4(c)(iii) As AgBr is being precipitated out (i.e. there is a saturated solution of AgBr), its ionic product equals K_{sp}.
At this point,
$(7.563 \times 10^{-5})[Br^-] = 5.0 \times 10^{-13}$
$[Br^-]$ remaining $= 6.611 \times 10^{-9}$ mol dm^{-3}

$[Br^-]$ in sample $= \dfrac{65 \times 10^{-3}}{79.9} = 8.135 \times 10^{-4}$ mol dm^{-3}
$[Br^-]$ in mixture $= \dfrac{25}{52} \times 8.135 \times 10^{-4} = 3.911 \times 10^{-4}$ mol dm^{-3}

% remaining $= \dfrac{6.611 \times 10^{-9}}{3.911 \times 10^{-4}} \times 100\% = 1.69 \times 10^{-3}$ %

4(d)

	$Ag_3PO_4(s)$	$\rightleftharpoons$	$3Ag^+(aq)$	+	$PO_4^{3-}(aq)$
eqm conc / mol dm^{-3}	–		$3(4.26 \times 10^{-5})$ $= 1.278 \times 10^{-4}$		4.26×10^{-5}

$K_{sp} = [Ag^+]^3[PO_4^{3-}] = (1.278 \times 10^{-4})^3(4.26 \times 10^{-5})$
$= 8.891 \times 10^{-17}$ mol^4 dm^{-12}

Let solubility of Ag_3PO_4 in 0.020 mol dm^{-3} Na_3PO_4(aq) be w mol dm^{-3}.

	$Ag_3PO_4(s)$	$\rightleftharpoons$	$3Ag^+(aq)$	+	$PO_4^{3-}(aq)$
eqm conc / mol dm^{-3}	–		3w		w + 0.020

At equilibrium in the saturated solution, $[PO_4^{3-}] = (w + 0.020)$ mol dm^{-3}
$[Ag^+] = 3w$ mol dm^{-3}

Since Ag_3PO_4 is sparingly soluble in water and the presence of PO_4^{3-} ions from Na_3PO_4 further suppresses its solubility, w << 0.020. Thus, (w + 0.020) ≈ 0.020.

$K_{sp} = [Ag^+]^3[PO_4^{3-}]$
$8.891 \times 10^{-17} = [Ag^+]^3(w + 0.020) \approx [Ag^+]^3(0.020)$
$[Ag^+]^3 = \dfrac{8.891 \times 10^{-17}}{0.020}$
$[Ag^+] = \underline{1.64 \times 10^{-5} \text{ mol dm}^{-3}}$

4(e) The white precipitate <u>**S** is $Mg(OH)_2$</u> as it is insoluble in excess NaOH(aq). Hence **Q** contains Mg^{2+}. <u>**Q** is $MgCl_2$</u>.

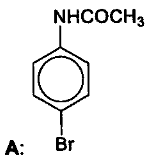
The white solid <u>**T** is SiO_2</u> as it does not undergo acid-base reaction with dilute acids or bases. <u>**R** is SiH_4</u>.

$$SiH_4 + 2O_2 \longrightarrow SiO_2 + 2H_2O$$

P contains Mg and Si. Hence, <u>**P** is Mg_2Si</u>.

5(a)(i)

Compound **A**:



5(a)(ii) Step 1: CH_3COCl
Step 2: NaOH(aq), heat

5(b)(i) $H_2CO_3(aq) \rightleftharpoons HCO_3^-(aq) + H^+(aq)$

When $[H^+]$ increases, by Le Chatelier's Principle, the equilibrium position shown above shifts to the left to partially offset the increase in $[H^+]$ by favouring the backward reaction of the equilibrium, resulting in a small decrease in pH.

5(b)(ii) $pH = pK_a + \lg(\frac{20}{1})$

$7.4 = pK_a + \lg(\frac{20}{1})$

$pK_a = 6.10$

5(b)(iii) Given: original $[H_2CO_3(aq)] = 0.0020$ mol dm^{-3}
Since the ratio of $HCO_3^-(aq)$ to $H_2CO_3(aq)$ is 20:1
Original $[HCO_3^-(aq)] = 0.0020 \times 20 = 0.040$ mol dm^{-3}

When $[H_2CO_3(aq)]$ increases to 0.0024 mol dm^{-3}, $[HCO_3^-(aq)]$ drops to $0.040 - 0.0004 = 0.0396$ dm^{-3}

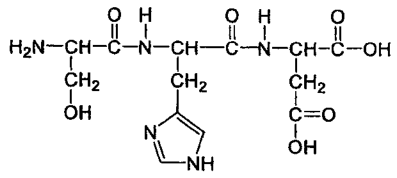
New pH when this happens $= 6.1 + \lg(\frac{0.0396}{0.0024})$
$= 7.3175$

Change in pH $= 7.3175 - 7.4 = -0.0825$

5(c)(i) An Arrhenius acid releases H^+ ions in **aqueous** solution.

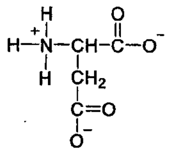
5(c)(ii) The basicity of each N atom depends on the availability of its lone pair of electrons on the nitrogen atom to form a dative covalent bond with a proton.
For N atom (1), the lone pair of electrons is not delocalised into the ring, but for N atom (2), the lone pair of electrons is delocalised into the ring and hence is less available for coordination with a proton.

5(c)(iii)



5(c)(iv) They are not the same compound. For ser-his-asp, the N−terminus is free on the ser residue and C−terminus is free on the asp residue while for asp-his-ser it is the other way round. (They are constitutional isomers of each other.)

5(c)(v)



5(d)(i) 0

5(d)(ii) Amount of $NR_3H^+Cl^- = \frac{0.025}{291.5} = 8.576 \times 10^{-5}$ mol
$[NR_3H^+] = 8.576 \times 10^{-5}$ mol $\div$ 10×10^{-3} dm^3
$= 8.576 \times 10^{-3}$ mol dm^{-3}

$NR_3H^+ \rightleftharpoons NR_3 + H^+$
At equilibrium, $[H^+] = [NR_3]$
$[NR_3H^+]$eqm $\approx$ $[NR_3H^+]$initial $= 8.576 \times 10^{-3}$ mol dm^{-3}
since NR_3H^+ is a weak acid with a small K_a

$[H^+] = \sqrt{(10^{-9.1})(8.576 \times 10^{-3})}$
$= 2.6100 \times 10^{-6}$
$pH = -\lg(2.6100 \times 10^{-6}) = 5.58$

5(d)(iii) $pH = pK_a + \lg(\frac{[NR_3]}{[NR_3H^+]})$
$7.4 = 9.1 + \lg(\frac{[NR_3]}{[NR_3H^+]})$
$\lg(\frac{[NR_3]}{[NR_3H^+]}) = -1.7$
$\frac{[NR_3]}{[NR_3H^+]} = 10^{-1.7} = 0.01995$
Ratio of NR_3 to NR_3H^+ = 1 : 50 **or** 2 : 100
Since there is 1 uncharged for every 50 charged means we have 2 uncharged for every 100 charged; hence sufficient to cross the blood-brain barrier to cause drowsiness.