2021 H2 Chemistry Y6 Prelim Paper 1 Suggested Solutions

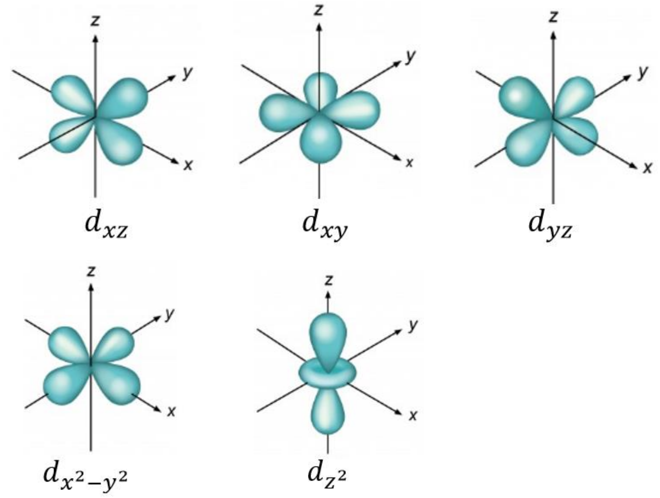
Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Answer	B	B	D	C	A	A	C	D	C	D	B	A	C	B	D

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

Question 1 (B)

Electronic configuration of Cu:
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^1$
(**not** $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9\ 4s^2$ – see Atomic Structure notes if you are unsure why)

Number of electrons in d orbitals with 4 lobes = 8 (d_{z^2} does not have 4 lobes)



Question 2 (B)

In Period 2, there are two irregularities in the first ionisation energies of the elements. One irregularity occurs at Group 13 (i.e. B) and the other occurs at Group 16 (i.e. O).

Two irregularities are also observed in the second ionisation energies at Group 14 (removing e^- from C^+) and at Group 17 (removing e^- from F^+). A quick way to realise is to check the Data Booklet.

Therefore, **K**, the element with the lower 2nd IE can be either from either Group 14 or Group 17, corresponding to carbon and fluorine respectively.

Question 3 (D)

Q is non-volatile (does not vapourise easily) eliminates nitrogen dioxide which has a simple covalent structure with weak instantaneous dipole-induced dipole interactions and is a gas at rtp.

Q does not conduct electricity in its standard state eliminates sodium as metals can conduct electricity.

Q dissolves in water eliminates silicon dioxide is insoluble in water due to its giant covalent structure.

Sodium oxide is the only option that

- is non-volatile (due to strong ionic bonds holding the giant ionic lattice),
- does not conduct electricity in its standard state (no mobile ions as charge carriers in solid state), and
- dissolves in water (by reacting with water to form NaOH(aq)).

Question 4 (C)

BeF_2 is the simplest compound of beryllium and fluorine.

F–Be–F

In BeF_2, Be is sp hybridised and contain two unhybridised p-orbitals which, in this molecule, are empty. Hence Be in BeF_2 can *accept* 2 pairs of electrons into its two unhybridised p-orbitals.

1	**Incorrect.** • F donates a lone pair to Be which accepts the pair of electrons from F, thus the arrow representing the dative bond should point from F to Be.
2	**Correct.** • With 2 empty unhybridised p-orbitals, Be can accept 2 pairs of electrons from 2 F i.e. Be in BeF_2 forms 2 dative bonds with 2 fluorines from other BeF_2, resulting in the polymeric structure.
3	**Correct.** • Similarly, BeF_2 can form 2 dative bonds with two F^- to give BeF_4^{2-}.

Question 5 (A)

X, **Y**, and **Z** are Period 3 elements.
Oxide of **X** is amphoteric ⇒ **X** is A*l*
Oxide of **Y** is basic ⇒ **Y** is Na or Mg
Oxide of **Z** is acidic ⇒ **Z** is non-metal (P, S, C*l*)

Since **Z** is a non-metal, it forms anions. Since **X** and **Y** are metals, they form cations.

Since ionic radii of cations are smaller than that of anions (formed from non-metals) and ionic radii decreases from Na^+ to Al^{3+}, ionic radii increases in this order **X** < **Y** < **Z**.

Question 6 (A)

Highest K_a implies strongest weak acid. A cation with higher charge density has stronger polarising power and distort the electron cloud of water molecules to a greater extent and weaken O–H bonds to a larger extent.

	element	ionic radii / nm
A	Co^{3+}	0.055
B	Mg^+	0.065
C	Mn^{2+}	0.083
D	V^{3+}	0.064

Since Co^{3+} has the highest charge and smallest ionic radius, $[Co(H_2O)_6]^{3+}$ is the most acidic and has the highest K_a.

Question 7 (C)

At constant T and constant number of moles of gas, pV = nRT = constant.

CH_3OH and SiH_4 have a molar mass of 32 g/mol which is lower than that of 81 g/mol for both HBr and H_2Se. When equal masses of each gas is used, there are more number of moles of CH_3OH and SiH_4 than HBr and H_2Se.

Thus, CH_3OH and SiH_4 will have a higher pV value (Options C or D).

CH_3OH can form strong hydrogen bonds and hence deviates more from ideal gas behaviour than SiH_4 which can only form weak instantaneous-dipole induced-dipole attractions. Hence Option C is correct.

Question 8 (D)

You need to check whether the following reaction is spontaneous by checking whether it has a positive $E^\ominus_{cell}$.

$$2\mathbf{Fe^{2+}} + X_2 \rightarrow 2Fe^{3+} + 2X^-$$

From *Data Booklet*,

$F_2 + 2e^- \rightleftharpoons 2F^-$ $E^\ominus = +2.87$ V

$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$ $E^\ominus = +1.36$ V

$Br_2 + 2e^- \rightleftharpoons 2Br^-$ $E^\ominus = +1.07$ V

$I_2 + 2e^- \rightleftharpoons 2I^-$ $E^\ominus = +0.54$ V

$Fe^{3+} + e^- \rightleftharpoons \mathbf{Fe^{2+}}$ $E^\ominus = +0.77$ V

For the reaction between Fe^{2+} and I_2,
$E^\ominus_{cell} = E^\ominus_{cathode} - E^\ominus_{anode} = 0.54 - (0.77) = -0.23$ V

Since $E^\ominus_{cell}$ for reaction between I_2 is less than zero, the reaction is not spontaneous and I_2 cannot oxidise Fe^{2+} to Fe^{3+}.

Question 9 (C)

Using algebraic method:

(1) $N_2(g) + 5/2\ O_2(g) \rightarrow N_2O_5(g)$
$\Delta H_f = ???$ kJ mol^{-1}
(2) $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$
$\Delta H = -114.1$ kJ mol^{-1}
(3) $4NO_2(g) + O_2(g) \rightarrow 2N_2O_5(g)$
$\Delta H = -110.2$ kJ mol^{-1}

1/2 × **(3)** to get **(4)**

(4) $2NO_2(g) + 1/2\ O_2(g) \rightarrow N_2O_5(g)$
$\Delta H = -55.1$ kJ mol^{-1}
(5) $N_2(g) + O_2(g) \rightarrow 2NO(g)$
$\Delta H = +180.5$ kJ mol^{-1}

Add **(2)**, **(4)** and **(5)** to get **(1)**

(1) $N_2(g) + 5/2\ O_2(g) \rightarrow N_2O_5(g)$
$\Delta H_f = -114.1 + (-55.1) + 180.5$
$= +11.3$ kJ mol^{-1}

Question 10 (D)

This question tests students on heterogeneous catalysis (by iron, in the Haber Process), which involves the understanding that there are active sites on the catalyst surface for reactants to adsorb onto for reaction.

At low pressures of N_2, the active sites on the catalyst surface are not saturated with N_2, hence initial rate depends on the partial pressure of N_2.

At moderate or high pressures of N_2, most, if not all, of the active sites present on the catalyst surface are taken up by N_2. Consequently, any increase in the partial pressure of N_2 has no effect on the initial rate of reaction.

Question 11 (B)

Since concentration of compound **P** decreases to 25% (i.e. ¼)of its initial concentration in 1 hour,

$$\underbrace{C_0 \xrightarrow{t_{1/2}} \tfrac{1}{2}C_0 \xrightarrow{t_{1/2}} \tfrac{1}{4}C_0}_{1\text{ h}}$$

2 half-lives ⇒ 1 h
1 half-life ⇒ 30 minutes

Question 12 (A)

By considering the slow step, the rate equation for step 2 is $\text{rate} = k_2[\text{O}\,\bullet][\text{O}_3]$

but O• is an intermediate, thus [O•] cannot be in the overall rate equation.

Using the equilibrium constant of step 1,

$$K_1 = \frac{[\text{O}\,\bullet][\text{O}_2]}{\text{O}_3}$$

$$[\text{O}\,\bullet] = \frac{K_1[\text{O}_3]}{[\text{O}_2]}$$

Substituting this into the rate equation from step 2,

$$\text{rate} = k_2\frac{K_1[\text{O}_3]}{[\text{O}_2]}[\text{O}_3]$$

$$\text{rate} = k_2K_1\frac{[\text{O}_3]^2}{[\text{O}_2]}$$

Thus, statements 1 and 2 are correct.

Statement 3 is correct because $[\text{O}_2]$ is the denominator – when $[\text{O}_2]$ increases, rate decreases.

Question 13 (C)

Rate is a measure of how the fast the reaction proceeds. Yield is about how much product is formed and is related to position of equilibrium.

1	**Correct.** • At high temperature, more reactant particles move faster and have energy higher than activation energy, resulting in a faster reaction.
2	**Incorrect.** • At high temperature, position of equilibrium of the reaction shifts to the left to favour the endothermic backward reaction to remove excess heat, resulting in a lower yield.
3	**Incorrect.** • Pressure does not affect rate constant as rate constant is only affected by activation energy and temperature.
4	**Correct.** • Presence of a catalyst lowers the activation energy, thus rate constant increases, resulting in a faster reaction.

Question 14 (B)

$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$

$\Delta G^{\ominus} = (-\Delta S^{\ominus})T + \Delta H^{\ominus}$

$y \;=\; (m)x + c$

The correct graph should have a positive y-intercept since the reaction is endothermic ($\Delta H^{\ominus} > 0$). Options B and C are possible answers.

At high T, the ratio of [products]/[reactants] at equilibrium is lower than 1 means that there are more reactants than products. Therefore, the position of equilibrium lies to the left, thus $\Delta G^{\ominus}$ must be greater than 0 at high T.

Question 15 (D)

$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$ equilibrium 1

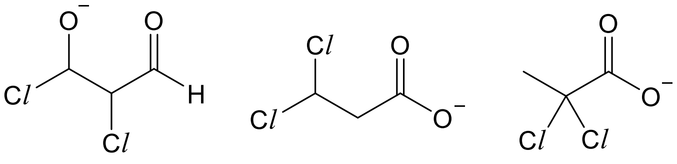
Option A is incorrect as water is neutral at all temperature since $[H^+]$ is still equals to $[OH^-]$ regardless of temperature.

Increasing temperature increases K_w i.e. the position of equilibrium 1 to shift to the right,

- favouring the forward reaction that is endothermic, thus option B is incorrect.
- implying that there is less water molecules and more ions, thus option C is incorrect.

Option D is correct as temperature increases from 293 K to 303 K, K_w increases, thus pK_w decreases and pOH = ½ pK_w decreases, thus $[OH^-]$ increases.

Question 16 (C)



R' < **P'** < **Q'**

increasing stability of conjugate bases,
hence increasing acidity of corresponding acid,
increasing K_a and decreasing pK_a

Conjugate base of **Q** and **P** are more stable than that of **R** as the carboxylate anions are resonance-stabilised while the alkoxide anion in **R'** is not. Conjugate base of **Q** is the most stable as it has two electronegative chlorine atoms nearest to the

–COO⁻ which can disperse the negative charge to a greater extent through electron withdrawing inductive effects.

Question 17 (C)

Amount of NaOH added $= \frac{30}{1000} \times 1 = 0.0300\,mol$

Amount of ethanoic acid added

$= \frac{35}{1000} \times 1 = 0.0350\,mol$

$NaOH + CH_3COOH \rightarrow CH_3COONa + H_2O$

NaOH is the limiting reagent, thus 0.03 mol of ethanoate is formed and 0.005 mol of ethanoic acid is in excess.

Using $pH = pK_a + \lg\left(\frac{[conjugate\ base]}{[weak\ acid]}\right)$,

$$pH = -\lg(1.8 \times 10^{-5}) + \lg\left(\frac{\frac{0.03}{total\ volume}}{\frac{0.005}{total\ volume}}\right) = 5.52$$

Thus, statement 1 is incorrect.

Statement 2 is correct as the effective buffer range = $pK_a \pm 1$ and 5.52 is within 4.74 ± 1.

Statement 3 is incorrect as there is more conjugate base (CH_3COO^-) than weak acid (CH_3COOH) so the buffer can better resist pH changes when a small amount of acid is added.

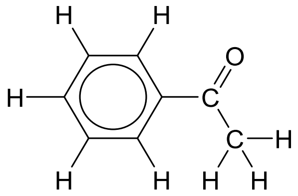
Question 18 (A)

$Hg_2Br_2(s) \rightleftharpoons Hg_2^{2+}(aq) + 2Br^-(aq)$

Let s be the solubility of Hg_2Br_2

$$K_{sp} = 6.4 \times 10^{-23} = [Hg_2^{2+}][Br^-]^2$$
$$= (s)(2s)^2 = 4s^3$$
$$s = (6.4 \times 10^{-23} \div 4)^{\frac{1}{3}} = 2.52 \times 10^{-8}\ \text{mol dm}^{-3}$$

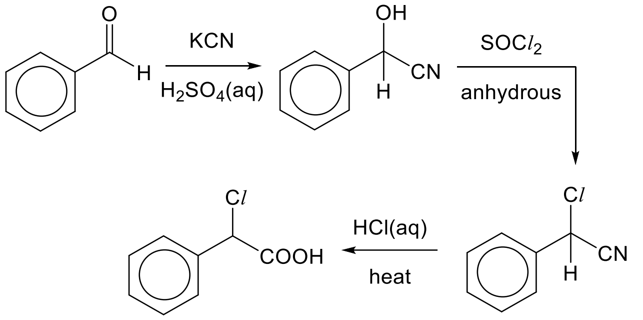
Question 19 (D)



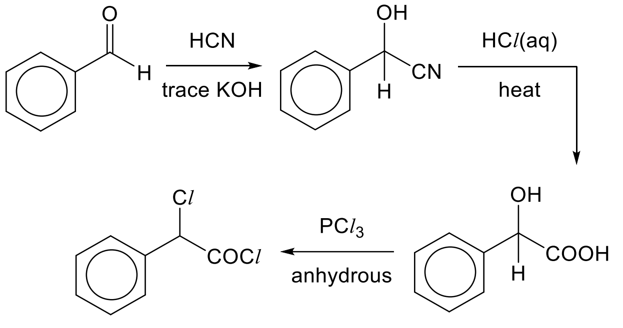
17 σ **bonds**	• 5 C–H bonds on benzene • 3 C–H bonds on $-CH_3$ • 6 C–C bonds on benzene • 1 $C_{benzene}–C_{ketone}$ • 1 $C_{ketone}–C_{ketone}$ • 1 C–O
8 π **electrons**	• 6 from π e⁻ cloud of benzene • 2 from C=O π bond

Question 20 (A)

(A)

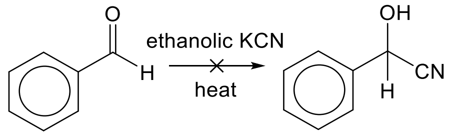


(B)



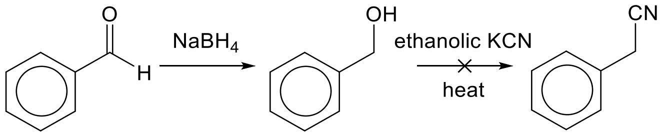
not intended product

(C)



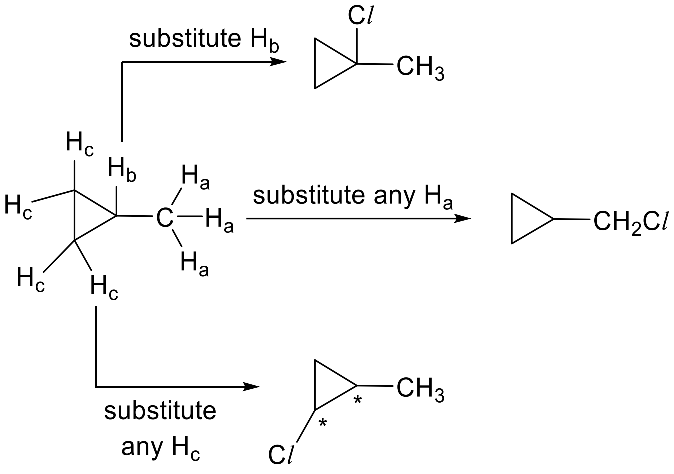
ethanolic KCN, heat is used for nucleophilic substitution of halogenoalkanes, not nucleophilic addition of carbonyls

(D)

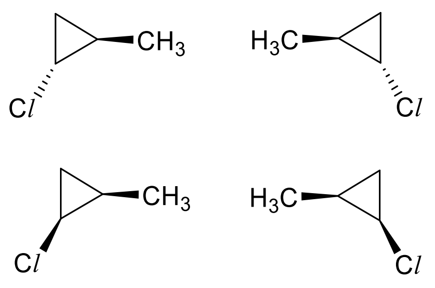


alcohols do not undergo nucleophilic substitution with ethanolic KCN

Question 21 (C)



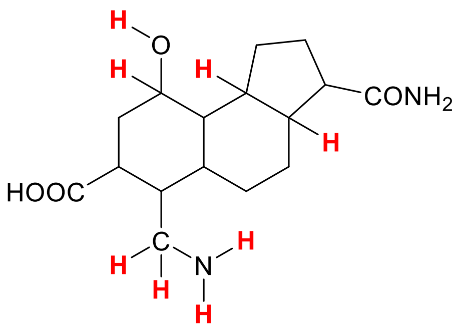
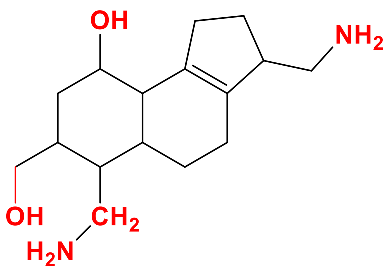
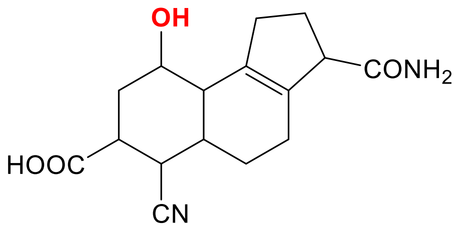
2 chiral centres = max 2^2 stereoisomers
Of the 4 possible stereoisomers shown below, none of them contain a plane of symmetry (which would make some of the stereoisomers identical) i.e. no meso compounds present.



Question 22 (C)

A	**Incorrect.** Both **V** and **W** will not react with Na_2CO_3(aq) as there are no carboxylic acid functional group present.
B	**Incorrect.** Both **V** and **W** will decolourise purple $KMnO_4$ as **V** undergoes benzene side chain oxidation while **W** undergoes oxidative cleavage of alkene. No CO_2 gas is evolved in the reactions with **V** and **W**.
C	**Correct.** Only **V** will react with neutral $FeCl_3$(aq) to give a violet colouration due to presence of phenol. **W** does not react with neutral $FeCl_3$(aq).
D	**Incorrect.** Both **V** and **W** will decolourise orange Br_2(aq). The phenol group in **V** undergoes electrophilic substitution with Br_2(aq) while the alkene group in **W** undergoes electrophilic addition with Br_2(aq).

Question 23 (D)

1	**Incorrect.** 8 hydrogen atoms will be incorporated since H_2, Pt reduces the ketone, alkene and nitrile. 
2	**Incorrect.** 2 primary amine groups will be formed as $LiAlH_4$ reduces the ketone, carboxylic acid, nitrile and amide but not the alkene. 
3	**Correct.** $NaBH_4$ can only reduce aldehydes (not present in this molecule) and ketone and only 1 secondary alcohol group is formed. 

Question 24 (A)

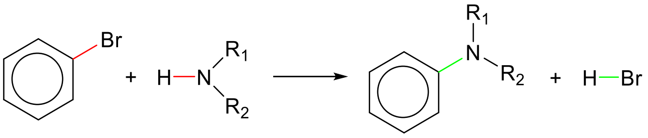
Take note that **equal amounts** (i.e. equal no. of moles) of **X** and **Y** were used and the y-axis of the graph is the **mass** of precipitate formed.

1	**Correct.** Both **X** and **Y** are primary alkyl halides which react via S_N2 mechanism. **Y** is more sterically hindered and will react slower. Since the ppt formed for both **X** and **Y** is $AgCl$, the mass of ppt formed will be the same.
2	**Correct.** **X** is an acyl chloride while **Y** is primary alkyl halide. Acid chlorides undergo hydrolysis significantly faster than alkyl halides as the sp^2 carbon atom is less

	hindered and more electron deficient as it is bonded to electronegative atoms (O and C*l*). Since the ppt formed for both **X** and **Y** is AgC*l*, the mass of ppt formed will be the same.
3	**Incorrect. X** will undergo hydrolysis faster due to weaker C−Br bond as compared to C−C*l* bond in **Y**. If 1 mol of **X** and 1 mol of **Y** were used, 1 mol of AgBr and 1 mol of AgC*l* will be formed respectively i.e. equal moles of ppt are formed. However, since the molar masses of AgBr and AgC*l* are different, the mass of ppt formed will not be the same.

Question 25 (B)

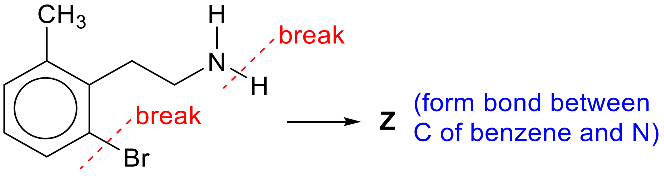
This is a pattern recognition question, where the question teaches you about an unseen reaction. The way to approach such a question is to use the example given to identify what **bonds** have been **formed and broken**, and that knowledge to apply it to the question given.

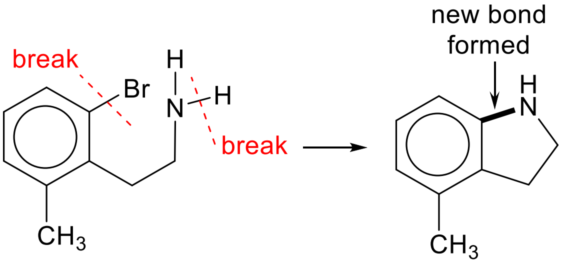


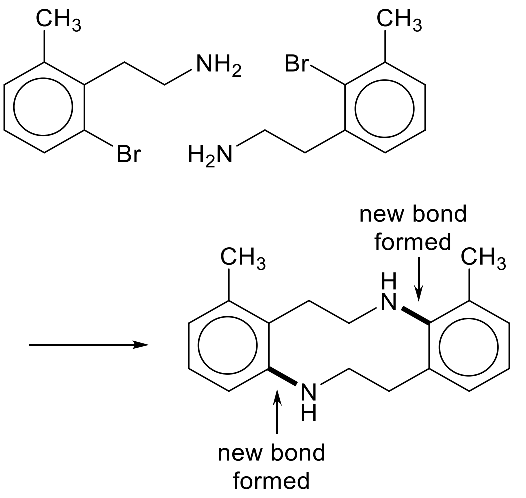
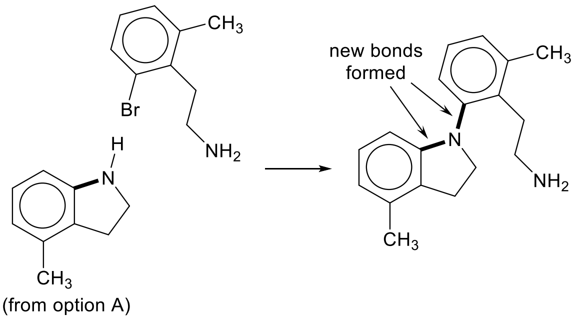
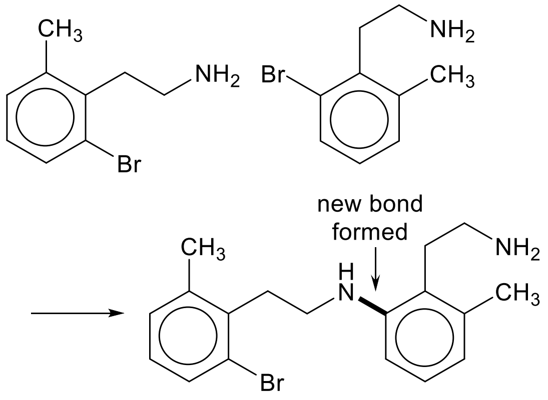
Bonds broken = C–Br and N–H

Bonds formed = C–N and H–Br

Apply this to the structure given.



A	Possible structure for **Z**, intramolecular reaction 

B	Not possible. **this is not the compound given in the question** 
C	Possible structure for **Z**, can be formed from product in Option A with another reactant. 
D	Possible structure for **Z** 

Question 26 (A)

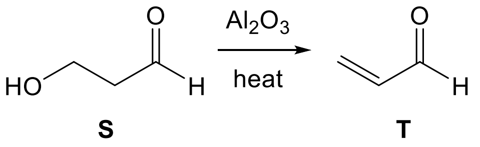
S gives an orange ppt with 2,4-DNPH implies that an aldehyde or ketone is present.

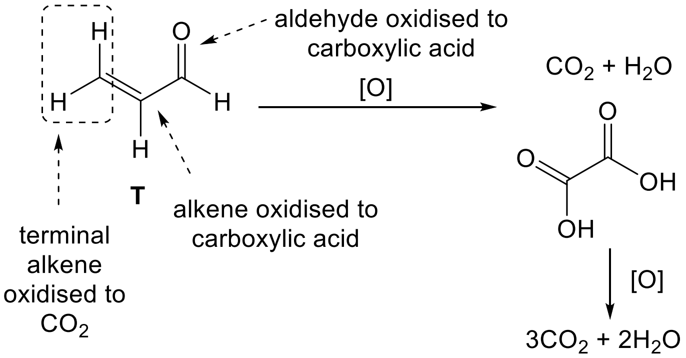
S reacts with aluminium oxide, to give **T** as the only organic compound formed implies that **S** contains alcohol functional group which undergoes elimination of water to form an alkene in **T**. 1 mol of **T** reacts with 1 mol of Br_2(aq) implies that there is only 1 C=C.

T reacts with hot acidified potassium manganate(VII) to give no organic product implies that all the carbon atoms are lost as carbon dioxide.

Through a process of guessing a structure and checking it against the information above, we can eliminate the possibility of a ketone and tertiary alcohol.

The following scheme shows **S** and **T** which satisfy the information provided.





Question 27 (B)

Explanation comes after question 30.

Question 28 (D)

X ($C_9H_{12}O_2$)

- C:H ≈ 1:1 and the products formed after **X** reacts with acidified $K_2Cr_2O_7$ contains a benzene ring.

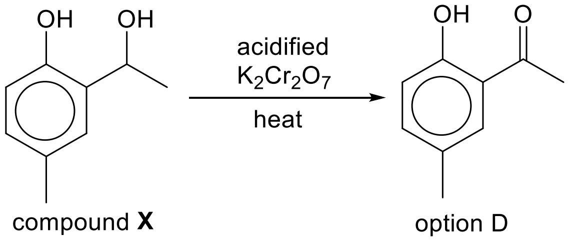
X gives yellow ppt with alkaline aqueous iodine

- **X** contains either –$COCH_3$ and/or –$CH(OH)CH_3$

X decolourises Br_2 in CCl_4

- **X** contains either a phenol or alkene

Students should make use of the structures in the options and work "backwards" to find a structure for **X** which satisfy the conditions above.

A	**Incorrect**. This structure has 8 carbons i.e. one carbon has been lost as CO_2 when **X** was oxidised with $K_2Cr_2O_7$. However, this is not possible as $K_2Cr_2O_7$ cannot oxidise alkenes, nor benzene side chain. Therefore, there is no possible structure of **X** that gives option A when reacted with acidified $K_2Cr_2O_7$.
B	**Incorrect**. This structure, B, has 9 carbons i.e. all carbons in **X** are still present in this structure. We know that **X** contains an alkene or a phenol due to **X** decolourising Br_2. The structure of **X** that gives B cannot contain an alkene, since all 9 carbons in **X** are present in B. Since $K_2Cr_2O_7$ does not affect phenols, the absence of phenol in B would mean that there was no phenol in X. Hence, there is no possible structure of **X** that gives option B when reacted with acidified $K_2Cr_2O_7$.
C	**Incorrect**. Same explanation as A.
D	**Correct**. This structure, D, has 9 carbons i.e. all carbons in **X** are still present in this structure. The phenol in D was inherited from **X**. Therefore, **X** contains a phenol which allows it to decolourise Br_2(aq). Since D was obtained by oxidising **X** with $K_2Cr_2O_7$, the –$COCH_3$ in D could have been a –$CH(OH)CH_3$ in **X**. Therefore, a possible structure of **X** that gives D is shown below.  This structure of **X** satisfies the molecular formula, decolourises Br_2 and gives a positive iodoform test.

Question 29 (A)

$N_2(g) + 4H_2O(l) + 4e^- \rightleftharpoons N_2H_4(aq) + 4OH^-(aq)$ $E^{\ominus} = -1.16V$ equilibirum 1
$N_2H_4(aq) + 2H_2O(l) + 2e^- \rightleftharpoons 2NH_3(aq) + 2OH^-(aq)$ $E^{\ominus} = +0.10$ V equilibirum 2

Since +0.10 V > −1.16V, N_2H_4/NH_3 half-cell undergoes reduction and N_2/N_2H_4 half-cell undergoes oxidation.

For N_2/N_2H_4 half-cell: $N_2H_4(aq) + 4OH^-(aq) \rightarrow N_2(g) + 4H_2O(l) + 4e^-$
For N_2H_4/NH_3 half-cell: $N_2H_4(aq) + 2H_2O(l) + 2e^- \rightarrow 2NH_3(aq) + 2OH^-(aq)$
Overall reaction: $3N_2H_4(aq) \rightarrow N_2(g) + 4NH_3(aq)$

Statement 1 is correct. $E^{\ominus}_{cell} = E^{\ominus}_{cathode} - E^{\ominus}_{anode} = +0.10 - (-1.16) = +1.26$ V > 0, thus overall reaction (decomposition of $N_2H_4(aq)$) is spontaneous.

Statement 2 is correct. Increasing pH increases $[OH^-(aq)]$ and by LCP, position of equilibrium 1 will shift to the left, making the E_{anode} less positive (or more negative) and thus $E_{cell} > E^{\ominus}_{cell}$.

Statement 3 is correct. Addition of water will cause the position of equilibrium 2 to shift to the right (side with more aqueous species), making the $E_{cathode}$ more positive and thus $E_{cell} > E^{\ominus}_{cell}$. Note that, addition of water does not increase the $[H_2O(l)]$ as $[H_2O(l)]$ is a constant.

Question 30 (B)

From *Data Booklet*,
$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$ $E^{\ominus} = -0.83V$
$2H^+ + 2e^- \rightleftharpoons H_2$ $E^{\ominus} = 0.00$ V

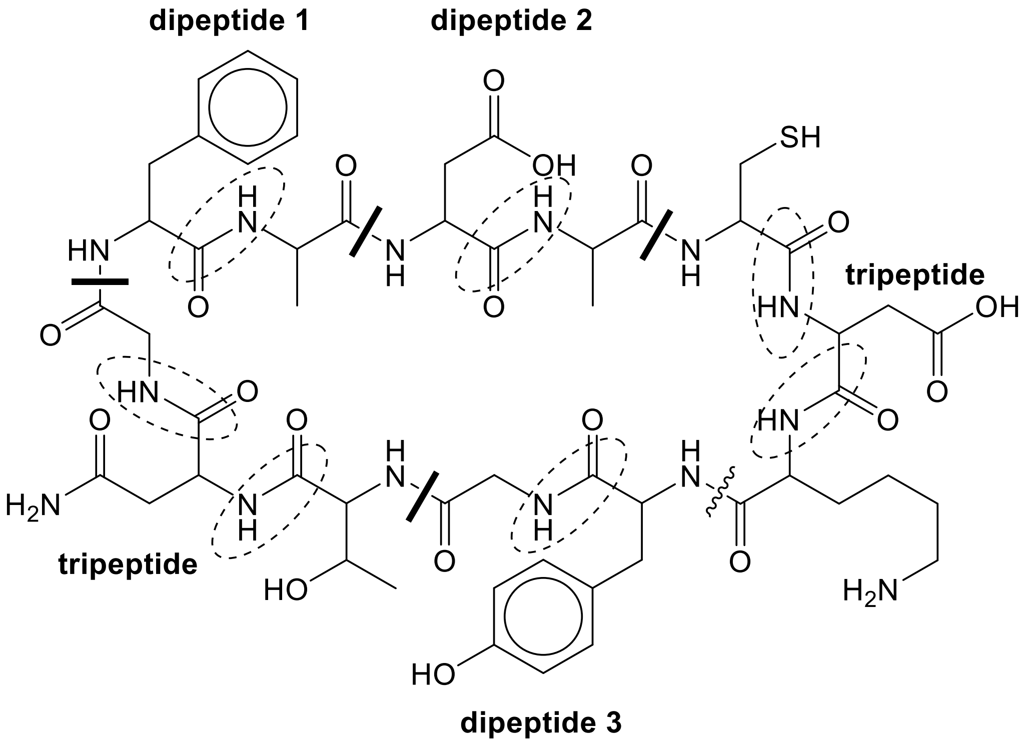
For H^+/ H_2 half-cell: $2H^+ + 2e^- \rightarrow H_2$ (cathode, reduction)
For H_2O/ H_2 half-cell: $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ (anode, oxidation)
Overall reaction: $2H^+ + 2OH^- \rightarrow 2H_2O$

$E^{\ominus}_{cell} = E^{\ominus}_{cathode} - E^{\ominus}_{anode} = 0.00 - (-0.83) = +0.83$ V

$\Delta G^{\ominus}$ for $2H^+ + 2OH^- \rightarrow 2H_2O = -nFE^{\ominus} = -(2)(96500)(+0.83) = -160.2$ kJ mol^{-1}

$\Delta G^{\ominus}$ of neutralisation i.e. $\Delta G^{\ominus}$ for $H^+ + OH^- \rightarrow H_2O$ i.e. $= -80.1$ kJ mol^{-1}

Question 27 (B)



〰 represents peptide bond hydrolysis by enzyme Y

— represents peptide bond hydrolysis by enzyme Z

⬭ represents unhydrolyzed peptide bond remaining

Note: 1 dipeptide consists of 2 amino acid residues and only 1 amide bond