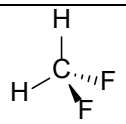
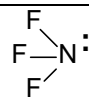
2023 H2 Chemistry Preliminary Examinations Paper 1 Suggested Solutions

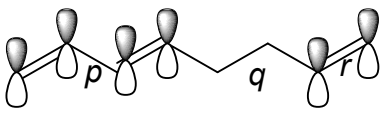
1	2	3	4	5	6	7	8	9	10
D	D	A	A	B	D	C	D	C	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
C	B	B	C	C	C	C	B	D	C
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
D	C	D	D	B	B	A	D	B	B

1 (D)

	shape	structure	polar molecule?
CH_2F_2	tetrahedral (4 bond pairs)		yes
SF_4	see-saw (4 bond pairs, 1 lone pair)		yes
NF_3	trigonal pyramidal (3 bond pairs, 1 lone pair)		yes
BeF_2	linear (2 bond pairs)	F–Be–F	no

2 (D)

r is a carbon-carbon double bond hence it is stronger than q, which is a carbon-carbon single bond. p has partial double bond character due to continuous side-on overlap of 4 p-orbitals (see diagram). Hence it is stronger than a carbon-carbon single bond but weaker than a carbon-carbon double bond.



3 (A)

Substances with giant covalent structure *generally* <u>do not</u> conduct electricity *in all physical states* since all its valence electrons are used up for covalent bonding.

4 (A)

The largest increase in ionisation energy occurs between the 9th and 10th ionisation energy. The largest ionisation energy is used to remove the 10th electron. Hence, the 10th electron is from an inner shell, which experiences stronger electrostatic forces of attraction with the nucleus.

Since there are 9 outer electrons, there must be 8 in n = 2 electron shell and 1 electron in n = 3 valence electron shell.

As such, the element must be in Group 1 and it would be Na.

5 (B)

Down the group, nuclear charge and shielding effect increase. The increase in the number of protons does not explain the increase in atomic radius of the elements (Option 1 is incorrect).

The increase in the number of electronic shells increases the distance between the valence electron and nucleus, which result in a net <u>decrease</u> in strength of electrostatic forces of attraction between the nucleus and valence electrons (option 2 is correct; option 3 is incorrect)

6 (D)

For graphs of V against T,

$pV = nRT \Rightarrow V = (\frac{nR}{p})\ T$

V is directly proportional to T, i.e. V vs T graph is a straight line with a positive gradient.

Since X has a higher mass (i.e. higher n), the gradient ($\frac{nR}{p}$) for X will be steeper (than Y).

For graphs of (pV/T) against p,

$pV = nRT \Rightarrow (pV/T) = nR$

The graph would show a horizontal line, with y-intercept = nR.

A	Incorrect**.** Since X has a higher n, X should have a higher y-intercept value than Y.
B	Incorrect, because the shape of the graph is incorrect.
C	Incorrect, because the shape of the graph is incorrect.

7 (C)

Since X is a period 3 chloride and forms a solution with a pH of 3, X is likely to be $AlCl_3$ and the solution contains Al^{3+} ions. When $NH_3(aq)$ is added to Al^{3+} ions, a white ppt of $Al(OH)_3$ is formed, which is insoluble in excess $NH_3(aq)$.

8 (D)

The stronger the H–X bond strength, the more thermally stable the hydrogen halide.
Down Group 17, the H–X bond strength decreases. Thus, the thermal stability of the hydrogen halides <u>decreases</u>.

Halogens tend to undergo reduction and act as oxidising agents in redox reactions. Down the group, the tendency of the halogen gaining electrons decreases as can be seen by their less positive $E^{\ominus}$ values. Hence, the oxidising power of the halogens <u>decreases</u> down the group.

9 (C)

A	9.60 g of ozone: $\frac{9.6}{48} = 0.2$ mol of O_3
B	14.2 g of chlorine: $\frac{14.2}{71} = 0.2$ mol of Cl_2
C	2.41×10^{23} molecules of methyl ethanoate: $\frac{2.41 \times 10^{23}}{6.02 \times 10^{23}} =$ 0.4 mol of $CH_3CO_2CH_3$
D	2.40 dm^3 of carbon dioxide: $\frac{2.4}{24} = 0.1$ mol of CO_2

10 (B)

1	Correct. Since cerium (IV) sulfate is an oxidising agent, it oxidises H_2O_2 to O_2 as shown in the following half-equation: $H_2O_2 \rightarrow O_2 + 2H^+ + 2e^-$. The gas given off is O_2.
2	Correct. Since the mole ratio of the reaction between Ce^{4+} and H_2O_2 is **2**:**1**, the 2 mol of e^- released from H_2O_2 must react with 2 mol of Ce^{4+}. **2**Ce^{4+} + <u>$2e^-$</u> $\rightarrow$?? **1**$H_2O_2 \rightarrow O_2 + 2H^+$ + <u>$2e^-$</u> i.e. **2**Ce^{4+} + <u>$2e^-$</u> $\rightarrow$ **2**Ce^{3+} The final oxidation state of Ce is +3.
3	Incorrect. The overall reaction is $H_2O_2 + 2Ce^{4+} \rightarrow 2Ce^{3+} + O_2 + 2H^+$. If $KMnO_4$ were used as the titrant, the titration reaction would be $2MnO_4^- + 5H_2O_2 + 6H^+ \rightarrow 2Mn^{2+} + 5O_2 + 8H_2O$ From the two equations, 1 mole of H_2O_2 requires 2 moles of Ce^{4+} but only requires $\frac{2}{5}$ moles of MnO_4^-. Hence, for the same concentration of titrant, the titre volume would be smaller than 25.00 cm^3.

11 (C)

Number of moles of $Ba(OH)_2 = \frac{20.0}{1000} \times 1.00 = 0.02$ mol

Number of moles of $CH_3COOH = \frac{20.0}{1000} \times 2.50 = 0.05$ mol

$2CH_3COOH + Ba(OH)_2 \longrightarrow Ba(CH_3COO)_2 + 2H_2O$

Since $Ba(OH)_2$ is the limiting reagent, amount of $H_2O = 0.04$ mol
Total volume = 20.0 + 20.0 = 40.0 cm^3

$q = mc\Delta T = 40.0 \times 4.18 \times (37.5 - 25) = 2090$ J

$\Delta H_n^{\ominus} = -\frac{2090}{0.04} = -52250$ J $mol^{-1} = -52.3$ kJ mol^{-1}

12 (B)

A	Incorrect. Hydration is an exothermic process as ion-dipole interactions are formed between water molecules and the ions.
B	Correct. Energy is required for the formation of gaseous atoms in atomisation.
C	Incorrect. The enthalpy change of formation can be either exothermic or endothermic.
D	Incorrect. The enthalpy change of solution can be either exothermic or endothermic.

13 (B)

1	Correct. The increase in temperature favours the backward endothermic reaction, thus decreasing the yield of NH_3.
2	Correct. Increasing the volume, decreases the total pressure. Hence, the backward reaction is favoured as it produces more gas particles, thus decreasing the yield of NH_3.
3	Incorrect. A catalyst speeds up the rate of both the forward and backward reactions by the same extent. The yield of NH_3 is, therefore, unaffected.

14 (C)

From the slow step, rate α $[N_2O_2][O_2]$
From step 1, the rate of formation of N_2O_2 depends on [NO] i.e. $[N_2O_2]$ α $[NO]^2$

rate α $[N_2O_2][O_2]$
rate α $[NO]^2[O_2]$
rate = $k[NO]^2[O_2]$

1	Correct. The overall order is 2+1 = 3.
2	Incorrect. The rate equation contains both NO and O_2.
3	Correct. Summing up both steps gives the overall equation $2NO + O_2 \rightarrow 2NO_2$. If the reaction occurred via single-step mechanism, then the overall equation is also the equation of the slow step. In that case, the rate equation is rate = $k[NO]^2[O_2]$.

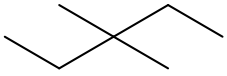
15 (C)

A	Incorrect. During auto-ionisation of water, $H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$, equimolar H^+ and OH^- will be produced, causing $[H^+] = [OH^-]$,
B	Incorrect. Since $K_w = [H^+][OH^-]$, $[H^+] = \sqrt{K_w}$ At 30 °C, $[H^+] = \sqrt{1.44 \times 10^{-14}} = 1.20 \times 10^{-7}$ mol dm^{-3}
C	Correct. Since $[H^+] = 1.2 \times 10^{-7}$ mol dm^{-3}, pH = $-\lg(1.20 \times 10^{-7}) = 6.92 < 7$.
D	Incorrect. Since $[H^+] = 1.2 \times 10^{-7}$ mol dm^{-3}, pH = $-\lg(1.20 \times 10^{-7}) = 6.92 < 7$.

16 (C)

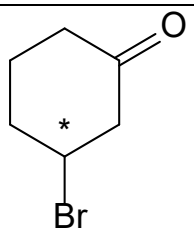
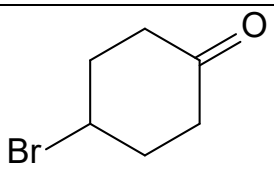
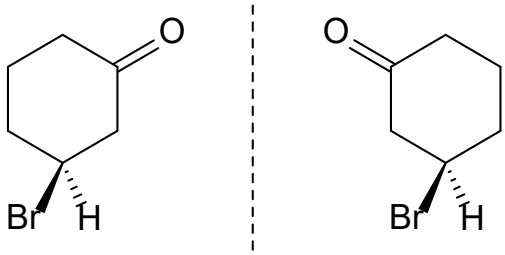
As the range of rapid pH change is unknown, the best indicator can only be determined using the pH at equivalence (pH 8.72). Thymol blue is the choice of indicator as the pH of equivalence lies within the pH range for its colour change.

17 (C)

A	Incorrect. HBr is formed during the <u>propagation</u> step.
B	Incorrect. Hexane is <u>not</u> a suitable solvent for the reaction because hexane can also undergo free radical substitution with the reactant Br_2. This generates undesirable products.
C	Correct. The reaction only involves homolytic fission and fusion.
D	Incorrect. $CH_3CH_2C(CH_3)_2CH_2CH_3$ is <u>not</u> produced from the reaction. $CH_3CH_2C(CH_3)_2CH_2CH_3$ refers to 

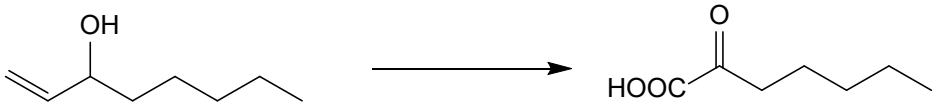
18 (B)

The reaction produces 2 possible products (which are structural isomers) and have the following structures.

<table>
<tr><td>  </td><td>  </td></tr>
<tr><td colspan="2">Next, consider the number of stereoisomers from each of the structural isomers.</td></tr>
<tr><td>  </td><td>does not exhibit enantiomerism because it has no chiral centres and contains a plane of symmetry</td></tr>
<tr><td>This product can exist as two enantiomers</td><td>This product does not have stereoisomers.</td></tr>
</table>

Therefore, total number of isomers = 2 + 1 = 3

19 (D)



M_r: 128.0

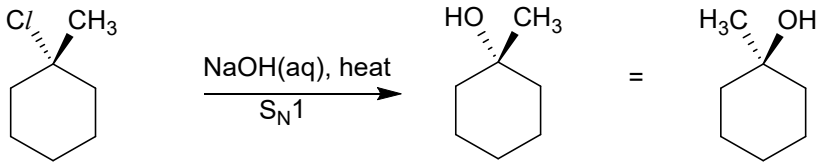
contains 2 sp^2 C

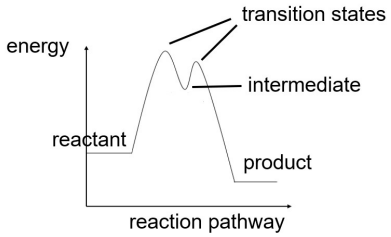
M_r: 144.0

contains 2 sp^2 C

A	Incorrect. Octenol has a <u>lower</u> molecular mass than Z.
B	Incorrect. Octenol and Z <u>cannot</u> be distinguished by addition of PCl_5, because both give white fumes of HCl when reacted with PCl_5.
C	Incorrect. Z <u>cannot</u> be formed by heating octenol with acidified $K_2Cr_2O_7$ because $K_2Cr_2O_7$ is a weaker oxidising agent and does not cleave the C=C bond.
D	Correct. Octenol and Z both contain two sp^2 hybridised carbons.

20 (C)



1	Incorrect. Compound Q has a plane of symmetry and does not have a chiral centre. The product of this reaction also does not have a chiral centre and, hence, it does not contain a 1:1 mixture of 2 enantiomers i.e. it is not a racemix mixture.
2	Correct. S_N1 reaction proceeds through the formation of two transition states. 
3	Incorrect. Since the reaction proceeds via an S_N1 mechanism, only compound Q is in the slow step. Increasing the concentration of sodium hydroxide would not increase the rate of reaction.

21 (D)

1	Incorrect. Bromoethane and chloroethane do not react with aqueous ethanolic silver nitrate to give white fumes in the absence of heat. When heated, both compounds will form a ppt with silver nitrate. However, no ppt was seen after heating.
2	Incorrect. Benzoyl iodide reacts with aqueous ethanolic silver nitrate to give white fumes of HI and AgI ppt. Upon heating, chloroethane will undergo nucleophilic substitution to release Cl^- which will ppt to form AgCl. AgCl will dissolve upon addition of excess ammonia, <u>but AgI will remain.</u>
3	Correct. Benzoyl chloride reacts with aqueous ethanolic silver nitrate to give white fumes of HCl and AgCl ppt. Upon heating, iodobenzene will not undergo nucleophilic substitution due to the partial double bond character of C–I i.e. no I^- is released to form AgI ppt. The AgCl ppt will dissolve upon addition of excess ammonia.

22 (C)

In the conversion, only the ketone is reduced to a secondary alcohol. The carboxylic acid and alkene needs to remain unaffected.

A	Incorrect. $LiAlH_4$ will also reduce the carboxylic acid group.
B	Incorrect. H_2 will also reduce the alkene (C=C).
C	Correct. $NaBH_4$ only reduces aldehydes or ketones.
D	Incorrect. Sn, conc. HCl, heat are the reagents and conditions to reduce nitrobenzene.

23 (D)

1	Correct. Hot acidified $K_2Cr_2O_7$ will hydrolyse (acidic hydrolysis) the ester bond and oxidise the secondary alcohol in the 1st compound but not the tertiary alcohol in the 2nd compound.
2	Incorrect. Hot acidified $KMnO_4$ cannot be used as both compounds have side-chains on the benzene ring that can be oxidised.
3	Incorrect. Br_2 (aq) cannot be used as both compounds have a phenol group, which will be brominated (di-brominated for 1st compound but mono-brominated for 2nd compound).
4	Correct. I_2, NaOH (aq), heat will hydrolyse (basic hydrolysis) the ester bond and produce a yellow CHI_3 precipitate with the alcohol group in the 1st compound but not the alcohol group in the 2nd compound.

24 (D)

Acidity: $CH_3COOH > C_6H_5OH > CH_3CH_2OH$

In general, $HA + H_2O \rightleftharpoons H_3O^+ + A^-$

The acidity of a compound depends on the relative stability of its conjugate base anion (A^-). The more stable the conjugate base, the more acidic the compound will be.

In the ethanoate ion ($CH_3CO_2^-$), the negative charge on oxygen is dispersed over the two highly electronegative oxygen atoms resulting in two equivalent resonance structures. Hence, $CH_3CO_2^-$ ion is resonance-stabilised to a larger extent than $C_6H_5O^-$ ion.

In the phenoxide ion ($C_6H_5O^-$), the p-orbital of O overlaps with the π-electron cloud of the benzene ring so that the negative charge on O disperse into the benzene ring. The dispersal of negative charge stabilises $C_6H_5O^-$ ion but this resonance stabilisation is not as great as that in the $CH_3CO_2^-$ ion.

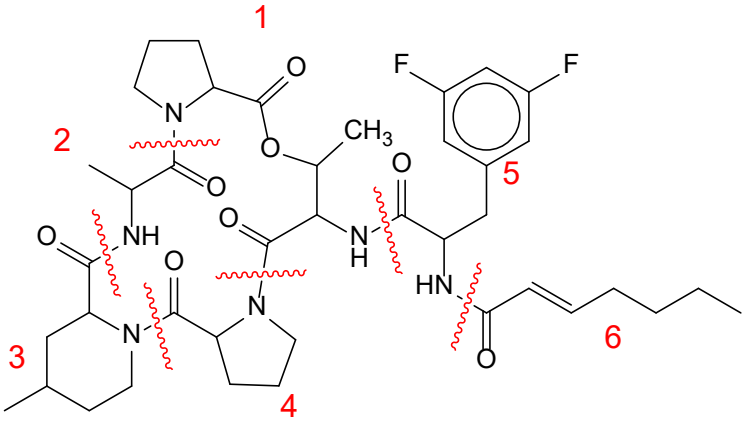
In the ethoxide ion ($CH_3CH_2O^-$), the electron-donating alkyl (ethyl) group intensifies the negative charge on O atom, which destabilises $CH_3CH_2O^-$ ion. Therefore, $CH_3CH_2O^-$ is the least stable.

25 (B)

1	Incorrect. Only aliphatic aldehydes give a brick-red precipitate with Fehling's solution, so aromatic aldehyde X will not.
2	Correct. Only the aldehyde group in X can undergo nucleophilic addition with HCN, so 1 mol of X will react with 1 mol of HCN.
3	Incorrect. The carboxylic acid group in 1 mol of X reacts with excess sodium metal to give 0.5 mol of hydrogen gas instead of 1 mol. $RCOOH + Na \rightarrow RCOO^-Na^+ + \frac{1}{2} H_2$

26 (B)

6 fragments will be produced upon hydrolysing the peptide bonds (amide bonds). Note that the peptidase enzyme does **not** hydrolyse ester bonds.



27 (A)

$E^\ominus(H^+/H_2) = 0.00$ V and $E^\ominus(Cr^{3+}/Cr) = -0.74$ V

Since $E^\ominus(H^+/H_2)$ is more positive than $E^\ominus(Cr^{3+}/Cr)$, H^+/H_2 electrode is the cathode while Cr^{3+}/Cr electrode is the anode.

Under standard conditions, $E^\ominus_{cell} = 0.00 - (-0.74) = +0.74$ V

For E_{cell} (+0.77 V) to be more positive than $E^\ominus_{cell}$ (+0.74 V), either $E_{cathode}$ has become more positive, or E_{anode} has become more negative.

A	Correct. The decrease in $[Cr^{3+}]$ from the standard concentration of 1.0 mol dm^{-3} causes E_{anode} to become more negative, hence E_{cell} is more positive than $E^\ominus_{cell}$.
B	Incorrect. An increase in pressure of H_2 from 1 bar to 2 bar causes $E_{cathode}$ to become less positive, hence E_{cell} is less positive than $E^\ominus_{cell}$.
C	Incorrect. Since ethanoic acid is a weak acid which only partially dissociates in aqueous solution, $[H^+] < 1.0$ mol dm^{-3}, hence $E_{cathode}$ is less positive, hence E_{cell} is less positive than $E^\ominus_{cell}$.
D	Incorrect. Changes to electrode sizes do not affect E values.

28 (D)

Since $E^{\ominus}(O_2/OH^-)$ is more positive than $E^{\ominus}(Al(OH)_3/Al)$, the air electrode is the cathode while the aluminium electrode is the anode. Hence electrons flow from the aluminium electrode to the air electrode.

$E^{\ominus}_{cell} = 0.40 - (-2.31) = +2.71$ V

$\Delta G^{\ominus} = -nFE^{\ominus} = -(12)(96500)(2.71) = -3138\ 000$ J mol^{-1} = –3140 kJ mol^{-1}

29 (B)

At the cathode, $2H^+ + 2e^- \rightarrow H_2$

No. of moles of $H_2 = \frac{302}{24000} = 0.01258$ mol

No. of moles of electrons, $n_e = 2 \times 0.01258 = 0.02516$ mol

$Q = It = n_e \times 6.02 \times 10^{23} \times$ charge on 1 electron

$(1.22)(30 \times 60) = 0.02516 \times 6.02 \times 10^{23} \times$ charge on 1 electron

charge on 1 electron = 1.45×10^{-19} C

30 (B)

1	Incorrect. From the Data Booklet, the atomic radius of a transition element like V (0.135 nm) is smaller than that of an s-block element like Ca (0.197 nm) in the same period.
2	Incorrect. The melting point of V is higher than Ca due to stronger metallic bonding, as both the 3d and 4s electrons of V can contribute to the 'sea' of delocalised electrons.
3	Correct. V as a transition element can display variable oxidation states when it forms compounds (by using its 3d and 4s electrons for bonding), unlike Ca, which only exists in the +2 oxidation state by losing 2 valence electrons.