HWA CHONG INSTITUTION
2021 C2 H2 CHEMISTRY PRELIMINARY EXAM
SUGGESTED SOLUTIONS

ANSWERS:

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

Comments

1 B

In order to find the number of valence electrons in the **G**$^+$ ion, we take the difference between all the successive ionisation energies to find the one with the greatest difference.

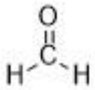
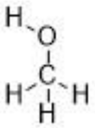
No of electrons removed	1	2	3	4	5	6
Ionisation energy/ kJ mol^{-1}	1907	2914	4964	6274	21 267	25 431
Difference in IE		1007	2050	1310	14993	4164

After analysing the table, we can see that the greatest jump in ionisation energy is when the 5th electron is removed. This means that the **G**$^+$ ion has 4 electrons in its valence shell.

Therefore, **G** would have 5 electrons in the valence shell, and belong to group 15.

2 A

1 HCHO, CH_3OH

<table>
<tr><td>HCHO
</td><td>CH_3OH
</td></tr>
<tr><td>Intermolecular force:
Permanent dipole-permanent dipole interactions</td><td>Intermolecular Force:
Hydrogen bonding</td></tr>
</table>

CH_3OH has the higher boiling point. (strength of dispersion forces similar since number of electrons for each molecule is similar.)

2 BF_3: Simple covalent compound. Dispersion forces present between the non-polar molecules of BF_3.

$\mathrm{A}l\mathrm{F}_3$: Ionic compound. Ionic bonds present between oppositely charged ions.

$\mathrm{A}l\mathrm{F}_3$ has the higher boiling point.

3 $CH_3CH_2CH_2CH_2CH_3$, $C(CH_3)_4$

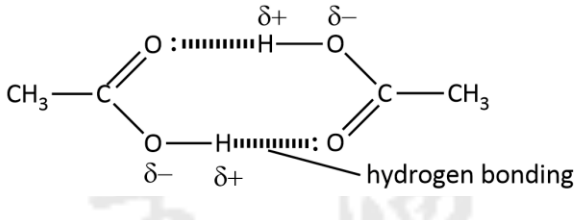
Both compounds are simple non-polar covalent molecules, with same number of electrons. However, $C(CH_3)_4$ is a branched chain hydrocarbon while $CH_3CH_2CH_2CH_2CH_3$ is a straight chain hydrocarbon. $CH_3CH_2CH_2CH_2CH_3$ has linear shape and greater surface area of contact between molecules, hence more extensive dispersion forces. $CH_3CH_2CH_2CH_2CH_3$ has the higher boiling point.

3 **A**

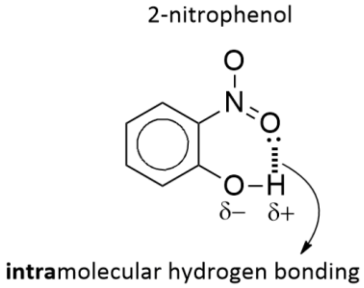
Option **A**: Both NH_3 and HF can form only one hydrogen bond on average per molecule. Hence while it is true that HF has a higher boiling point than NH_3, it is because the hydrogen bonds between HF molecules are stronger than the hydrogen bonds between NH_3 molecules. F more electronegative than N, so there is higher partial positive charge on the H of HF, hence the hydrogen bonds between HF molecules are stronger.

Option **B**: In the solid state, H_2O molecules are held at fixed positions and arranged in an orderly manner to form a regular lattice such that hydrogen bonding is maximised to four per molecule. The hydrogen bonding between water molecules in ice are positioned in a roughly tetrahedral shape around each O atom. This produces an open lattice, with empty spaces between the H_2O molecules. The more random arrangement of hydrogen bonding in liquid water results in H_2O molecules packing much more closely and, together, take up less space. So the lattice structure of ice occupies a larger volume for the same mass of liquid water, hence ice has a lower density than liquid water.

Option **C**: CH_3CO_2H dimerises in non-aqueous solvents as shown in the following diagram.



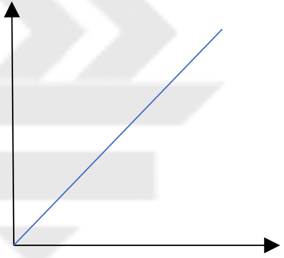
Option **D**: In 2-nitrophenol, the –OH and –NO_2 groups can form intramolecular hydrogen bonding, so there is less extensive intermolecular hydrogen bonding between 2-nitrophenol molecules compared to between 4-nitrophenol molecules. Therefore, less energy is needed to overcome the intermolecular hydrogen bonding for 2-nitrophenol to boil, hence its lower boiling point. (The words 'less extensive' refers to lower average number of hydrogen bonds present in the same mass of 2-nitrophenol molecules *as* compared to 4-nitrophenol molecules.)



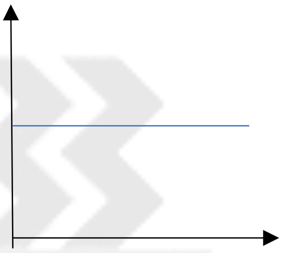
Refer to Section 8.3 on hydrogen bonding in Chemical Bonding Lecture Notes.

4 **C**

For options **A**, **B** and **D**, the graph is a straight line passing through the origin.



For option **C**, the graph is a horizontal line parallel to the x axis.



In order to derive the shape of the graph, start from the ideal gas equation: pV = nRT

For each of the options, find the relationship the different terms have based on the ideal gas equation. E.g. for option B

pV= nRT

Since density = $\frac{mass}{V}$

pV= $\frac{mass}{M_r}$ RT

p= $\frac{mass}{V}\frac{RT}{M_r}$

Since $\frac{RT}{M_r}$ is constant, p is directly proportional to density.

5 C

	C_xH_y (l)	+	$(x+\frac{y}{4})$ O_2 (g)	→	xCO_2 (g)	+	$\frac{y}{2}H_2O$ (l)
Initial gas volume/ cm^3	-		100		-		-
Final gas volume/ cm^3	-		25		60		
Reacting volume/ cm^3			**75**		**60**		

Since the gaseous mixture contracted by 15 cm^3 after the reaction, the total volume of excess O_2 and CO_2 = 85cm^3

When the gaseous mixture was passed through NaOH (aq), the volume of gas contracted another 60cm^3. This implies that the volume of CO_2 is **60 cm^3**.

The volume of excess oxygen is therefore 25cm^3. Hence 100 – 25 = **75 cm^3** of O_2 reacted with the hydrocarbon.

The ratio of vol of O_2 reacted: vol of CO_2 produced = $x+\frac{y}{4}$: x = 75 : 60

Hence the ratio of x: y = 1:1.

Any hydrocarbon with C:H of 1:1 could be the answer.

6 D

1 Relative atomic mass = 0.9499 × 32 + 0.0075 × 33 + 0.0425 × 34 + 0.0001 × 36

2 This is a correct definition.

3 The angle of deflection in an electric field is directly proportional to the charge/ mass ratio. Since the charges of the isotopes are the same (all +1), the lightest isotope will have the largest angle of deflection.

7 B

No. of moles of zinc = 13.1/ 65.4 = 0.200 mol
No. of moles of Cu^{2+} = $\frac{150}{1000} \times 1$ = 0.150 mol

Cu^{2+} is the limiting reagent.

$q = m_{solution}c\Delta T = 150 \times 4.20 \times 15 = 9450$ J

$\Delta H_{rxn} = -\frac{9450}{0.15} = -63\ 000\ J\ mol^{-1} = -63.0\ kJ\ mol^{-1}$

8 C

1 The enthalpy change of neutralisation is defined as the energy evolved when one mole of water is formed from a reaction between an acid and a base. This equation shows the formation of 2 moles of water. Hence this equation is twice that of the enthalpy change of neutralisation.

2 As ethanoic acid is a weak acid, its conjugate base is a weak base that is able to hydrolyse partially in water to give OH^- ions.

$$CH_3CO_2^- + H_2O \rightleftharpoons CH_3CO_2H + OH^-$$

As such the pH of a solution of CH_3CO_2Na is greater than 7.

3 When a weak acid is neutralised by a base, the enthalpy change of neutralisation will be slightly less exothermic as energy is absorbed to ionise the un-ionised weak acid.

9 D

Given the rate equation, rate = $k[BrO_3^-][Br^-][H^+]^2$

To determine **x**:
Since the order with respect to $[H^+]$ is 2, when the $[H^+]$ is doubled from 0.40 to 0.80 mol dm^{-3} in experiment 1 to 2, 1/t will be four times its original value. Hence **x** = 0.10 × 4 = 0.40 s^{-1}.

To determine **y**:
Since the order with respect to $[Br^-]$ is 1, when the $[Br^-]$ is doubled from 0.04 to 0.08 mol dm^{-3} in experiment 1 to 3, 1/t will be double its original value. Hence y = 0.10 × 2 = 0.20 s^{-1}.

To determine **z**:
When $[H^+]$ and $[BrO_3^-]$ are both doubled from experiment 1 to 4, if there is no change to $[Br^-]$, then 1/t would be $0.10 \times 2 \times 2^2 = 0.80$. Since actual 1/t is 1.60 s^{-1}, the $[Br^-]$ must also be higher resulting in a faster rate of reaction.

Compare the initial rate of 0.10 s^{-1} and 1.60 s^{-1} :
Let the multiplication factor of $[Br^-]$ be ***a***
$\boldsymbol{a} \times 2 \times 2^2 = (1.60 \div 0.10)$
$\boldsymbol{a} = 2$

z = 2 × 0.04 = 0.08 mol dm^{-3}

10 D

The overall equation is the sum of all individual steps:
$2\mathbf{A} \rightarrow \mathbf{C}$
$\mathbf{C} + \mathbf{B} \rightarrow \mathbf{D}$
$\mathbf{D} + \mathbf{B} \rightarrow \mathbf{E}$

$\mathbf{2A + 2B} + \cancel{\mathbf{C}} + \cancel{\mathbf{D}} \rightarrow \cancel{\mathbf{C}} + \cancel{\mathbf{D}} + \mathbf{E}$
Overall: $2\mathbf{A} + 2\mathbf{B} \rightarrow \mathbf{E}$
Statement 1 is correct.

The rate equation of the slow step is: rate = $k_2\mathrm{P_B P_C}$
Since the concentration of intermediates do **not** appear in the rate equation, the $\mathrm{P_C}$ is replaced by the $\mathrm{P_A}$ (assuming step is a fast equilibrium) i.e $\mathrm{P_C} = K_1\mathrm{P_A}^2$
Hence, rate = $k\mathrm{P_A}^2\mathrm{P_B}$ where $k = k_2K_1$

This suggests that the initial rate of formation of **E** is proportional to the initial partial pressure of **A**, raised to the power of 2. Thus, statement 3 is correct.

Analysis of the units of the rate constant:
atm $\mathrm{s^{-1}}$ = (Units of k) × $\mathrm{atm^2}$ ×atm
Units of k = $\mathrm{atm^{-2}\ s^{-1}}$
Therefore statement 2 is correct.

11 A

Decreasing the temperature will cause both forward and backward reactions to slow down, hence both rate constants k_f and k_b will decrease. Hence either option **A** or **B** is correct.

Decreasing the temperature will change K_c since K_c is dependent on temperature. Hence option **B** is incorrect and **A** is the answer.

To deduce *how* K_c has changed (whether increase or decrease), we can look at the equilibrium shift. Since the forward reaction is exothermic, based on LCP, a decrease in temperature will favour the forward reaction, and the position of equilibrium will shift to the right. This means that K_c must have increased (such that Q becomes < K when T decreases, and a shift in POE to the right will re-establish the equilibrium.)

12 D

$\mathrm{p}K_{a1} = 1.9$
$K_{a1} = 0.0126$

$$K_{a1} = \frac{[H^+][HSO_3^-]}{[H_2SO_3]}$$

$[\mathrm{H^+}]^2 = K_{a1}[\mathrm{H_2SO_3}]$
$[\mathrm{H^+}]^2 = 0.0126 \times 0.1$ (assuming that $[\mathrm{H^+}] << [\mathrm{H_2SO_3}]_{\mathrm{initial}}$)
$[\mathrm{H^+}] = 0.0355$ mol $\mathrm{dm^{-3}}$
pH = 1.45
Statement **A** is incorrect.

$n(H_2SO_3) = 0.1 \times (25.0/1000) = 2.5 \times 10^{-3}$ mol
Since 1 mol of H_2SO_3 reacts with 2 mol of NaOH to form SO_3^{2-}, n(NaOH) required for complete neutralisation to form $SO_3^{2-} = 5.0 \times 10^{-3}$ mol
Complete neutralisation to form SO_3^{2-} occurs at the second pH jump i.e. at **50 cm^3** of NaOH.
Hence, $[NaOH] = 5.0 \times 10^{-3} \div \mathbf{50.0}/1000 = 0.10$ mol dm^{-3}
Statement **B** is incorrect.

From the graph, the region of rapid pH change for the first equivalence point is between pH 3 and 5. However, the working range of thymol blue does not coincide with this range.
Statement **C** is incorrect.
(Note that the working range of thymol blue does in fact coincide with the region of rapid pH change between 8 and 9, so thymol blue would be a suitable indicator for the second equivalence point.)

HSO_3^- can act as a Bronsted acid as well as a Bronsted base.
The question gave two pK$_a$ values:
$H_2SO_3 \rightleftharpoons HSO_3^- + H^+$ $pK_a = 1.9$
$HSO_3^- \rightleftharpoons SO_3^{2-} + H^+$ $pK_a = 7.1$
Hence the second pK_a value for H_2SO_3 is the pK_a value of HSO_3^- i.e. 7.1.
HSO_3^- is the conjugate base of H_2SO_3,
hence pK_b of $HSO_3^- = 14 - (pK_a$ of $H_2SO_3) = 14 - 1.9 = 12.1$.
Statement **D** is correct.

13 C

At low pH	pH = 2.1	1st equivalence point	pH = 7.2	2nd equivalence point	pH = 12.4	3rd equivalence point	At high pH
Mainly H_3PO_4	H_3PO_4 and $H_2PO_4^-$ in a 1:1 ratio	Mainly $H_2PO_4^-$	$H_2PO_4^-$ and HPO_4^{2-} in a 1:1 ratio	Mainly HPO_4^{2-}	HPO_4^{2-} and PO_4^{3-} in a 1:1 ratio	Mainly PO_4^{3-}	Mainly PO_4^{3-}

At pH 7, only the first deprotonation would have taken place, and the major species present would be $H_2PO_4^-$ and HPO_4^{2-}.

14 A

$IP = 0.0010 \times 1 \times 10^{19} = 1 \times 10^{-22}$ mol^2 dm^{-6}
IP > K_{sp} of CuS, CuS will precipitate.
IP > K_{sp} of ZnS, ZnS will precipitate.
IP < K_{sp} of NiS, NiS will **not** precipitate.

15 A

Solution 1: $Cr_2O_7^{2-} + 14H^+ + 6e \rightleftharpoons 2Cr^{3+} + 7H_2O$ (+1.33 V) Oxidation
Solution 2: $H_2O_2 + 2H^+ + 2e \rightleftharpoons 2H_2O$ (+1.77 V) Reduction
$E^\ominus_{cell} > 0$, electrons flow from X to Y.

Solution 1: $H_2O_2 + 2H^+ + 2e \rightleftharpoons 2H_2O$ (+1.77 V) Reduction
Solution 2: $Cl_2 + 2e \rightleftharpoons 2Cl^-$ (+1.36 V) Oxidation
$E^\ominus_{cell} > 0$, electrons flow from Y to X.

Solution 1: $Co^{3+} + e \rightleftharpoons Co^{2+}$ (+1.89 V) Reduction
Solution 2: $Fe^{3+} + e \rightleftharpoons Fe^{2+}$ (+0.77 V) Oxidation
$E^\ominus_{cell} > 0$, electrons flow from Y to X.

Solution 1: $Co^{3+} + e \rightleftharpoons Co^{2+}$ (+1.89 V)
Solution 2: $Fe^{3+} + e \rightleftharpoons Fe^{2+}$ (+0.77 V)
$E^\ominus_{cell} < 0$, there is no reaction (or electron flow).

16 D

For electrolytic cells connected in series, the same number of electrons will pass through each cell.
n(Au) deposited = 4.0 ÷ 197.0 = 0.0203 mol
n(e) transferred = 0.0203 × 3 = 0.0609 mol
Since 0.0609 mol of electrons was transferred, and 1 mol of Cu^{2+} requires 2 mol of electrons for reduction, 0.0305 mol of Cu was deposited.
Mass of Cu deposited = 0.0305 × 63.5 = 1.93 g

17 B

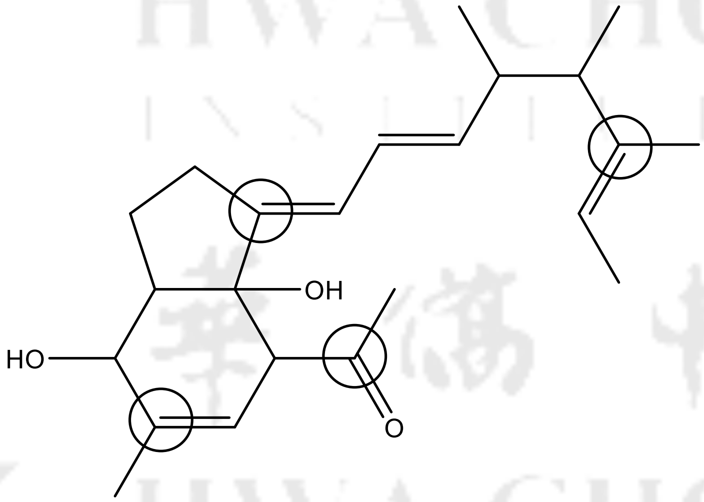
This question tests understanding of homolytic and heterolytic fission and their representations in the form of full or half curved arrows.

Homolytic fission should be represented by half curved arrows. They should always occur in pairs, hence option **C** is incorrect.

Heterolytic fission should be represented by a single full curve arrow, hence option **A** is wrong This single full arrow should also point towards the more electronegative atom in a covalent bond, hence option **D** is incorrect.

18 B

This question can be done by focusing only on the C=C and C=O carbon atoms. Alkene and ketone groups can be reduced by hydrogen gas in the presence of Pt catalyst. The circled carbons in the diagram below show where the additional chiral centres are formed after the reduction reaction.



19 C

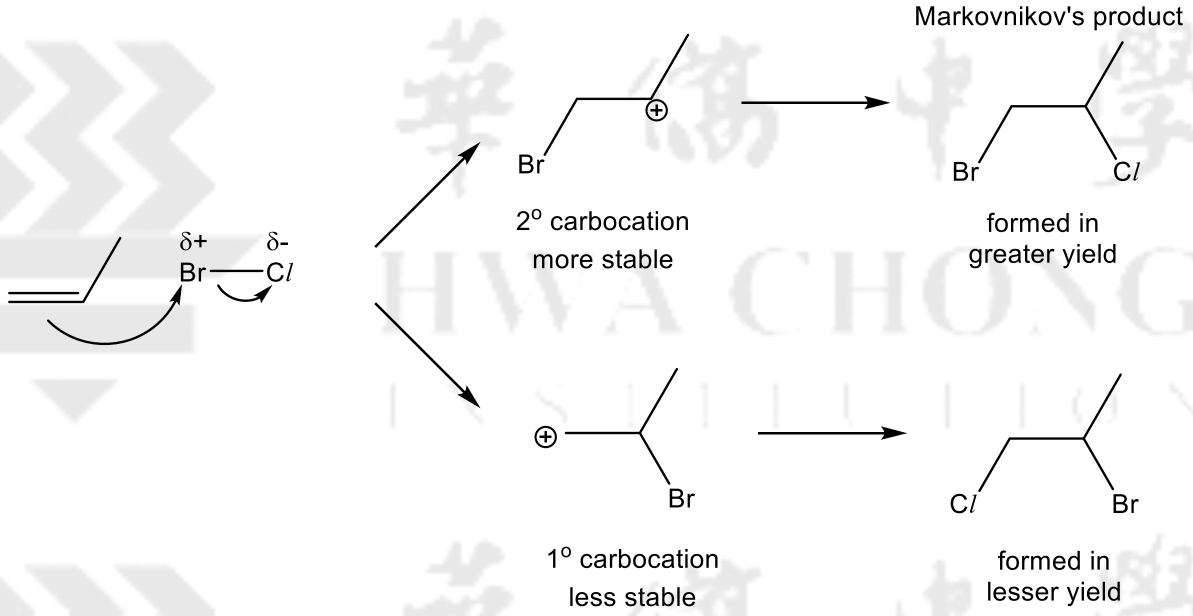
The catalytic converter gets rids of unwanted gases in exhaust fumes in cars by catalysing redox reactions between these gases which ordinarily cannot happen at the temperatures found in the car engine or exhaust systems.

Options 1 and 3 are redox reactions that are catalysed in the converter. Option 2 shows both the hydrocarbon and carbon monoxide on the left side of the equation becoming oxidised which is not possible as there is no species being reduced (i.e. lack of redox couple).

20 D

Electrophilic addition occurs between BrC*l* and propene (an unsymmetical alkene). Hence Markovnikov's rule must be applied to deduce the major product (present in greatest yield).

Since C*l* is more electronegative than Br, the partial positive charge is found on Br and when the electron-deficient Br bonds to the propene, it should bond to the carbon atom of the C=C which gives the more substituted carbocation which is more stable due to the larger number of electron-donating alkyl groups.



21 C

Option **A**: Only benzene has delocalised electrons where the six π electrons are delocalised over the six carbon atoms in the structure. The two π electrons in cyclohexene are localised between two sp^2-hybridised carbon atoms.

Option **B**: Cyclohexene decolorises yellow-orange aqueous bromine at room temperature but benzene decolorises reddish-brown **liquid** bromine upon warming with Fe(s) or $FeBr_3$(s) under anhydrous conditions (**absence** of moisture or water).

Option **C**: Carbon dioxide and water will be formed from complete combustion.

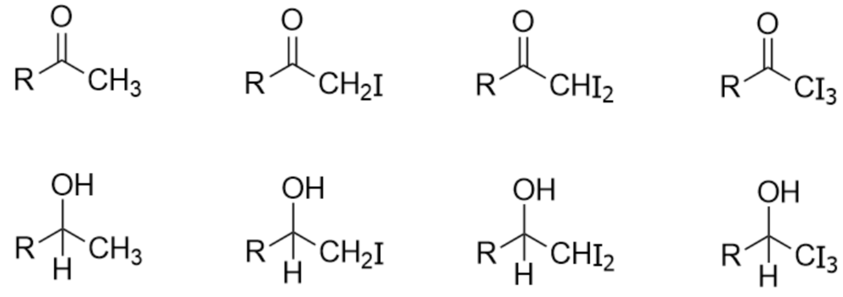
Option **D**: Cyclohexene is **not** planar, it has four sp^3-hybridised carbon atoms which are tetrahedral about each of them.

22 C

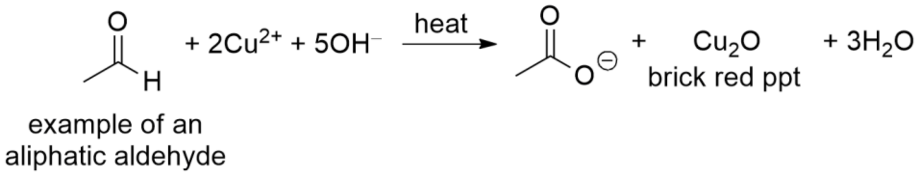
Each OH group will give only ½ mole of hydrogen gas. Since there are 8 x 3 OH groups in the 8 repeat units in the glucose polymer, 8 x 3 ÷ 2 = 12 moles of hydrogen gas will be formed. The two ends of the polymer have 4 OH groups each, which gives 4 x 2 ÷ 2 = 4 moles of hydrogen gas. Hence the total amount of hydrogen gas given off = 16 moles.

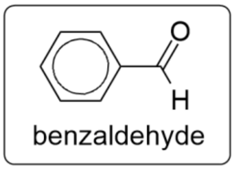
23 D

The following compounds (R = H or alkyl) will be oxidised by alkaline aqueous iodine to give a yellow precipitate CHI_3, this is also known as a positive iodoform test.



Only an aliphatic aldehyde will be oxidised by Fehling's reagent to give a brick red precipitate Cu_2O, benzaldehyde (aromatic aldehyde) will give a negative test with Fehling's reagent.





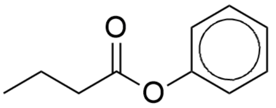
Option **A** is incorrect. Both the primary alcohol and ketone groups will give a negative iodoform test and a negative test with Fehling's reagent.

Option **B** is incorrect. The aliphatic aldehyde group will give a positive test with Fehling's reagent but the ester $-OCOCH_3$ group will give a negative iodoform test.

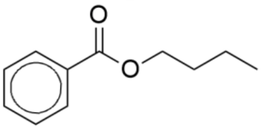
Option **C** is incorrect. The $-CH(OH)(CH_3)$ group will give a positive iodoform test but the benzaldehyde group will give a negative test with Fehling's reagent.

Option **D** is correct. The $-CH(OH)(CH_2I)$ group will give a positive iodoform test while the aliphatic aldehyde group will give a positive test with Fehling's reagent.

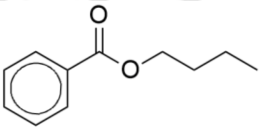
24 C

The structure of phenyl butanoate is  .

Option **A** is incorrect as there will be **no** condensation (nucleophilic acyl substitution) reaction due to phenol being a weak nucleophile. Due to the delocalisation of the lone pair of electrons on the oxygen atom of phenol into the benzene ring, the lone pair of electrons on the oxygen atom of phenol is thus less available (and unable) to attack the electron-deficient carboxyl carbon of the carboxylic acid (the electrophile) to form the ester. Refer to Carboxylic Acids Lecture Notes Section 4.5.1.

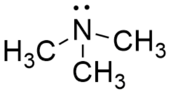
Option **B** is incorrect as butyl benzoate  will be formed instead. Note that this reaction of alcohol and carboxylic acid with conc. acid is slow and reversible, so a lower yield of butyl benzoate will be obtained as compared to option **D**.

Option **C** is correct as phenyl butanoate will be formed from the condensation reaction between the acyl chloride and phenol at room temperature. This nucleophilic acyl substitution reaction is possible because acyl chloride is a stronger electrophile as compared to carboxylic acid in option **A** despite phenol being a weak nucleophile. The acyl carbon in acyl chloride is more electron-deficient than the carboxyl carbon of the carboxylic acid due to the highly electronegative $\mathrm{C}l$ atom which withdraws electrons through inductive effect from the C=O group, making the acyl chloride more susceptible to nucleophilic attack by phenol. In addition, the chloride ion, $\mathrm{C}l^-$, is a better leaving group than hydroxide ion, OH^-. Refer to Carboxylic Acids Lecture Notes Section 5.4.

Option **D** is incorrect as butyl benzoate  will be formed instead from the condensation reaction between the acyl chloride and alcohol at room temperature.

25 B

Option **A** is incorrect. There is **no** delocalisation of the lone pair of electrons on the nitrogen atom of trimethylamine since there are no 3 or more adjacent p orbitals in the molecule. The electron density on the nitrogen atom of trimethylamine is localised on the nitrogen atom.



triethylamine

Option **B** is correct.

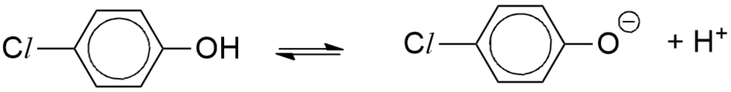
A Lewis base is a species that donates an electron pair. The following equation shows trimethylamine (Lewis base) donating a lone pair to a proton (H^+) which acts as the Lewis acid (electron pair acceptor).

$$(CH_3)_3N + HCl \rightarrow (CH_3)_3NH^+ + Cl^-$$

The increasing number of electron-donating methyl groups from methylamine (1 methyl group) to trimethylamine (3 methyl groups) attached to the nitrogen atom increases the electron density about the nitrogen atom, causing the lone pair on the nitrogen atom to be more available for donation to a proton, making trimethylamine the strongest Lewis base.

Option **C** is incorrect. Methyl groups are electron-donating, not electron-withdrawing. Electron-withdrawing groups would decrease the electron density about the nitrogen atom, causing the lone pair on the nitrogen atom to be less available for donation to a proton, making the base a weaker base.

Option **D** is incorrect. Trimethylamine has no net charge, there is **no** negative charge on the nitrogen atom of trimethylamine. Nitrogen is more electronegative than carbon, hence nitrogen has a partial negative charge (δ−), but **not** a negative charge. The concept of the negative charge on an oxygen atom being dispersed by an electron-withdrawing group, hence stabilising the conjugate base, thus making an organic acid dissociate to a larger extent, can be applied, for example, to explain why 4-chlorophenol is more acidic than phenol.



26 B

Compound Y has the following functional groups: alkene, aldehyde and chloroalkane

Compound Z has the following functional groups: 2^o alcohol and amide

Option **1**: 2,4-DNPH reacts with aldehydes and ketones. Compound Y (contains aldehyde) will give an orange ppt while compound Z will not.

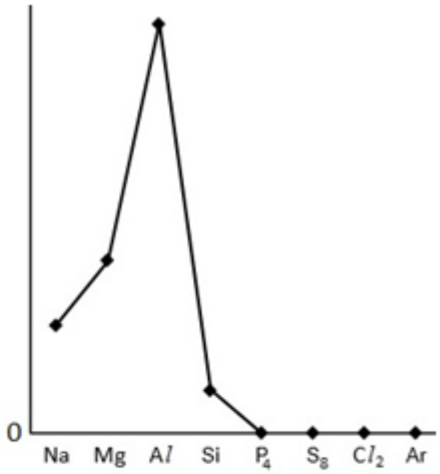
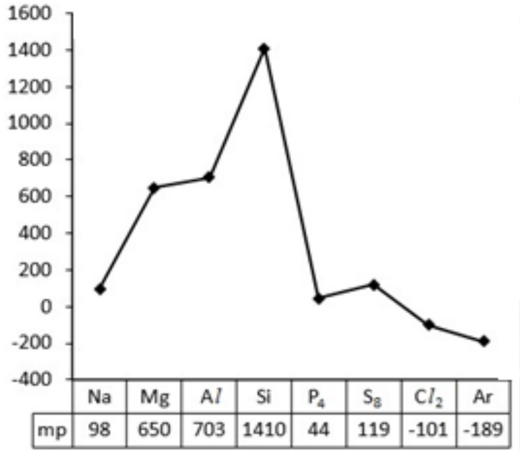
Option **2**: Hot acidified $Cr_2O_7^{2-}$ can oxidise 1^o alcohols, 2^o alcohols and aldehydes. Compound Y will get oxidised as it contains an aldehyde. Compound Z will also get oxidised as it contains a 2^o alcohol.

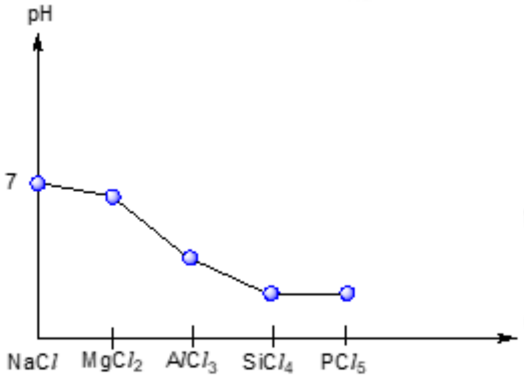
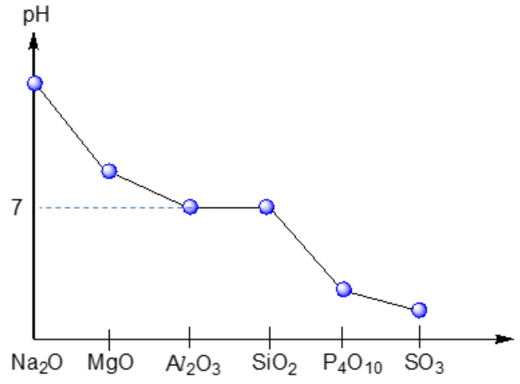
Option **3**: Hot aqueous NaOH can react with halogenoalkanes, esters, amides and nitriles. Compound Y (contains chloroalkane) will react via nucleophilic substitution to give Cl^- but this does not give an observable change unless $AgNO_3$ is added. Compound Z (contains amide) reacts via hydrolysis to form gaseous NH_3 which can be detected with moist red litmus paper turning blue.

Hence only options **1** and **3** may distinguish between compounds Y and Z.

27 A

This is a recall question, testing knowledge of the trends below:

electrical conductivity of the element	melting point of the element
	
Na, Mg and A*l* have **giant metallic structures**. From Na to A*l*, the **number of valence electrons that can be contributed per atom increases**. Therefore, electrical conductivity increases. Si has a **giant molecular structure**. As a **metalloid**, it is a **semiconductor**. In the **simple covalent molecules** P_4, S_8 and Cl_2, outer electrons are held strongly in covalent bonds and are not free to move about. Ar exists as neutral discrete **atoms**. All four do not contain mobile charge carriers and therefore do not conduct electricity.	Na, Mg and A*l* have giant metallic structures. From Na to A*l*, there is an **increase in the number of valence electrons** that can be **contributed per atom**. In addition, from Na^+ to Al^{3+}, charge increases but ionic radius decreases so **charge density increases**. Hence, the strength of metallic bonding increases and melting point increases. Si has a very high melting point due to its giant molecular structure. A lot of energy is needed to overcome the many **strong covalent bonds between Si atoms** during melting. P_4, S_8 and Cl_2 are non-polar simple covalent molecules with **weak dispersion forces between molecules**. Ar is monoatomic with **weak dispersion forces between atoms**. S_8 has the **largest number of electrons / electron cloud**, followed by P_4, then Cl_2, then Ar. Therefore, strength of dispersion forces decreases in that same order, energy needed to overcome dispersion forces during melting decreases. So S_8 has the highest melting point.

pH of the chloride when added to water	pH of the oxide when added to water
	
Na^+ has **low charge density**, and hence no hydrolysis occur. The solution thus remains neutral at **pH 7**. Due to the **higher charge density** of Mg^{2+} compared to Na^+, the hydrated magnesium ion undergoes **slight hydrolysis** to form an acidic solution around **pH 6.5**. $[Mg(H_2O)_6]^{2+}(aq) + H_2O(l)$ $\rightleftharpoons [Mg(H_2O)_5OH]^{+}(aq) + H_3O^{+}(aq)$ Due to the **higher charge density** of Al^{3+} compared to Mg^{2+}, the hydrated aluminium complex undergoes **hydrolysis to a further extent** than $Mg^{2+}(aq)$, resulting in an acidic solution around **pH 3.** $[Al(H_2O)_6]^{3+}(aq) + H_2O(l)$ $\rightleftharpoons [Al(H_2O)_5OH]^{2+}(aq) + H_3O^{+}(aq)$ **Complete hydrolysis** occurs to result in a strongly acidic solution (**pH 1**) containing hydrochloric acid. $SiCl_4(l) + 4H_2O(l) \rightarrow SiO_2.2H_2O(s) + 4HCl(aq)$ $PCl_5(s) + 4H_2O(l) \rightarrow H_3PO_4(aq) + 5HCl(aq)$	Na_2O dissolves in water and forms a strong alkaline solution around **pH 13**. $Na_2O(s) + H_2O(l) \rightarrow 2Na^{+}(aq) + 2OH^{-}(aq)$ MgO has very slow reaction and limited solubility in water. Some magnesium hydroxide is formed but is only sparingly soluble, hence forms an alkaline solution of around **pH 9**. $MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(s)$ $Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^{-}(aq)$ Al_2O_3 and SiO_2 are **insoluble in water** hence **pH is 7**. Too much energy is needed to overcome the strong ionic bonding in Al_2O_3 and the extensive covalent bonding in SiO_2. P_4O_{10} and SO_3 react violently with water to give an acidic solution around **pH 2** and **pH 1**, respectively. $P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$ $SO_3(l) + H_2O(l) \rightarrow H_2SO_4(aq)$

28 D

Option **A** is incorrect. This statement does not explain the variation in type of bonding. Instead, it explains why the highest oxidation number of the elements in oxides and chlorides increases across Period 3.

Option **B** is incorrect. This statement does not explain the variation in type of bonding. Instead, it explains why the atomic radius of the elements generally decreases across Period 3. This statement also explains why the first ionisation energy of the elements generally increases across Period 3.

Option **C** is incorrect. This statement is irrelevant.

Option **D** is correct. The difference in electronegativity between the elements in a compound explains why the bonding of oxides and chlorides changes from ionic to covalent across Period 3.

29 B

Option **1** is correct as bond energy of F─F is lower.
From Data Booklet,

	F─F	C*l*─C*l*	Br─Br
Bond energy / kJ mol^{-1}	158	244	193

Option **2** is incorrect. Bond energy of H─F is higher, hence more energy is needed to break a H─F bond, thus HF has a higher thermal stability.
From Data Booklet,

	H─F	H─C*l*	H─Br
Bond energy / kJ mol^{-1}	562	431	366

Option **3** is correct. $E^\ominus(F_2/F^-)$ is higher, hence F^- has a lower tendency to undergo oxidation, hence F^- has a lower reducing power.

	F^-	Cl^-	Br^-
$E^\ominus$ / V for $X_2 + 2e^- \rightleftharpoons 2X^-$	+2.87	+1.36	+1.07
Reducing power of halide ion	Lowest		Highest

30 B

Reduction of VO_3^- to form V^{2+} in three steps as follows:

$Zn^{2+} + 2e^- \rightleftharpoons Zn$ $E^\ominus = -0.76\text{ V}$ [O]
$VO_3^- + 4H^+ + e^- \rightleftharpoons VO^{2+} + 2H_2O$ $E^\ominus = +1.00\text{ V}$ [R]
Reduction of VO_3^- to VO^{2+} by Zn,
$E^\ominus_{cell} = +1.00 - (-0.76) = +1.76\text{ V} > 0$, hence reaction is spontaneous.

ON of V changes from +5 to +4

$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$ $E^\ominus = +0.34\text{ V}$ [R]
Further reduction of VO^{2+} to V^{3+} by Zn,
$E^\ominus_{cell} = +0.34 - (-0.76) = +1.10\text{ V} > 0$, hence reaction is spontaneous.

ON of V changes from +4 to +3

$V^{3+} + e^- \rightleftharpoons V^{2+}$ $E^\ominus = -0.26\text{ V}$ [R]
Further reduction of V^{3+} to V^{2+} by Zn,
$E^\ominus_{cell} = -0.26 - (-0.76) = +0.50\text{ V} > 0$, hence reaction is spontaneous.

ON of V changes from +3 to +2

Further reduction of V^{2+} to V by Zn is **not** spontaneous.
$V^{2+} + e^- \rightleftharpoons V$ $E^\ominus = -1.20\text{ V}$ [R]
$E^\ominus_{cell} = -1.20 - (-0.76) = -0.44\text{ V} < 0$, hence reaction is **not** spontaneous.

ON of V changes from +2 to 0