1 As dilute H_2SO_4 is added to aqueous $Ba(OH)_2$, all $Ba^{2+}(aq)$ ions present in solution will precipitate out as $BaSO_4(s)$, a white precipitate, while the OH^- is neutralised by H^+ to form H_2O. Hence, the number of ions present in solution decreases. **A**

$$H_2SO_4(aq) + Ba(OH)_2(aq) \longrightarrow \mathbf{BaSO_4(s) + 2H_2O(l)}$$

When dilute H_2SO_4 is added in excess, the number of ions present in solution increases as $H_2SO_4(aq)$ ionises completely in solution.

$$H_2SO_4(aq) \longrightarrow 2H^+(aq) + SO_4^{2-}(aq)$$

2 **C**

Oxidation: $Fe \longrightarrow Fe^{2+} + 2e^-$
Reduction: $Fe^{3+} + e^- \longrightarrow Fe^{2+}$
Overall: $\mathbf{Fe + 2Fe^{3+} \longrightarrow 3Fe^{2+}}$

	Fe	+	$2Fe^{3+}$	$\longrightarrow$	$3Fe^{2+}$
initial (mol)	1		5		0
change (mol)	–1		–2		+3
remaining (mol)	0		**3**		**3**

Given that reaction goes to completion, you may complete the above table using each of the options to come up with the remaining values below.

	n(Fe)	$n(Fe^{3+})$	$n(Fe^{2+})$
A	0	0	3
B	0	1	3
C	0	**3**	**3**
D	0.5	0	4.5

Alternatively,
for $n(Fe^{2+})$ formed = **3** (start with the smallest whole no.) = $n(Fe^{3+})$ left
initial n(Fe) : $n(Fe^{3+})$
1 (reacted) 2 (reacted) + 3 (left)
1 5 (option **C**)

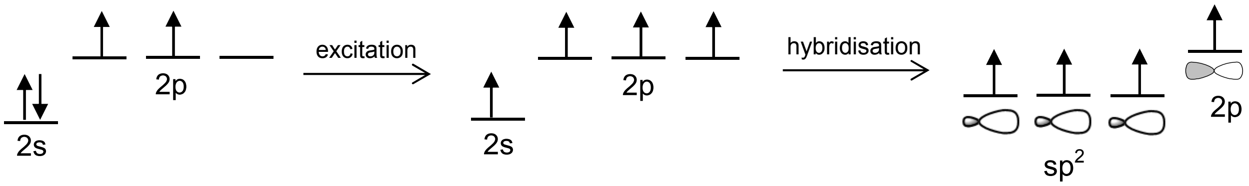
3 **B**

$$\text{angle of deflection } \alpha \frac{\text{charge}}{\text{mass}}$$

angle of deflection of $^{241}Am^+$ = +2° $\left(\alpha \frac{1}{241}\right)$

angle of deflection of $^{32}S^-$ = $-\frac{241}{32} \times (+2) = -15.1°$

4 Each carbon atom in a molecule of ethene is sp^2 hybridised. **D**



5 **A** At constant T, **D**

$pV = nRT \Rightarrow p = a(\frac{1}{V})$ where $a = nRT$ = constant

A graph of p against $\frac{1}{V}$ is a straight line that passes through the origin.

B $pV = nRT$
$pV = aT$ where $a = nR$ = constant

A graph of pV against T is a straight line that passes through the origin.

C At constant T,
$pV = nRT \Rightarrow pV = a$ where $a = nRT$ = constant

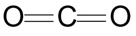
A graph of pV against V is a horizontal line with y–intercept = a

D At constant p,

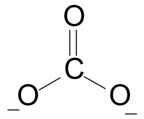
$pV = nRT \Rightarrow V = aT$ where $a = \frac{nR}{p}$ = constant

A graph of V against T is a straight line that passes through the origin.

6 **A** **C**

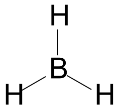


180°

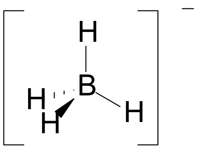


120°

B

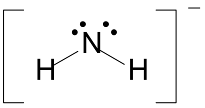


120°

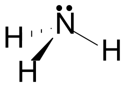


109.5°

C

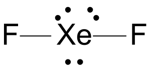


105°

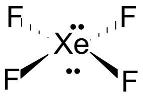


107°

D

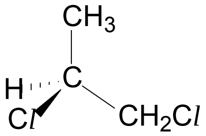


180°

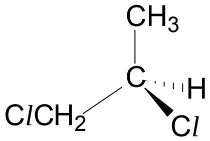


90°

7 **A**

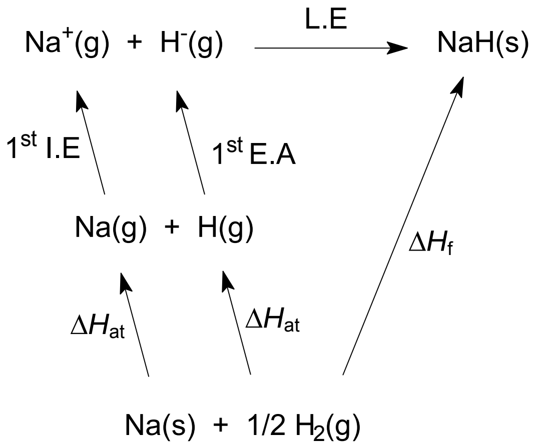


and



are a pair of optical isomers with identical physical properties (except their interactions with plane–polarised light)

8 **A**



9 $[Cu(H_2O)_6]^{2+} + EDTA^{4-} \rightleftharpoons [Cu(EDTA)]^{2-} + 6H_2O$ **B**

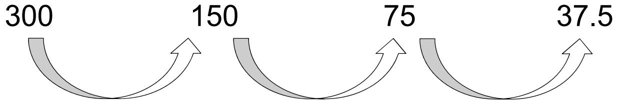
A There is an increase in the number of particles (from 2 to 7) hence ΔS for the forward reaction is positive.

B The oxidation state of Cu remains unchanged at +2.

C Since the coordination number of Cu in $[Cu(H_2O)_6]^{2+}$ and that in $[Cu(EDTA)]^{2-}$ is 6, 6 coordinate (dative) bonds are broken and 6 coordinate (dative) bonds are formed during this ligand exchange reaction.

D Since the coordination number of Cu in $[Cu(H_2O)_6]^{2+}$ and that in $[Cu(EDTA)]^{2-}$ is 6, both $[Cu(H_2O)_6]^{2+}$ and $Cu(EDTA)]^{2-}$ are octahedral complexes.

10 **C**



3 half–lives ⇒ 24 hours (1 day)
1 half–life ⇒ 24 / 3 = 8 hours

11 $E^\ominus(Ni^{2+}/Ni) = -0.25$ V **C**

$E^\ominus(Cr^{3+}/Cr^{2+}) = -0.41$ V	$E^\ominus(Mn^{2+}/Mn) = -1.18$ V	$E^\ominus(Pb^{2+}/Pb) = \mathbf{-0.13\ V}$	$E^\ominus(V^{2+}/V) = -1.20$ V
$E^\ominus(Cr^{3+}/Cr) = -0.74$ V			

$E^\ominus_{cell} = E^\ominus_{reduction} - E^\ominus_{oxidation}$
$E^\ominus_{reduction} - (-0.25)$
$= \mathbf{-0.13} - (-0.25)$
$= +0.12$ V

When $E^\ominus_{cell} > 0$, reaction is spontaneous.

12 At anode (oxidation): $2Cl^- \longrightarrow Cl_2 + \mathbf{2e^-}$ **A**
At cathode (reduction): $2H_2O + \mathbf{2e^-} \longrightarrow H_2 + 2OH^-$

$n(Cl^-) = n(NaCl) = 58.5 \times 10^3 / (23.0 + 35.5) = 1000$ mol
$n(Cl_2) = ½ \times n(Cl^-) = ½ \times 1000 = 500$ mol
mass of $Cl_2 = 500 \times (35.5 \times 2) = 35500$ g = 35.5 kg

$n(H_2) = ½ \times n(Cl^-) = ½ \times 1000 = 500$ mol
mass of $H_2 = 500 \times (1.0 \times 2) = 1000$ g = 1 kg

$n(NaOH) = n(OH^-) = n(Cl^-) = 1000$ mol
mass of NaOH = 1000 x (23.0 + 16.0 + 1.0) = 40000 g = 40 kg

13 **A** At 7 min, the concentration of the gases remains constant. This means that the system has reached dynamic equilibrium. At dynamic equilibrium, the rate of forward reaction equals rate of backward reaction with no net change in the concentration of gases. **B**

B At dynamic equilibrium at 7 min,

$$K_c = \frac{[COCl_2]}{[CO][Cl_2]} = \frac{0.2}{0.8 \times 0.6} = 0.417 \text{ mol}^{-1} \text{ dm}^3$$

C At 7.5 min, the concentrations of all the gases in the equilibrium mixture increase. This is due to the decrease in volume as a result of an increase in pressure at constant temperature. After 7.5 min, the concentration of CO and Cl_2 decreases, at the same time the concentration of $COCl_2$ increases. This shows that the position of equilibrium has shifted to the right in accordance with *Le Chatelier's Principle*. (The forward reaction is accompanied by a decrease in the number of moles of gas molecules. Increasing the pressure will shift the position of equilibrium to the right to decrease the pressure by producing fewer gas molecules.)

D At 10 min, the concentration of Cl_2 increases as more Cl_2 is added to the equilibrium mixture. According to *Le Chatelier's Principle*, the position of equilibrium shifts to the right to remove some of the excess Cl_2. Thus, the concentration of CO and Cl_2 decreases while that of $COCl_2$ increases.

14 **A**

	$CO_2(g)$	+	$H_2(g)$	$\rightleftharpoons$	$CO(g)$	+	$H_2O(g)$
initial (mol)	1		1		0		0
change (mol)	–x		–x		+x		+x
eqm (mol)	1 – x		1 – x		x		x

Total no. of moles at eqm = 1 – x + 1 – x + x + x = 2

$p(CO_2) = p(H_2) = \frac{1-x}{2} \times 1 \text{atm} = \frac{1-x}{2} \text{ atm}$

$p(CO) = p(H_2O) = \frac{x}{2} \times 1 \text{atm} = \frac{x}{2} \text{ atm}$

$$K_p = \frac{p(CO) \times p(H_2O)}{p(CO_2) \times p(H_2)} = \frac{(\frac{x}{2})^2}{(\frac{1-x}{2})^2} = 0.726$$

$$\frac{x}{1-x} = \sqrt{0.726}$$

$$x = 0.460$$

$\therefore$ mole fraction of CO = x/2 = 0.460/2 = 0.230

15 NH_4^+ is the conjugate acid of a weak base, NH_3. **D**

NH_4^+ dissociates partially in water to produce H_3O^+ as follows:
$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$

$Mg(OH)_2(s)$ then undergoes an acid–base reaction (neutralisation) with the H_3O^+ ions produced.
$Mg(OH)_2(s) + 2H_3O^+(aq) \longrightarrow Mg^{2+}(aq) + 4H_2O(l)$

16 $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$ **A**

$$K_a = \frac{[NH_3][H_3O^+]}{[NH_4^+]}$$

$$10^{-(14-4.74)} = \frac{[NH_3][10^{-9}]}{[NH_4^+]}$$

$$\frac{[NH_3]}{[NH_4^+]} = 0.5495$$

Let V = volume (in dm^3) of 0.1 mol dm^{-3} NH_3 added,
$[NH_3]$ after mixing = (V x 0.1) / (V + 0.01)
$[NH_4^+]$ after mixing = 0.01 x 0.1 / (V + 0.01) = 0.001 / (V + 0.01)

$$\frac{[NH_3]}{[NH_4^+]} = \frac{0.1V}{0.001} = 0.5495$$

$$V = 5.50 \times 10^{-3}\ dm^3 = 5.50\ cm^3$$

17 $Ca(NO_3)_2(s) \longrightarrow CaO(s) + 2NO_2(g) + \frac{1}{2} O_2(g)$ **C**

1 mol of $Ca(NO_3)_2$ undergoes thermal decomposition to produce 2.5 mol of gaseous products.

Volume of gas produced at r.t.p = 2.5 x 24 = 60 dm^3

18 **C**

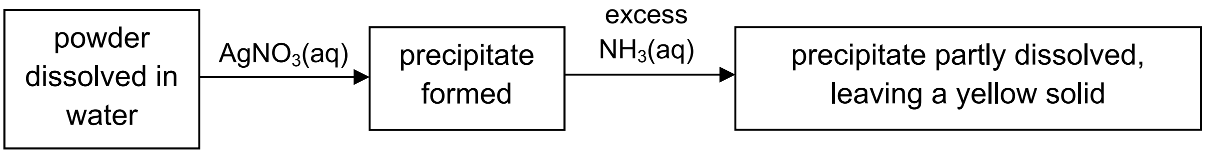
A All the Group VII elements are coloured with increasing intensity down the group. F_2 is pale yellow in colour.

B Acid strength of HX increases down Group VII due to decreasing bond strength of H–X. Hence, HF is the weakest acid.

C Increasing atomic radius down Group VII usually leads to weaker covalent bonds. One exception in this trend is fluorine, which has a weak F–F bond. This could be due to the lone pairs of electrons on the **small** fluorine atoms being so close together that they strongly repel each other, hence weakening the bond.

D The melting points of Group VII elements increase down the group due to stronger instantaneous dipole–induced dipole (id–id) attraction between the X_2 molecules. Hence, F_2 has the lowest m.p.

19 **D**



The yellow solid is AgI. The other ppt soluble in excess $NH_3(aq)$ is $AgCl$. Hence, the powder consists of NaI and NaCl, which dissolve in water to produce I^- and Cl^- ions.

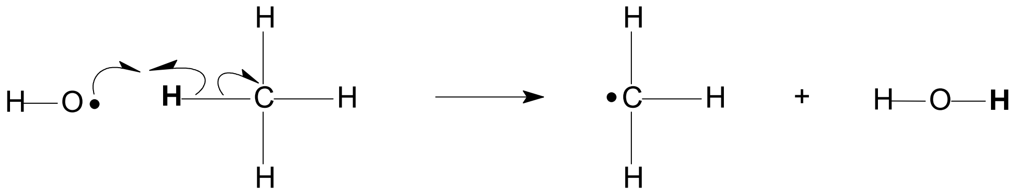
20 dmpe is a *bidentate* ligand, i.e. each ligand forms 2 coordinate (dative) bonds with the central metal ion due to presence of a lone pair of electrons on each of the P atoms. **C**

The formula of the complex anion in $Na_2[Mo(CN)_2(CO)_2(dmpe)]$ is $[Mo(CN)_2(CO)_2(dmpe)]^{2-}$.

Hence, coordination number of Mo in $[Mo(CN)_2(CO)_2(dmpe)]^{2-}$ is 2 + 2 + 2 = 6.

Let the oxidation state of Mo in $[Mo(CN)_2(CO)_2(dmpe)]^{2-}$ be x,
$x + 2(-1) + 2(0) + 0 = -2$
$x = 0$

21 **B**



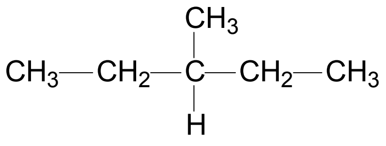
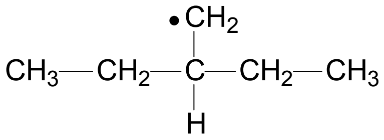
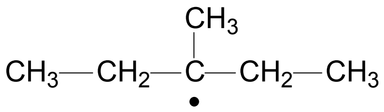
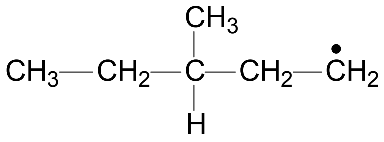
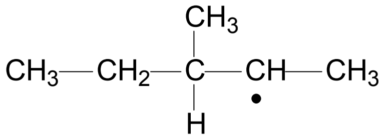
The reaction involves the breaking of a C–H covalent bond in CH_4 with one of the bonded electrons going to each atom, forming two radicals ($\bullet CH_3$ and $\bullet H$) ⇒ homolytic fission

The unpaired electron in the hydrogen radical ($\bullet H$) and that in the hydroxyl radical ($\bullet OH$) then pair up to form a σ bond (O–H bond).

Note: Heterolytic fission is the breaking of a covalent bond with both of the bonded electrons going to one of the atoms, forming a cation and an anion.

The total number of electrons in the two reacting species is 9($\bullet OH$) + 10(CH_4) = 19. Hence, option D is incorrect.

22 **C**

	R•
 $CH_3CH_2CH(CH_3)CH_2CH_3$ 3-methylpentane	 $CH_3CH_2CH(\bullet CH_2)CH_2CH_3$
	 $CH_3CH_2\dot{C}(CH_3)CH_2CH_3$
	 $CH_3CH_2CH(CH_3)CH_2\dot{C}H_2$
	 $CH_3CH_2CH(CH_3)\dot{C}HCH_3$

23 **A**

A Absence of alkene group in compound Z, hence Z is not likely to undergo electrophilic addition.

B Presence of benzene ring in compound Z, hence Z is likely to undergo electrophilic substitution.

C Presence of chloroalkane group ($–CH_2Cl$) in compound Z, hence Z is likely to undergo nucleophilic substitution.

D Presence of nitrobenzene group ($C_6H_5NO_2$) in compound Z, hence Z is likely to undergo reduction to form phenylamine ($C_6H_5NH_2$).

24 **D**

A $RCH(OH)CH_3 \xrightarrow[\text{warm}]{I_2,\ OH^-(aq)} RCO_2^- \xrightarrow{H^+(aq)} RCO_2H$

B $RCH(CH_3)_2 \xrightarrow[\text{heat}]{KMnO_4,\ OH^-(aq)} RCO_2^- \xrightarrow[\text{heat}]{H^+(aq)} RCO_2H$

C $RCH(CH_3)OCOCH_3 \xrightarrow[\text{heat}]{KMnO_4,\ OH^-(aq)} RCO_2^- \xrightarrow{H^+(aq)} RCO_2H$

D $RCHBrCH_3 \xrightarrow[\text{heat}]{NaCN(\text{ethanolic})} RCH(CN)CH_3 \xrightarrow[\text{heat}]{H^+(aq)} RCH(CO_2H)CH_3$ *Fenoprofen*

25 **C**

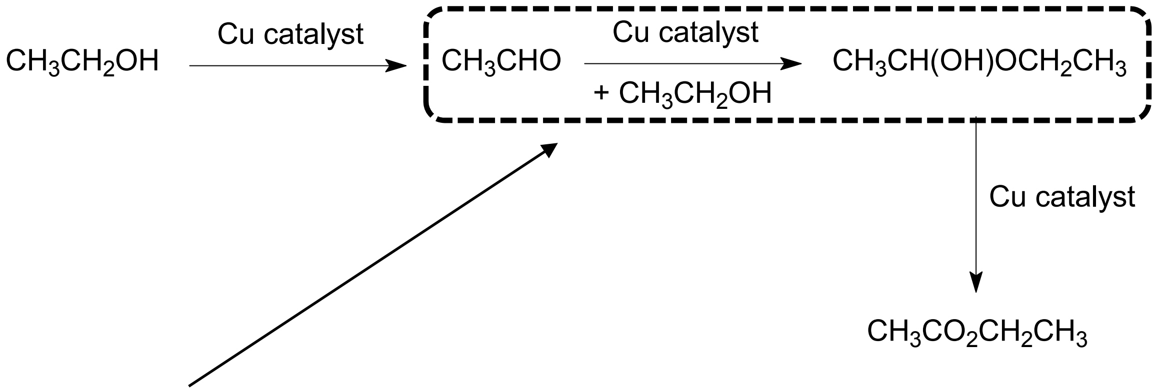
A $CH_2{=}CHCH_3 + Cl_2(g) \longrightarrow CH_2ClCHClCH_3$

B No reaction

C $CH_3CH_2CH_2OH + PCl_5 \longrightarrow \mathbf{CH_3CH_2CH_2Cl} + POCl_3 + HCl$

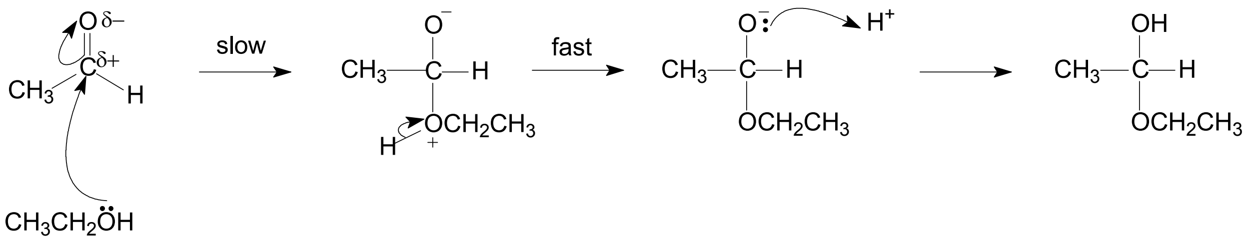
D No reaction

26 **B**



CH_3CHO undergoes *nucleophilic addition* with CH_3CH_2OH (nucleophile) to form $CH_3CH(OH)OCH_2CH_3$.

Mechanism (FYI)

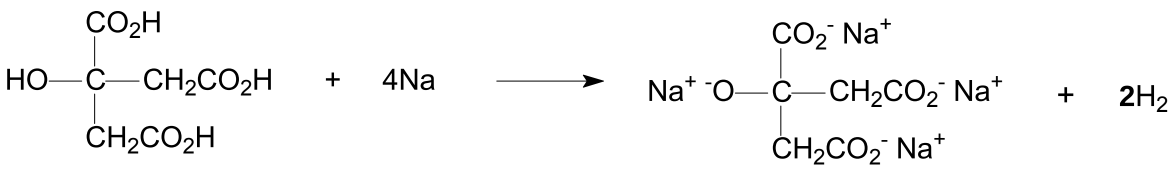


27 Ethanoyl chloride (CH_3COCl) undergoes hydrolysis in water to produce CH_3CO_2H and HCl. HCl is a strong acid which ionises completely in water. Hence, the resulting solution formed would have the lowest pH. **B**

Chloroethanoic acid ($ClCH_2CO_2H$) and ethanoic acid (CH_3CO_2H) are weak acids which ionise partially in water. Chloroethanoic acid is a stronger acid than ethanoic acid as the presence of the electron–withdrawing Cl group further stabilises the carboxylate ion and hence, the dissociation of chloroethanoic acid to form carboxylate ion and H^+ is more favoured.

Ethyl ethanoate ($CH_3CO_2CH_2CH_3$) is a neutral ester.

28 **B**

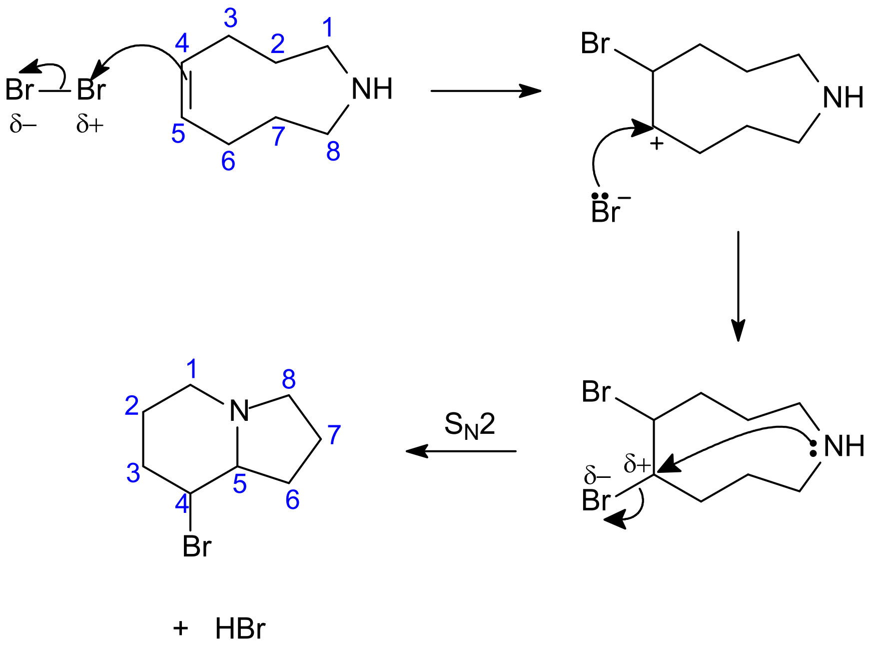


$$HO-\underset{CH_2CO_2H}{\overset{CO_2H}{C}}-CH_2CO_2H \;+\; 4Na \longrightarrow Na^+\,{}^-O-\underset{CH_2CO_2^-\,Na^+}{\overset{CO_2^-\,Na^+}{C}}-CH_2CO_2^-\,Na^+ \;+\; 2H_2$$

citric acid

One mole of –OH group reacts with one mole of Na to produce ½ mole of H_2.

29 *Mechanism (FYI)* **D**



The final step of the mechanism involves *nucleophilic substitution*.

Note: The initial step of the mechanism involves electrophilic addition of Br_2 with the alkene functional group.

30 **D**

	an alkaline solution wrt	**an acidic solution wrt**	**an acidic solution wrt**
	aspartic acid (Asp) pI = 2.8	glycine (Gly) pI = 6.0	leucine (Leu) pI = 6.0
structure of a.a. at pH 4.0	CO_2^- CH_2 $H_3\overset{+}{N}CHCO_2^-$	$H_3\overset{+}{N}CH_2CO_2H$	$CH(CH_3)_2$ CH_2 $H_3\overset{+}{N}CHCO_2H$
migrate to	anode (+)	cathode (−)	cathode (−)

Glycine (Gly) has a lower molecular mass and hence, it migrates faster than leucine (Leu) towards the cathode.

31 **A**

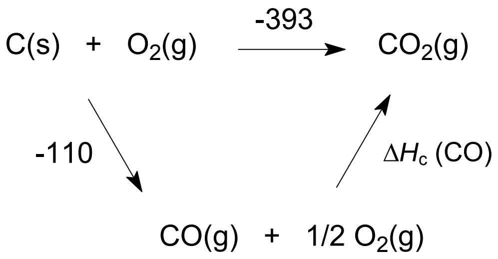
1 $^{38}_{18}Ar$ No. of electrons = 18
No. of neutrons = 38 – 18 = 20

2 $^{40}_{20}Ca^{2+}$ No. of electrons = 20 – 2 = 18
No. of neutrons = 40 – 20 = 20

3 $^{39}_{19}K^+$ No. of electrons = 19 – 1 = 18
No. of neutrons = 39 – 19 = 20

32 **1** Since the enthalpy change of formation of carbon dioxide is more exothermic than that of carbon monoxide, carbon dioxide is energetically more stable (lower in energy) than carbon monoxide. **A**

2



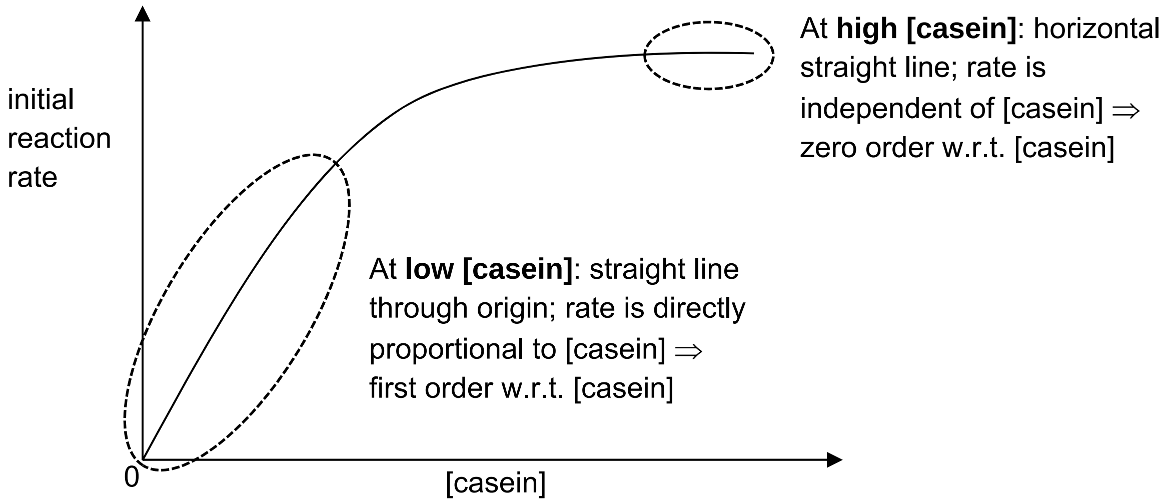
ΔH_c (CO) = –(–110) – 393 = –283 kJ mol^{-1}

3 The enthalpy change of combustion of carbon is more exothermic (–393 kJ mol^{-1}) than the enthalpy change of combustion of carbon monoxide (–283 kJ mol^{-1}).

or

The enthalpy change of combustion of carbon, ΔH_c (C), is more exothermic than the enthalpy change of combustion of carbon monoxide, ΔH_c (CO), as ΔH_c (C) also includes the enthalpy change of the *partial* combustion of C to CO.

33 **C**



At **high [casein]**: horizontal straight line; rate is independent of [casein] ⇒ zero order w.r.t. [casein]

At **low [casein]**: straight line through origin; rate is directly proportional to [casein] ⇒ first order w.r.t. [casein]

The relationship between reaction rate and [trypsin] cannot be deduced from the graph.

34 **1** Across the period (from Na to C*l*), nuclear charge of atom increases due to increase in proton number. Screening effect remains relatively constant as the additional electron is added to the same quantum shell. Thus, effective nuclear charge increases and the electrons are more strongly attracted to the nucleus. Hence, across the period (from Na to C*l*), atomic radius decreases. **A**

Note: The large jump from Cl to Ar is because the last point on the graph shows the van der Waals' radius of Ar, while the other points show metallic or covalent radii.

2 Across each isoelectronic series, there is an increasing attraction between the increasing number of protons and the same number of electrons. Thus, ionic radius in both isoelectronic cations and anions decreases. From Si^{4+} to P^{3-}, there is an additional third quantum shell which results in an increase in screening effect. Hence, ionic radius increases from Si^{4+} to P^{3-}.

3 Na, Mg and A*l* are good electrical conductors as their metallic lattices contain delocalised electrons. Electrical conductivity increases from Na to A*l* as the number of delocalised electrons increases. Si is a semi–conductor as the electrons within the covalent bonds are held tightly and not easily delocalised. P, S, C*l* and Ar are non–conductors as there are no delocalised electrons in their simple molecular structures.

35 **1** With cold KOH(aq): **D**

$$2KOH + Cl_2 \longrightarrow \underset{-1}{K\mathbf{Cl}} + \underset{+1}{K\mathbf{ClO}} + H_2O$$

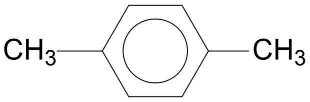
With hot KOH(aq):

$$6KOH + 3Cl_2 \longrightarrow \underset{-1}{5K\mathbf{Cl}} + \underset{+5}{K\mathbf{ClO_3}} + 3H_2O$$

2 $\text{conc. } H_2SO_4 + Cl_2 \longrightarrow \text{no reaction}$

3 $NaI + Cl_2 \longrightarrow NaCl + I_2$

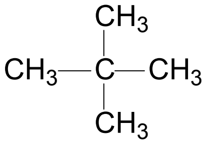
36 **1** The carbon atoms in the benzene ring are planar and hence, the carbon atom of each of the methyl groups attached to the planar benzene ring will lie in one plane. **B**



2 The atoms involved in the triple bond are linear carbon atoms and hence, the carbon atoms of the methyl groups attached to the linear carbon atoms will lie in the same plane.

$CH_3—C\equiv C—CH_3$

3 The central carbon atom is tetrahedral and hence, only two carbon atoms of the methyl groups will lie in the same plane of the central carbon atom.

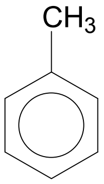


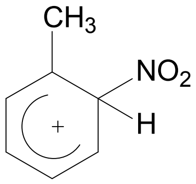
$C(CH_3)_4$

37 **B**

reactant **intermediate**

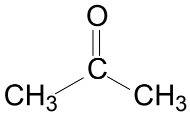
1

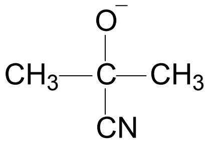




reactive carbon atom: trigonal planar (sp^2 hybridised) → tetrahedral (sp^3 hybridised)

2

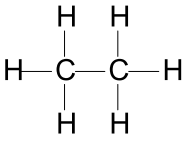




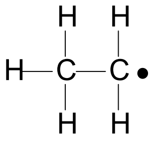
$CH_3C(O^-)(CN)CH_3$

reactive carbon atom: trigonal planar (sp^2 hybridised) → tetrahedral (sp^3 hybridised)

3



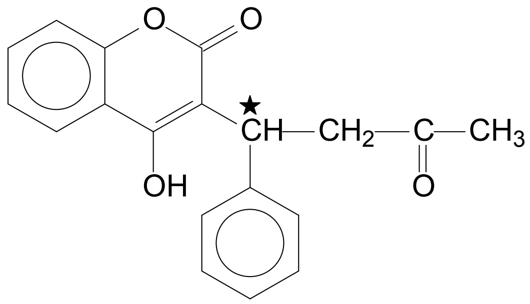
CH_3CH_3



$CH_3CH_2\bullet$

reactive carbon atom: tetrahedral (sp^3 hybridised) → trigonal planar (sp^2 hybridised)

38 **1** **D**



Warfarin ★ chiral carbon

2 $C_{19}H_{16}O_4 + 21O_2 \longrightarrow 19CO_2 + 8H_2O$

n(*Warfarin*) = 0.10 / 308.0 = 3.2467×10^{-4} mol
n(CO_2) = 19 x 3.2467×10^{-4} = 6.1688×10^{-3} mol
mass of CO_2 produced = 6.1688×10^{-3} x 44.0 = <u>0.27 g</u>

3 One mole of *Warfarin* reacts with <u>one</u> mole of 2,4–dinitrophenylhydrazine (presence of one mole of ketone group).

39 **1** **D**

$$CH_3CH_2CO_2CH_2CH_3 \xrightarrow[\text{heat}]{\text{NaOH(aq)}} CH_3CH_2CO_2^- + \mathbf{CH_3CH_2OH}$$

2

$$C_6H_5Br \xrightarrow[\text{heat}]{\text{NaOH(aq)}} \text{no reaction}$$

3

$$C_6H_5CONH_2 \xrightarrow[\text{heat}]{\text{NaOH(aq)}} C_6H_5CO_2^- + NH_3$$

40 **1** The mechanical action of whisking breaks the weak van der Waals' forces and hydrogen bonds between the **R** groups of the amino acid residues in the protein chain, resulting in denaturation. **D**

2 The acidic condition does **not** disrupt the hydrogen bonds between the >C=O and >N–H groups of the peptide linkages in the protein chain as peptides are neutral and hence do not react with the H^+ present.

3 Foaming of the egg white does **not** destroy the peptide linkages in the protein chain as denaturation does not affect the primary structure of a protein.