

Section A

For each question there are four possible answers, **A**, **B**, **C**, and **D**. Choose the **one** you consider to be correct and shade your choice on the answer sheet provided.

- 1 For indoor air quality safety standards, the maximum safe tolerance level of carbon monoxide gas is $6 \times 10^{-4} \text{ m}^3$ of carbon monoxide in 1 m^3 of air. Given that a typical room measures 4 m by 4 m by 3 m, calculate the number of molecules of carbon monoxide present in the room at this tolerance level at room temperature and pressure?

- A** 1.13×10^{24}
B 7.22×10^{23}
C 1.51×10^{22}
D 7.22×10^{20}

Answer: B

For 1 m^3 of air, 6×10^{-4} of CO is allowed
 For $4 \times 4 \times 3 = 48 \text{ m}^3$ of air, volume of CO = $48 \times 6 \times 10^{-4} = 0.0288 \text{ m}^3 = 28.8 \text{ dm}^3$
 Number of moles of CO = $28.8 / 24 = 1.20 \text{ mol}$
 Number of molecules
 = $1.20 \times (6.02 \times 10^{23})$
 = 7.22×10^{23}

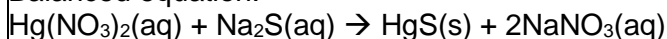
- 2 Soluble mercury compounds such as mercury(II) nitrate are highly toxic. One removal method involves the treatment of wastewater contaminated with mercury(II) nitrate with sodium sulfide to produce solid mercury(II) sulfide and sodium nitrate solutions.

Calculate the mass of mercury(II) sulfide formed when 0.020 dm^3 of $0.100 \text{ mol dm}^{-3}$ sodium sulfide reacts with 0.050 dm^3 of $0.010 \text{ mol dm}^{-3}$ mercury(II) nitrate?

- A** 0.117 g **B** 0.133 g **C** 0.280 g **D** 0.466 g

Answer: A

Balanced equation:



No. of moles of Na_2S

$$= 0.020 \times 0.100 = 2.00 \times 10^{-3} \text{ mol}$$

No. of moles of $\text{Hg}(\text{NO}_3)_2$

$$= 0.050 \times 0.010 = 5.00 \times 10^{-4} \text{ mol}$$

$2.00 \times 10^{-3} \text{ mol}$ of Na_2S will require $2.00 \times 10^{-3} \text{ mol}$ of $\text{Hg}(\text{NO}_3)_2$ for complete reaction.

Since $5.00 \times 10^{-4} \text{ mol}$ of $\text{Hg}(\text{NO}_3)_2$ is used (lesser than 2.00×10^{-3} needed), thus $\text{Hg}(\text{NO}_3)_2$ is limiting.

No. of moles of $\text{HgS} = 5.00 \times 10^{-4} \text{ mol}$

Mass of HgS

$$= (5.00 \times 10^{-4}) \times (201 + 32.1) = 0.11655 \text{ g}$$

$$= 0.117 \text{ g}$$

- 3 Gaseous particle **X** has a proton number n , and a charge of $+1$.
Gaseous particle **Y** has a proton number $(n+1)$, and is isoelectronic with **X**.

Which statement about **X** and **Y** is correct?

- A** When placed in an electric field, the angle of deflection for **X** is the same as that of **Y**.
- B** **X** requires more energy than **Y** when a further electron is removed from each particle.
- C** **X** releases more energy than **Y** when an electron is added to particle.
- D** **X** has a larger radius than **Y**.

Answer: D

Particle **X**

Number of protons	n
Number of electrons	$n-1$

Thus **X** has a charge of $+1$

Particle **Y**

Number of protons	$n+1$
Number of electrons	$n-1$

Thus **Y** has a charge of -2

A is incorrect.

Angle of deflection $\propto \frac{\text{charge}}{\text{mass}}$

Y has double the charge of **X** (-2 as compared to $+1$), however, the atomic mass of **Y** is not double that of **X** (**X** and **Y** are consecutive elements as deduced from their proton numbers). Thus their charge/mass ratios will not be the same.

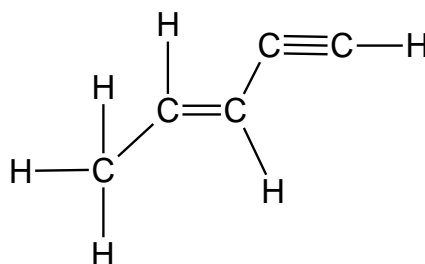
B is incorrect. As **X** has one less proton than **Y**, it has a smaller nuclear charge. As both particles are isoelectronic (same number of inner shell electrons), shielding effect will be the similar. Effective nuclear of **X** will be smaller. The valence electrons of **X** will be less strongly attracted to the nucleus. Thus less energy is needed to remove the outermost electron.

C is incorrect. **X** releases lesser energy than **Y** when an electron is added. The attractive force between the incoming electron and the nucleus is weaker than that for **Y** as **X** has smaller effective nuclear charge.

D is correct. Same explanation as Option B. **X** has a smaller nuclear charge (fewer protons than **Y**) and the same shielding effect as **Y** (same number of inner shell electrons). Effective nuclear of **X** will be smaller. The valence electrons of **X** will be less strongly attracted to the nucleus. Thus the radius of **X** is larger than that of **Y**.

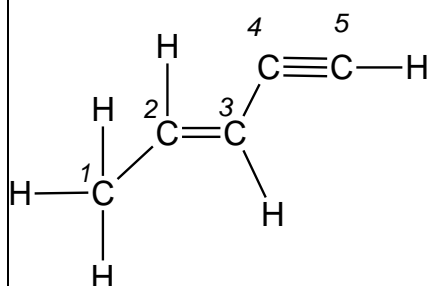
- 4 Covalent bonds are formed by orbital overlap. The shape of unsaturated hydrocarbon molecules can be explained in terms of hybridisation of orbitals.

Which bond is not present in the molecule shown below?



- A** σ bond formed by $2sp^3 - 2sp^2$ overlap.
B σ bond formed by $2sp^3 - 2sp$ overlap.
C σ bond formed by $1s - 2sp$ overlap.
D π bond formed by $2p - 2p$ overlap.

Answer: B



A is correct. There is a σ bond formed by $2sp^3 - 2sp^2$ overlap present between C1-C2.

B is incorrect. There isn't any σ bond formed by $2sp^3 - 2sp$ overlap present.

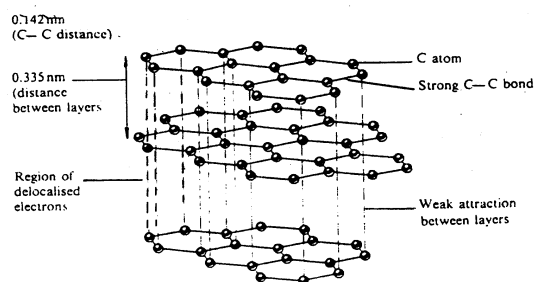
C is correct. There is a σ bond formed by $1s - 2sp$ overlap present between hydrogen atom and C5.

D is correct. There is a π bond formed by $2p - 2p$ overlap present between C2-C3 and C4-C5.

5 Which statement about graphite is **not** correct?

- A The carbon-carbon bonds in graphite are shorter than those in diamond.
- B It can act as a good lubricant due to the weak forces of attraction between the layers of atoms.
- C Carbon to carbon distances between the planes of hexagonal rings are smaller than those within the planes.
- D It acts as a good conductor of electricity in the direction parallel to the planes containing hexagonal rings of carbon.

Answer: C



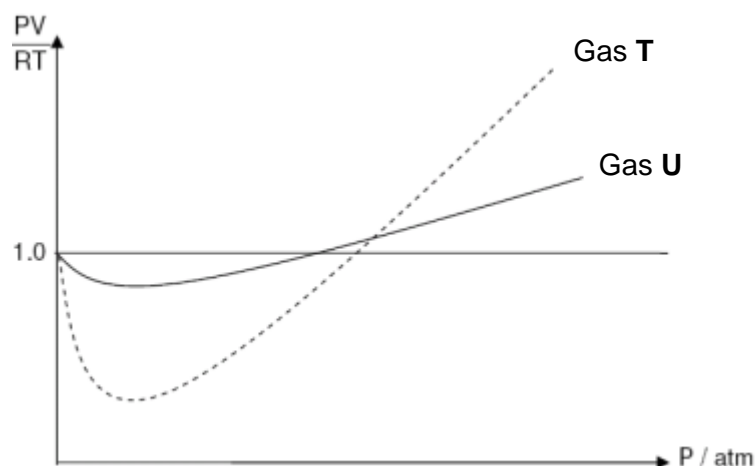
A is true. The carbon-carbon bonds in graphite are formed by sp^2 - sp^2 overlap whereas carbon-carbon bonds in diamond are formed by sp^3 - sp^3 overlap. sp^2 - sp^2 overlap is more effective than sp^3 - sp^3 overlap due to the greater s-character, thus the C-C bond length in graphite is shorter.

B is true. The weak id-id forces between the layers allow the layers to slide past one another, thus graphite is a good lubricant.

C is false. Carbon to carbon distances between the planes of hexagonal rings (weak id-id interactions) are longer than those within the planes (strong C-C covalent bonds).

D is true. Within each layer, each carbon atom is covalently bonded to three other carbon atoms using 3 of the 4 valence electrons. The presence of delocalised electrons between the layers accounts for graphite being a good conductor when a potential difference is applied along the layer. It does not conduct across the layer.

6



Which of the following could be the identities of the gases?

	Gas T	Gas U
A	H ₂ (g) at 298 K	CO ₂ (g) at 298 K
B	CH ₄ (g) at 298 K	NH ₃ (g) at 298 K
C	O ₂ (g) at 500 K	O ₂ (g) at 298 K
D	N ₂ (g) at 298 K	N ₂ (g) at 500 K

Answer: D

From graph, Gas T deviates more from ideality than Gas U.

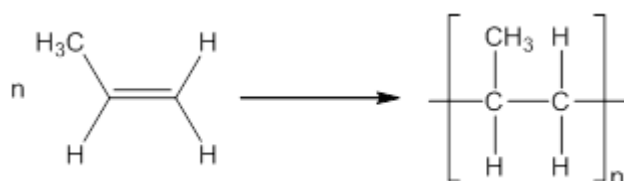
A is incorrect. Deviation of CO₂ from ideal gas behaviour is larger than that of H₂. CO₂ has a greater number of electrons than O₂, thus the electron cloud is more polarisable, resulting in stronger instantaneous dipole-induced dipole interactions between CO₂ molecules.

B is incorrect. Deviation of NH₃ from ideal gas behaviour is larger than that of CH₄. There is stronger hydrogen bonding between NH₃ molecules than instantaneous dipole-induced dipole interactions between CH₄ molecules.

C is incorrect. Deviation of O₂(g) at 298 K from ideal gas behaviour is larger than that at 500 K. At higher temperatures, particles in a gas possess large kinetic energy and are able to overcome intermolecular forces of attraction such that these attractions can be considered to be insignificant and negligible.

D is correct. Deviation of N₂(g) at 500 K from ideal gas behaviour is smaller than that at 298 K. At higher temperatures, particles in a gas possess large kinetic energy and are able to overcome intermolecular forces of attraction such that these attractions can be considered to be insignificant and negligible.

- 7 The polymerisation of propene to form polypropene occurs readily at room temperatures.



What will be the signs of ΔG , ΔH and ΔS for the polymerisation reaction at room temperature?

	ΔG	ΔH	ΔS
A	+	–	–
B	+	+	–
C	–	+	–
D	–	–	–

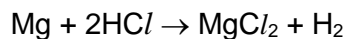
Answer: D

Question states that the reaction is spontaneous at room temperature, thus ΔG is negative.

The overall reaction involves the breaking of a C-C π bond and the formation of C-C σ bond. Since the σ bond is stronger than the π bond, the energy released from the formation of the σ bond is greater than the energy absorbed for the breaking of the π bond. Thus ΔH is negative.

The sign for ΔS is negative as there is a decrease in the number of molecules, thus there are fewer ways of arranging the molecules, level of disorderliness decreases.

- 8 The rate of the redox reaction between hydrochloric acid and Mg



can be followed by measuring the time taken for the same volume of hydrogen to be produced from a range of hydrochloric acid concentrations.

To find the order with respect to hydrochloric acid, which would be the most suitable graph to plot using the data?

- A** [HCl] against time
- B** [HCl] against $\frac{1}{\text{time}}$
- C** Volume H₂ against time
- D** Volume H₂ against $\frac{1}{\text{time}}$

Answer: B

A is incorrect. Using graph of [HCl] against time, the order of reaction with respect to hydrochloric acid cannot be found but only the instantaneous rate of reaction can be found by finding drawing tangent and calculate the gradient to the tangent at different time.

B is correct. The rate equation proposed is $\text{Rate} = k[\text{HCl}]^n$. Since question has mentioned that time taken for the same volume of hydrogen to be produced, $1/\text{time}$ will thus be deemed as rate. If order of reaction with respect to hydrochloric acid is 1 ($n=1$), the appropriate graph, $\text{rate} = [\text{HCl}]$ against $1/\text{time}$ (also deemed as rate) will be a straight line with positive gradient and the gradient = k .

C is incorrect. As the question mentioned that the data collected is time taken to produce the same volume when different concentrations of hydrochloric acid, the graph of volume of hydrogen against time will be the same even different concentrations of hydrochloric acid is used.

D is incorrect. As the question mentioned that the data collected is time taken to produce the same volume when different concentrations of hydrochloric acid, the graph of volume of hydrogen against $1/\text{time}$ will be the same despite that different concentrations of hydrochloric acid are used.

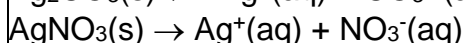
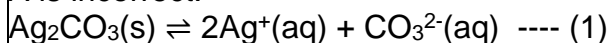
- 9** The numerical value of the solubility product of nickel(II) carbonate is 6.6×10^{-9} while that of silver carbonate is 2.1×10^{-11} at 25 °C.

Which of the following statements is true?

- A** Addition of silver nitrate increases the solubility of silver carbonate.
- B** The solubility of silver carbonate is higher than the solubility of nickel(II) carbonate.
- C** Addition of nitric acid to a solution containing nickel(II) carbonate increases the solubility product of nickel(II) carbonate.
- D** Nickel(II) carbonate precipitates first when sodium carbonate is added to a solution containing equal concentrations of nickel(II) and silver ions.

Answer: B

A is incorrect.



Addition of silver nitrate increases $[\text{Ag}^+]$ in eqm 1, the position of eqm 1 shifts LHS, the solubility should decrease.

B is correct

$$K_{\text{sp}} = [\text{Ag}^+]^2[\text{CO}_3^{2-}] = 2.1 \times 10^{-11}$$

$$K_{\text{sp}} = (2s)^2(s)$$

$$s = \sqrt[3]{\frac{2.1 \times 10^{-11}}{4}} = 1.73 \times 10^{-4} \text{ mol dm}^{-3}$$

$$K_{\text{sp}} = [\text{Ni}^{2+}][\text{CO}_3^{2-}] = 6.6 \times 10^{-9}$$

$$s = \sqrt{6.6 \times 10^{-9}} = 8.14 \times 10^{-5} \text{ mol dm}^{-3}$$

From the above calculation it is seen that the solubility of silver carbonate is higher than that of nickel(II) carbonate.

C is incorrect. Solubility product is only affected by temperature. Therefore addition of nitric acid cannot change the magnitude of solubility product.

D is incorrect.

$$\text{Assuming } [\text{Ni}^{2+}] = [\text{Ag}^+] = 0.100 \text{ mol dm}^{-3}$$

$$K_{\text{sp}} = [\text{Ni}^{2+}][\text{CO}_3^{2-}] = 6.6 \times 10^{-9}$$

$$[\text{CO}_3^{2-}] = \frac{6.6 \times 10^{-9}}{0.100} = 6.6 \times 10^{-8} \text{ mol dm}^{-3}$$

$$K_{\text{sp}} = [\text{Ag}^+]^2[\text{CO}_3^{2-}] = 2.1 \times 10^{-11}$$

$$[\text{CO}_3^{2-}] = \frac{2.1 \times 10^{-11}}{0.100^2} = 2.1 \times 10^{-9} \text{ mol dm}^{-3}$$

Since lower $[\text{CO}_3^{2-}]$ needed to see first trace of silver carbonate is lower than that of nickel (II) carbonate, silver carbonate should be precipitated out first.

10 What is the pH of 10 cm³ of 0.05 mol dm⁻³ sodium benzoate?

$$[K_{\text{a}} \text{ of benzoic acid} = 6 \times 10^{-5} \text{ mol dm}^{-3}]$$

A 6.46

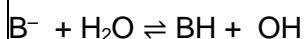
B 7.46

C 8.46

D 9.46

Answer: C

Let the salt B⁻ be the benzoate salt.



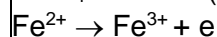
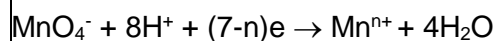
$$\begin{aligned}
 K_b &= K_w / K_a \\
 &= 1 \times 10^{-14} / 6 \times 10^{-6} \\
 &= 1.6667 \times 10^{-10} \text{ mol dm}^{-3} \\
 K_b &= \frac{[\text{OH}^-][\text{BH}]}{[\text{B}^-]} = 1.6667 \times 10^{-10} \\
 \frac{[\text{OH}^-]^2}{[\text{B}^-]} &= 1.6667 \times 10^{-10} \\
 [\text{OH}^-] &= \sqrt{1.6667 \times 10^{-10} \times 0.05} \\
 &= 2.8868 \times 10^{-6} \text{ mol dm}^{-3} \\
 \text{pOH} &= -\log(2.8868 \times 10^{-6}) = 5.5395 \\
 \text{pH} &= 14 - 5.5395 = 8.46
 \end{aligned}$$

- 11 A sample of 20.0 cm³ of 0.20 mol dm⁻³ iron(II) sulfate is titrated against 0.05 mol dm⁻³ potassium manganate(VII) in the presence of excess fluoride ions. It is found that 20.0 cm³ of the manganate(VII) solution is required to reach the end-point.

What is the oxidation number of manganese at end-point?

- A +3
B +4
C +5
D +6

Answer: A



$$\text{no of mol of electrons gained by Mn} = (7-n) \times \frac{20}{1000} \times 0.05 = 0.00100 \text{ mol}$$

$$\text{no of mol of electrons lost by Fe} = \frac{20}{1000} \times 0.20 = 0.00400 \text{ mol}$$

$$\text{no of mol of electrons lost by Fe} = \text{no of mol of electrons gained by Mn}$$

$$(7-n) = 4$$

$$n = 3$$

Thus the new oxidation state of Mn is +3.

Alternative method:

0.00400 mol of Fe²⁺ lost 0.00400 mol of electron to Mn

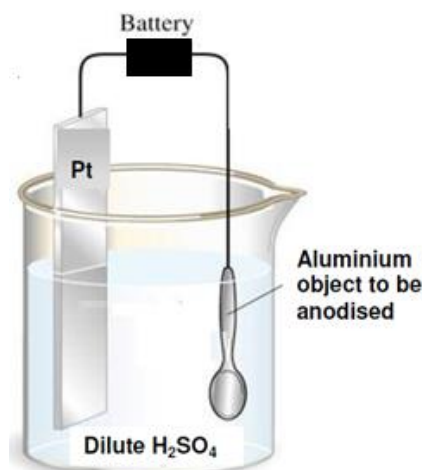
0.00100 mol of MnO₄⁻ gained 0.00400 mol of electron from Fe²⁺

1 mol of MnO₄⁻ gained 0.004/0.001 = 4 mol of electron from Fe²⁺

The original oxidation state of Mn in MnO₄⁻ is +7 and the Mn gained 4 electrons, thus the new oxidation state is +3.

- 12 Anodisation is a process to increase corrosion resistance and surface hardness in aluminium objects.

A possible set up for the process is shown as below:



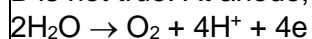
Which of the following statements about the anodisation of aluminium is true?

- A** Aluminium dissolves at the anode.
- B** Hydrogen gas is liberated at the anode.
- C** Water is oxidised at the anode to form oxygen gas.
- D** Replacing the electrolyte with NaOH(aq) will cause the reaction to cease.

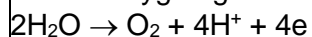
Answer: C

A is not true. In this electrolytic process, water is oxidised in preference to aluminium. Therefore, aluminium is not oxidised hence it is not dissolved.

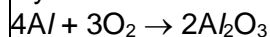
B is not true. At anode, water from electrolyte is oxidised to oxygen gas.



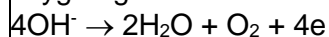
C is true. The purpose of the process is to allow water from the electrolyte to be oxidised to form oxygen gas.



Oxygen liberated then reacts with the aluminium object at the anode to form the protective layer of aluminium oxide.



D is not true. During the process, hydroxide ions from electrolyte can be oxidised to form oxygen gas at the anode. Therefore, the process does not stop.



- 13** Which of the following elements forms an oxide with a giant structure and a chloride which is readily hydrolysed?

- A** Silicon
- B** Barium
- C** Sodium

D Phosphorus

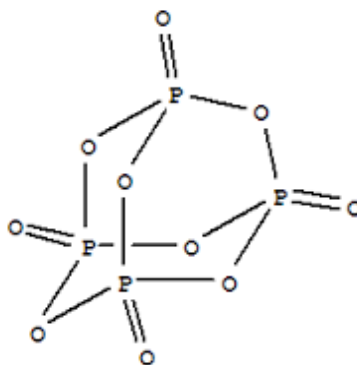
Answer: A

A is correct. The oxide of silicon, SiO_2 , exists as a giant covalent structure while the chloride of silicon, SiCl_4 , hydrolyses in water to form SiO_2 and HCl .

B is incorrect. Barium oxide has a giant ionic lattice structure and barium chloride does not undergo hydrolysis.

C is incorrect. Similar explanation to B.

D is incorrect. Phosphorus pentoxide has a simple molecular structure although phosphorus pentachloride undergoes hydrolysis readily.



Structure of P_4O_{10}

14 An element in Period 3 has the following properties:

- Its first ionisation energy is larger than both the elements before and after it across the period.
- It conducts electricity.
- It reacts slowly with cold water but react readily with steam to give a gas.

Which statement about this element is **not** correct?

- A** It has a high melting and boiling point.
- B** It forms an oxide that produces a solution that is acidic when added to water.
- C** It forms a chloride that produces a solution that is slightly acidic when added to water.
- D** Its oxidation state in compounds usually follows the group number it belongs to in the Periodic Table.

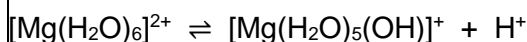
Answer: B

The element is magnesium.

A is correct. The strong metallic bonding in magnesium results in its high melting and boiling point.

B is incorrect. Magnesium oxide is basic in nature and does not produce H^+ .

C is correct. When dissolved in water, hydrated Mg^{2+} is formed. Due to its relatively high charge density, Mg^{2+} partially hydrolyses in water.



D is correct. It has an oxidation state of +2.

- 15 The following report appeared in a newspaper article.

Drums of bromine broke open after a vehicle crash on the motorway. Traffic was diverted as purple gaseous bromine drifted over the road (it is denser than air), causing irritation to drivers' eyes. Firemen sprayed water over the scene of the accident, dissolving the bromine and washing it away.

What is wrong with the report?

- A Bromine does not dissolve in water.
- B Bromine does not vapourise readily.
- C Bromine is less dense than air.
- D Bromine is not purple.

Answer: D

A is correct. Bromine dissolves in water to form an orange solution.

B is correct. Bromine has a relatively high boiling point due to its big and polarisable electron cloud and hence stronger instantaneous dipole–induced dipole forces.

C is correct. Bromine has a molecular weight of 160 grams per mole, which is denser than air, which has a molecular weight of 28 grams per mole (mainly nitrogen gas).

D is incorrect. Bromine exists as a red-brown gas.

- 16 When crystalline potassium chromate(VI) was dissolved in water, a yellow solution **Q** was formed. Addition of dilute sulfuric acid to **Q** gave an orange solution **R**. When hydrogen sulfide was bubbled through solution **R**, there was a color change in the solution and yellow sulfur was produced.

Which process **did not** occur in the above experiment?

- A Ligand exchange

- B** Redox reaction
- C** Precipitation
- D** Acid-base

Answer: A

K_2CrO_4 dissolves in water to give **Q**, CrO_4^{2-} .

Q undergoes acid-base reaction to give **R**, $\text{Cr}_2\text{O}_7^{2-}$. **R** undergoes redox reaction with H_2S where sulfur was precipitated.

- 17** Chlorine compounds show oxidation states ranging from -1 to $+7$.

What are the reagents and conditions necessary for the oxidation of chlorine gas into a compound containing chlorine in the $+5$ oxidation state?

- A** Cold dilute NaOH
- B** Hot concentrated NaOH
- C** Concentrated H_2SO_4 at room temperature
- D** $\text{AgNO}_3(\text{aq})$ followed by $\text{NH}_3(\text{aq})$ at room temperature

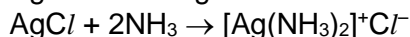
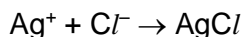
Answer: B

A is incorrect. The compound formed is NaOCl and the oxidation state of chlorine in the compound is $+1$.

B is correct. The compound formed is NaClO_3 and the oxidation state of chlorine in the compound is $+5$.

C is incorrect. No reaction occurs between chlorine gas and sulfuric acid.

D is incorrect. $\text{Cl}_2 + \text{H}_2\text{O} \rightleftharpoons \text{HClO} + \text{HCl}$



Cl in product does not have oxidation state of $+5$.

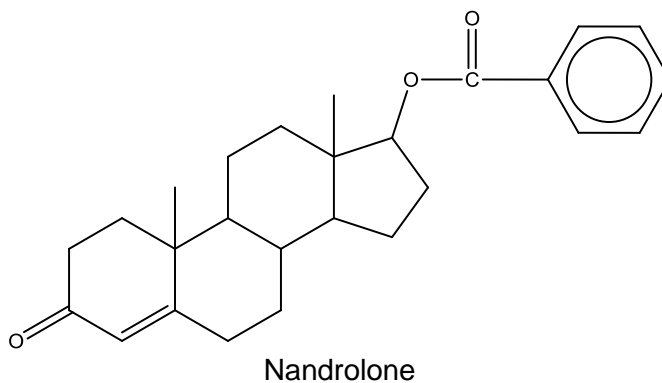
- 18** Which statement correctly **defines** a transition element?

- A** Transition elements form many coloured compounds.
- B** Transition elements or their compounds are widely used as catalysts.
- C** Transition elements form one or more stable ions with partially filled d-orbitals.
- D** Transition elements exhibit more than one oxidation state in their compounds.

Answer: C

A transition element is defined as a d-block element which forms one or more stable ions with partially filled d-orbitals.

19 How many stereoisomers does a molecule of Nandrolone has?



A 8

B 16

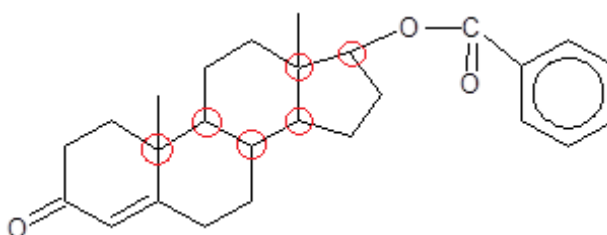
C 32

D 64

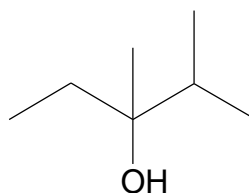
Answer: D

A chiral carbon has four different groups attached to it. Nandrolone has 6 chiral carbons. Double bond within a ring cannot exhibit cis-trans isomerism.

Total number of stereoisomers = $2^6 = 64$



20 The structure of compound **Z** is as seen below:

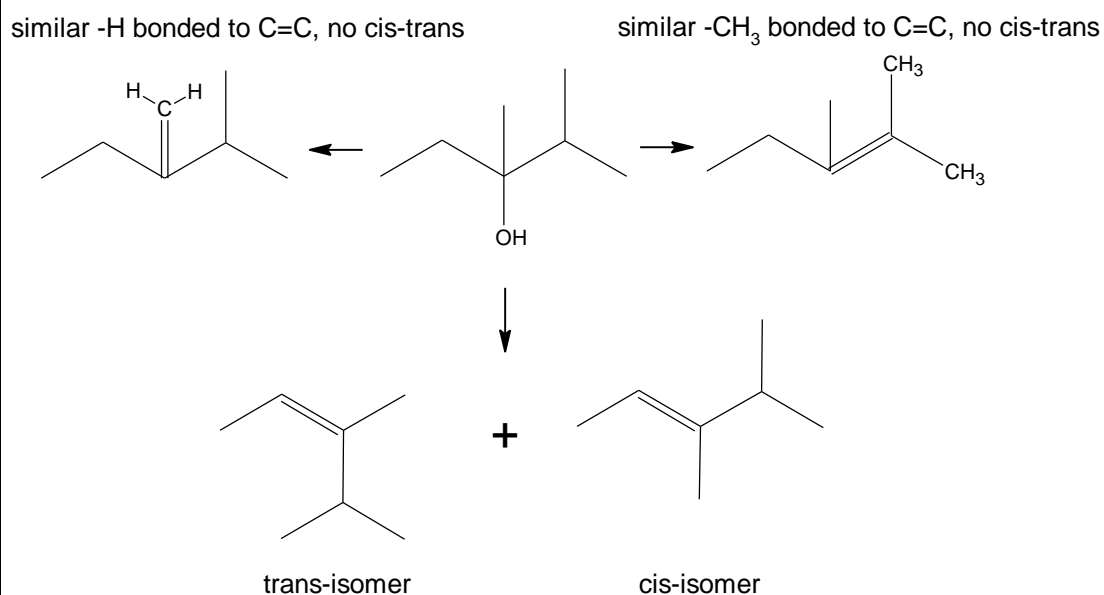
Compound **Z**

It is completely reacted with hot concentrated H_2SO_4 to form compound **Y**. What is the total number of isomers of **Y**?

- A** 2 **B** 3 **C** 4 **D** 5

Answer: **C**

This is an elimination reaction. The $-\text{OH}$ group and a H atom on a adjacent C atom are removed to form an alkene.

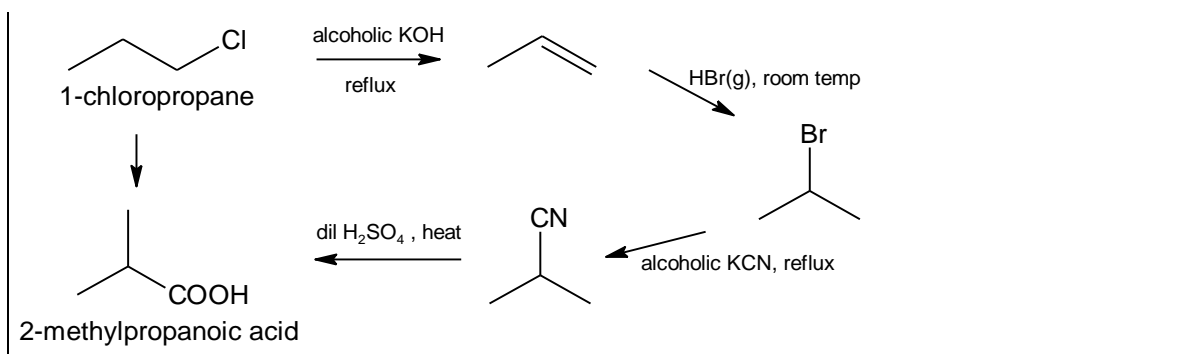


- 21** 2-methylpropanoic acid can be synthesised from 1-chloropropane through a series of reactions.

Which set of reagents, used in sequential order, would be the most suitable for this synthesis?

- A** PCl_5 , acidified KMnO_4
B ethanolic KCN , dilute HCl
C aqueous KOH , HCl , ethanolic KCN , dilute HCl
D ethanolic KOH , HBr , ethanolic KCN , dilute H_2SO_4

Answer: **D**



22 Which statement about ethanal and propanone is **not** correct?

- A Both give a positive tri-iodomethane test.
- B Both react with 2,4-dinitrophenylhydrazine reagent.
- C Both may be prepared by the oxidation of an alcohol.
- D Both react with hot acidified sodium dichromate(VI).

Answer: D

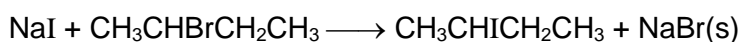
A is correct. Both compounds contain $\text{—}\overset{\text{O}}{\parallel}\text{C—CH}_3$ structure and will produce a yellow ppt, CHI₃ with aqueous alkaline iodine.

B is correct. Both compounds contain $\text{—}\overset{\text{O}}{\parallel}\text{C—}$ functional group and will produce an orange ppt with 2,4-DNPH.

C is correct. Ethanal is an aldehyde that can be prepared by the oxidation of a primary alcohol. Propanone is a ketone that can be prepared by the oxidation of a secondary alcohol.

D is incorrect. Cr₂O₇²⁻ can only oxidise ethanal but not propanone. Aldehydes can be further oxidised to carboxylic acids but ketones cannot be further oxidised.

23 When sodium iodide in propanone is added to an optically active sample of 2-bromobutane, a sodium bromide precipitate is formed after 13 minutes upon heating.



The experiment was repeated several times and the rate equation was found to be

$$\text{Rate} = k[\text{CH}_3\text{CHBrCH}_2\text{CH}_3][\text{NaI}]$$

Which of the following statements is **not** correct?

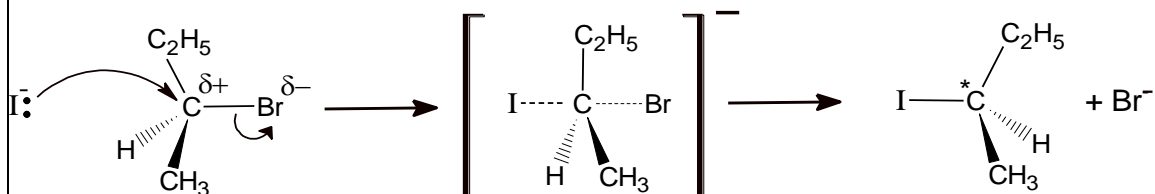
- A The mechanism involves a reactive intermediate.
- B The organic product sample obtained rotates the plane of polarised light.
- C A similar experiment, using 1-bromobutane, will produce a precipitate in less than 13 minutes.
- D A similar experiment, using 2-chlorobutane, will take more than 13 minutes to produce a precipitate.

Answer: A

A is incorrect. The rate equation shows that both reactants are involved in the rate-determining step. Hence, it is S_N2 mechanism where no intermediate is formed.

B is correct. The reactant is chiral and all its molecules undergo an inversion of configuration to remain as a chiral compound. The product will display optical activity.

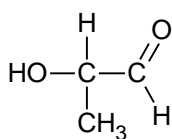
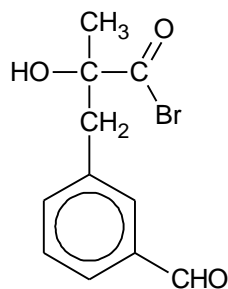
For example, the starting optically active sample contains 40% (+) and 60% (-) isomers. After S_N2 reaction, the product sample obtained will contain 60% (+) and 40% (-) isomers which is still optically active and rotate the plane of polarised light.



C is correct. 1-bromobutane is a primary halogenoalkane while 2-bromobutane is a secondary halogenoalkane. With a primary halogenoalkane, the attacking nucleophile experiences less steric hindrance when attacking the $C^{\delta+}$ and reacts more readily and the precipitate is produced faster.

D is correct. The $C-I$ bond is shorter than the $C-Br$ bond and has higher bond energy. More energy is needed to break the bond and the rate of reaction of 2-chlorobutane will be slower than that of 2-bromobutane.

- 24 Which reagent can be used to distinguish between compounds **R** and **S** under suitable conditions?

**R****S**

- A** Acidified potassium dichromate (VI)
- B** Alkaline copper(II) solution
- C** Sodium metal
- D** Phosphorus pentachloride

Answer: B

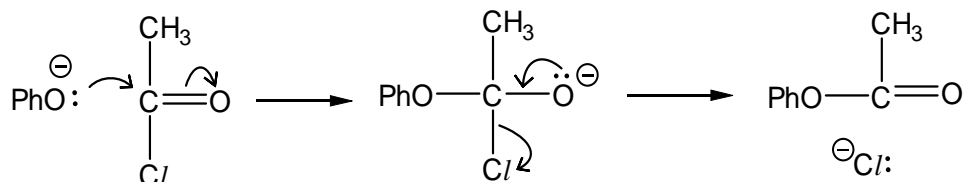
A cannot be used for the distinguishing test as it will oxidise the secondary alcohol and aldehyde in **R** as well as the aldehyde in **S**. Orange acidified $\text{K}_2\text{Cr}_2\text{O}_7$ will turn green.

B can be used for the distinguishing test. **R** is an aliphatic aldehyde and reacts to form a brick red precipitate of Cu_2O . **S** is an aromatic aldehyde and will not be able to reduce alkaline copper(II) solution.

C cannot be used for the distinguishing test. Na will react with -OH groups in both **R** and **S** and give off H_2 gas.

D cannot be used for the distinguishing test. PCl_5 will react with -OH groups in both **R** and **S** to produce white fume of HCl.

- 25** The two-stage reaction sequence given shows a possible mechanism for the reaction between phenoxide ion and ethanoyl chloride.



where Ph = phenyl

How should the *overall* reaction be classified?

- A** Electrophilic addition
- B** Nucleophilic addition
- C** Electrophilic substitution

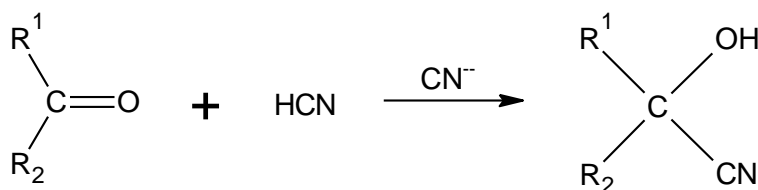
D Nucleophilic substitution

Answer: D

In the first step, PhO^- behaves as a nucleophile by attacking the $\text{C}^{\delta+}$ that is attached to O and Cl atoms.

At the end of the reaction, the Cl^- has left the molecule after being substituted.

- 26** Cyanohydrins can be made from carbonyl compounds by generating CN^- ions from HCN in the presence of a weak base.



In a similar reaction, $^-\text{CH}_2\text{COOCH}_3$ ions are generated from $\text{CH}_3\text{COOCH}_3$ by strong bases.

Which compound can be made from an aldehyde and $\text{CH}_3\text{COOCH}_3$?

- A** $\text{CH}_3\text{CH}(\text{OH})\text{COOCH}_3$
B $\text{CH}_3\text{COOCH}_2\text{CH}(\text{OH})\text{CH}_3$
C $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_2\text{COOCH}_3$
D $(\text{CH}_3)_2\text{C}(\text{OH})\text{CH}_2\text{COOCH}_3$

Answer: C

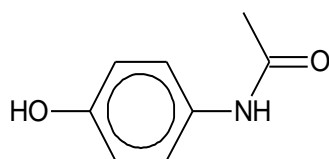
A is incorrect. The nucleophile used is $^-\text{COOCH}_3$.

B is incorrect. The nucleophile used is $\text{CH}_3\text{COOCH}_2^-$.

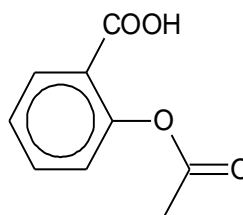
C is correct. The nucleophile used is $^-\text{CH}_2\text{COOCH}_3$ and it reacts with an aldehyde $\text{CH}_3\text{CH}_2\text{CHO}$.

D is incorrect. The nucleophile used is $^-\text{CH}_2\text{COOCH}_3$ but it reacts with a ketone CH_3COCH_3 .

- 27** Two common drugs administered when a patient experiences headache or fever are paracetamol and aspirin.

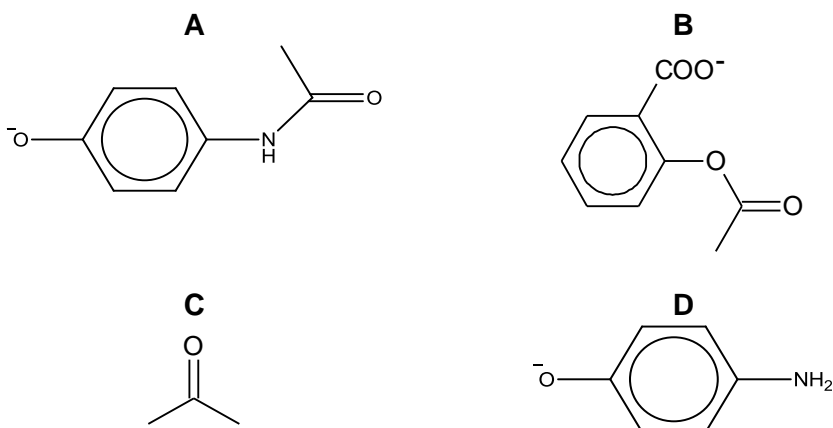


paracetamol



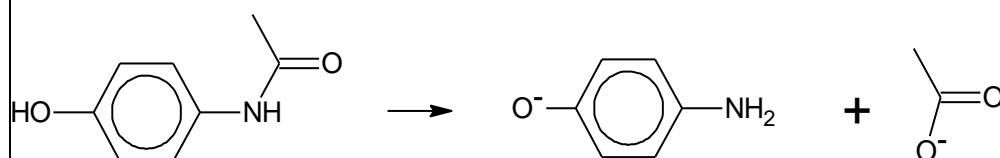
aspirin

A solution of the two drugs was hydrolysed using hot aqueous sodium hydroxide. Which organic product would be produced?

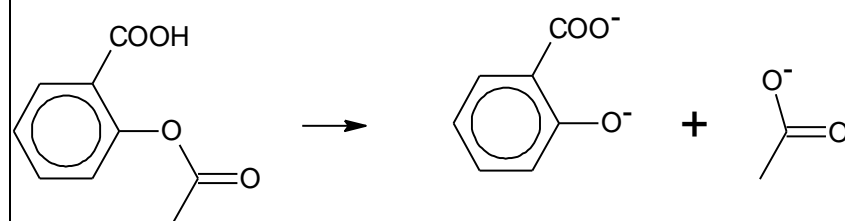


Answer: D

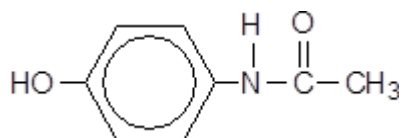
Alkaline hydrolysis of the amide bond in paracetamol produces the following:



Alkaline hydrolysis of the ester bond in aspirin produces the following:



- 28** Acetaminophen is a drug used in headache remedies. It has the following structure:



Acetaminophen

Which of the following reagents reacts with Acetaminophen?

- A** Sodium carbonate
B Cold sodium hydroxide

- C** Alkaline aqueous iodine
- D** 2,4-dinitrophenylhydrazine

Answer: B

A has no reaction. There is no -COOH present to react with the sodium carbonate.

B will react with the acidic phenol group in acetaminophen in a neutralisation reaction.

C has no reaction. The $\begin{array}{c} \text{O} \\ || \\ \text{-C-CH}_3 \end{array}$ structure is present but no C or H is directly bonded to C=O for the reaction to occur.

D has no reaction. The aldehyde and ketone functional groups are not present.

- 29** Which sequence shows the correct order of increasing pK_b in an aqueous solution of equal concentration?

- A** $\text{C}_2\text{H}_5\text{CONH}_2 < \text{C}_6\text{H}_5\text{NH}_2 < \text{C}_2\text{H}_5\text{NH}_2 < \text{C}_2\text{H}_5\text{NH}_3^+$
- B** $\text{C}_2\text{H}_5\text{NH}_2 < \text{C}_6\text{H}_5\text{NH}_2 < \text{C}_2\text{H}_5\text{NH}_3^+ < \text{C}_2\text{H}_5\text{CONH}_2$
- C** $\text{C}_2\text{H}_5\text{NH}_2 < \text{C}_6\text{H}_5\text{NH}_2 < \text{C}_2\text{H}_5\text{CONH}_2 < \text{C}_2\text{H}_5\text{NH}_3^+$
- D** $\text{C}_2\text{H}_5\text{NH}_3^+ < \text{C}_2\text{H}_5\text{CONH}_2 < \text{C}_2\text{H}_5\text{NH}_2 < \text{C}_6\text{H}_5\text{NH}_2$

Answer: C

Increasing pK_b means becoming less basic.

The electron donating C_2H_5 group in $\text{C}_2\text{H}_5\text{NH}_2$ makes the lone pair of electrons on N atom most available for donation to a proton and therefore the strongest base.

In $\text{C}_6\text{H}_5\text{NH}_2$, the lone pair of electrons on N atom is delocalised into the benzene ring, making it less available for donation to a proton. Phenylamine is therefore a weaker base than aliphatic amines.

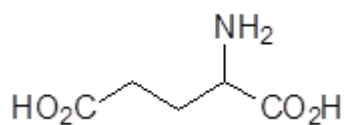
In $\text{C}_2\text{H}_5\text{CONH}_2$, the lone pair of electrons on N atom is delocalised over the carbonyl C=O and hence not available for donation to a proton.

In $\text{C}_2\text{H}_5\text{NH}_3^+$, there are no lone pair of electrons on the N atom for donation to a proton.

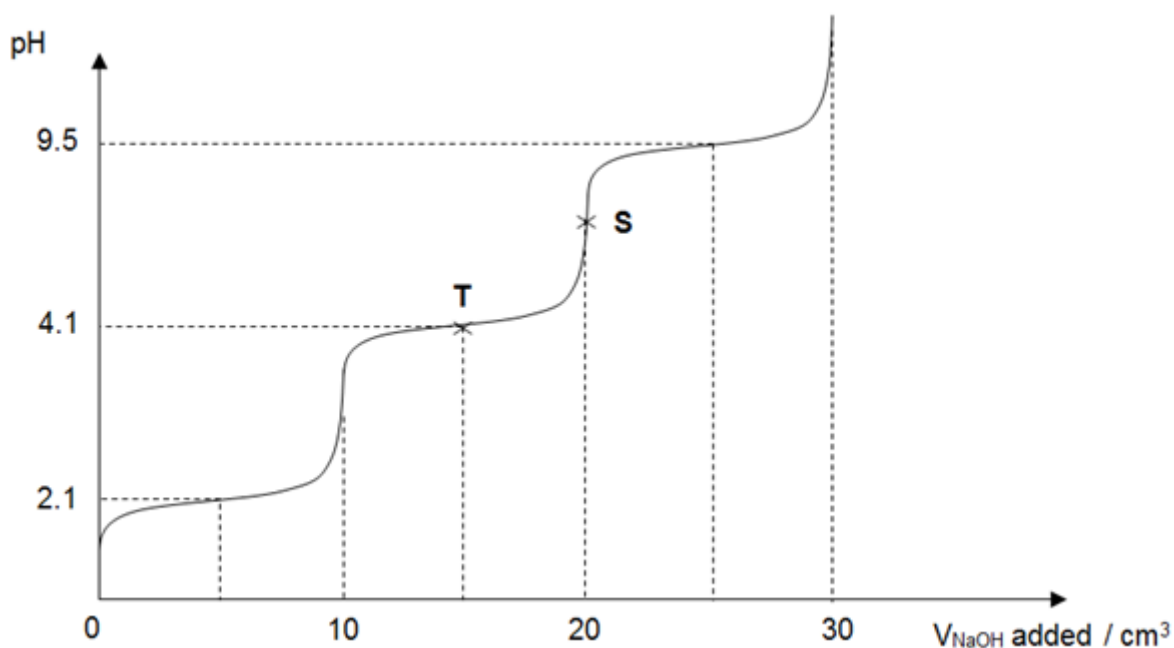
-NH_3^+ is an acidic group with a proton for donation.

30

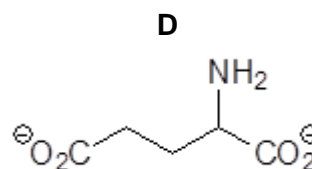
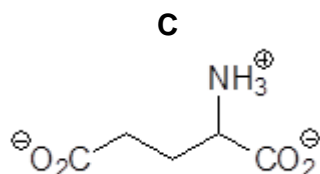
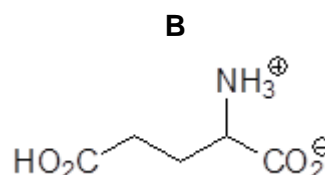
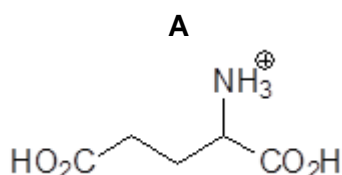
There are three $\text{p}K_{\text{a}}$ values associated with glutamic acid: 2.1, 4.1 and 9.5.



The pH-volume curve obtained when 30 cm^3 of NaOH is added to 10 cm^3 of the protonated form of glutamic acid of the same concentration is given below.

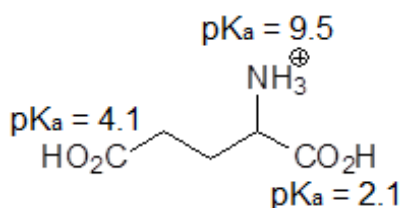


Which of the following is the major species present at point **S**?



Answer: C

The protonated form of glutamic acid and its associated pK_a values are:



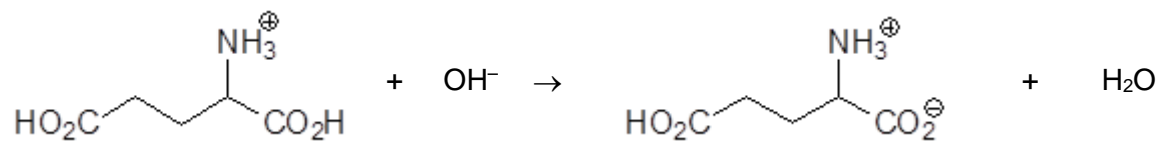
-COOH with pK_a of 2.1 is the most acidic. $-NH_3^+$ is an electron withdrawing group and disperses the negative charge of $-COO^-$ of its conjugate base and stabilises it. $-NH_3^+$ is closer to $-COOH$ with pK_a of 2.1 than $-COOH$ with pK_a of 4.1. Hence, the dissociation of the carboxylic acid with pK_a of 2.1 occurs to a larger extent.

Carboxylic acid is more acidic than protonated amine ($-NH_3^+$) as the conjugate base of the carboxylic acid ($-COO^-$) is resonance stabilised. Hence, the dissociation of the carboxylic acid occurs to a larger extent than $-NH_3^+$.

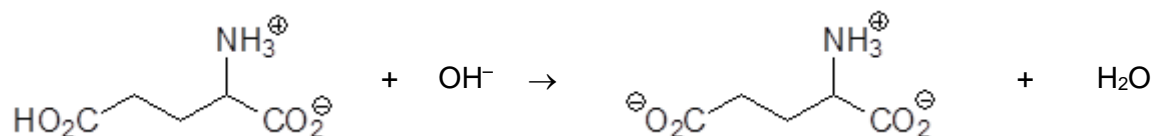
Adding NaOH would result in three equivalence points being obtained as shown in the

graph.

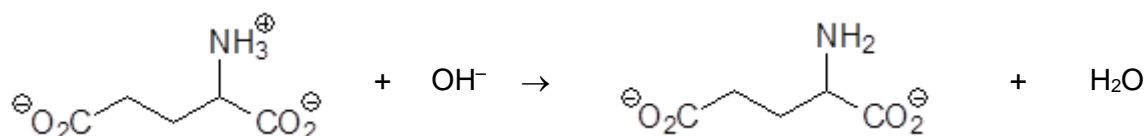
The 1st equivalence point is achieved when 10 cm³ of NaOH was added:



At point S, the 2nd equivalence point is achieved when 20 cm³ of NaOH was added:



The 3rd equivalence point is achieved when 30 cm³ of NaOH was added:



Section B

For each of the questions in this section, one or more of the three numbered statements **1** to **3** may be correct.

Decide whether each of the statements is or is not correct (you may find it helpful to pick a tick against the statements that you consider to be correct).

The responses **A** to **D** should be selected on the basis of

A	B	C	D
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

No other combination of statements is used as a correct response.

- 31** The radius and charge of each of the six ions are shown below.

ion	J ⁺	L ⁺	M ²⁺	X ⁻	Y ⁻	Z ²⁻
radius / nm	0.14	0.18	0.15	0.14	0.18	0.15

The ionic solids JX, LY and MZ are of the same lattice type. Which of the following statements are correct?

- The melting point increases in the order LY < JX < MZ.
- The numerical value of hydration energy of X⁻ is smaller than that of Z²⁻.
- The solution containing M²⁺ ions is more acidic than the solution containing J⁺ ions.

Answer: A

Option 1 is correct. JX, LY and MZ are ionic solids, thus their melting points are determined by the strength of electrostatic forces of attraction between the oppositely charged ions. The larger the magnitude of the lattice energy, the higher the melting point.

$$\text{Lattice energy} \propto \left| \frac{q^+ \times q^-}{r^+ + r^-} \right|$$

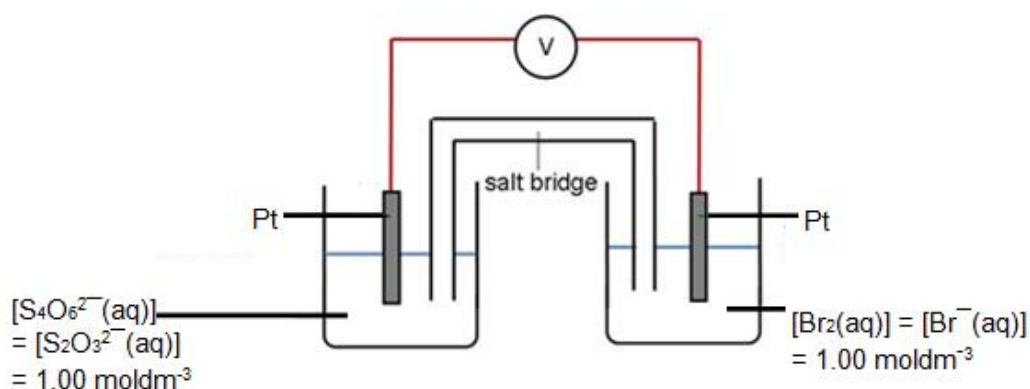
Lattice energy for JX, LY and MZ are: 3.57, 2.78 and 13.3 respectively. Thus melting point increases in the order LY < JX < MZ.

Option 2 is correct. Numerical value of hydration energy is dependent on the charge density of the ion $\left(\frac{q}{r}\right)$. Charge density of X⁻ is $1 / 0.14 = 7.14$ while that of Z²⁻ is $2 / 0.15 = 13.3$.

Thus the numerical value of hydration energy of X⁻ is smaller than that of Z²⁻.

Option 3 is correct. Charge density of M²⁺ is $2 / 0.15 = 13.3$ while that of J⁺ is $1 / 0.14 = 7.14$. Hence, M²⁺ has a higher charge density and thus a higher polarising power. M²⁺ draws electron density from the datively bonded water molecule towards itself more and weaken the O-H bond to a greater extent. This gives rise to a more acidic solution.

32 Use of the *Data Booklet* is relevant to this question.

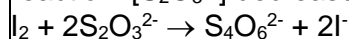


Which of the following will increase the cell potential?

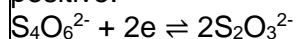
- 1 Adding iodine crystals into the anodic half cell.
- 2 Adding solid silver nitrate into the cathodic half cell.
- 3 Increasing the concentration of $\text{Br}_2(\text{aq})$ in the $\text{Br}_2(\text{aq})/\text{Br}^-(\text{aq})$ half cell.

Answer: C

Option 1 is incorrect. Adding iodine crystals remove thiosulfate ions through redox reaction. $[\text{S}_2\text{O}_3^{2-}]$ decreases while $[\text{S}_4\text{O}_6^{2-}]$ will increase at the anode.



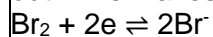
The equilibrium at anode will be disturbed. According to Le Chatelier's principle, the position of equilibrium shift right to replenish the $\text{S}_2\text{O}_3^{2-}$ ions lost and to use up the $\text{S}_4\text{O}_6^{2-}$ ions which were added from the above redox reaction. This makes $E^\circ_{\text{oxd (anode)}}$ to be more positive.



E°_{cell} becomes less positive as the $E^\circ_{\text{red (cathode)}}$ of same magnitude subtracts a larger positive $E^\circ_{\text{oxd (anode)}}$.

Option 2 is correct. Solid silver nitrate removes Br^- ions in the cathode. This reduces $[\text{Br}^-]$.
 $\text{Ag}^+(\text{aq}) + \text{Br}^-(\text{aq}) \rightarrow \text{AgBr}(\text{s})$

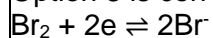
The equilibrium at cathode will be disturbed. According to Le Chatelier's principle, the position of equilibrium will shift to right to replenish bromide ions which are precipitated out. This makes $E^\circ_{\text{red (cathode)}}$ to be more positive.



$$E^\circ_{\text{cell}} = E^\circ_{\text{red (cathode)}} - E^\circ_{\text{oxd (anode)}}$$

E°_{cell} becomes more positive as the more positive $E^\circ_{\text{red (cathode)}}$ subtracts positive $E^\circ_{\text{oxd (anode)}}$ which has the same magnitude.

Option 3 is correct. At the cathode,



Increasing $[\text{Br}_2]$ shifts the equilibrium at cathode towards right. Le Chatelier's principle predicts that position of equilibrium shifts to the right to use up the bromine added. This makes $E^\circ_{\text{red (cathode)}}$ to be more positive.

$$E^\circ_{\text{cell}} = E^\circ_{\text{red (cathode)}} - E^\circ_{\text{oxd (anode)}}$$

E°_{cell} becomes more positive as the more positive $E^\circ_{\text{red (cathode)}}$ subtracts positive $E^\circ_{\text{oxd (anode)}}$ which has the same magnitude.

- 33** From the position of the elements present in the Periodic Table and the physical properties of the compounds, which compounds are covalent?

- | | | |
|----------|--------------------------------|--------------------------|
| 1 | $(\text{CH}_3)_2\text{SiCl}_2$ | b.p. 70°C |
| 2 | GeCl_4 | b.p. 86°C |
| 3 | AlBr_3 | b.p. 265°C |

Answer: A

$(\text{CH}_3)_2\text{SiCl}_2$ is covalent. This can be inferred from its low boiling point and that it resembles $(\text{CH}_3)_2\text{CCl}_2$ since both Si and C are in the same group.

GeCl_4 is covalent. Similar reasoning as above since both Ge and Si are in the same group.

AlBr_3 is covalent as its boiling point is relatively low. Al^{3+} has a high charge density and polarises the electron cloud of Cl^- such that AlCl_3 is covalent. Since Br^- is more polarisable due to larger electron cloud than Cl^- , AlBr_3 is likely to be covalent.

- 34** Use of the Data Booklet is relevant to this question.

The oxides of titanium, iron and nickel are used as catalysts in the industries.

Which properties are titanium, iron and nickel likely to have in common?

- | | |
|----------|---------------------------|
| 1 | similar ionic radii |
| 2 | high melting points |
| 3 | variable oxidation states |

Answer: A

Titanium, iron and nickel belong to the first row of the d-block transition elements.

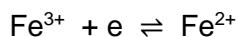
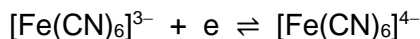
They have similar ionic radii due to the increase in shielding effect which is largely cancelled out by the increase in nuclear charge. The effective nuclear charge remains relatively constant across the first row of the d-block elements.

They have high melting points due to the strong metallic bonding, as both their 4s and 3d electrons have similar energy and can be delocalised.

They have variable oxidation states as both the 3d and 4s orbitals are similar in energy. The 4s and some (or all) of the 3d electrons can be removed without requiring too much energy.

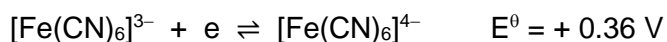
35 Use of the Data Booklet is relevant to this question.

With reference to the two half equations below, which statements are correct?



- 1 $[\text{Fe}(\text{CN})_6]^{3-}$ is more stable than Fe^{3+}
- 2 $[\text{Fe}(\text{CN})_6]^{4-}$ is a stronger reducing agent than Fe^{2+}
- 3 Both $[\text{Fe}(\text{CN})_6]^{3-}$ and Fe^{3+} can oxidize MnO_4^{2-} to MnO_4^-

Answer: B

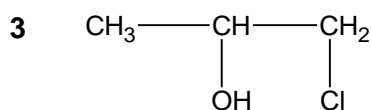
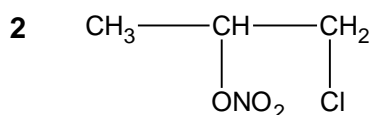
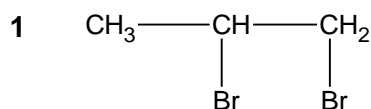


Option 1 is correct. From the reduction potential values, it can be inferred that CN^- stabilises the higher oxidation state of Fe (Fe^{3+}) to a greater extent than H_2O .

Option 2 is correct. The reduction potential of $[\text{Fe}(\text{CN})_6]^{3-}$ is less positive than that of Fe^{3+} , hence $[\text{Fe}(\text{CN})_6]^{3-}$ is a weaker oxidising agent than Fe^{3+} . Thus $[\text{Fe}(\text{CN})_6]^{4-}$ is a stronger reducing agent than Fe^{2+} .

Option 3 is incorrect. Reduction potential of $\text{MnO}_4^-/\text{MnO}_4^{2-}$ is +0.56 V, hence the cell potential for the reaction of $[\text{Fe}(\text{CN})_6]^{3-}$ and MnO_4^- is -0.20 V. Since the cell potential is negative, the reaction is non-spontaneous.

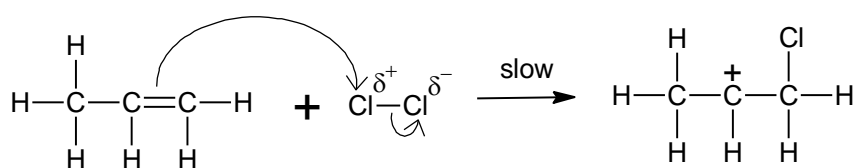
36 Propene is found to react with chlorine in the presence of aqueous sodium bromide and sodium nitrate. Which of the following are not possible products of the reaction?



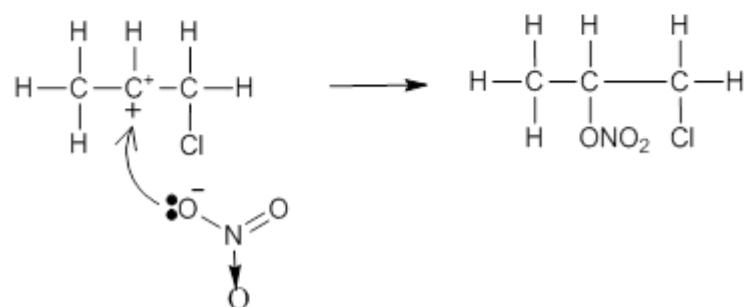
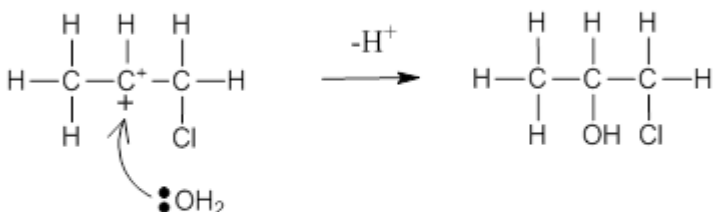
Answer: D

The reaction proceeds via electrophilic addition, during which a carbocation intermediate is

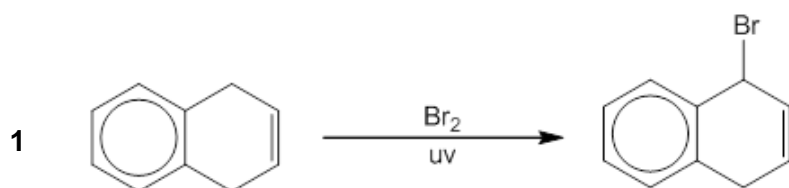
formed.

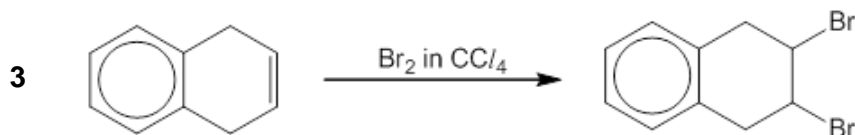


The carbocation reacts with the different nucleophiles present, giving rise to only these possible products.



37 Which of the following reactions will not give a good yield of the desired product?

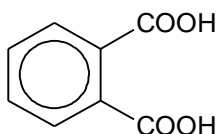




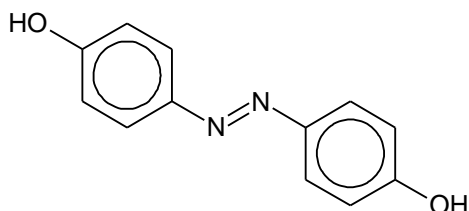
Answer: B

Both reactions 1 and 2 will not give a good yield of the desired product.

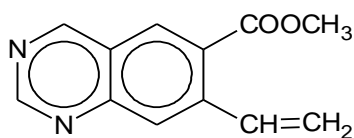
Reaction 1 is free radical substitution which can lead to multiple substitution due to the numerous C–H bonds present.

In reaction 2,  will be formed by the oxidation of the two side chains of the benzene structure.

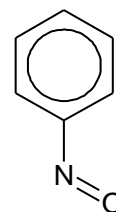
38 The three compounds **E**, **F** and **G** have the following structures?



E



F



G

Which statements about **E**, **F** and **G** are correct?

- 1 **E** and **G** have the same empirical formula.
- 2 **E** and **F** are isomers
- 3 The M_r of **F** is exactly twice that of **G**

Answer: A

Option 1 is correct.

The molecular formula of **E** is $C_{12}H_{10}N_2O_2$

The molecular formula of **G** is C_6H_5NO

Therefore, the empirical formula of **E** and **G** are the same, C_6H_5NO

Option 2 is correct.

The molecular formula of **E** is $C_{12}H_{10}N_2O_2$

The molecular formula of **F** is $C_{12}H_{10}N_2O_2$

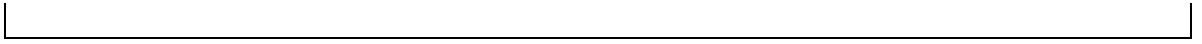
Therefore, **E** and **F** have the same molecular formula but different structural formula. They are isomers.

Option 3 is correct.

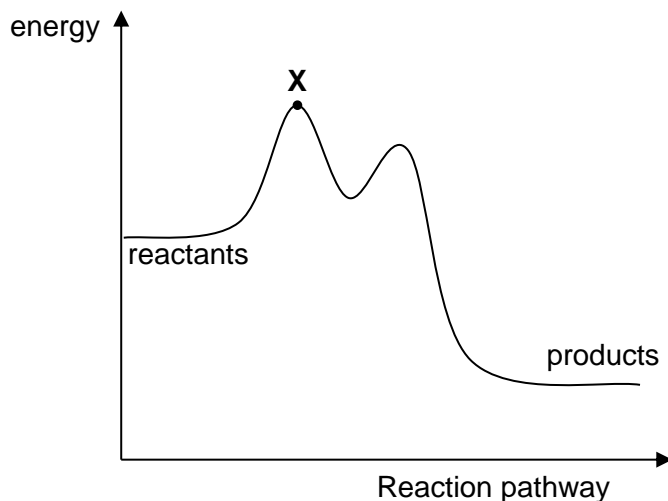
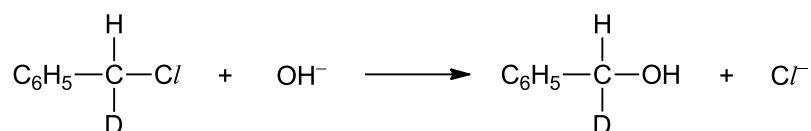
The molecular formula of **F** is $C_{12}H_{10}N_2O_2$

The molecular formula of **G** is C_6H_5NO

Since **F** has twice the number of atoms of each element in **G**, the M_r of **F** is exactly twice that of **G**.

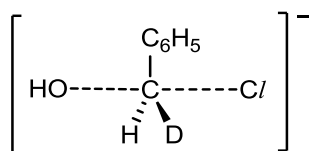


- 39 The energy profile for the following reaction is shown below. [D = ^2H]



Which conclusions can be drawn?

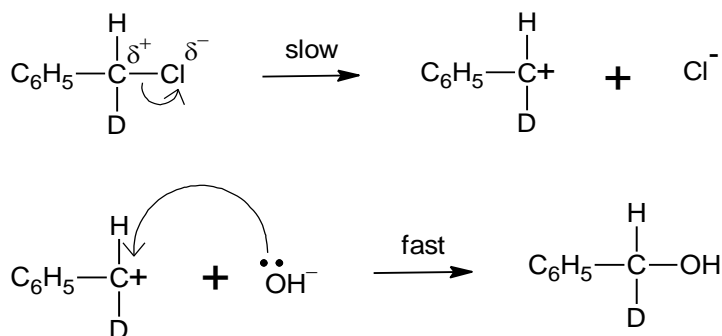
- 1 The product has no effect on the rotation of plane polarised light.
- 2 The rate of reaction can be increased by increasing concentration of OH^- .
- 3 The structure of the transition state at point X is



Answer: D

Option 1 is correct.

The graphs shows 2-steps in the mechanism. Hence, it is $\text{S}_{\text{N}}1$ mechanism.



The carbocation intermediate formed is planar, allowing OH^- to approach from either side of the plane, forming equimolar amount of both enantiomers. Therefore, the product does not display any optical activity due to the rotation of polarised light cancelling off each other

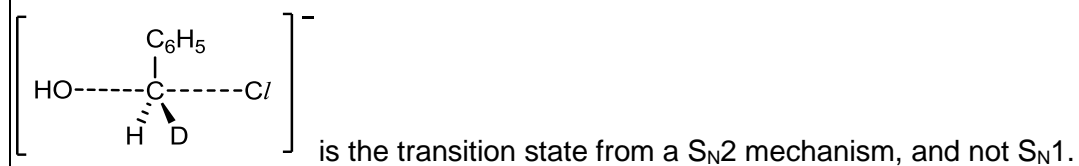
due to being equal but opposite in direction of rotation.

Option 2 is not correct.

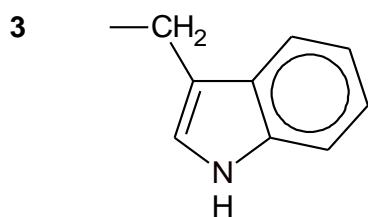
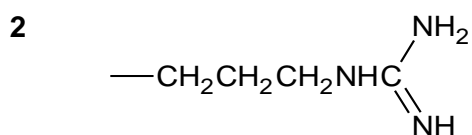
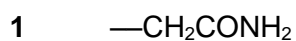
From the slow step of the mechanism, $\text{rate} = k[\text{C}_6\text{H}_5\text{CH}(\text{Cl})\text{D}]$

Therefore, the rate of reaction is independent of $[\text{OH}^-]$.

Option 3 is not correct.



- 40 Which groups within an amino acid are able to form a cross-chain link to stabilise the tertiary structure of a protein?



Answer: A

All of the above shown are R groups of α -amino acids which are used to stabilise the tertiary structure of a protein.