1 In which species are the numbers of protons, neutrons and electrons **all** different?

A ${}^{19}_{9}F^{-}$ **B** ${}^{23}_{11}Na^{+}$ **C** ${}^{31}_{15}P$ **D** ${}^{32}_{16}S^{2-}$

Answer: **B**

${}^{19}_{9}F^{-}$ 9 protons, 10 neutrons, 10 electrons

${}^{23}_{11}Na^{+}$ 11 protons, 12 neutrons, 10 electrons *(all different)*

${}^{31}_{15}P$ 15 protons, 16 neutrons, 15 electrons

${}^{32}_{16}S^{2-}$ 16 protons, 16 neutrons, 18 electrons

2 Beams of charged particles are deflected by an electric field. When a beam of protons passes through an electric field of constant strength, the angle of deflection is +12 °.

In another experiment under identical conditions, particle Y is deflected by an angle of – 4 °.

What could be the composition of particle Y?

	protons	neutrons	electrons
1	1	2	2
2	3	3	5
3	4	5	1

A 1, 2 and 3 **B** 1 and 2 **C** 1 only **D** 3 only

Answer: **B**

Magnitude of angle deflected $\propto$ charge/mass
charge/mass for ${}^{1}H^{+}$ = 1 $\Rightarrow$ deflected by 12 ^{o} for 1 unit of charge/mass

To be deflected through angle of – 4 ^{o} (i.e. opposite side of protons),
particle Y should be negatively-charged, with charge/mass = – 1/3

Option 1: charge/mass = – 1/3 ✓
Option 2: charge/mass = – 2/6 = – 1/3 ✓
Option 3: charge/mass = + 3/9 = + 1/3 ✗

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

In which pair of compounds does the first molecule have a smaller bond angle than the second molecule?

A BF_3, NH_3

B H_2O, H_2S

C $BeCl_2$, SCl_2

D XeF_4, $SiCl_4$

Answer: **D**

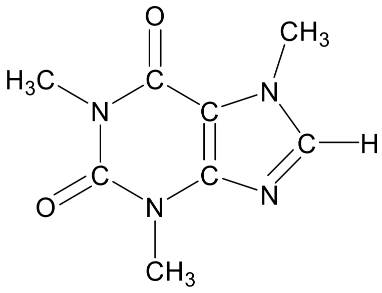
A: BF_3 (trigonal planar; bond angle 120^o) > NH_3 (trigonal pyramidal; bond angle 107^o)

B: Both H_2O and H_2S have bent shape. As O is more electronegative than S, bond pairs of electrons are nearer to the central O atom. There is greater repulsion between bond pairs in H_2O and thus bond angle of H_2O > bond angle of H_2S.

C: $BeCl_2$: 2 bond pairs and 0 lone pairs around Be atom $\Rightarrow 180^o$
$SnCl_2$: 2 bond pairs and 1 lone pairs round Sn atom $\Rightarrow 118^o$

D: XeF_4 (square planar; bond angle $\sim 90\,^o$) < $SiCl_4$ (tetrahedral; bond angle $109.5\,^o$)

4 To produce decaffeinated coffee, pure liquid CO_2 is sometimes used to extract caffeine from coffee beans.



caffeine

It was discovered that the solubility of caffeine greatly increased when a mixture of ethanol and liquid CO_2 was used.

Which interaction best explains why caffeine is more soluble in the ethanol-CO_2 mixture as compared to liquid CO_2?

A instantaneous dipole - induced dipole interactions

B permanent dipole - permanent dipole interactions

C hydrogen bonding

D dative covalent bond

Answer: **C**

Ethanol can form hydrogen bond to both caffeine and CO_2, allowing greater solubility.

5 Which graph does **not** share the same general shape as the other three graphs according to the ideal gas law for a fixed mass of gas with pressure *p*, volume V and temperature T in Kelvin?

A p against $\frac{1}{V}$ (at constant T)

B pV against p (at constant T)

C pV against V (at constant T)

D $\frac{V}{T}$ against T (at constant p)

Answer: **A**

From pV = nRT,

A: $\boldsymbol{p} = nRT\left(\frac{1}{V}\right)$ ⇒ straight line through origin

B & C: $\boldsymbol{pV}$ = nRT = **constant** at constant T ⇒ horizontal straight line

D: $\frac{\mathbf{V}}{\mathbf{T}} = nR/p$ = **constant** at constant p ⇒ horizontal straight line

6 Which statements about Group 2 elements are correct?

1 The charge density of cations increases down the Group.

2 The reducing strength of the elements increases down the Group.

3 The minimum temperature needed for the thermal decomposition of Group 2 carbonates increases down the Group.

4 The melting point of MgO is higher than CaO due to the higher polarising power of Mg^{2+}.

A 1 and 3 **B** 1 and 4 **C** 2 and 3 **D** 2 and 4

Answer: **C**

1 is incorrect:
Down the group, ionic charge remains constant while the cationic radius increases.
Hence, **charge density of Group 2 cations decreases down the group**.

2 is correct:
Down the group, **$E^{\ominus}$ value becomes more negative.**
⇒ Group 2 element becomes more easily oxidised (i.e. loses valence electrons more easily)
⇒ Reducing strength increases down the group.

3 is correct:
Down the group, charge density and polarising power of the cation decreases. Hence, the ability of the cation to distort the electron cloud and break the C−O bond in CO_3^{2-} decreases. Therefore, **Group 2 carbonates become thermally more stable** down the group i.e. **more energy (higher temperature) needed** for thermal decomposition to occur.

4 is incorrect:
$\left|\text{lattice energy}\right| \propto \dfrac{q_+ \times q_-}{r_+ + r_-}$. Mg^{2+} has a higher ionic charge and smaller ionic radius than Ca^{2+} which results in a greater **magnitude of lattice energy**. **Ionic bonds in MgO are stronger than that in CaO and require <u>more energy</u> to break**. Concept of charge density and polarising power is not applied here.
Hence, only statements 2 and 3 are correct.

7 Due to its radioactive nature, the properties of astatine, At, have to be estimated based on its position in the Periodic Table.

Which prediction concerning At or its compounds is correct?

A Astatine is a weaker oxidising agent than iodine.

B Astatine is a liquid at room temperature.

C Astatine forms diatomic molecules which dissociate into atoms less readily than iodine molecules.

D Hydrogen astatide has a higher decomposition temperature than hydrogen iodide.

Answer: **A**

Option A is correct: Oxidising power decreases down Group 17, so astatine should be a weaker oxidising agent than iodine.

Option B is incorrect: Boiling and melting point increases down the group. Iodine is already a solid at room temperature, hence astatine, with a higher melting point, would also exist as a solid at room temperature.

Option C is incorrect: Due to astatine's larger atomic radius, the extent of orbital overlap between two At atoms would be smaller as compared to between two I atoms. Hence, the At–At bond would be weaker and hence At_2 would dissociate more readily than I_2.

Option D is incorrect: Down the Group, ease of thermal decomposition of the Group 17 hydrides increases. ⇒ thermal stability: HF > HC*l* > HBr > HI

8 Sodium thiosulfate ($Na_2S_2O_3$) is used in the textile industry to remove any excess chlorine from bleaching processes by reducing it to chloride ions.

10 cm^3 of 0.20 mol dm^{-3} of sodium thiosulfate requires 192 cm^3 of chlorine gas for complete reaction at room temperature and pressure.

Which of the following is a possible formula of the sulfur-containing product?

A H_2S **B** S **C** SO_2 **D** HSO_4^-

Answer: **D**

Amount of $S_2O_3^{2-}$ = $0.20 \times \frac{10}{1000}$ = 0.00200 mol

Amount of Cl_2 = $\frac{192}{24000}$ = 0.00800 mol

$Cl_2 + 2e^- \longrightarrow 2Cl^-$
Amount of e^- gained by Cl_2 = 2(0.00800) = 0.0160 mol
= Amount of electrons lost by $S_2O_3^{2-}$

$$\frac{n_{e^-}}{n_{S_2O_3^{2-}}} = \frac{0.0160}{0.00200} = 8 \Rightarrow S_2O_3^{2-} \equiv 8e^- \equiv 2S$$

Since there are 2 S atoms per $S_2O_3^{2-}$, each of the S atom would lose 4 electrons.

Initial oxidation state of S in $S_2O_3^{2-}$ = +2
Final oxidation state of S in product = +2 + 4 = +6

Only HSO_4^- has sulfur with the oxidation state of +6

9 Aqueous solutions of **P**, **Q** and **R** react according to the following equation:

$$\mathbf{P} + 3\mathbf{Q} + 2\mathbf{R} \longrightarrow \mathbf{T} + \mathbf{U}$$

The kinetics of the above reaction was studied and the experimental results obtained are shown in the table below.

experiment	volume of **P** / cm^3	volume of **Q** / cm^3	volume of **R** / cm^3	volume of water / cm^3	relative initial rate
1	20	20	20	20	16
2	20	10	40	10	32
3	10	10	20	40	4
4	20	10	20	30	8

What is the rate equation for the above reaction?

A Rate = k[**P**][**Q**]

B Rate = k[**P**][**Q**][**R**]

C Rate = k[**P**][**Q**][**R**]^2

D Rate = k[**P**][**Q**]^2[**R**]^2

Answer: **C**

Since V_{total} is kept constant, volume of reactant used is directly proportional to its concentration in the final reaction mixture.

Comparing Experiments 3 and 4,
When [**P**] doubled, while keeping [**Q**] and [**R**] constant, the initial rate also doubled.
Order of reaction w.r.t **P** = **<u>1</u>**

Comparing Experiments 2 and 4,
When [**R**] doubled, while keeping [**P**] and [**Q**] constant, initial rate increased 4 times.
Order of reaction w.r.t **R** = **<u>2</u>**

Comparing Experiments 1 and 3, let rate = k[**P**][**Q**]^x[**R**]^2

$$\frac{rate_1}{rate_3} = \frac{k(20)(20)^x(20)^2}{k(10)(10)^x(20)^2}$$

$$4 = 2(2)^x$$

$$2 = 2^x$$

$$x = 1$$

Order of reaction w.r.t **Q** = **<u>1</u>**

10 The following data may be useful for this question.

$\Delta H_f^\ominus(N_2H_4(l)) = +50.6$ kJ mol^{-1}

$\Delta H_f^\ominus(N_2O_4(g)) = +9.2$ kJ mol^{-1}

$\Delta H_f^\ominus(H_2O(g)) = -241.8$ kJ mol^{-1}

Hydrazine, $N_2H_4(l)$, reacts with dinitrogen tetroxide, $N_2O_4(g)$, to form nitrogen gas and water vapour.

$$2N_2H_4(l) + N_2O_4(g) \longrightarrow 3N_2(g) + 4H_2O(g)$$

What is the enthalpy change for this reaction?

A +1078 kJ mol^{-1}

B –1078 kJ mol^{-1}

C +1754 kJ mol^{-1}

D –1754 kJ mol^{-1}

Answer: **B**

$\Delta H_r^\ominus = \Sigma\Delta H_f^\ominus(\text{products}) - \Sigma\Delta H_f^\ominus(\text{reactants})$

$= [3(0) + 4(-241.8)] - [2(50.6) + 9.2]]$

$= -1077.6 \approx \underline{\mathbf{-1078\ kJ\ mol^{-1}}}$

11 Travellers to countries with cold climate may sometimes use heat packs to keep warm.

The heat pack is made up of a supersaturated solution of sodium ethanoate and a small metal disc containing very small crystals of sodium ethanoate.

When the disc is broken, small crystals of sodium ethanoate are released into the solution to catalyse the crystallisation reaction of sodium ethanoate.

What are the correct signs for ΔH and ΔS in this reaction?

	ΔH	ΔS
A	+	–
B	+	+
C	–	+
D	–	–

Answer: **D**

Heat pack releases heat, so ΔH is negative.
Since sodium ethanoate is crystallised (to form solid), ΔS is negative.

[Turn over

12 When 0.20 mol of hydrogen gas and 0.15 mol of iodine gas are heated at 723 K until equilibrium is established, the equilibrium mixture is found to contain 0.02 mol of iodine gas. The equation for the reaction is as follows:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

What is the correct numerical value for the equilibrium constant, K_c?

A 12.1 **B** 48.3 **C** 92.9 **D** 185.7

Answer: **B**

	$H_2(g)$ +	**$I_2(g)$ $\rightleftharpoons$**	**$2HI(g)$**
Initial amount / mol	0.20	0.15	0
Change in amount / mol	–0.13	–0.13	+0.26
Equilibrium amount / mol	0.07	0.02	0.26

$$K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{\left(\frac{0.26}{V}\right)^2}{\left(\frac{0.07}{V}\right)\left(\frac{0.02}{V}\right)} = \mathbf{48.3}$$

13 Which of the following gives the correct relative strengths of the acids and bases in the reaction?

$$HPO_4^{2-}(aq) + H_2BO_3^{-}(aq) \rightleftharpoons H_2PO_4^{-}(aq) + HBO_3^{2-}(aq) \qquad K_c > 1$$

	acids	**bases**
A	$H_2PO_4^- > H_2BO_3^-$	$HBO_3^{2-} > HPO_4^{2-}$
B	$H_2PO_4^- > HPO_4^{2-}$	$HBO_3^{2-} > H_2BO_3^-$
C	$H_2BO_3^- > H_2PO_4^-$	$HPO_4^{2-} > HBO_3^{2-}$
D	$H_2BO_3^- > HBO_3^{2-}$	$HPO_4^{2-} > H_2PO_4^-$

Answer: **C**

$HPO_4^{2-}(aq) + H_2BO_3^{-}(aq) \rightleftharpoons H_2PO_4^{-}(aq) + HBO_3^{2-}(aq)$

base acid conjugate acid of HPO_4^{2-} conjugate base of $H_2BO_3^-$

Since $K_c > 1$, there is higher $[H_2PO_4^-]$ and $[HBO_3^{2-}]$, and lower $[HPO_4^{2-}]$ and $[H_2BO_3^-]$ at equilibrium.

Since $[H_2PO_4^-] > [H_2BO_3^{2-}]$, this suggests $H_2BO_3^-$ has a greater tendency to donate H^+.

Hence, $H_2BO_3^-$ is a stronger acid than $H_2PO_4^-$.

Since $[HBO_3^{2-}] > [HPO_4^{2-}]$, this suggests HPO_4^{2-} has a greater tendency to accept H^+. Hence, HPO_4^{2-} is a stronger base than HBO_3^{2-}.

14 The table below shows the values of the ionic product of water, K_w, at two different temperatures.

temperature / °C	K_w / mol^2 dm^{-6}
25	1.00×10^{-14}
62	1.00×10^{-13}

Which statements are correct for pure water?

1 At 62 °C, pH < 7.

2 At 62 °C, pH = 14 – pOH.

3 The ionic dissociation of water is an exothermic process.

A 1 only **B** 2 only **C** 1 and 2 **D** 2 and 3

Answer: **A**

At 62 °C, $K_w = [H^+][OH^-] = 1.00 \times 10^{-13}$
$[H^+] = [OH^-] = 3.16 \times 10^{-7}$ mol dm^{-3}
pH = 6.5 (1 is correct)

At 62 °C, pH = 13 – pOH (2 is incorrect)

Dissociation of water involves the breaking the bonds, hence it is an endothermic process. (3 is incorrect)

15 An acidified solution contains 0.10 mol dm^{-3} of $ZnSO_4$ and 0.10 mol dm^{-3} of $CuSO_4$. Hydrogen sulfide gas, H_2S, is blown through the solution until it is saturated with H_2S at 15 °C. The concentration of S^{2-}(aq) in the solution reaches 10^{-35} mol dm^{-3}.

The solubility product of ZnS at 15 °C is 10^{-24} mol^2 dm^{-6} and that of CuS is 10^{-40} mol^2 dm^{-6}.

Which statement describes what happens in the solution?

A No precipitate is formed.

B ZnS only is precipitated.

C CuS only is precipitated.

D Both ZnS and CuS are precipitated.

Answer: **C**
Ionic product of ZnS = $[Zn^{2+}]\,[S^{2-}] = (0.10)\,(10^{-35}) = 10^{-36}$ mol^2 dm^{-6} ($<10^{-24}$)
Ionic product of CuS = $[Cu^{2+}]\,[S^{2-}] = (0.10)\,(10^{-35}) = 10^{-36}$ mol^2 dm^{-6} ($>10^{-40}$)
Hence, only CuS gets precipitated.

[Turn over

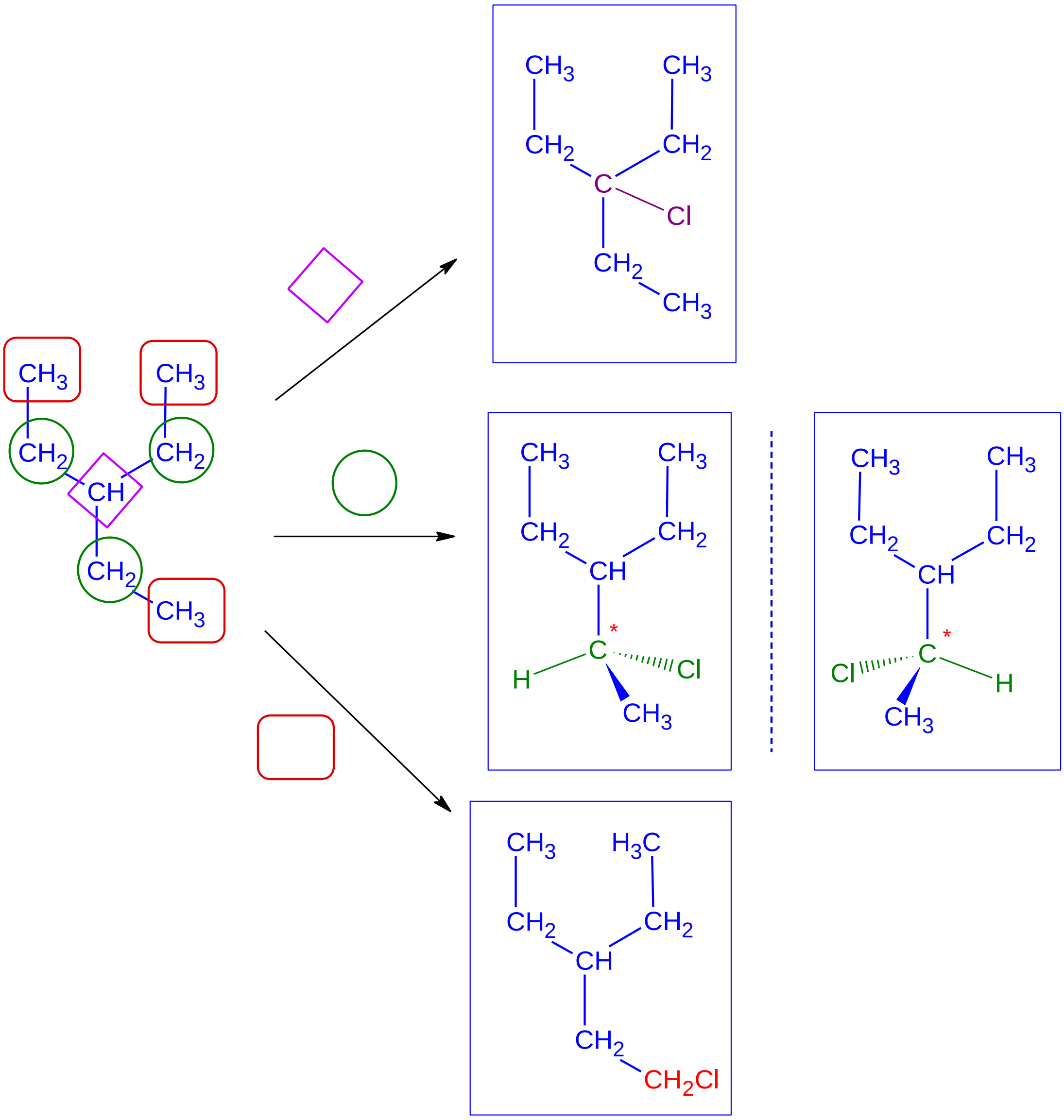
16 $(CH_3CH_2)_3CH$ can react with limited chlorine under *uv* light to produce monochloro-compounds.

How many possible isomers (including stereoisomers) of monochloro-compounds can $(CH_3CH_2)_3CH$ produce?

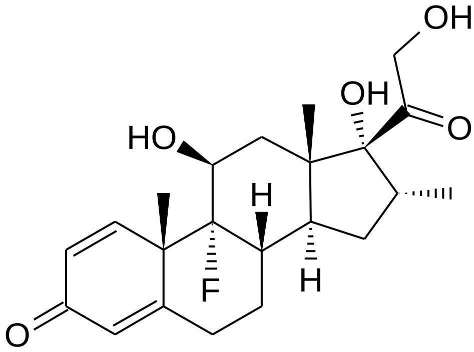
A 3 **B** 4 **C** 5 **D** 6

Answer: **B**

There are 3 possible monochloro-compounds, in which one of the isomers is able to exhibit enantiomerism due to the presence of chiral carbon.



17 *Dexamethasone* is a corticosteroid commonly used to treat many inflammatory and autoimmune disorders. It received prominence as it showed high efficacy for patients with severe COVID-19 symptoms who need either mechanical ventilation or supplemental oxygen.

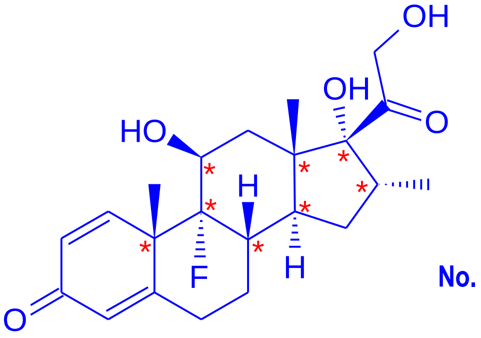


dexamethasone

How many possible stereoisomers exist for *dexamethasone*?

A 2^7 **B** 2^8 **C** 2^9 **D** 2^{10}

Answer: **B**



No. of chiral C atoms = 8

C=C in the ring cannot exhibit cis-trans isomerism

[Turn over

18 Which compounds may be a possible product of the reaction of $C_6H_5OCOCHBrCH_3$ with sodium hydroxide under different conditions?

1 $C_6H_5CO_2Na$

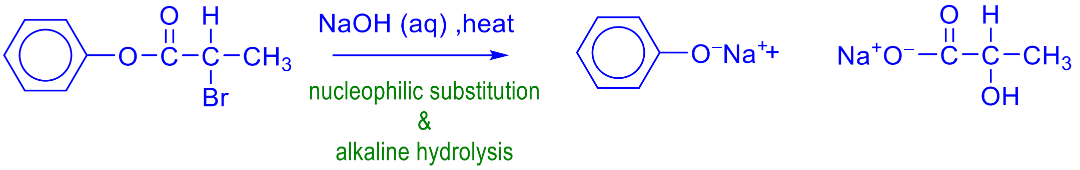
2 $CH_3CH(OH)CO_2Na$

3 $C_6H_5OCOCH=CH_2$

A 1, 2 and 3 **B** 1 and 2 **C** 2 and 3 **D** 3 only

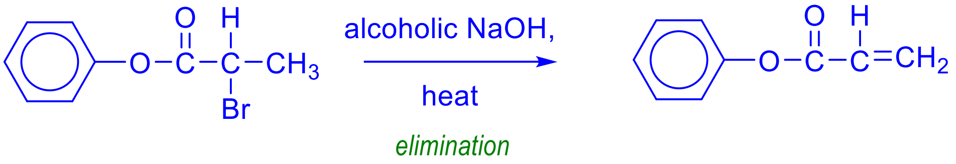
Answer: **C**

The bromoalkane can undergoes **nucleophilic substitution** and the **ester group undergoes alkaline hydrolysis when heated with NaOH (aq)**.



(Option 2 is correct)

The bromoalkane can also undergo **elimination when heated with alcoholic NaOH**.

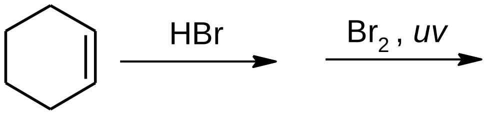


(Option 3 is correct)

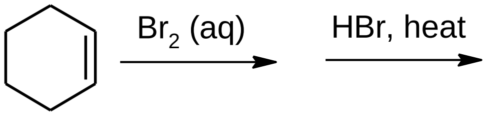
There are other possible products that can form from the reaction above, but they are not in the options provided. Option 1 will not be formed as benzoate cannot be formed.

19 Which reaction scheme will **not** give a good yield of 1,2-dibromocyclohexane?

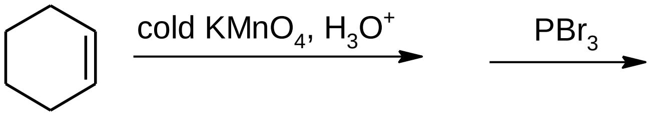
A



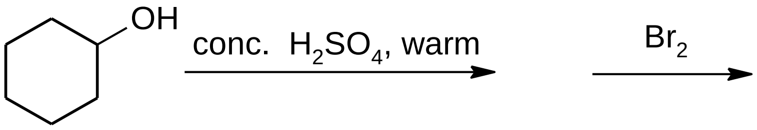
B



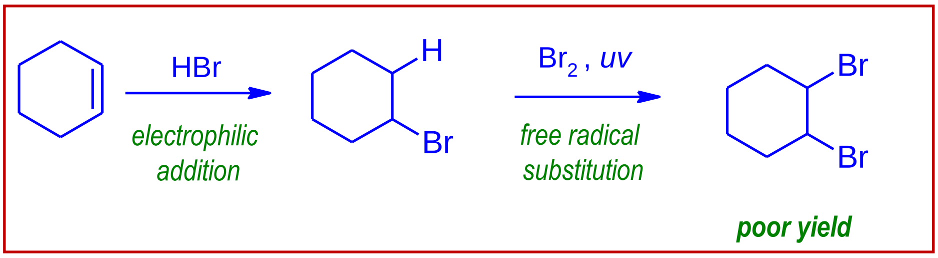
C

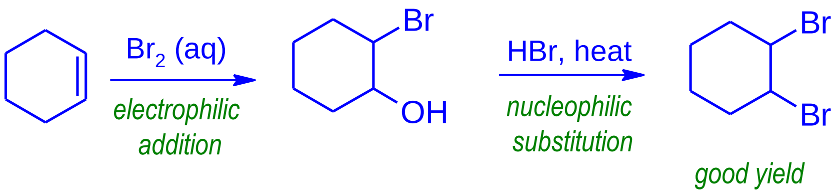


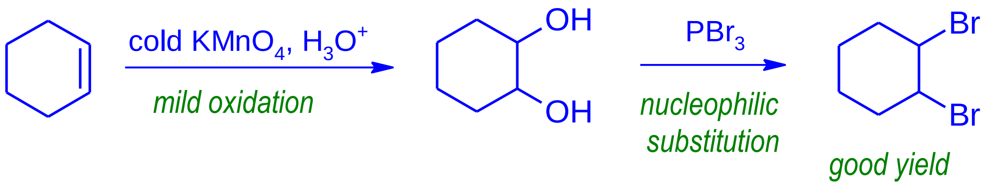
D

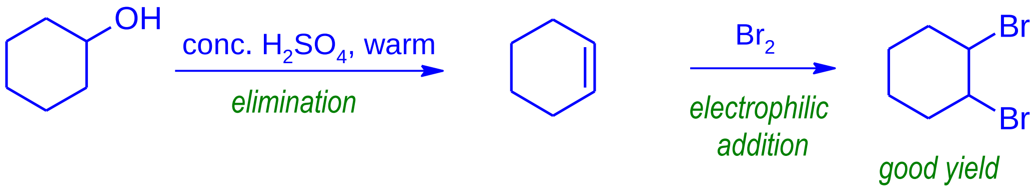


Answer: **A**



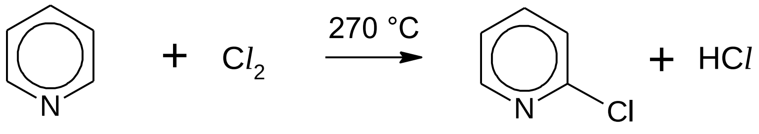






20 Pyridine, like benzene, is an aromatic compound.

In the presence of Cl_2, cyclohexene undergoes an addition reaction at room temperature. However, unlike an alkene, pyridine undergoes a substitution reaction with Cl_2 only at high temperatures.



pyridine

Which statement does **not** help to explain for this observation?

A Pyridine is resonance stabilised.

B Chlorine is not sufficiently electrophilic.

C Pyridine is a weaker nucleophile than cyclohexene.

D The lone pair on N atom of pyridine increases the electron density of the π electron cloud.

Answer: **D**

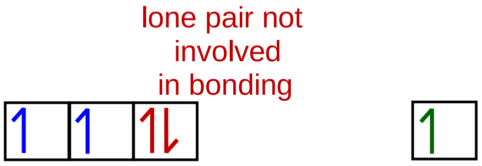
Like benzene, pyridine is **resonance stabilised** due to delocaliation of the π electrons cloud. Addition reactions result in the destruction of the ring of delocalised π electrons in pyridine which is energetically not feasible. Hence pyrdine would undergo electrophilic substitution but not electrophilic addition to preserve the stable aromatic ring structure. Option A is valid.

Delocalisation of the π electrons of pyridine makes the **π electrons less susceptible to electrophilic attack** compared to the **π electrons localised in C=C in cyclohexene, increasing the π electrons density of C=C**. Option C is valid.

Thus, a **stronger electrophile is needed for pyridine ring**. Option B is valid.

In pyridine, the **lone pair on N atom resides in the sp^2 hybridised orbital**. Hence, it does not increase the electron density of the π electrons, which can only be possible if the lone pair resides in the unhybridised p orbital. Option D is invalid

Note: Hybridisation of N in pyridine is sp^2



sp^2
usually involved in
σ bond formation with
head-on overlap of orbitals

unhybridised p
usually involved in
π bond formation with
sideway overlap of orbitals

21 A student carried out an experiment to study the ease of hydrolysis of a series of bromine containing compounds, and recorded the observations based on the addition of acidified silver nitrate solution.

Which of the following gives the expected results?

	time taken for precipitate to appear shortest ⟶ longest		
A	C_6H_5Br	$CH_2BrCONH_2$	CH_3COBr
B	$CH_2BrCONH_2$	C_6H_5Br	CH_3COBr
C	CH_3COBr	C_6H_5Br	$CH_2BrCONH_2$
D	CH_3COBr	$CH_2BrCONH_2$	C_6H_5Br

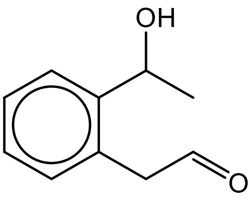
Answer: **D**

Rate of hydrolysis:
CH_3COBr (acyl bromide) > $CH_2BrCONH_2$ (alkyl bromide) > C_6H_5Br (halogenoarene)

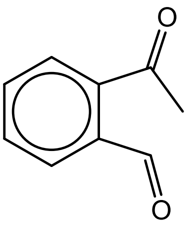
Rate α $\frac{1}{\text{time taken}}$

Time taken for ppt to appear:
CH_3COBr (acyl bromide) > $CH_2BrCONH_2$ (alkyl bromide) > C_6H_5Br (halogenoarene)
(shortest) (longest)

22 Which reagent could be used to distinguish between compound **X** and compound **Y**?



X



Y

A 2,4-dinitrophenylhydrazine

B alkaline aqueous iodine

C Tollens' reagent

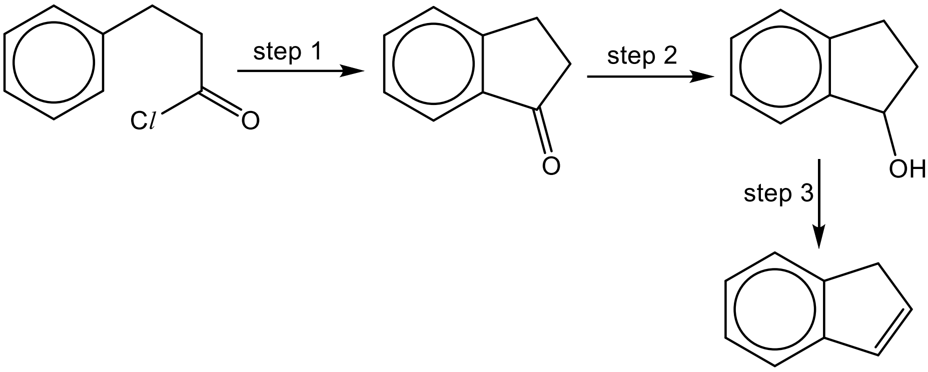
D Fehling's solution

Answer: **D**

[Turn over

X contains aliphatic aldehyde and secondary alcohol (a methyl alcohol too).
Y contains aromatic aldehyde and methyl ketone.
Only aliphatic aldehyde in **Y** will form brick-red ppt with Fehling's solution.

23 A sequence of reactions is shown below.



Which is the correct list of reagents and conditions for the sequence?

	step 1	step 2	step 3
A	A*l*C*l*$_3$(aq)	H_2, Ni	A*l*$_2$O$_3$, heat
B	A*l*C*l*$_3$(s)	LiA*l*H$_4$ in dry ether	conc. H_3PO_4, heat
C	A*l*C*l*$_3$(aq)	NaBH$_4$ in methanol	conc. H_3PO_4, heat
D	A*l*C*l*$_3$(s)	H_2, Ni	alcoholic KOH, heat

Answer: **B**

Step 1 involves an electrophilic substitution reaction with A*l*C*l*$_3$(s) acting as Lewis acid. Note that A*l*C*l*$_3$(aq) contains $[Al(H_2O)_6]^{3+}$ and the A*l* in $[Al(H_2O)_6]^{3+}$ is not able to accept lone pair of electrons.

In Step 2, the reduction of carbonyl to alcohol requires H_2, Ni catalyst at high pressure. LiA*l*H$_4$ in dry ether and NaBH$_4$ in methanol will reduce carbonyl group.

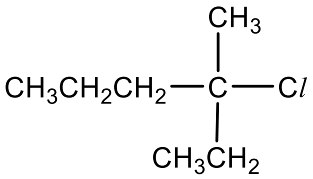
In Step 3, both A*l*$_2$O$_3$ and conc. H_3PO_4 with heating will cause the alcohol to undergo elimination to form alkene. Alcoholic KOH is the reagent for elimination of halogenoalkane to form alkene.

24 Which reaction will **not** form a racemic mixture of products?

A CH_3CHO with HCN

B CH_3CH_2Br with NaOH(aq)

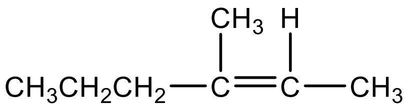
C



$CH_3CH_2CH_2-\underset{CH_3CH_2}{\overset{CH_3}{C}}-Cl$

with alcoholic KCN

D



$CH_3CH_2CH_2-\overset{CH_3}{C}=\overset{H}{C}-CH_3$

with HC*l*

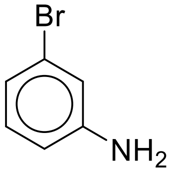
Answer: **B**

CH_3CH_2Br (1° halogenoakane) undergoes S_N2 with NaOH(aq) to form CH_3CH_2OH. Both the reactant and product do not contain chiral C and racemic mixture will not be formed.

For option **A** (aldehyde), nucleophilic addition will occur. It involves a trigonal planar sp^2 hybridised carbonyl carbon atom. The nucleophile can attack from either the top or bottom of the plane with equal probability, resulting in the formation of a racemic mixture.

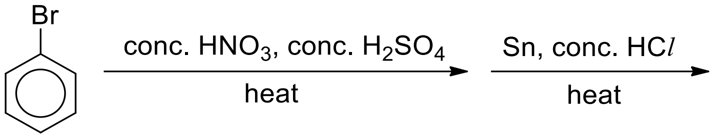
For option **C** (3° halogenoakane) and D (alkene), nucleophilic substitution S_N1 and electrophilic addition will occur respectively. Both mechanisms involve a trigonal planar sp^2 hybridised carbocation intermediate. The nucleophile can attack from either the top or bottom of the plane with equal probability, resulting in the formation of a racemic mixture.

25 Which is the best sequence for synthesising 3-bromophenylamine?

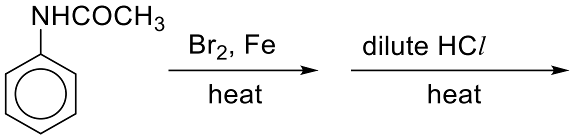


3-bromophenylamine

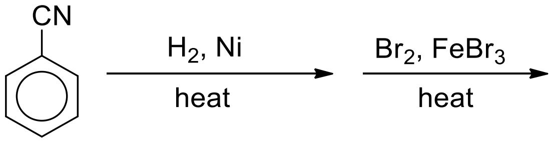
A



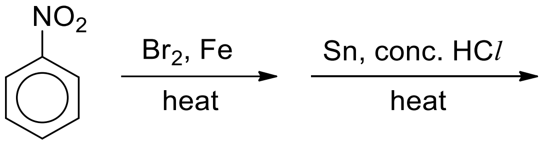
B



C



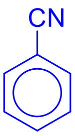
D



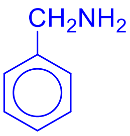
Answer: **D**

For option **A** and **B**: –Br and $-NHCOCH_3$ are 2,4 directing groups and will not yield 3-bromophenylamine.

For option **C**,

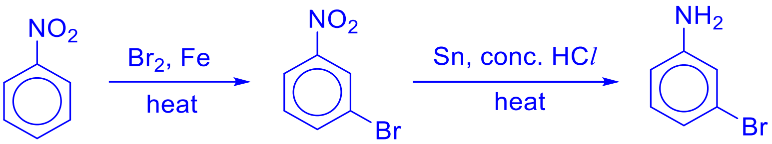


is reduced to



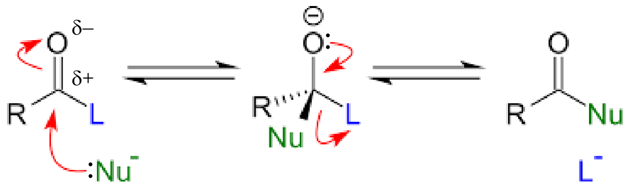
not phenylamine

For option **D**, $-NO_2$ group is 3-directing.



3-bromophenylamine

26 Carboxylic acid and their derivatives tend to undergo reactions involving a nucleophile. The mechanism of such a reaction is shown below.



R = alkyl, aryl, H
L = OH, OR, NH_2, C*l*, Br, etc
Nu = nucleophile

Which statements concerning the mechanism are correct?

1 One of the steps involves an addition reaction.

2 One of the steps involves an elimination reaction.

3 The overall reaction is nucleophilic acyl substitution.

A 1, 2 and 3 **B** 1 and 3 **C** 2 and 3 **D** 3 only

Answer: **A**

The first step is an addition reaction which involves a nucleophilic attack on an electrophilic carbonyl carbon, forming a tetrahedral alkoxide intermediate.

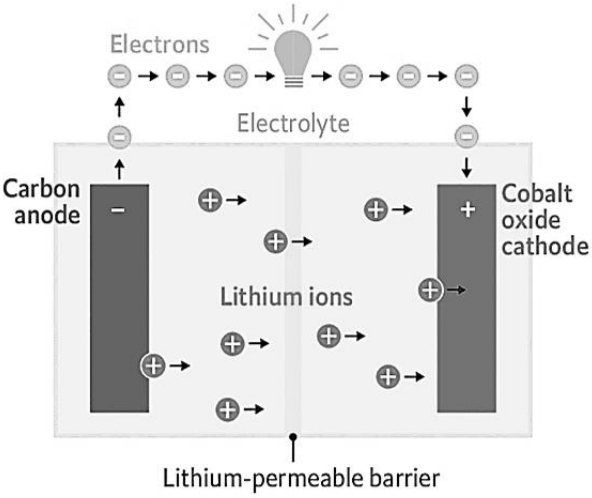
The second step is an elimination reaction. Elimination of the L allows the C=O carbonyl bond to reform thus creating a new acyl compound.

The overall reaction is nucleophilic acyl substitution which involves the substitution of the leaving group, L, that was bonded to the acyl (C=O) group.

[Turn over

27 Electric vehicles are mostly powered by lithium-ion batteries.

The diagram of a typical lithium-ion battery is given below.



The equation at the anode is given as $LiC_6 \rightarrow C_6 + Li^+ + e^-$.

The overall equation of the cell is $LiC_6 + CoO_2 \rightarrow C_6 + LiCoO_2$.

What is the equation at the cathode?

A $CoO_2 + Li^+ + e^- \rightarrow LiCoO_2$

B $Co^{2+} + O_2 + 2e \rightarrow CoO_2$

C $CoO_2 + e^- \rightarrow CoO_2^-$

D $Li^+ + Co + O_2 + e \rightarrow LiCoO_2$

Answer: **A**

Combining the overall equation and the anode equation, and by observing that the Li^+ electrolyte is involved in both half–cells, option A provides the best equation at the cathode.

Anode – Oxidation: $LiC_6 \rightarrow C_6 + Li^+ + e^-$
Cathode – Reduction: $CoO_2 + Li^+ + e^- \rightarrow LiCoO_2$
Overall: $LiC_6 + CoO_2 \rightarrow C_6 + LiCoO_2$

28 An impure copper rod containing zinc and silver is purified by connecting it to the anode of an electrolytic cell. The electrolyte is a 1.0 mol dm^{-3} solution of $CuSO_4$.

A current is passed through the cell for 2 h.

Which observation is **not** correct?

A The anode decreases in mass.

B The cathode increases in mass.

C The blue electrolyte decolourises.

D The Ag impurity deposits at the bottom of the electrolyte.

Answer: **C**

$Zn^{2+} + 2e^- \rightleftharpoons \mathbf{Zn}$ $E^\ominus = -0.76$ V
$Cu^{2+} + 2e^- \rightleftharpoons \mathbf{Cu}$ $E^\ominus = +0.34$ V
$Ag^+ + e^- \rightleftharpoons \mathbf{Ag}$ $E^\ominus = +0.80$ V

In the process of purification, the anode decreases in mass due to losing Zn as Zn^{2+} and Cu as Cu^{2+}, while the cathode increases in mass of Cu. The Ag is not oxidised and is deposited at the bottom of electrolyte solution as anode sludge.

The electrolyte will remain blue because the Cu^{2+} used up at the cathode will be replenished when Cu from the anode is oxidised to Cu^{2+}.

29 Cadmium, Cd, is a Group 12 element in the d-block of the Periodic Table.

What is the main reason why Cd is not classified as a typical transition element?

1 Its complexes are colourless.
2 It has a low melting point of 321 °C.
3 It forms compounds with fully filled 4d orbitals.
4 It does not form compounds with variable oxidation numbers.

A 1, 2, 3 and 4 **B** 1 and 2 **C** 3 only **D** 4 only

Answer: **C**

By definition, and according to IUPAC's classification, the key reason why Group 12 elements are not transition elements is due to their fully filled d orbitals. The other statements, 1, 2 and 4, are correct but they are not the reasons for the classification.

[Turn over

30 The Wacker process is an industrial procedure developed to convert ethene to ethanal.

In this reaction, ethene and oxygen gas are bubbled into an aqueous solution of $[PdCl_4]^{2-}$ at high pressure.

The mechanism of the process is given below.

Step 1: $[PdCl_4]^{2-} + CH_2{=}CH_2 + H_2O \rightarrow CH_3CHO + Pd + 2HCl + 2Cl^-$
Step 2: $Pd + 2CuCl_2 + 2Cl^- \rightarrow [PdCl_4]^{2-} + 2CuCl$
Step 3: $2CuCl + \frac{1}{2} O_2 + 2HCl \rightarrow 2CuCl_2 + H_2O$

Which statement concerning the reaction is correct?

A $[PdCl_4]^{2-}$ is a homogeneous catalyst.

B Pd is a heterogeneous catalyst.

C $CuCl_2$ is an intermediate.

D $CuCl$ is a side product.

Answer: **A**

Step 1: $\cancel{[PdCl_4]^{2-}} + CH_2{=}CH_2 + \cancel{H_2O} \rightarrow CH_3CHO + \cancel{Pd} + \cancel{2HCl} + \cancel{2Cl^-}$

Step 2: $\cancel{Pd} + \cancel{2CuCl_2} + \cancel{2Cl^-} \rightarrow \cancel{[PdCl_4]^{2-}} + \cancel{2CuCl}$

Step 3: $\cancel{2CuCl} + \frac{1}{2} O_2 + \cancel{2HCl} \rightarrow \cancel{2CuCl_2} + \cancel{H_2O}$

Overall: $CH_2{=}CH_2 + \frac{1}{2} O_2 \rightarrow CH_3CHO$

Option A (correct): $[PdCl_4]^{2-}$ is a homogeneous catalyst in the same phase as ethene, consumed in step 1 and regenerated in step 2.

Option B (incorrect): Pd is an intermediate in this reaction.

Option C (incorrect): $CuCl_2$ is a catalyst in this reaction.

Option D (incorrect): $CuCl$ is an intermediate in this reaction.

Answers:

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