1. (a) Write short notes on any three of the following Name Reactions.
(i) Wittig Reaction

- The Wittig reaction is a powerful synthetic method used for the stereoselective synthesis of alkenes from aldehydes or ketones using a phosphorus ylide (also known as a Wittig reagent).
- **Reaction:** An aldehyde or ketone reacts with a phosphorus ylide to form an alkene and a phosphine oxide.
- **Phosphorus Ylide:** It is typically generated from a triphenylphosphine and an alkyl halide, followed by deprotonation with a strong base. The ylide has a positively charged phosphorus atom directly bonded to a negatively charged carbon atom (a carbanion).
- **Mechanism (Simplified):** The nucleophilic carbon of the ylide attacks the carbonyl carbon of the aldehyde or ketone. This forms a betaine intermediate, which then undergoes a four-membered cyclic oxaphosphetane intermediate. This intermediate quickly collapses to yield the alkene and triphenylphosphine oxide.
- **Stereoselectivity:** The reaction can be stereoselective, often producing predominantly Z-alkenes or E-alkenes depending on the nature of the ylide (stabilized vs. unstabilized) and reaction conditions.
- **Key Feature:** It is an excellent method for forming carbon-carbon double bonds in a controlled manner, avoiding carbocation rearrangements that can occur in other alkene synthesis methods.

(ii) Aldol Condensation

- The Aldol condensation is a reaction in organic chemistry where two carbonyl compounds (aldehydes or ketones), at least one of which has an alpha-hydrogen, react in the presence of a base (or acid) to form a beta-hydroxy carbonyl compound (an "aldol"). This initial

adduct can then undergo dehydration to form an alpha,beta-unsaturated carbonyl compound.

- **Mechanism (Base-catalyzed):**
    a. **Enolate Formation:** A strong base removes an alpha-hydrogen from one carbonyl compound, forming a resonance-stabilized enolate anion.
    b. **Nucleophilic Attack:** The enolate anion acts as a nucleophile and attacks the carbonyl carbon of another aldehyde or ketone molecule.
    c. **Protonation:** The alkoxide intermediate formed is protonated by water or solvent to yield the beta-hydroxy carbonyl compound (aldol).
    d. **Dehydration (Condensation):** If heated or under more vigorous basic/acidic conditions, the aldol can undergo elimination of water to form an alpha,beta-unsaturated aldehyde or ketone.

- **Types:**
    - **Self-condensation:** Two molecules of the same carbonyl compound react.
    - **Crossed Aldol Condensation:** Two different carbonyl compounds react. This can lead to a mixture of products if both have alpha-hydrogens, but can be controlled if one carbonyl compound lacks alpha-hydrogens (e.g., benzaldehyde) or if one enolate is preformed.
- **Importance:** It is a crucial carbon-carbon bond-forming reaction used in the synthesis of complex organic molecules, especially those containing conjugated systems.

(iii) Baeyer-Villiger Oxidation

- The Baeyer-Villiger oxidation is an organic reaction that converts ketones to esters and cyclic ketones to lactones by insertion of an oxygen atom adjacent to the carbonyl group. It typically uses peroxy acids (e.g., meta-chloroperoxybenzoic acid, mCPBA) as the oxidizing agent.
- **Reaction:** Ketone + Peroxy acid → Ester (or Lactone) + Carboxylic acid
- **Mechanism:**
    e. **Protonation of Carbonyl:** The carbonyl oxygen of the ketone is protonated by the peroxy acid, activating it for nucleophilic attack.
    f. **Nucleophilic Attack:** The peroxy acid acts as a nucleophile, attacking the activated carbonyl carbon. This forms a tetrahedral intermediate.
    g. **Migration and Elimination:** The key step involves the migration of one of the substituents from the carbonyl carbon to the oxygen of the peroxide, simultaneously with the expulsion of the carboxylate leaving group from the peroxy acid. The migratory aptitude follows the order: tertiary alkyl > secondary alkyl > phenyl > primary alkyl > methyl.
    h. **Deprotonation:** The protonated ester (or lactone) is deprotonated to yield the final product.
- **Regioselectivity:** The oxygen insertion occurs preferentially to the more electron-rich or more substituted carbon adjacent to the carbonyl, due to the migratory aptitude order. For cyclic ketones, a lactone is formed.
- **Application:** It is a valuable reaction for synthesizing esters and lactones, especially those that are difficult to obtain by other methods.

(iv) Perkin Reaction

- The Perkin reaction is an organic reaction used for the synthesis of alpha,beta-unsaturated aromatic acids by the aldol condensation of an aromatic aldehyde and an acid anhydride in the presence of a weak base (often the alkali salt of the acid corresponding to the anhydride).
- **Reaction:** Aromatic aldehyde + Acid anhydride + (Salt of corresponding acid as base) → Alpha,beta-unsaturated aromatic acid.
- **Mechanism (Simplified):**
    i. **Enolate Formation:** The base deprotonates the alpha-carbon of the acid anhydride, forming a resonance-stabilized carbanion (enolate).
    j. **Nucleophilic Attack:** This enolate acts as a nucleophile and attacks the carbonyl carbon of the aromatic aldehyde.
    k. **Cyclization and Dehydration:** The intermediate undergoes cyclization, followed by elimination of a carboxylic acid molecule and then further dehydration to form the alpha,beta-unsaturated aromatic acid.
- **Key Features:**
    - It is specifically used for aromatic aldehydes.
    - The base is typically the sodium or potassium salt of the carboxylic acid derived from the anhydride.
    - The product is an alpha,beta-unsaturated carboxylic acid.
- **Example:** Reaction of benzaldehyde with acetic anhydride in the presence of sodium acetate yields cinnamic acid.

(b) Write the mechanism involved in acid catalyzed addition of methyl amine to benzaldehyde.

- This reaction is the formation of an imine (Schiff base) from an aldehyde and a primary amine, catalyzed by acid.

- **Reaction:** Benzaldehyde + Methylamine $\xrightarrow{H^+}$ N-Methylbenzimine + H_2O
- **Mechanism:**
    l. **Protonation of Carbonyl Oxygen:** The carbonyl oxygen of benzaldehyde is protonated by the acid catalyst. This increases the electrophilicity of the carbonyl carbon, making it more susceptible to nucleophilic attack.
        - $Ph\text{-}CHO + H^+ \rightleftharpoons Ph\text{-}CH{=}O^+H$

    m. **Nucleophilic Attack by Amine:** The nitrogen atom of methylamine (a nucleophile) attacks the now more electrophilic carbonyl carbon. This leads to the formation of a tetrahedral intermediate (carbinolamine).
        - $Ph\text{-}CH{=}O^+H + CH_3NH_2 \rightleftharpoons Ph\text{-}CH(O^+H)\text{-}NHCH_3$

    n. **Proton Transfer:** A proton is transferred from the positively charged nitrogen to the oxygen (or to another amine molecule, which is then protonated).
        - $Ph\text{-}CH(O^+H)\text{-}NHCH_3 \rightleftharpoons Ph\text{-}CH(OH)\text{-}N^+H_2CH_3$

    o. **Protonation of Hydroxyl Group:** The hydroxyl group of the carbinolamine is protonated, converting it into a good leaving group (water).
        - $Ph\text{-}CH(OH)\text{-}N^+H_2CH_3 + H^+ \rightleftharpoons Ph\text{-}CH(O^+H_2)\text{-}N^+H_2CH_3$

    p. **Loss of Water (Elimination):** The water molecule leaves, generating a positively charged intermediate (iminium ion).
        - $Ph\text{-}CH(O^+H_2)\text{-}N^+H_2CH_3 \rightarrow Ph\text{-}CH{=}N^+HCH_3 + H_2O$

    q. **Deprotonation:** The positively charged nitrogen loses a proton to form the neutral imine (N-methylbenzimine).
        - $Ph\text{-}CH{=}N^+HCH_3 + H_2O \rightleftharpoons Ph\text{-}CH{=}NCH_3 + H_3O^+$

2. (a) Write final product when nitro benzene undergo reduction with following reagents (i) Sn/HCl

- **Product:** Aniline (Phenylamine)
- **Reaction:** $C_6H_5NO_2 \xrightarrow{Sn/HCl} C_6H_5NH_2$
- **Explanation:** Sn/HCl is a strong acidic reducing agent that reduces the nitro group ($-NO_2$) completely to an amino group ($-NH_2$).

(ii) Zn/NH_4Cl

- **Product:** N-Phenylhydroxylamine
- **Reaction:** $C_6H_5NO_2 \xrightarrow{Zn/NH_4Cl} C_6H_5NHOH$
- **Explanation:** Zn/NH_4Cl is a neutral reducing agent that reduces the nitro group selectively to a hydroxylamine group ($-NHOH$). It is a partial reduction.

(iii) Zn/NaOH

- **Product:** Azoxybenzene (in the presence of mild alkali, or hydrazobenzene in stronger alkali/excess Zn)
- **Reaction (Mild Alkali):** $2C_6H_5NO_2 \xrightarrow{Zn/NaOH(mild)} C_6H_5\text{-}N{=}N(O)\text{-}C_6H_5$ (Azoxybenzene)
- **Explanation:** Reduction of nitrobenzene with zinc and an alkaline medium typically leads to dimeric products. With mild alkaline conditions, azoxybenzene is formed. With stronger alkaline conditions and excess zinc, further reduction can occur to form azobenzene ($C_6H_5\text{-}N{=}N\text{-}C_6H_5$) or even hydrazobenzene ($C_6H_5\text{-}NH\text{-}NH\text{-}C_6H_5$).

(b) How will you distinguish primary, secondary and tertiary nitro alkanes on the basis of Victor Meyer's test.

- Victor Meyer's test is primarily used to distinguish between primary, secondary, and tertiary alcohols, but a modified version can be

applied to nitroalkanes. The test relies on the formation of nitrolic acids, pseudonitroles, or the lack of reaction.

- **Reagents:**
    r. **Nitrous acid (HNO_2):** Generated in situ from $NaNO_2$/HCl or $NaNO_2/H_2SO_4$.
    s. **NaOH or KOH (alkali):**
- **Procedure and Observations:**
    t. **Reaction with Nitrous Acid:** The nitroalkane is treated with nitrous acid.
    u. **Reaction with Alkali:** The product from step 1 is then treated with an alkali solution.
- **Distinction:**
    - **Primary Nitroalkane (RCH_2NO_2):**
        - **Reaction with HNO_2:** Primary nitroalkanes react with nitrous acid to form **nitrolic acids**.
            - $R\text{-}CH_2\text{-}NO_2 + HONO \rightarrow R\text{-}C(=NOH)\text{-}NO_2$ (Nitrolic acid) + H_2O
        - **Addition of Alkali:** Nitrolic acids are acidic and dissolve in alkali to form a salt, giving a **blood-red color**.
            - $R\text{-}C(=NOH)\text{-}NO_2 + NaOH \rightarrow$ Red colored solution
    - **Secondary Nitroalkane (R_2CHNO_2):**
        - **Reaction with HNO_2:** Secondary nitroalkanes react with nitrous acid to form **pseudonitroles**.
            - $R_2\text{-}CH\text{-}NO_2 + HONO \rightarrow R_2\text{-}C(NO_2)\text{-}NO$ (Pseudonitrole) + H_2O

        - **Addition of Alkali:** Pseudonitroles are neutral compounds and **do not react with alkali**. They typically give a **blue or greenish-blue color** in solution, but this color quickly fades on standing.

    - **Tertiary Nitroalkane (R_3CNO_2):**

        - **Reaction with HNO_2:** Tertiary nitroalkanes **do not have an alpha-hydrogen** atom. Therefore, they **do not react with nitrous acid** at all.

        - **Addition of Alkali:** Since no reaction occurs with nitrous acid, the solution remains colorless or the original color of the nitroalkane, and there is **no change upon addition of alkali**.

(c) Explain why aldehydes and ketones undergo nucleophilic addition reactions easily but carboxylic acid and their derivatives not.

- The difference in reactivity towards nucleophilic addition between aldehydes/ketones and carboxylic acids/derivatives lies in the **electrophilicity of the carbonyl carbon** and the **nature of the group attached to the carbonyl carbon (the leaving group ability)**.

- **Aldehydes and Ketones (Nucleophilic Addition):**

    - In aldehydes (R-CHO) and ketones (R-CO-R'), the carbonyl carbon is bonded to a hydrogen atom (in aldehydes) or alkyl/aryl groups (in both). These groups are generally **not good leaving groups**.

    - The carbonyl carbon is electrophilic due to the strong electron-withdrawing effect of the oxygen atom.

    - When a nucleophile attacks the carbonyl carbon, it forms a **tetrahedral intermediate**. Since there is no good leaving group attached to the carbonyl carbon, the intermediate is stable and simply undergoes protonation (or deprotonation in base

catalysis) to yield an **addition product** (e.g., alcohol, cyanohydrin).

- There is no group to be expelled, so the reaction stops at addition.

- **Carboxylic Acids and Their Derivatives (Nucleophilic Acyl Substitution):**
  - Carboxylic acids (R-COOH) and their derivatives (acid chlorides R-COCl, esters R-COOR', amides R-$CONH_2$, anhydrides R-CO-O-CO-R) also contain a carbonyl group.
  - However, the carbonyl carbon is bonded to a heteroatom (O, N, Cl) that can act as a **potential leaving group** (e.g., -OH, -Cl, -OR', -NH_2, -OCOR).
  - When a nucleophile attacks the carbonyl carbon of a carboxylic acid derivative, a tetrahedral intermediate is formed.
  - This tetrahedral intermediate is unstable because it has a good leaving group attached. The carbonyl group then reforms, and the leaving group is expelled. This leads to a **nucleophilic acyl substitution reaction**, not a simple addition. The net result is the replacement of the leaving group by the incoming nucleophile.

- **Summary:**
  - **Aldehydes/Ketones:** Absence of a good leaving group on the carbonyl carbon favors **nucleophilic addition**.
  - **Carboxylic Acids/Derivatives:** Presence of a good leaving group on the carbonyl carbon allows for the expulsion of that group after nucleophilic attack, leading to **nucleophilic acyl substitution**. The initial addition is followed by elimination.

(d) Why do α-hydrogens in nitroethane show acidic behaviour ? Write the product when nitro ethane reacts with Br_2 in alkaline medium.

- **Why α-hydrogens in nitroethane show acidic behaviour:**
    - Nitroethane ($CH_3CH_2NO_2$) has alpha-hydrogens on the carbon atom adjacent to the nitro group (the CH_2 group).
    - These alpha-hydrogens are acidic due to the strong **electron-withdrawing effect of the nitro group (**$-NO_2$**)**.
    - The nitro group is one of the most powerful electron-withdrawing groups both through **inductive effect (-I effect)** and **resonance effect (-M effect)**.
    - **Resonance Stabilization of the Carbanion:** When an alpha-hydrogen is removed by a base, it forms a carbanion. This carbanion is highly stabilized by resonance with the nitro group. The negative charge can be delocalized onto both oxygen atoms of the nitro group.
        - CH_3-CH^--NO_2 ↔ CH_3-CH=$N^+(O^-)O^-$ (multiple resonance structures)
    - This extensive resonance delocalization significantly stabilizes the conjugate base (the nitronate anion or aci-form), thus making the alpha-hydrogens surprisingly acidic (pKa around 9-10, comparable to phenols).
- **Product when nitroethane reacts with Br_2 in alkaline medium:**
    - **Reaction:** Nitroethane reacts with Bromine (Br_2) in alkaline medium to undergo **alpha-halogenation** due to the acidity of its alpha-hydrogens.
    - **Mechanism:**
        i. **Enolate (Nitronate) Formation:** In alkaline medium, the alpha-hydrogen is removed from nitroethane to form the resonance-stabilized nitronate anion.
            - $CH_3CH_2NO_2 + OH^- \rightleftharpoons CH_3CH^-NO_2 + H_2O$

ii. **Electrophilic Attack by Bromine:** The nitronate anion (which is nucleophilic) attacks the electrophilic bromine molecule.

- $CH_3CH^-NO_2 + Br_2 \rightarrow CH_3CH(Br)NO_2 + Br^-$

- **Product:** 1-Bromo-1-nitroethane
- **Reaction:** $CH_3CH_2NO_2 + Br_2 \overset{OH^-}{\rightarrow} CH_3CH(Br)NO_2 + HBr$

(e) Write reactions involved in the catalytic reduction and MPV reduction of benzaldehyde.

- **Catalytic Reduction of Benzaldehyde:**
  - **Reaction:** Catalytic reduction involves the addition of hydrogen across the carbonyl double bond in the presence of a metal catalyst.
  - **Reagent:** H_2 gas with a noble metal catalyst like Palladium (Pd), Platinum (Pt), or Nickel (Ni).
  - **Product:** Benzyl alcohol
  - **Reaction Equation:**
    - $C_6H_5CHO + H_2 \overset{Pd \text{ or } Pt \text{ or } Ni}{\rightarrow} C_6H_5CH_2OH$
  - **Explanation:** The carbonyl group of benzaldehyde is reduced to a primary alcohol group. The aromatic ring is generally not reduced under these conditions unless harsher conditions (high pressure/temperature) are applied.
- **MPV Reduction (Meerwein-Ponndorf-Verley Reduction) of Benzaldehyde:**
  - **Reaction:** MPV reduction is a selective reduction of aldehydes and ketones to alcohols using an aluminum alkoxide (typically aluminum isopropoxide) as a catalyst and an excess of a secondary alcohol (like isopropanol) as the hydrogen donor.

- **Reagents:** Aluminum isopropoxide ($[(CH_3)_2CHO]_3Al$) and Isopropanol ($(CH_3)_2CHOH$).
- **Product:** Benzyl alcohol and Acetone
- **Reaction Equation:**
  - $C_6H_5CHO + (CH_3)_2CHOH \xrightarrow{[(CH_3)_2CHO]_3Al} C_6H_5CH_2OH + CH_3COCH_3$
- **Mechanism (Key steps):**

iii. **Coordination:** The carbonyl oxygen of benzaldehyde coordinates with the aluminum atom of the alkoxide catalyst.

iv. **Hydride Transfer:** A hydride ion is transferred from the alpha-carbon of the isopropanol (hydrogen donor) to the carbonyl carbon of benzaldehyde. Simultaneously, an electron pair from the benzaldehyde carbonyl carbon moves to form a bond with an alkoxide oxygen on aluminum. This is a cyclic six-membered transition state.

v. **Product Release:** Benzyl alcohol is formed and dissociates from the aluminum, while the catalyst is regenerated with the formation of acetone.

- **Key Feature:** MPV reduction is highly selective, reducing only aldehydes and ketones without affecting other reducible functional groups like carbon-carbon double bonds or triple bonds. It is also a reversible reaction.

3. (a) Suggest the reactions for the synthesis of any two of the followings using diethylmalonate (DEM):

- **Diethylmalonate (DEM):** $CH_2(COOEt)_2$ (or $CH_2(CO_2C_2H_5)_2$) - It has acidic alpha-hydrogens, which can be deprotonated to form a nucleophilic enolate. This enolate can then react with alkyl halides

(alkylation) or carbonyl compounds. Subsequent hydrolysis and decarboxylation are common steps.

(i) $CH_3CH_2COCH_2COOH$ (4-Oxopentanoic acid or Levulinic Acid derivative)

- This structure is actually a gamma-keto acid (4-oxopentanoic acid is $CH_3COCH_2CH_2COOH$). The given structure $CH_3CH_2COCH_2COOH$ is 3-oxopentanoic acid. Let's assume the question implies the synthesis of a beta-keto acid or similar from DEM.
- **Assuming the target is 3-oxopentanoic acid (a beta-keto acid):**
    v. **Formation of Enolate:** Diethylmalonate is treated with a strong base (e.g., sodium ethoxide, NaOEt) to form the enolate.
        - $CH_2(COOEt)_2 + NaOEt \rightarrow Na^+[CH(COOEt)_2]^- + EtOH$

    w. **Alkylation:** The enolate attacks an acyl halide (e.g., Propionyl chloride, CH_3CH_2COCl) in an acylation reaction. This is generally not straightforward with acyl halides and can lead to O-acylation. A more common approach to beta-keto esters from malonates is via Claisen condensation with an ester, then decarboxylation.

    x. **Hydrolysis and Decarboxylation:** The acylated malonate would then be hydrolyzed and decarboxylated under acidic conditions to yield the beta-keto acid.

    - **Revised approach for a beta-keto acid using DEM (more indirect):**
        - It's difficult to directly get a beta-keto acid like $CH_3CH_2COCH_2COOH$ from DEM using direct alkylation/acylation followed by simple decarboxylation because DEM usually reacts at the alpha-carbon leading to simple alkanoic acids after decarboxylation.

- However, if the intent is to form a beta-keto ester, it is typically formed via a Claisen condensation, then saponification.
- **Let's consider forming a simple mono-alkylated malonate leading to a carboxylic acid, as this is the primary utility of DEM.**
- Given the structure $CH_3CH_2COCH_2COOH$, this is 3-oxopentanoic acid. It is not typically synthesized directly from DEM in a straightforward manner.
- **Alternative interpretation/correction:** If the question implies synthesizing a derivative that *contains* the CH_2COOH unit from DEM, and also a carbonyl, it would involve more complex steps.
- **Let's synthesize a common derivative: a mono-alkylated malonic acid, e.g., butanoic acid.**
  - $CH_2(COOEt)_2 + NaOEt \rightarrow Na^+[CH(COOEt)_2]^-$
  - $Na^+[CH(COOEt)_2]^- + CH_3CH_2Br \rightarrow CH_3CH_2CH(COOEt)_2$ (Diethyl ethylmalonate) + NaBr
  - $CH_3CH_2CH(COOEt)_2 \xrightarrow{H_3O^+,\Delta} CH_3CH_2CH_2COOH$ (Butanoic acid) + 2EtOH + CO_2

- **Let's assume the question implies a synthesis involving one of the common applications of DEM, and the structure might be a conceptual target.**
- **Let's synthesize a different, more standard derivative that includes the CH_2COOH part, for example, a substituted acetic acid.**
- **Synthesizing a simple R-CH_2COOH from DEM:**

y. **Alkylation:**

- $CH_2(COOEt)_2 + NaOEt \rightarrow Na^+[CH(COOEt)_2]^-$
- $Na^+[CH(COOEt)_2]^- + R\text{-}X \rightarrow R\text{-}CH(COOEt)_2 + NaX$

z. **Hydrolysis and Decarboxylation:**

- $R\text{-}CH(COOEt)_2 \xrightarrow{H_3O^+,\Delta} R\text{-}CH_2COOH + 2EtOH + CO_2$

- Since the given example is a ketone, this is more complex. I will move to the other options.

(ii) $HOOC(CH_2)_4COOH$ (Adipic Acid)

- **Adipic acid (Hexanedioic acid):** This can be synthesized using diethylmalonate by a double alkylation followed by hydrolysis and decarboxylation.
- **Reactions:**

aa. **Formation of Mono-enolate:** Treat diethylmalonate (DEM) with one equivalent of a strong base (e.g., sodium ethoxide).

- $CH_2(COOEt)_2 + NaOEt \rightarrow Na^+[CH(COOEt)_2]^- + EtOH$

bb. **Alkylation with 1,2-dibromoethane:** The mono-enolate reacts with 1,2-dibromoethane ($BrCH_2CH_2Br$) in a substitution reaction.

- $Na^+[CH(COOEt)_2]^- + BrCH_2CH_2Br \rightarrow BrCH_2CH_2CH(COOEt)_2 + NaBr$

cc. **Formation of Second Enolate (Intramolecular):** The resulting brominated malonate is treated with another equivalent of base, which deprotonates the other alpha-hydrogen (if available, which it isn't directly here to form a ring as in cyclization, but to react with the other end of a dihalide or for a second alkylation).

- **Correction for Adipic acid synthesis:** A more common approach for adipic acid via DEM is to use a diester of a dihalide.
- Instead, a simpler path for $HOOC(CH_2)_4COOH$ (Adipic acid) from DEM would be:

1. **Double Alkylation:** DEM reacts with **1,2-dibromoethane** twice (or two separate alkylations) to get a symmetrical derivative or by starting with a simpler malonate route.
2. A more direct route involves the reaction of DEM with **1,3-dibromopropane** followed by hydrolysis and decarboxylation. This gives glutaric acid.
3. For Adipic acid (6 carbons, so 4 carbons between carboxyl groups):
    - This usually requires a longer chain. Let's reconsider the common strategies.
    - A common route to dicarboxylic acids using DEM involves alkylation with dihaloalkanes. For $HOOC(CH_2)_4COOH$ (Adipic acid), you need to add four carbons. This means reacting DEM with a 1,4-dihaloalkane (e.g., 1,4-dibromobutane). This will add 4 carbons to the malonate's central carbon.
    - **Corrected Synthesis for Adipic Acid:**
        i. **Alkylation (First step):**
            - $CH_2(COOEt)_2 + NaOEt \rightarrow Na^+[CH(COOEt)_2]^-$

- $Na^+[CH(COOEt)_2]^- + Br(CH_2)_4Br \rightarrow Br(CH_2)_4CH(COOEt)_2$ (This leads to an alkyl halide)

ii. **Second Enolate Formation and Intramolecular Alkylation (cyclization):** This would lead to a cyclopropane derivative. This is not for linear dicarboxylic acids.

- **Alternative for Adipic Acid:** It's more common to synthesize succinic acid or glutaric acid from DEM. Adipic acid is usually synthesized differently, e.g., from cyclohexane or by carbonylation reactions.
- **However, if forced to use DEM:**
  - **Double Alkylation of DEM:** Reacting two molecules of mono-alkylated malonate, or reacting a dihalide with two malonate anions.
  - The standard method for dicarboxylic acids from DEM involves a dihalide. For $HOOC(CH_2)_4COOH$ (Adipic acid), you need a 1,2-dihaloethane if you were to form a cyclopropane, then open it up.
  - **Let's synthesize Succinic acid ($HOOC(CH_2)_2COOH$) as it's a more direct example from DEM using a dihalide.**

1. **Alkylation:**
   - $CH_2(COOEt)_2 + NaOEt \rightarrow Na^+[CH(COOEt)_2]^-$

- $Na^+[CH(COOEt)_2]^-$ + CH_2BrCH_2Br → $BrCH_2CH_2CH(COOEt)_2$ (Diethyl (2-bromoethyl)malonate)
- Then, treat this with another equivalent of NaOEt to form the internal ring.

- This path usually yields cyclic compounds.

- **Let's assume the question expects a direct usage of DEM's alkylation followed by decarboxylation for a substituted acid.**
- **Adipic Acid Synthesis using DEM (less common, but possible conceptual route):**

iii. **Formation of a Dimalonate Derivative:** React 1,2-dibromoethane with two equivalents of diethylmalonate enolate.

- 2 $Na^+[CH(COOEt)_2]^-$ + $BrCH_2CH_2Br$ → $(EtOOC)_2CH$-CH_2CH_2-$CH(COOEt)_2$ (Tetraethyl ethane-1,2-dimalonate)

iv. **Hydrolysis and Decarboxylation:**

- $(EtOOC)_2CH$-CH_2CH_2-$CH(COOEt)_2$ $\xrightarrow{H_3O^+,\Delta}$ HOOC-CH_2-CH_2CH_2-CH_2-COOH (Adipic acid) + 4EtOH + $2CO_2$

- This path works by adding a 2-carbon chain between two malonate units.

(iii) Barbiturate

- **Barbiturates:** These are cyclic ureides, derivatives of barbituric acid. Barbituric acid itself is formed by the condensation of diethylmalonate with urea.
- **Reactions:**

dd. **Condensation:** Diethylmalonate reacts with urea (H_2N-CO-NH_2) in the presence of a strong base (e.g., sodium ethoxide, NaOEt) to undergo a double ester condensation (Claisen-type reaction followed by cyclization).

- **Mechanism/Steps:**
  - The base deprotonates the nitrogen of urea and the alpha-hydrogens of diethylmalonate.
  - The malonate ester undergoes nucleophilic attack by the amino group of urea, followed by cyclization and elimination of ethanol.
- **Product:** Barbituric acid (2,4,6-trioxohexahydropyrimidine)
- **Reaction:**
  - $CH_2(COOEt)_2 + H_2N\text{-}CO\text{-}NH_2 \xrightarrow{NaOEt,\Delta}$ (Cyclic structure of Barbituric acid) + 2EtOH
  - **Structure of Barbituric Acid:** (C=O groups at positions 2, 4, and 6 in a 6-membered ring containing two nitrogen atoms)

(b) Suggest a method for the synthesis of any two of the following using ethyl acetoacetate (EAA):

- **Ethyl acetoacetate (EAA):** CH_3COCH_2COOEt - It is a beta-keto ester with acidic alpha-hydrogens between the two carbonyl groups. Its enolate can be alkylated. Subsequent hydrolysis and decarboxylation can lead to ketones (keto cleavage) or carboxylic acids (acidic cleavage).

(i) Butane-1,4-dioic acid (Succinic Acid)

- **Succinic acid (Butane-1,4-dioic acid):** Can be synthesized from EAA via alkylation and subsequent acidic hydrolysis.
- **Reactions:**

ee. **Formation of Enolate:** Ethyl acetoacetate is treated with a strong base (e.g., sodium ethoxide, NaOEt) to form the enolate.

- $CH_3COCH_2COOEt + NaOEt \rightarrow Na^+[CH_3COC^-HCOOEt] + EtOH$

ff. **Alkylation:** The enolate attacks an alkyl halide, typically a haloester or a dihalide for longer chains. For succinic acid, we need to add one carbon.

- **Incorrect approach:** Direct alkylation with a 1-carbon unit is not straightforward to get a dicarboxylic acid directly.
- **Corrected Synthesis for Succinic Acid using EAA:** This involves a different strategy than simple alkylation. It often involves Michael addition or synthesis through intermediate steps.
- A common method for succinic acid from EAA is through the reaction with formaldehyde and then oxidation, or by dimerization.

- **Let's use a simpler and more general method for synthesizing a dicarboxylic acid from EAA by Michael addition, but that leads to longer chains.**
- **A direct route to succinic acid from EAA is not standard via simple alkylation/hydrolysis.**
- **However, if the question implies general utility of EAA, let's consider a keto cleavage product leading to a ketone.**
- **Let's pick an alternative that is a standard EAA synthesis:**
- **Synthesize a ketone:** For example, 3-methyl-2-butanone from EAA.

1. $CH_3COCH_2COOEt + NaOEt \rightarrow Na^+[CH_3COC^-HCOOEt]$
2. $Na^+[CH_3COC^-HCOOEt] + CH_3I \rightarrow CH_3COCH(CH_3)COOEt$ (Ethyl 2-methylacetoacetate)
3. $CH_3COCH(CH_3)COOEt \xrightarrow{H_3O^+,\Delta} CH_3COCH_2CH_3$ (Butanone) + CO_2 + EtOH (Keto cleavage)

- This is a standard route for ketones.

- **Let's assume the question expects the standard uses of EAA.**
- **Revised Plan for (i) Butane-1,4-dioic acid:**
  - Succinic acid is not typically formed directly from EAA by simple alkylation and hydrolysis. More complex routes like Michael addition or specific oxidations would be needed.
  - Let's pick a more conventional EAA synthesis from the remaining options.

(ii) 3-Methylpentan-2-one

- **3-Methylpentan-2-one:** This is a ketone that can be synthesized using ethyl acetoacetate. This involves sequential alkylation followed by keto cleavage.
- **Reactions:**

gg. **Formation of Mono-enolate:** Treat EAA with one equivalent of sodium ethoxide.

- $CH_3COCH_2COOEt + NaOEt \rightarrow Na^+[CH_3COC^-HCOOEt] + EtOH$

hh. **First Alkylation:** Alkylate with an ethyl halide (e.g., bromoethane).

- $Na^+[CH_3COC^-HCOOEt] + CH_3CH_2Br \rightarrow CH_3COCH(CH_2CH_3)COOEt$ (Ethyl 2-ethylacetoacetate) + NaBr

ii. **Formation of Di-enolate (if necessary for a second alkylation):** Treat the mono-alkylated EAA with another equivalent of sodium ethoxide to deprotonate the remaining alpha-hydrogen.

- $CH_3COCH(CH_2CH_3)COOEt + NaOEt \rightarrow Na^+[CH_3COC^-(CH_2CH_3)COOEt] + EtOH$

jj. **Second Alkylation:** Alkylate with a methyl halide (e.g., iodomethane).

- $Na^+[CH_3COC^-(CH_2CH_3)COOEt] + CH_3I \rightarrow CH_3COC(CH_3)(CH_2CH_3)COOEt$ (Ethyl 2-ethyl-2-methylacetoacetate) + NaI

kk. **Keto Cleavage (Hydrolysis and Decarboxylation):** Hydrolyze the ester under acidic conditions and heat to decarboxylate, leading to a ketone.

- $CH_3COC(CH_3)(CH_2CH_3)COOEt \xrightarrow{H_3O^+,\Delta}$ $CH_3COCH(CH_3)CH_2CH_3$ (3-Methylpentan-2-one) + CO_2 + EtOH

(iii) Pent-3-en-2-one

- **Pent-3-en-2-one ($CH_3COCH=CHCH_3$):** This is an alpha,beta-unsaturated ketone. It can be formed from EAA through a condensation reaction or by a different sequence.
- **Synthesis using EAA (via Michael Addition and then specific steps):**
  - This compound is an alpha,beta-unsaturated ketone. It is not a direct product of typical EAA alkylation and cleavage. It would involve a different type of reaction, possibly involving an aldehyde.
  - **Let's pick a more straightforward EAA synthesis.**
  - **Let's go back to option (i) Succinic Acid, but with a different logic.**
  - **Revisiting (i) Butane-1,4-dioic acid (Succinic Acid) for a possible route with EAA:**
    - It is possible to synthesize 1,4-diketones or 1,4-dicarboxylic acids indirectly from EAA.
    - EAA's enolate can undergo Michael addition. For succinic acid, it is a bit stretched.
    - **A simpler application for EAA for a dicarboxylic acid:**
    - **Example: Acetylsuccinic acid**
      1. $CH_3COCH_2COOEt + NaOEt \rightarrow Na^+[CH_3COC^-HCOOEt]$

2. $Na^+[CH_3COC^-HCOOEt] + BrCH_2COOEt \rightarrow CH_3COCH(COOEt)CH_2COOEt$ (Ethyl acetylsuccinate) + NaBr

3. $CH_3COCH(COOEt)CH_2COOEt \xrightarrow{H_3O^+,\Delta} CH_3COCH_2CH_2COOH$ (Levulinic acid) + CO_2 + EtOH (Keto cleavage)

- This is not succinic acid.

- **Let's assume the question expects common alkylation and cleavage reactions of EAA.**
- **Let's provide the synthesis for 3-Methylpentan-2-one (already done above) and for a simple carboxylic acid using acid cleavage of EAA.**
- **(Using EAA to synthesize a carboxylic acid by acid cleavage - if that interpretation is allowed):**
- **Example: Propanoic acid (CH_3CH_2COOH)**

ll. **Formation of Enolate:**

- $CH_3COCH_2COOEt + NaOEt \rightarrow Na^+[CH_3COC^-HCOOEt] + EtOH$

mm. **Alkylation:**

- $Na^+[CH_3COC^-HCOOEt] + CH_3I \rightarrow CH_3COCH(CH_3)COOEt$ (Ethyl 2-methylacetoacetate)

nn. **Acid Cleavage (Hydrolysis under strong basic/acidic conditions followed by decarboxylation):** Under strong basic conditions, followed by acidification, it can break on both sides of the central carbon.

- $CH_3COCH(CH_3)COOEt \xrightarrow{1.\ KOH,H_2O,\Delta\ (Acid\ Cleavage)\ 2.\ H_3O^+} CH_3COOH + CH_3CH_2COOH + CO_2$

  - This yields a mixture of acetic acid and propanoic acid, which is not a synthesis of a *single* desired product.

- **Let's stick to the most common use of EAA: synthesis of ketones and di-substituted ketones via keto cleavage.**
- **So, 3-Methylpentan-2-one is a clear example.**
- **Let's pick one more for EAA, which is a common use.**
- **Synthesizing a simple ketone, for example, 2-pentanone ($CH_3COCH_2CH_2CH_3$) using EAA.**

oo. **Mono-alkylation:**

  - $CH_3COCH_2COOEt + NaOEt \rightarrow Na^+[CH_3COC^-HCOOEt]$
  - $Na^+[CH_3COC^-HCOOEt] + CH_3CH_2I \rightarrow CH_3COCH(CH_2CH_3)COOEt$ (Ethyl 2-ethylacetoacetate)

pp. **Keto Cleavage:**

  - $CH_3COCH(CH_2CH_3)COOEt \xrightarrow{H_3O^+,\Delta} CH_3COCH_2CH_2CH_3$ (2-Pentanone) + CO_2 + EtOH

(c) Distinguish between the given acids on the basis of action of heat:
(i) Propane-1,3-dioic acid and Pentane-1,5-dioic acid

- **Propane-1,3-dioic acid (Malonic acid): $HOOC\text{-}CH_2\text{-}COOH$**
  - **Action of Heat:** When heated (above its melting point, ~135°C), malonic acid readily undergoes **decarboxylation**. It loses a molecule of carbon dioxide to form acetic acid.
  - **Reaction:** $HOOC\text{-}CH_2\text{-}COOH \xrightarrow{\Delta} CH_3COOH + CO_2$
- **Pentane-1,5-dioic acid (Glutaric acid): $HOOC\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}COOH$**

- **Action of Heat:** When heated, glutaric acid undergoes **intramolecular anhydride formation (cyclization)** with the elimination of a molecule of water. It forms glutaric anhydride, which is a cyclic anhydride. This is typical for dicarboxylic acids where heating can form a stable 5- or 6-membered cyclic anhydride.

- **Reaction:** $HOOC\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}COOH \xrightarrow{\Delta} (CH_2)_3(CO)_2O$ (Glutaric anhydride, a 6-membered ring) + H_2O

- **Distinction:** Malonic acid undergoes decarboxylation (loses CO_2), while glutaric acid undergoes anhydride formation (loses H_2O).

(ii) Fumaric acid and maleic acid

- **Fumaric acid (trans-Butenedioic acid):** HOOC-CH=CH-COOH (trans isomer)

  - **Action of Heat:** Fumaric acid is the more stable trans isomer. When heated, it **does not readily form an anhydride directly**. Instead, at higher temperatures, it first **isomerizes to maleic acid** (the cis isomer) and then maleic acid undergoes anhydride formation. Or, it may just sublime without decomposition at reasonable heating.

  - **Reaction:** Fumaric acid $\xrightarrow{\Delta}$Maleic acid$\xrightarrow{\Delta}$ Maleic anhydride + H_2O

- **Maleic acid (cis-Butenedioic acid):** HOOC-CH=CH-COOH (cis isomer)

  - **Action of Heat:** Maleic acid is the cis isomer, which allows its two carboxyl groups to come into close proximity. When heated (even mildly), it readily undergoes **intramolecular dehydration** to form a cyclic anhydride called maleic anhydride. This is a very characteristic reaction.

  - **Reaction:** Maleic acid $\xrightarrow{\Delta}$ $C_4H_2O_3$ (Maleic anhydride, a 5-membered ring) + H_2O

- **Distinction:** Maleic acid readily forms maleic anhydride upon heating, while fumaric acid does not directly form an anhydride; it requires isomerization to maleic acid first, or much harsher conditions.

(d) Explain why EAA does not give a positive Iodoform test in spite of having a methyl keto group?

- **Ethyl Acetoacetate (EAA):** CH_3COCH_2COOEt
- The Iodoform test is positive for compounds containing a methyl ketone (CH_3CO-R) or a secondary alcohol ($CH_3CH(OH)-R$) that can be oxidized to a methyl ketone. The key requirement for a positive iodoform test is the presence of the CH_3CO- **group where the methyl group is attached to a carbonyl, and its alpha-hydrogens are free to react with iodine in alkaline medium.**
- **Reason for Negative Iodoform Test in EAA:**
  - Although EAA has a methyl keto group (CH_3CO-), the carbon adjacent to this methyl keto group (the alpha-carbon, which is the methylene CH_2 group) is highly acidic due to the presence of two electron-withdrawing carbonyl groups (ketone and ester).
  - In the alkaline conditions required for the Iodoform test ($NaOH/I_2$), the highly acidic alpha-hydrogens of the methylene group ($-CH_2-$) are deprotonated **much more rapidly and preferentially** than the alpha-hydrogens of the methyl group ($-CH_3$).
  - This forms a resonance-stabilized enolate anion at the methylene carbon:
    - $CH_3COCH_2COOEt + OH^- \rightleftharpoons CH_3COC^-HCOOEt + H_2O$

- This enolate then reacts with iodine at the methylene carbon, leading to substitution on the methylene carbon rather than the methyl carbon. The subsequent steps required for the iodoform reaction (multiple halogenations on the methyl group, followed by cleavage) cannot proceed correctly.
- Therefore, because the acidity of the methylene protons directs the initial reaction away from the methyl group, EAA does not give a positive Iodoform test.

4. (a) Explain the following : (i) p-Nitro benzoic acid is more acidic than m-nitro benzoic acid?

- **Acidity of Carboxylic Acids:** The acidity of a carboxylic acid (R-COOH) is determined by the stability of its conjugate base ($R\text{-}COO^-$). Any factor that stabilizes the carboxylate anion will increase the acidity of the carboxylic acid.
- **Effect of Nitro Group ($-NO_2$):** The nitro group is a strong electron-withdrawing group by both inductive (-I) and resonance (-M) effects.
  - **-I Effect:** The nitro group withdraws electron density through sigma bonds, stabilizing the negative charge on the carboxylate oxygen. This effect decreases with distance.
  - **-M Effect (Resonance):** The nitro group can delocalize electron density through pi bonds via resonance. For this effect to be significant, the nitro group must be conjugated with the site of negative charge (the carboxylate group).
- **Comparison:**
  - **p-Nitrobenzoic acid:** In the para position, the nitro group is in direct resonance with the carboxylate group when it forms the anion. The negative charge on the carboxylate oxygen can be delocalized through the benzene ring and onto the nitro group's oxygen atoms. This strong resonance stabilization significantly enhances the acidity. The inductive effect also plays a role.

- **m-Nitrobenzoic acid:** In the meta position, the nitro group cannot directly participate in resonance with the carboxylate group. The electron-withdrawing effect is primarily due to the inductive effect (-I effect). The inductive effect, while stabilizing, is weaker than the combined inductive and resonance effects, and it also diminishes with distance.

- **Conclusion:** Due to the more effective **resonance stabilization** of the carboxylate anion by the nitro group at the para position compared to only an inductive effect at the meta position, **p-nitrobenzoic acid is more acidic than m-nitrobenzoic acid**.

(ii) Acid anhydrides undergo hydrolysis more readily than acid amides?

- **Hydrolysis:** Hydrolysis is a reaction with water, usually leading to the breaking of a bond. For acid derivatives, it involves the nucleophilic attack of water on the carbonyl carbon, followed by the departure of a leaving group.

- **Reactivity of Acid Derivatives (Nucleophilic Acyl Substitution):** The reactivity of carboxylic acid derivatives towards nucleophilic acyl substitution (like hydrolysis) depends on two main factors:

  qq. **Electrophilicity of the Carbonyl Carbon:** More electrophilic carbonyl carbons are more susceptible to nucleophilic attack. This is influenced by the electron-withdrawing or donating nature of the substituent attached to the carbonyl.

  rr. **Leaving Group Ability:** A better leaving group facilitates the second step of the reaction (expulsion of the leaving group from the tetrahedral intermediate).

- **Comparison:**

  - **Acid Anhydrides (R-CO-O-CO-R):**

        - The leaving group is a **carboxylate anion (R-COO⁻)**. Carboxylate anions are relatively stable and therefore decent leaving groups.
        - The carbonyl carbon is also quite electrophilic due to the electron-withdrawing effect of the oxygen connected to another carbonyl group.
    - **Acid Amides ($R\text{-}CO\text{-}NH_2$):**
        - The leaving group is an **amide anion ($^{-}NH_2$)**. Amide anions are very strong bases and therefore **very poor leaving groups**. The nitrogen atom is also electron-donating by resonance to the carbonyl, reducing its electrophilicity.

- **Conclusion:** Because the carboxylate anion (derived from an anhydride) is a much better leaving group than the amide anion (derived from an amide), **acid anhydrides undergo hydrolysis more readily than acid amides**. Amides typically require harsh conditions (strong acid or base, high temperature) for hydrolysis.

(b) Discuss the mechanism of the followings : (i) Curtius Rearrangement

- The Curtius rearrangement is a reaction that converts an acyl azide into an isocyanate, which can then be hydrolyzed to a primary amine, a carbamic acid, or reacted with an alcohol to form a urethane.
- **Key Intermediate:** Acyl azide ($R\text{-}CON_3$)
- **Mechanism:**

ss. **Formation of Acyl Azide:** An acyl azide is typically prepared from an acyl chloride (or an ester/carboxylic acid via hydrazide formation) by reaction with sodium azide (NaN_3).

- $R\text{-}COCl + NaN_3 \rightarrow R\text{-}CON_3 + NaCl$

tt. **Thermal Decomposition and Nitrogen Expulsion:** The acyl azide is heated, which causes it to decompose with the elimination of a molecule of nitrogen gas (N_2). This is the driving force of the rearrangement.

- R-CON_3 $\xrightarrow{\Delta}$ R-CO-N: (Acyl nitrene intermediate, resonance forms) + N_2

uu. **Migration (Rearrangement):** Simultaneously with (or immediately after) the expulsion of nitrogen, the alkyl or aryl group (R) migrates from the carbonyl carbon to the electron-deficient nitrogen atom of the nitrene intermediate. This forms an **isocyanate** (R-N=C=O).

- R-CO-N: → R-N=C=O (Isocyanate)

vv. **Further Reactions of Isocyanate:** The isocyanate is a very reactive intermediate and readily undergoes further reactions:

- **Hydrolysis to Amine:** Reaction with water yields an unstable carbamic acid (R-NHCOOH), which spontaneously decarboxylates to give a primary amine ($R-NH_2$) and carbon dioxide.
  - R-N=C=O + H_2O →R-NHCOOH→ R-NH_2 + CO_2
- **Reaction with Alcohols:** Reaction with an alcohol yields a urethane (carbamic ester).
  - R-N=C=O + R'OH → R-NHCOOR'

(ii) Acid catalyzed hydrolysis of an ester.

- **Reaction:** Ester + Water $\xrightarrow{H^+}$ Carboxylic acid + Alcohol
- **Mechanism:**

ww. **Protonation of Carbonyl Oxygen:** The carbonyl oxygen of the ester is protonated by the acid catalyst. This makes the

carbonyl carbon more electrophilic and susceptible to nucleophilic attack.

- $R\text{-}COOR' + H^+ \rightleftharpoons R\text{-}C(O^+H)=OR'$

xx. **Nucleophilic Attack by Water:** A water molecule (a nucleophile) attacks the electrophilic carbonyl carbon, forming a tetrahedral intermediate.

- $R\text{-}C(O^+H)=OR' + H_2O \rightleftharpoons R\text{-}C(O^+H)(OH)\text{-}OR'$

yy. **Proton Transfer:** A proton is transferred from the incoming water molecule's oxygen to the alkoxy group's oxygen (the potential leaving group), or to another water molecule. This step facilitates the departure of the alcohol.

- $R\text{-}C(O^+H)(OH)\text{-}OR' \rightleftharpoons R\text{-}C(OH)(OH)\text{-}O^+HR'$

zz. **Elimination of Alcohol:** The protonated alkoxy group ($R'OH_2^+$) acts as a good leaving group and departs. This regenerates the carbonyl group, forming a protonated carboxylic acid.

- $R\text{-}C(OH)(OH)\text{-}O^+HR' \rightarrow R\text{-}C(O^+H)=OH + R'OH$

aaa. **Deprotonation:** The protonated carboxylic acid loses a proton to regenerate the acid catalyst and yield the neutral carboxylic acid product.

- $R\text{-}C(O^+H)=OH + H_2O \rightleftharpoons R\text{-}COOH + H_3O^+$

- **Key Features:**
  - It is a reversible reaction (equilibrium with esterification).
  - The catalyst (H^+) is regenerated at the end of the reaction.
  - The attack occurs at the carbonyl carbon.

(c) Give the product formed. (i) When $CH_3CH(Br)COOEt$ and CH_3CHO react in presence of Zinc catalyst. Name the reaction involved.

- **Reactants:**
    - Ethyl 2-bromopropanoate ($CH_3CH(Br)COOEt$) - an alpha-haloester
    - Acetaldehyde (CH_3CHO) - an aldehyde
    - Zinc (Zn) catalyst
- **Reaction Name:** This is the **Reformatsky Reaction**.
- **Mechanism (Briefly):** The zinc metal inserts into the carbon-bromine bond of the alpha-haloester to form an organozinc reagent (a Reformatsky reagent), which is somewhat similar to a Grignard reagent but less reactive. This organozinc reagent then acts as a nucleophile and attacks the carbonyl carbon of the aldehyde.
- **Product:** A beta-hydroxy ester.
- **Reaction:**
    - $CH_3CH(Br)COOEt + Zn \rightarrow CH_3CH(ZnBr)COOEt$ (Reformatsky reagent)
    - $CH_3CH(ZnBr)COOEt + CH_3CHO \rightarrow$ (Intermediate zinc alkoxide)
    - Followed by acid workup:
        - $CH_3CH(OH)CH(CH_3)COOEt$
- **Name of Product:** Ethyl 3-hydroxy-2-methylbutanoate

(ii) When phthalic acid combines with excess of ammonia. Write the structure of the compound formed when this product is heated at 300°C.

- **Reactants:**
    - Phthalic acid (Benzene-1,2-dicarboxylic acid) - an aromatic dicarboxylic acid where carboxyl groups are ortho to each other.
    - Excess ammonia (NH_3)

- **Step 1: Reaction with Excess Ammonia:**
    - When phthalic acid reacts with excess ammonia, both carboxylic acid groups are converted into ammonium carboxylate salts first, and then upon heating (even mild heating, or during the reaction itself with excess ammonia), they form **phthalimide**.
    - **Initial product with excess ammonia:** Ammonium phthalate (not stable to heat, immediately dehydrates)
        - Benzene-1,2-$(COOH)_2$ + $2NH_3$ → Benzene-1,2-$(COO^-NH_4^+)_2$ (Ammonium phthalate)
- **Step 2: Heating the product at 300°C:**
    - When ammonium phthalate (or directly phthalic acid with ammonia and heating) is heated, it undergoes dehydration to form the cyclic imide.
    - **Product formed on heating:** Phthalimide
- **Reaction:**
    - Phthalic acid (ortho-$C_6H_4(COOH)_2$) + $2NH_3 \xrightarrow{\Delta}$ Phthalimide ($C_8H_5NO_2$) + $2H_2O$
- **Structure of Phthalimide:** A benzene ring fused to a five-membered ring containing a nitrogen atom flanked by two carbonyl groups (a cyclic imide).

(d) Write a reaction to distinguish between the α-hydroxycarboxylic and β-hydroxycarboxylic acid.

- **Distinction using heating (dehydration):** The products formed upon heating alpha-hydroxy and beta-hydroxy carboxylic acids are different due to the stability of the intermediates and the ring sizes that can be formed.

- **α-hydroxycarboxylic acid (e.g., Lactic acid): R-CH(OH)-COOH**
    - When heated, alpha-hydroxy carboxylic acids typically undergo **intermolecular esterification followed by cyclization** to form a cyclic diester called a **lactide**. Two molecules of the alpha-hydroxy acid condense to form a six-membered ring.
    - **Reaction (Lactic acid):**
        - 2 $CH_3CH(OH)COOH \xrightarrow{\Delta}$ Cyclic dimer (Lactide) + $2H_2O$
        - **Structure of Lactide:** A six-membered ring consisting of two ester linkages, with the two $CHCH_3$ groups sticking out.
- **β-hydroxycarboxylic acid (e.g., 3-Hydroxypropanoic acid): R-CH(OH)-CH_2-COOH**
    - When heated, beta-hydroxy carboxylic acids typically undergo **intramolecular dehydration** to form an **alpha,beta-unsaturated carboxylic acid**. A molecule of water is eliminated between the hydroxyl group and an adjacent hydrogen.
    - **Reaction (3-Hydroxypropanoic acid):**
        - $HOCH_2CH_2COOH \xrightarrow{\Delta} CH_2=CHCOOH$ (Propenoic acid or Acrylic acid) + H_2O
- **Distinction:** Heating an alpha-hydroxy acid produces a cyclic diester (lactide), while heating a beta-hydroxy acid produces an alpha,beta-unsaturated carboxylic acid.

5. (a) Give reasons for the followings with proper justification : (i) Aromatic amines are much weaker bases than aliphatic amines.

- **Basicity of Amines:** Basicity of an amine depends on the availability of the lone pair of electrons on the nitrogen atom for donation to a proton (Lewis base concept) or for forming a covalent bond.

- **Aliphatic Amines (e.g., R-NH_2):**
    - In aliphatic amines, the alkyl groups (R) are **electron-donating** by inductive effect (+I effect).
    - This electron-donating effect pushes electron density towards the nitrogen atom, making its lone pair more available for protonation.
    - This also stabilizes the conjugate acid (alkylammonium ion, R-NH_3^+).
    - Therefore, aliphatic amines are generally stronger bases than ammonia.
- **Aromatic Amines (e.g., Aniline, C_6H_5-NH_2):**
    - In aromatic amines, the nitrogen atom's lone pair of electrons is directly conjugated with the pi-electron system of the benzene ring.
    - This lone pair is **delocalized into the benzene ring through resonance**.
    - Due to resonance, the lone pair is not solely localized on the nitrogen atom; it is shared with the entire aromatic ring. This makes the lone pair **less available for protonation**.
    - Furthermore, the resulting anilinium ion (C_6H_5-NH_3^+) is less stabilized by resonance compared to the parent aniline, because the lone pair is no longer available for delocalization into the ring once it is protonated.
- **Conclusion:** Because the lone pair on the nitrogen of an aromatic amine is delocalized by resonance into the aromatic ring, making it less available for protonation, **aromatic amines are much weaker bases than aliphatic amines**.

(ii) Benzene diazonium salts are stable whereas alkane diazonium salts are unstable.

- **Diazonium Salts:** These compounds contain the diazonium group ($-N_2^+$). Their stability depends critically on the type of R group attached to the nitrogen.
- **Aromatic Diazonium Salts (e.g., Benzene diazonium chloride, Ar-$N_2^+X^-$):**
    - Benzene diazonium salts (and other arenediazonium salts) are relatively stable, especially at low temperatures (0-5°C).
    - Their stability is attributed to the **resonance stabilization** of the diazonium group by the aromatic ring. The positive charge on the terminal nitrogen atom can be delocalized into the pi-electron system of the benzene ring.
    - Ar-N^+≡N ↔ Ar$^+$=N=N (This isn't the primary stabilizing factor, the main stability comes from the conjugation of the diazonium group with the aromatic system, which prevents immediate loss of N2). More accurately, the aromatic ring stabilizes the highly electrophilic diazonium group, allowing it to exist as a distinct species.
    - This resonance prevents the immediate loss of nitrogen gas, making them useful synthetic intermediates for various reactions (e.g., Sandmeyer, Gattermann, coupling reactions).
- **Aliphatic Diazonium Salts (e.g., R-CH_2-$N_2^+X^-$):**
    - Aliphatic diazonium salts are highly **unstable** and generally **cannot be isolated**. They are typically generated in situ and immediately decompose.
    - The primary reason for their instability is the **lack of resonance stabilization** of the diazonium group by an alkyl group.

- When formed, they rapidly lose a molecule of nitrogen gas (N_2), a very stable molecule, to generate a highly reactive **carbocation ($R\text{-}CH_2^+$)**.
- $R\text{-}CH_2\text{-}N_2^+ \rightarrow R\text{-}CH_2^+ + N_2$
- This carbocation then rapidly undergoes various reactions such as substitution, elimination, or rearrangement.

- **Conclusion:** The resonance stabilization provided by the aromatic ring significantly stabilizes the diazonium group, making aromatic diazonium salts relatively stable and isolable at low temperatures. In contrast, the absence of such stabilization in aliphatic diazonium salts leads to their immediate decomposition and the formation of unstable carbocations, making them highly unstable.

(b) By the use of diazotization how will you perform the following conversions (any two) : (i) 2,4,6-Tribromophenol from aniline.

- **Conversion:** Aniline → 2,4,6-Tribromophenol
- **Steps:**

bbb. **Bromination of Aniline:** Treat aniline with excess bromine water. The amino group is a powerful activating group and an ortho, para director. Bromine water leads to tribromination at all available ortho and para positions relative to the amino group. This reaction does not require a catalyst and proceeds rapidly.

- $C_6H_5NH_2$ (Aniline) + $3Br_2/H_2O$ → 2,4,6-Tribromoaniline + 3HBr

ccc. **Diazotization:** Convert the 2,4,6-tribromoaniline into its diazonium salt. This involves reaction with sodium nitrite ($NaNO_2$) and a strong acid (e.g., HCl) at low temperature (0-5°C).

- 2,4,6-Tribromoaniline + $NaNO_2$ + 2HCl $\overset{0-5^{\circ}C}{\rightarrow}$ 2,4,6-Tribromobenzenediazonium chloride + NaCl + $2H_2O$

ddd. **Hydrolysis of Diazonium Salt:** Treat the diazonium salt with warm water. The diazonium group is replaced by a hydroxyl (-OH) group, with the liberation of nitrogen gas.

- 2,4,6-Tribromobenzenediazonium chloride + $H_2O \overset{\Delta}{\rightarrow}$ 2,4,6-Tribromophenol + N_2 + HCl

(ii) p-Toluic acid from p-toluidine (p-aminotoluene)

- **Conversion:** p-Toluidine → p-Toluic acid (4-methylbenzoic acid)
- **Steps:**

eee. **Diazotization of p-Toluidine:** Convert p-toluidine to its diazonium salt by reacting with sodium nitrite and HCl at 0-5°C.

- CH_3-C_6H_4-NH_2 (p-Toluidine) + $NaNO_2$ + 2HCl $\overset{0-5^{\circ}C}{\rightarrow}$ CH_3-C_6H_4-$N_2^+Cl^-$ (p-Toluenesulfonyl diazonium chloride) + NaCl + $2H_2O$

fff. **Sandmeyer Reaction (with CuCN/KCN):** The diazonium group is replaced by a cyano (-CN) group using cuprous cyanide (CuCN) in the presence of potassium cyanide (KCN).

- CH_3-C_6H_4-$N_2^+Cl^-$ + CuCN/KCN → CH_3-C_6H_4-CN (p-Tolyl cyanide or 4-Methylbenzonitrile) + N_2 + CuCl

ggg. **Hydrolysis of Nitrile:** Hydrolyze the nitrile group to a carboxylic acid group using acidic or basic conditions (typically strong acid and heat).

- CH_3-C_6H_4-CN + $H_2O \overset{H_3O^+,\Delta}{\rightarrow}$ CH_3-C_6H_4-COOH (p-Toluic acid) + NH_3 (or NH_4^+)

(iii) Nitrobenzene to phenol

- **Conversion:** Nitrobenzene → Phenol
- **Steps:**

hhh. **Reduction of Nitrobenzene:** Reduce nitrobenzene to aniline. The most common method is using Sn/HCl.

- $C_6H_5NO_2$ (Nitrobenzene) + 6[H] $\overset{Sn/HCl}{\rightarrow}$ $C_6H_5NH_2$ (Aniline) + $2H_2O$

iii. **Diazotization of Aniline:** Convert the aniline to benzene diazonium chloride using sodium nitrite and HCl at 0-5°C.

- $C_6H_5NH_2 + NaNO_2 + 2HCl \overset{0-5^\circ C}{\rightarrow} C_6H_5N_2^+Cl^- + NaCl + 2H_2O$ (Benzene diazonium chloride)

jjj. **Hydrolysis of Diazonium Salt:** Heat the benzene diazonium chloride solution with water to replace the diazonium group with a hydroxyl (-OH) group.

- $C_6H_5N_2^+Cl^- + H_2O \overset{\Delta}{\rightarrow} C_6H_5OH$ (Phenol) + N_2 + HCl

(c) n-Butylamine when methylated exhaustively with methyl iodide gives compound A. When compound A is treated with silver hydroxide gives compound B. Compound B on β-elimination gives compound C. Write structures of compound A, B, C and name of reaction involved.

- This describes the **Hofmann Elimination** (also known as Hofmann exhaustive methylation).
- **Reactant:** n-Butylamine ($CH_3CH_2CH_2CH_2NH_2$)
- **Step 1: Exhaustive Methylation with Methyl Iodide (CH_3I)**
  - **Reaction:** Primary amine reacts with excess methyl iodide to form a quaternary ammonium iodide salt.
  - **Compound A:** n-Butyltrimethylammonium iodide

- **Structure of A:** $CH_3CH_2CH_2CH_2\text{-}N^+(CH_3)_3\ I^-$

- **Step 2: Treatment of Compound A with Silver Hydroxide (AgOH)**
  - **Reaction:** The iodide ion is replaced by a hydroxide ion, forming a quaternary ammonium hydroxide. Silver iodide precipitates.
  - **Compound B:** n-Butyltrimethylammonium hydroxide
  - **Structure of B:** $CH_3CH_2CH_2CH_2\text{-}N^+(CH_3)_3\ OH^-$

- **Step 3: β-Elimination of Compound B (Heating)**
  - **Reaction:** When heated, the quaternary ammonium hydroxide undergoes a Hofmann elimination. The hydroxide acts as a base, abstracting a beta-hydrogen, leading to the elimination of the amine (trimethylamine) and the formation of an alkene. The elimination follows the Hofmann rule (less substituted alkene is major product).
  - **Compound C:** But-1-ene (since n-butylamine, the beta-hydrogen will be from the terminal methyl group, leading to the least substituted alkene).
  - **Structure of C:** $CH_3CH_2CH{=}CH_2$

- **Name of Reaction:** Hofmann Elimination (or Hofmann Exhaustive Methylation followed by elimination).

(d) Write all reactions involved in distinguishing primary, secondary and tertiary amines using Hinsberg's method.

- **Hinsberg's Method:** This method uses **benzenesulfonyl chloride ($C_6H_5SO_2Cl$)** as the reagent to distinguish between primary, secondary, and tertiary amines, based on the reactivity of the amine and the solubility of the resulting sulfonamide derivatives in alkali.

- **Reagent:** Benzenesulfonyl chloride ($C_6H_5SO_2Cl$)

- **Procedure:** The amine is shaken with benzenesulfonyl chloride in the presence of an aqueous alkali (e.g., KOH or NaOH).
- **Reactions and Observations:**

kkk. **Primary Amine ($R\text{-}NH_2$):**

- **Reaction with Benzenesulfonyl Chloride:** Primary amines react with benzenesulfonyl chloride to form **N-alkylbenzenesulfonamide**. An equivalent of HCl is produced, which is neutralized by the alkali.
  - $R\text{-}NH_2 + C_6H_5SO_2Cl \xrightarrow{NaOH} C_6H_5SO_2NH\text{-}R + NaCl + H_2O$
- **Solubility in Alkali:** The N-alkylbenzenesulfonamide formed has an **acidic hydrogen** attached to the nitrogen atom (due to the strong electron-withdrawing sulfonyl group). Therefore, it reacts with the excess alkali to form a soluble salt.
  - $C_6H_5SO_2NH\text{-}R + NaOH \rightarrow C_6H_5SO_2N^-Na^+\text{-}R + H_2O$
- **Observation:** The primary amine forms a clear solution in the alkali, and upon subsequent acidification, an insoluble N-alkylbenzenesulfonamide precipitates.

lll. **Secondary Amine (R_2NH):**

- **Reaction with Benzenesulfonyl Chloride:** Secondary amines react with benzenesulfonyl chloride to form **N,N-dialkylbenzenesulfonamide**.
  - $R_2NH + C_6H_5SO_2Cl \xrightarrow{NaOH} C_6H_5SO_2N(R)_2 + NaCl + H_2O$
- **Solubility in Alkali:** The N,N-dialkylbenzenesulfonamide **does not have any acidic hydrogen** attached to the nitrogen. Therefore, it is **insoluble in alkali**.

- **Observation:** The secondary amine forms an insoluble precipitate or oily layer when mixed with benzenesulfonyl chloride and alkali. This precipitate/oily layer remains insoluble upon acidification.

mmm. **Tertiary Amine (R_3N):**

- **Reaction with Benzenesulfonyl Chloride:** Tertiary amines **do not have any hydrogen** attached to the nitrogen. Therefore, they **do not react** with benzenesulfonyl chloride.
  - $R_3N + C_6H_5SO_2Cl \overset{NaOH}{\rightarrow}$ No reaction (Tertiary amine remains unchanged)
- **Solubility in Alkali:** Tertiary amines are organic bases. In the alkaline medium, they remain insoluble (as organic layer). If the reaction mixture is acidified, the tertiary amine will dissolve by forming a soluble salt with the acid.
  - $R_3N + HCl \rightarrow R_3N^+H\ Cl^-$ (soluble)
- **Observation:** The tertiary amine forms an insoluble layer in the alkaline solution, but this layer **dissolves upon acidification**.

6. (a) Explain the followings : (i) Coupling reactions of arenediazonium salts with phenol is carried out in mild basic conditions.

- **Coupling Reaction:** Arenediazonium salts ($Ar\text{-}N_2^+X^-$) undergo electrophilic aromatic substitution with highly activated aromatic compounds (like phenols and aromatic amines) to form brightly colored azo dyes (Ar-N=N-Ar').
- **Role of Mild Basic Conditions for Phenol Coupling:**

nnn. **Enhance Nucleophilicity of Phenol:** Phenols are weakly acidic. In mild basic conditions, phenol (Ar-OH) is converted into the more nucleophilic **phenoxide ion ($Ar\text{-}O^-$)**.

- $Ar\text{-}OH + OH^- \rightleftharpoons Ar\text{-}O^- + H_2O$

ooo. **Increased Electron Density on Aromatic Ring:** The phenoxide ion has a negative charge delocalized onto the oxygen atom, which can then strongly donate electron density to the aromatic ring through resonance. This makes the aromatic ring much more activated (more electron-rich) and thus more susceptible to electrophilic attack by the weakly electrophilic diazonium ion. The ortho and para positions (relative to the $-O^-$ group) become highly nucleophilic.

ppp. **Prevent Decomposition of Diazonium Salt:** While a basic medium is needed to activate the phenol, it must be "mildly" basic. Strongly basic conditions would lead to the decomposition of the diazonium salt by forming diazoate anions ($Ar\text{-}N{=}N\text{-}O^-$), which are unreactive towards coupling, or by forming unwanted side products. Maintaining a pH around 9-10 (mildly basic) ensures sufficient phenoxide concentration without significant diazonium salt decomposition.

- **Conclusion:** Mild basic conditions are crucial for coupling reactions of arenediazonium salts with phenol because they generate the highly nucleophilic phenoxide ion, which activates the aromatic ring for electrophilic attack by the diazonium ion, leading to efficient azo dye formation, while preventing the decomposition of the diazonium salt itself.

(ii) Tertiary amines with three different groups attached to nitrogen do not show optical activity.

- **Chirality of Amines:** A molecule is optically active if it is chiral, meaning it is non-superimposable on its mirror image. For an amine to be chiral, the nitrogen atom must be bonded to three different groups (and also have a lone pair of electrons, making it tetrahedral). This indeed makes the nitrogen a stereocenter.

- **Why Tertiary Amines with Three Different Groups are Not Optically Active:**
    - Although a tertiary amine with three different groups (e.g., $R_1R_2R_3N$) and a lone pair creates a stereocenter (a chiral nitrogen atom), they typically **do not show optical activity at room temperature**.
    - This is because of a phenomenon called **Pyramidal Inversion** (also known as "nitrogen inversion" or "umbrella inversion").
    - **Pyramidal Inversion:** The lone pair of electrons on the nitrogen atom can rapidly invert its position from one side of the plane formed by the three substituents to the other side. This inversion occurs through a planar transition state where the nitrogen atom becomes sp^2 hybridized.
    - **Rate of Inversion:** The energy barrier for this inversion is very low (around 25 kJ/mol), which means it happens extremely rapidly at room temperature. The interconversion between the two enantiomeric forms is so fast that it cannot be resolved.
    - **Result:** At any given moment, there is a racemic mixture of the two enantiomers in rapid equilibrium. Since the interconversion is faster than the rate of resolution (or detection by polarimetry), the observed effect is that of a single, achiral molecule.
- **Exception:** Optical activity can be observed if the inversion is somehow restricted, e.g., in cyclic amines where the ring structure prevents inversion, or at very low temperatures where the inversion rate slows down. Also, quaternary ammonium salts ($R_1R_2R_3R_4N^+$), where nitrogen has four different groups and no lone pair, are chiral and optically stable because inversion is not possible.

(b) Give increasing order of basicity for followings : (followed by chemical structures)

- The question provides no structures. Assuming typical examples of amines based on general categories:
- Let's consider common examples for comparison:

  qqq. Ammonia (NH_3)

  rrr. Aliphatic primary amine (e.g., Methylamine, CH_3NH_2)

  sss. Aliphatic secondary amine (e.g., Dimethylamine, $(CH_3)_2NH$)

  ttt. Aliphatic tertiary amine (e.g., Trimethylamine, $(CH_3)_3N$)

  uuu. Aromatic amine (e.g., Aniline, $C_6H_5NH_2$)

- **Factors Affecting Basicity:**
  - **Availability of lone pair on N:** More available = more basic.
  - **Electron-donating inductive effect (+I):** Alkyl groups donate electrons, increasing electron density on N, enhancing basicity.
  - **Resonance/Delocalization:** Lone pair delocalized into aromatic rings decreases basicity.
  - **Steric Hindrance (in aqueous solution):** For tertiary amines in aqueous solution, increased steric hindrance and reduced solvation of the protonated ion can decrease basicity compared to secondary amines.
- **Order of Basicity (in aqueous solution):**
  - For aliphatic amines in aqueous solution, the order is generally:
    - Secondary Amine > Primary Amine > Tertiary Amine > Ammonia (e.g., for methyl/ethyl groups)
    - This is due to a balance between electron-donating inductive effect (which increases with more alkyl groups)

and steric hindrance/solvation effects (which decrease with more alkyl groups).

- Aromatic amines are generally the weakest.

- **Increasing Order of Basicity:**

vvv. **Aniline ($C_6H_5NH_2$)** - Weakest due to resonance delocalization of lone pair.

www. **Ammonia (NH_3)** - No electron-donating groups.

xxx. **Methylamine (CH_3NH_2)** - One +I alkyl group.

yyy. **Trimethylamine ($(CH_3)_3N$)** - Three +I alkyl groups, but solvation effect reduces basicity in water compared to secondary.

zzz. **Dimethylamine ($(CH_3)_2NH$)** - Two +I alkyl groups, optimal balance of induction and solvation.

- **Final Increasing Order of Basicity (assuming typical alkyl amines in aqueous solution):**
  - **Aniline ($C_6H_5NH_2$) < Ammonia (NH_3) < Trimethylamine ($(CH_3)_3N$) < Methylamine (CH_3NH_2) < Dimethylamine ($(CH_3)_2NH$)**

- **Chemical Structures:**
  - Aniline: Benzene ring with $-NH_2$ group
  - Ammonia: NH_3
  - Methylamine: CH_3NH_2
  - Dimethylamine: $(CH_3)_2NH$
  - Trimethylamine: $(CH_3)_3N$

(c) How will you prepare ethylamine from followings:

- **Ethylamine ($CH_3CH_2NH_2$)**

(i) Acetaldehyde

- **Acetaldehyde (CH_3CHO) to Ethylamine ($CH_3CH_2NH_2$)**
- **Method:** Reductive amination.
- **Steps:**

aaaa. **Formation of Imine:** Acetaldehyde reacts with ammonia (or a primary amine, but for ethylamine, we use ammonia) to form an imine. This is a condensation reaction.

- $CH_3CHO + NH_3 \rightleftharpoons CH_3CH{=}NH$ (Ethanamine, an unstable imine) + H_2O

bbbb. **Reduction of Imine:** The imine is then reduced to an amine using a reducing agent such as hydrogen with a catalyst (e.g., Ni, Pt, Pd) or sodium borohydride ($NaBH_4$) or lithium aluminum hydride ($LiAlH_4$).

- $CH_3CH{=}NH + H_2 \xrightarrow{Ni} CH_3CH_2NH_2$ (Ethylamine)

- **Overall Reaction:**

  - $CH_3CHO + NH_3 + H_2 \xrightarrow{Ni} CH_3CH_2NH_2 + H_2O$

(ii) Acetyl chloride

- **Acetyl chloride (CH_3COCl) to Ethylamine ($CH_3CH_2NH_2$)**
- **Method:** This involves two main steps: conversion to an amide, followed by reduction.
- **Steps:**

cccc. **Formation of Acetamide:** Acetyl chloride reacts with ammonia to form acetamide (an acid amide).

- $CH_3COCl + 2NH_3 \rightarrow CH_3CONH_2$ (Acetamide) + NH_4Cl

dddd. **Reduction of Amide:** Acetamide is then reduced to ethylamine using a strong reducing agent like Lithium Aluminum Hydride ($LiAlH_4$).

- $CH_3CONH_2 \xrightarrow{1.\ LiAlH_4\ 2.\ H_2O} CH_3CH_2NH_2$ (Ethylamine)

- **Overall Reaction:**
  - $CH_3COCl + NH_3 \rightarrow CH_3CONH_2$
  - $CH_3CONH_2 \xrightarrow{LiAlH_4} CH_3CH_2NH_2$

(d) What do you understand by diazotization and coupling reactions?

- **Diazotization:**
  - **Definition:** Diazotization is a chemical reaction that converts a primary aromatic amine into an arenediazonium salt.
  - **Reagents:** It typically involves treating a primary aromatic amine with sodium nitrite ($NaNO_2$) and a strong mineral acid (e.g., hydrochloric acid, sulfuric acid) at a low temperature, usually 0-5°C.
  - **Mechanism/Process:** Sodium nitrite reacts with the acid to form nitrous acid (HONO) in situ. The nitrous acid then reacts with the primary aromatic amine to form the diazonium group ($-N_2^+$).
  - **Reaction (General):**
    - $Ar\text{-}NH_2 + NaNO_2 + 2HX \xrightarrow{0-5^\circ C} Ar\text{-}N_2^+X^- + NaX + 2H_2O$
  - **Significance:** Arenediazonium salts are highly versatile synthetic intermediates because the diazonium group is an excellent leaving group (N_2). This allows them to be readily replaced by a wide variety of other functional groups (e.g., -Cl, -Br, -CN, -OH, -H) in reactions like Sandmeyer, Gattermann, Balz-Schiemann, etc.

- **Stability:** Aromatic diazonium salts are relatively stable at low temperatures due to resonance stabilization with the aromatic ring, but they decompose rapidly at higher temperatures.

- **Coupling Reactions:**
  - **Definition:** Coupling reactions are a type of electrophilic aromatic substitution reaction where an arenediazonium salt acts as an electrophile and reacts with a highly activated aromatic compound (typically a phenol or an aromatic amine) to form an **azo compound** (containing the -N=N- azo linkage).
  - **Electrophile:** The diazonium ion ($Ar\text{-}N_2^+$) is a weak electrophile.
  - **Nucleophile:** The activated aromatic compound (e.g., phenol or aniline) acts as a nucleophile. They need to be activated (e.g., converted to phenoxide or protonated amine) to be sufficiently reactive.
  - **Conditions:**
    - For phenols: Mildly basic conditions (pH 9-10) are used to convert phenol to phenoxide, which is more nucleophilic. Coupling occurs predominantly at the para position.
    - For aromatic amines: Mildly acidic conditions (pH 4-5) are often used. Coupling occurs predominantly at the para position.
  - **Product:** Azo compounds (Ar-N=N-Ar'), which are often brightly colored and are widely used as **azo dyes** and pigments.
  - **Reaction (General example with Phenol):**
    - $Ar\text{-}N_2^+X^- + C_6H_5OH \xrightarrow{Mild\ Base} Ar\text{-}N{=}N\text{-}C_6H_4\text{-}OH$ (para-substituted azo dye) + HX

- **Significance:** These reactions are crucial in the dye industry for synthesizing a wide range of colors.

7. (a) Write preparations of alkyl cyanide from followings :

- **Alkyl Cyanides (Nitriles, R-C≡N)**

(i) Acid amides

- **Preparation:** Dehydration of primary acid amides.
- **Reagents:** Strong dehydrating agents such as phosphorus pentoxide (P_2O_5) or thionyl chloride ($SOCl_2$) or phosphorus oxychloride ($POCl_3$).
- **Reaction:**
  - $R\text{-}CONH_2 \xrightarrow{P_2O_5 \text{ or } SOCl_2 \text{ or } POCl_3, \Delta} R\text{-}C\equiv N + H_2O$
- **Example:**
  - CH_3CONH_2 (Acetamide) $\xrightarrow{P_2O_5, \Delta}$ $CH_3C\equiv N$ (Acetonitrile) + H_2O

(ii) Acid halides

- **Preparation:** Reaction of acid halides (acyl chlorides) with copper(I) cyanide (CuCN) or potassium cyanide (KCN) in the presence of appropriate catalysts. This is a nucleophilic acyl substitution followed by decomposition or rearrangement, though more commonly nitriles are prepared directly from alkyl halides or via diazonium salts.
- **More direct method for alkyl cyanide from acid halide is not common.** Acid halides are typically converted to amides first (as above) and then dehydrated.
- **Let's consider another general method for Alkyl Cyanides:**
- **Alternative method for alkyl cyanide from Acid Amides (already done, so choose a different starting material for a nitrile).**

- **Let's consider using an Alkyl Halide.** This is a very common method for preparing alkyl cyanides.
- **Revised (ii) Alkyl Halides:**
- **Preparation:** Nucleophilic substitution reaction of alkyl halides with alkali metal cyanides (e.g., NaCN or KCN).
- **Reagent:** NaCN or KCN (in an alcoholic or aqueous-alcoholic solvent).
- **Reaction:**
  - $R\text{-}X + NaCN \xrightarrow{Ethanol/Water,\Delta} R\text{-}C{\equiv}N + NaX$
- **Example:**
  - CH_3CH_2Br (Bromoethane) + $KCN \xrightarrow{Ethanolic\ KCN,\Delta} CH_3CH_2C{\equiv}N$ (Propanenitrile) + KBr

(b) Explain acidic and alkaline hydrolysis of ethyl cyanide.

- **Ethyl Cyanide (Propanenitrile): $CH_3CH_2C{\equiv}N$**
- **Hydrolysis:** The hydrolysis of nitriles converts the nitrile group (-C≡N) into a carboxylic acid group (-COOH) or its derivative. It can be carried out under acidic or alkaline conditions.
- **(i) Acidic Hydrolysis:**
  - **Reagents:** Dilute strong acid (e.g., HCl, H_2SO_4) and heat.
  - **Mechanism:**
    i. **Protonation of Nitrogen:** The nitrogen atom of the nitrile is protonated by the acid, making the carbon more electrophilic.
      - $R\text{-}C{\equiv}N + H^+ \rightleftharpoons R\text{-}C{\equiv}N^+H$

ii. **Nucleophilic Attack by Water:** Water (a nucleophile) attacks the electrophilic carbon.

- $R\text{-}C(OH)=N^{+}H$

iii. **Proton Transfer & Tautomerization:** Proton transfers and tautomerization lead to the formation of an imidic acid (R-C(OH)=NH).

iv. **Further Protonation and Water Attack:** The imidic acid undergoes further protonation and another nucleophilic attack by water, eventually forming a tetrahedral intermediate.

v. **Loss of Ammonia (or Ammonium Ion):** Ammonia (or ammonium ion, NH_4^+) is eliminated, and the carbonyl group of the carboxylic acid is formed.

- **Product:** Carboxylic acid (Propanoic acid) and Ammonium salt (if acid is in excess).
- **Reaction:**

- $CH_3CH_2C{\equiv}N + 2H_2O + H^+ \xrightarrow{\Delta} CH_3CH_2COOH + NH_4^+$

- **(ii) Alkaline Hydrolysis:**
  - **Reagents:** Strong base (e.g., NaOH, KOH) and heat.
  - **Mechanism:**

vi. **Nucleophilic Attack by Hydroxide:** The hydroxide ion (a strong nucleophile) attacks the electrophilic carbon of the nitrile.

- $R\text{-}C{\equiv}N + OH^- \rightleftharpoons R\text{-}C(O^-)=N$

vii. **Protonation/Tautomerization:** Protonation of the nitrogen (from water) and tautomerization leads to the formation of an iminate anion.

viii. **Further Hydroxide Attack:** Another hydroxide ion attacks, leading to the formation of an amide intermediate.

- R-C(O^-)=NH (Amidate anion)
- This amide intermediate can further hydrolyze.

ix. **Elimination of Amide/Ammonia & Carboxylate Formation:** An amide is formed first, which then hydrolyzes to the carboxylate salt. Ammonia is liberated.

- **Product:** Carboxylate salt (Sodium propanoate) and Ammonia.
- **Reaction:**
  - $CH_3CH_2C{\equiv}N + H_2O + OH^- \xrightarrow{\Delta} CH_3CH_2COO^- + NH_3$ (then add H+ to get acid CH_3CH_2COOH)
  - Or, if written to final acid after workup:
  - $CH_3CH_2C{\equiv}N + H_2O \xrightarrow{NaOH,\Delta} CH_3CH_2COONa \xrightarrow{H^+} CH_3CH_2COOH + NH_3$

(c) Explain Thorpe nitrile condensation.

- **Thorpe Nitrile Condensation (or Thorpe-Ziegler Reaction for cyclization):**
  - **Definition:** The Thorpe nitrile condensation is a base-catalyzed self-condensation of two nitrile molecules (or a nitrile with another nitrile-containing compound) to form a beta-iminonitrile. This reaction is particularly useful for forming cyclic iminonitriles when applied intramolecularly (Thorpe-Ziegler cyclization).
  - **Reagents:** Nitriles with at least one alpha-hydrogen, and a strong base (e.g., sodium alkoxide, sodium hydride, sodium amide).
  - **Mechanism (Key steps):**

x. **Alpha-Hydrogen Abstraction:** A strong base abstracts an acidic alpha-hydrogen from one nitrile molecule, forming a carbanion (nitrile anion).

- $R\text{-}CH_2\text{-}C{\equiv}N + Base^- \rightarrow R\text{-}CH^-\text{-}C{\equiv}N + H\text{-}Base$

xi. **Nucleophilic Attack:** The nitrile carbanion acts as a nucleophile and attacks the electrophilic carbon atom of the cyano group of a second nitrile molecule.

- $R\text{-}CH^-\text{-}C{\equiv}N + R\text{-}C{\equiv}N \rightarrow R\text{-}CH(C{\equiv}N)\text{-}C(R){=}N^-$ (Anion)

xii. **Protonation:** The resulting imine anion is protonated to form a beta-iminonitrile.

- $R\text{-}CH(C{\equiv}N)\text{-}C(R){=}N^- + H\text{-}Base \rightarrow R\text{-}CH(C{\equiv}N)\text{-}C(R){=}NH$ (Beta-iminonitrile) + $Base^-$

- **Further Reactions:** The beta-iminonitrile product can be readily hydrolyzed under acidic or basic conditions to form beta-keto nitriles, or further hydrolyzed to beta-keto acids, and then decarboxylated to give ketones.
- **Significance:** The Thorpe condensation is an important method for forming new carbon-carbon bonds, especially for synthesizing cyclic compounds (cyclic ketones or dinitriles) through intramolecular cyclization (Thorpe-Ziegler reaction), where large rings can be formed.

(d) How will you prepare acetaldehyde by hydrogen cyanide.

- **Acetaldehyde (CH_3CHO) from Hydrogen Cyanide (HCN) - Not directly possible.**
- Hydrogen cyanide (HCN) itself is a C1 synthon. To get acetaldehyde (a C2 compound), you would typically need a starting material that already has two carbons or a way to build up the carbon chain.

- **Assuming the question means starting with a derivative that includes a nitrile and then converting it to acetaldehyde:**
- **Let's assume the question meant starting with a reactant that *can be prepared* from hydrogen cyanide or involves it, for example, from an alkyl cyanide or from a Grignard reagent derived from HCN related chemistry.**
- **This is an unusual question, as HCN is usually used to add one carbon (as in cyanohydrin formation), not to prepare an aldehyde with more carbons.**
- **A common way to get an aldehyde from a nitrile (not HCN itself but a derivative) is through the Stephen reduction or by reduction with DIBAL-H.**
- **Let's assume the question implicitly asks for the synthesis of acetaldehyde starting from a compound that *could* hypothetically be formed from some initial reaction involving HCN, but that's a stretch.**
- **If we interpret "by hydrogen cyanide" as "starting with a compound that can react with HCN," it would be: from CH_3MgBr and HCN, then hydrolysis.**
- **Let's assume the question implies using an alkyl cyanide that has been formed, which then yields acetaldehyde. This requires the nitrile to be ethyl cyanide (propanenitrile). This would yield propionaldehyde, not acetaldehyde.**
- **The most logical way to get Acetaldehyde (C2) from a cyanide-related reaction would be from a 1-carbon starting material that can be elongated. But HCN is C1.**
- **Let's consider a possible reaction path involving HCN to get a derivative that then leads to acetaldehyde.**
- **Path:** Methyl Cyanide (Acetonitrile) to Acetaldehyde.

- This isn't from HCN, but from CH_3CN. If the question implies "from a nitrile," then this is relevant.

- **From Acetonitrile ($CH_3C\equiv N$) to Acetaldehyde (CH_3CHO):**
  - **Method 1: Stephen Reduction (partial reduction of nitrile to aldehyde):**
    - **Reagents:** $SnCl_2$/HCl (stannous chloride and hydrochloric acid), followed by hydrolysis.
    - **Reaction:**
      - $CH_3C\equiv N + 2[H] \xrightarrow{SnCl_2/HCl} CH_3CH=NH_2^+Cl^-$ (Imine salt)
      - $CH_3CH=NH_2^+Cl^- + H_2O \rightarrow CH_3CHO$ (Acetaldehyde) + NH_4Cl
  - **Method 2: Reduction with DIBAL-H (Diisobutylaluminium Hydride):**
    - **Reagents:** DIBAL-H at low temperature, followed by aqueous workup. DIBAL-H is a bulky reducing agent that adds one hydride to the nitrile.
    - **Reaction:**
      - $CH_3C\equiv N \xrightarrow{1.\ DIBAL-H,\ -78^\circ C\ 2.\ H_2O} CH_3CHO$ (Acetaldehyde)

- **Conclusion:** While HCN itself cannot directly form acetaldehyde by itself, if the question meant "from a nitrile" where the nitrile is acetonitrile (CH_3CN), then Stephen reduction or DIBAL-H reduction would be appropriate.
- **If the question strictly means "by using hydrogen cyanide as a reactant to form acetaldehyde," it's generally not possible**

directly. Perhaps it implies a multi-step synthesis where HCN is one of the initial reagents.

8. (a) Explain mechanism of reaction when primary amine reacts with chloroform in presence of KOH.

- This is the **Carbylamine Reaction (also known as Isocyanide Test)**. It is a characteristic test for primary amines.
- **Reaction:** A primary amine reacts with chloroform ($CHCl_3$) and a strong base (e.g., alcoholic KOH) to produce an isocyanide (carbylamine), which has a very offensive odor.
    - $R\text{-}NH_2 + CHCl_3 + 3KOH \xrightarrow{\Delta} R\text{-}NC + 3KCl + 3H_2O$
- **Mechanism:**

eeee. **Formation of Dichlorocarbene:** The strong base (KOH) deprotonates chloroform to form trichloromethyl anion, which then rapidly loses a chloride ion to generate **dichlorocarbene (Cl_2C:)**, a highly reactive neutral intermediate.

- $CHCl_3 + OH^- \rightleftharpoons {}^-CCl_3 + H_2O$
- ${}^-CCl_3 \rightarrow :CCl_2$ (Dichlorocarbene) $+ Cl^-$

ffff. **Nucleophilic Attack by Amine:** The primary amine, acting as a nucleophile, attacks the electron-deficient carbon of dichlorocarbene. This forms an adduct.

- $R\text{-}NH_2 + :CCl_2 \rightarrow R\text{-}N^+H_2\text{-}CCl_2^-$

gggg. **Proton Transfers:** The adduct undergoes two successive deprotonations by the base and two successive eliminations of chloride ions.

- $R\text{-}N^+H_2\text{-}CCl_2^- + OH^- \rightarrow R\text{-}NH\text{-}CCl_2^- + H_2O$
- $R\text{-}NH\text{-}CCl_2^- + OH^- \rightarrow R\text{-}N^-\text{-}CCl_2 + H_2O$

hhhh. **Elimination of Chloride Ions:** The nitrogen lone pair helps to expel the two chloride ions sequentially, leading to the formation of the isocyanide.

- $R\text{-}N^{-}\text{-}CCl_2 \rightarrow R\text{-}N{=}C^{-} + Cl^{-}$
- $R\text{-}N{=}C^{-} + Cl^{-} \rightarrow R\text{-}N{\equiv}C$ (Isocyanide) + Cl^{-} (overall loss of 2HCl from the intermediate, consumed by base)

- **Overall:** The reaction involves the initial formation of dichlorocarbene, which then reacts with the primary amine through a series of deprotonation and elimination steps to yield the isocyanide. This test is highly sensitive and specific for primary amines.

(b) Write reactions given by nitriles and isonitriles.

- **Reactions of Nitriles (Alkyl Cyanides, R-C≡N):**

iiii. **Hydrolysis (Acidic or Alkaline):**

- **Product:** Carboxylic acids or carboxylate salts, and ammonia/ammonium salt.
- $R\text{-}C{\equiv}N \xrightarrow{H_3O^{+},\Delta} R\text{-}COOH + NH_4^{+}$
- $R\text{-}C{\equiv}N \xrightarrow{OH^{-},\Delta} R\text{-}COO^{-} + NH_3$

jjjj. **Reduction:**

- **Product:** Primary amines.
- **Reagents:** $LiAlH_4$ (Lithium Aluminum Hydride) or H_2/Ni (catalytic hydrogenation).
- $R\text{-}C{\equiv}N \xrightarrow{1.\ LiAlH_4\ 2.\ H_2O} R\text{-}CH_2NH_2$

kkkk. **Grignard Reaction:**

- **Product:** Ketones (after hydrolysis).

- **Reagents:** Grignard reagent (R'MgX), followed by hydrolysis.
- R-C≡N + R'MgX →[R-C(R')=NMgX] $\overset{H_3O^+}{\rightarrow}$ R-CO-R' + NH_3

lllll. **Stephen Reduction:**

- **Product:** Aldehydes (via imine intermediate).
- **Reagents:** $SnCl_2$/HCl, followed by hydrolysis.
- R-C≡N $\overset{1.\ SnCl_2/HCl\ 2.\ H_2O}{\rightarrow}$ R-CHO

mmmm. **Reaction with DIBAL-H:**

- **Product:** Aldehydes.
- **Reagents:** Diisobutylaluminium Hydride (DIBAL-H) at low temperature, followed by hydrolysis.
- R-C≡N $\overset{1.\ DIBAL-H\ 2.\ H_2O}{\rightarrow}$ R-CHO

nnnn. **Thorpe Nitrile Condensation:**

- **Product:** Beta-iminonitriles (can be hydrolyzed to beta-keto nitriles/ketones).
- **Reagents:** Strong base.
- 2 R-CH_2C≡N $\overset{Base}{\rightarrow}$ R-CH(CN)-C(R)=NH

- **Reactions of Isonitriles (Isocyanides, R-N≡C):**

oooo. **Hydrolysis (Acidic):**

- **Product:** Primary amine and formic acid (or formate salt).
- **Reagents:** Acid (e.g., HCl) and heat.
- R-N≡C + $2H_2O$ + H^+ $\overset{\Delta}{\rightarrow}$ R-NH_2 + HCOOH

pppp. **Reduction:**

- **Product:** Secondary amines.
- **Reagents:** H_2/Ni (catalytic hydrogenation) or $LiAlH_4$.
- R-N≡C + $2H_2 \xrightarrow{Ni \text{ or } LiAlH_4}$ R-NH-CH_3 (N-methyl primary amine)

qqqq. **Oxidation:**

- **Product:** Isocyanates.
- **Reagents:** Oxygen, ozone, or mercuric oxide.
- R-N≡C + [O] → R-N=C=O

rrrr. **Addition Reactions (e.g., with HCl):**

- **Product:** Formimidoyl chlorides.
- R-N≡C + HCl → R-NH=CCl

ssss. **Reaction with Sulfur:**

- **Product:** Isothiocyanates.
- R-N≡C + S → R-N=C=S

(c) Write the name and structure of product when (i) Methyl isocyanide is reduced with platinum in presence of H_2(g).

- **Reactant:** Methyl isocyanide ($CH_3N≡C$)
- **Reaction:** Reduction with H_2/Pt (catalytic hydrogenation).
- **Product:** Secondary amine, specifically N-methylethanamine (or dimethylamine, as isocyanides add a methyl group to nitrogen upon reduction).
- **Structure:** CH_3-NH-CH_3
- **Name of Product:** N-Methylmethanamine (or Dimethylamine)

(ii) Hydrolysis of methaneisonitrile undergoes in presence of acid

- **Reactant:** Methaneisonitrile (Methyl isocyanide, $CH_3N{\equiv}C$)
- **Reaction:** Acidic hydrolysis.
- **Product:** Primary amine (methylamine) and formic acid.
- **Structure:** CH_3NH_2 and HCOOH
- **Name of Product:** Methylamine and Formic Acid

9. (d) Write at least four important physical properties of isocyanide. Write significance of ambident ion.

- **Four Important Physical Properties of Isocyanides:**

tttt. **Characteristic Odor:** They have extremely foul, highly unpleasant, and penetrating odors, often described as pungent or cadaverous. This distinctive odor is used as a test (carbylamine test) for primary amines.

uuuu. **Boiling Points:** They are typically volatile liquids, often having boiling points similar to or slightly higher than their isomeric nitriles.

vvvv. **Polarity:** Isonitriles are highly polar molecules due to the significant dipole moment arising from the carbon-nitrogen triple bond and the difference in electronegativity. The carbon has a positive charge, and the nitrogen has a negative charge ($R\text{-}N^{+}{\equiv}C^{-}$).

wwww. **Toxicity:** Many isocyanides are highly toxic and should be handled with extreme care.

xxxx. **Solubility:** Lower molecular weight isocyanides are generally sparingly soluble in water but soluble in organic solvents.

- **Significance of Ambident Ion:**

- **Definition:** An ambident ion (or ambident nucleophile) is a nucleophile that has two or more different atoms through which it can attack an electrophile. These atoms possess electron pairs (lone pairs or pi-electrons) that can be donated to form a new bond.
- **Example: Cyanide ion (CN^-)**
  - The cyanide ion is a classic example of an ambident nucleophile. It has two potential sites for nucleophilic attack:
    1. The carbon atom: ($^-C{\equiv}N$) - It is more nucleophilic due to higher polarizability and lower electronegativity compared to nitrogen.
    2. The nitrogen atom: ($C{\equiv}N^-$) - It is less nucleophilic but still capable of attacking.
  - **Significance in Reactions:**
    3. **Formation of Isomeric Products:** When an ambident ion reacts with an electrophile, it can lead to the formation of two different isomeric products, depending on which atom acts as the nucleophilic site.
       - For example, the reaction of alkyl halides (R-X) with cyanide (CN^-):
         - Reaction through carbon yields nitriles (alkyl cyanides, R-C≡N), which are the major products with alkali metal cyanides (e.g., KCN).
         - Reaction through nitrogen yields isocyanides (alkyl isocyanides, R-N≡C), which are formed in significant amounts when silver cyanide (AgCN) is used

(due to silver's preference for bonding with nitrogen).

4. **Control of Selectivity:** Understanding ambident nucleophiles is crucial for controlling reaction selectivity in organic synthesis. By carefully choosing the solvent, catalyst, or counterion, chemists can influence which nucleophilic site reacts, thereby directing the synthesis towards a desired isomer.
5. **Explaining Reaction Outcomes:** It explains why certain reactions produce mixtures of products or why a specific reagent is required to favor one isomer over another.

- **Other examples:** Nitrite ion (NO_2^-), enolates (e.g., from beta-keto esters like EAA, which can alkylate on C or O).