Class : 11

2023 – 24

AMINES

Structure of Amines

- Nitrogen orbitals in amines are sp^3 hybridised and the geometry of amines is pyramidal.
- Due to the presence of unshared pair of electrons, the angle $C-N-E$, (where E is C or H) is less than $109.5°$; for instance, it is $108°$ in case of trimethylamine.

Classification

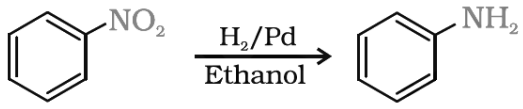
Amines are classified as primary $(1°)$, secondary $(2°)$ and tertiary $(3°)$ depending upon the number of hydrogen atoms replaced by alkyl or aryl groups in ammonia molecule.

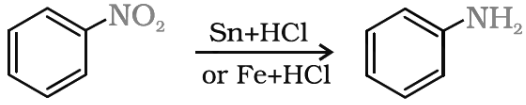
Nomenclature

- In common system, an aliphatic amine is named by prefixing alkyl group to amine, i.e., alkylamine as one word (e.g., methylamine).
- In secondary and tertiary amines, when two or more groups are the same, the prefix di or tri is appended before the name of alkyl group. In IUPAC system, primary amines are named as alkanamines. The name is derived by replacement of 'e' of alkane by the word amine. For example, CH_3NH_2 is named as methanamine.
- In case, more than one amino group is present at different positions in the parent chain, their positions are specified by giving numbers to the carbon atoms bearing $-NH_2$ groups and suitable prefix such as di, tri, etc. is attached to the amine. The letter 'e' of the suffix of the hydrocarbon part is retained. For example, $H_2N-CH_2-CH_2-NH_2$ is named as ethane-1, 2-diamine.
- To name secondary and tertiary amines, we use locant N to designate substituent attached to a nitrogen atom. For example, $CH_3NHCH_2CH_3$ is named as N methylethanamine and $(CH_3CH_2)_3N$ is named as N, N-diethylethanamine. In arylamines, $-NH_2$ group is directly attached to the benzene ring. $C_6H_3NH_2$ is the simplest example of arylamine. In common system, it is known as aniline.
- While naming arylamines according to IUPAC system, suffix ' e ' of arene is replaced by 'amine'. Thus in IUPAC system, $C_6H_5-NH_2$ is named as benzenamine.

Preparation of Amines

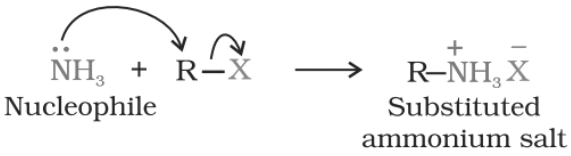
- **Reduction of nitro compounds :** Nitro compounds are reduced to amines by passing hydrogen gas in the presence of finely divided nickel, palladium or platinum and also by reduction with metals in acidic medium.

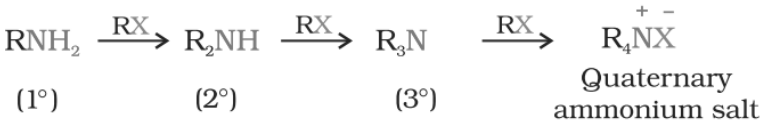
(i) 

(ii) 

Reduction with iron scrap and hydrochloric acid is preferred because $FeCl_2$ formed gets hydrolysed to release hydrochloric acid during the reaction.

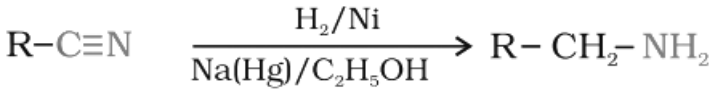
Ammonolysis of alkyl halides : An alkyl or benzyl halide on reaction with an ethanolic solution of ammonia undergoes nucleophilic substitution reaction in which the halogen atom is replaced by an amino $(-NH_2)$ group. This process of cleavage of the $C-X$ bond by ammonia molecule is known as ammonolysis.



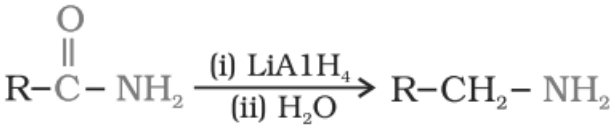


The free amine can be obtained from the ammonium salt by treatment with a strong base.

- Ammonolysis has the disadvantage of yielding a mixture of primary, secondary and tertiary amines and also a quaternary ammonium salt, However, primary amine is obtained as a major product by taking large excess of ammonia.
- The order of reactivity of halides with amines is RI > RBr > RCI.
- **Reduction of nitriles :** Nitriles on reduction with lithium aluminium hydride $(LiAlH_4)$ or catalytic hydrogenation produce primary amines.



- **Reduction of amides :** The amides on reduction with lithium aluminium hydride yield amines.



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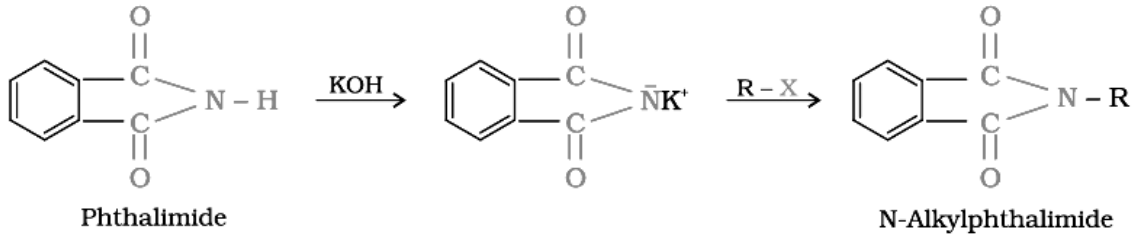
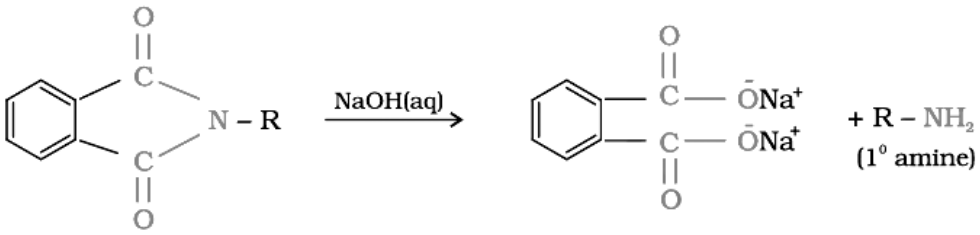
- **Gabriel phthalimide synthesis :** Gabriel synthesis is used for the preparation of primary amines. Aromatic primary amines cannot be prepared by this method because aryl halides do not undergo nucleophilic substitution with the anion formed by phthalimide.





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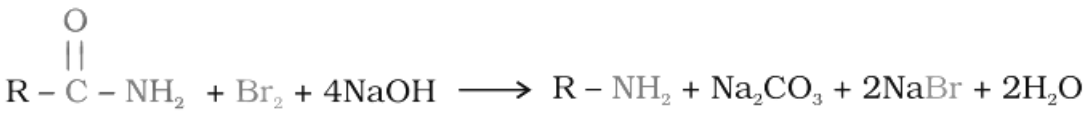
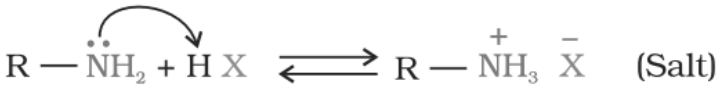
- **Hoffmann bromamide degradation reaction :** Hoffmann developed a method for preparation of primary amines by treating an amide with bromine in an aqueous or ethanolic solution of sodium hydroxide.
- The amine so formed contains one carbon less than that present in the amide.



Physical Properties

- The lower aliphatic amines are gases with fishy odour. Primary amines with three or more carbon atoms are liquid and still higher ones are solid.
- Aniline and other arylamines are usually colourless but get coloured on storage due to atmospheric oxidation.
- Lower aliphatic amines are soluble in water because they can form hydrogen bonds with water molecules. Solubility decreases with increase in molar mass of amines due to increase in size of the hydrophobic alkyl part. Higher amines are essentially insoluble in water.
- Amines are soluble in organic solvents like alcohol, ether and benzene. You may remember that alcohols are more polar than amines and form stronger intermolecular hydrogen bonds than amines.
- Primary and secondary amines are engaged in intermolecular association due to hydrogen bonding between nitrogen of one and hydrogen of another molecule. This intermolecular association is more in primary amines than in secondary amines as there are two hydrogen atoms available for hydrogen bond formation in it. Tertiary amines do not have intermolecular association due to the absence of hydrogen atom available for hydrogen bond formation. The order of boiling points of isomeric amines is as follows:
- Primary $>$ Secondary $>$ Tertiary
- Boiling points of amines are lower than those of alcohols and carboxylic acids of comparable molecular masses.

Chemical Reactions

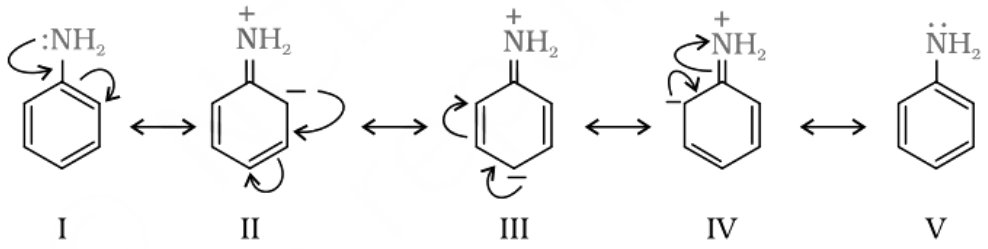
- **Basic character of amines :** Amines, being basic in nature, react with acids to form salts.
- 
- Amines have an unshared pair of electrons on nitrogen atom due to which they behave as Lewis base.
- Larger the value of K_b or smaller the value of pK_b, stronger is the base.
- Aromatic amines are weaker bases than ammonia due to the electron withdrawing nature of the aryl group.
- Basic character of an amine depends upon the ease of formation of the cation by accepting a proton from the acid. The more stable the cation is relative to the amine, more basic is the amine.
- The basic nature of aliphatic amines should increase with increase in the number of alkyl groups. This trend is followed in the gaseous phase. The order of basicity of amines in the gaseous phase follows the expected order: tertiary amine $>$ secondary amine $>$ primary amine $>$ NH_3.
- In the aqueous phase, the substituted ammonium cations get stailised not only by electron releasing effect of the alkyl group $(+I)$ but also by solvation with water molecules. The greater the size of the ion, lesser will be the solvation and the less stabilised is the ion.
- There is a subtle interplay of the inductive effect, solvation effect and steric hinderance of the alkyl group which decides the basic strength of alkyl amines in the aqueous state.
- The order of basic strength in case of methyl substituted amines and ethyl substituted amines in aqueous solution is as follows:

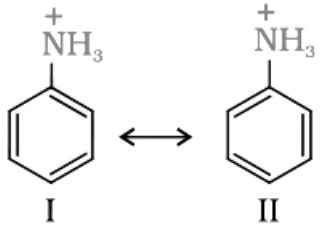
  $$(C_2H_5)_2NH > (C_2H_5)_3\ N > C_2H_5NH_2 > NH_3$$

  [+ I effect dominates over H - bonding]

  $$(CH_3)_2NH > CH_3NH_2 > (CH_3)_3\ N > NH_3$$

  [H $-$ bonding effect dominates over +I effect]
- pK_b value of aniline is quite high because in aniline or other arylamines, the $-NH_2$ group is attached directly to the benzene ring. It results in the unshared electron pair on nitrogen atom to be in conjugation with the benzene ring and thus making it less available for protonation.
- Aniline is a resonance hybrid of the five structures. On the other hand, anilinium ion obtained by accepting a proton can have only two resonating structures. Greater the number of resonating structures, greater is the stability. Thus you can infer that aniline (five resonating structures) is more stable than anilinium ion. Hence, the proton acceptability or the basic nature of aniline or other aromatic amines would be less than that of ammonia.



- 

- In case of substituted aniline, it is observed that electron releasing groups like $-OCH_3, -CH_3$ increase basic strength whereas electron withdrawing groups like $-NO_2, -SO_3H, -COOH, -X$ decrease it.
- **Alkylation :** Amines undergo alkylation on reaction with alkyl halides.
- **Acylation :** Aliphatic and aromatic primary and secondary amines react with acid chlorides, anhydrides and esters by nucleophilic substitution reaction. This reaction is known as acylation.
- The products obtained by acylation reaction are known as amides. The reaction is carried out in the presence of a base stronger than the amine, like pyridine, which removes HCl so formed and shifts the equilibrium to the right hand side.
- Amines also react with benzoyl chloride (C_6H_5COCl). This reaction is known as benzoylation.

Carbylamine reaction : Aliphatic and aromatic primary amines on heating with chloroform and ethanolic potassium hydroxide form isocyanides or carbylamines which are foul smelling substances. Secondary and tertiary amines do not show this reaction. This reaction is known as carbylamine reaction or isocyanide test and is used as a test for primary amines.

$$R - NH_2 + CHCl_3 + 3KOH \rightarrow R - NC + 3KCl + 3H_2O$$

Reaction with nitrous acid : Three classes of amines react differently with nitrous acid which is prepared in situ from a mineral acid and sodium nitrite.

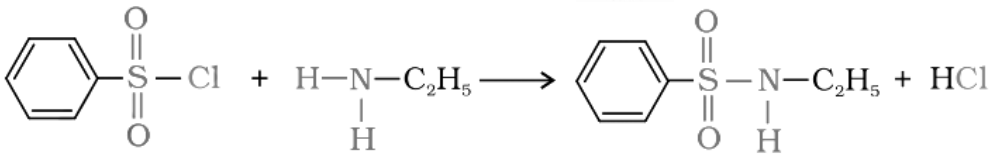
Primary aliphatic amines react with nitrous acid to form aliphatic diazonium salts which being unstable, liberate nitrogen gas quantitatively and alcohols. Quantitative evolution of nitrogen is used in estimation of amino acids and proteins.

$$R{-}NH_2 + HNO_2 \xrightarrow{NaNO_2 + HCl} [R{-}\overset{+}{N}_2\overset{-}{Cl}] \xrightarrow{H_2O} ROH + N_2 + HCl$$

- Aromatic amines react with nitrous acid at low temperatures (273-278 K) to form diazonium salts. to form diazonium salts.

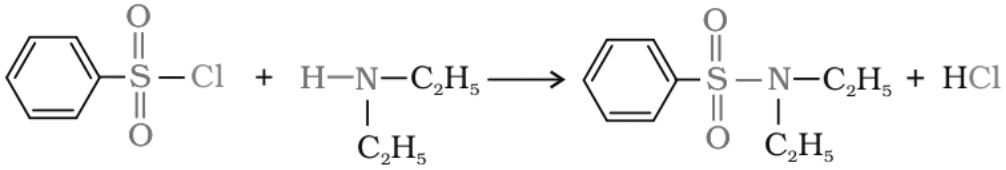
$$\underset{\text{Aniline}}{C_6H_5 - NH_2} \xrightarrow[273 - 278\ K]{NaNO_2 + 2HCl} \underset{\text{Benzenediazonium chloride}}{C_6H_5 - \overset{+}{N}_2\overset{-}{Cl}} + NaCl + 2H_2O$$

- **Reaction with arylsulphonyl chloride :** Benzenesulphonyl chloride $(C_6H_5SO_2Cl)$, which is also known as Hinsberg's reagent, reacts with primary and secondary amines to form sulphonamides.
- The reaction of benzenesulphonyl chloride with primary amine yields N-ethylbenzenesulphonyl amide.



N-Ethylbenzenesulphonamide
(soluble in alkali)

- The hydrogen attached to nitrogen in sulphonamide is strongly acidic due to the presence of strong electron withdrawing sulphonyl group. Hence, it is soluble in alkali.
- In the reaction with secondary amine, N, N diethylbenzenesulphonamide is formed.

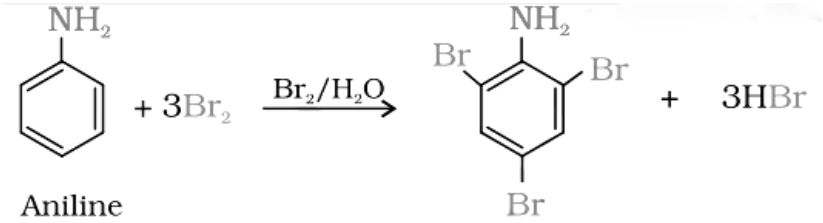


N,N-Diethylbenzenesulphonamide

Since N, N-diethylbenzene sulphonamide does not contain any hydrogen atom attached to nitrogen atom, it is not acidic and hence insoluble in alkali.

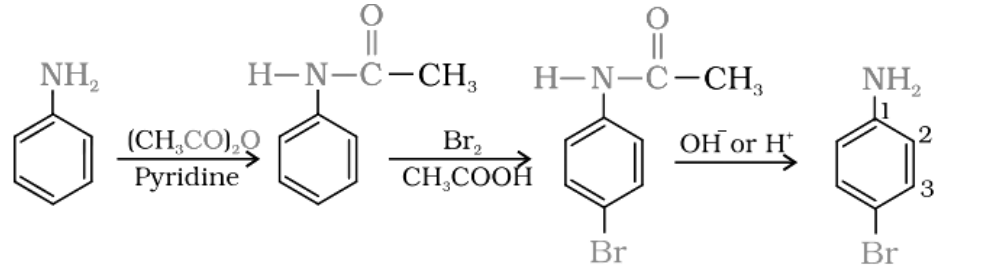
- Tertiary amines do not react with benzenesulphonyl chloride. This property of amines reacting with benzenesulphonyl chloride in a different manner is used for the distinction of primary, secondary and tertiary amines and also for the separation of a mixture of amines.
- However, these days benzenesulphonyl chloride is replaced by p-toluenesulphonyl chloride.

Electrophilic substitution : The $-NH_2$ group is ortho and para directing and a powerful activating group.
Bromination: Aniline reacts with bromine water at room temperature to give a white precipitate of 2,4,6-tribromoaniline.



Aniline 2,4,6-Tribromoaniline

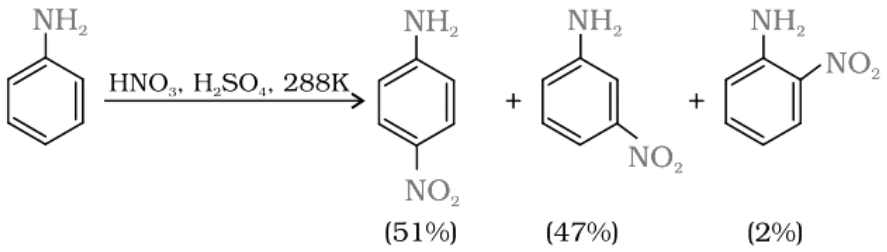
Activating effect of $-NH_2$ can be controlled by protecting the $-NH_2$ group by acetylation with acetic anhydride, then carrying out the desired substitution followed by hydrolysis of the substituted amide to the substituted amine.



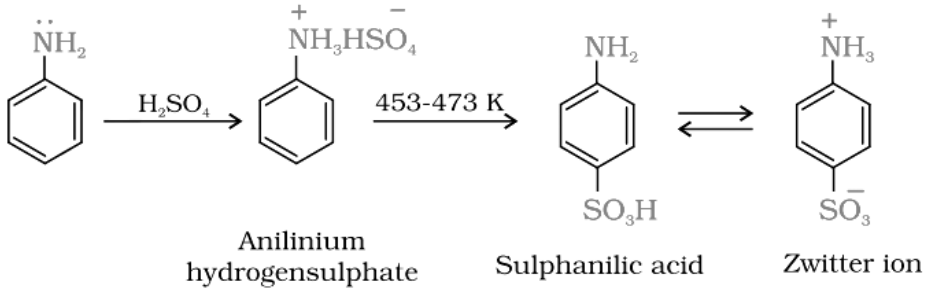
Aniline *N*-Phenylethanamide (Acetanilide) (Major) 4-Bromoaniline

In case of acetanilide, the lone pair of electrons on nitrogen is less available for donation to benzene ring by resonance. Therefore, activating effect of $-NHCOCH_3$ group is less than that of amino group.

- **Nitration:** Direct nitration of aniline yields tarry oxidation products in addition to the nitro derivatives. Moreover, in the strongly acidic medium, aniline is protonated to form the anilinium ion which is meta directing. That is why besides the ortho and para derivatives, significant amount of meta derivative is also formed.



Sulphonation: Aniline reacts with concentrated sulphuric acid to form anilinium hydrogensulphate which on heating with sulphuric acid at 453-473K produces p-aminobenzene sulphonic acid, commonly known as sulphanilic acid, as the major product.



- Aniline does not undergo Friedel-Crafts reaction (alkylation and acetylation) due to salt formation with aluminium chloride, the Lewis acid, which is used as a catalyst. Due to this, nitrogen of aniline acquires positive charge and hence acts as a strong deactivating group for further reaction.

Methods of Preparation of Diazonium Salts

- Benzenediazonium chloride is prepared by the reaction of aniline with nitrous acid at $273-278\ \mathrm{K}$.
- Nitrous acid is produced in the reaction mixture by the reaction of sodium nitrite with hydrochloric acid. The conversion of primary aromatic amines into diazonium salts is known as diazotisation. Due to its instability, the diazonium salt is not generally stored and is used immediately after its preparation.

$$C_6H_5NH_2 + NaO_2 + 2HCl \xrightarrow{273\text{-}278k} C_6H_5\overset{+}{N_2}\overset{-}{Cl} + NaCl + 2H_2O$$

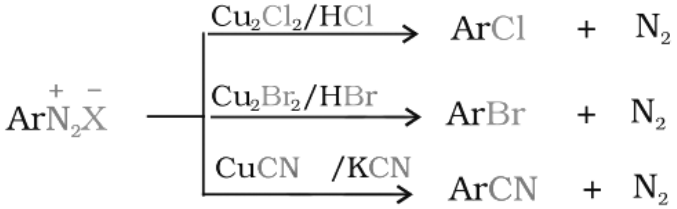
Physical Properties

- Benzenediazonium chloride is a colourless crystalline solid. It is readily soluble in water and is stable in cold but reacts with water when warmed. It decomposes easily in the dry state.
- Benzenediazonium fluoroborate is water insoluble and stable at room temperature.

Chemical Reactions

- Reactions involving displacement of nitrogen : Diazonium group being very good leaving group, is substituted by other groups such as Cl^-, Br, I, CN^- and OH^- which displace nitrogen from the aromatic ring. The nitrogen formed escapes from the reaction mixture as a gas.

Replacement by halide or cyanide ion: The Cl, Br and CN - nucleophiles can easily be introduced in the benzene ring in the presence of $Cu(I)$ ion. This reaction is called Sandmeyer reaction.



- Chlorine or bromine can also be introduced in the benzene ring by treating the diazonium salt solution with corresponding halogen acid in the presence of copper powder. This is referred as Gatterman reaction.
- The yield in Sandmeyer reaction is found to be better than Gattermann reaction.
- **Replacement by iodide ion:** Iodine is not easily introduced into the benzene ring directly, but, when the diazonium salt solution is treated with potassium iodide, iodobenzene is formed.

$$\mathrm{Ar\overset{+}{N}_2\overset{-}{Cl} + Cl \longrightarrow ArI + KCl + N_2}$$

- **Replacement by fluoride ion:** When are nediazonium chloride is treated with fluoroboric acid, arene diazonium fluoroborate is precipitated which on heating decomposes to yield aryl fluoride.

$$\mathrm{ArN\overset{+}{N}_2\overset{-}{Cl} + HBF_4 \longrightarrow Ar + \overset{+}{N}B_2\overline{BF}_4 \rightarrow - F + BF_3 + N_2}$$

- **Replacement by H:** Certain mild reducing agents like hypophosphorous acid (phosphinic acid) or ethanol reduce diazonium salts to arenes and themselves get oxidised to phosphorous acid and ethanal, respectively.

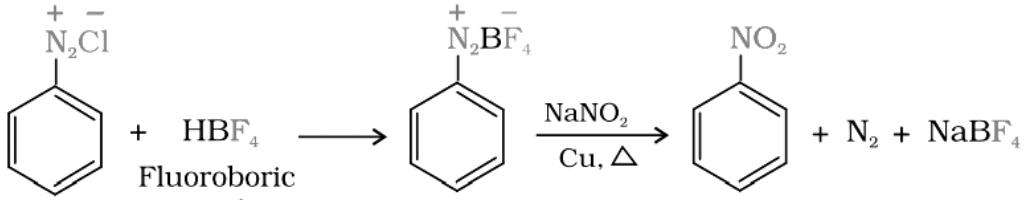
$$\mathrm{Ar\overset{+}{N}_2\overset{-}{C} + H_3PO_4 + H_2O \longrightarrow ArH + N_2 + H_3PO_3 + HCl}$$

$$\mathrm{ArN\overset{+}{N}_2\overset{-}{Cl} + CH_3CH_2OH \longrightarrow ArH + N_2 + CH_3CHO + HCl}$$

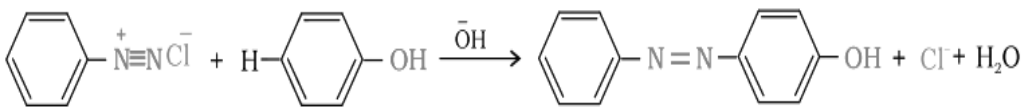
Replacement by hydroxyl group: If the temperature of the diazonium salt solution is allowed to rise upto 283 K, the salt gets hydrolysed to phenol.

$$\mathrm{Ar\overset{+}{N}_2\overset{-}{Cl} + H_2O \longrightarrow ArOH + N_2 + HCl}$$

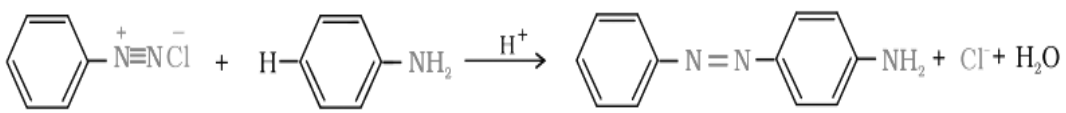
- **Replacement by $-NO_2$ group:** When diazonium fluoroborate is heated with aqueous sodium nitrite solution in the presence of copper, the diazonium group is replaced by $-NO_2$ group.



- **Reactions involving retention of diazo group coupling reactions ;**
- The azo products obtained have an extended conjugate system having both the aromatic rings joined through the $-N = N$ - bond.
- These compounds are often coloured and are used as dyes.
- Benzene diazonium chloride reacts with phenol in which the phenol molecule at its para position is coupled with the diazonium salt to form *p* hydroxyazobenzene. This type of reaction is known as coupling reaction.
- Similarly the reaction of diazonium salt with aniline yields p-aminoazobenzene. This is an example of electrophilic substitution reaction.



p-Hydroxyazobenzene (orange dye)



p-Aminoazobenzene
(yellow dye)

- **Importance of Diazonium Salts in Synthesis of Aromatic Compounds**
- The diazonium salts are very good intermediates for the introduction of $-Cl, -Br, -I, -CN, -OH, -NO_2$ groups into the aromatic ring.
- Aryl fluorides and iodides cannot be prepared by direct halogenation
- The cyano group cannot be introduced by nucleophilic substitution of chlorine in chlorobenzene but cyanobenzene can be easily obtained from diazonium salt.

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