13 AMINES

Can you recall ?

- Write some examples of nitrogen containing organic compounds.
- What are the types of amines?

Amines are nitrogen containing organic compounds having basic character. Amines are present in many natural compounds like proteins, vitamins, hormones and plant products like nicotine.

13.1 Classification of Amines :

Amines are classified as primary (1°), secondary (2°) and tertiary (3°) amines. Their structures are obtained in simple way by replacing one, two or three hydrogen atoms of NH_3 molecule by alkyl/aryl groups (see Table 13.1).

Secondary and tertiary amines are further classified as simple / symmetrical amines and mixed / unsymmetrical amines. When all the alkyl or aryl groups on nitrogen are same, it is a simple amine. If these groups are different, then the amine is a mixed amine.

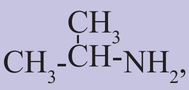
Amines are also divided into two major classes, namely, aliphatic and aromatic amines on the basis of nature of the groups attached to the nitrogen atom.

Use your brain power

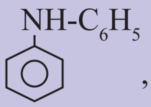
Classify the following amines as simple/mixed; 1°, 2°, 3° and aliphatic or aromatic.

$(C_2H_5)_2NH$, $(CH_3)_3N$, $C_2H_5\text{-}NH\text{-}CH_3$,

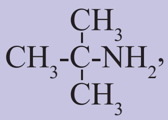
$C_6H_5\text{-}NH_2$,



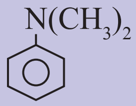
$CH_3\text{-}\overset{\overset{CH_3}{|}}{CH}\text{-}NH_2$,



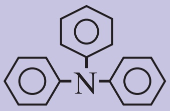
,



$CH_3\text{-}\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}\text{-}NH_2$,



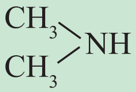
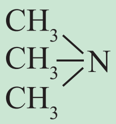
,



Remember...

Other organic compounds like alkyl halides or alcohols are classified as 1°, 2°, 3° depending upon the nature of the carbon atom to which functional group is attached where as amines are classified depending upon the number of alkyl or aryl groups directly attached to the nitrogen atom. Thus, isopropyl amine is 1^0 amine, but isopropyl alcohol is 2^0 alcohol.

Table 13.1 Types of amines

Type	Functional group		Examples	
	Name	Formula	Formula	Common Name
Primary amine, (1^0)	Amino	$-NH_2$	$C_2H_5\text{-}NH_2$	Ethylamine
Secondary amine, (2^0)	Imino	$>NH$	 $\begin{matrix}CH_3\\CH_3\end{matrix}\!>\!NH$	Dimethylamine
Tertiary amine, (3^0)	Tertiary nitrogen	$\geq N$	 $\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\!\geq\! N$	Trimethylamine

13.2 Nomenclature of Amines :

13.2.1 Common names : Common names of aliphatic amines are given by writing the name of alkyl group followed by suffix-amine, that is, 'alkyl amine'. In the case of mixed amines, the names of alkyl groups are written in alphabetical order. If two or three identical alkyl groups are attached to nitrogen atom, the prefix 'di-' or 'tri-' is added before the name of alkyl group. The parent arylamine, C_6H_5-NH_2, is named as aniline. Other aromatic amines are named as derivatives of aniline (see Table 13.2).

13.2.2 IUPAC names : In IUPAC system, primary amines are named by replacing the ending 'e' of the parent alkane by suffix -amine (alkanamine). A locant indicating the position of amino group is added before the suffix amine. When two or more amino groups are present, the prefix 'di-', 'tri-' etc. are used with proper locant. In this case the ending 'e' of parent alkane is retained.

Secondary or tertiary amines are named as N-substituted derivatives of primary amines. The largest alkyl group attached to nitrogen is taken as the parent alkane and other alkyl groups as N-substituents. While naming arylamines ending 'e' of arene is replaced by 'amine'. The common name of aniline is also accepted by IUPAC (see Table 13.2).

Remember...

The name of amine (common or IUPAC) is always written as one word. For example : C_2H_5-NH_2 Ethylamine (Ethanamine)

Try this...

Draw possible structures of all the isomers of $C_4H_{11}N$. Write their common as well as IUPAC names.

13.3 Preparation of Amines :

13.3.1 : By ammonolysis of alkyl halides :

When alkyl halide is heated with alcoholic solution of excess ammonia it undergoes nucleophilic substitution reaction in which the halogen atom is replaced by an amino ($-NH_2$) group to form primary amine. This process of breaking of C-X bond by ammonia is known as ammonolysis. The reaction is also known as alkylation of ammonia. The reaction is carried out in a sealed tube at 373 K. It may be noted that the primary amine obtained in the 1st step is stronger nucleophile than ammonia. Hence, it further reacts with alkyl halide to form secondary and tertiary amines and finally quaternary ammonium salt if NH_3 is not used in large excess.

$$\text{R-X} + \underset{\text{(excess)}}{\text{NH}_3\text{(alc).}} \xrightarrow{\Delta} \underset{1^0\ \text{amine}}{\text{R-NH}_2}$$

The order of reactivity of alkyl halides with ammonia is R-I > R-Br > R-Cl.

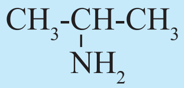
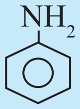
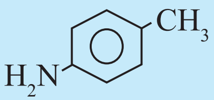
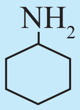
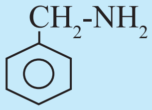
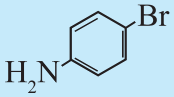
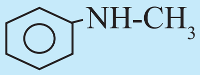
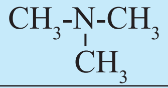
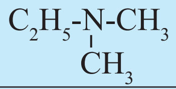
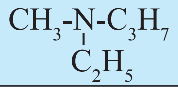
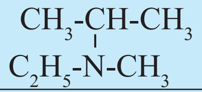
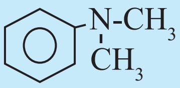
Use your brain power

- Write chemical equations for

  1. reaction of alc. NH_3 with C_2H_5I.
  2. Ammonolysis of benzyl chloride followed by the reaction with two moles of CH_3-I.

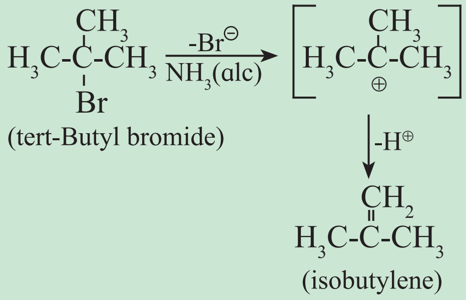
- Why is ammonolysis of alkyl halide not a suitable method for the preparation of primary amine ?

Table 13.2 : Common and IUPAC names of some alkyl and arylamines

Amines	Common names	IUPAC names
a. Primary amines :		
CH_3-NH_2	Methylamine	Methanamine
CH_3-CH_2-CH_2-NH_2	n-Propylamine	Propan-1-amine
 $\underset{NH_2}{CH_3\text{-}CH\text{-}CH_3}$	Isopropylamine	Propan-2-amine
H_2N-CH_2-CH_2-NH_2	Ethylenediamine	Ethane-1, 2-diamine
CH_2=CH-CH_2-NH_2	Allylamine	Prop-2-en-1-amine
	Aniline/ Phenylamine	Aniline or Benzenamine
H_2N-$(CH_2)_6$-NH_2	Hexamethylenediamine	Hexane-1, 6-diamine
	p-Toluidine	4-Methylaniline
	Cyclohexylamine	Cyclohexanamine
	Benzylamine	Phenylmethanamine
	p-Bromoaniline	4-Bromoaniline or 4-Bromobenzenamine
b. Secondary Amines		
CH_3-NH-CH_3	Dimethylamine	N-methylmethanamine
CH_3-CH_2-NH-CH_3	Ethylmethylamine	N-methylethanamine
	Methylphenylamine	N-methylaniline or N-methylbenzenamine
C_6H_5-NH-C_6H_5	Diphenylamine	N-Phenylbenzenamine
c. Tertiary Amines		
 $\underset{CH_3}{CH_3\text{-}N\text{-}CH_3}$	Trimethylamine	N, N-Dimethylmethanamine
 $\underset{CH_3}{C_2H_5\text{-}N\text{-}CH_3}$	Ethyldimethylamine	N, N-Dimethylethanamine
 $\underset{C_2H_5}{CH_3\text{-}N\text{-}C_3H_7}$	Ethylmethyln-propylamine	N-Ethyl-N-methyl propan-1-amine
 $\overset{CH_3\text{-}CH\text{-}CH_3}{C_2H_5\text{-}N\text{-}CH_3}$	Ethylmethylisopropylamine	N-Ethyl-N-methyl propan-2-amine
	N, N-Dimethylaniline	N, N-Dimethylbenzenamine

Do you know ?

When tert-butyl bromide is treated with alcoholic NH_3, isobutylene is formed. This is the result of elimination reaction preferred over nucleophilic substitution through the stable tertiary butyl carbocation intermediate.



13.3.2 Reduction of nitrocompounds :

Aliphatic and aromatic nitrocompounds can be reduced to primary amines by using metal-acid mixture (Sn/HCl or Fe/HCl or Zn/HCl) or catalytic hydrogenation (H_2/Ni or Pt or Pd) or $LiAlH_4$ in ether.

$$R\text{-}NO_2 + 6[H] \xrightarrow{Sn/HCl} R\text{-}NH_2 + 2H_2O$$

13.3.3 Reduction of alkyl cyanide (alkanenitriles) :

Can you recall ?

- How is alkyl halide converted into alkyl cyanide ?

Primary amines can be obtained by the reduction of alkyl cyanide with sodium and ethanol. This is known as **Mendius reduction**. The reaction can also be brought about by lithium aluminium hydride.

$$R\text{-}C{\equiv}N + 4[H] \xrightarrow[\text{or } LiAlH_4]{Na/C_2H_5OH} \underset{1^\circ \text{ amine}}{R\text{-}CH_2\text{-}NH_2}$$

Problem 13.1 : Write reaction to convert methyl bromide into ethyl amine ? Also, comment on the number of carbon atoms in the starting compound and the product.

Solution : Methyl bromide can be converted into ethyl amine in two stage reaction sequence as shown below.

$$CH_3\text{-}Br + KCN \longrightarrow CH_3\text{-}CN + KBr$$

$$CH_3\text{-}CN \xrightarrow[\text{(reduction)}]{Na/C_2H_5OH} CH_3\text{-}CH_2\text{-}NH_2$$

The starting compound methyl bromide contains one carbon atom while the product ethylamine contains two carbon atoms. A reaction in which number of carbons increases involves a step up reaction. The overall conversion of methyl bromide into ethyl amine is a step up conversion.

Use your brain power

Use your brain power:

Identify ‘A’ and ‘B’ in the following conversions.

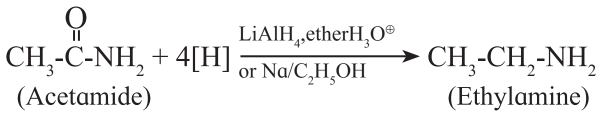
(i) $CH_3\text{-}I \xrightarrow{KCN} A \xrightarrow{Na/C_2H_5OH} B$

(ii) $CH_3\text{-}Br \xrightarrow{AgNO_2} A \xrightarrow{Sn/HCl} B$

(iii) $C_2H_5\text{-}I \xrightarrow{AgCN} A \xrightarrow{Na/C_2H_5OH} B$

13.3.4 By reduction of amides :

Primary amines having same number of carbon atoms can be obtained by the reduction of amides by $LiAlH_4$ in ether or by Na/C_2H_5OH.



$$\underset{\text{(Acetamide)}}{CH_3\text{-}\overset{O}{\overset{\|}{C}}\text{-}NH_2} + 4[H] \xrightarrow[\text{or } Na/C_2H_5OH]{LiAlH_4,\text{ether}H_3O^{\oplus}} \underset{\text{(Ethylamine)}}{CH_3\text{-}CH_2\text{-}NH_2}$$

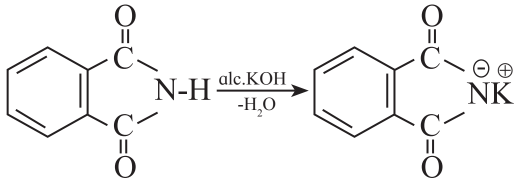
13.3.5 Gabriel phthalimide synthesis : This method is used for the synthesis of primary amine. It involves the following three stages.

i. Formation of potassium salt of phthalimide from phthalimide on reaction with alcoholic potassium hydroxide.

ii. Formation of N-alkyl phthalimide from the potassium salt by reaction with alkyl halide.

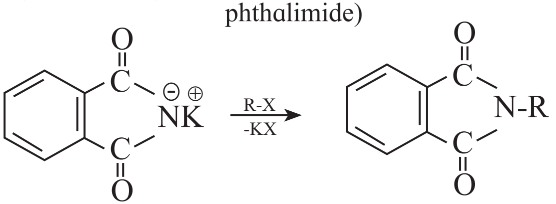
iii. Alkaline hydrolysis of N-alkyl phthalimide to form the corresponding primary amine.

i.



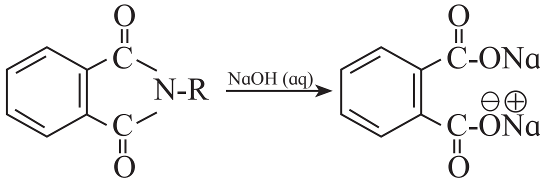
(Phthalimide) (Potassium salt of phthalimide)

ii.



(N-Alkylphthalimide)

iii.



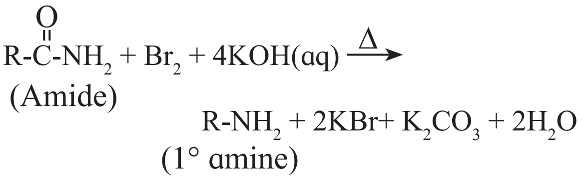
(sodium phthalate)

+ R-NH$_2$
(1° amine)

Aromatic amines cannot be prepared by this method because aryl halides do not undergo nucleophilic substitution with the anion formed by phthalimide.

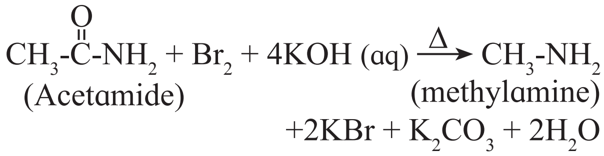
13.3.6 By Hofmann degradation (Hofmann rearrangement / Hofmann bromamide degradation / Hofmann hypobromite degradation) :

This is a good laboratory method for the conversion of an amide into primary amine containing one carbon less. The reaction is brought about by warming the amide with bromine and concentrated aqueous KOH solution.



$$\underset{\text{(Amide)}}{R\text{-}\overset{O}{\overset{\|}{C}}\text{-}NH_2} + Br_2 + 4KOH(aq) \xrightarrow{\Delta} \underset{(1^\circ\ \text{amine})}{R\text{-}NH_2} + 2KBr + K_2CO_3 + 2H_2O$$

For example :



$$\underset{\text{(Acetamide)}}{CH_3\text{-}\overset{O}{\overset{\|}{C}}\text{-}NH_2} + Br_2 + 4KOH\ (aq) \xrightarrow{\Delta} \underset{\text{(methylamine)}}{CH_3\text{-}NH_2} + 2KBr + K_2CO_3 + 2H_2O$$

The overall result is removal of the $-\overset{O}{\overset{\|}{C}}-$ group from the amide. As the product contains one carbon atom less than the original amide. It is a **step down** reaction.

Use your brain power

Write the chemical equations for the following conversions :

i. Methyl chloride to ethylamine.

ii. Benzamide to aniline.

iii. 1, 4 - Dichlorobutane to hexane - 1, 6 - diamine.

iv. Benzamide to benzylamine.

13.4 Physical properties of Amines :

13.4.1 Intermolecular forces, boiling points and solubility : The N-H bond in amines is polar because the electronegativities of Nitrogen (3.0) and Hydrogen (2.1) are different. Due to the polar nature of N-H bond primary and secondary amines have intermolecular hydrogen bonding. The intermolecular hydrogen bonding is to greater extent in primary amine than in secondary amines, because primary amines have two hydrogen atoms bonded to nitrogen for hydrogen bond formation (see Fig 13.1).

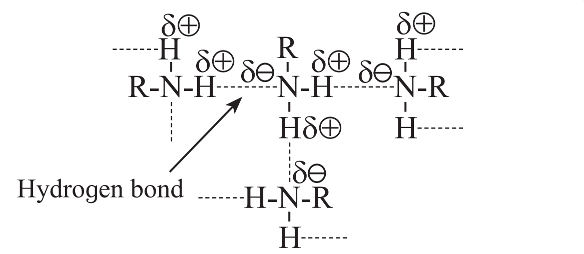


Fig. 13.1 : Intermolecular hydrogen bonding in primary amines

Tertiary amines do not have intermolecular hydrogen bonding as there is no hydrogen atom on nitrogen of tertiary amine. But due to polar N-C bonds, tertiary amines are polar molecules, and have intermolecular dipole-dipole attractive forces. Thus intermolecular forces of attraction are strongest in primary amines and weakest in tertiary amines.

The observed order of boiling points of isomeric amines is : primary amine > secondary amine > tertiary amine (see Table 13.3 serial numbers 1, 2, 3). It can be explained on the basis of the intermolecular forces in them.

The lower aliphatic amines are gases with fishy odour, middle members are liquids and higher members are solids under ordinary temperature and pressure.

Aniline and other arylamines are usually colourless liquids but get coloured as they are easily oxidised by air.

Due to their ability to form hydrogen bond with water molecule, lower aliphatic amines are soluble in water (see Fig. 13.2). Solubility of amines decreases with increase in molar mass of amines due to increase in size of hydrophobic alkyl group. Aromatic amines and higher aliphatic amines are insoluble in water.

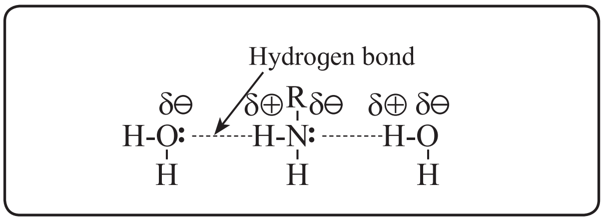


Fig. 13.2 : Hydrogen bonding between amine and water molecule

Since N-H bonds in amines are less polar than O-H bond in alcohol, water solubilities of alcohols, amines and alkanes of comparable molar mass in water are in the decreasing order: **alcohols > amines > alkanes.**

The order of boiling points of alkanes, amines, alcohols and carboxylic acid of comparable molar mass is as follows :

Alkanes < Amines < Alcohols < Carboxylic acid. (Table 13.3, serial number 4, 5, 6, 7)

Use your brain power

Arrange the following :

a. In decreasing order of the b.p.

C_2H_5-OH, C_2H_5-NH_2, $(CH_3)_2NH$

b. In increasing order of solubility in water:

C_2H_5-NH_2, C_3H_7-NH_2, C_6H_5-NH_2

Table 13.3 Boiling points of alkane, alcohol and amines of similar molar masses

Sr. No	Compound	Molar mass	B.P. (K)
1	n-$C_4H_9NH_2$	73	350.8
2	$(C_2H_5)_2NH$	73	329.3
3	$C_2H_5N(CH_3)_2$	73	310.5
4	C_2H_5COOH	74	414.4
5	n-C_4H_9OH	74	390.3
6	$(CH_3)_3C$-NH_2	73	318.15
7	$C_2H_5CH(CH_3)_2$	72	300.8

13.5 Basicity of Amines

The basic nature of amines is due to presence of a lone pair of electrons on the nitrogen atom. In terms of Lewis theory, amines are bases because they can share a lone pair of electrons on 'N' atom with an electron deficient species. For example : Trimethylamine shares its lone pair of electrons with the electron deficient boron trifluoride.

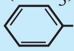
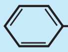
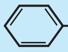
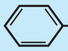
$$Me_3N\!: + BF_3 \longrightarrow Me_3\overset{\oplus}{N}\text{-}\overset{\ominus}{B}F_3$$

Basic strength of amines is expressed quantitatively as K_b or pK_b value. In terms of Lowry-Bronsted theory, the basic nature of amines is explained by writing the following equilibrium.

$$\underset{\text{(amine)}}{\geqslant N\!:} + H_2O \rightleftharpoons \underset{\text{(conjugate acid)}}{\geqslant \overset{\oplus}{N}\text{-}H} + \overset{\ominus}{O}H \;\ldots\ldots\ldots\; (13.1)$$

In this equilibrium amine accepts $H^{\oplus}$, hence an amine is a Lowry-Bronsted base. For stronger base, this equilibrium shifts towards right, thereby the K_b value is larger and pK_b value is smaller and vice versa (refer to Chapter 3). Table 13.4 gives pK_b values of some amines.

Table 13.4 : pK_b Values of some amines in aqueous medium

Amine	Structural Formula	pK_b value
Primary alkanamines :		
Methanamine	$CH_3\text{-}NH_2$	3.38
Ethanamine	$CH_3\text{-}CH_2\text{-}NH_2$	3.29
Propan-2-amine	$(CH_3)_2\text{-}CH\text{-}NH_2$	3.40
Phenylmethanamine	 $\text{-}CH_2\text{-}NH_2$	4.70
Secondary alkanamines :		
N-Methylmethanamine	$(CH_3)_2NH$	3.27
N-Ethylethanamine	$(CH_3CH_2)_2NH$	3.00
Tertiary alkanamines :		
N, N-Dimethylmethanamine	$(CH_3)_3N$	4.22
N, N-Diethylethanamine	$(CH_3CH_2)_3N$	3.25
Ammonia	NH_3	4.75
Arylamines :		
Benzenamine (aniline)	 $\text{-}NH_2$	9.38
N-Methylaniline	 $\text{-}NHCH_3$	9.30
N, N-Dimethylaniline	 $\text{-}N(CH_3)_2$	8.92

13.5.1 : Basic strength of aliphatic amines :

The trend in the observed pK_b values (see table 13.4) and basic strength of 1°, 2°, 3° amines and NH_3 can be represented as shown below :

Order of pK_b values:

$NH_3 > R\text{-}NH_2 > R_2NH < R_3N$

Order of basic strength :

$NH_3 < R\text{-}NH_2 < R_2NH > R_3N$ .... (13.2)

Thus as per the observed pK_b values of the aliphatic amines, **secondary amines are the strongest bases**. Basic strength increases as we move from NH_3 to $R\text{-}NH_2$ and from $R\text{-}NH_2$ to R_2NH, but basic strength decreases as we move from R_2NH to R_3N (Table 13.4).

The basic strength and the corresponding pK_b value depends upon the position of the equilibrium shown in Eq. (13.1). Greater the stabilization of the conjugate acid more on right side the equilibrium will lie and stronger will be the base and smaller will be its pK_b value.

Can you recall ?

- What is meant by +I effect ?
- Which of the following species is better stabilized and by which effect ?

$CH_3\text{-}\overset{\oplus}{C}H_2$ and $CH_3\text{-}\overset{\oplus}{C}H\text{-}CH_3$

Basicity of amines is related to the structural effects which influence stabilization of various species. Greater is the stabilization of the protonated amine, that is, the conjugate acid, greater is the basicity of the amine.

Use your brain power

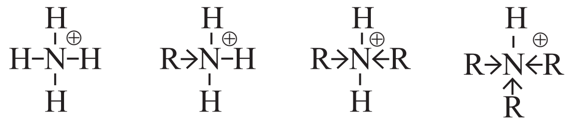
Refer to pK_b values from Table 13.4 and answer which compound from the following pairs is stronger base ?

i. $CH_3\text{-}NH_2$ and $(CH_3)_2NH$

ii. $(C_2H_5)_2NH$ and $(C_2H_5)_3N$

iii. NH_3 and $(CH_3)_2CH\text{-}NH_2$

a. Influence of +I effect on stabilization of conjugate acids of aliphatic amines and NH_3 can be represented as shown below :



An alkyl group exerts electron releasing inductive effect (+I) which stabilizes positive charge on atom bonded to it. As we move from conjugate acid of ammonia ($NH_4^{\oplus}$) to that of tertiary amine ($R_3NH^{\oplus}$), the number of alkyl groups (R) bonded to Nitrogen goes on increasing steadily. This results in increasing stabilization of the conjugate acids and thereby an increasing order of basic strength is expected.

Order of stabilization :

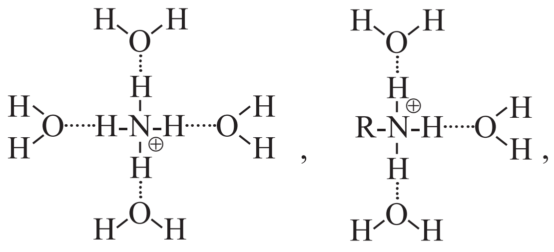
$$\overset{\oplus}{N}H_4 < R\text{-}\overset{\oplus}{N}H_3 < R_2\overset{\oplus}{N}H_2 < R_3\overset{\oplus}{N}\text{-}H$$

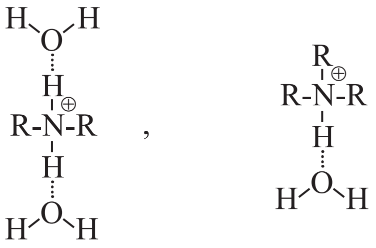
Expected order of basic strength :

$$NH_3 < R\text{-}NH_2 < R_2NH < R_3N$$

The expected order of basic strength on the basis of +I effect differs from the observed order (Eq.13.2). It is seen that the observed increasing basic strength from ammonia to 1° amine and from 1° amine to 2° amine is explained on the basis of increased stabilization of conjugate acids by +I effect of increased number of alkyl (R) groups. However, decreased basic strength of 3° amine implies that the conjugate acid of 3° amine is less stabilized even though the +I effect of three alkyl groups in $R_3\overset{\oplus}{N}H$ is expected to be large. This is suggestive of existance of another influencing factor in stabilization of conjugate acids of amines.

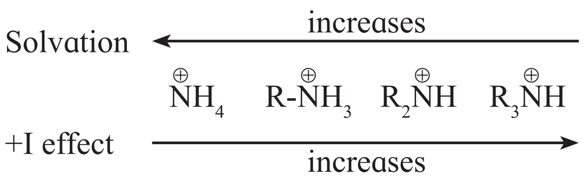
b. Influence of solvation by water on stabilization of conjugate acids of aliphatic amines and ammonia can be represented as shown below :





The solvent water stabilizes the conjugate acid by hydrogen bonding through the 'H' bonded to the '$N^{\oplus}$'. The number of 'H' atoms bonded to the '$N^{\oplus}$' decreaes from 4 in $NH_4^{\oplus}$ to 1 in $R_3NH^{\oplus}$. As a result $NH_4^{\oplus}$ is best stabilized by solvation while the stabilization by solvation is very poor in $R_3NH^{\oplus}$.

c. Combined influence of +I effect and solvation on stabilization if conjugate acids of aliphatic amines decides the observed basic strength and pK_b value. These two influencing factors operate in opposite directions.



The net results is that as we move from NH_3 to RNH_2 to R_2NH, the basic strength increases due to better stabilization of the corresponding conjugate acids. But 3° amine is weaker base than 2° amine because the stabilization of conjugate acid of 3° amine by solvation is very poor.

13.5.2 Basicity of arylamines :

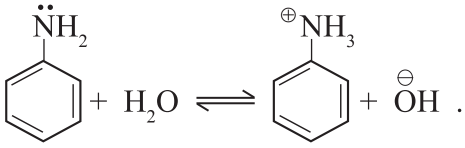
Can you recall ?

Refer to Table 13.4 and answer :

Are the pK_b values of aniline, N-methylaniline and N, N-dimethylaniline larger or smaller than those of NH_3 and CH_3NH_2 ?

Which one of the two, aniline or CH_3NH_2, is a stronger base ?

From the pK_b values we understand that arylamines in general are weaker bases than ammonia and aliphatic amines. Strength of arylamines is explained in accordance with Lowery Bronsted theory by writing the following equilibrium (Eq. 13.3) For aniline (similar to eq. 13.1).

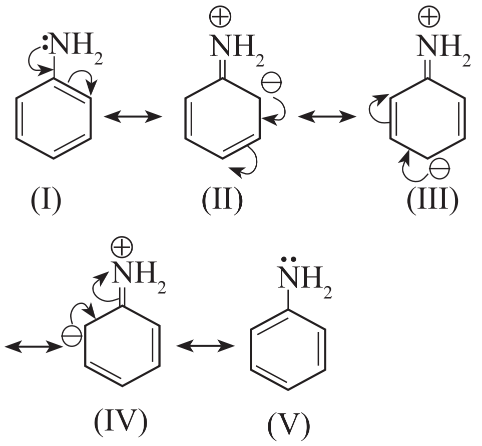


.... (13.3)

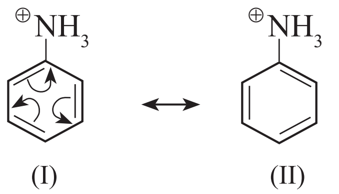
(Base) (Conjugate acid)

Here, both the species base and conjugate acid, are resonance stabilized but to different extent.

In arylamines, the $-NH_2$ group is attached directly to an aromatic ring. The lone pair of electrons on nitrogen is conjugated to the aromatic ring and is less available for protonation. Aniline is resonance stabilized by the following five resonance structures.



On the other hand anilinium ion obtained by accepting a proton does not have lone pair of electrons on nitrogen. Hence it can be stabilized by only two resonance structures and therefore less stabilized than aniline.



As a result the equilibrium (13.3) is shifted towards left side. This makes aniline (and also other arylamines) weaker bases than aliphatic amines and ammonia.

Use your brain power

Arrange the following amines in decreasing order of their basic strength -

NH_3, $CH_3\text{-}NH_2$, $(CH_3)_2NH$, $C_6H_5NH_2$.

13.6 Chemical properties of amines

13.6.1 Laboratory test for amines :

a. Test for amines as the 'base' : All amines 1°, 2° and 3° are basic compounds. Aqueous solution of water soluble amines turns red litmus blue.

The 'basic' nature of amines is detected in laboratory by reaction with aqueous solution of strong mineral acid HCl.

$$\underset{\text{(amine)}}{\geqslant N:} + HCl(aq) \longrightarrow \underset{\text{(a substituted ammonium chloride)}}{\geqslant \overset{\oplus}{N}\text{-}H(aq) + Cl^{\ominus}(aq)}$$

$$\geqslant \overset{\oplus}{N}\text{-}H(aq) + Cl^{\ominus}(aq) + \underset{\text{(excess)}}{NaOH(aq)} \longrightarrow \geqslant N: + NaCl(aq) + H_2O$$

Water insoluble amine dissolves in aqueous HCl due to formation of water soluble substituted ammonium chloride, which on reaction with excess aqueous NaOH regenerates the original insoluble amine.

b. Diazotization reaction/ Orange dye test: In a sample of aromatic primary amine, 1-2 mL of conc. HCl is added. The aqueous solution of $NaNO_2$ is added with cooling. This solution is transfered to a test tube containing solution of β naphthol in NaOH. Formation of orange dye indicates presence of aromatic primary amino group. (It may be noted that temperature of all the solutions and reaction mixtures is maintined near 0°C throughout the reaction).

The reactions involved in this test will be discussed in section 13.7.2.

13.6.2: Alkylation of amines : Hofmann's exhaustive alkylation : When a primary amine is heated with excess of primary alkyl halide it gives a mixture of secondary amine, tertiary amine along with tetraalkylammonium halide (also refer to sec. 13.3.1).

$$\underset{\text{(1° Amine)}}{R\text{-}NH_2} \xrightarrow[-HX]{R\text{-}X} \underset{\text{(2° Amine)}}{R_2NH} \xrightarrow[-HX]{R\text{-}X} \underset{\text{(3° Amine)}}{R_3N} \xrightarrow[-HX]{R\text{-}X} \underset{\text{(Tetraalkyl ammonium halide)}}{R_4\overset{\oplus}{N}X^{\ominus}}$$

If excess of alkyl halide is used tetraalkyl ammonium halide is obtained as major product. The reaction is known as exhaustive alkylation of amines.

The tetraalkylammonium halides are called quaternary ammonium salts which are crystalline solids. They are the derivatives of ammoium salts in which all the four hydrogen atoms attached to nitrogen in $\overset{\oplus}{N}H_4$ are replaced by four alkyl groups (same or different). Primary, secondary and tertiary amines consume three, two and one moles of alkyl halide respectively to get converted into quaternary ammonium salt. The reaction is carried out in presence of mild base $NaHCO_3$, to neutralize the large quantity of HX formed. If the alkyl halide is methyl iodide, the reaction is called exhaustive methylation of amines.

For example : When methylamine is heated with excess methyl iodide, it gives tetramethyl ammonium iodide.

$$CH_3\text{-}NH_2 + CH_3\text{-}I \xrightarrow{\Delta} (CH_3)_2NH + HI$$

$$(CH_3)_2NH + CH_3\text{-}I \xrightarrow{\Delta} (CH_3)_3N + HI$$

$$(CH_3)_3N + CH_3\text{-}I \xrightarrow{\Delta} (CH_3)_4\overset{\oplus}{N}I^{\ominus}$$

Use your brain power

$$C_2H_5\text{-}NH_2 + \underset{\text{excess}}{C_2H_5\text{-}I} \xrightarrow{\Delta} ?$$

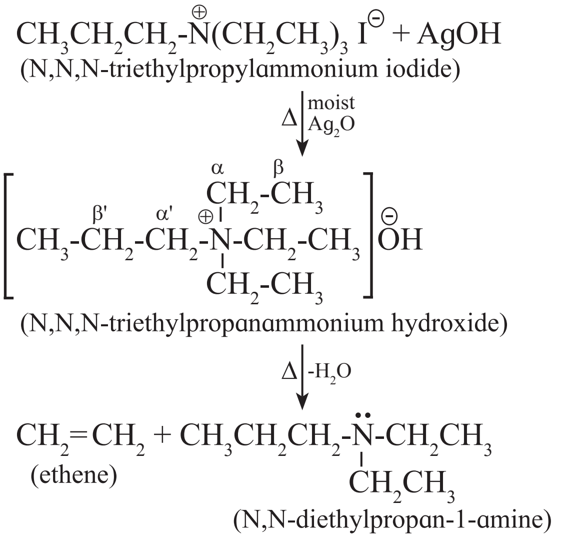
$$(C_2H_5)_2NH + \underset{\text{excess}}{CH_3\text{-}I} \xrightarrow{\Delta} ?$$

$$C_6H_5\text{-}NH_2 + \underset{\text{excess}}{CH_3\text{-}I} \xrightarrow{\Delta} ?$$

13.6.3 Hofmann Elimination :

When tetraalkylammonium halide is hetated with moist silver oxide, it gives quanternary ammonium hydroxide which is a deliquescent crystalline solid, and strongly basic like NaOH or KOH. Quaternary ammonium hydroxides on strong heating undergo β-elimination to give an alkene, the reaction is called Hofmann elimination. The least substituted alkene is obtained as major product (in contrast to Saytzeff elimination)

For example :



$$\underset{\text{(N,N,N-triethylpropylammonium iodide)}}{CH_3CH_2CH_2\text{-}\overset{\oplus}{N}(CH_2CH_3)_3\ I^{\ominus}} + AgOH$$

$$\Big\downarrow \Delta \ \text{moist } Ag_2O$$

$$\underset{\text{(N,N,N-triethylpropanammonium hydroxide)}}{\left[CH_3\text{-}\overset{\beta'}{C}H_2\text{-}\overset{\alpha'}{C}H_2\text{-}\overset{\oplus}{N}(\overset{\alpha}{C}H_2\text{-}\overset{\beta}{C}H_3)\text{-}CH_2\text{-}CH_3\,(CH_2\text{-}CH_3)\right]\overset{\ominus}{O}H}$$

$$\Big\downarrow \Delta \ \text{-}H_2O$$

$$\underset{\text{(ethene)}}{CH_2{=}CH_2} + \underset{\text{(N,N-diethylpropan-1-amine)}}{CH_3CH_2CH_2\text{-}\ddot{N}(CH_2CH_3)\text{-}CH_2CH_3}$$

Use your brain power

Complete the following reaction:

$$CH_3\text{-}CH_2\text{-}\overset{\oplus}{N}(CH_3)_3I^{\ominus} \xrightarrow[Ag_2O]{Moist} ? \xrightarrow{\Delta}$$

Do you know ?

- Acetylcholine is a quaternary ammonium salt which occurs in nervous system and functions as neurotransmitter

  $CH_3\text{-}CO\text{-}O\text{-}CH_2\text{-}CH_2\text{-}\overset{\oplus}{N}(CH_3)_3$

- Quaternary ammonium salts are also present in cationic detergents.

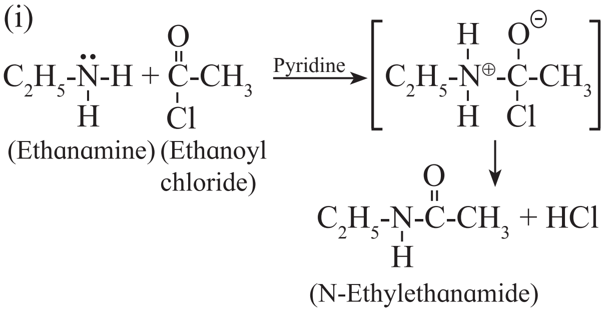
13.6.4 Acylation of amines :

Can you recall ?

- What is an acyl group ?
- How are alcohols acylated ?

Aliphatic and aromatic primary and secondary amines undergo acylation reaction. These amines contain replaceable hydrogen atoms (positively polarised H) on the nitrogen atom. These hydrogen atoms are replaced by acyl groups such as acetyl group. On reaction of amines with acetyl chloride or acetic anhydride, acetyl derivative of amine is obtained. It is also called amide. Amide is less basic than the amine. Acylation is a nucleophilic substitution reaction. The reaction is carried out in presence of strong base like pyridine, which neutralizes the acid produced during the reaction. For example :

(i)

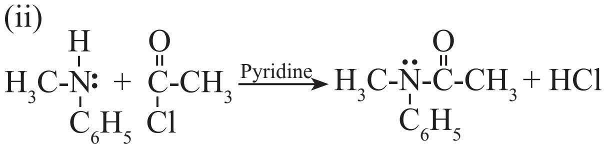


$$C_2H_5-\underset{H}{\ddot{N}}-H + \underset{Cl}{\overset{O}{\overset{\|}{C}}}-CH_3 \xrightarrow{Pyridine} \left[C_2H_5-\underset{H}{\overset{H}{N^{\oplus}}}-\underset{Cl}{\overset{O^{\ominus}}{C}}-CH_3\right] \downarrow C_2H_5-\underset{H}{N}-\overset{O}{\overset{\|}{C}}-CH_3 + HCl$$

(Ethanamine) (Ethanoyl chloride)

(N-Ethylethanamide)

(ii)



$$H_3C-\underset{C_6H_5}{\overset{H}{\ddot{N}}}: + \underset{Cl}{\overset{O}{\overset{\|}{C}}}-CH_3 \xrightarrow{Pyridine} H_3C-\underset{C_6H_5}{\ddot{N}}-\overset{O}{\overset{\|}{C}}-CH_3 + HCl$$

(N-Methylaniline) (N-methyl-N-phenylethanamide)

Benzoyl chloride also gives similar reaction with amines.

Use your brain power

- $CH_3-NH_2 + Ph-CO-Cl \longrightarrow$?
- $(CH_3)_3N + Ph-CO-Cl \longrightarrow$?

13.6.5 Carbylamine reaction :

Aliphatic or aromatic primary amines on heating with chloroform give foul (offensive) smelling products called alkyl/aryl isocyanides or carbylamines. This reaction is a test for primary amines. Secondary and tertiary amines do not give this test.

$$\underset{(1° \text{ amine})}{R-NH_2} + CHCl_3 + 3KOH \xrightarrow{\Delta} \underset{(\text{Alkyl isocyanide})}{R-NC} + 3KCl + 3H_2O$$

Use your brain power

Write the carbylamine reaction by using aniline as starting material.

13.6.6 Reaction with nitrous acid :

Primary, secondary and tertiary amines react differently with nitrous acid. Reactions of only primary amines will be considered here.

Can you tell ?

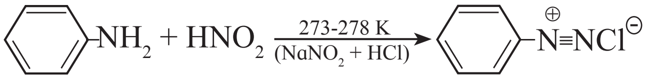
- What is the formula of nitrous acid ?
- Can nitrous acid be stored in bottle ?

Nitrous acid is an unstable compound. Hence it is prepared *in situ* by adding aqueous sodium nitrite to hydrochloric acid already mix with the substrate, that is amine.

a. Aliphatic primary amines on reaction with nitrous acid form aliphatic diazonium salts as very unstable intermidiates which decompose immediately by reaction with solvent water. Corresponding alcohol is formed as the product of the reaction and nitrogen gas is liberated .

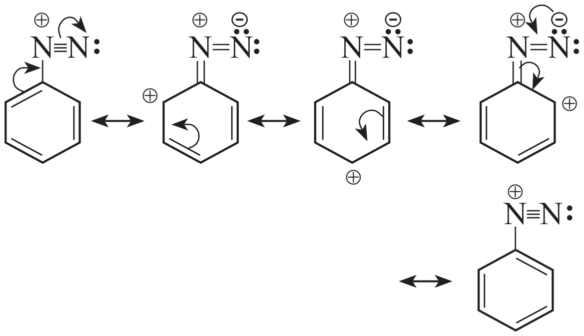
$$R-NH_2 + HNO_2 \xrightarrow[(NaNO_2 + HCl)]{273\text{-}278\ K} \underset{(\text{alkyl diazonium chloride})}{\left[R-\overset{\oplus}{N}_2\ Cl^{\ominus}\right]} \xrightarrow{H_2O} R-OH + N_2\uparrow + HCl$$

b. Aromatic primary amines react with nitrous acid to form diazonium salts which have reasonable stability at 273 K.



(benzene diazonium chloride)

Aryl diazonium salts are resonance stabilized and useful as versatile intermidiates to obtain a variety of products.



13.7 Reactions of arene diazonium salts:

Aryl diazonium salts show two types of reactions.

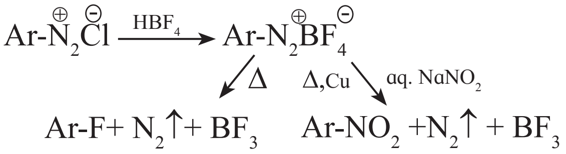
13.7.1 Reactions involving displacement of diazo group : The diazonium group ($-N_2^{\oplus}$) is a very good leaving group due to the positive charge on nitrogen atom bonded to aromatic ring. As a result, the arene diazonium salts undergo nucleophilic substitution reaction with a variety of nucleophiles. Table 13.5 shows reactions of diazonium salts involving displacement of diazo group.

Table 13.5 Reactions of arene diazonium salts

Title of reaction	Substrate	Reagent	Products
Sandmeyer reaction (good yield)	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{X}$	$\xrightarrow{\text{CuCl/HCl}}$	$\text{Ar-Cl}+N_2$
	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{X}$	$\xrightarrow{\text{CuBr/HBr}}$	$\text{Ar-Br}+N_2$
	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{X}$	$\xrightarrow{\text{CuCN/KCN}}$	$\text{Ar-CN}+N_2$
Gatterman reaction	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{X}$	$\xrightarrow[\text{HCl}]{\text{Cu powder}}$	$\text{Ar-Cl}+N_2$
	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{X}$	$\xrightarrow[\text{HBr}]{\text{Cu powder}}$	$\text{Ar-Br}+N_2$
Iodoarene formation	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{Cl}$	$\xrightarrow{\text{KI}}$	$\text{Ar-I}+N_2$
Mild Reduction	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{Cl}$	$\xrightarrow[H_2O]{H_3PO_2}$	$\text{Ar-H}+N_2+H_3PO_3+\text{HCl}$
	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{Cl}$	$\xrightarrow{CH_3\text{-}CH_2\text{-}OH}$	$\text{Ar-H}+N_2+CH_3CHO+\text{HCl}$
Phenol formation	$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{Cl}$	$\xrightarrow[\text{283 K}]{H_2O}$	$\text{Ar-OH}+N_2+\text{HCl}$

Reaction with fluoroboric acid :

Arene diazonium salt on reaction with fluoroboric acid gives precipitate of diazonium fluoroborate which on heating decomposes to yield fluoroarene. On the other hand when heated with aqueous sodium nitrite in presence of copper it gives nitroarene.



$$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{Cl} \xrightarrow{HBF_4} \text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{BF_4}$$

$$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{BF_4} \xrightarrow{\Delta} \text{Ar-F}+N_2\uparrow+BF_3$$

$$\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{BF_4} \xrightarrow[\text{aq. NaNO}_2]{\Delta,\text{Cu}} \text{Ar-NO}_2+N_2\uparrow+BF_3$$

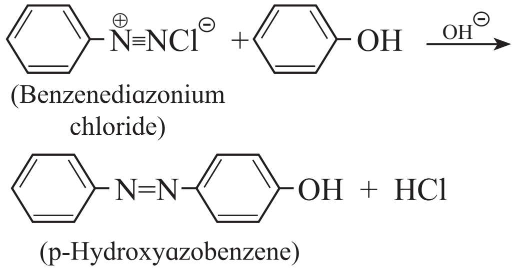
Use your brain power

Complete the following reactions :

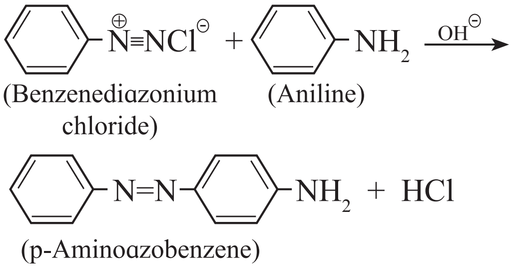
- $\text{Ar-NH}_2 \xrightarrow{?} \text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{Cl} \xrightarrow[\text{Cupprous chloride}]{\text{HCl}} ?$
- $\text{Ar-}\overset{\oplus}{N}_2\overset{\ominus}{Cl} \xrightarrow{H_3PO_2} ?$

13.7.2 Reactions involving retention of diazo group: (Coupling reactions) :

Arene diazonium salts when treated with certain reactive aromatic compounds such as phenols or aromatic amines, give azo compounds. These have extended conjugated system of double bonds in which two aromatic rings are joined through azo group -N=N-. This reaction is called **azo coupling**. Azo compounds are brightly coloured and are used as dyes. This is an example of electrophilic aromatic substitution reaction. Here the electrophiles are positively charged diazonium ions. Substitution usually occurs para to the ring activating group. For example : Benzenediazonium chloride reacts with phenol in mild alkaline medium to give p-Hydroxyazobenzene (orange dye).



Azo coupling with β-naphthol in NaOH is used as a confirmatory test for primary aromatic amines. Benzenediazonium chloride reacts with aniline in mild alkaline medium to give p-aminoazo-benzene (yellow dye.)

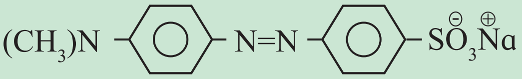


(Benzenediazonium chloride) (Aniline)

(p-Aminoazobenzene)

Do you know ?

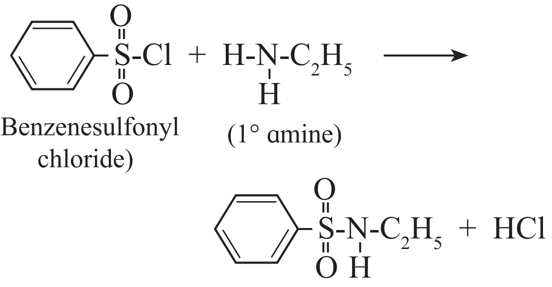
The acid-base indicator methyl orange is an azo dye.



13.8 Reaction with arenesulfonyl chloride :

(Hinsberg's test) : Benzenesulfonyl chloride ($C_6H_5SO_2Cl$) is known as **Hinsberg's reagent**.

a. Ethyl amine (primary amine) reacts with benzenesulfonyl chloride to form N-ethyl benzenesulfonyl amide.

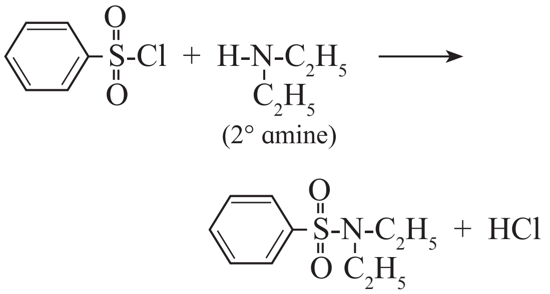


(Benzenesulfonyl chloride) (1° amine)

(N-Ethylbenzene sulfonamide)
(Soluble in alkali)

The hydrogen attached to nitrogen in sulfonamide ethanamine (a primary amine) is strongly acidic. Hence it is soluble in alkali.

b. Diethyl amine reacts with benzene-sulfonyl chloride to give N, N- diethyl benzene sulfonamide.



(2° amine)

(N, N-diethylbenzene sulfonamide)

N,N-diethylbenzenesulfonamide does not contain any H-atom attached to nitrogen atom. Hence it is not acidic and does not dissolve in alkali.

Can you tell ?

- Do tertiary amines have 'H' bonded to 'N' ?
- Why do tertiary amines not react with benzene sulfonyl chloride ?

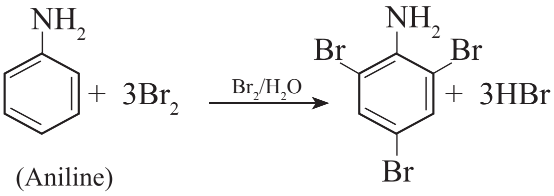
Use your brain power

How will you distinguish between methylamine, dimethylamine and trimethylamine by Hinsberg's test ?

13.9 Electrophilic aromatic substitution in aromatic amines :

Amino group is ortho and para directing and powerful ring activating group. As a result aromtic amines readily undergo electrophilic substitution reactions.

a. Bromination : Aniline reacts with bromine water at room temperature to give a white precipitate of 2,4,6- tribromoaniline.

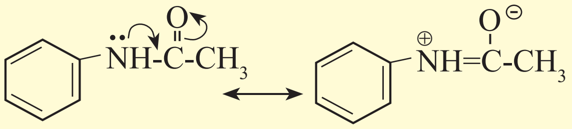


(Aniline)

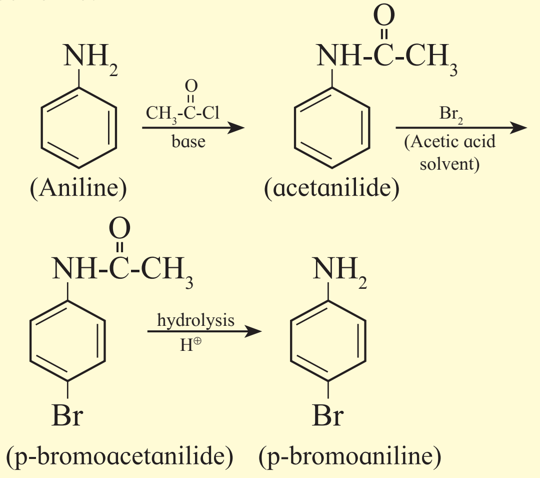
(2,4,6-tribromoaniline)

Problem 13.1 : Write the scheme for preparation of p-bromoaniline from aniline. Justify your answer.

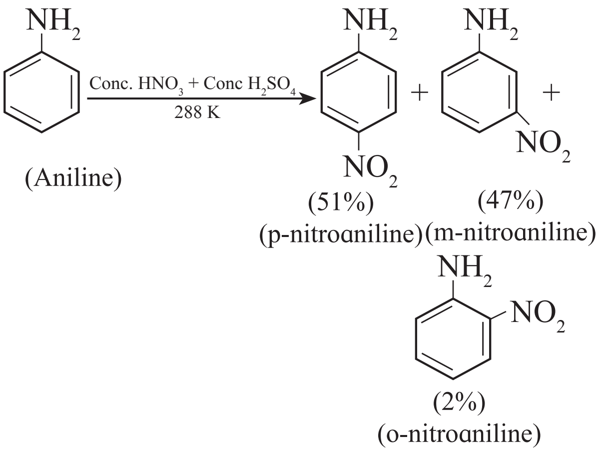
Solution : NH_2- group in aniline is highly ring activating and o-/p- directing due to involvement of the lone pair of electrons on 'N' in resonance with the ring. As a result, on reaction with Br_2 it gives 2,4,6-tribromoniline. To get a monobromo product, it is necessary to decrease the ring activating effect of $-NH_2$ group. This is done by acetylation of aniline. The lone pair of 'N' in acetanilide is also involved in resonance in the acetyl group. To that extent ring activation decreases.



Hence, acetanilide on bromination gives a monobromo product p-bromoacetanilide. After monobromination the original $-NH_2$ group is regenerated. The protection of $-NH_2$ group in the form of acetyl group is removed by acid catalyzed hydrolysis to get p-bromoaniline, as shown in the following scheme.



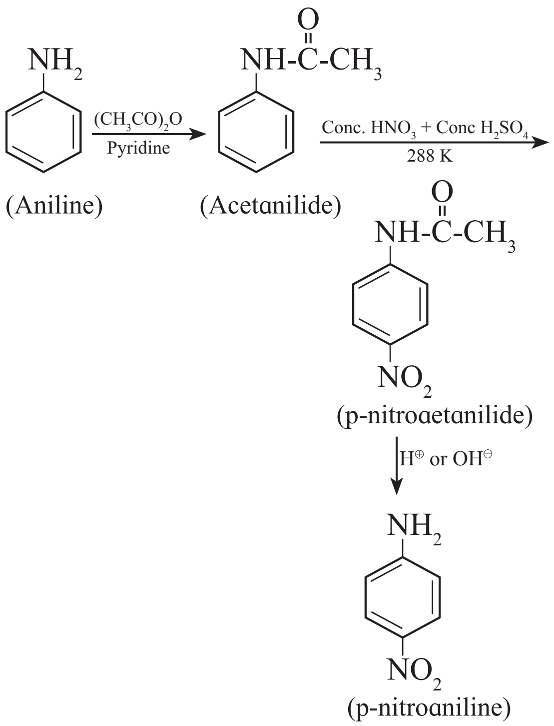
b. Nitration : Direct nitration of aniline yeilds a mixture of ortho, meta and para nitroanilines. In acidic medium $-NH_2$ group is protonated to $-\overset{\oplus}{N}H_3$ group which is meta-directing and deactivating. Hence considerable amount of m-nitroaniline is obtained.



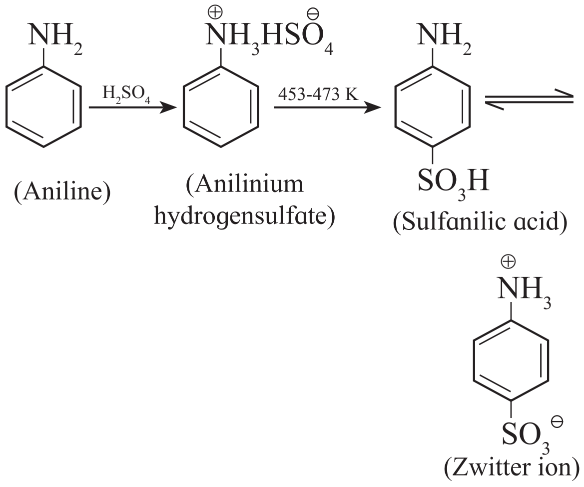
Internet my friend

Search the pK_a or pK_b values of ortho, meta and para nitroaniline on internet and arrange them in increasing order of their basic strength.

However, to get p-nitroaniline as major product, $-NH_2$ group is first protected by acetylation, nitration is carried out and then amide is hydrolysed.



c. Sulfonation : Aniline reacts with concerntrated sulfuric acid to form anilinium hydrogen sulfate which on heating with sulfuric acid at 453-473K produces p-aminobenzene sulfonic acid (sulfanilic acid) as major product.



Sulfanilic acid exists as a salt; called **dipolar ion or zwitter ion**. It is produced by the reaction between an acidic group and a basic group present in the same molecule.

Use your brain power

- Can aniline react with a Lewis acid ?
- Why aniline does not undergo Friedel Craft's reaction using aluminium chloride ?

Exercises

1. Choose the most correct option.

i. The hybridisation of nitrogen in primary amine is ....

a. sp   b. sp^2 c. sp^3 d. sp^3d

ii. Isobutylamine is an example of ....

a. 2° amine   b. 3° amine

c. 1° amine

d. quaternary ammonium salt.

iii. Which one of the following compounds has the highest boiling point ?

a. n-Butylamine   b. sec-Butylamine

c. isobutylamine   d. tert-Butylamine

iv. Which of the following has the highest basic strength ?

a. Trimethylamine   b. Methylamine

c. Ammonia   d. Dimethylamine

v. Which type of amine does produce N_2 when treated with HNO_2 ?

a. Primary amine   b. Secondary amine

c. Tertiary amine

d. Both primary and secondary amines

vi. Carbylamine test is given by

a. Primary amine

b. Secondary amine

c. Tertiary amine

d. Both secondary and tertiary amines

vii. Which one of the following compounds does not react with acetyl chloride ?

a. $CH_3\text{-}CH_2\text{-}NH_2$ b. $(CH_3\text{-}CH_2)_2NH$

c. $(CH_3\text{-}CH_2)_3N$ d. $C_6H_5\text{-}NH_2$

viii. Which of the following compounds will dissolve in aqueous NaOH after undergoing reaction with Hinsberg reagent ?

a. Ethylamine   b. Triethylamine

c. Trimethylamine   d. Diethylamine

ix. Identify 'B' in the following reactions

$CH_3\text{-}C\equiv N \xrightarrow{Na/C_2H_5OH} A \xrightarrow{NaNO_2/dilHCl} B$

a. $CH_3\text{-}CH_2\text{-}NH_2$ b. $CH_3\text{-}CH_2\text{-}NO_2$

c. $CH_3\text{-}CH_2N_2^{\oplus}Cl^{\ominus}$ d. $CH_3\text{-}CH_2\text{-}OH$

x. Which one of the following compounds contains azo linkage ?

a. Hydrazine

b. p-Hydroxyazobenzene

c. N-Nitrosodiethylamine

d. Ethylenediamine

2. Answer in one sentence.

i. Write reaction of p-toluenesulfonyl chloride with diethylamine.

ii. How many moles of methylbromide are required to convert ethanamine to N, N-dimethyl ethanamine ?

iii. Which amide does produce ethanamine by Hofmann bromamide degradation reaction?

iv. Write the order of basicity of aliphatic alkylamine in gaseous phase.

v. Why are primary aliphatic amines stronger bases than ammonia ?

vi. Predict the product of the following reaction.

Nitrobenzene $\xrightarrow{\text{Sn/Conc. HCl}}$?

vii. Write the IUPAC name of benzylamine.

viii. Arrange the following amines in an increasing order of boiling points.

n-propylamine, ethylmethyl amine, trimethylamine.

ix. Write the balanced chemical equations for the action of dil H_2SO_4 on diethylamine.

x. Arrange the following amines in the increasing order of their pK_b values.

Aniline, Cyclohexylamine, 4-Nitroaniline

3. Answer the following

i. Identify A and B in the following reactions.

$C_6H_5CH_2Br \xrightarrow[\text{KCN}]{\text{alco.}} A \xrightarrow{\text{Na/ethanol}} B.$

ii. Explain the basic nature of amines with suitable example.

iii. What is diazotisation ? Write diazotisation reaction of aniline.

iv. Write reaction to convert acetic acid into methylamine.

v. Write a short note on coupling reactions.

vi. Explain Gabriel phthalimide synthesis.

vii. Explain carbylamine reaction with suitable examples.

viii. Write reaction to convert (i) methanamine into ethanamine (ii) Aniline into p-bromoaniline.

ix. Complete the following reactions :

a. $C_6H_5N_2^{\oplus}Cl^{\ominus} + C_2H_5OH \longrightarrow$

b. $C_6H_5NH_2 + Br_2(aq) \longrightarrow$?

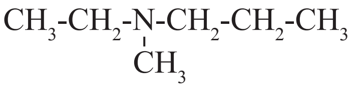
x. Explain Ammonolysis of alkyl halides.

xi. Write reaction to convert ethylamine into methylamine.

4. Answer the following.

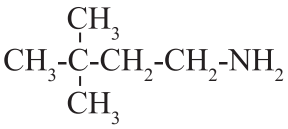
i. Write the IUPAC names of the following amines :

a.



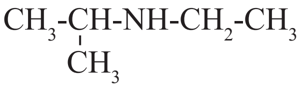
$CH_3\text{-}CH_2\text{-}N(CH_3)\text{-}CH_2\text{-}CH_2\text{-}CH_3$

b.



$CH_3\text{-}C(CH_3)_2\text{-}CH_2\text{-}CH_2\text{-}NH_2$

c.



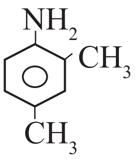
$CH_3\text{-}CH(CH_3)\text{-}NH\text{-}CH_2\text{-}CH_3$

ii. What are amines ? How are they classified ?

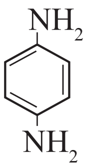
iii. Write IUPAC names of the following amines.

a. $H_2N\text{-}(CH_2)_6\text{-}NH_2$

b.



c.



iv. Write reactions to prepare ethanamine from

a. Acetonitrile

b. Nitroethane

c. Propionamide

v. What is the action of acetic anhydride on ethylamine, diethylamine and triethylamine ?

vii. Distinguish between ethylamine, diethylamine and triethylamine by using Hinsberg's reagent ?

viii. Write reactions to bring about the following conversions :

a. Aniline into p-nitroaniline

b. Aniline into sulphanilic acid ?

Activity :

- **Prepare a chart of azodyes, colours and its application.**
- **Prepare a list of names and structures of N-containing ingredients of diet.**