

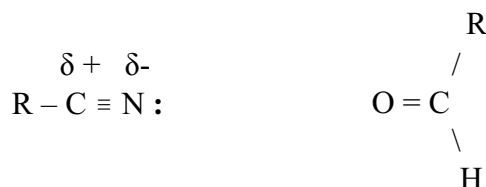
Organic Nitrogen Compounds

Three types of nitrogen compounds:

Nitriles (formerly called cyanides)	$-C \equiv N$
Nitro	$-C - NO_2$
Amino	$-C - NH_2$

The nitrogen compounds are very reactive and are therefore useful as intermediates in synthesis.

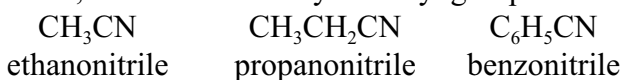
Nitriles



Nitriles are similar to carbonyl compounds in having π bonds with the carbon. The $-C \equiv N$ group is formed by a σ bond and two π bonds, the $R - C \equiv N$ is linear and polar. The nitrogen atom has a lone pair.

Nomenclature

General Formula: $R - C \equiv N$, where R is an alkyl or aryl group

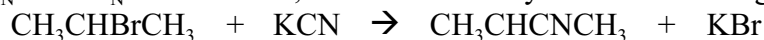


The $-C \equiv N$ group is named using the suffix - nitrile when it is the principal group and the prefix cyano - when it is not. When the suffix - nitrile is used, the carbon of the functional group is counted as part of the root, see above.

Preparation of Nitriles

- From a halogenoalkane: $RX + KCN$ in the presence of a polar solvent
ex. Meths, acetone, ethanol (halogenoalkanes don't dissolve in water).

Recall: S_N1 and S_N2 mechanism, order of reactivity of different halogens is $I > Br > Cl$:

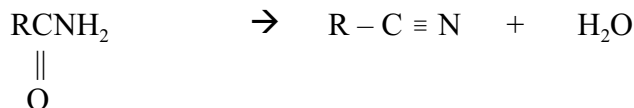


This is a general method for any alkyl nitrile, it does not work for arene compounds, because the halogenoarenes are not so reactive, (why?).

- By Dehydration of a Carbon - Nitrogen compound

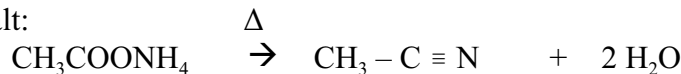
Dehydrating agent usually used is diphosphorus pentoxide, P_2O_5

i) From an amide:



example: butanamide $\xrightarrow{\quad}$ butanonitrile

ii) an ammonium salt:



Physical Properties $-C^{\delta+} \equiv N^{\delta-}$

These are very similar to halogenoalkane. Generally colourless liquids with a pleasant sweetish odour, having higher boiling and melting points because the nitrile molecules are polar, having a permanent dipole.

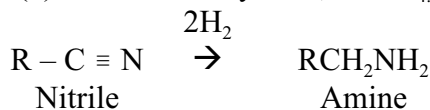
The solubility in water depends on the molar mass, lower members are soluble except nitriles are much more poisonous.

Chemical Properties

Nitriles are unsaturated which means that addition reactions are possible. They are used as intermediates.

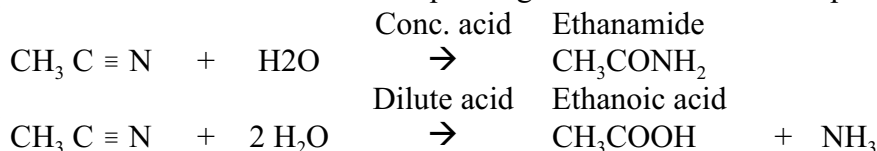
1. Reduction (addition of hydrogen)

Reducing agents are: (a) LiAlH_4 in dry ether, (b) sodium and ethanol, (c) hydrogen in the presence of nickel catalyst (d) sodium borohydride, NaBH_4 .



2. Hydrolysis (breaking up in the presence of water)

Mineral acids or aqueous alkalis hydrolyse nitriles when boiled together under reflux. The products are either an amide or an acid depending on how much water is present...

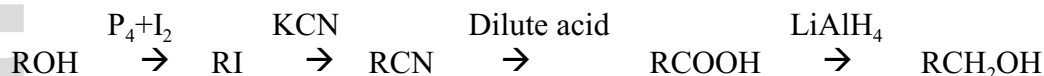


3. Industrially propenenitrile, $\text{H}_2\text{C} = \text{CH} - \text{C} \equiv \text{N}$, (commonly called acrylonitrile, and is the origin of the name of the polymer 'acrylic', known also by its trade name: Orlon, Courtelle and Acrilan), is polymerised to poly(propenenitrile)

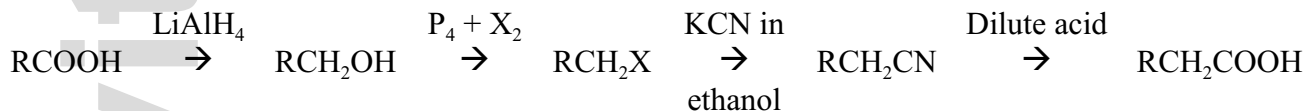
Lengthening a Carbon Chain

An additional CH_2 group can be added to a molecule by making use of a nitrile. In this way a compound can be converted to its next higher homologue.

The series of reactions for ROH to RCH_2OH is:



The series for converting RCOOH to RCH_2COOH is:



Examples:

- i) $\text{CH}_3\text{OH} \rightarrow \text{CH}_3\text{COOH}$
- ii) $\text{C}_3\text{H}_7\text{OH} \rightarrow \text{C}_3\text{H}_7\text{CH}_2\text{OH}$
- iii) $\text{CH}_3\text{COOH} \rightarrow \text{CH}_3\text{CH}_2\text{COOH}$

Note the sequence of reversible reactions...



Try these:

- 1) $\text{C}_2\text{H}_2 \rightarrow \text{CH}_3\text{COOH}$
- 2) $\text{C}_2\text{H}_5\text{Br} \rightarrow \text{C}_2\text{H}_5\text{COOH}$

Nitro Compounds

Structure of nitro compounds involves:

- (i) a C – N bond and
- (ii) delocalisation of π -bond

The nitrogen atom is directly attached to the carbon atom of the alkyl group.

Nomenclature

CH_3NO_2
Nitromethane

$\text{CH}_3\text{CHNO}_2\text{CH}_3$
2-nitropropane

$\text{C}_6\text{H}_5\text{NO}_2$
nitrobenzene

Preparation

1. Vapour phase nitration of alkanes

A good yield of nitroalkane can be obtained by heating the alkane with $\text{HNO}_3(\text{g})$ at $\sim 400^\circ\text{C}$. This process is used commercially.

2. Nitrobenzene can be obtained by refluxing C_6H_6 with a nitrating mixture, (concentrated HNO_3 and H_2SO_4)

Mechanism – electrophilic substitution:

Why is concentrated H_2SO_4 necessary?

What temperature condition is necessary to obtain the mono substituted product?

What disubstituted product is obtained? Why?

Why is toluene nitrated more readily? What product is obtained?

Why does the nitration of phenol also take place readily? What product is obtained?

Which is more acidic: phenol, 2-nitro- / 4-nitro- phenol, or 2,4,6-trinitrophenol? Explain.

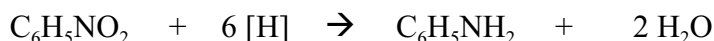
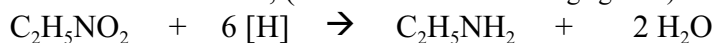
Physical Properties

These are like those of nitriles. The nitro compounds have high melting and boiling points since they have a strongly polar character. They're sparingly soluble in water. Nitro-compounds are unstable, decompose releasing large amounts of heat, e.g. trinitrotoluene.

Chemical Properties

The link between the nitrogen atom and the benzene nucleus is very stable because of the delocalisation of the lone pairs of electrons of the N atom into the C_6H_6 ring $\therefore \text{C}_6\text{H}_5\text{NO}_2$ is very stable. However the N atom is strongly electron withdrawing \therefore the nitro group deactivates the benzene ring, so that normal reactions of the C_6H_6 nucleus occur (but very slowly), resulting further substitution in the _____ position.

All nitro compounds can be reduced, (what is a suitable reducing agents?) to amines:



If there are two nitro groups, then it is possible to reduce one of them by controlling the amount of the reducing agent...

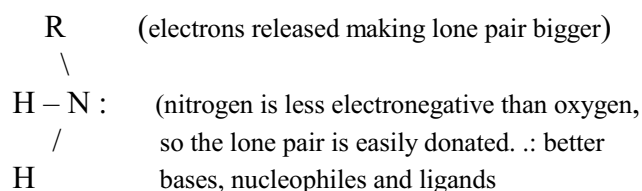


Chemistry of Amines and Amino Acids

Amines are compounds in which one or more of the hydrogens in ammonia are replaced by alkyl or aryl groups. It is therefore not surprising that they react in similar ways to ammonia. Amines are a distinct class of compounds whose main characteristic is the basicity of the lone electron pair on nitrogen. Amines are useful as basic reagents in a variety of reactions. The most notable occurrences of amines is as structural components of amino acids.

It is most helpful to think of these compounds in relation to those they resemble. Amines are like ammonia. The reactive site is the lone pair of electrons, which can:

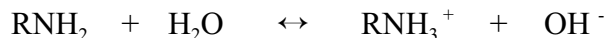
- i. attack slightly positive hydrogen atoms \therefore acting as a base,
- ii bond with an electron-deficient carbon atom \therefore acting as a nucleophile,
- ii bond with a transition metal cation \therefore acting as a ligand (Ligands are compounds that form dative covalent bonds with transition metal ions, e.g. ethane-1,2-diamine, commonly called ethylene diamine, often encountered as a bidentate ligand.)



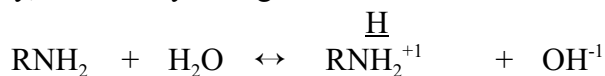
Ammonia is pyramidal with bond angles of approximately 107° . This is because the lone pair of electrons repels than do the bonding pairs of electrons in the N — H bonds.

Amines retain this basic pyramidal shape.

The amine will ionize in water as:



to give its conjugate acid, the alkylammonium ion (RNH_3^+), thus acting as a Bronsted base. Alternatively, a base may be regarded as an electron donor (Lewis base):



The strength of a base in aqueous solution may be measured by the equilibrium constant for the ionization reaction:



Which may be conveniently expressed on a logarithmic scale by means of $\text{p}K_b$ value such that: $\text{p}K_b = -\log_{10} K_b$ where K_b is the ionizing constant of the base.

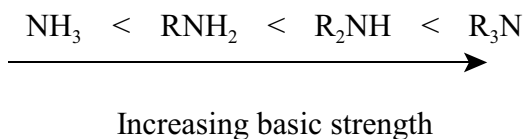
Stronger bases will then have smaller $\text{p}K_b$ values and vice-versa

Note: It is often convenient to express the strength of a base in terms of the $\text{p}K_a$ value of its conjugate acid, which refers to ionization by proton loss. Stronger bases have higher $\text{p}K_a$ values, (high $\text{p}K_a$, \therefore weak acid but strong conjugate base):

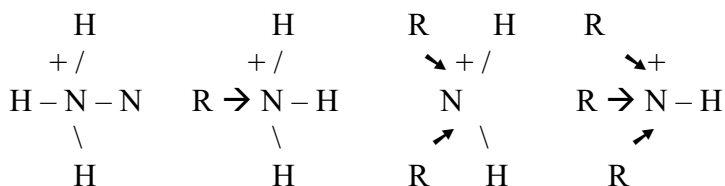
Ammonia	$\text{p}K_a = 9.25$
Methylamine	$\text{p}K_a = 10.64$
Dimethylamine	$\text{p}K_a = 10.72$
Diethylamine	$\text{p}K_a = 10.93$
aniline	$\text{p}K_a = 4.62$

Example:

The basic strength would be expected to increase in the series:



The alkyl joined to the nitrogen releases electrons towards the nitrogen better than a hydrogen atom does. This allows the lone pair on the nitrogen to be more prominent than it is on ammonia. Also the positive inductive effect allows the stabilization of the positive charge on the substituted ammonium cation (cf. carbocation). So amines tend to be stronger bases and better nucleophiles than ammonia.



A secondary amine is the most basic. The electron releasing alkyl groups suggest that the more groups on nitrogen the more basic it will be ($3^\circ > 2^\circ > 1^\circ$) but there is a steric effect of the alkyl groups around the nitrogen. With a tertiary amine, the alkyl groups inhibit approach of the nitrogen to the acid, decreasing the basicity.

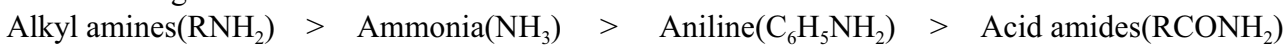
Another important factor is the presence of the N-H groups in the ammonium salt, $\text{R}_2\text{N}^+\text{H}_2\text{X}^-$, these N-H groups are capable of hydrogen bonding with the solvent, $\text{N} \cdots \text{H} \cdots \text{OH}_2$, further stabilizing the product. With secondary amines the electronic effects, solvent effects and steric effects are balanced to make secondary amines most basic. The usual basicity order is $2^\circ > 1^\circ \approx 3^\circ$

Quaternary ammonium compounds such as $(\text{CH}_3)_4\text{N}^+ \text{OH}^-$ are completely ionized in aqueous solution and comparable to potassium hydroxide in basic strength. Aliphatic primary amines are stronger bases than ammonia, an ethyl group having a slightly greater effect than a methyl group. The introduction of a secondary alkyl group produces a further increase in basic strength, but the effect is much less marked than with the first.

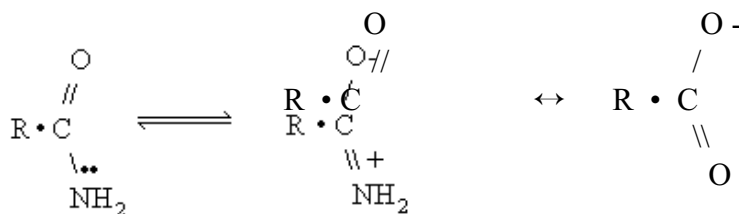
Aniline is a much weaker base than ammonia as it is stabilized by resonance in the unionized form. The lone pair of electrons of the nitrogen atom interacts with the π -electrons of the benzene ring and thus participates in the delocalisation; \therefore nitrogen is electron deficient and will not readily donate the electron pair to a proton, H^+ , thus aniline becomes a weaker base. This effect is increased when two phenyl groups are attached to the nitrogen atom in diphenylamine ($\text{pK}_a=0.8$) and triphenylamine is not basic at all.

The NH_2 group on the benzene ring strongly activates that ring to electrophilic aromatic substitution. So strong is the activation that Br_2 reacts, without a catalyst, to give not only the monosubstitution product but the tribromo derivatives (2,4,6-tribromoaniline)

Basic strength:



Amides are much weaker bases than amines and the almost complete loss of the basic character of the nitrogen atom may be attributed to the delocalisation of the unshared pair of electrons of the nitrogen atom:



Nomenclature

Amines may be regarded as derivatives of ammonia, in which 1,2 or 3 of the hydrogen atoms have been replaced by alkyl or aryl groups. The functional groups present are $-\text{NH}_2$ in primary amines, $=\text{NH}$ in secondary amines, and $\equiv\text{N}$ in tertiary amines. Amines can be named as with an alkylamine or as an alkanamine. Ex:

Primary amine (1 ^o)	Secondary amine (2 ^o)	Tertiary amine (3 ^o)
$\text{R}-\text{NH}_2$	R_2NH	R_3N
CH_3NH_2	$(\text{CH}_3)_2\text{NH}$	$(\text{CH}_3)_3\text{N}$
methylamine or aminomethane	Dimethylamine	Trimethylamine

When there are two or more substituents they are written in alphabetical order.

A fourth class of compounds may be regarded as tetra-alkyl or tetra-aryl derivatives of ammonium salts in aqueous ammonia. Their general formulae are NR_4^+X^- & NR_4^+OH^-

Arylamines are generally named as the parent aromatic amine. Aniline, (often called phenylamine and sometimes as aminobenzene), 2-bromoaniline and 3-nitroaniline are typical examples. If a methyl group is also attached to the benzene ring, the common name is ortho-toluidine, meta-toluidine and para-toluidine.

$(\text{C}_6\text{H}_5)(\text{CH}_3)-\text{NH}$ is called N-methylphenylamine (the substituents are listed in alphabetical order), the N- indicates that the methyl group is bonded to the nitrogen, rather than to the benzene ring.

Physical Properties

Very similar to the equivalent sort of halogen compound as far as volatility and melting point are concerned, both for alkyl and aryl amines. Short chain alkyl amines are readily soluble in water. Primary and secondary amines can hydrogen bond to one another. However, as nitrogen is less electronegative than oxygen, the $\text{N} \cdots \text{H} \cdots \text{N}$ bonds are weaker than $\text{O} \cdots \text{H} \cdots \text{O}$ bonds in alcohols, the solutions formed are basic. Phenylamine is sparingly soluble in water due to the benzene ring, which can not form hydrogen bonds. Methylamine is a gas at room temperature and ethylamine is a volatile liquid. Aliphatic amines have a pungent, fishy smell similar to that of ammonia; rotting fish and animal flesh smell of di- and triamines produced by the decomposition of proteins.

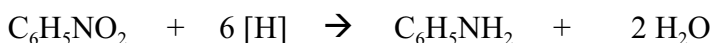
Preparation

1. Reaction of ammonia (NH₃) to halogenoalkane

Applies to alkanes only (because the halogen in C₆H₅X is held too firmly), treat RX + NH₃ in a polar solvent such as alcohol. Works well except poor yield of primary amine is obtained, in practice some secondary and tertiary amines also obtained. (Recall: S_N1 or S_N2)

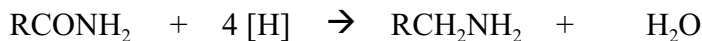
2. Reduction of nitro compounds

Nitroalkanes and nitroarenes are reduced by hydrogen in the presence of nickel or Sn(or Fe) + HCl



3. Reduction of a nitrile or an amide

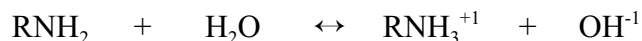
Reduce a nitrile with Na + C₂H₅OH or H₂ in the presence of Ni or LiAlH₄ in ether.



This method works well for alkanes, but not for arenes.

Chemical Reactions

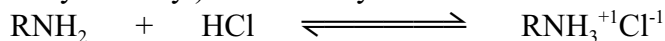
1. Reaction with water:



Many amines will form basic solutions (pH > 7, turn litmus red → blue), in the same way as NaOH or KOH. There is no equivalent reaction for aromatic amines, since aniline is insoluble in water, however it is soluble in excess hydrochloric acid to form an ionic compound: C₆H₅NH₃⁺¹Cl⁻¹: phenylammonium chloride.

2. Reaction with acids:

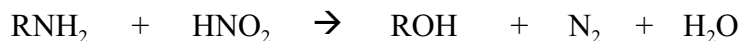
Amines (both alkyl and aryl) react readily with mineral acids to form white crystalline solids:



This reaction can be reversed by the addition of alkalis to regenerate the amine

3. Reaction with Nitrous acid (Nitric (III) acid), HNO₂:

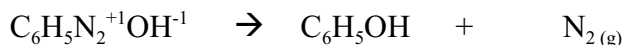
The acid, HNO₂, a blue solution itself is so unstable that it cannot be used. It is produced from its sodium salt and a mineral acid (NaNO₂ + HCl → HNO₂ + NaCl). Primary amines form N_{2(g)} and an alcohol:



With arylamines, the intermediate compound, benzenediazonium hydroxide (a dye), (FYI: a diazonium ion is the $R-N^{+1} \equiv N$, called an alkyl or an aryl diazonium ion), is more stable and this is produced:

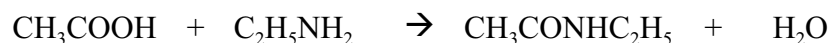


Nitrogen and a hydroxyl compound are formed by hydrolysis when the diazonium salt is warmed (similar to that of alkylarenes):



4. Reaction with a carboxylic acid:

Primary amines produce an amide (a peptide linkage, $-C O - N H$):



Reactions of Aniline

Aryl groups withdraw electrons from the nitrogen atom by overlap of the lone pair electrons with the delocalised π -system on the benzene ring, so aryl amines are weaker bases than ammonia.

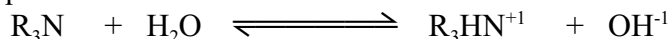
The substituents $-NH_2$, $-NHR$, and $-NR_2$ release electrons onto the aromatic ring and so make it more reactive towards electrophilic substitution. The 2- and 4- positions are most activated.

Assignment

- 1.(a) Explain why propylamine is classed as a Bronsted-Lowry base.
- (b) Explain why propylamine is a stronger base than ammonia.
- (c) Propylamine is obtained from the reaction between 1-bromopropane and an excess of ammonia. Name the type of reaction taking place and outline a mechanism.
- (d) Propylamine can also be prepared from propanenitrile, CH_3CH_2CN . Name the type of reaction involved and write an equation for the reaction. What advantage does this method have over that in part (c)?

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- (a) The basic strength of nitrogen containing compounds can be considered in terms of the following equilibrium:



Explain how the equilibrium constant is related to the basic strength and what feature of R_3NH^{+1} leads to a high basic strength. 2

- (b) The following are a series of pK_b values:

NH_3	CH_3NH_2	$(CH_3)_2NH$	CH_3CONH_2
4.75	3.36	3.28	14.5

State and explain the basic strength of the three organic compounds relative to ammonia. 6

- (c) Explain the very large difference between the pK_b values of phenylamine (aniline) ($pK_b = 9.4$) and that of cyclohexylamine ($pK_b = 3.4$) 2

3.

Compound **A**, C_2H_7N , a primary amine, is obtained by treatment of an iodoalkane, **B** with ammonia. Reaction of **B** with aqueous sodium hydroxide yields compound **C**, C_2H_6O . **C** is reacted with acidified potassium dichromate to yield **D**, $C_2H_4O_2$. **D** reacts with PCl_5 evolving $HCl(g)$, and to yield **E**, C_2H_3OCl

- (a) Deduce structures for compounds **A** to **E**, giving your reasoning and accounting for all the reactions involved. 10
- (b) (i) Name the type of reaction which occurs when the iodoalkane, **B**, reacts with aqueous sodium hydroxide. 1
(ii) In this reaction, what is the reactive species provided by aqueous sodium hydroxide? 1
(iii) To which mechanistic class does this reactive species belong electrophile, nucleophile, free radical or oxidant? 1
- (c) (i) What type of reaction is occurring when **C** is changed into **D**? 1
(ii) Explain what is the role of potassium dichromate. 2
- (d) Substance **E** reacts vigorously with water to form an acidic solution.
(i) Give the name of the substance **E**.
(ii) Write a balanced equation for the reaction of **E** with water. 2

1

4.

- (a) Phenylamine can be obtained from benzene by a two-stage process.
(i) Give equations for the reactions involved, and state the conditions required.
(ii) Say how phenylamine is isolated from the reaction mixture.
- (b) Give an example of a reaction which shows phenylamine acting as
(i) a Bronsted-Lowry base
(ii) a Lewis base
- (c) Give the name and structural formulae of the organic product formed when phenylamine reacts with aqueous bromine.

5.

- (a) Explain why phenylamine is a weaker base than (phenylmethyl)amine, $C_6H_5CH_2NH_2$
- (b) Write an equation for the formation of (phenylmethyl)amine from benzenecarbonitrile, C_6H_5CN , and name the type of reaction involved. 2
- (c) (Phenylmethyl)amine can also be obtained from the reaction between (bromomethyl)benzene, $C_6H_5CH_2Br$, and ammonia. Name the type of reaction involved and explain why this method of synthesis is not effective as that in part (b). 3

6. (a) Explain the very large difference between the pK_b values of phenylamine, (9.4) and that of cyclohexylamine, (3.4).
(b) Which is expected to have a higher boiling point: a 1^o or a 3^o amine. Justify your choice.
(c) Which is a stronger nucleophile: CH_3NH_2 or $(CH_3)_2NH$. Rationalize your choice.