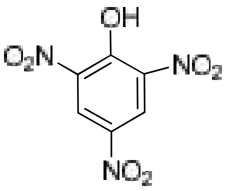
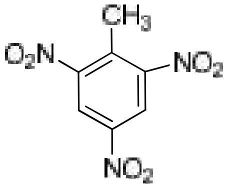
NITRO COMPOUNDS

Nitro compounds are an important class of organic compounds that are recognized by the presence of one of more nitro functional groups (NO_2) bonded directly to the carbon of the hydrocarbon chain or aromatic ring. Nitro compounds are usually prepared by different synthetic techniques but a few of them are naturally occurring.

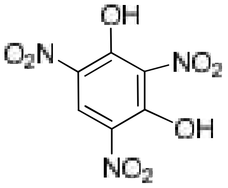
Nitro compounds are explosive in nature, especially when they contain more than one nitro group. It is because of this reason nitro group has often been classified as explosophore group (a group that makes explosives). The explosive nature of this group is due to the fact that on thermal decomposition they yield molecular nitrogen plus considerable amount of energy is also released. Some of the most common explosive compounds are trinitrophenol (picric acid), trinitrotoluene (TNT) and trinitroresorcinol (styphnic acid).



picric acid
(trinitrophenol)



2-methyl-1,3,5-trinitrobenzene
(trinitrotoluene)

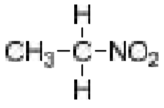


2,4,6-trinitrobenzene-1,3-diol
(styphnic acid)

Nitro compounds are considered to be derivatives of hydrocarbons in which one or more hydrogen atoms are substituted by nitro group. They are further classified as aliphatic or aromatic nitro compounds, depending upon whether the nitro group is bonded to an alkyl or aryl group. Aliphatic nitro compounds also called as nitroparaffins are colourless liquids, used chiefly as industrial solvents eg nitromethane, nitroethane and nitropropane.

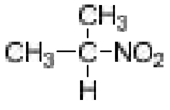
Aliphatic nitro compound	$R-NO_2$	CH_3-NO_2	$C_2H_5-NO_2$	$C_3H_7-NO_2$
		nitromethane	nitroethane	1-nitropropane

They are further classified as primary, secondary or tertiary depending upon whether the nitro group is bonded to primary, secondary or tertiary carbon atom.



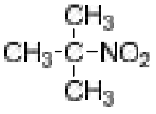
$$CH_3-\underset{H}{\overset{H}{C}}-NO_2$$

nitroethane
(primary nitroalkane)



$$CH_3-\underset{H}{\overset{CH_3}{C}}-NO_2$$

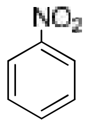
2-nitropropane
(secondary nitroalkane)



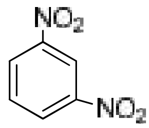
$$CH_3-\underset{CH_3}{\overset{CH_3}{C}}-NO_2$$

2-methyl-2-nitropropane
(tertiary nitroalkane)

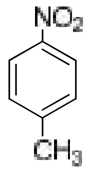
In aromatic nitro compound also called nitroarenes, one or or more hydrogen of the benzene ring are substituted by nitro group. Some of the important aromatic nitro compounds are nitrobenzene, m-dinitrobenzene, p-nitrotoluene,



1-nitrobenzene



1,3-dinitrobenzene
(m-dinitrobenzene)



1-methyl-4-nitrobenzene
(p-nitrotoluene)

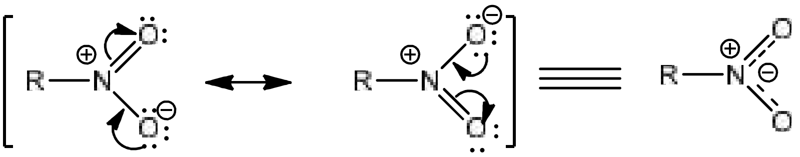
Nitro compounds are well differentiated from their isomeric nitrous ester, commonly called alkyl nitrites, in which the carbon is not directly bonded to the nitrogen but to the oxygen

$$R-CH_2-O-N=O$$

alkyl nitrite

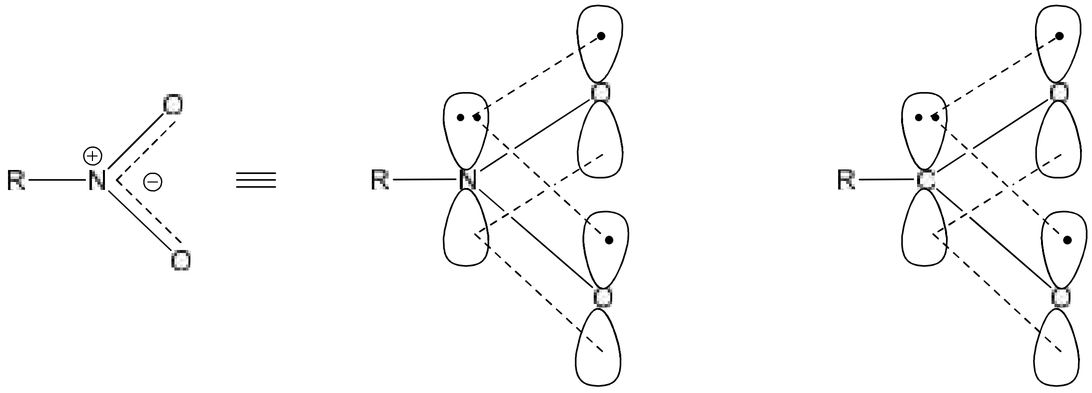
Structure of Nitro group

Nitro group is considered to be a resonance hybrid (III) of two equivalent canonical structures I and II



I II III

The sigma bond skeleton of nitro group involves the use of three sp^2 hybrid orbital on nitrogen, forming three sigma bonds-one with the carbon of the alkyl group and two with the oxygen atoms. But nitrogen still has one unhybridized *p* orbital with an unshared electron pair and each oxygen atom also have one half filled p orbital. These three orbtials overlap sideways producing a delocalized π molecular orbital, which encompasses all the three atoms.



nitroalkane

carboxylate anion

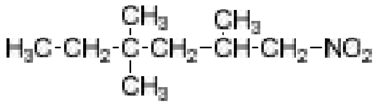
This hybrid structure is supported by the fact that the two N-O bond lengths are same-121pm, which is less than the N-O single bond (136 pm) but more than the N-O double bond (115pm). Thus this structure of nitroalkanes is isoelectronic with the carboxylate anion structure.

Nomenclature

According to the IUPAC nomenclature nitro compounds are named by adding the permanent prefix ‘nitro’ to the name of the parent hydride. The position of any substitutent if present is however indicated by the Arabic numbers 1,2,3.......etc with the carbon bearing the nitro group gets the lowest priority number.

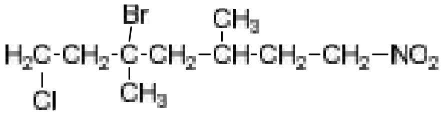
$H_3C\text{-}CH_2\text{-}NO_2$

nitroethane



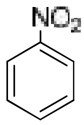
$H_3C\text{-}CH_2\text{-}\underset{CH_3}{\overset{CH_3}{C}}\text{-}CH_2\text{-}\overset{CH_3}{CH}\text{-}CH_2\text{-}NO_2$

2,4,4-trimethyl-1-nitrohexane

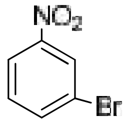


$H_2\underset{Cl}{C}\text{-}CH_2\text{-}\underset{CH_3}{\overset{Br}{C}}\text{-}CH_2\text{-}\overset{CH_3}{CH}\text{-}CH_2\text{-}CH_2\text{-}NO_2$

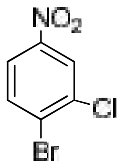
5-bromo-7-chloro-3,5-dimethyl-1-nitroheptane



1-nitrobenzene



1-bromo-3-nitrobenzene



1-bromo-2-chloro-4-nitrobenzene

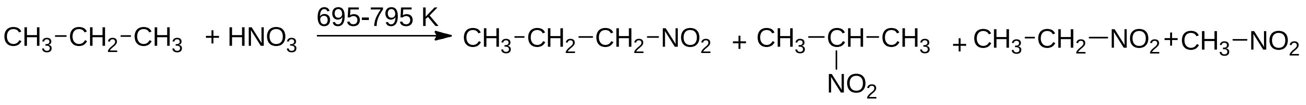
Methods of Preparations

(a) Preparation of nitroalkanes

(i) From saturated hydrocarbons: Alkanes react with nitric acid or dinitro tetraoxide in liquid or vapour phase to form nitro derivatives. Hence the reaction is called **vapour phase nitration**

$$CH_4 + HNO_3 \xrightarrow{675\ K} \underset{\text{nitromethane}}{CH_3{-}NO_2} + H_2O$$

When higher alkanes are nitrated, mixtures of nitroalkanes including those formed by the rupture of carbon-carbon bond are also obtained.



$$CH_3\text{-}CH_2\text{-}CH_3 + HNO_3 \xrightarrow{695\text{-}795\ K} CH_3\text{-}CH_2\text{-}CH_2\text{-}NO_2 + CH_3{-}\underset{NO_2}{CH}{-}CH_3 + CH_3\text{-}CH_2{-}NO_2 + CH_3{-}NO_2$$

1-Nitro-propane 2-Nitro-propane Nitro-ethane Nitro-methane

As nitroalkanes are chiefly used as industrial solvents, as a result this method is widely used for the commercial production of nitroalkanes as the mixture of nitroalkanes formed can be separated by fractional distillation.

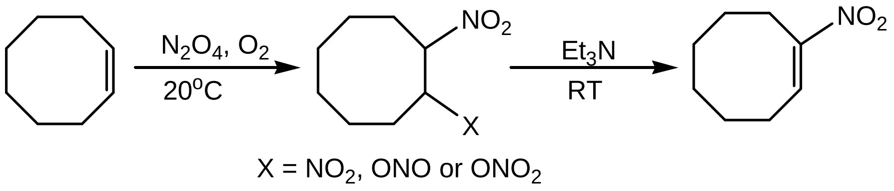
Available evidence suggests that the reaction proceeds by free radical mechanism.

$$HO{-}NO_2 \xrightarrow{\Delta} H\dot{O} + \dot{N}O_2$$

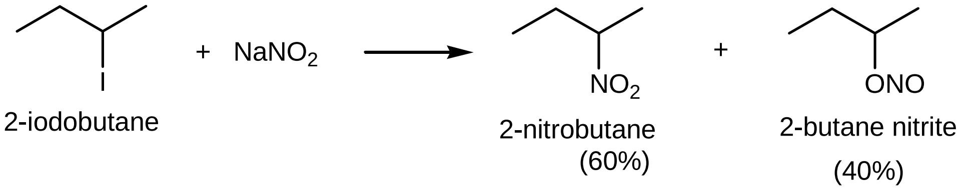
$$R{-}H + H\dot{O} \longrightarrow \dot{R} + H{-}OH$$

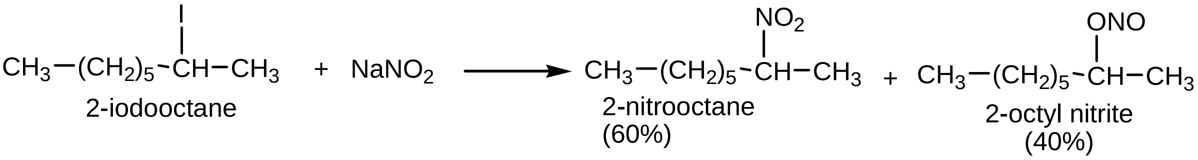
$$\dot{R} + \dot{N}O_2 \longrightarrow R{-}NO_2$$

(ii) From unsaturated hydrocarbons: Alkenes are nitrated in good yield by dinitrogen tetraoxide in the presence of oxygen to give a mixture of vic dinitro compounds. Base catalyzed elimination reaction leads to the generation of nitroalkene



(iii) From alkyl halides: Primary and secondary nitroalkanes are synthesized by heating alkyl bromides or iodides with lithium, potassium or sodium nitrite in dimethyformamide or dimethylsulphoxide.





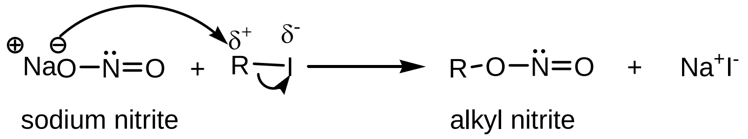
$$\underset{\text{2-iodooctane}}{CH_3-(CH_2)_5-\overset{I}{\overset{|}{C}}H-CH_3} + NaNO_2 \longrightarrow \underset{\text{2-nitrooctane (60\%)}}{CH_3-(CH_2)_5-\overset{NO_2}{\overset{|}{C}}H-CH_3} + \underset{\text{2-octyl nitrite (40\%)}}{CH_3-(CH_2)_5-\overset{ONO}{\overset{|}{C}}H-CH_3}$$

Nitrite ion (O-N=O) being an ambident nucleophile has two sites (oxygen and nitrogen) through which it can attack alkyl halide. Attack through nitrogen gives nitro compound, whereas attack through oxygen gives nitrite.

However better yield of primary nitroalkanes may be obtained if silver nitrite in place of sodium nitrite is used.

$$\underset{\text{1-iodooctane}}{CH_3-(CH_2)_6-CH_2-I} + AgNO_2 \longrightarrow \underset{\text{1-nitrooctane (85\%)}}{CH_3-(CH_2)_6-CH_2-NO_2} + \underset{\text{1-octyl nitrite (15\%)}}{CH_3-(CH_2)_6-CH_2-ONO}$$

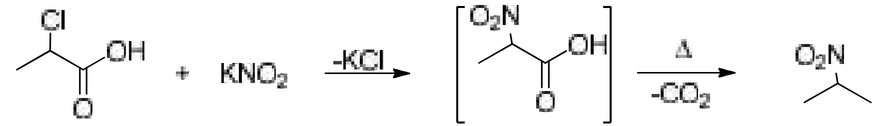
$$CH_3-CH_2-Br + AgNO_2 \longrightarrow CH_3-CH_2-NO_2 + AgBr$$



This method of preparation is not suitable for the synthesis of aromatic compounds.

(iv) From halocarboxylic acids: Lower members of the nitroalkanes and specifically nitromethane is prepared by reaction of chloroacetic acid with sodium nitrite or potassium nitrite. Nitroacetic acid, which is formed as an intermediate product decarboxylates to yield nitromethane

$$Cl{-}CH_2{-}COOH + NaNO_2 \xrightarrow{-NaCl} [NO_2{-}CH_2{-}COOH] \xrightarrow[-CO_2]{\Delta} CH_3{-}NO_2$$



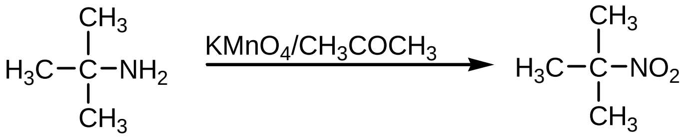
2-chloropropanoic acid

2-nitropropane

(v) From amines: Primary amines on oxidation with peracids through a series of steps yield nitro compounds

$$R{-}NH_2 \xrightarrow{[O]} \underset{\text{hydroxylamine}}{[RNHOH]} \xrightarrow{[O]} \underset{\text{nitroso compound}}{[RNO]} \xrightarrow{[O]} \underset{\text{nitro compound}}{R{-}NO_2}$$

Primary amines in which the amino group is bonded to a tertiary carbon can be oxidized with potassium permanganate in aqueous acetone to nitro compound in 70-83% yield



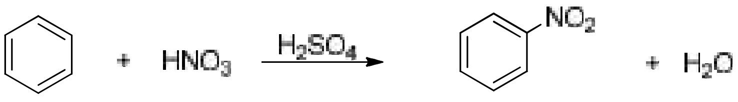
$$H_3C{-}C(CH_3)_2{-}NH_2 \xrightarrow{KMnO_4/CH_3COCH_3} H_3C{-}C(CH_3)_2{-}NO_2$$

2-methylpropan-2-amine 2-methyl-2-nitropropane

(b) Preparation of nitroarenes

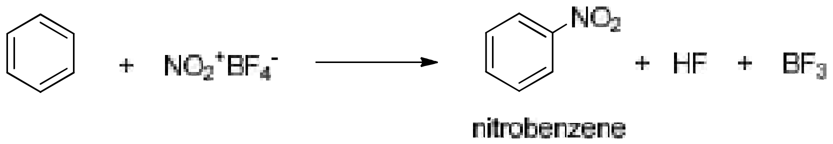
Aromatic hydrocarbons react with concentrated nitric acid directly or in the presence of strong acid catalyst namely sulphuric acid to form nitro derivatives. Since hydrogen is replaced by monovalent nitro group, this reaction is called nitration.

The selection of the nitrating agent depends upon the reactivity of substrate. The most common amongst them is a mixture of concentrated nitric acid and concentrated sulphuric acid known as nitrating mixture. Concentrated sulphuric acid is used as it accelerates the nitration process by increasing the concentration of electrophilic nitronium ion.

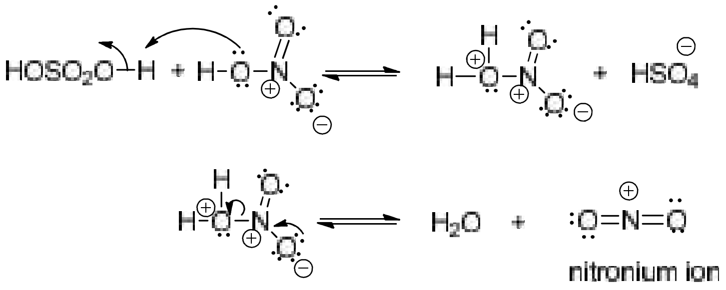


nitrobenzene

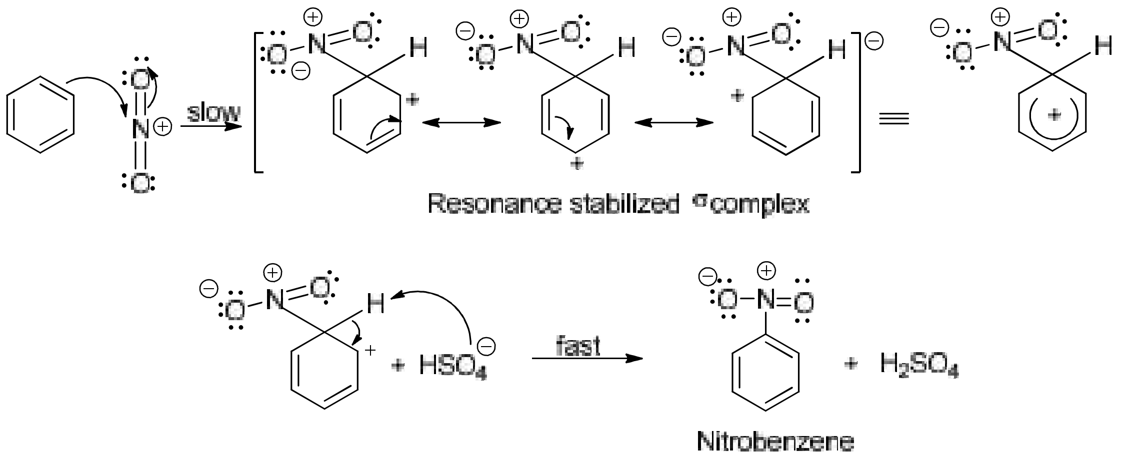
However nitration can also be carried out with potassium nitrate or by using nitric acid in the presence of acetic acid or organic solvents. Evidence for nitration taking place with the formation of nitronium cation comes from a number of sources: (a) on electrolysis of a solution of nitric acid in fuming sulphuric acid, nitric acid migrates to cathode. (b) Salts such as nitronium perchlorate ($NO_2^+ClO_4^-$) and nitronium fluoborate ($NO_2^+BF_4^-$) have been isolated. (c) Raman spectra successfully points to the presence of nitronium cations in these solutions.



Mechanism: The nitration reaction is initiated by acid catalyzed dehydration of nitric acid by concentrated sulphuric acid, to form the electrophilic nitronium ion (NO_2^+), the active species in the reaction and the one responsible for the incorporation of nitro group onto the aromatic ring.



The mechanism involves the reaction of the electrophile nitronium ion with the aromatic ring to form the intermediate sigma complex or arenium ion (I), followed by removal of a proton by the basic hydrogen sulphate ion to form the nitro derivative.



Physical properties

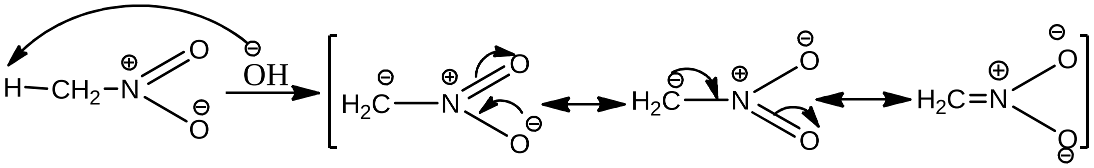
Nitroalkanes are moderately toxic, colourless liquids with pleasant agreeable odour, while their aromatic counterpart are colourless or pale yellow liquids or solids with some distinct odour, like that of bitter almonds. All nitro compounds are highly polar and they have large dipole moment (in the range of 3-4D) in comparison to other organic compounds, hence are useful solvents for some ionic reactions. Due to the polarity, nitro compounds are higher boiling in comparison to the parent hydrocarbon, of comparable molecular mass. Besides they also higher boiling in comparison to less polar isomeric alkyl nitrites.

Lower members of the nitroalkane family are sparingly soluble in water, while the higher nitroalkanes and aromatic nitro compounds are completely insoluble. However all nitro compounds-both nitroalkanes and nitroarenes are readily soluble in nearly all organic solvents.

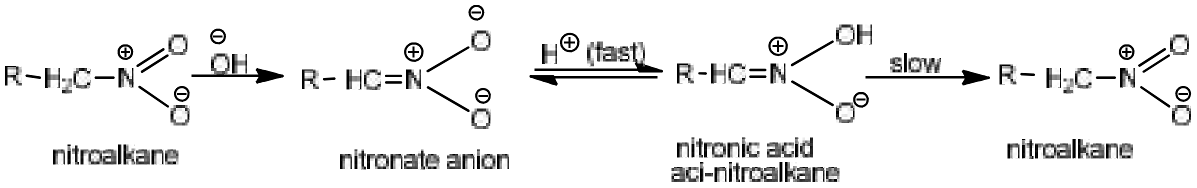
Most nitroalkanes are quite stable and their distillation can be carried out without decomposition. Nitroarenes and chiefly polynitroarenes on the other hand are unstable and they decompose with explosive violence, when heated. Hence they cannot be distilled under atmospheric pressure

Chemical properties

Acidic character: Due to the strong electron withdrawing nature of the nitro group (-I effect) the α-hydrogen bonded to the carbon atom bearing the nitro group is acidic, which can easily be abstracted by a base. The resulting anion, usually referred to as nitronate ion is stabilized by resonance.

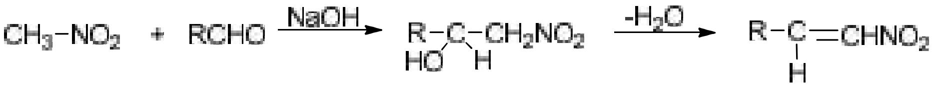


It is for this reason, primary and secondary nitroalkanes dissolves in NaOH or KOH forming salts. This alkaline solution on careful acidification with a weak acid gives isomer of primary and secondary nitroalkanes, known as **aci-nitro form,** which slowly changes to more stable nitroalkane. The slowness of the back ionization process led to the description of nitroalkanes as **pseudo-acids**. The aci-nitro compounds are more soluble in water, have higher melting point and are relatively stronger acids in comparison to the parent nitroalkane.

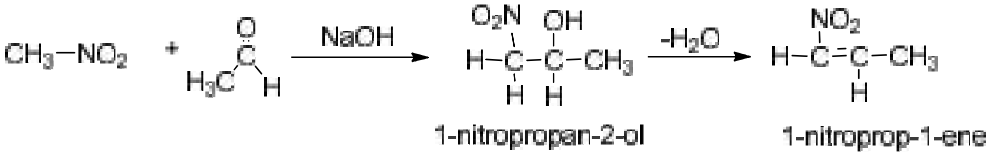


Reaction in which nitroalkanes in aci-nitro form acts as nucleophiles

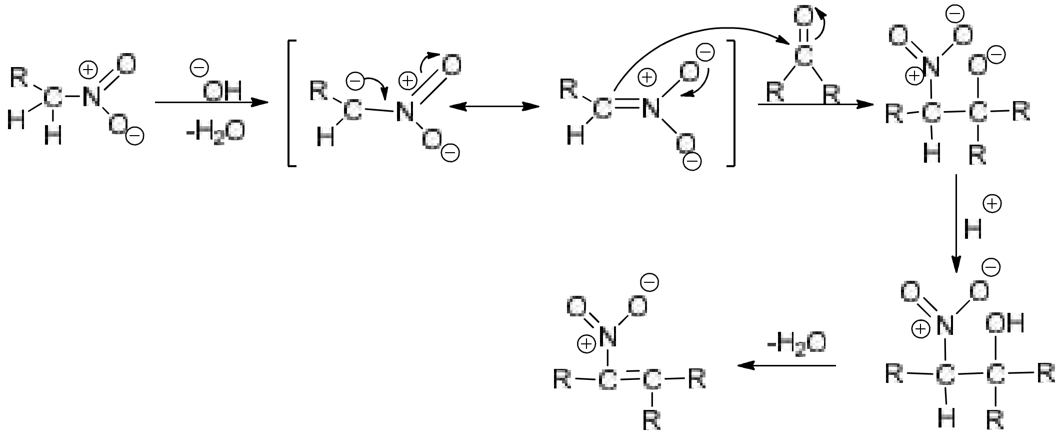
Henry reaction: A reaction, quite similar to aldol reaction, in which a carbon-carbon is formed by reaction of nitro compound having α-hydrogen (in aci form) with aldehyde or ketone to form β-nitro alcohol. The nitro alcohol may also lose a molecule of water to give α-nitroalkene.



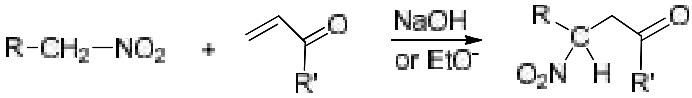
$$CH_3{-}NO_2 + RCHO \xrightarrow{NaOH} R{-}\underset{HO\ \ H}{C}{-}CH_2NO_2 \xrightarrow{-H_2O} R{-}\underset{H}{C}{=}CHNO_2$$



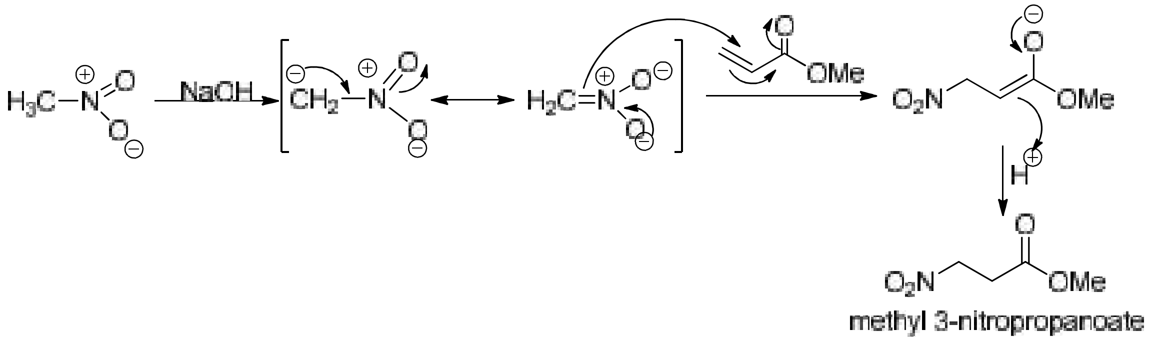
Mechanism: The reaction take place by following mechansim



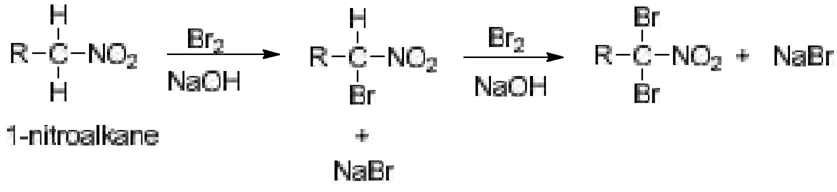
Michael addition: α,β unsaturated esters and carbonyl compounds , react with primary and secondary nitro alkanes (in their aci-nitro form) in presence of basic catalyst like sodium ethoxide or diethyamine in an alcohol solvent to give Michael addition product in good yield.

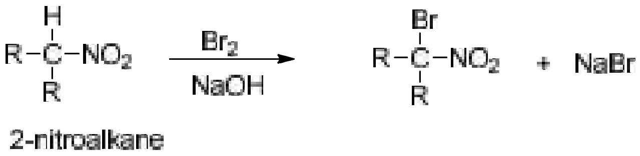


Mechanism:



Halogenation: Primary and secondary nitroalkanes are readily halogenated with chlorine or bromine in the presence of base to form chloro or bromo nitroalkanes. During the reaction all α-hydrogens are replaced by halogens.





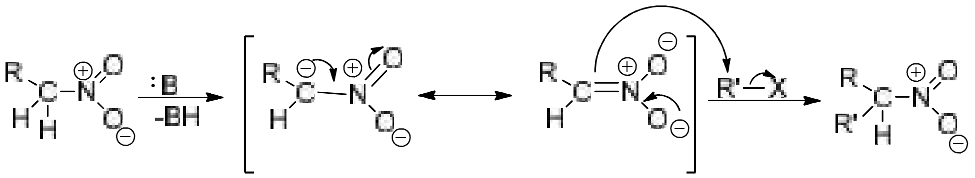
This method of halogenation has been used for the synthesis of chloropicrin, an important insecticide from nitromethane

$$H_3C-NO_2 + 3Cl_2 + 3NaOH \longrightarrow Cl_3C-NO_2 + NaCl + 3H_2O$$

nitromethane

Chloropicrin
(trichloronitromethane)

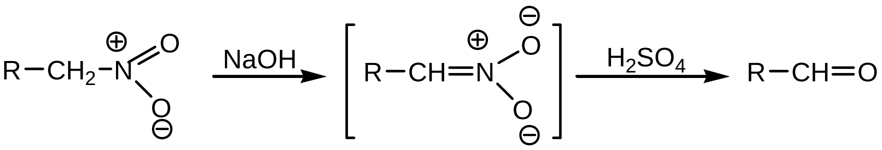
Alkylation: The anion generated as a result of the deprotonation of the nitroalkanes , react with carbon electrophiles to yield a wide variety of nitro containing products. The deprotonation can very easily be carried out with butyllithium followed by reaction with alkyl halide.

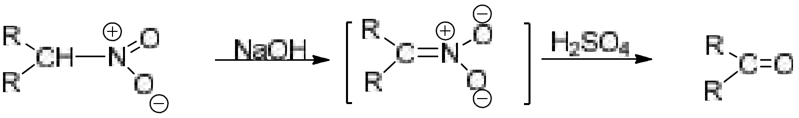


HMPA = hexamethylphosphoramide

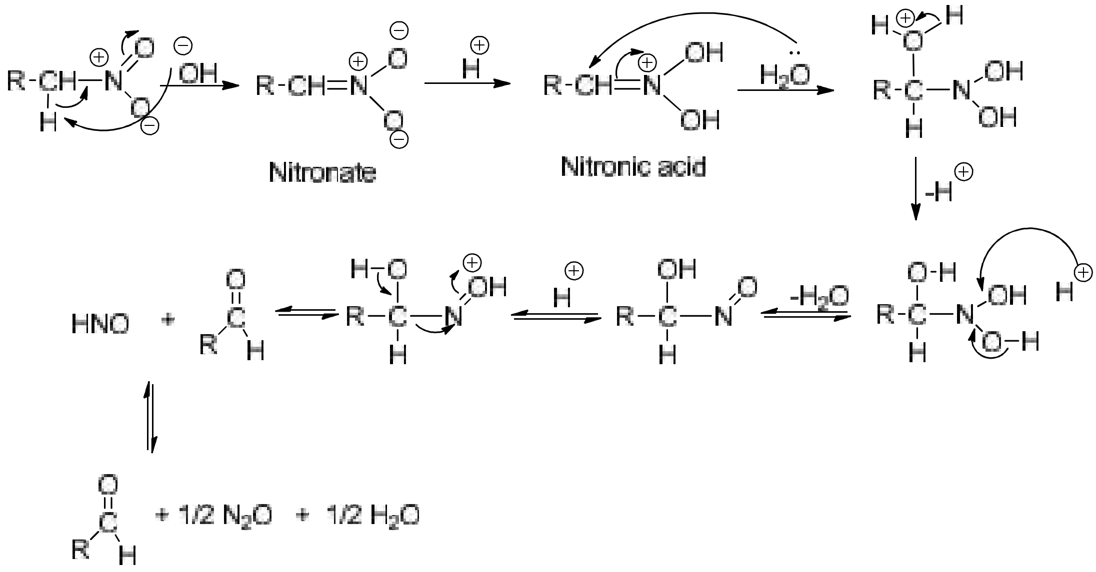
Reaction in which aci-nitro form acts as electrophiles

Nef Reaction: The reaction involves hydrolysis of primary and secondary nitroalkanes to aldehydes or ketones and nitrous oxide. Nitroalkanes are first converted to their sodium salt and then hydrolyzed by concentrated sulphuric acid to aldehydes and ketones.

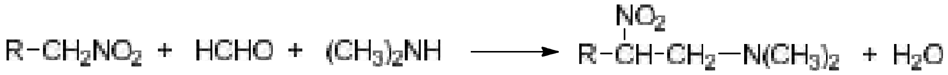




Mechanism:



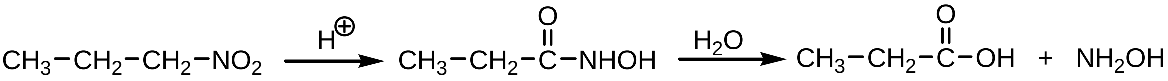
Mannich reaction: Primary and secondary nitroalkanes undergo mannich reaction with primary and secondary aliphatic amines and formaldehyde, yielding nitroamines in high yield.



$$R-CH_2NO_2 + HCHO + (CH_3)_2NH \longrightarrow R-\overset{NO_2}{\overset{|}{C}}H-CH_2-N(CH_3)_2 + H_2O$$

Hydrolysis (cleavage of nitroalkanes): The C-N bond of the primary and secondary nitroalkanes are split by strong mineral acid. Primary nitroalkanes are first converted to hydroxamic acid, which are then hydrolyzed to hydroxylamine and carboxylic acid.

$$\underset{\text{nitroethane}}{CH_3-CH_2-NO_2} \xrightarrow[H_2O]{H^{\oplus}} \underset{\text{acetic acid}}{CH_3-COOH} + \underset{\text{hydroxylamine}}{NH_2OH}$$

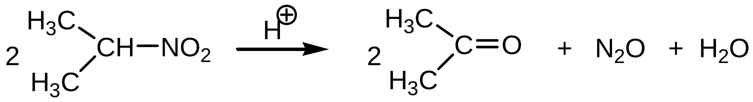


$$CH_3-CH_2-CH_2-NO_2 \xrightarrow{H^{\oplus}} CH_3-CH_2-\overset{O}{\overset{\|}{C}}-NHOH \xrightarrow{H_2O} CH_3-CH_2-\overset{O}{\overset{\|}{C}}-OH + NH_2OH$$

1-nitropropane — Hydroxamic acid (N-hydroxypropionamide) — propionic acid

This method of hydrolysis of nitroalkanes has been used for the industrial preparation of hydroxylamine

Secondary nitroalkanes on hydrolysis yield ketones and nitrous oxide



$$2\,(H_3C)_2CH-NO_2 \xrightarrow{H^{\oplus}} 2\,(H_3C)_2C=O + N_2O + H_2O$$

2-nitropropane — propan-2-one (acetone)

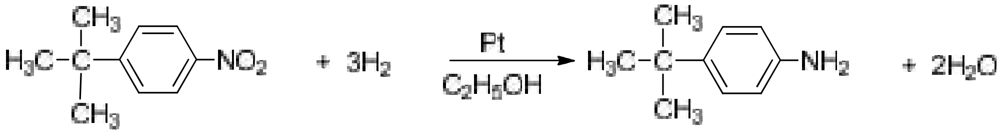
Tertiary nitro compounds are however unaffected by hydrochloric acid

Reduction of Nitro compounds: Nitro group can easily be reduced to a variety of products, depending upon the type of reagent and the reaction conditions used. But if the reaction is allowed to completition then the final product of the reaction is primary amines. Thus the overall reduction of nitro compound to primary amine takes place in following steps

$$C_6H_5-NO_2 \longrightarrow C_6H_5-N=O \longrightarrow C_6H_5-NHOH \longrightarrow C_6H_5-NH_2$$

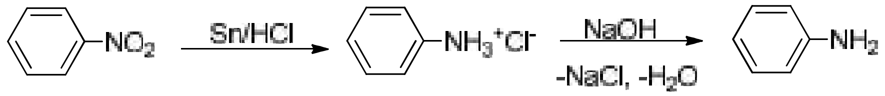
Nitrosobenzene Phenylhydroxylamine Aniline

(a) Catalytic reduction: Nitro group can be easily reduced by catalytic hydrogenation- hydrogenation carried out in the presence of catalyst like raney nickel, platinium or palladium-carbon.



1-tert-butyl-4-nitrobenzene 4-tert-butylaniline

(b) Reduction in acidic medium: This is an older and effective method of reducing aromatic nitro compounds to primary amine. The process involves heating the nitro compound with finely divided metal and concentrated hydrochloric acid. The metal most commonly used are iron, tin and zinc.

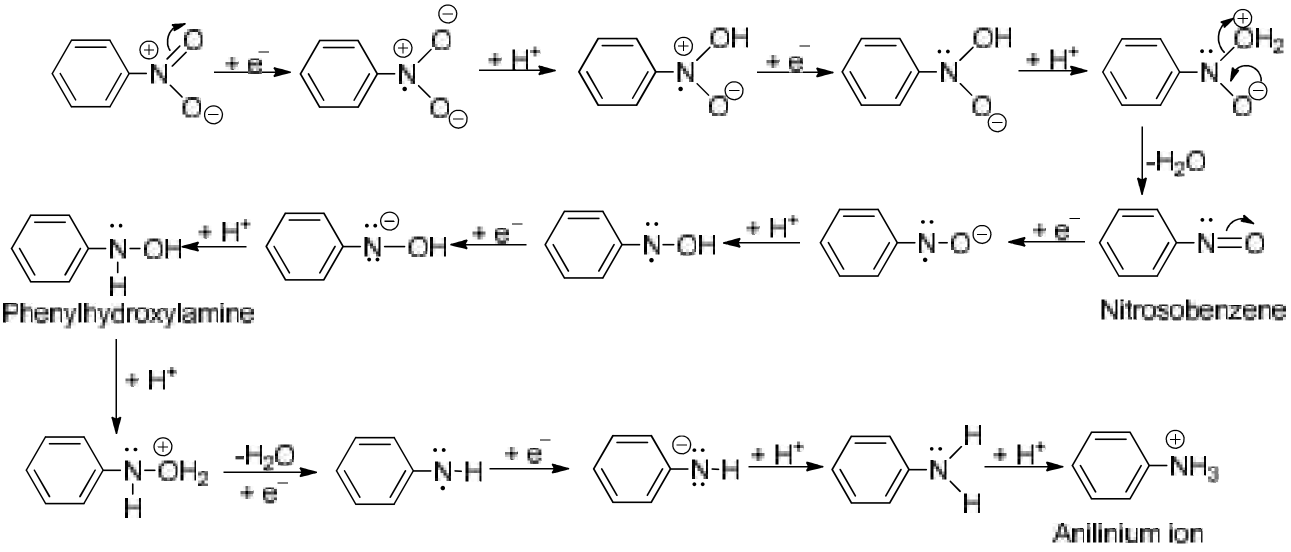


Nitrobenzene Aniline

However when reduction is carried out with stannous chloride and hydrochloric acid, a mixture of N-alkylhydroxylamine and oxime are obtained

$$R-CH_2\text{-}NO_2 \xrightarrow{SnCl_2/HCl} R-CH_2\text{-}NHOH + R-CH=NOH$$

Mechanism: The reduction of nitro group to amino group takes place in several steps, involving transfer of electron/s (from metal) and protons (from acids)



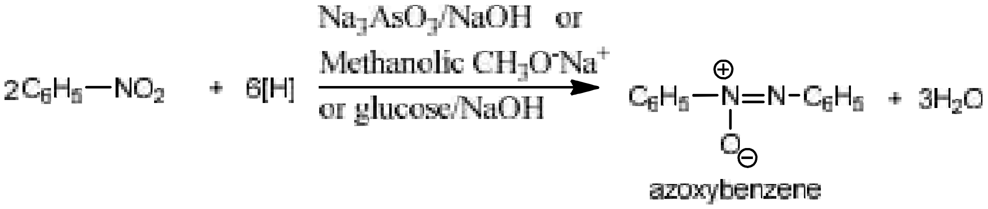
(c) Reduction in neutral medium: In neutral medium aliphatic as well as aromatic nitro compounds are reduced to hydroxylamines. The best reagent for carrying out this reduction is a combination of metallic zinc and ammonium chloride.

$$CH_3\text{—}NO_2 + 4[H] \xrightarrow{Zn/NH_4Cl} CH_3\text{—}NHOH + H_2O$$

nitromethane — N-methylhydroxyl amine (N-hydroxymethanamine)

(d) Reduction in alkaline medium: Reduction of aromatic nitro compounds yield a variety of products, depending upon the type of reagent/s used

(i) Nitrobenzene when heated with sodium hydroxide and anhydrous glucose, methanolic sodium methoxide or alkaline sodium arsenite yield azoxybenzene



$$2C_6H_5\text{—}NO_2 + 6[H] \xrightarrow[\text{or glucose/NaOH}]{Na_3AsO_3/NaOH \text{ or Methanolic } CH_3O^-Na^+} C_6H_5\text{—}\overset{\oplus}{\underset{O^{\ominus}}{N}}{=}N\text{—}C_6H_5 + 3H_2O$$

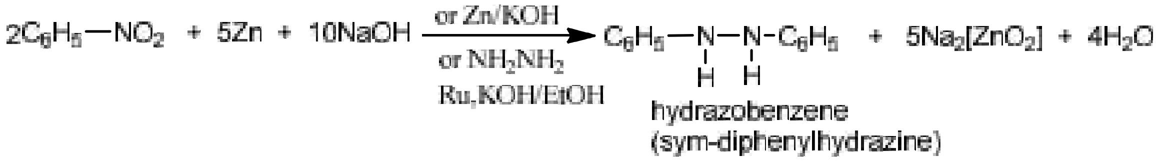
azoxybenzene

(ii) Nitrobenzene on reduction with zinc and sodium hydroxide yields azobenzene

$$2C_6H_5\text{—}NO_2 + 4Zn + 8NaOH \longrightarrow C_6H_5\text{—}N{=}N\text{—}C_6H_5 + 4Na_2[ZnO_2] + 4H_2O$$

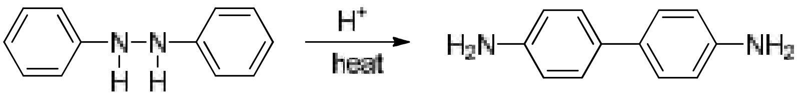
azobenzene (1,2-diphenyldiazene)

(iii) Nitrobenzene on reduction with zinc and slightly concentrated solution sodium hydroxide (in comparison to ii) or with zinc and caustic potash solution or hydrazine in presence of ruthenium catalyst and alcoholic KOH yields hydrazobenzene

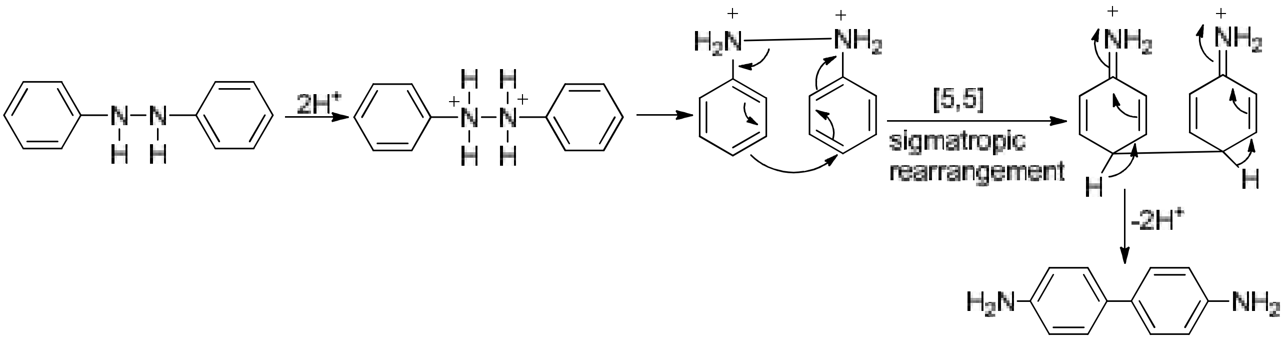


$$2C_6H_5{-}NO_2 + 5Zn + 10NaOH \xrightarrow[\text{or } NH_2NH_2 \;\; Ru, KOH/EtOH]{\text{or } Zn/KOH} C_6H_5{-}\underset{H}{N}{-}\underset{H}{N}{-}C_6H_5 + 5Na_2[ZnO_2] + 4H_2O$$

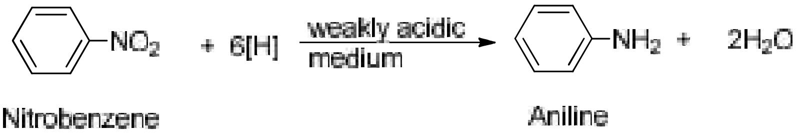
Hydrazobenzene on boiling with aqueous HCl or H_2SO_4 isomerizes to p-Benzidine (4,4'-diamino diphenyl). Some secondary products like o-benzidine, o-semidine and p-semidine are also formed. This acid catalyzed rearrangement of hydrazobenzene to benzidine is called Benzidine rearrangement.



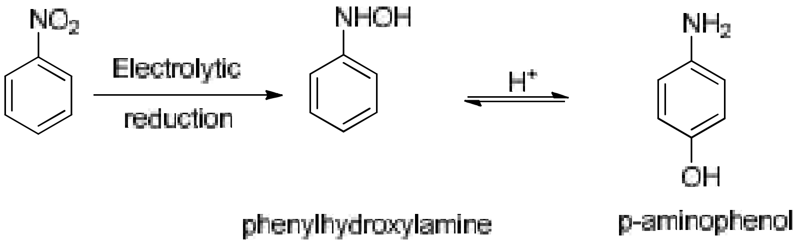
Mechanism: The reaction is thought to proceed intramolecularly via concerted [5,5] sigmatropic rearrangement



(e) Electrolytic reduction: The product obtained by electrolytic reduction depends upon pH of the medium. When electrolytic reduction is carried out in weakly acidic medium, then aniline is the product.

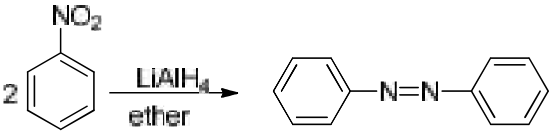


When electrolytic reduction takes place in strongly acidic medium, nitrobenzene is first reduced to phenyl hydroxyl amine which then rearranges to p-aminophenol

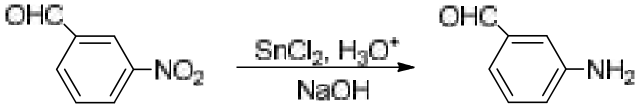


(f) Reduction with lithium aluminium hydride: Aliphatic nitro compounds on reduction with lithium aluminium hydride give primary amines whereas aromatic nitro compounds yield azo compound

$$CH_3CH_2-NO_2 \xrightarrow[\text{ether}]{LiAlH_4} CH_3CH_2-NH_2$$

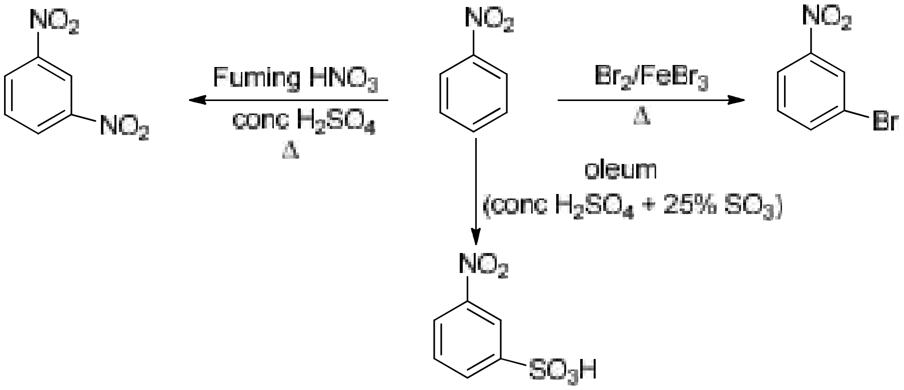


(g) Partial reduction: Reduction of nitro group has also been carried out with tin (II) chloride, particularly when other reducible groups are also present



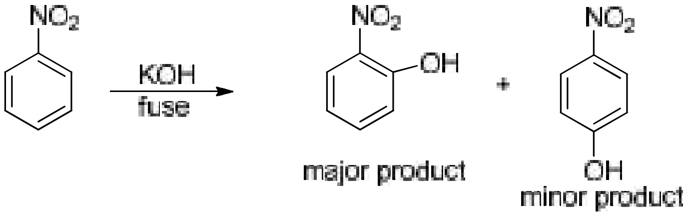
3-Nitrobenzaldehyde 3-aminobenzaldehyde

Electrophilic Substitution Reaction: Aromatic nitro compounds like other aromatic compounds also undergo electrophilic aromatic substitution reactions like nitration , sulphonation and halogenations. But due to electron withdrawing nature of the nitro group it deactivates the ortho and para position of the ring towards further electrophilic substitution reaction. This selective deactivation leaves only one reactive site-meta, hence meta substituted products are obtained.



Nitrobenzene however do not undergo Friedel Crafts reactions.

Nucleophilic substitustion Reaction: Ortho and para position of nitrobenzene are easily attacked by nucleophiles. Nitrobenzene on reaction with fused KOH yields o-nitrophenol as the major product whereas p-nitrophenol is formed in traces.



However if a second nitro group is present at o- or p- position, then this nitro group can be displaced by different nucleophiles