Kirk-Othmer Encyclopedia of Chemical Technology.

NITRO ALCOHOLS

A nitro alcohol is formed when an aliphatic nitro compound with a hydrogen atom on the nitro-bearing carbon atom reacts with an aldehyde in the presence of a base. Many such compounds have been synthesized, but only those formed by the condensation of formaldehyde (qv) and the lower nitroparaffins (qv) are marketed commercially. The condensation may occur one to three times, depending on the number of hydrogen atoms on the nitro-substituted carbon (R and R′ = H or alkyl), and yield nitro alcohols with one to three hydroxyl groups.

$$RR'CHNO_2 + CH_2O \rightleftharpoons^{OH^-} RR'C(CH_2OH)NO_2$$

$$RCH(CH_2OH)NO_2 + CH_2O \rightleftharpoons^{OH^-} RC(CH_2OH)_2NO_2$$

$$HC(CH_2OH)_2NO_2 + CH_2O \rightleftharpoons^{OH^-} C(CH_2OH)_3NO_2$$

In additionto the mononitro compounds, monohydric and dihydric dinitro alcohols have been prepared but are not available commercially. The formation, properties, and reactions of nitro alcohols have been reviewed (1, 2).

1. Physical Properties

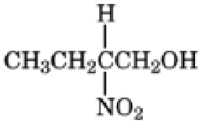
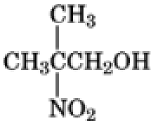
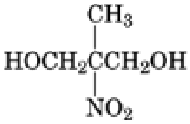
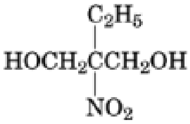
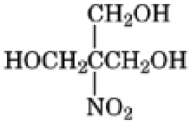
The physical properties of the commercially available nitro alcohols are given in Table 1. Except for nitrobutanol, these nitro alcohols are white crystalline solids when pure. They are thermally unstable above 100°C and purification by distillation is a hazardous procedure.

The nitro alcohols generally are soluble in water and in oxygenated solvents, eg, alcohols. The monohydric nitro alcohols are soluble in aromatic hydrocarbons; the diols are only moderately soluble even at 50°C; at 50°C the triol is insoluble.

2. Chemical Properties

The nitro alcohols can be reduced to the corresponding alkanolamines (qv). Commercially, reduction is accomplished by hydrogenation of the nitro alcohol in methanol in the presence of Raney nickel. Convenient operating conditions are 30°C and 6900 kPa (1000 psi). Production of alkanolamines constitutes the largest single use of nitro alcohols.

Table 1. Physical Properties and Toxicity Data of Nitro Alcohols[a]

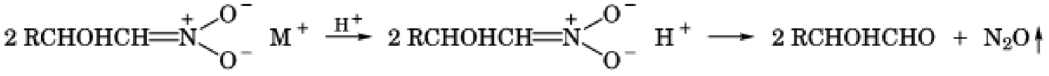
Compound	CAS Registry Number	Structural formula	Mol wt	Mp, °C	Bp, °C	Solubility in water at 20°C g/100 mL	LD_{50}, g/kg
2-nitro-1-butanol (NB)	[609-31-4]	 $CH_3CH_2\overset{H}{\underset{NO_2}{C}}CH_2OH$	119.12	−47 to −48	105[b]	54	1.2
2-methyl-2-nitro-1-propanol (NMP)	[76-39-1]	 $CH_3\overset{CH_3}{\underset{NO_2}{C}}CH_2OH$	119.12	90	94[c]	350	1.0
2-methyl-2-nitro-1,3-propanediol (NMPD)	[77-49-6]	 $HOCH_2\overset{CH_3}{\underset{NO_2}{C}}CH_2OH$	135.12	ca 160	dec	80	4.0
2-ethyl-2-nitro-1,3-propanediol (NEPD)	[597-09-1]	 $HOCH_2\overset{C_2H_5}{\underset{NO_2}{C}}CH_2OH$	149.15	56	dec	400	2.8
2-hydroxymethyl-2-nitro-1,3-propanediol (TRIS NITRO)	[126-11-4]	 $HOCH_2\overset{CH_2OH}{\underset{NO_2}{C}}CH_2OH$	151.12	175–176	dec	220	1.9

[a] Ref. 3.

[b] At 1.3 kPa (10 mm Hg).

[c] At 1.95 kPa (15 mm Hg).

Nitro alcohols form salts upon mild treatment with alkalies. Acidification causes separation of the nitro group as N_2O from the parent compound, and results in the formation of carbonyl alcohols, ie, hydroxy aldehydes, from primary nitro alcohols and ketols from secondary nitro alcohols.



$$2\,RCHOHCH{=}\overset{+}{N}\genfrac{}{}{0pt}{}{O^-}{O^-}\;M^+ \xrightarrow{H^+} 2\,RCHOHCH{=}\overset{+}{N}\genfrac{}{}{0pt}{}{O^-}{O^-}\;H^+ \longrightarrow 2\,RCHOHCHO + N_2O\uparrow$$

Nitro alcohols react with amines to form nitro amines. Such a reaction can be carried out with a wide variety of primary and secondary amines, both aliphatic and aromatic; a basic catalyst is required if aromatic amines are involved. The products of reactions between dihydric nitro alcohols and amines are nitrodiamines, many of which are good fungicides (qv). Dihydric nitro alcohols, primary amines, and formaldehyde react to yield nitrohexahydropyrimidines (4). Nitrohexahydropyrimidines can be reduced to the corresponding amines, some of which are good fungicides or bactericides, eg, hexetidine [141-94-6] (5-amino-1,3–bis(2-ethylhexyl)-5-methylhexahydropyrimidine).

Esters of nitro alcohols with primary alcohol groups can be prepared from the nitro alcohol and an organic acid, but nitro alcohols with secondary alcohol groups can be esterified only through the use of an acid chloride or anhydride. The nitrate esters of the nitro alcohols are obtained easily by treatment with nitric acid (qv). The resulting products have explosive properties but are not used commercially.

On dehydration, nitro alcohols yield nitro-olefins. The ester of the nitro alcohol is treated with caustic or is refluxed with a reagent, eg, phthalic anhydride or phosphorus pentoxide. A milder method involves the use of methane sulfonyl chloride to transform the hydroxyl into a better leaving group. Yields up to 80% after a reaction time of 15 min at 0°C have been reported (5). In aqueous solution, nitro alcohols decompose at pH 7.0 with the formation of formaldehyde. One mole of formaldehyde is released per mole of monohydric nitro alcohol, and two moles of formaldehyde are released by the nitrodiols. However, 2-hydroxymethyl-2-nitro-1,3-propanediol gives only two moles of formaldehyde instead of the expected three moles. The rate of release of formaldehyde increases with the pH or the temperature or both.

3. Manufacture and Processing

The nitro alcohols available in commercial quantities are manufactured by the condensation of nitroparaffins with formaldehyde [50-00-0]. These condensations are equilibrium reactions, and potential exists for the formation of polymeric materials. Therefore, reaction conditions, eg, reaction time, temperature, mole ratio of the reactants, catalyst level, and catalyst removal, must be carefully controlled in order to obtain the desired nitro alcohol in good yield (6). Paraformaldehyde can be used in place of aqueous formaldehyde. A wide variety of basic catalysts, including amines, quaternary ammonium hydroxides, and inorganic hydroxides and carbonates, can be used. After completion of the reaction, the reaction mixture must be made acidic, either by addition of mineral acid or by removal of base by an ion-exchange resin in order to prevent reversal of the reaction during the isolation of the nitro alcohol (see Ion exchange).

The purification of liquid nitro alcohols by distillation should be avoided because violent decompositions and detonation have occurred when distillation was attempted. However, if the distillation of a nitro alcohol cannot be avoided, the utmost caution should be exercised. Reduced pressure should be utilized, ie, ca 0.1 kPa ($<$1 mm Hg). The temperature of the liquid should not exceed 100°C; hot water should be used as the heating bath. A suitable explosion-proof shield should be placed in front of the apparatus. At any rise in pressure, the distillation should be stopped immediately. The only commercially produced liquid nitro alcohol, 2-nitro-1-butanol, is not distilled because of the danger of decomposition. Instead, it is isolated as a residue after the low boiling impurities have been removed by vacuum treatment at a relatively low temperature.

4. Economic Aspects

The nitro alcohols in Table 1 are manufactured in commercial quantities; however, three of the five of them are used only for the production of the corresponding amino alcohols. 2-Methyl-2-nitro-1-propanol (NMP) is available as the crystalline solid or as a mixture with silicon dioxide. 2-Hydroxymethyl-2-nitro-1,3-propanediol is available as the solid ($9.15/kg), a 50% solution in water ($2.33/kg), a 25% solution in water ($1.41/kg), or as 1-oz (28.3-g) tablets ($76.00/case of 144).

5. Health, Safety, and Environmental Factors

Acute oral LD_{50} data for nitro alcohols in mice are given in Table 1. Because of their low volatility, the nitro alcohols present no vapor inhalation hazard. They are nonirritating to the skin and, except for 2-nitro-1-butanol, are nonirritating when introduced as a 1 wt % aqueous solution in the eye of a rabbit. When 0.1 mL of 1 wt % commercial-grade 2-nitro-1-butanol in water is introduced into the eyes of rabbits, severe and permanent corneal scarring results. This anomalous behavior may be caused by the presence of a nitro-olefin impurity in the unpurified commercial product.

Because it is the nitro alcohol with greatest potential for human exposure, additional testing of 2-hydroxymethyl-2-nitro-1,3-propanediol has been conducted. In a 90-day dermal study in rats, no effects were observed with animals exposed to 1000 mg/kg/d except for a slight yellow staining at the site of application. No teratogenic effects were noted in either rats or rabbits when tested by gavage. Additionally, 2-hydroxymethyl-2-nitro-1,3-propanediol was not found to be mutagenic in *in vitro* tests, ie, the salmonella reverse-mutation test, a chromosome aberration study with Chinese hamster ovary cells, and in an unscheduled DNA synthesis study with primary rat hepatacytes.

In a battery of tests, which determine the tendency of chemicals to inhibit aquatic organisms, accumulate in such organisms, and degrade in the environment, 2-hydroxy-2-nitro-1,3-propanediol was found to have low potential for harm in the environment (7).

6. Uses

The nitro alcohols are useful as intermediates for chemical synthesis. In particular, they are used to introduce a nitro functionality and, by reduction of the resultant intermediate, an amino functionality.

6.1. Antimicrobials

In slightly alkaline aqueous solutions, nitro alcohols are useful for the control of microorganisms, eg, in cutting fluids, cooling towers, oil-field flooding, drilling muds, etc (8–15) (see Industrial antimicrobial agents; Petroleum). However, only 2-hydroxymethyl-2-nitro-1,3-propanediol (TRIS NITRO) is registered by the U.S. Environmental Protection Agency (EPA). Under the provisions of the 1988 amendments to the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), EPA has published a “reregistration eligibility document” which allows for the continued registration of this useful biocide (16).

6.2. Polymers

All nitro alcohols are sources of formaldehyde for cross-linking in polymers of urea, melamine, phenols, resorcinol, etc (see Amino resins and plastics). Nitrodiols and 2-hydroxymethyl-2-nitro-1,3-propanediol can be used as polyols to form polyester or polyurethane products (see Polyesters; Urethane polymers). 2-Methyl-2-nitro-1-propanol is used in tires to promote the adhesion of rubber to tire cord (qv). Nitro alcohols are used as hardening agents in photographic processes, and 2-hydroxymethyl-2-nitro-1,3-propanediol is a cross-linking agent for starch adhesives, polyamides, urea resins, or wool, and in tanning operations (17–25). Wrinkle-resistant fabric with reduced free formaldehyde content is obtained by treatment with 2-methyl-2-nitro-1-propanol as the cross-linker (26).

6.3. Stabilizers

Nitro alcohols can be used to prevent the decomposition of *p*-phenylenediamine color-developing agents (27). 2-Hydroxymethyl-2-nitro-1,3-propanediol and 2-nitro-1-butanol have been used as additives for the stabilization of 1,1,1-trichloroethane.

6.4. Other

2-Nitro-1-butanol is an excellent solvent for many polyamide resins, cellulose acetate butyrate, and ethylcellulose. It can be utilized in paint removers for epoxy-based coatings. 2-Hydroxymethyl-2-nitro-1,3-propanediol is useful for control of odors in chemical toilets. Its slow release of formaldehyde ensures prolonged action to control odor, and there is no reodorant problem which sometimes is associated with the use of free formaldehyde. 2-Hydroxymethyl-2-nitro-1,3-propanediol solutions are effective preservative and embalming fluids. The slow liberation of formaldehyde permits thorough penetration of the tissues before hardening.

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