ANILINE AND ITS DERIVATIVES

1. Introduction

Aniline (benzenamine) [62-53-3] is the simplest of the primary aromatic amines. It was first produced in 1826 by dry distillation of indigo. In 1840 the same oily liquid was obtained by heating indigo with potash, and it was given the name aniline. The structure of aniline was established in 1843 with the demonstration that it could be obtained by reduction of nitrobenzene.

Aromatic amines can be produced by reduction of the corresponding nitro compound, the ammonolysis of an aromatic halide or phenol, and by direct amination of the aromatic ring. At present, the catalytic reduction of nitrobenzene is the predominant process for manufacture of aniline. To a smaller extent aniline is also produced by ammonolysis of phenol.

Important analogs of aniline include the toluidines, xylidines, anisidines, phenetidines, and its chloro-, nitro-, *N*-acetyl, *N*-alkyl, *N*-aryl, *N*-acyl, and sulfonic acid derivatives.

2. Physical Properties

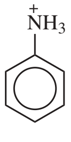
Pure, freshly distilled aniline is a colorless, oily liquid that darkens on exposure to light and air. It has a characteristic sweet, aminelike aromatic odor. Aniline is miscible with acetone, ethanol, diethyl ether, and benzene, and is soluble in most organic solvents. Its solubility characteristics in water are as follows:

Temperature, °C	Parts aniline per 100 parts water	Parts water per 100 parts aniline
25	3.5	5.0
90	6.4	9.9

The physical properties of aniline are given in Table 1 and vapor pressure data in Table 2.

3. Chemical Properties

Aromatic amines are usually weaker bases than aliphatic amines as illustrated by the difference in pK_a of the conjugate acids of aniline (1), p$K_a = 4.63$ and cyclohexylamine (2), p$K_a = 10.66$.



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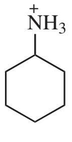

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Table 1. **Physical Properties of Aniline**

Property	Value
molecular formula	C_6H_7N
molecular weight	93.129
boiling point, °C	
101.3 kPa[a]	184.4
4.4 kPa[a]	92
1.2 kPa[a]	71
freezing point, °C	−6.03
density, liquid, g/mL	
20/4°C	1.02173
20/20°C	1.022
density, vapor (at bp, air = 1)	3.30
refractive index, $n^{20}{}_{\mathrm{D}}$	1.5863
viscosity, mPa·s(=cP)	
20°C	4.35
60°C	1.62
enthalpy of dissociation, kJ/mo[b]	21.7
heat of combustion, kJ/mol[b]	3394
ionization potential, eV	7.70
dielectric constant, at 25°C	6.89
dipole moment at 25°C (calcd), C·m[c]	5.20×10^{-30}
specific heat at 25°C, J/(g·K)[b]	2.06
heat of vaporization, J/g[b]	478.5
flash point, °C	
closed cup	70
open cup	75.5
ignition temperature, °C	615
lower flammable limit, vol %	1.3

[a] To convert kPa to mm Hg, multiply by 7.5.
[b] To convert J to cal, divide by 4.184.
[c] To convert C·m to debye, multiply by 3×10^{29}.

This is due to a resonance effect. Aniline is stabilized by sharing its nitrogen lone-pair electrons with the aromatic ring. In the anilinium ion, the resonance stabilization is disrupted by the proton bound to the lone pair.

Aromatic amines form addition compounds and complexes with many inorganic substances, such as zinc chloride, copper chloride, uranium tetrachloride, or boron trifluoride. Various metals react with the amino group to form metal anilides; and hydrochloric, sulfuric, or phosphoric acid salts of aniline are important intermediates in the dye industry.

Table 2. **Vapor Pressure of Aniline**

Temperature, °C	Vapor pressure, kPa[a]	Temperature, °C	Vapor pressure, kPa[a]
175	80	139	28
162	53	119	13
151	40	102	7

[a] To convert kPa to mm Hg, multiply by 7.50.

3.1. *N*-Alkylation. A number of methods are available for preparation of *N*-alkyl and *N,N*-dialkyl derivatives of aromatic amines. Passing a mixture of aniline and methanol over a copper–zinc oxide catalyst at 250°C and 101 kPa (1 atm) reportedly gives *N*-methylaniline [100-61-8] in 96% yield (1). Heating aniline with methanol under pressure or with excess methanol produces *N,N*-dimethylaniline [121-69-7] (2,3).

In the presence of sulfuric acid, aniline reacts with methanol to form *N*-methyl- and *N,N*-dimethylaniline. This is a two-step process

$$C_6H_5NH_2 + CH_3OH \longrightarrow C_6H_5NHCH_3 + H_2O$$

$$C_6H_5NHCH_3 + CH_3OH \longrightarrow C_6H_5NH(CH_3)_2 + H_2O$$

and a study of its kinetics (4) shows that reaction rate is proportional to the concentration of aniline in the first step and the concentration of *N*-methylaniline in the second step. With 50% excess methanol, the reaction equilibrium reaches 99% *N,N*-dimethylaniline at 200°C. Reaction is clean with little by-product formation up to 230°C. At higher temperatures, ring alkylation and formation of formaldehyde, from oxidation of methanol, are observed.

Other catalysts that can be used are boron trifluoride (5), copper–chromium oxides (6), phosphoric acid (7), and silica–alumina (8). Under similar conditions, ethanol yields *N*-ethylaniline [103-69-5] and *N,N*-diethylaniline [91-66-7] (9, 10).

N-Alkylation can also be carried out with the appropriate alkyl halide or alkyl sulfate. Reaction of aniline with ethylene, in the presence of metallic sodium supported on an inert carrier such as carbon or alumina, at high temperature and pressure yields *N*-ethyl- or *N,N*-diethylaniline (11). At pressures below 10 MPa (100 atm), the monosubstituted product predominates.

Mixtures of *N*-alkylanilines can usually be separated by fractional distillation. Mixtures of the methyl or ethyl derivatives have also reportedly been separated by converting the *N*-ethyl or the *N*-methyl derivative to the nonvolatile salt with *p*-toluenesulfonic acid (12) or phthalic anhydride (13), followed by distillation.

Catalytic alkylation of aniline with diethyl ether, in the presence of mixed metal oxide catalysts, preferably titanium dioxide in combination with molybdenum oxide and/or ferric oxide, gives 63% *N*-alkylation and 12% ring alkylation (14).

Diphenylamine [122-39-4] is produced by heating aniline with aniline hydrochloride at 290°C and 2 MPa (21 atm) in an autoclave (15).

$$C_6H_5NH_2 + C_6H_5NH_2HCl \longrightarrow C_6H_5NHC_6H_5 + NH_3 + HCl$$

The by-product ammonia is vented from the reactor during the course of the reaction. Unconverted aniline is distilled off at the end of the reaction and the diphenylamine is washed with aqueous hydrochloric acid to remove trace amounts of aniline. The product is then washed with water and purified in a refining still.

The use of ammonium fluoroborate (NH_4BF_4) as a catalyst for this reaction, is claimed to be advantageous, since the catalyst can be recycled and is noncorrosive to ferrous metals (16).

Diphenylamine can also be produced by passing the vapors of aniline over a catalyst such as alumina, or alumina impregnated with ammonium fluoride (17). The reaction is carried out at 480°C and about 700 kPa (7 atm). Conversion per pass, expressed as parts diphenylamine per 100 parts of reactor effluent, is low (18–22%), and the unconverted aniline must be recycled. Other catalysts disclosed for the vapor-phase process are alumina modified with boron trifluoride (18), and alumina activated with boric acid or boric anhydride (19).

3.2. Ring Alkylation. The aromatic ring undergoes alkylation under certain conditions. For example, 2-ethylaniline [103-69-5], 2,6-diethylaniline [579-66-8], or a mixture of the two are obtained in high yield when aniline is heated with ethylene in the presence of aluminum–anilide catalyst (formed by heating aluminum and aniline) at 330°C and 4–5 MPa (40–50 atm) (20). *N*-Ethylaniline is alkylated in a similar manner, but at 205°C yields only *N*-ethyl-2-ethylaniline [578-54-1]. Other olefins can also be used to form ring-alkylated products, but the reaction rate decreases as the molecular weight of the olefin increases. A number of patents, claiming a variety of catalysts, have been issued in this area (21–24).

N-Alkylaniline and *N,N*-dialkylaniline hydrochlorides can be rearranged to *C*-alkyl anilines by heating the salts to 200–300°C. In this reaction, known as the Hofmann-Martius rearrangement, the alkyl group preferentially migrates to the para position. If this position is occupied, the ortho position is alkylated.

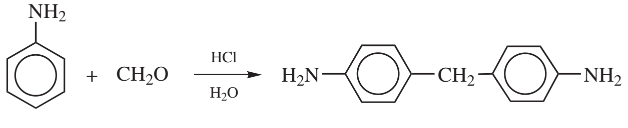
3.3. Acylation. Aromatic amines react with acids, acid chlorides, anhydrides, and esters to form amides. In general, acid chlorides give the best yield of the pure product. The reaction with acetic, propionic, butanoic, or benzoic acid can be catalyzed with phosphorus oxychloride or trichloride.

N-Phenylsuccinimide [83-25-0] (succanil) is obtained in essentially quantitative yield by heating equivalent amounts of succinic acid and aniline at 140–150°C (25). The reaction of a primary aromatic amine with phosgene leads to formation of an arylcarbamoyl chloride, that when heated loses hydrogen chloride to form an isocyanate. Commercially important isocyanates are obtained from aromatic primary diamines.

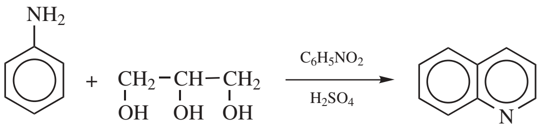
Conversion of aniline to acetanilide [103-84-4], by reaction with acetic anhydride, is a convenient method for protecting the amino group. The acetyl group can later be removed by acid or base hydrolysis.

3.4. Condensation. Depending on the reaction conditions, a variety of condensation products are obtained from the reaction of aromatic amines with aldehydes, ketones, acetals, and orthoformates.

Primary aromatic amines react with aldehydes to form Schiff bases. Schiff bases formed from the reaction of lower aliphatic aldehydes, such as formaldehyde and acetaldehyde, with primary aromatic amines are often unstable and polymerize readily. Aniline reacts with formaldehyde in aqueous acid solutions to yield mixtures of a crystalline trimer of the Schiff base, methylenedianilines, and polymers. Reaction of aniline hydrochloride and formaldehyde also yields polymeric products; and under certain conditions, the predominant product is 4,4′-methylenedianiline [101-77-9] (26), an important intermediate for 4,4′-methylenebis(phenylisocyanate) [101-68-8], or MDI.

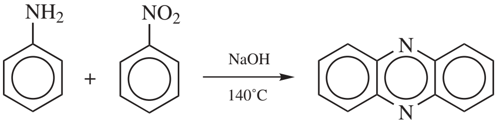


3.5. Cyclization. Aniline, nitrobenzene, and glycerol react under acid catalysis (Skraup synthesis) to form quinoline [91-22-5] (27).

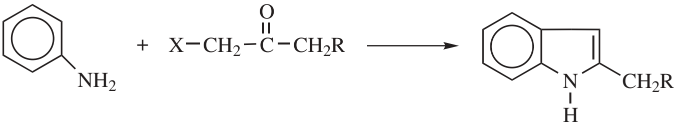


By substituting paraldehyde for glycerol, 2-methylquinoline [27601-00-9] may be synthesized. The Skraup synthesis is regarded as an example of the broader Doebner-von Miller synthesis. In the case of the Skraup synthesis, the glycerol undergoes an acid-catalyzed dehydration to provide a small concentration of acrolein that is the reactive species. If acrolein itself is used as a reactant, it would polymerize. Crotonaldehyde is the reactive intermediate in the Doebner-von Miller synthesis (28).

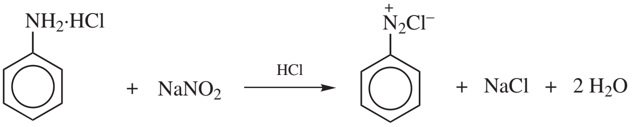
Many substituted quinolines are intermediates for antimalarials. The 2,4-di-substituted quinolines are produced from aniline and 1,3-diketones by the Combes quinoline synthesis (28). The reaction of aniline with nitrobenzene in the presence of dry sodium hydroxide at 140°C leads to formation of phenazine [92-82-0] and by-products (Wohl-Aue synthesis) (29).



Aromatic amines react with 1-haloketones or 1-hydroxyketones to yield substituted indoles. This reaction is known as the Bischler indole synthesis (30).



3.6. Reaction with Nitrous Acid. Primary, secondary, and tertiary aromatic amines react with nitrous acid to form a variety of products. Primary aromatic amines form diazonium salts.



Secondary aromatic amines form *N*-nitrosamines and tertiary aromatic amines undergo ring nitrosation to yield *C*-nitroso products.

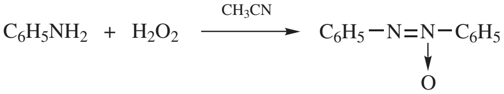
Aromatic diazonium salts are usually not isolated and react further to yield the desired product. Their reactions can be grouped in two categories: (*1*) those in which nitrogen is lost and the diazonium group is replaced by hydroxyl, hydrogen, nitrile, halogen, or aryl groups; and (*2*) those in which the diazonium ion can act as an electrophile in aromatic substitution reactions, that is, coupling reactions, with an activated aromatic compound.

Coupling of the diazonium salts with phenols and amines forms the basis for manufacture of a number of commercial dyes.

3.7. Oxidation.

Aromatic amines can undergo a variety of oxidation reactions, depending on the oxidizing agent and the reaction conditions. For example, oxidation of aniline can lead to formation of phenylhydroxylamine, nitrosobenzene, nitrobenzene, azobenzene, azoxybenzene or *p*-benzoquinone. Oxidation was of great importance in the early stages of the development of aniline and the manufacture of synthetic dyes, such as aniline black and Perkin's mauve.

Nitroso compounds are formed selectively via the oxidation of a primary aromatic amine with Caro's acid [7722-86-3] (H_2SO_5) or Oxone (Du Pont trademark) monopersulfate compound ($2KHSO_5 \cdot KHSO_4 \cdot K_2SO_4$); aniline black [13007-86-8] is obtained if the oxidation is carried out with salts of persulfuric acid (31). Oxidation of aromatic amines to nitro compounds can be carried out with peroxytrifluoroacetic acid (32). Hydrogen peroxide with acetonitrile converts aniline in a methanol solution to azoxybenzene [495-48-7] (33), perborate in glacial acetic acid yields azobenzene [103-33-3] (34).

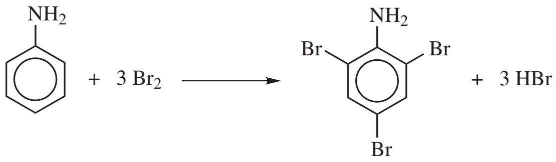


$$C_6H_5NH_2 + H_2O_2 \xrightarrow{CH_3CN} C_6H_5{-}N{=}\underset{\underset{O}{\downarrow}}{N}{-}C_6H_5$$

Oxidation of aniline with a mixture of manganese dioxide and sulfuric acid has been used commercially for production of *p*-benzoquinone [106-51-4] (35).

3.8. Halogenation.

The presence of the amino group activates the ortho and para positions of the aromatic ring and, as a result, aniline reacts readily with bromine or chlorine. Under mild conditions, bromination yields 2,4,6-tribromoaniline [147-82-0].



Controlled halogenation can be achieved by halogenation of the *N*-acetyl derivative of the aromatic amine, followed by hydrolysis of the acetyl group.

Chlorine in the presence of hydrogen chloride in an anhydrous organic solvent yields 2,4,6-trichloroaniline [634-93-5] (36,37). A mixture of aniline vapor and chlorine, diluted with an inert gas, over activated carbon at 400°C yields *o*-chloroaniline [95-51-2] (38). Aniline when treated with chlorine gas, in an aqueous mixture of sulfuric acid and acetic acid, at 105–115°C gives an 85–95% yield of *p*-chloranil [118-75-2] (39).

3.9. Sulfonation.

Aniline reacts with sulfuric acid at high temperatures to form *p*-aminobenzenesulfonic acid (sulfanilic acid [121-57-3]). The initial product, aniline sulfate, rearranges to the ring-substituted sulfonic acid (40). If the para position is blocked, the *o*-aminobenzenesulfonic acid derivative is isolated. Aminosulfonic acids of high purity have been prepared by sulfonating a mixture of the aromatic amine and sulfolane with sulfuric acid at 180–190°C (41).

In the reaction of anilinium sulfate [542-16-5] with fuming sulfuric acid, the major products are *m*- and *p*-aminobenzenesulfonic acid with less than 2% of the ortho isomer. With excess concentrated sulfuric acid (96.8–99.9%) at 60–100°C, the sulfate salt gives mainly the ortho and para isomers of the sulfonic acid (42).

When *p*-aminobenzenesulfonic acid is heated with sulfuric acid and phosphorus pentoxide, 2-amino-1,3,5-benzenetrisulfonic acid [64775-08-4] is the product (43).

3.10. Nitration. Direct nitration of aromatic amines with nitric acid is not a satisfactory method, because the amino group is susceptible to oxidation. The amino group can be protected by acetylation, and the acetylamino derivative is then used in the nitration step. Nitration of acetanilide in sulfuric acid yields the 4-nitro compound that is hydrolyzed to *p*-nitroaniline [100-01-6].

Nitration of aromatic amines with urea nitrate in sulfuric acid is reported to yield the *p*-nitro derivative exclusively (44). When the para position is blocked, the meta product is obtained in excellent yield.

3.11. Reduction. Hydrogenation of aromatic amines leads to formation of cycloalkylamines, dicycloalkylamines, or both, depending on the reaction conditions and the type of catalyst used. Hydrogenation of aniline in the liquid phase at 25 MPa (250 atm) over a cobalt–alumina catalyst at 140°C yields cyclohexylamine [108-91-8] in 80% yield (45). Dicyclohexylamine [101-83-7] is produced when aniline is hydrogenated in the vapor phase over a nickel-on-pumice catalyst (46). When aniline is hydrogenated at 160–200°C in the presence of a ruthenium–palladium catalyst, supported on γ-alumina impregnated with sodium hydroxide, the product mixture is 19.3% cyclohexylamine and 80.3% dicyclohexylamine (47). Hydrogenation with a similar ruthenium–palladium catalyst supported on γ-alumina treated with manganese and chromium salts gives 91.1% cyclohexylamine and 8.8% dicyclohexylamine (48).

Addition of ammonia to the hydrogenator, 1.5 to 5 parts per 100 parts aniline, has been reported to selectively yield cyclohexylamine (49). The reduction is carried out at 160 to 180°C and 2 to 5 MPa (20 to 50 atm) with a ruthenium-on-carbon catalyst.

Cyclohexylamine is also manufactured on a commercial scale by hydrogenation of nitrobenzene without intermediate separation of aniline.

4. Manufacturing and Processing

The predominant process for manufacture of aniline is the catalytic reduction of nitrobenzene with hydrogen. The reduction is carried out in the vapor phase (50–55) or liquid phase (56–60). A fixed-bed reactor is commonly used for the vapor-phase process and the reactor is operated under pressure. A number of catalysts have been cited and include copper, copper on silica, copper oxide, sulfides of nickel, molybdenum, tungsten, and palladium–vanadium on alumina or lithium–aluminum spinels. Catalysts cited for the liquid-phase processes include nickel, copper or cobalt supported on a suitable inert carrier, and palladium or platinum or their mixtures supported on carbon.

As an example of the vapor-phase process, nitrobenzene vapor and hydrogen are mixed and passed through a fluidized bed of copper-on-silica catalyst at 280–290°C and 500 kPa (5 atm). The reaction gas is filtered, cooled to condense aniline and water, and the excess hydrogen is recycled. The yield reported is 99.5% (42). The catalyst bed is regenerated by passing hot air through the bed to burn off the carbonaceous deposits. The aniline and water condensate are separated, and the latter is sent to the wastewater column. The organic phase is dried and the product is distilled.

Du Pont uses a liquid-phase hydrogenation process that employs a palladium–platinum-on-carbon catalyst. The process uses a plug-flow reactor that achieves essentially quantitative yields, and the product exiting the reactor is virtually free of nitrobenzene.

The old Bechamp batch process for reduction of nitrobenzene (iron–hydrochloric acid) is obsolete; however, Mobay Chemical Corporation is operating a plant using this process for production of pigment grade iron oxide as well as aniline.

The ammonolysis of phenol (61–65) is a commercial process in Japan. Sunoco (formerly Aristech Chemical Corporation) currently operates a plant at Haverhill, Ohio to convert phenol to aniline. The plant's design is based on Halcon's process (66). In this process, phenol is vaporized, mixed with fresh and recycled ammonia, and fed to a reactor that contains a proprietary Lewis acid catalyst. The gas leaving the reactor is fed to a distillation column to recover ammonia overhead for recycle. Aniline, water, phenol, and a small quantity of by-product diphenylamines are recovered from the bottom of the column and sent to the drying column, where water is removed.

A key feature of the Halcon process is the use of low pressure distillation (less than 80 kPa = 12 psi) to break the phenol–aniline azeotrope and allow economical separation of aniline from phenol (67).

5. Economic Aspects

Table 3 lists the U.S. producers of aniline and their capacities.

Other suppliers include BASF, Ludwigshafen, Germany and Narmada Chematur Petrochemicals, Gujrat, India.

Table 3. **U.S. Producers of Aniline and their Capacities**[a]

Producer	Capacity $\times 10^6$ kg ($\times 10^6$ lb)
BASF, Geismar, La.	206 (455)
Bayer, New Martinsville, W.Va.	18 (40)
DuPont, Beaumont, Tex.	127 (280)
First Chemical, Baytown, Tex.	113 (250)
First Chemical, Pascagoula, Miss.	154 (340)
Rubicon, Geismar, La.	395 (870)
Sunoco, lronton, Ohio	68 (150)
Total	*1081 (2385)*

[a] Ref. 68.

Table 4. **Specifications for Commercial-Grade Aniline**

	Value		
Property	Minimum	Maximum	Typical analysis
aniline, %	99.9		99.95
nitrobenzene, ppm		2.0	0.1
water, %		0.05	0.03
color[a], APHA		100	30

[a] When freshly distilled, aniline is a colorless oily liquid which darkens on exposure to light or air.

Demand in 2000 was 823×10^6 kg (1815×10^6 lb). Projected demand for 2004 is 959×10^6 kg (2115×10^6 lb). Demand equals production plus imports less exports. Although somewhat depressed by comparison to its performance in recent years, aniline should continue to produce better than GDP growth.

Prices have remained stable over the period 1995–2000. List price was \$0.20–0.23/kg (\$0.45–0.50/lb) tanks, fob, Current price \$0.37–0.39/lb tanks, fob.

6. Specifications

A number of chemical methods can also be used for identification of aniline (69). Table 4 gives the specifications for a typical commercial-grade aniline.

7. Analytical Methods

7.1. Infrared. The infrared spectra of primary amines show a characteristic absorption doublet in the region of 3500 – 3300 cm^{-1} because of the N–H stretching vibrations. Primary amines also show an N–H scissoring absorption in the range of 1650 – 1590 cm^{-1}. Secondary amines have a single N–H stretching absorption band in the 3500 – 3300 cm^{-1} range and the bands associated with the bending vibrations are weak or absent. Tertiary amines, as expected, show no absorption in the N–H region and thus are difficult to identify by infrared spectroscopy.

7.2. Ultraviolet. Benzene has a series of relatively low intensity absorption bands in the region of 230 to 270 nm. When there is a substituent on the ring with nonbonding electrons, such as an amino group, there is a pronounced increase in the intensity of these bands and a shift to longer wavelength. Aniline shows an absorption band at 230 nm ($\varepsilon = 8600$) and a secondary band at 280 nm ($\varepsilon = 1430$). Protonation of the amino groups reduces these effects and the spectrum resembles that of the unsubstituted benzene.

7.3. Nuclear Magnetic Resonance. The nmr spectrum of aromatic amines shows resonance attributable to the N–H protons and the protons of any *N*-alkyl substituents that are present. The N–H protons usually absorb in the δ 3.6–4.7 range. The position of the resonance peak varies with the concentration of the amine and the nature of the solvent employed. In aromatic amines, the resonance associated with N–CH protons occurs near δ 3.0, somewhat further downfield than those in the aliphatic amines.

7.4. Gas Chromatography. Aniline and many of its derivatives are volatile and can be analyzed by gas–liquid chromatography. The method offers a rapid and accurate procedure for determination of aniline in mixtures and is the method of choice for quality control used by producers of aniline.

8. Storage and Handling

The flash point of aniline (70°C) is well above its normal storage temperature; but, aniline should be stored and used in areas with minimum fire hazard (70). Air should not be allowed to enter equipment containing aniline liquid or vapor at temperatures equal to or above its flash point.

Strong oxidizing agents, such as nitric acid, perchloric acid, or ozone may cause aniline to oxidize spontaneously. Hexachloromelamine [2428-04-8] and trichloromelamine [12379-38-3] react violently with aniline, and in confined conditions the mixtures will explore or catch fire.

Aniline is slightly corrosive to some metals. It attacks copper, brass, and other copper alloys, and use of these metals should be avoided in equipment that is used to handle aniline. For applications in which color retention is critical, the use of 400-series stainless steels is recommended.

Aniline is shipped in tank truck and tank car quantities and is classified by the U.S. Department of Transportation (DOT) as a Class B poison (UN 1547), and must carry a poison label.

Wastes contaminated with aniline may be listed as RCRA Hazardous Waste, and if disposal is necessary, the waste disposal methods used must comply with U.S. federal, state, and local water pollution regulations. The aniline content of wastes containing high concentrations of aniline can be recovered by conventional distillation. Biological disposal of dilute aqueous aniline waste streams is feasible if the bacteria are acclimated to aniline. Aniline has a 5-day BOD of 1.89 g of oxygen per gram of aniline.

Aniline can be safely incinerated in properly designed facilities. It should be mixed with other combustibles such as No. 2 fuel oil to ensure that sufficient heating values are available for complete combustion of aniline to carbon dioxide, water, and various oxides of nitrogen. Abatement of nitrogen oxides may be required to comply with air pollution standards of the region.

9. Health and Safety Factors

Aniline is highly toxic and may be fatal if swallowed, inhaled, or absorbed through the skin. Aniline vapor is mildly irritating to the eye, and in liquid form it can be a severe eye irritant and cause corneal damage. The first sign of aniline poisoning is cyanosis, a bluish tinge to the lips and tongue, caused by conversion of the blood hemoglobin to methemoglobin. As methemoglobin concentration of the blood rises above a certain level, death may result from anoxia.

The U.S. Department of Labor (OSHA) has ruled that an employee's exposure to aniline in an 8-h work shift of a 40-h work week shall not exceed an 8-h time-weighted average (TWA) of 5 ppm vapor in air, 2 ppm skin. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a threshold limit value (TLV) of 2 ppm aniline vapor in air, TWA for an 8-h work day (71).

Based on tests with laboratory animals, aniline may cause cancer. The National Cancer Institute (NCI) and the Chemical Industry Institute of Toxicology (CIIT) conducted lifetime rodent feeding studies, and both studies found tumors of the spleen at high dosage (100–300 mg/kg per day of aniline chloride). CIIT found no tumors at the 10–30 mg/kg per day feeding rates. The latter value is equivalent to a human 8-h inhalation level of 17–50 ppm aniline vapor. In a short term (10-d) inhalation toxicity test by Du Pont, a no-effect level of 17 ppm aniline vapor was found for rats. At high levels (47–87 ppm), there were blood-related effects which were largely reversible within a 13-d recovery period (70).

In view of the above, aniline should be handled in areas with adequate ventilation and skin exposure should be avoided by wearing the proper safety equipment. Recommended personal protective equipment includes hard hat with brim, chemical safety goggles, full length face shield, rubber gauntlet gloves, rubber apron, and rubber safety shoes or rubber boots worn over leather shoes.

10. Uses

The major uses of aniline are in the manufacture of polymers, rubber, agricultural chemicals, dyes and pigments, pharmaceuticals, and photographic chemicals. Production of MDI (4,4-methylene diphenyl diisoyanate) accounts for 85% of aniline use. Other uses: rubber processing chemicals, 9%; herbicides, 2%; dyes and pigments, 2%; speciality fibers, 1%; miscellaneous including explosives, epoxy curing agents, and pharmaceuticals, 1%.

New uses for aniline described in recent patents include; aniline disulfide derivatives for treating allergic diseases (72), aniline compound in a hair dye composition and method of dyeing hair (73), and fluorine-containing aniline compounds as a starting material for insecticides (74).

The major consuming use MDI is tied to depressed economic conditions, but MDI growth continues to expand as new uses of polyurethanes are promoted outside traditional construction and refrigeration areas.

11. Methylenedianiline

Commercial production of 4,4′-methylenedianiline [101-77-9] (4,4′-MDA) is carried out by the acid catzlyzed reaction of formaldehyde with aniline. All processes produce polymeric MDA (PMDA), which consists of mixtures of isomers and oligomers of MDA. The amounts of MDA and oligomers are varied to produce products that have different applications. The isomeric distribution and the amount of MDA in the PMDA can be varied within wide ranges, depending on the needs of the consumer. More than 99% of the manufactured PMDA products are used in reactions with phosgene to produce the corresponding isocyanates for use in polyurethanes. The resultant polymeric isocyanates (PMDI) are either sold commercially or are purified to isolate 4,4′-methylenediphenyldiisocyanate (MDI) [101-68-8]. Only 15–20% of the total PMDI manufactured in the United States is consumed in the monomeric form. All of the MDA and PMDA produced is consumed in industries that are “destructive” of MDA’s chemical identity. Thus MDA loses its unique chemical identity and is not encountered by household consumers.

The term MDA is sometimes used for pure 4,4′-MDA as well as the oligomeric mixture PMDA. Similar inconsistencies are encountered for the isocyanate derivatives (MDI and PMDI). Synonyms for 4,4′-methylenedianiline include MDA, 4,4′-MDA, methylenedianiline, 4,4′-methylenebisaniline, dianilinomethane, 4-(4′-aminobenzyl)aniline, 4,4′-diaminodiphenyl-methane, 4,4′-methylene-bis(benzenamine), bis(*p*-aminophenyl)methane, DADPM, DAPM, and DDM. The *p,p*′-and 4,4′-designations are used interchangeably. Synonyms for the oligomeric MDA mixtures include polyaminopolyphenylamine, polymethylenepolyphenylamine, and PMDA. In this section MDA will stand for 4,4′-MDA and/or its isomers, and PMDA is a mixture of MDA and MDA oligomers.

11.1. Physical Properties. The physical and chemical properties of 4,4′-MDA and a typical PMDA are listed in Table 5.

Table 5. **Physical and Chemical Properties of MDA and PMDA**

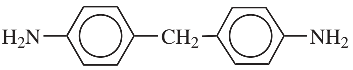
Property	4,4′-MDA	PMDA[a]
CAS Registry Number	[101-77-9]	[25214-70-4]
molecular formula	$C_{15}H_{14}N_2$	
RTECS accession number[b]	BY5425000	
molecular weight	198.3	
active hydrogen equivalent weight	49.6	51
melting point, °C	93	60–80
heat of vaporization, kJ/mol[c]	95.4	
specific heat, J/(g · °C)	2.1	2.1
heat of fusion, kJ/mol[c]	19.6	~19.6
flash point, °C	227	238
boiling point, °C	238 at 1.33 kPa[d]	398 at 101.3 kPa[d]
vapor pressure, Pa[d]	2.7×10^{-5} at 25°C	1.3 at 100°C
density, g/mL	1.070 at 103°C	1.07 at 70°C
viscosity, mPa · s (= cP)	8.3 at 100°C	80 at 70°C
approximate solubility, g/100 mL solvent at 25°C		
acetone	273.0	
benzene	9.0	
carbon tetrachloride	0.7	
ethyl ether	9.5	
methanol	143.0	
water	0.1	

[a] For PMDA containing approximately 70% MDA.

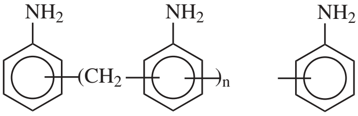
[b] Registry of Toxic Effcts of Chemical Substances.

[c] To conert kJ to kcal, divide by 4.184.

[d] To convert kPa to mm Hg, multiply by 7.5.



4,4′-methylenedianiline (MDA)

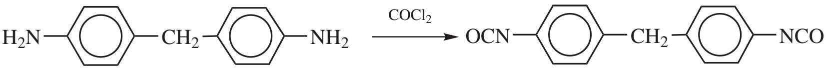


polymeric MDA (PMDA)

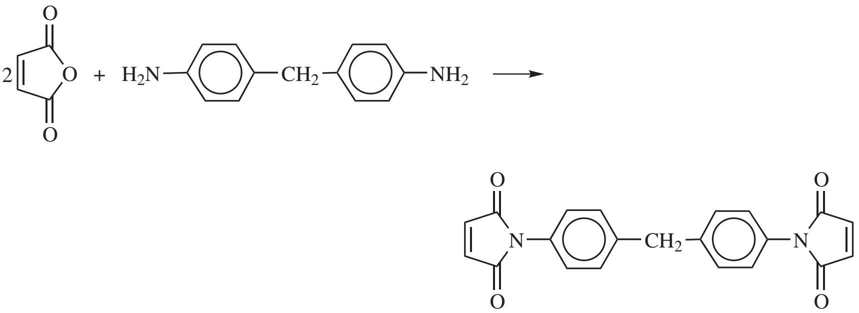
Purified 4,4′-MDA is a light tan to white crystalline solid with a faint aminelike odor. It slowly oxidizes in air with a darkening in color. PMDA mixtures are yellow to brown supercooled liquids or waxy solids.

11.2. Chemical Properties. MDA reacts similarly to other aromatic amines under the proper conditions. For example, nitration, bromination, acetylation, and diazotization (75–77) all give the expected products. Much of the chemistry carried out on MDA takes advantage of the difunctionality of the molecule in reacting with multifunctional substrates to produce low and high molecular weight polymers.

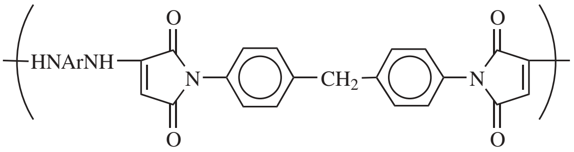
The most important commercial process is the reaction of MDA with an excess of phosgene to form the corresponding isocyanate, 4,4′-methylene-diphenyldiisocyanate, MDI, $C_{15}H_{10}N_2O_2$. The reaction proceeds through the formation of a primary carbamyl chloride that is decomposed with heating and the removal of HCl.



MDA reacts with acid anhydrides to form amides. In the reaction with maleic anhydride both of the amino hydrogens are replaced to form the imide, *N,N′*-(methylenedi-*p*-phenylene) dimaleimide [1367-54-5] $C_{21}H_{14}N_2O_4$.



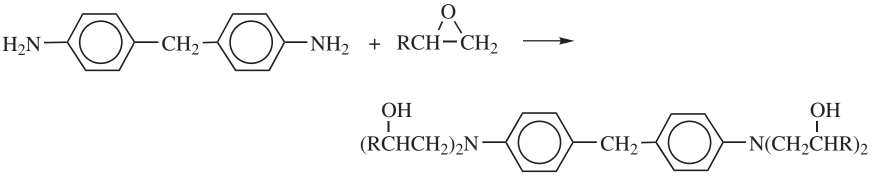
The bismaleimide can then be polymerized by reaction with additional amine to form polyaminobismaleimide or by radiation-induced homopolymerization to form polybismaleimide (78).



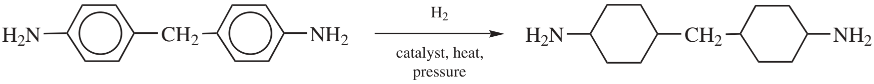
polyaminobismaleimide

The reaction of diphenic anhydride with excess MDA proceeds through an imide ring opening to produce a linear polymer, or it can react with PMDA to form a cross-linked polymer (79).

All of the amine hydrogens are replaced when MDA or PMDA reacts with epoxides to form amine based polyols. These polyols can be used in reactions with isocyanates to form urethanes or with additional epoxide to form cross-linked thermoset resins.



High temperature and high pressure reactions of MDA with hydrogen in the presence of noble metal catalysts convert 4,4′-MDA into bis(4-aminocyclohexyl)-methane (H_{12}MDA) [1761-71-3] ($C_{13}H_{26}N_2$). The products are a mixture of cis and trans isomers that can be controlled to some extent by the proper choice of catalyst and reaction conditions (80–86).



11.3. Manufacture and Processing.

MDA and oligomers (PMDA) are produced by the acid catalyzed condensation of aniline [62-53-3) (C_6H_7N) with formaldehyde [50-00-0] (CH_2O). The reaction does not lead to a single product, but to a mixture of 4,4′-, 2,4′-, and 2,2′-isomers and oligomeric MDAs. The amounts of MDA isomers and oligomers formed depend on the ratios of aniline, formaldehyde, and acid used, as well as the reaction temperature and time. Figure 1 shows a simpplified pathway to the formation of 4,4′-MDA. Similar routes can be drawn for the formation of 2,4′-MDA, 2,2′-MDA, and higher oligomers. The initial reaction of aniline with formaldehyde produces *N*-methylolaniline [61224-32-6] (C_7H_9NO). This product loses water rapidly to form the Schiff base (intermediate A) (86,87). The Schiff base reacts with aniline to form two types of aminals, linear (LA) and cyclic (HHT). The relative amounts of the aminals formed depend on the ratio of aniline to formaldehyde. For example, when aniline: formaldehyde molar ratios of >2:1 are employed, the predominant

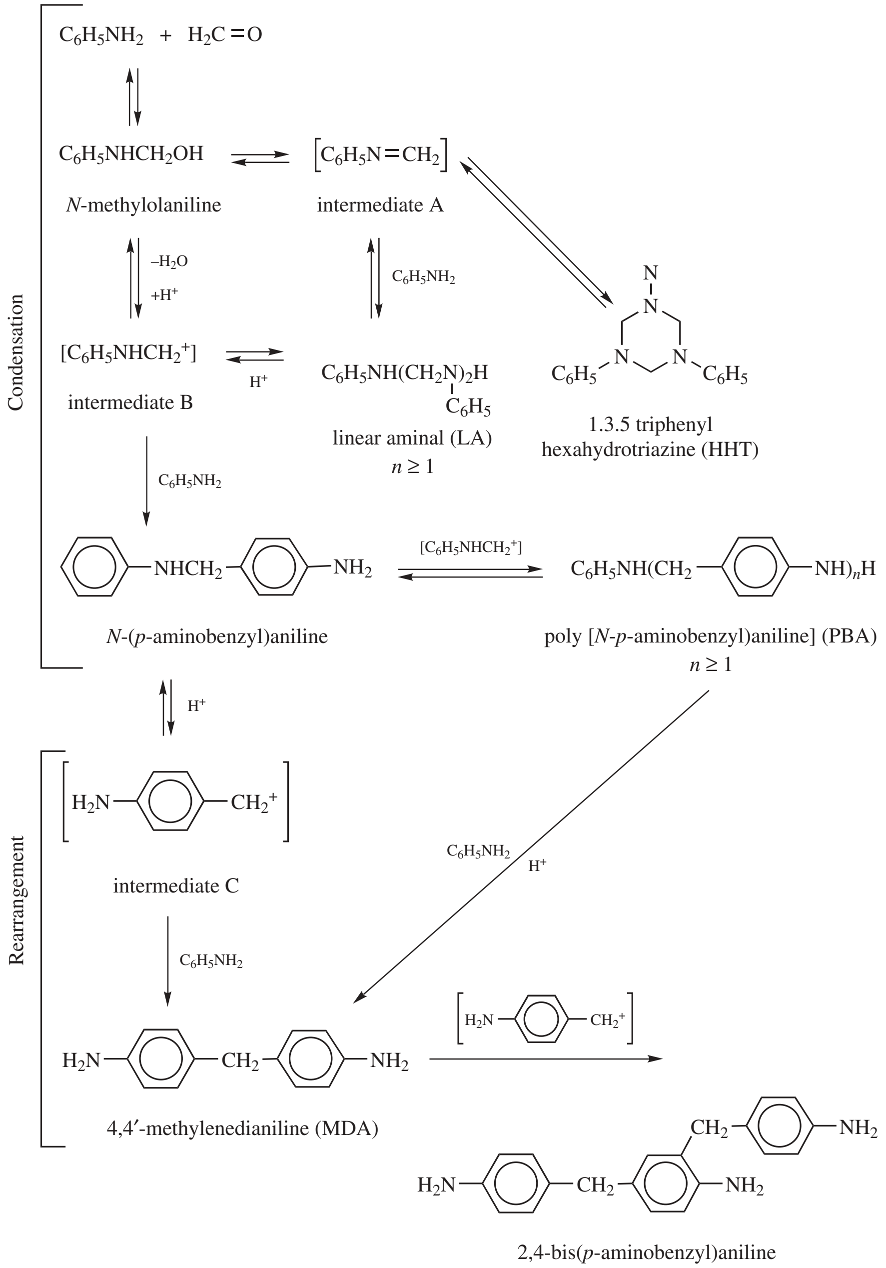


Fig. 1. Reaction of aniline with formaldehyde.

product is the linear aminal with $n = 1$. If the reaction is carried out in base or in neutral solution, the reactions stop at this stage. A process for preparing methylenedianiline by reacting aniline and formaldehyde with or without are and catalyst has been reported (88).

MDA does not form in the absence of acid. The aminals and the *N*-methylolaniline decompose rapidly in acid solution to form an anilinium ion (intermediate B). This reactive intermediate combines with aniline to form *N*(*p*-aminobenzyl)aniline [17272-83-2] ($C_{13}H_{14}N_2$) which reacts with intermediate B in the presence of acid to form oligomeric benzylamines (PBA) that exist in equilibrium with the monomer. The formation of this equilibrium mixture completes the condensation phase of the synthesis. Almost all of the side reactions take place during the condensation phase of the reaction. The typical side products formed are the *N*-methyl and quinazoline derivatives of aniline and MDA (86,89). Commercial processes have been successful in minimizing these side reactions.

The final step (rearrangement stage of the reaction) is decomposition to form the *p*-aminobenzyl carbonium ion (intermediate C) and alkylation of aniline to form 4,4′-MDA. In this step all of the secondary amine intermediates are converted to primary amine final products. Direct alkylation of PBA with aniline has also been hypothesized to form MDA without the formation of intermediate C (90). The formation of MDA is not reversible under normal reaction conditions. Almost all of the other reactions depicted are reversible to some extent. From a commercial standpoint the most important reactions taking place are the formation of oligomers, ie, the reaction of MDA with intermediate C or PBA. It is these reactions, which cannot be suppressed, that are responsible for the current development of MDA technology. MDA is formed slowly during the reaction and therefore is susceptible to further alkylation to form 2,4-bis(*p*-aminobenzyl)aniline [25834-80-4] ($C_{20}H_{21}N_3$). Further alkylations produce an oligomeric mixture.

The reaction of aniline with formaldehyde can be carried out in a single reactor (Fig. 2). However, most commercial processes probably use multiple reactors, which provide greater control of the MDA isomer distribution and oligomeric content of the final product (90–93). Use of hydrochloric acid and high reaction temperatures necessitates the use of corrosion resistant metallurgy. Normally the acid is first mixed with excess aniline, which causes an exotherm. Formaldehyde is then added, with efficient agitation and at low temperatures (<50°C), to the anilinaniline hydrochloride solution. The reaction is usually staged to control the condensation and rearrangement steps. The final reaction temperatures are normally 80–120°C. After completion of reaction, the acidic PMDA is treated with aqueous sodium hydroxide to neutralize the excess acid. A large amount of salt is formed during this step; thus the plants must be located near an outlet capable of handling the generated salt water (normally a seacoast).

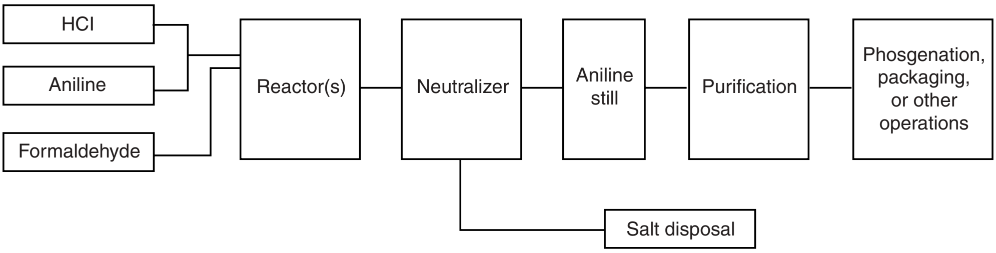


Fig. 2. Methylenedianiline process.

Processes that recycle the acid and eliminate the salt disposal problem have been patented (94,95). The organic layer is then washed with water and stripped to remove unreacted aniline and water. The unreacted aniline is recycled back to the beginning of the reaction. The product may be purified to isolate pure 4,4′-MDA, packaged for shipment, or treated with phosgene to produce the corresponding isocyanate. The 4,4′-MDA is normally sold in flaked or granular form in lined steel drums. Depending on the MDA content, PMDA is sold as a waxy solid or a yellow to brown viscous supercooled liquid in steel drums.

Process parameters can be varied to change the MDA isomer distribution and oligomeric content of PMDA products. Generally, aniline to formaldehyde molar ratios of 2 to 5 are used. To increase the MDA content, higher ratios of aniline to formaldehyde are employed. Increasing the acid to aniline ratio also increases the 4,4′-MDA content of the diamine fraction. Historically, the polyurethane industry consumes as much of the 4,4′-MDI isomer as possible. There has been an increasing demand for higher 2,4′-MDI and 2,4′-PMDI products to be used as replacements for toluenediisocyanate (TDI). Low acid and high aniline to formaldehyde ratios increase the 2,4′-MDA content of the diamine fraction. At the lower aniline to formaldehyde ratios the tendency is to form higher oligomers. The 2,4′-MDA is more reactive toward alkylation than the 4,4′-MDA isomer. Commercial processes do not employ molar excesses of acid to aniline. Acid catalysis is necessary to form MDA, and HCl is the acid of choice. Silica (96), clay (97–99), ethanesulfonic acid (100), and tungsten (101,102) are among the catalysts that have been patented. All of these processes possess some commercial drawbacks, eg, high expense, severe reaction conditions, and/or poor yields of 4,4′-MDA. High reaction temperatures result in a decrease in the MDA content of the product. Reaction time and water content also affect the oligomeric distribution of the product; both should be minimized for maximum MDA formation (103). Water is introduced into the reaction from the hydrochloric acid used to make the aniline hydrochloride solution, from the formaldehyde, which is normally sold in water solution (formalin), and as a reaction product in the condensation phase of the reaction.

Commercially, the PMDA mixtures are normally treated with phosgene to produce the corresponding isocyanates. These isocyanate mixtures, commonly called polymeric MDI (PMDI), are sold directly and have varied chemical compositions. The 4,4′-MDI can be separated from the PMDI products by distillation or crystallization (103,104). The amount of 4,4′-MDI that is removed depends on marketing conditions. The residues are also viable commercial products.

Commercially, a small amount of the 4,4′-MDA is isolated by distillation from PMDA. Depending on the process employed, the removal of MDA can be partial (as is done with the isocyanates) or total. Partial removal of MDA gives some processing latitude but yields of 4,4′-MDA are reduced. Distillation residues from PMDA manufacture that contain less than 1% MDA pose a disposal problem. Processes for the regeneration of MDA by heating these residues in the presence of aniline and an acid catalyst have been patented (105–107). Waste disposal of PMDA is expensive and reclamation processes could become commercially viable. The versatility of the isocyanate process, however, can be used to avoid the formation of low MDA content distillation residues.

Table 6. **U.S. Producers of MDI (Methyl Diphenyl Diisocyanate) and Their Capacities**[a]

Producer	Capacity × 10^6 kg (×10^6 lb)
BASF, Geismar, LA	261 (575)
Bayer, Baytown, TX	229 (505)
Bayer, New Martinsville, WV	73 (160)
Dow Chemical, La Porte, TX	181 (400)
Rubicon, Geismar, LA	381 (840)
Total	*1125 (2480)*

[a] Ref. 108

11.4. Economic Aspects. Table 6 lists the U.S. producers of MDI and their capacities. Quantities are per year of polymeric and pure MDI. A mixture of MDI and its dimer and trimer are produced. Pure MDI is distilled from the mixture and is used for reaction injection molding, thermoplastic elastomers, and adhesives. The polymeric form is used to make rigid and semi-rigid polyurethane foams. The market split is 80% polymeric and 20% pure MDI (108).

Demand has been depressed compared to recent years, but MDI is expected to grow. The major consuming area, rigid foams, is expected to expand, however, as new uses outside the traditional construction and refrigeration sectors are found.

Demand in 2000 was 626×10^6 kg (1382×10^6 lb), projected for 2004 is 773×10^6 kg (1705×10^6 lb). Demand is production plus imports minus exports. Expected growth is 4.1% through 2004 (108).

Prices (1995–2000) $0.60–0.64/kg ($1.34–1.41/lb) list, polymeric, MDI bulk cl frt alld. Current price is $0.64/kg ($1.41/lb), market prices are below list at $0.25–0.34/kg ($0.55–0.75/lb) (108).

11.5. Specifications and Standards. The 4,4′-MDA is sold commercially with a diamine assay of 98–99%. The major impurity the 2,4′-MDA isomer, which can be present in amounts up to 3%. PMDA products are normally defined by hydrogen equivalent weight and viscosity. Typical products exhibit a 50 hydrogen equivalent weight and a viscosity of 80 – 140 mPa · s(= cP) at 70°C. PMDA products normally contain, in addition to the isomers and oligomers of MDA, small amounts of aniline, water, chlorides, and various alkylated amines. All MDA products should be stored in sealed containers in a cool dry area.

11.6. Analytical Methods. The characterizations of MDA and PMDA are similar to those normally used for aromatic amines. In the manufacture of PMDA, the MDA isomer distribution and the formation of side products is determined primarily by gas chromatography (109,110). The amine content is determined by acid titration or diazotization. PMDA oligomeric distributions are determined by hplc or gpc techniques (111) and are estimated by viscosity measurements. Liquid chromatographic and spectrophotometric monitoring methods have been developed to determine ppm to low ppb quantities in workplace environments (111,112) urine (113), reacted polyurethanes (114), and epoxy systems (115). All of the environmental methods of analysis employ a collection technique that is sensitive to the presence of aerosols and are capable of quantitating MDA down to 10 ppb (v/v). OSHA recommends using Method #57 for monitoring purposes (116).

11.7. Health and Safety Factors. All of the toxicity data on MDA have been collected using either 4,4′-MDA or the corresponding hydrochloride salt. The information discussed in this section can also be used for commercial products containing MDA or PMDA. Because MDA is a potentially hazardous chemical, worker exposure shduld be kept to a minimum. For complete health and safety information on MDA consult references 120 and (117–119).

The recommended threshold limit value (TLV) of MDA is 100 ppb for an 8-h time-weighted average (TWA) skin. MDA is a suspected human carcinogen (116,118,119). The oral LD_{50} = 830 mg/kg. In May of 1989 OSHA proposed a new standard for regulating MDA. The proposal cites a permissible exposure limit (PEL) for occupational exposure of MDA to an 8-h TWA of 10 ppb and a STEL (short-term exposure limit) of 100 ppb for a 15-min TWA (121,122). The standard does not apply if initial monitoring shows less than the action level of 5 ppb for an 8-h TWA (airborne) and if no dermal exposure is likely. The employer is required to implement engineering and work practices (eg, respirators) to maintain employee exposure levels at less than or equal to the permissible exposure limit. The proposal also includes having a changing room and showers for changing all contaminated clothing after a work shift; employer laundering of clothing; removal of clothing prior to eating, drinking, smoking, etc; and washing hands and face prior to eating. If food and beverages are consumed in the work area, the employer is expected to provide a positive pressure eating area. All surfaces must be maintained as free as possible from visible accumulations of MDA. The employer is responsible for conducting medical surveillance and record keeping, as well as for conducting periodic monitoring of the area according to existing exposure level guidelines.

The major exposure route in workers who experience MDA poisoning is by skin contact. If there is a likelihood of skin or eye contact, proper protective clothing (including gloves, head coverings, impervious shoes, aprons, coveralls, or other full body clothing) must be worn. Skin absorption is increased if the MDA is dissolved in an organic solvent. Face shields and/or goggles should be worn where appropriate. Care must be taken to minimize contamination of individuals and their personal environment from exposure to MDA. The low vapor pressure of MDA poses a minimum risk of MDA inhalation. However, grinding and drumming of MDA produces dust and vapors, which can cause inhalation problems. In addition, many operations require heating MDA to keep the material molten. It is therefore recommended that respirators be worn while handling MDA to keep exposures to a minimum.

There are no reports of cancer in humans as a result of MDA exposure. Acute exposures of MDA have caused epigastric pain, fever, jaundice, and other symptoms consistent with hepatitis. These effects, however, appear to be reversible. No liver damage has yet been observed from chronic exposure to MDA. Skin sensitivity and staining occurs in some individuals. In animals, chronic administration of MDA produces hepatic cirrhosis, liver lesions, and enlargement of the spleen, liver, and kidneys. MDA has also proved to be carcinogenic in rats and mice, causing liver and thyroid tumors. No cancers have been formed in dogs. Structurally similar compounds have been shown to cause cancer in laboratory animals (119). If appreciable amounts of MDA are swallowed, vomiting should be induced. If eye exposure does occur, the eyes should be flushed with water for 30 min. Skin exposures should be washed with soap and water. Medical attention should be obtained promptly whenever an exposure occurs. There are always dangers involved with the misuse of any chemical. However, with attention to proper work practices and policies, this valuable intermediate can be utilized safely.

11.8. Uses. More than 99% of all the PMDA produced is used directly in the manufacture of the corresponding isocyanates (MDI and PMDI). Two types of isocyanates are sold, monomeric (MDI) and polymeric (PMDI). The PMDI products are available commercially in varying viscosities from 50 to 2000 mPa · s (= cP), containing from 25 to 60% monomeric MDI. The major use for PMDI products (80%) is in the manufacture of rigid foam, which is primarily used in housing and refrigeration insulation applications. (construction, 50%; refrigeration, 12%; packaging 18%; tank and pipe insulation, 3%; other uses include transportation marine flotation and furniture, 7%) (108). Other uses for PMDI products include reaction-injection molding applications, 13%; cast elastomers, 2%; miscellaneous uses are in thermoplastic resins and foundry core binders, 5% (108). MDI contains approximately 98% of the 4,4′-isomer and is used to manufacture thermoplastic resins (eg, films, gaskets, tubing), spandex fibers, and coatings. Because MDI is a solid at room temperature, a significant portion of the commercially produced pure MDI is converted to liquid products by either modifying the MDI with carbodiimide linkages or reaction with polyols to produce isocyanate terminated prepolymers. These products are used in automotive reaction injection molding (RIM), coatings, and recreation and military applications. MDI and PMDI products containing more than 10% of the 2,4′-MDI isomer are becoming available for use in nonrigid foam applications. These products are able to compete with toluenediisocyanate (TDI) in physical properties of the final products without the severe handling limitations normally needed for TDI. Nonisocyanate uses for MDA or PMDA include epoxy resin curing agents, wire coating applications, plastic fibers, polyurethane coreactants, an intermediate for pigments and dyes, intermediates for the preparation of polyamide–imide resins, reinforced composite materials, and military applications. Perhydrogenated 4,4′-MDA (H_{12}MDA or PACM) is used in light-stable elastomers and coatings. The H_{12}MDA is converted to the corresponding isocyanate, bis(4-isocyanatocyclohexyl) methane [5124-30-1] ($C_{15}H_{22}N_2O_2$) or H_{12}MDI, and is used in automotive safety glass and biomedical applications.

12. Other Derivatives

Most derivatives of aniline are not obtained from aniline itself, but are prepared by hydrogenation of their nitroaromatic precursors. The exceptions, for example, *N*-alkylanilines, *N*-arylanilines, sulfonated anilines, or the *N*-acyl derivatives, can be prepared from aniline and have been discussed. Nitroanilines are usually prepared by ammonolysis of the corresponding chloronitrobenzene. Special isolation methods may be required for some derivatives if the boiling points are close and separation by distillation is not feasible. Table 7 lists some of the derivatives of aniline that are produced commercially.

Table 7. **Aniline Derivatives**

Class of compound and common name	Molecular formula	CAS Registry Number	Condensed structural formula	Appearance	Melting point, °C	Boiling point, °C	Commercial derivatives and uses
salts							
aniline hydrochloride	$C_6H_7N{\cdot}ClH$	[142-04-1]	$C_6H_5NH_2{\cdot}HCl$	white solid	198	245	Aniline black
aniline sulfate	$C_6H_7N{\cdot}1/2H_2O_4S$	[542-16-5]	$(C_6H_5NH_2)_2{\cdot}H_2SO_4$	white crystals			sulfanilic acid
N-alkyl, *N*-aryl							
N-methylaniline	C_7H_9N	[100-61-8]	$C_6H_5NHCH_3$	yellow liquid	−57	194.6	
N,N-dimethylaniline	$C_8H_{11}N$	[121-69-7]	$C_6H_5N(CH_3)_2$	yellow liquid (darkens in air)	2	193−194	vanillin; Michler's ketone; alkylating agents; dyes
N-ethylaniline	$C_8H_{11}N$	[103-69-5]	$C_6H_5NHC_2H_5$	colorless liquid (darkens in air)	−63.5	204.7	explosive stabilizer; dyes
N,N-diethylaniline	$C_{10}H_{15}N$	[91-66-7]	$C_6H_5N(C_2H_5)_2$	pale yellow liquid	−38.8	215−216	alkylating agent
N-benzyl-*N*-ethylaniline	$C_{15}H_{17}N$	[92-59-1]					
$C_6H_5N(C_2H_5)CH_2C_6H_5$	light yellow oil		314	triphenylmethane dyes			
diphenylamine	$C_{12}H_{11}N$	[122-39-4]	$C_6H_5NHC_6H_5$	white crystals, floral odor	54−55	302	rubber antioxidants; phenothiazine
C-alkyl							
o-toluidine	C_7H_9N	[95-53-4]	$H_3CC_6H_4NH_2$	yellow liquid (darkens in air)		200−202	triphenylmethane dyes; safranine colors
m-toluidine		[108-44-1]		colorless liquid	−30.4	203−204	dyes

Table 7 (*Continued*)

Class of compound and common name	Molecular formula	CAS Registry Number	Condensed structural formula	Appearance	Melting point, °C	Boiling point, °C	Commercial derivatives and uses
p-toluidine		[106-49-0]		white crystals	44–45	200–201	Basic Red 9; Acid Green 25
2,3-xylidine	$C_8H_{11}N$	[87-59-2]	$(H_3C)_2C_6H_3NH_2$	liquid		221–222	
2,4-xylidine		[95-68-1]		liquid	16	214	Solvent Orange 7; Direct Violet 14
2,5-xylidine		[97-78-3]		oily liquid	15.5	213.5	*p*-xyloquinone; Red 26; Direct Violet 7
2,6-xylidine		[87-62-7]		colorless liquid	11–12	216–217	formerly in dyes
3,4-xylidine		[95-64-7]		solid	51	226	synthetic riboflavin
3,5-xylidine		[108-69-0]		oil	9.8	220–221	azo dyes
C-alkoxy							
o-anisidine	C_7H_9NO	[90-04-0]	$H_3COC_6H_4NH_2$	yellow liquid (darkens in air)	5–6	225	guaiacol synthesis; Direct Red 24; Solvent Red 1
m-anisidine		[536-90-3]		oily liquid	−1 – 1	251	
p-anisidine		[104-94-9]		white solid	57	243	dyes
o-phenetidine	$C_8H_{11}NO$	[94-70-2]	$H_5C_2OC_6H_4NH_2$	oily liquid		231–233	dyes
p-phenetidine		[156-43-4]		liquid (darkens in air)	3–4	254–255	phenacetin; phenocoll; rubber antioxidant; dyes
p-cresidine	$C_8H_{11}NO$	[120-71-8]	$H_3CO(CH_3)C_6H_3NH_2$	white crystals	52–54	235	FD&C Red 40
N-acyl							
formanilide	C_7H_7NO	[103-70-8]	$HCONHC_6H_5$	white crystals	50	271	analgesic and antipyretic
acetanilide	C_8H_9NO	[103-84-4]	$CH_3CONHC_6H_5$	colorless crystals	114.3	304	intermediate for sulfa drugs; hydrogen peroxide stabilizer; azo dyes

acetoacetanilide	$C_{10}H_{11}NO_2$	[102-01-2]	$CH_3COCH_2CONHC_6H_5$	white crystals	86		intermediate for pyrazolones and pyrimidines; Hansa yellows; benzidine yellow pigments
chloroanilines							
2-chloroaniline	C_6H_6ClN	[95-51-2]	$ClC_6H_4NH_2$	colorless liquid	−14	208–210	dyes
3-chloroaniline		[108-42-9]		colorless liquid	−10	230–231	dyes
4-chloroaniline		[106-47-8]		colorless liquid	72.5	232	azoic dye coupling Component 10 and 15
2,5-dichloroaniline	$C_6H_5Cl_2N$	[95-82-9]	$Cl_2C_6H_3NH_2$	needle crystals	51	251	dyes
3,4-dichloroaniline		[95-76-1]		white crystals	71.5	272	herbicides; dyes
sulfonated anilines							
orthanilic acid	$C_6H_7NO_3S$ dyes	[88-21-1]	$H_2NC_6H_4SO_3H$	colorless crystals		>320 dec	
metanilic acid		[121-47-1]		white crystals	dec		Acid Yellow 36, Direct Yellow 44 dyes
sulfanilic acid		[121-57-3]		white crystals	288		Acid Orange 1; Food Yellow 3 dyes
nitroanilines							
2-nitroaniline	$C_6H_6N_2O_2$	[88-74-4]	$O_2NC_6H_4NH_2$	golden crystals	71–72	284	Vat Orange 7 and Red 14 dyes
3-nitroaniline		[99-09-2]		yellow crystals	114	305–307 dec	synthetic intermediate; dyes
4-nitroaniline		[100-01-6]		pale yellow crystals	148–149	332	dyes; intermediate for 1,4-phenylenediamine
2,4-dinitroaniline	$C_6H_5N_3O_4$	[97-02-9]	$(O_2N)_2C_6H_3NH_2$	yellow crystals	187–188		Pigment Orange 5; dyes
2,4,6-trinitroaniline	$C_6H_4N_4O_6$	[489-98-5]	$(O_2N)_3C_6H_2NH_2$	yellow solid	192–195	explodes	explosives; detonators

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