Using this method a known weight of dimethylaniline was determined to the extent of 100.3% and a mixture of dimethylaniline and dimethyl-*p*-toluidine to the extent of 99.2%.

Summary

1. A method of separation, determination and subsequent isolation of primary, secondary and tertiary amines in a mixture of ring- and nitrogen-methylated aromatic amines was developed using a modified Hinsberg reaction with a mixture of pyridine and benzene as the solvent. On synthetic mixtures containing five primary, three secondary and two tertiary amines the method has an accuracy expressed as a standard deviation (absolute per cent.) of ±1.6% for the primary amines, ±2.3% for the secondary amines and ±0.3% for the tertiary amines.

2. The Hinsberg method, when applied to the amines in question in an aqueous medium in the usual manner, involves side reactions and lack of complete reaction which vitiate it as a quantitative method. With synthetic mixtures of amines such as were used in this work, low values were obtained for primary amines, high values for tertiary amines and erratic values for secondary amines.

3. Increasing methylation of the ring for the primary amines in question results in sulfonamides which are of decreasing acidity, as indicated by the tendency to hydrolyze in alkaline solution to yield benzene-extractable sulfonamides, and from which it is increasingly difficult to regenerate the amines with hydrochloric acid.

4. Solutions of the amines in excess acid may be titrated potentiometrically and a fairly sharp "break" obtained at the point of neutralization of the excess acid provided the solution has previously been saturated with sodium chloride.

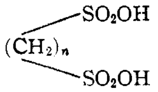
Bound Brook, N. J. Received March 28, 1945

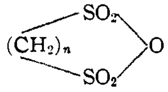
[Contribution from the Laboratory of Organic Chemistry of the University of Wisconsin]

Ethane-1,2- and Propane-1,3-disulfonic Acids and Anhydrides

By S. M. McElvain, Arthur Jelinek[1] and Kurt Rorig

In connection with some other work in this Laboratory, it became necessary to prepare ethane-1,2-disulfonic acid (I, $n = 2$). This acid has previously been obtained in a number of ways, either by direct preparation or as an oxidation product isolated in the characterization of other substances.[2] The melting point of the acid has been variously reported as 104,[3] 100[4] and 97°.[5]


I


II

The most direct method of preparation of this acid involves its isolation from the sodium salt which may be obtained in high (*ca.* 90%) yields from the Strecker reaction with ethylene bromide and sodium sulfite.[6] This method was used in the work now reported and the free acid was isolated from the sodium salt by first converting this salt to the barium salt and then decomposing the latter with sulfuric acid.

The acid obtained in this manner is a light gray powder which melts, after drying at 40° at 1 mm. for five hours or at 140° at atmospheric pressure for four hours, at 111–112°. This acid, however, has a neutral equivalent corresponding to the dihydrate; on short exposure to air it absorbs sufficient moisture to lower the melting point well below 100°. When this hydrated acid is further dried at 145° and 1 mm. pressure for six hours, the anhydrous acid with the correct neutral equivalent and sulfur content is obtained. The anhydrous acid melts sharply at 172–174°; in contrast to the hydrated acid it is somewhat soluble in anhydrous ether and quite soluble in dioxane. Unless special precautions are taken in handling or storing the anhydrous acid, it absorbs sufficient moisture from the air to lower the melting point considerably.

When the molten, anhydrous acid is heated in a sublimation apparatus at 190–200° and 1 mm. pressure, the cyclic anhydride (II, $n = 2$) slowly condenses in the cooled portion of the apparatus. Further evaporations and condensations of this condensate give the pure anhydride which melts at 145–146°. Approximately 20% of the original acid remains as a charred residue from the initial evaporation. This is probably the result of formation of a non-volatile, intermolecular anhydride. Ethane-1,2-disulfonic anhydride (II, $n = 2$) rapidly absorbs moisture from the air and dissolves readily in cold water.

Ethanedisulfonyl chloride is probably the most thoroughly investigated derivative of ethanedisulfonic acid. It is readily prepared by the action of phosphorus pentachloride on the sodium salt of the acid. Kohler[4] was the first to observe that this acid chloride reacted with water and alcohols to

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[1] Wisconsin Alumni Research Foundation Research Assistant, 1941–1944.

[2] Suter, "The Organic Chemistry of Sulfur," John Wiley and Sons, Inc., New York, N. Y., 1944, p. 167.

[3] Miolati, *Ann.*, **262**, 61 (1891).

[4] Kobler, *Am. Chem. J.*, **19**, 728 (1897).

[5] Zuffanti and Hendrickson, This Journal, **63**, 2999 (1941).

[6] Refs. 4 and 5; *cf.* also Bender, *Ann.*, **148**, 96 (1868), James, *J. Chem. Soc.*, **43**, 44 (1883), and Autenrieth and Rudolf, *Ber.*, **34**, 3473 (1901).

yield, mainly, ethylenesulfonic acid, $CH_2{=}CH\text{-}SO_3H$, sulfur dioxide and hydrogen chloride instead of the parent disulfonic acid. In the present work it has been found possible to convert this acid chloride into the corresponding disulfonic acid by heating with 20% fuming sulfuric acid at 120°. The theoretical amount of chlorosulfonic acid for the reaction

$$(CH_2SO_2Cl)_2 + 2H_2SO_4 \longrightarrow (CH_2SO_3H)_2 + 2ClSO_2OH$$

distils from the reaction mixture and about 52% of ethanedisulfonic acid may be recovered from the residue.

Esters of ethanedisulfonic acid cannot be prepared from the acid chloride; an alcohol in the presence of pyridine or a sodium alkoxide produces ethylenesulfonic acid and sulfur dioxide, as does direct hydrolysis or alcoholysis. Heretofore, the esters have been prepared from the silver salt of the acid and an alkyl iodide, *e. g.*, ethyl iodide. It has been found possible in the present work to prepare the ethyl ester directly by the reaction of the anhydrous acid in ether solution with ketene diethylacetal. The yields of the diester are not high (*ca.* 40%), but this is probably due to the separation of the intermediate (III) from the reaction medium so that esterification of the second sulfonic acid group and the formation of IV is hindered. These intermediate products are stable at the boiling point of ether, but decompose at about 100° into ethyl acetate and the sulfonic esters.

$$(CH_2SO_3H)_2 + CH_2{=}C(C_2H_5)_2 \longrightarrow$$

$$\underset{\text{III}}{CH_3C(OC_2H_5)_2O_3SCH_2CH_2SO_3H} \xrightarrow{CH_2{=}C(OC_2H_5)_2}$$

$$\underset{\text{IV}}{CH_3C(OC_2H_5)_2O_3SCH_2CH_2SO_3C(OC_2H_5)_2CH_3}$$

$$\text{III and IV} \xrightarrow{100^\circ} C_2H_5O_3SCH_2CH_2SO_3H + (CH_2SO_3C_2H_5)_2 + CH_3COOC_2H_5$$

When the order of mixing of the reactants was reversed, *i. e.*, the acid added to the ketene acetal so that an excess of the latter was present to favor the formation of IV, considerable amounts of ethyl O-ethylacetoacetate and higher polymers of the acetal[7] were formed. In contrast to the incomplete esterification of the disulfonic acid with ketene acetal, the monobasic acid, ethylenesulfonic acid, is converted into its ethyl ester in 70–80% yields by this reagent.

Zuffanti and Hendrickson[5] reported propane-1,3-disulfonic acid (I, $n = 3$) to be a liquid *boiling* at 157° (1.4 mm.). In view of the properties described above for ethane-1,2-disulfonic acid it seemed advisable to prepare this acid and determine whether it could be converted into the corresponding cyclic anhydride (II, $n = 3$). The application of the Strecker reaction to trimethylene bromide gave a 56% yield of sodium propane-1,3-disulfonate contaminated with small amounts of sodium bromide. The barium salt of this acid, in contrast to the ethane homolog, is too soluble in water to be used in the isolation of the free acid. This acid was prepared by saturating a concentrated aqueous solution of the sodium salt with hydrogen chloride and, after filtration of the precipitated sodium chloride, evaporation of the aqueous solution under diminished pressure.

The light brown *solid* acid so obtained was very hygroscopic; exposure to the air for a short time changed a granular sample to a sirup. This affinity for moisture made the determination of the melting point of the acid difficult and the best value obtained was 120–125°. Zuffanti and Hendrickson[5] obtained their liquid acid by decomposition of a methanol solution of the sodium salt with hydrogen chloride. Repetition of this procedure yielded the same solid product as was obtained from the aqueous solution. The neutral equivalent of this product indicated that it contained one molecule of water of hydration.

When the molten acid was heated in a sublimation apparatus at 150–170° and 0.2 mm. pressure, a solid anhydride, melting at 193–196° and having the correct neutral equivalent and sulfur content for II ($n = 3$), was obtained in 60–69% yields. In contrast to the corresponding ethane homolog, the propanedisulfonic anhydride is not noticeably hygroscopic and does not dissolve in cold water, but is slowly dissolved (in about fifteen minutes) by boiling water. This behavior corresponds to that of the only other aliphatic disulfonic anhydride which appears to have been reported in the literature. The six-membered ring anhydride, $\underline{O_2SCH_2C(CH_3){=}CHSO_2O}$, obtained by Suter and Malkemus[8] by the action of thionyl chloride on 2-methylpropylene-1,3-disulfonic acid, was found to have a low hygroscopicity and to be quite resistant to hydrolysis.

An attempt to prepare the pure propanedisulfonic acid from an aqueous solution of its anhydride was unsuccessful. When the water was removed at room temperature under low pressure (1.0 mm. or less) the white crystalline acid still contained some water of hydration as shown by the neutral equivalent; when this hydrated acid was heated to higher temperatures (not over 100°) under low pressure, it rapidly changed to a brown mass from which no satisfactory product could be isolated.

Thionyl chloride was found to be a very satisfactory reagent for the dehydration of the hydrated ethane- and propanedisulfonic acids. Although these acids are insoluble in this reagent, each of them is converted by it at the refluxing temperature into the anhydrous acid after about two hours, and into the anhydride after about twelve hours. Since the yields of these products are practically quantitative, this method of dehydration is to be preferred over the more tedious and destructive evaporation under low pressure described above.

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[7] McElvain and Kundiger, THIS JOURNAL, **64**, 254 (1942).

[8] Suter and Malkemus, THIS JOURNAL, **63**, 978 (1941).

Experimental

Ethane-1,2-disulfonic Acid.—To a rapidly stirred and boiling solution of 600 g. of sodium sulfite in 2 liters of water was added 450 g. of ethylene bromide over a period of two hours. The solution then was refluxed for an hour after the organic layer had disappeared. On cooling the resulting aqueous solution to 5° crystals of sodium ethanedisulfonate separated and were filtered off. To the filtrate was added 310 g. of sodium sulfite and the above process repeated with the addition of 230 g. of ethylene bromide. After removal of the second crop of crystals, the filtrate was evaporated to incipient crystallization, cooled to 0° and the third crop of crystals separated. The three crops of crystals were combined and recrystallized from water by dissolving in the minimum quantity of boiling water. The yield of sodium ethanedisulfonate after drying at 140° amounted to 746 g. (88%).

A hot saturated aqueous solution of 100 g. of this salt was treated with a hot saturated aqueous solution of 105 g. of barium chloride dihydrate. The heavy granular precipitate which separated was filtered from the cooled solution and washed free of chloride ions. The barium salt was suspended in water and treated with an equivalent of sulfuric acid and, after filtering off the precipitated barium sulfate on a sintered glass funnel, the filtrate was evaporated to dryness on a steam-bath. The residue (about 50 g.) was recrystallized from acetic acid containing a small amount (5–10%) of acetic anhydride. A yield of 40–45 g. (41–46%) of the ethane-1,2-disulfonic acid dihydrate, m. p. 111–112°, neutral equivalent 114 (calcd. 113), was obtained.

This dihydrate was quantitatively converted to the anhydrous ethane-1,2-disulfonic acid, m. p. 172–174°, neutral equivalent 96.5 (calcd. 95), when heated at 145° and 1.0 mm. pressure for six hours.

Anal. Calcd. for $C_2H_6O_6S_2$: S, 33.7. Found: S, 33.8.

Ethane-1,2-disulfonic Anhydride.—A 4-g. sample of the anhydrous ethane-1,2-disulfonic acid was placed in an 8" × 1$^1/_4$" sublimation tube held at an angle of about 25° by a metal cooling jacket that surrounded the upper half of the tube. The lower portion of the tube containing the acid was heated at 190–200° and 1 mm. pressure so long as solid material condensed on the cooled portion of the tube (about six hours). This condensate was scraped out and placed in a clean tube and again heated at the same pressure but at 150–160°. The condensate from this evaporation was removed and the heating of the residue continued at 190–200°. The condensate from this latter evaporation was reheated at 150–160° and condensed. After several of these alternate high and low temperature evaporations, 2.4 g. (66%) of the anhydride was collected. This product melted at 139–142° and had a neutral equivalent of 88 (calcd. 86). After trituration of the anhydride with anhydrous ether to remove traces of the sulfonic acid, the anhydride melted at 145–146° and had a neutral equivalent of 87.

Anal. Calcd. for $C_2H_4O_5S_2$: S, 37.2. Found: S, 37.0.

Ethane-1,2-disulfonic Acid from Ethane-1,2-disulfonyl Chloride.—In a 125-ml. flask connected to a condenser by a glass joint was placed 50 g. of the ethanedisulfonyl chloride[1] and 100 ml. of 20% fuming sulfuric acid. This mixture was heated in an oil-bath at 120° for eight hours. The pressure in the system then was lowered to 12 mm. whereupon 51 g. (100%) of chlorosulfonic acid distilled out at 65–72°. After standing overnight a finely divided solid separated from the sulfuric acid remaining in the reaction flask. The sulfuric acid was cooled to 0° and filtered through a sintered glass filter. The collected precipitate was the anhydrous ethane-1,2-disulfonic acid as shown by its solubility in absolute ether (neither the dihydrate nor the anhydride are soluble in this solvent). The acid was dissolved in water, sulfate ions were removed with barium hydroxide and, after removal of the barium sulfate, the solution was evaporated to dryness. After drying at 100°, the residue of the disulfonic acid dihydrate weighed 25.8 g. (52%) and melted at 109–111°.

Ethyl Ethane-1,2-disulfonate.—To a rapidly stirred suspension of 5.7 g. of the anhydrous acid in 25 ml. of absolute ether was added dropwise a solution of 8.1 g. of ketene diethylacetal in 25 ml. of ether over a period of about five minutes. An insoluble oil began to appear immediately beneath the ether. After the acetal had been added the ether was removed from the reaction mixture by distillation from a steam-bath. When no more ether distilled over, the oily residue in the flask was carefully heated with a free flame whereupon a mixture of ether and ethyl acetate distilled over. The residue from this distillation was triturated with cold ether and the ethereal solution washed several times with water. After drying and removing the ether 3 g. (41%) of the ethyl ester, m. p. 76–78°, remained. Sublimation of this material at 80° and 1 mm. pressure gave a product melting at 78–79° which was identical with a sample of the ester prepared by the reaction of silver ethanedisulfonate with ethyl iodide.[4]

Ethyl Ethylenesulfonate.—When the above esterification procedure with ketene acetal was applied to a 6.5 g. sample ethylenesulfonic acid,[4] 3.7 g. (77%) of ethyl acetate and 6.1 g. (75%) of ethyl ethylenesulfonate, b. p. 95–96° (14 mm.), $n^{20}\text{D}$, 1.4300, were isolated as reaction products. This sulfonic ester was identical with the one prepared from the silver salt of the acid and ethyl iodide. The preparation of this ester in 17% yield from ethylene sulfonyl chloride and ethyl alcohol in aqueous sodium hydroxide solution was recently reported.[9]

Propane-1,3-disulfonic Acid and Anhydride.—To a vigorously stirred and boiling solution of 165 g. of sodium sulfite in 550 ml. of water was added 132 g. of trimethylene bromide over a period of one and a half hours. After another hour of refluxing and stirring the organic layer had disappeared. On cooling to 0° no salt crystallized from the solution. The solution was again heated to boiling, 88 g. of sodium sulfite and 70 g. of trimethylene bromide added and the mixture refluxed overnight. After cooling to room temperature, 46.5 g. of separated crystals was filtered off. The filtrate was treated with 10 ml. of 40% hydrobromic acid to destroy any remaining sulfite and then evaporated on a steam-bath until crystals began to appear in the hot solution. On cooling to room temperature a second crop of crystals (86.6 g.) separated and was filtered off. After deducting the weight of sodium bromide (Volhard titration) in these two crops of crystals, a 56% yield of the disodium propane-1,3-disulfonate was obtained. Recrystallization of the sulfonate from a minimum quantity of hot water removed the sodium bromide.

A solution of 3.32 g. of the disodium sulfonate in 10 ml. of water was saturated with hydrogen chloride. The precipitated sodium chloride was filtered off on a sintered glass funnel and the filtrate evaporated to a sirup on a steam-bath. This sirup, after heating at 100° and 0.2 mm. pressure for three days, was converted to 2.15 g. of light-brown, hygroscopic crystals of a propane-1,3-disulfonic acid hydrate that melted with previous sintering at 120–125° and had a neutral equivalent of 107 (calcd. for the anhydrous acid, 102). When the sirup was dried at this pressure but at room temperature for three to eight days, the acid was obtained as white crystals that showed a neutral equivalent of 114 (see below for the preparation of the anhydrous acid with thionyl chloride).

Heating of the propanedisulfonic acid in the sublimation apparatus at 160–165° and 0.2 mm. slowly converted it to the anhydride which condensed in the cooled portion of the tube. It was necessary to cover the acid with a plug of glass wool to prevent spattering of the molten acid onto the anhydride condensate. From 0.75 g. of the disulfonic acid, 0.47 g. of the anhydride, m. p. 180–190° dec., neutral equivalent 94.8 (calcd. 93), was obtained. Resublimation of this anhydride for an analytical sample gave a product that melted at 193–196° dec.; neutral equivalent, 92.8.

Anal. Calcd. for $C_3H_6O_5S_2$: S, 34.4. Found: S, 34.5.

Dehydration of the Sulfonic Acids with Thionyl Chloride.—A mixture of 1.02 g. of the hydrated propanedisul-

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(9) Alderman and Hanford, U. S. Patent 2,348,705.

fonic acid and 10 ml. of thionyl chloride in a flask with a glass joint reflux condenser was heated at the refluxing temperature of the latter compound for two hours. After cooling, the thionyl chloride was removed by distillation and the residue dried at room temperature and 1.0 mm. pressure for two hours. The **propane-1,3-disulfonic acid** so obtained weighed 0.91 g., was a light gray powder that melted at 120–124°, and had a neutral equivalent of 103 (calcd. 102).

Anal. Calcd. for $C_3H_8O_6S_2$: S, 31.4. Found: S, 31.3.

A sample of ethane-1,2-disulfonic acid dihydrate, m. p. 110–112°, treated in a similar manner was quantitatively converted into the anhydrous acid, m. p. 172–174°. A 0.68-g. sample of the dihydrate after twelve hours refluxing with thionyl chloride was converted into 0.51 g. (97%) of the ethane disulfonic anhydride, m. p. 140–143°; neutral equivalent 88. By a similar treatment the hydrated propane-1,3-disulfonic acid was converted into the corresponding anhydride, m. p. 194–196°; neutral equivalent, 94.5.

Summary

The properties of the anhydrous ethane-1,2- and propane-1,3-disulfonic acids are described. Each of these acids may be converted into the corresponding cyclic anhydride either by heat or by the action of thionyl chloride.

Ethane-1,2-disulfonyl chloride is converted by fuming sulfuric acid into the parent disulfonic acid.

The esterification of ethane-1,2-disulfonic acid and ethylenesulfonic acid is satisfactorily accomplished with ketene diethylacetal.

MADISON, WISCONSIN RECEIVED JUNE 20, 1945

[CONTRIBUTION FROM THE RESEARCH LABORATORY OF RALPH L. EVANS ASSOCIATES]

N-Alkylethylenediamines

BY FRED LINSKER AND RALPH L. EVANS

Since the direct monoalkylation of ethylenediamine had been reported as unsuccessful by Schneider,[1] the synthesis of alkylethylenediamines was repeatedly attempted through indirect methods. A summary of the previous work in this field is given by Aspinall,[2] who in the same paper presented a novel approach to the problem.

Recently it was observed in this Laboratory[3] that reactive aromatic halogen compounds such as *o*- and *p*-nitrochlorobenzene could be condensed with substantially anhydrous ethylenediamine to give good yields of the expected mono- and *sym*-di-N-substituted ethylenediamines depending upon the ratio of starting materials used. In accordance with these findings it was believed that alkyl halides would react in a similar fashion with anhydrous ethylenediamine and a series of experiments was conducted to verify this assumption.

Diverging from Schneider's unsuccessful use of alkyl iodides on 70% ethylenediamine, we worked with alkyl chlorides and bromides and highly concentrated (95%) ethylenediamine. The latter can be prepared easily by several convenient methods from the commercially available (65–70%) product. Recommended are the dehydration with sodium hydroxide[4] and the heat decomposition of the ethylenediamine–zinc oxalate compound.[5]

Experimental

Preparation.—The condensation may be effected by refluxing the mixture of the two components as such or in a solvent such as ethyl alcohol or *n*-butanol. A large excess of ethylenediamine is used in order to avoid the formation of other than the monoalkyl derivatives and to bind the hydrochloric acid which is formed in the reaction. The procedure followed for N-*n*-octyl-ethylenediamine is typical. To 5 g. (0.08 mole) of ethylenediamine (95%) and 3.1 g. (0.02 mole) of *n*-octyl chloride was added sufficient absolute ethyl alcohol (40 cc.) to dissolve the two immiscible liquids. The solution was refluxed for three hours in an oil-bath and ethyl alcohol was evaporated, causing the residual liquid to separate into two layers. The upper layer was separated, 30 cc. of water added and the precipitated white solid was extracted with ether. The ether extract was dried over anhydrous sodium sulfate and the solvent evaporated; yield 3 g. In order to remove the last traces of unchanged ethylenediamine, the crude product was suspended in 20 cc. of water and the ether extraction repeated.

The dihydrochloride was prepared by bubbling dry hydrogen chloride through the solution of the base in dry ether.

The dipicrate was formed in alcoholic medium and recrystallized in this case from water; in all other cases from alcohol.

While in the case of the saturated alkyl halides studied, the reaction proceeds smoothly to give excellent yields of the desired products, allyl chloride reacts very vigorously with ethylenediamine, the yield of allylethylenediamine being only 28% of the theoretical. This may be due to side reactions occurring at the double bond. In this case the allyl chloride (38 g.) was added slowly with stirring to 130 g. of 95% ethylenediamine. The resulting solution was heated to reflux temperature for thirty minutes and distilled under atmospheric pressure. Most of the liquid distilled at 117–137° and a crystalline residue remained in the flask. The distillate was fractionated and the fraction boiling at 160–170° was collected (13.6 g.).

In order to obtain the dihydrochloride 1 g. of base was dissolved in 3 cc. of ethyl alcohol and 1 cc. of concentrated hydrochloric acid was added. The mixture was evaporated to dryness and the residue recrystallized from alcohol–acetone.

Properties

The free bases from octyl up are low-melting, white, waxy solids, insoluble in water, soluble in alcohol, ether, benzene and chloroform. They form dipicrates and combine with two acid equivalents to yield neutral salts. The dihydrochlorides, sulfates, and dinitrates are sparingly soluble in water, but the diacetates and some other salts with organic acids dissolve readily in this solvent. The solutions of these "soaps in reverse" show lowered

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[1] Schneider, *Ber.*, **28**, 3073 (1895).

[2] Aspinall, THIS JOURNAL, **63**, 852 (1941).

[3] Linsker and Evans, *J. Org. Chem.*, in press.

[4] Wilson, *Ind. Eng. Chem.*, *Ind. Ed.*, **27**, 868 (1935).

[5] John C. Bailar, Jr., THIS JOURNAL, **56**, 955 (1934).