double bond in the 1,4-diamino-2-butene compounds including treatment of either the free bases or the dihydrochlorides in such media as air, water, ether, chloroform and benzene, the following were settled on as producing the desired addition products in the highest yields.

In general the 1,4-diaminobutene dihydrochloride (5 g.) was dissolved in methanol (150–200 ml.) and dry tank chlorine gas passed into the solution at room temperature for 30 minutes. The solutions were allowed to stand for one to four hours until precipitation of the product seemed to be completed. The colorless, powdery products were removed by filtration and washed with cold methanol. In some instances the yields were increased by adding dry ether to the reaction mixture filtrates. The products were recrystallized either from methanol, from methanol and water, or from methanol–ether mixtures. These compounds were more soluble in water than in methanol. Contamination of these compounds with the starting material often raised rather than lowered the m.p. of the product.

**1,4-Bisdimethylamino-2,3-dichlorobutane dihydrochloride:** yield 60%, m.p. 238° dec.

*Anal.* Calcd. for $C_8H_{20}N_2Cl_4$: C, 33.60; H, 7.04; N, 9.79; Cl, 49.54; $Cl^-$, 24.77. Found: C, 33.72; H, 7.22; N, 9.59; Cl, 49.26; $Cl^-$, 24.55.

**1,4-Dipiperidino-2,3-dichlorobutane dihydrochloride:** yield 70%, m.p. 248° dec. *Anal.* Calcd. for $C_{14}H_{28}N_2Cl_4$: C, 45.91; H, 7.70. Found: C, 45.80; H, 7.74.

**1,4-Dimorpholino-2,3-dichlorobutane dihydrochloride:** yield 60%, m.p. 245° dec.

*Anal.* Calcd. for $C_{12}H_{24}N_2O_2Cl_4$: C, 38.94; H, 6.53; $Cl^-$, 19.15. Found: C, 39.34; H, 6.59; $Cl^-$, 18.8.

None of the above compounds released iodine from acidified potassium iodide solutions, showing that no positive (on nitrogen) chlorine was present. It has not yet been possible to obtain the 2,3-dichloro addition product of 1,4-bisdibenzylamino-2-butene dihydrochloride.

LINCOLN, NEBRASKA

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE UNIVERSITY OF ROCHESTER]

# An Infrared Study of Hydrogen Bonding Involving the Thiol Group[1]

BY DEREK PLANT, D. STANLEY TARBELL AND CARL WHITEMAN

RECEIVED SEPTEMBER 10, 1954

A study of the infrared spectra of a series of aminothiols of the type $R_2N(CH_2)_nSH$ ($n$ = 3 or 4) has given no indication of hydrogen bonding involving the –S–H group. Further studies on mixtures of sulfoxides and thiol compounds, and on thiobenzoic acid alone, indicate that hydrogen bonding through the –S–H group is negligible. The –S–D stretching frequency in thiophenol-*d* and *n*-hexanethiol-*d* has been found to occur at 1839 and 1870 cm.$^{-1}$, respectively. The synthesis of several new aminothiols and aminoalcohols is reported. Thiol compounds are found to react with carbon tetrachloride in the presence of tertiary bases at room temperature to yield mainly the disulfide and the amine hydrochloride; the reaction presumably involves a displacement with the formation of $-SCCl_3$ compounds, which then react further.

Cryoscopic,[2] spectroscopic[3] and calorimetric[4] studies indicate that the thiol group shows only a slight tendency to form hydrogen bonds, and it has been suggested[5] that an important reason for the differing chemical properties of oxygen and sulfur analogs is the relative absence of hydrogen bonding in the latter. It seemed desirable to investigate the hydrogen bonding ability of the thiol group in more detail,[6] and the most favorable cases appeared to be[3a,7] aminothiols of type I

$$R_2N(CH_2)_nSH \quad \text{I}$$

A series of these compounds, where $R_2$ is $(C_2H_5)_2$, $(C_6H_5)_2$ and piperidyl, was accordingly prepared and studied. Most of these compounds are described adequately in Table II. An unexpected complication, discussed later, prevented the use of carbon tetrachloride as solvent for the infrared measurements, but the results of measurements in benzene solution and in the pure liquid are given in Table I. There is no evidence for the expected shift in the –S–H frequency, and with the piperidyl derivatives, the frequency in solution was actually lower than in the pure liquid. *n*-Hexanethiol absorbed at 2555 cm.$^{-1}$ compared to 2584 cm.$^{-1}$ for most of the aminothiols.

TABLE I

ABSORPTION IN THE S-H REGION OF COMPOUNDS OF TYPE $R_2N(CH_2)_nSH$

| Compound $R_2$ | $n$ | Pure liquid | Absorption, cm.$^{-1}$ 0.2 $M$ soln. in benzene |
|---|---|---|---|
| $(C_2H_5)_2$ | 3 | 2584 | 2584 |
| $(C_2H_5)_2$ | 4 | 2584 | 2584 |
| $C_5H_{10}$[a] | 3 | 2617 | 2584 |
| $C_5H_{10}$[a] | 4 | 2617 | 2584 |
| $(C_6H_5)_2$ | 3 | 2577 | 2584 |

[a] 1-Piperidyl.

It has been found that the sulfoxide grouping is a strong donor grouping for the formation of hydrogen bonds with hydroxyl groups[8] and we therefore investigated the effect of added diphenyl sulfoxide and the crystalline aliphatic diisobutyl sulfoxide on the –S–H frequency of benzene solutions of thiophenol and of thiobenzoic acid. In 0.2 $M$ solution in benzene, thiophenol and thiobenzoic acid showed bands at 2584 and 2577 cm.$^{-1}$, respec-

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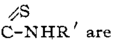
[1] This research was supported by the United States Air Force, through the Office of Scientific Research of the Air Research and Development Command. This article is not subject to copyright.

[2] (a) K. Auwers, *Z. physik. Chem.*, **12**, 689 (1893); (b) K. Auwers and M. Dohrn, *ibid.*, **30**, 529 (1899); the observation that thioamides of the type  $R\overset{\overset{S}{/\!/}}{C}-NHR'$ are associated does not prove that the sulfur atom is involved in the hydrogen bonding (G. Hopkins and L. Hunter, *J. Chem. Soc.*, 638 (1942); T. G. Heafield, G. Hopkins and L. Hunter, *Nature*, **149**, 218 (1942); A. A. Burrows and L. Hunter, *J. Chem. Soc.*, 4118 (1952); M. St. C. Flett, *ibid.*, 347 (1953)).

[3] (a) W. Gordy and S. C. Stanford, THIS JOURNAL, **62**, 497 (1940); R. H. Saunders, M. J. Murray and F. F. Cleveland, *ibid.*, **64**, 1230 (1942).

[4] M. J. Copley, C. S. Marvel and C. Ginsberg, *ibid.*, **61**, 3161 (1939).

[5] D. S. Tarbell and D. P. Harnish, *Chem. Revs.*, **49**, 36 (1951); P. J. Hawkins, D. S. Tarbell and P. Noble, Jr., THIS JOURNAL, **75**, 4462 (1953).

[6] It has been suggested recently that hydrogen bonding involving sulfur is important in determining the properties of proteins and polypeptides; (a) R. E. Benesch and R. Benesch, *ibid.*, **75**, 4367 (1953); (b) R. Cecil, *Biochem. J.*, **47**, 572 (1950).

[7] F. T. Wall and W. F. Claussen, THIS JOURNAL, **61**, 2679 (1939).

[8] D. Barnard, J. M. Fabian and H. P. Koch, *J. Chem. Soc.*, 2442 (1949).

TABLE II

A. PROPERTIES OF AMINOTHIOLS AND DERIVATIVES

$R_2N(CH_2)_nSR'$

| | | | | | Analyses, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Carbon | | Hydrogen | | Nitrogen | |
| $R_2$ | $n$ | R′ | M.p., °C. | Formula | Calcd. | Found | Calcd. | Found | Calcd. | Found |
| $(C_2H_5)_2$[a] | 3 | $COC_6H_3(NO_2)_2\cdot HCl$[b] | 126–128 | $C_{14}H_{19}N_3O_5S\cdot HCl$ | 44.50 | 44.50 | 5.06 | 5.53 | 11.12 | 11.20 |
| $(C_2H_5)_2$ | 4 | $C_6H_3(NO_2)_2\cdot HCl$[c] | 147–148 | $C_{14}H_{21}N_3O_4S\cdot HCl$ | 46.21 | 46.02 | 6.09 | 5.66 | 11.55 | 11.67 |
| $(C_2H_5)_2$[e] | 4 | *b* | 156–157 | $C_{15}H_{21}N_3O_5S\cdot HCl$ | 45.97 | 45.71 | 5.65 | 5.63 | 10.72 | 10.62 |
| $C_5H_{10}$[d,e] | 3 | *b* | 172–173 | $C_{15}H_{19}N_3O_5S\cdot HCl$ | 46.21 | 46.52 | 5.17 | 5.27 | 10.77 | 11.00 |
| $C_5H_{10}$[d] | 3 | *c* | 196–198 | $C_{14}H_{19}N_3O_4S\cdot HCl$ | 46.46 | 46.81 | 5.57 | 5.82 | 11.61 | 11.97 |
| $C_5H_{10}$[d] | 4 | *b* | 172–173 | $C_{16}H_{21}N_3O_5S\cdot HCl$ | 47.58 | 47.86 | 5.49 | 5.97 | 10.40 | 10.68 |
| $C_5H_{10}$[d] | 4 | *c* | 183–184 | $C_{15}H_{21}N_3O_4S\cdot HCl$ | 47.93 | 48.14 | 5.89 | 6.16 | 11.17 | 11.15 |

B. PROPERTIES OF $R\text{—}\underset{R'}{N}(CH_2)_3X$

| | | | | | Analyses, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Carbon | | Hydrogen | | Nitrogen | |
| R | R′ | X | M.p., °C. | Formula | Calcd. | Found | Calcd. | Found | Calcd. | Found |
| $C_6H_5$ | $C_6H_5$ | OH[g] | 150–155[h] | $C_{15}H_{17}NO$ | 79.26 | 79.06 | 7.53 | 7.49 | 6.16 | 6.00 |
| $C_6H_5$ | $C_6H_5$ | OH[i] | 138–140[f] | $C_{15}H_{17}NO\cdot HCl$ | 68.30 | 68.61 | 6.87 | 6.82 | 5.30 | 5.38 |
| $n$-$C_3H_7$ | H | OH | 105[j] | $C_6H_{15}NO$ | 61.49 | 61.87 | 12.90 | 13.13 | 11.94 | 12.37 |
| $n$-$C_3H_7$ | H | Cl | 237–238[k] | $C_6H_{14}ClN\cdot HCl$ | 41.87 | 41.79 | 8.78 | 8.87 | 8.13 | 7.95 |

[a] Parent aminothiol described by H. Gilman, *et al.*, THIS JOURNAL, **67**, 1845 (1945). [b] 3,5-Dinitrothiolbenzoate hydrochloride. [c] 2,4-Dinitrophenyl sulfide hydrochloride. [d] 1-Piperidyl. [e] Parent aminothiol described by S. C. Laskowski and R. O. Clinton, *ibid.*, **69**, 519 (1947). [f] $n^{24}D$ 1.4962. [g] Prepared in 28% yield by the action of 3-iodopropanol (Henry, *Chem. Zentr.*, **68**, II, 344 (1897)) on diphenylamine in ethanol with potassium carbonate. [h] B.p. at $2 \times 10^{-3}$ mm. [i] The hydrochloride was obtained by dry hydrogen chloride in ethyl acetate. It was crystallized from alcohol–ethyl acetate, and was unstable in air. The m.p. was taken in a sealed tube. [j] B.p. at 17 mm.; $n^{25}D$ 1.4450. Goldberg and Whitmore, THIS JOURNAL, **59**, 2280 (1937), reported $n^{20}D$ 1.4519, and gave only an analysis of the picrate. [k] Prepared from the propylaminopropanol with thionyl chloride in chloroform, followed by dry hydrogen chloride. The free base, 3-propylamino-1-propyl chloride, but not the hydrochloride, was reported by Elderfield, *et al.*, THIS JOURNAL, **68**, 1579 (1946).

tively, and these frequencies were unchanged in solutions to which was added an equimolar amount of the aromatic or the aliphatic sulfoxide.

The foregoing results indicate that hydrogen bonding involving the –S–H group plays a negligible role in determining the properties of these thiol compounds. In view of this and of the observation[9] that sulfides show very weak donor properties in formation of hydrogen bonds, it seems unlikely that hydrogen bonding between a thiol group and a disulfide or a monosulfide group is likely to be important in polypeptides.[6]

The frequency of the –S–D bond in mercaptans does not seem to have been reported,[10] and we have therefore prepared $C_6H_5SD$ and $C_6H_{13}SD$ by treating the mercapto compounds with sodium hydride followed by addition of heavy water. The distilled products showed no absorption in the 2600 cm.$^{-1}$ region, when measured in the pure liquid, but showed new bands at 1839 and 1870 cm.$^{-1}$, respectively.

The calculated frequency for the –S–D group in the two cases, based on the observed –S–H frequency,[11] is 1830 cm.$^{-1}$ for *n*-hexanethiol-*d* and 1870 cm.$^{-1}$ for thiophenol-*d*.

During attempts to determine infrared spectra of the $R_2N(CH_2)_nSH$ series in carbon tetrachloride solution, a crystalline precipitate was observed to form rapidly at room temperature, although the freshly prepared solution was clear. The precipitate was found to be mainly the aminothiol hydrochloride, which implied that an alkylation of the mercapto group by the solvent had occurred, followed by liberation of hydrogen chloride.

The reaction was investigated more in detail for 3-(1′-piperidyl)-1-propanethiol, which after several days in carbon tetrachloride at room temperature yielded 56% of starting material and 14% the corresponding disulfide, isolated as the dihydrochloride.

Hexanethiol in carbon tetrachloride containing an equivalent amount of pyridine gave only a trace of pyridine hydrochloride, but when an equivalent amount of triethylamine was used, a 91% yield of triethylamine hydrochloride was isolated after four days at room temperature. The solution yielded 70% of the dihexyl disulfide, and 9% of the original thiol. Triethylamine alone after four days in carbon tetrachloride gave 15% of the amine hydrochloride.

Thiols are known to react with carbon tetrachloride in the presence of the strong base sodium ethoxide as[12]

$$RSH + CCl_4 \xrightarrow[EtOH]{NaOEt} RSSR + CH(SR)_3$$

The occurrence of reaction in the presence of the much weaker base triethylamine is another indication of the very high nucleophilic reactivity of the thiol group.[13] The reaction presumably involves

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(9) G. F. Zellhoeffer, M. J. Copley and C. S. Marvel, THIS JOURNAL, **60**, 1337 (1938).

(10) A. H. Nielsen and H. H. Nielsen, *J. Chem. Phys.*, **5**, 280 (1937), find a band in gaseous $D_2S$ with a center at about 2000 cm.$^{-1}$; $H_2S$ shows a band at 2558 cm.$^{-1}$ (C. R. Bailey, J. W. Thompson and J. B. Hale, *ibid.*, **4**, 625 (1936)), which apparently corresponds to –S–H absorption in mercaptans.

(11) W. West, in "Physical Methods of Organic Chemistry," (edited by A. Weissberger), 2nd Ed., Vol. 1, part II, p. 1333; F. A. Miller, in "Organic Chemistry" (edited by H. Gilman), Vol. III, p. 144.

(12) H. J. Backer and P. L. Stedehouder, *Rec. trav. chim.*, **52**, 437 (1933).

(13) For examples of the high nucleophilicity of sulfur, see O. R. Quayle and E. E. Royals, THIS JOURNAL, **64**, 226 (1942); P. B. de la Mare and C. A. Vernon, *J. Chem. Soc.*, 3331 (1952).

alkylation by carbon tetrachloride to form $RSCCl_3$, which then reacts further.[14]

The preparation of the aminothiols $R_2N(CH_2)_nSH$ was carried out best in one step from the aminoalcohols by conversion to the thiouronium salt with thiourea and hydrobromic acid, followed by basic hydrolysis of the thiouronium salt.[15] This method failed for the preparation of 3-(*n*-propylamino)-1-propylthiol (II) from the corresponding alcohol III; the thiouronium salt appeared to be formed

$$\begin{array}{llll} C_3H_7NH(CH_2)_3X & \text{II}, X = SH & \text{IV}, X = Cl \\ & \text{III}, X = OH & \text{V}, X = SCH_2C_6H_5 \end{array}$$

but was decomposed by alkali. The preparation of the aminothiol II was approached[16] by treatment of the chloro compound IV with benzyl mercaptan, followed by debenzylation with sodium–liquid ammonia. However, the resulting crude aminothiol II was air-oxidized very rapidly to the disulfide, and could be isolated only as the disulfide. This ease of oxidation of the secondary aminothiol II was striking, in view of the fact that the tertiary aminothiols could be isolated in the thiol form readily, and were stable to air oxidation.

## Experimental[17]

The 3-aminopropanols and 4-aminobutanols were prepared in general by the action of 3-chloropropanol or 4-chlorobutanol on two equivalents of the secondary amine in alcohol, in the presence of a small amount of sodium iodide.

**3-Diphenylamino-1-propanethiol.**—The following procedure is typical of the conversion of the aminoalcohols to the aminothiols. 3-Diphenylamino-1-propanol (26.0 g., 0.114 mole) and thiourea (8.65 g., 0.456 mole) were dissolved in hydrobromic acid (77.7 g. of a 48% solution, 0.456 mole of HBr) and refluxed for 8 hr. After cooling, a solution of sodium hydroxide (18.2 g.) in water (150 cc.) was added and the mixture refluxed for 2 hr. under nitrogen. After cooling, it was extracted three times with ether (350 cc.), the ethereal extract was washed with water, once with brine and dried over sodium sulfate. After removal of the ether at atmospheric pressure, the residual mercaptan was distilled under vacuum in a short path still. The yield 22.5 g. (81%) distilled at a bath temperature of 145° at $2 \times 10^{-4}$ mm. It was redistilled three times for analysis.

*Anal.* Calcd. for $C_{15}H_{17}NS$: C, 74.03; H, 7.04; N, 5.75. Found: C, 74.41; H, 7.24; N, 6.01.

**3-Propylamino-1-propyl Benzyl Sulfide Hydrochloride (V).**—3-Propylamino-1-propyl chloride hydrochloride (25 g.) was refluxed under nitrogen for 1.5 hr. with 18 g. of benzyl mercaptan in 150 cc. of alcohol containing sodium ethoxide from 6.68 g. of sodium. After cooling, the sodium chloride was removed by filtration through Supercel, and the precipitate was washed well with alcohol. The combined filtrates were treated with dry hydrogen chloride gas and evaporated to dryness under under reduced pressure. The residue was dissolved in isopropyl alcohol and a small inorganic precipitate removed by filtration. Ether was added to the filtrate until it was slightly cloudy and it was set aside for 24 hr. The white crystalline solid which precipitated weighed 36 g. (95%) and melted, after recrystallization from ethyl acetate, at 119–120°. *Anal.* Calcd. for $C_{13}H_{21}NS{\cdot}HCl$: C, 60.09, H, 8.53, N, 5.38. Found: C, 60.18, H, 8.80; N, 5.72.

**3-Propylamino-1-propanethiol (II) and the Disulfide.**—3-Propylamino-1-propyl benzyl sulfide hydrochloride (30.0 g.) was dissolved in liquid ammonia (300 cc.). Small pieces of sodium were then added with gentle swirling until the deep blue color persisted for 45 min. The excess sodium was destroyed by the addition of a little ammonium chloride and the ammonia was removed by evaporation under reduced pressure. Alcohol was added to the residue and the sodium chloride removed by filtration. The filtrate was cooled to 0°, acidified with anhydrous hydrogen chloride and the alcohol removed by evaporation under reduced pressure. The residual sirup crystallized as needles on trituration with ethyl acetate to yield 18.7 g. (95%) of the hydrochloride of II. Crystallization of the crude hydrochloride from alcohol–ethyl acetate gave a product of m.p. 262–263°. This melting point was undepressed in admixture with the product obtained by either iodine or hydrogen peroxide oxidation of the crude hydrochloride of II. It was concluded that the crude hydrochloride was readily air-oxidized to the corresponding disulfide dihydrochloride.

*Anal.* Calcd. for $C_{12}H_{28}N_2S_2{\cdot}2HCl$: C, 42.71; H, 8.96; N, 8.29; S, 19.00; Cl, 21.01. Found: C, 43.03; H, 8.92; N, 8.06; S, 19.27; Cl, 21.30.

A solution of sodium methoxide (from 0.64 g. of sodium) in absolute methanol (25 cc.) was added to the crude hydrochloride of II (4.7 g.) dissolved in 25 cc. of absolute methanol. The precipitated sodium chloride was removed by filtration. The alcohol was removed from the filtrate by evaporation under reduced pressure and the residual sirup was distilled in a short path still; the colorless distillate of the disulfide (2.88 g.) came over at $2 \times 10^{-3}$ mm., and block temp. of 140°.

The compound did not give a nitroprusside test for the thiol group, and showed no thiol absorption band in the infrared. Redistillation gave the analytical sample, $n^{25}D$ 1.5146.

*Anal.* Calcd. for $C_6H_{15}NS$: C, 54.08; H, 11.34; N, 10.50. Calcd. for $C_{12}H_{28}N_2S_2$: C, 54.49; H, 10.67; N, 10.59. Found: C, 54.36; H, 11.08; N, 10.81.

**Reaction between 3-Piperidyl-1-propanethiol and Carbon Tetrachloride.**—3-Piperidyl-1-propanethiol (10 g.) was dissolved in pure carbon tetrachloride (70 ml.), and set aside at room temperature. After 0.5 hr. an oil had separated which slowly crystallized. After 4 days, dry hydrogen chloride was passed through the mixture which was then extracted with water. This aqueous extract was made basic with ammonia and extracted twice with ether. The ethereal extract was washed with brine, dried over sodium sulfate and the ether was removed by evaporation under reduced pressure. The residue was distilled in a short path still.

The first fraction which distilled below 105° ($10^{-4}$ mm.) (block temperature) weighed 5.56 g. It was converted into a crystalline hydrochloride with dry hydrogen chloride. The product, after recrystallization from alcohol–ethyl acetate, melted at 187–188°, undepressed on admixture with an authentic specimen of 3-piperidyl-1-propanethiol hydrochloride.

*Anal.* Calcd. for $C_8H_{17}NS{\cdot}HCl$: C, 49.08; H, 9.26; N, 7.15. Found: C, 49.00; H, 9.35; N, 7.25.

The second fraction, which distilled at 160–175° $10^{-4}$ mm. (block temperature) weighed 1.35 g. It was converted into its hydrochloride with dry hydrogen chloride and recrystallized from alcohol–ethyl acetate: it formed colorless needles, m.p. 223–224°, undepressed on admixture with an authentic specimen of the disulfide of 3-piperidyl-1-propanethiol hydrochloride (prepared by iodine oxidation of the thiol).

*Anal.* Calcd. for $C_{16}H_{32}N_2S_2{\cdot}2HCl$: C, 49.33; H, 8.79; N, 7.19. Found: C, 49.16; H, 8.86; N, 7.27.

An undistillable residue remained.

**Bis-(3-piperidyl-1-propylthio)-methane Dihydrochloride.**—This compound was prepared for comparison with the products of the reaction of the aminothiol and carbon tetrachloride above. 3-Piperidyl-1-propanethiol hydrochloride (4.0 g.) was dissolved in water (5 cc.) containing 40% formalin solution (2 cc.). It was set aside at room temperature overnight and then heated on a steam-bath for 30 min. After cooling, it was made alkaline with dilute sodium hydroxide solution and extracted with ether. The ethereal extract was washed twice with water, once with brine and dried over anhydrous sodium sulfate. Most of the ether

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[14] The reaction is probably somewhat similar to that of dibenzyl phosphite with carbon tetrachloride in the presence of a base (F. R. Atherton, H. T. Openshaw and A. R. Todd, *J. Chem. Soc.*, 660 (1945); F. R. Atherton and A. R. Todd, *ibid.*, 674 (1947).

[15] General method of R. L. Frank and P. V. Smith, This Journal, **68**, 2103 (1946) for conversion of alcohols to thiols.

[16] *Cf.* J. Baddiley and E. M. Thain, *J. Chem. Soc.*, 800 (1952).

[17] Microanalyses by Miss Annette Smith and Micro-Tech Laboratories. All m.p.'s are uncorrected.

was removed by evaporation under reduced pressure and dry hydrogen chloride passed into the residue. The solid hydrochloride was removed by filtration and after crystallization from ethyl acetate–alcohol melted at 221–222°.

*Anal.* Calcd. for $C_{17}H_{34}N_2S_2 \cdot 2HCl$: C, 50.60; H, 8.99; N, 6.94. Found: C, 50.46; H, 8.77; N, 6.57.

**Thiophenol-*d*.**—Sodium hydride (1.3 g.) was suspended in pure dioxane (50 cc.) and thiophenol (5.5 g.) added. When the hydrogen evolution ceased, heavy water (4 cc.) was added and the mixture set aside at room temperature overnight. Carbon dioxide was then passed into the mixture and the precipitate removed by centrifugation. The dioxane extract was dried over anhydrous sodium sulfate and the dioxane was removed by evaporation under reduced pressure. The residue was distilled twice in a short path still, b.p. 75° (13 mm.), (block temperature), $n^{20}_D$ 1.5468.

**Hexanethiol-*d*.**—Hexanethiol (5 g.) was dissolved in anhydrous ether (50 cc.) and sodium hydride (1.02 g.) added. When the hydrogen evolution ceased, heavy water (3 cc.) was added. After 30 min. the ethereal layer was decanted, dried over anhydrous sodium sulfate and the ether removed by evaporation under reduced pressure. The residue was distilled at 40 mm., b.p. 56–58°.

**Measurements of Infrared Spectra.**—The spectra were measured with a Perkin–Elmer Spectrophotometer, Model 12 AB, equipped with a calcium fluoride prism (synthetic crystal, apex angle 67.5°, polished faces 78 × 66 mm. high). Background absorption was reduced to a minimum by passing slowly through the optical path water-pumped nitrogen, dried in Drierite towers. Permanent cells with rocksalt plates were used. Spectra for the benzene solutions were taken in cells of 0.251 mm. thickness. Spectra for the pure compounds were taken in cells of 0.025 mm. thickness; the slit width in the 3.7–4.0 $\mu$ region was 0.072 mm.

The spectra of the pure deuterated compounds and their hydrogen analogs were obtained using the standard rock salt prism in the Perkin–Elmer instrument with slit widths of 0.023 mm. in the 3.9 $\mu$ region and of 0.033 mm. in the 5.4 $\mu$ region.

ROCHESTER, NEW YORK

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[CONTRIBUTION FROM THE U. S. NAVAL ORDNANCE LABORATORY]

# Ester Cleavage in 100% Sulfuric Acid[1]

BY ARTHUR BRADLEY AND MARION E. HILL

RECEIVED AUGUST 11, 1954

It has been found that protonation ($i = 2.0$) of organic esters in concentrated sulfuric acid is ordinarily followed by cleavage into three particles ($i = 3.0$). The cleavage rate is strongly retarded by negative groups in the acid and accelerated by such groups in the alcohol portion of the ester. The results are discussed in connection with possible mechanisms for the reaction.

Both Treffers and Hammett[2] and Newman[3] have reported the complete hydrolysis of methyl mesitoate on pouring a freshly prepared sulfuric acid solution of this ester onto ice and water. Kuhn and Corwin[4] and Kuhn[5] applied this procedure to various aliphatic and aromatic esters and reported recoveries of acid ranging from 0% with ethyl acetate and ethyl benzoate to 76% with chloroethyl anisate and isopropyl anisate. They also found that cellosolve benzoate kept at 53° in sulfuric acid for five minutes gave 2.5 times the yield of benzoic acid obtained after two minutes at room temperature. Newman, Craig and Garrett[6] converted methyl benzoate to benzoic acid in 81% yield by heating at 90° for 15 minutes.

We have extended this work by investigating the effects of time and elevated temperature on a number of suitable esters, and in many cases have achieved considerable hydrolysis of compounds that previously were considered to be stable in this medium. Whereas methyl[2] and ethyl[5] benzoates were recovered unchanged after being dissolved in sulfuric acid at room temperature and poured onto ice after two minutes, they were completely cleaved by warming their sulfuric acid solutions to 50° for one and two hours, respectively. The yields of acid from these and other esters after varying intervals at 25, 50 and 75° are shown in Tables I and II.

TABLE I

HYDROLYSIS OF ESTERS

PERCENTAGE RECOVERY OF BENZOIC ACID AT 25°

| | 2 min. | 15 min. | 1 hr. | 3 hr. | 24 hr. |
|---|---|---|---|---|---|
| Methyl benzoate | | | 2 | 34 | 70 |
| Ethyl benzoate | | | 0 | 12 | 48[a] |
| Trichloroethyl benzoate | 33[4] | 50 | 74 | | |
| Isopropyl benzoate | 36[5] | 47 | 62 | 64 | |
| Phenyl benzoate | | 57 | 71 | 75 | |
| Tribromoethyl benzoate | | | 44 | | |

[a] After three days or seven days 75% benzoic acid was obtained.

TABLE II

PERCENTAGE RECOVERY OF ACID AT 50°

| | 5 min. | 20 min. | 1 hr. | 5 hr. | 24 hr. | 3 days |
|---|---|---|---|---|---|---|
| Methyl benzoate | 30 | 55 | 74 | 77 | | |
| Ethyl benzoate | | 29 | 57[a] | 75 | 77 | |
| Trichloroethyl benzoate | 68 | 69 | 70 | | | |
| Trichloroethyl 3,5-dinitrobenzoate | | | | | | 0 (87)[b] |
| Methyl *p*-nitrobenzoate | | | | 10 | 49 | 80 |
| Methyl 3,5-dinitrobenzoate | | | | | 9 | 26 (52)[b] |
| Methyl 3,5-dinitrobenzoate (4.0% $SO_3$) | | | | | 77 | |

[a] After two hours 71% benzoic acid was obtained. [b] Recovered ester in parentheses.

At elevated temperatures, particularly at 75° with a slight excess of sulfur trioxide, sulfonation of benzoic acid appeared to take place. At room temperature, however, this side reaction was not significant, and yields over 75% are considered quantitative.[4]

These results amply justify the generalization in the literature[4,7] that negative substituents en-

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[1] Presented before the Organic Division at the 126th Meeting of the American Chemical Society, New York City, September, 1954.

[2] H. P. Treffers and L. P. Hammett, THIS JOURNAL, **59**, 1708 (1937).

[3] (a) M. S. Newman, *ibid.*, **63**, 2431 (1941); (b) M. S. Newman, H. G. Kuivila and A. B. Garrett, *ibid.*, **67**, 704 (1945).

[4] L. P. Kuhn and A. H. Corwin, *ibid.*, **70**, 3370 (1948).

[5] L. P. Kuhn, *ibid.*, **71**, 1575 (1949).

[6] M. S. Newman, R. A. Craig and A. B. Garrett, *ibid.*, **71**, 869 (1949).

[7] L. F. Audrieth and J. Kleinberg, "Non-Aqueous Solvents," John Wiley and Sons, Inc., New York, N. Y., 1953, p. 186.