bromomethylbenzeneboronic acid (dried 2 hr. in a desiccator) was added, and the mixture was stirred under gentle reflux for 11 hr. It was cooled to room temperature, treated with 12 ml. of 3 *N* hydrochloric acid and filtered from the precipitated inorganic salt. The filtrate was concentrated to a yellow semi-solid and this was crystallized from about 600 ml. of 33% ethanol to give 21.7 g. (67.7%) of white crystals, m.p. 220–223°. The analytical sample was twice recrystallized from water and dried at about 2 mm. at room temperature for 36 hr.

Anal. Calcd. for $C_{16}H_{22}BNO_7$: C, 54.71; H, 6.31; N, 3.98. Found: C, 54.62; H, 6.43; N, 3.85.

***p*-(2-Carboxy-2-acetaminoethyl)-benzeneboronic Acid (IX).**—A mixture of 21.7 g. of VIII and 180 ml. of 5% aqueous sodium hydroxide was stirred under reflux for 3.75 hr. To the cooled solution 90 ml. of 3 *N* hydrochloric acid was added slowly, and the resulting mixture was heated under reflux for 1 hr. The residue from concentration *in vacuo* of the mixture was crystallized from the minimum amount of water to give 13.5 g. (87%) of white crystalline IX, m.p. 168–170°.

Anal. Calcd. for $C_{11}H_{14}BNO_5$: C, 52.60; H, 5.62; N, 5.57. Found: C, 52.30; H, 5.78; N, 5.43.

***p*-(2-Carboxy-2-aminoethyl)-benzeneboronic Acid (4-Boronophenylalanine) VII.**—A mixture of 13.5 g. of IX and a solution of 16 g. of sodium hydroxide in 250 ml. of water was stirred under reflux for 9 hr. The solution was acidified by the careful addition of 25 ml. of concentrated hydrochloric acid, which caused the separation of a white solid. The *p*H of the mixture was adjusted to 6.2 with ammonium hydroxide, and the mixture was concentrated to 100 ml. *in vacuo*. (In subsequent preparations it was found that a purer product resulted when the final volume was 175 ml.) After storage overnight in the refrigerator the solid was separated and washed with water. The yield of VII was 8.3 g. (74%), m.p. 285–290° dec.

Anal. Calcd. for $C_9H_{12}BNO_4$: C, 51.69; H, 5.79; N, 6.70. Found: C, 51.74; H, 6.00; N, 6.66.

Properties of 4-Boronophenylalanine (VII).—4-Boronophenylalanine readily formed a hydrochloride by treating a small amount (0.1–0.2 g.) of it with 3 ml. of 1 *N* HCl and then slowly evaporating to dryness. The white crystals thus obtained had m.p. 200–203° and were very soluble in water. The infrared spectrum (Nujol) of the hydrochloride showed the presence of an un-ionized carboxyl group by the strong band present at 1740 cm.$^{-1}$, in contrast to the free amino acid, which has an ionized carboxyl group (strong absorption at 1640 cm.$^{-1}$).

Treatment of a boronic acid with sodium hydroxide is known to effect deboronation[11] and should, in this case, produce phenylalanine. A solution of 0.5 g. of 4-boronophenylalanine in 20 ml. of 5% sodium hydroxide, contained in a copper flask, was refluxed for 48 hr. The solution was then filtered through a sintered funnel while still hot, neutralized to *p*H 3 with hydrochloric acid, and then adjusted to *p*H 5.7 with ammonium hydroxide. The white inorganic material which precipitated at this point was filtered off, and the filtrate evaporated almost to dryness *in vacuo*. The resulting white residue was taken up in 10 ml. of water and warmed to dissolve any soluble inorganic material. Next the remaining white solid was filtered off. It had m.p. 235–240°. This low m.p. suggested the possibility of a mixture of 4-boronophenylalanine and phenylalanine. This was verified by descending paper chromatography, using a butanol–acetic acid–water solvent system (40:10:50). Samples of 4-boronophenylalanine, phenylalanine, 50% 4-boronophenylananine–50% phenylalanine mixture, and the sample obtained by the sodium hydroxide treatment were spotted on the paper and migration allowed to proceed at 35° for 7 hours. The paper was then dried at room temperature overnight, sprayed with a 0.4% solution of ninhydrin in water-saturated butanol, and developed by heating to 50–60° for 30 minutes. The R_f values obtained are as follows: 4-boronophenylalanine, 0.46; phenylalanine, 0.69; 50% 4-boronophenylalanine–50% phenylalanine, 0.69, 0.46; product of sodium hydroxide treatment, 0.69, 0.46. Further evidence for the presence of phenylalanine as the deboronation product lies in the fact that the infrared spectrum of this product is similar to that of phenylalanine, and differs only in the presence of several additional absorption bands which are probably due to impurities.

4-Boronophenylalanine may be titrated and gives a titration curve similar in shape to that of a normal amino acid. The sample was dissolved in excess sodium hydroxide and titrated with 0.1 *N* HCl, the *p*H being measured by means of a Beckman *p*H meter equipped with a glass–calomel electrode system. That the boronic acid function has a pK_a' of the same magnitude as the ammonium ion was demonstrated by the fact that on the basic side of the titration curve two equivalents of acid were required for neutralization of 4-boronophenylalanine, while phenylalanine required only one equivalent.

---

[11] A. D. Ainley and F. Challenger, *J. Chem. Soc.*, 2171 (1930).

URBANA, ILLINOIS

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF VANDERBILT UNIVERSITY]

Organic Disulfides and Related Substances. I. Oxidation of Thiols to Disulfides with Lead Tetraacetate[1]

BY LAMAR FIELD AND JOHN E. LAWSON[2]

RECEIVED AUGUST 19, 1957

Lead tetraacetate was used for oxidizing thiols to disulfides typifying various classes, including alkyl, benzyl, aryl, substituted aryl, heterocyclic and acyl. One mole of the tetraacetate oxidized two of thiol. The tetraacetate did not cleave 2-mercaptoethanol but instead oxidized it smoothly to the disulfide. An amount sufficient for reaction only with benzenethiol or pinacol in a mixture of both effected oxidation of the thiol and little or no cleavage of the glycol.

The selectivity of lead tetraacetate has made it a valuable oxidant for synthesis and determination of structure.[3] There seemed a good likelihood that its use could be extended profitably to organic disulfides either for conventional reactions[3] not involving sulfur or for reactions of the sulfur atoms such as oxidation or cleavage. Comment on lead tetraacetate in relation to disulfides seems to have been made only by Bourne and co-workers[4] who, in a study of sugar mercaptals, mentioned its oxidation of α-toluenethiol but not the yield or quality of the disulfide formed.

---

[1] Presented at the Southeastern Regional Meeting of the American Chemical Society at Durham, N. C., Nov. 14–16, 1957. Abstracted from a portion of the Ph.D. dissertation of J.E.L., August, 1957. The authors are indebted to the Office of Ordnance Research, U. S. Army, for support of this work. Helpful suggestions were contributed by Paul E. Drummond.

[2] Du Pont Postgraduate Teaching Fellow, 1955–1957.

[3] For reviews, see (a) W. A. Waters in "Organic Chemistry, An Advanced Treatise," H. Gilman, Ed., Vol. IV, John Wiley and Sons, Inc., New York, N. Y., 1953, p. 1185; (b) R. Criegee in "Newer Methods of Preparative Organic Chemistry," Interscience Publishers, Inc., New York, N. Y., 1948, p. 1.

[4] E. J. Bourne, W. M. Corbett, M. Stacey and R. Stephens, *Chemistry & Industry*, 106 (1954).

As a first step toward studying reactions of lead tetraacetate with organic disulfides, determination of whether it could be used effectively for preparing disulfides from thiols seemed worthwhile, both to afford preliminary indication of the stability of disulfides and a means of preparing them *in situ* from thiols in contemplated work. Although a number of oxidants are now available for thiols,[5] lead tetraacetate contrasts so markedly with them in its combination of characteristics that it seems a promising addition for several reasons: (1) formation of the disulfide linkage possibly could be followed by conventional reactions[3] elsewhere; (2) high oxidizing power[3b] is combined with high specificity; (3) side reactions with other oxidants, or their products, might be precluded; (4) benzene or acetic acid could afford systems homogeneous for the thiol and oxidant; and (5) these solvents, being nonaqueous, would be useful in preparing disulfides sensitive to water or highly soluble in it.

One molar proportion of lead tetraacetate was found to oxidize 1.9 proportions of benzenethiol and 1.8 of α-toluenethiol to the disulfides virtually in quantitative yield. These results are in accord with an indirect determination by Bourne, *et al.*,[4] and with the equation

$$2\ \mathrm{RSH} + \mathrm{Pb(OAc)_4} \longrightarrow \mathrm{RSSR} + \mathrm{Pb(OAc)_2} + 2\ \mathrm{HOAc}$$

Preparative procedures were developed for both of these disulfides.

In the use of lead tetraacetate with thiols of representative structural types, it generally was added during one to three hours to the thiol in benzene or acetic acid (sparingly soluble thiols). After a time, lead acetate was separated by chilling and filtration, by extraction of the disulfide, or (with acetic acid) by pouring into water. The disulfide was then purified.

Alkyl disulfides prepared were *n*-pentyl (83%), isopropyl (71%) and *t*-butyl (34%). The ease of oxidation of alkanethiols evidently is in the usual sequence of primary > secondary > tertiary,[6] because essentially those conditions which gave *n*-pentyl disulfide in 83% yield produced only 49% of isopropyl and 16% of *t*-butyl disulfide.

Since 2-carboxybenzenethiol gave the disulfide in 95% yield, an aromatic carboxyl group confers no disadvantage. On the other hand, 2-aminobenzenethiol gave the disulfide in a maximum yield of 21%; this poor result probably is connected with facile oxidation of the amino group, for example to an azo structure.[7] In contrast, the nitrogen atom in the heterocyclic nucleus of 2-mercaptobenzothiazole was not attacked by the tetraacetate, and the disulfide was obtained in 81% yield despite prolonged heating at about 75°.

Thiolacetic acid, oxidized as a representative acylthiol, gave only a fair yield of the disulfide (45%), but structurally is not a typical thiol.

The reaction of 2-mercaptoethanol with lead tetraacetate promised to be particularly interesting, because of the similarity of this thiol to 1,2-glycols which are cleaved to carbonyl compounds with great ease.[3] There was no indication of carbon–carbon cleavage, however, the corresponding disulfide being obtained as an oil in 91% yield. It was characterized by analysis and infrared spectrum, and by conversion to the bis-*p*-nitrobenzoate, m.p. 105.5–106.5°. Although the identity of this benzoate now seems unquestionable, at the outset we were puzzled by a m.p. reported for it of 145°.[8] Bennett and Whincop believed that they had obtained this ester by reaction of 2-mercaptoethanol with *p*-nitrobenzoyl chloride; they assumed that oxidation of the thiol was concurrent with esterification.[8] Our use of a procedure similar to theirs did, indeed, yield a compound of m.p. 146.5–147.5°, but it proved to be 2-mercaptoethanol bis-*p*-nitrobenzoate, which probably also was the compound isolated by Bennett and Whincop. It is noteworthy, incidentally, that we obtained the diester in spite of the use of nearly equimolar amounts of thiol and acid chloride.

The most probable explanation of the behavior of 2-mercaptoethanol with lead tetraacetate is simply that the sulfhydryl group is oxidized before cleavage of the glycol type can occur. Although one cannot dismiss the possibility that cleavage fails because a sulfhydryl group cannot act as a counterpart of an hydroxyl group, evidence was obtained that oxidation of a sulfhydryl group can in fact take precedence over cleavage, at least of a 1,2-glycol. Thus, when 0.2 mole of benzenethiol and 0.1 mole of pinacol competed in benzene for 0.1 mole of lead tetraacetate, sufficient for reaction with only one substance, phenyl disulfide was isolated in 99% yield. Addition of methanol to the benzene increased the relative rate of pinacol cleavage,[3b] but even so the extent of cleavage apparently did not exceed 21%. Since benzenethiol is more easily oxidized then alkanethiols[6] and glycols vary greatly in rate of cleavage,[9] however, caution should attend attempts at generalization from these results.

These results suggested that 3-mercapto-1,2-propanediol could be oxidized to the disulfide and then cleaved to an aldehyde, evidently isolated previously only as a polymer.[10] Formaldehyde apparently resulted, but no pure disulfide could be isolated. No effort was made to stop the reaction at the disulfide stage before cleavage, a minimum of 1–1.5 molar proportions of lead tetraacetate being used.

$$\mathrm{HOCH_2CH(OH)CH_2SH} \longrightarrow [\mathrm{HOCH_2CH(OH)CH_2S}]_2 \longrightarrow (\mathrm{OCHCH_2S})_2$$

It is interesting that the oxidation of thiols usually gave good results despite the tendency of lead salts to form mercaptides.[11] Changes in color and in the nature of solids which form as the oxidations proceed may be associated with changes in type of the lead salts.

---

(5) R. Connor in "Organic Chemistry, An Advanced Treatise," H. Gilman, Ed., Vol. I, 2nd ed., John Wiley and Sons, Inc., New York, N. Y., 1943, pp. 851, 861.

(6) M. S. Kharasch, W. Nudenberg and G. J. Mantell, *J. Org. Chem.*, **16**, 524 (1951); J. Maurin and R. Pâris, *Compt. rend.*, **231**, 1297 (1950).

(7) E. Baer and A. L. Tosoni, THIS JOURNAL, **78**, 2857 (1956); K. H. Pausacker and J. G. Scroggie, *J. Chem. Soc.*, 4003 (1954).

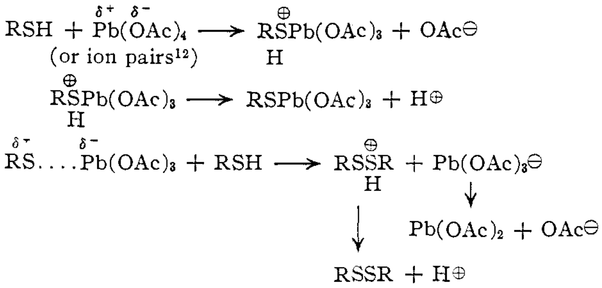
(8) G. M. Bennett and E. M. Whincop, *ibid.*, **119**, 1860 (1921).

(9) R. Criegee, L. Kraft and B. Rank, *Ann.*, **507**, 166 (1933).

(10) M. Gehrke and W. Kohler, *Ber.*, **64**, 2702 (1931). We are indebted to Evans Chemetics, Inc., New York, N. Y., for the mercaptodiol used in these experiments.

(11) Reference 5, p. 846.

Views of Levitt[12] on oxidation of thiols, conjoined with those on lead tetraacetate, afford a rather appealing sequence for this oxidation of thiols



$$\mathrm{RSH} + \overset{\delta+\ \ \delta-}{\mathrm{Pb(OAc)_4}} \longrightarrow \underset{\mathrm{H}}{\overset{\oplus}{\mathrm{RSPb(OAc)_3}}} + \mathrm{OAc}^{\ominus}$$

(or ion pairs[12])

$$\underset{\mathrm{H}}{\overset{\oplus}{\mathrm{RSPb(OAc)_3}}} \longrightarrow \mathrm{RSPb(OAc)_3} + \mathrm{H}^{\oplus}$$

$$\overset{\delta+}{\mathrm{RS}}\ldots\overset{\delta-}{\mathrm{Pb(OAc)_3}} + \mathrm{RSH} \longrightarrow \underset{\mathrm{H}}{\overset{\oplus}{\mathrm{RSSR}}} + \mathrm{Pb(OAc)_3}^{\ominus}$$

$$\mathrm{Pb(OAc)_3}^{\ominus} \longrightarrow \mathrm{Pb(OAc)_2} + \mathrm{OAc}^{\ominus}$$

$$\underset{\mathrm{H}}{\overset{\oplus}{\mathrm{RSSR}}} \longrightarrow \mathrm{RSSR} + \mathrm{H}^{\oplus}$$

Studies of reactions of disulfides with lead tetraacetate are now in progress.

Experimental[13]

Lead tetraacetate (LTA) was used as received from Arapahoe Chemicals, Inc., Boulder, Colo. (colorless crystals, moist with acetic acid; 88–95% lead tetraacetate). It was stored at 5°. Quantities specified were based on occasional iodometric titrations.[14]

Stoichiometry.—In an apparatus protected from moisture, 3.31 g. (30.0 mmoles) of benzenethiol in 10 ml. of dry benzene was added to 18.6 mmoles of lead tetraacetate (LTA) in 100 ml. of dry benzene during 15 minutes with swirling. After intermittent swirling for 30 minutes more, most of the benzene was removed below 25° in a rotating-flask evaporator. Excess LTA was then determined, using essentially the procedure of Dimroth and Schweizer,[14] by adding 17.5 ml. of acetic acid, 350 ml. of an aqueous solution containing 70 g. of sodium acetate trihydrate and 3.5 g. of potassium iodide. Benzene (50 ml.) was added to dissolve precipitated disulfide, and the iodine liberated (distributed between the two phases) was titrated immediately with 0.1035 *N* sodium thiosulfate solution to a starch end-point. The flask was closed and shaken vigorously after each addition of thiosulfate (62.20 ml.). Unconsumed LTA amounting to 3.2 mmoles, the ratio of moles of thiol oxidized to lead tetraacetate consumed was 1.9. The benzene layer (and benzene extracts) was washed with water, dried, and evaporated to 3.25 g. (99%) of phenyl disulfide, m.p. 56.5–60°, which after recrystallization (methanol) amounted to 2.86 g. (86%), m.p. and mixture m.p. 59–60°.

Similarly, with 3.73 g. (30 mmoles) of α-toluenethiol (redistilled, b.p. 98–101° (30 mm.)) and 18.2 mmoles of LTA, 1.8 mmoles of LTA was unconsumed, and moles of thiol oxidized/moles of LTA consumed therefore was 1.8. Benzyl disulfide recovered (3.74 g., m.p. 64–68.5°) amounted after recrystallization to 3.44 g. (93%), m.p. and mixture m.p. 69.5–71°.

Oxidation of Thiols.—Thiols were good commercial grades which usually were further purified by distillation or recrystallization. Unless otherwise stated, 55 mmoles of lead tetraacetate (LTA) and 100 mmoles of thiol were used, addition was effected with good stirring, solid (lead acetate) formed in reactions was removed by chilling of the mixture and then filtration, and distillation of the products was effected using a 1.5 × 4-cm. Vigreux column.

(a) **1-Pentanethiol.**—The thiol in benzene (5 ml.) was added (54 minutes) to the LTA in benzene (100 ml.). The temperature remained below 45°. A transient yellow precipitate formed as the thiol entered; the mixture soon became orange-brown. After 30 minutes, solid was removed and the filtrate distilled; yield of *n*-pentyl disulfide, 8.52 g. (83%), b.p. 82–89° (0.7–1.1 mm.), n^{25}D 1.4858–1.4872.[15]

(b) **2-Propanethiol.**—The LTA was added (2 hours) to the thiol in benzene (100 ml.) below 40° (cooling); the solution, yellow-green at first, soon became colorless as a white solid appeared. After 2 hours of stirring (25°), removal of solid and distillation of the filtrate gave 5.69 g. (76%) of isopropyl sulfide, b.p. 79–80° (30 mm.), n^{25}D 1.4877–1.4879. Redistillation left 5.32 g. (71%), b.p. 77–80° (30 mm.), n^{25}D 1.4883.[16]

Addition of the thiol to the LTA during only 1.25 hours, followed by immediate processing of the mixture resulted, after two distillations, in 3.70 g. (49%) of the disulfide, b.p. 78–80° (30 mm.), n^{25}D 1.4888. Foaming led to considerable difficulty in the distillation of the disulfide.

(c) **2-Methyl-2-propanethiol.**—The LTA was added (3 hours) to the thiol in 100 ml. of benzene. Solid separated slowly, and the mixture became yellow-orange. After 5 further hours of occasional stirring, removal of solid and distillation gave 4.14 g. (46%) of *t*-butyl disulfide, b.p. 74–97° (20 mm.), n^{25}D 1.4815–1.4993. Redistillation left 3.00 g. (34%), b.p. 85–94° (20 mm.), n^{25}D 1.4872–1.4918.[17]

Addition of the thiol to the LTA during 39 minutes and standing for 30 minutes resulted after distillation in only 1.46 g. (16%) of the disulfide, b.p. 71–89° (10 mm.), n^{25}D 1.4861–1.4952. Foaming also was troublesome in distillation of this disulfide.

(d) **α-Toluenethiol.**—The LTA was added (2 hours) to the thiol in 300 ml. of benzene. The mixture became green, then yellow as solid appeared. It gradually became brown and then, very suddenly, white. The temperature rose 6°. After 2 hours more of stirring, removal of solid and then of solvent (lead acetate appeared during removal of solvent and was separated by filtration) left benzyl disulfide which, recrystallized from petroleum ether, yielded 10.95 g. (89%) of the disulfide, m.p. 65–69°; after further recrystallization from methanol, 9.84 g. (80%), m.p. 70–71°.[18]

(e) **Benzenethiol.**—The thiol in 10 ml. of benzene was added (45 minutes) to the LTA in 300 ml. of benzene with swirling. The temperature rose negligibly. A transitory orange precipitate appeared with each addition of thiol. A yellow-brown gum slowly appeared, which later became less gummy and of lighter color. After 30 minutes of standing, solid was removed. Removal of solvent then left a solid which was extracted with ether. Removal of the ether and recrystallization of the residue (methanol) gave 9.66 g. (88%) of phenyl disulfide, m.p. and mixture m.p. 59–61°.

(f) **2-Carboxybenzenethiol.**—The thiol in 300 ml. of glacial acetic acid was heated at 49–53°, while the LTA was added (2 hours). A large amount of heavy yellow-white precipitate soon formed. The mixture was stirred at 50° for 2 hours more, cooled to 25°, and poured into 2 l. of water. Filtration separated nearly white solid which, washed and dried, amounted to 15.65 g. (102%) of bis-2-carboxyphenyl disulfide (2,2′-dithiodibenzoic acid),[19] m.p. 293–295° (uncor.). A solution of 0.78 g. in 20 ml. of 3% aqueous sodium carbonate was washed with ether and acidified; yield 0.73 g. (95% over-all), m.p. 293.5–295° (uncor.),[20] neut. equiv. 155 (calcd. 153).

(g) **2-Aminobenzenethiol.**—The thiol[21] in 10 ml. of benzene was added to the LTA in 100 ml. of benzene (52 minutes). A yellow color appeared which soon changed to red as black solid formed. The mixture became warm. After one hour it was chilled and treated with decolorizing carbon. Filtration and removal of solvent gave a mush which, in benzene, was extracted with dilute hydrochloric acid. The extract was washed, basified, and extracted with benzene; yield of bis-2-aminophenyl disulfide (*o,o*′-dithiodianiline),[19] 3.66 g. (29%), m.p. 79–86°. Recrystallizations (carbon tetrachloride) gave 2.66 g. (21%) of brown crystals, m.p. 91.5–92.5°, which did not depress the m.p. (89–91°) of purified authentic material.[21]

---

(12) L. S. Levitt, *J. Org. Chem.*, **20**, 1297 (1955).

(13) Melting points are corrected and boiling points are uncorrected. Analyses are by Clark Microanalytical Laboratory, Urbana, Ill., and Micro-Tech Laboratories, Skokie, Ill. We are indebted to Dr. E. A. Jones and Mr. C. E. Slade of the Physics Dept., Vanderbilt University, for infrared spectra (determined with a model 21 Perkin-Elmer instrument).

(14) O. Dimroth and R. Schweizer, *Ber.*, **56**, 1375 (1923).

(15) E. Miller, F. S. Crossley and M. L. Moore, THIS JOURNAL, **64**, 2322 (1942), reported b.p. 90–92° (1 mm.), n^{25}D 1.4875, 1.4868.

(16) D. T. McAllan, T. V. Cullum, R. A. Dean and F. A. Fidler, *ibid.*, **73**, 3627 (1951), reported b.p. 174°, n^{25}D 1.4891 for isopropyl disulfide with an estimated purity of 98.9 mole %.

(17) S. F. Birch, T. V. Cullum and R. A. Dean, *J. Inst. Petroleum*, **39**, 206 (1953), report b.p. 88° (21 mm.), n^{20}D 1.4899, for material of 99.77 mole % purity.

(18) F. H. McMillan and J. A. King, THIS JOURNAL, **70**, 4113 (1948), cite m.p. 70–71.5°.

(19) Name preferred by *C. A.*

(20) L. Gattermann, *Ber.*, **32**, 1151 (1899), reported m.p. 289°.

(21) Kindly provided by the American Cyanamid Co., New York 20, N. Y.

Addition of 50 mmoles of LTA to the thiol at 3–5° during 4.6 hours using 300 ml. of solvent, followed by a period of 1 hour at 25° gave 2.01 g. (16%) of green crystals, m.p. and mixture m.p. 89.5–91°; the same result was obtained by addition at 25°.

(h) **2-Mercaptobenzothiazole.**—The LTA was added (3 hours) to the thiol[22] in 400 ml. of glacial acetic acid at 72–75°. A fleeting brown color resulted upon entrance of thiol late in the addition. The mixture was stirred for 8 hours at 72–75°, cooled, and poured into ice-water (2 l.). Solid collected by filtration was washed with water and dried. 2-Benzothiazolyl disulfide was separated from lead salts in the solid by extraction into benzene using a Soxhlet apparatus (28 hours). The extract was concentrated until crystals appeared, then chilled at 5° overnight. Filtration separated 13.48 g. (81%) of 2-benzothiazolyl disulfide, yellow leaflets, m.p. 182.5–183.5°[23] (depressed to 148–173° by the original thiol).

(i) **Thiolacetic Acid.**—The LTA was added over 3 hours (28–30°) to the thiol in 300 ml. of benzene. Black solid which appeared soon became gray and flocculent. The mixture was stirred for 4 hours more and solvent removed at 25° in a rotating-flask evaporator. Ether extracts of the resulting mush were distilled. yielding 3.42 g. (45%) of acetyl disulfide, b.p. 60–61° (1 mm.), m.p. 19.5–20.5° (uncor.), $n^{25}\text{D}$ 1.5384.[24] Acetyl disulfide of this quality seemed stable in a sealed ampoule for 5 months, unlike less pure material which slowly deposited sulfur and evolved hydrogen sulfide.

(j) **2-Mercaptoethanol.**—Lead tetraacetate (0.256 mole) was added to 40.00 g. (0.51 mole) of the thiol in 1500 ml. of benzene during 1.8 hours (25–30°). The mixture soon became yellow; solid formed which later became gummy. Stirring was continued for 2 hours. After filtration, an acetonitrile extract of gum in the flask was combined with the filtrate and solvent removed in a rotating-flask evaporator. Distillation in a Hickman-type short-path still at 0.03–0.14 mm. gave 35.96 g. (91%) of bis-(2-hydroxyethyl) disulfide (2,2′-dithiodiethanol[19]), $n^{25}\text{D}$ 1.5579–1.5615. Redistillation in a short-path still (0.15 mm., jacket *ca.* 165°) gave disulfide with $n^{25}\text{D}$ 1.5585. Since the $n^{25}\text{D}$ differed somewhat from a reported value,[25] similarly distilled material was analyzed. The infrared spectrum (liquid film) showed strong absorption at 3305 cm.$^{-1}$ (presence of –OH),[26] but none in the region of 2550–2600 cm.$^{-1}$ (absence of –SH).[26]

Anal. Calcd. for $C_4H_{10}O_2S_2$: C, 31.15; H, 6.54. Found: C, 31.21; H, 6.58.

The original distillate (0.99 g., $n^{25}\text{D}$ 1.5605–1.5615) was heated with *p*-nitrobenzoyl chloride (2.86 g.) in 2 ml. of dry pyridine for 20 minutes at *ca.* 90°. The product was cooled, rubbed with aqueous bicarbonate, and recrystallized twice from aqueous acetone; yield 2.29 g. (79%) of bis-(2-*p*-nitrobenzoyloxyethyl) disulfide (2,2′-dithiodiethanol di-*p*-nitrobenzoate[19]) as pale yellow crystals, m.p. 105.5–107°; mixture m.p. 102.5–106.5° with presumably authentic material[27] of m.p. 102.5–105.5°. Further recrystallization resulted in a constant m.p. of 105.5–106.5°.

Anal. Calcd. for $C_{18}H_{16}N_2O_8S_2$: C, 47.78; H, 3.57; mol. wt., 452. Found: C, 48.12; H, 3.62; mol. wt. (ebullioscopic, in butanone), 455.

Bennett and Whincop[8] reported m.p. 145° for this derivative; however, their mol. wt. (353) or N% (6.1) do not both agree with any probable product of their reaction. When the thiol (855 mg., 11.0 mmoles) was heated with *p*-nitrobenzoyl chloride (2.23 g., 12 mmoles) in dry pyridine (1 ml.) for 3 minutes at *ca.* 90°, after isolation of the product as above and recrystallization (*n*-butyl acetate and acetone), there resulted 813 mg. (36%) of 2-mercaptoethanol bis-*p*-nitrobenzoate, m.p. 146–147.5°, the infrared spectrum of which showed no absorption in the hydroxyl or sulfhydryl regions (potassium bromide pellet). Further purification resulted in the constant m.p. 146.5–147.5°. This compound (mol. wt., calcd., 376) is probably identical with that of Bennett and Whincop who, we believe, were misled by an erroneous N%.

Anal. Calcd. for $C_{16}H_{12}N_2O_7S$: C, 51.06; H, 3.21; N, 7.45. Found: C, 50.82; H, 3.18; N, 7.68.

Pinacol and Benzenethiol in Competition for LTA.—The LTA (0.10 mole) was added during 1 hour to 22.03 g. (0.20 mole) of benzenethiol and 11.82 g. (0.10 mole) of pinacol[28] in 500 ml. of dry benzene. The temperature was kept at 25–30°. Pinacol and lead acetate were then removed by washing the mixture with water, solid matter being removed and discarded. The benzene solution was washed with aqueous alkali, to remove any benzenethiol, and dried. Removal of solvent left 21.66 g. (99%) of phenyl disulfide, m.p. 54–59°, amounting after two recrystallizations to 18.70 g. (86%), m.p. and mixture m.p. 59.5–60.5°.

When the experiment was repeated in benzene containing 25 mole % of methanol, acidification was necessary for liberation of thiol. Isolation as before gave 17.30 g. (79%) of phenyl disulfide, m.p. 57–59.5° (purified, 72%, m.p. and mixture m.p. 59.5–60.5°). Oxidation of the alkali wash with potassium iodide–iodine solution converted thiol present to phenyl disulfide; yield after recrystallization, 0.91 g. (4%), m.p. and mixture m.p. 59–60°. Since 4–21% of thiol was not oxidized by the tetraacetate, a corresponding amount of pinacol must have been cleaved.

NASHVILLE 5, TENN.

---

(22) Kindly provided by the Monsanto Chemical Co., Akron, Ohio.

(23) C. G. Moore, *J. Chem. Soc.*, 4232 (1952), reported m.p. 178.5-179°.

(24) H. Böhme and M. Clement, *Ann.*, **576**, 66 (1952), reported b.p. 105–106° (18 mm.), m.p. 21°.

(25) $n^{20}\text{D}$ 1.5652, W. D. Helmer, U. S. Patent 2,746,994 [*C. A.*, **51**, 461 (1957)].

(26) L. J. Bellamy, "The Infra-red Spectra of Complex Molecules," John Wiley and Sons, Inc., New York, N. Y., 1954.

(27) Prepared similarly from bis-(2-hydroxyethyl)-disulfide kindly supplied by the Thiokol Corporation, Trenton, N. J.

(28) Anhydrous, b.p. 173–175°, m.p. 42.5–44.5°; prepared from the hexahydrate by combination of methods of H. S. King and W. W. Stewart, *Proc. Trans. Nova Scotian Inst. Sci.*, **17**, 262 (1930); *C. A.*, **25**, 1799 (1931).