after which it was cooled. The isolated product was recrystallized from ligroin (b.p. 60–90°), yielding 34 g. (67%) of white crystalline rods, m.p. 62.5–65°. This compound shows a strong O–H absorption band at 3.1 μ in the infrared spectra.

Anal. Calcd. for C_7H_7ClOS (174.7): C, 48.02; H, 4.04; S, 18.38. Found: C, 48.12; H, 3.97; S, 18.80.

N-Methyl-*p*-aminobenzyl *p*-Chlorophenyl Sulfide from Hydroxymethyl *p*-Chlorophenyl Sulfide (XV), N-Methylaniline, and Hydrochloric Acid.—To a solution of 8.8 g. (0.05 mole) of hydroxymethyl *p*-chlorophenyl sulfide (XV) and 25 ml. of 95% ethanol was added with stirring a solution of 5.4 g. (0.05 mole) of N-methylaniline in 4.3 ml. (0.05 mole) of concentrated hydrochloric acid. The reaction mixture was refluxed for 30 min., after which it was cooled and made basic with 10% sodium hydroxide solution. The white crystalline solid was collected and washed thoroughly with water until neutral and dried. The yield of crude product was 11.7 g. (88%) which was almost identical with the yield obtained from the rearrangement of N-methyl-N-phenylaminomethyl *p*-chlorophenyl sulfide.[2] Recrystallization from ethanol gave 10.2 g. of white crystals, m.p. 109–111°.[2]

N-Methyl-*p*-aminobenzyl Benzyl Sulfide (XVIII).—To a stirred mixture of 12.4 g. (0.1 mole) of α-toluenethiol (benzyl mercaptan), 7.6 ml. (0.1 mole) of 37% formalin, and 30 ml. of 95% ethanol was added slowly a solution of 10.7 g. (0.1 mole) of N-methylaniline in 8.6 ml. (0.1 mole) of concentrated hydrochloric acid. Following a procedure similar to that used to prepare N-methyl-*p*-aminobenzyl aryl sulfides,[2] 18 g. (74%) of a crude product was obtained. After two recrystallizations from isopropyl alcohol, white needles, m.p. 36–38°, were obtained.

The compound was identified by the appearance of a characteristic N–H absorption band in the 2.93-μ region of the infrared spectrum. *para* substitution was indicated by a strong absorption band in the 12.1-μ region which is characteristic of two adjacent hydrogens.

Anal. Calcd. for $C_{16}H_{17}NS$ (243.4): C, 74.02; H, 7.04; N, 5.76; S, 13.18. Found: C, 74.12; H, 6.84; N, 5.75; S, 13.24.

Organic Sulfur Compounds. III.[1] Synthesis of 2-(Substituted alkylamino)ethanethiols[2]

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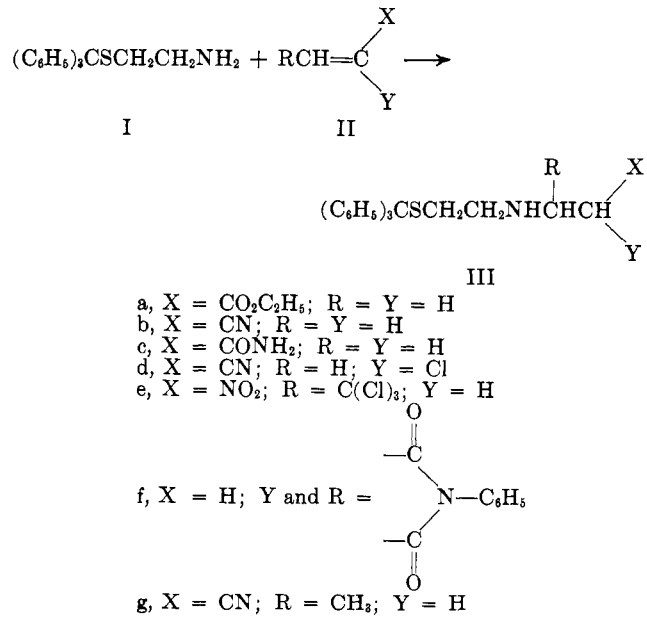
A two-step procedure for mercaptoethylation is described which can be used to prepare a number of 2-(alkylamino)ethanethiols containing additional functional groups. The N-(substituted alkyl)-N-2-tritylthioethylamines are obtained by adding 2-tritylthioethylamine to substrates containing activated double bonds. The addition products thus formed are converted by detritylation with mercuric acetate followed by treatment with hydrogen sulfide to 2-(substituted alkylamino)ethanethiols.

The potential use of 2-aminoethanethiols as antiradiation drugs[3] has created a recent interest in new methods for the synthesis of compounds in this class, particularly those containing additional functional groups.

A survey of the literature has indicated that the most general route for the preparation of 2-aminoethanethiols involves mercaptoethylation of amines with ethyl 2-mercaptoethylcarbonate or ethylene monothiocarbonate.[4] This procedure is an attractive route and has been used to prepare a number of 2-aminoethanethiols. However, except for one example the amines were simple alkyl or aryl amines containing no additional functional groups. Wineman and coworkers[5] have successfully prepared a few 2-aminoethanethiols containing hydroxyl or alkoxyl functions by prior preparation of ethylene sulfide followed by its treatment with an amine. The ease of polymerization of ethylene sulfide and its reactivity toward a number of functional groups limit the scope of this procedure.[6]

This paper describes our work on the preparation of 2-aminoethanethiols containing carbethoxy, cyano, carbamido, carboxy, carbohydrazido, and chloro groups. The reaction sequence used is shown in Charts I and II.

CHART I



2-Tritylthioethylamine (I), prepared from trityl mercaptan and 2-bromoethylamine hydrobromide, adds to compounds containing activated carbon–carbon double bonds to give crystalline addition products, III, in good yield (Table I). The addition reaction proceeds smoothly in ethanol at room temperature or lower in 1–8 hr. with the unsubstituted substrates, ethyl acrylate (IIa) and acrylonitrile (IIb); with substituted

(1) Paper II in this series: F. I. Carroll, J. D. White, and M. E. Wall, *J. Org. Chem.*, **28**, 1240 (1963).

(2) This investigation was supported by the Department of the Army and the U. S. Army Medical Research and Development Command, Contract No. DA-49-193-MD-2164.

(3) *Cf.* Symposium on Radiation-protective Agents, 141st National Meeting of the American Chemical Society, Washington, D. C., March 1962.

(4) D. D. Reynolds, D. L. Fields, and D. L. Johnson, *J. Org. Chem.*, **26**, 5130 (1961), and preceding papers.

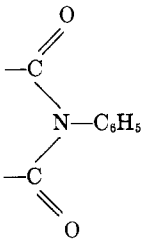
(5) R. J. Wineman, M. H. Gollis, J. C. James, and A. M. Pomponi, *ibid.*, **27**, 4222 (1962).

(6) C. C. J. Culvenor, W. Davis, and N. S. Heath, *J. Chem. Soc.*, 282 (1949).

TABLE I

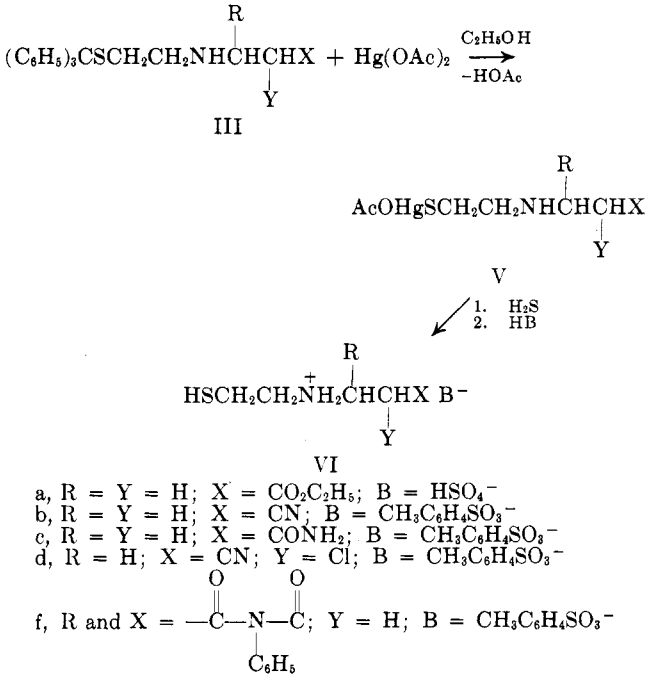
N-(SUBSTITUTED ALKYL)-N-2-TRITYLTHIOETHYLAMINES

$(C_6H_5)_3CSCH_2CH_2NHCHCH$ (R, X, Y)

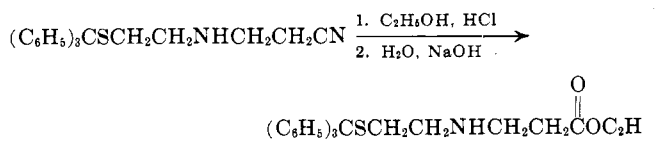
Compd. III	X	R, Y	Recrystn. solvent	Yield, %	M.p., °C.	Formula	Carbon, % Calcd.	Carbon, % Found	Hydrogen, % Calcd.	Hydrogen, % Found
a	$CO_2C_2H_5$	H, H	Ethyl acetate–petr. ether	88	77–79	$C_{26}H_{29}NO_2S$	74.42	74.68	6.99	7.03
b	CN	H, H	Ethanol	92	109–110	$C_{24}H_{24}N_2S$	77.37	77.33	6.49	6.58
c	$CONH_2$[a]	H, H	Acetonitrile	83	109.5–111	$C_{24}H_{26}N_2OS$	73.81	73.83	6.71	6.47
d	CN	H, Cl	Ethanol	73	135–137	$C_{24}H_{23}ClN_2S$	70.83	70.73	5.70	5.70
e	NO_2	$C(Cl)_3$, H	Ethanol	93	94.5–96	$C_{24}H_{23}Cl_3N_2O_2S$	56.53	56.49	4.55	4.86
f	H		Ethanol	96	142–143	$C_{31}H_{28}N_2O_2S$	75.58	75.41	5.73	5.85
g	CN	CH_3, H	Ethanol	51	101–104	$C_{25}H_{26}N_2S$	77.67	77.47	6.78	6.84

[a] See footnote 15.

CHART II



substrates containing electronegative substituents, α-chloroacrylonitrile (IId) and 3,3,3-trichloro-1-nitropropene (IIe); and with N-phenylmaleimide (IIf). With the less active acrylamide (IIc) and crotononitrile (IIg) the use of refluxing ethanol was required in order to obtain a good yield of IIIc and IIIg. The addition product IIIa was also prepared by treating IIIb with ethanolic hydrogen chloride followed by hydrolysis. The n.m.r. spectra of all the adducts showed a broad singlet at δ 1.22–1.87 (N–H) and a multiplet at 7.13–7.73 (aromatic protons) in addition to resonances



specific for each individual compound.[7] These results along with the elemental analysis, infrared spectrum, and method of preparation, confirm the structure III for the adducts. 2-Tritylthioethylamine failed to react with methacrylonitrile, methylmethacrylate, and ethyl crotonate. Attempts to force the reaction by the use of alkaline catalysts such as sodium ethoxide or tributyl ammonium hydroxide were unsuccessful. Elderfield and co-workers[8] found that *p*-anisidine did not add to ethyl acrylate under the influence of basic catalysts. However, in the presence of acetic acid a good yield of ethyl β-anisidinopropionate was obtained. When 2-tritylthioethylamine was refluxed with ethyl crotonate or methacrylonitrile in acetic acid, no addition took place. However, a 40–50% yield of N-(2-tritylthioethyl)acetamide (IV) was obtained. The structure was verified by infrared and n.m.r. spectra.

We have found that the addition products III were smoothly detritylated by treatment with mercuric acetate in ethanol to give the mercuric acetate sulfhydryl derivatives V. The infrared spectra of these derivatives showed acetate carbonyl absorption at 1570 to 1580 cm.$^{-1}$ and showed no aromatic absorption peaks.

The mercuric acetate sulfhydryl derivatives V, on treatment with hydrogen sulfide, were converted to the free thiols VI, isolated as the tosylate or hydrogen sulfate salts (see Table II). The infrared spectra of the adducts showed an absorption at 2500–2580 cm.$^{-1}$ (–SH) in addition to absorptions typical of the functional groups present. These results, along with the elemental analysis, quantitative sulfhydryl analysis, and n.m.r. spectra confirm the structure VI for the 2-aminoethanethiols.[9]

Other methods for removal of the S-trityl group of the adducts were investigated. According to Zervas

(7) The –NH resonance was masked by the strong CH_3– triplet at δ 1.22 of IIIa, however, the resonance at δ 1.22 integrated for 3.7 protons.

(8) R. C. Elderfield, W. J. Gensler, T. H. Bembry, C. B. Kremer, F. Brady, H. A. Hageman, and J. D. Head, *J. Am. Chem. Soc.*, **68**, 1259 (1946).

(9) The –SH band of 2-(2-carbohydrazidoethylamino)ethanethiol di-*p*-toluenesulfonate salt was masked by the broad NH^+ and NH_2^+ bands.

TABLE II

2-(SUBSTITUTED ALKYLAMINO)ETHANETHIOLS

$HSCH_2CH_2\overset{+}{N}H_2CHCH(R)(X)(Y)$ $CH_3C_6H_4SO_3^-$

Compd. VI	X	R, Y	Recrystn. solvent	Yield, %	M.p., °C.	% pure by SH analysis	Formula	Carbon, % Calcd.	Carbon, % Found	Hydrogen, % Calcd.	Hydrogen, % Found	Nitrogen, % Calcd.	Nitrogen, % Found	Sulfur, % Calcd.	Sulfur, % Found
a[a]	$CO_2C_2H_5$	H, H	Ethanol–ether	80	75–76	100	$C_7H_{17}NO_6S_2$	30.53	30.87	6.22	6.27	5.08	5.16	23.29	23.42
b	CN	H, H	Ethanol–ether	78	100–100.5	100	$C_{12}H_{18}N_2O_3S_2$	47.66	47.74	6.00	5.99	9.26	9.00	21.21	21.02
c	$CONH_2$	H, H	Ethanol–ether	88	124–124.5	100	$C_{12}H_{20}N_2O_4S_2$	44.98	44.77	6.29	6.37	8.74	8.73	20.01	20.21
d	CN	H, Cl	Acetonitrile	63	133–136 dec.	90	$C_{12}H_{17}ClN_2O_3S_2$	42.78	42.67	5.09	4.86	8.32	8.31	19.04	19.03
f	H		Acetonitrile	60	195–202 dec.	*b*	$C_{19}H_{22}N_2O_6S_2$	54.01	54.19	5.25	5.40	6.63	6.91	15.18	15.12
h	COOH[c]	H, H	Ethanol–ether	53	119–121	99	$C_{12}H_{19}NO_5S_2$	44.84	45.03	5.96	6.14	4.36	4.61	19.95	20.08
i		H, H	Acetonitrile–water	77	164–166	97	$C_{19}H_{29}N_3O_7S_3$	44.95	45.27	5.76	5.59	8.28	8.58	18.95	18.50

[a] Isolated as the hydrogen sulfate salt. See footnote 18. [b] This sample was too insoluble in water to analyze. [c] See footnote 19. [d] See footnote 20.

and co-workers,[10] S-tritylcysteine is readily cleaved to cysteine by treatment with hydrogen bromide in acetic acid. However, when IIIa was treated with hydrogen bromide in acetic acid at room temperature no detritylation occurred and an almost quantitative yield of the hydrobromide salt of IIIa was obtained. Treatment of IIIa with hydrogen bromide in acetic acid at higher temperatures afforded detritylation, but no mercaptan could be isolated from the reaction mixture. A sulfhydryl analysis of the products obtained from the treatment of IIIa with trifluoroacetic acid,[10] or *p*-toluenesulfonic acid in ethanol indicated that no mercaptan was formed. Treatment of IIIb with silver nitrate in methanol[10] afforded a crude unstable silver mercaptide isolated as a nitrate salt of the amine which showed peaks in the infrared at 2250 (C≡N), 1375, and 825 cm.$^{-1}$ (NO_3^-). Attempts to convert the silver mercaptide to the free mercaptan VIb with hydrogen chloride in a number of different solvents afforded impure products that could not be characterized but gave peaks in the infrared at 1375 and 825 cm.$^{-1}$ indicating the presence of nitrate salts. The freshly isolated products (50–70% mercaptan by sulfhydryl analysis) underwent gradual decomposition even under vacuum in the dark.

The free mercaptan VIe could not be obtained from the addition products IIIe. Treatment of IIIe with mercuric acetate gave a crude mercuric acetate derivative. The infrared spectrum showed nitro absorption at 1555 and 1380 cm.$^{-1}$, and acetate carbonyl absorption at 1570 cm.$^{-1}$. However, when this material was treated with hydrogen sulfide, none of the desired mercaptan VIe was obtained. The infrared spectrum of the crude product showed no nitro absorption peaks. Treatment of IIIe with hydrogen bromide in acetic acid yielded a hydroscopic oil that could not be purified.

$(C_6H_5)_3CSCH_2CH_2NHCHCH_2NO_2$ (CCl$_3$) — IIIe

$HSCH_2CH_2NHCHCH_2NO_2$ (CCl$_3$) — VIe

With the thiol group of IIIa protected by the S-trityl moiety, additional N-(substituted alkyl)-N-2-tritylthioethylamines could be prepared as outlined in Chart III. Hydrolysis of IIIa gave N-(2-carboxyethyl)-N-2-tritylthioethylamine (IIIh) and treatment of IIIa with hydrazine yielded N-(2-carbohydrazidoethyl)-N-2-tritylthioethylamine (IIIi).

The products IIIh and IIIi were converted to the corresponding 2-aminoethanethiols VIh and VIi, isolated as their tosylate salts, by reaction with mercuric acetate followed by treatment with hydrogen sulfide in ethanol (see Table II). The acid VIh was also obtained by the scheme shown in Chart IV. Benzylthioethylamines (VII)[11] added readily to ethyl acrylate to give the adduct VIII which was hydrolyzed to IX. The acid IX was converted to VIh by treatment with sodium in liquid ammonia followed by acidification with *p*-toluenesulfonic acid. The yield and purity of the mercaptan VIh obtained *via* the S-benzyl adduct was inferior to that obtained *via* the S-trityl adduct IIIa. A number of attempts to debenzylate the adduct VIII with sodium and liquid ammonia yielded impure and

(10) L. Zervas and I. Photaki, *J. Am. Chem. Soc.*, **84**, 3887 (1962).
(11) J. Baddiley and E. M. Thain, *J. Chem. Soc.*, 800 (1952).

CHART III

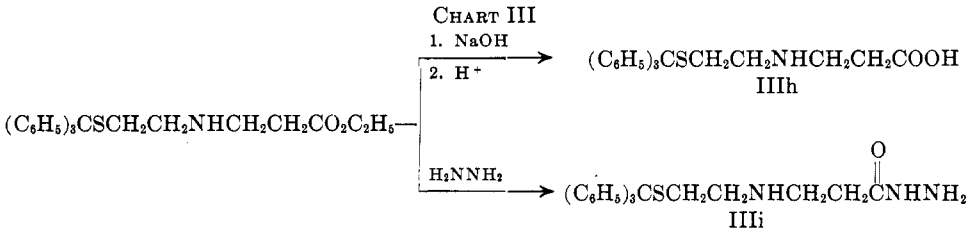
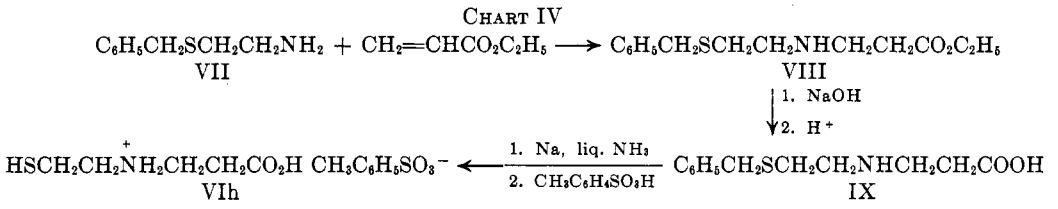


CHART IV



intractable products. These results indicate that in the presence of other functional groups the trityl moiety is superior to the benzyl moiety for protecting thiol groups.

The over-all results of adding 2-tritylthioethylamine to substrates containing carbon–carbon double bonds activated by electron-withdrawing groups (Chart I), followed by removal of the S-trityl protecting group (Chart II) gives a convenient two-step method of mercaptoethylation, which can be used to prepare 2-aminoethanethiols containing a number of other functional groups.

Experimental[12]

Materials.—The 2-bromoethylamine hydrobromide, ethyl acrylate, acrylonitrile, and acrylamide were obtained from Eastman Organic Chemicals Distillation Products Industries. The trityl mercaptan, 2-chloroacrylonitrile, ethyl crotonate, crotononitrile, and N-phenylmaleimide were obtained from Columbia Organic Chemicals Co., Inc. The methyl methacrylate was obtained from Rohm and Haas Co.

2-Tritylthioethylamine (I).—Sodium metal (0.20 g.-atom) was added to 200 ml. of absolute ethanol in a 500-ml. three-necked flask fitted with a mechanical stirrer, reflux condenser with a Drierite drying tube at the top, and a nitrogen inlet tube. After all of the sodium had reacted, 27.6 g. (0.1 mole) of trityl mercaptan was added followed by the addition of 20.4 g. (0.1 mole) of 2-bromoethylamine hydrobromide. The stirred reaction mixture was allowed to reflux overnight. The cooled reaction mixture was filtered and the filtrate was concentrated under vacuum. The residue was dissolved in ether and washed with water. The ether extracts were dried and concentrated to a small volume and petroleum ether (b.p. 30–60°) was added until the solution became cloudy. After cooling 30.9 g. (93%) of hard crystals were obtained, m.p. 85–92°. An analytical sample, prepared by further recrystallization from the same solvent, had m.p. 90–93°; ν_{max}^{KBr} 3400 broad (N–H), 3080, 3055, 3030 (aromatic C–H), 1592 (aromatic), and 743, 698 cm.$^{-1}$ (aromatic substitution peaks). The n.m.r. spectrum (deuteriochloroform) showed a singlet at δ 1.05 (NH<, 1.8H), a multiplet at 2.47 (SCH_2CH_2N<, 4H), and a multiplet at 7.38 (aromatic protons, 15H).

Anal. Calcd. for $C_{21}H_{21}NS$: C, 78.95; H, 6.82. Found: C, 78.68; H, 6.68.

A picrate was obtained from 2-tritylthioethylamine in ether and was recrystallized from ethanol, m.p. 190–191°.

Anal. Calcd. for $C_{27}H_{24}N_4O_7S$: C, 59.11; H, 4.41; N, 10.21. Found: C, 59.32; H, 4.33; N, 10.41.

3,3,3-Trichloro-1-nitropropene.—This material was obtained in a 57% over-all yield from chloral hydrate using the procedure for preparing nitro olefins reported by Carroll, White, and Wall[13]: b.p. 40–42° at 0.03 mm. (lit.[14] b.p. 88–89° at 16 mm.); $n^{25}D$ 1.5166 (lit.[14] $n^{25}D$ 1.5162).

N-(Substituted alkyl)-N-2-tritylthioethylamines (III).—These compounds were prepared by adding dropwise 0.01–0.05 mole of the activated olefin dissolved in 10–50 ml. of absolute alcohol to 0.01–0.05 mole of the 2-tritylthioethylamine dissolved in 15–75 ml. of absolute alcohol and cooled in an ice bath. The stirred solution was allowed to warm to room temperature.[15] The progress of the reaction was followed by thin layer chromatography[16] (CH_3OH). At the end of the reaction the product was obtained by concentration under vacuum. Results with individual compounds are given in Table I. The infrared and n.m.r. spectra of each of the adducts were consistant with the assigned structures IIIa–IIIg.

Unsuccessful Addition Reactions of 2-Tritylthioethylamine.—No adducts were obtained when 2-tritylthioethylamine was allowed to react with methacrylonitrile, methyl methacrylate, or ethyl crotonate in ethanol. The use of sodium ethoxide or tributyl ammonium hydroxide did not aid the reaction. When 2-tritylthioethylamine was refluxed in acetic acid with methacrylonitrile or ethyl crotonate, N-(2-tritylthioethyl)acetamide (IV) was obtained in 40–50% yield. The analytical sample was recrystallized from ethyl acetate: m.p. 175–177°; ν_{max}^{KBr} 3270 (N–H), 3090, 3065, 3035 (aromatic C–H), 1640, 1550 (amide I and II bands), 1598 (aromatic), and 702 cm.$^{-1}$ (aromatic substitution peak). The n.m.r. spectrum (deuteriochloroform) included a singlet at δ 1.87 [$CH_3C(O)N$, 2.6H], unsymmetrical triplet at 2.45 (CCH_2S, 2.0H), apparent quartet at 3.12 (NCH_2C, 2.0H), broad peak at 5.59 (O=CNHC, 1.0H), and a multiplet at 7.34 [$C(C_6H_5)_3$, 15.4H].

Anal. Calcd. for $C_{23}H_{23}NOS$: C, 76.41; H, 6.41; N, 3.87; S, 8.89. Found: C, 76.45; H, 6.46; N, 3.82; S, 8.93.

Preparation of N-(2-Carbethoxyethyl)-N-2-tritylthioethylamine (IIIa) from N-(2-Cyanoethyl)-N-2-tritylthioethylamine (IIIb).—Dry hydrogen chloride gas was passed into a cold solution–suspension of 3.2 g. (0.01 mole) of N-(2-cyanoethyl)-N-2-tritylthioethylamine in 100 ml. of ethanol until the solution was saturated. The reaction solution was allowed to warm to room temperature, concentrated under vacuum, dissolved in 150 ml. of water, made basic with sodium carbonate, and extracted with ether. The dried ether extracts were concentrated to give 3.47 g. of an oil. Crystallization from an ethyl acetate and petroleum ether mixture gave 2.80 g. (66.7%) of N-(2-carbethoxyethyl)-N-2-tritylthioethylamine, m.p. 77–80°. A mixture melting point with the product obtained by adding 2-tritylthioethylamine to ethyl acrylate occurred at 77–80°. The infrared spectrum of the two products were identical.

(12) The melting points obtained on a Kofler hot stage are corrected The boiling points are uncorrected. The infrared spectra were obtained using a Perkin-Elmer Model 221 spectrophotometer. The n.m.r. spectra were obtained using a Varian A-60 spectrometer with samples dissolved either in deuteriochloroform or pyridine (internal standard, tetramethylsilane) or deuterium oxide (internal standard, 3-trimethylsilyl-1-propanesulfonic acid sodium salt). Thin layer chromatograms were obtained using silica gel G. The chromatograms were developed with iodine vapor. Microanalyses were by Micro-Tech Laboratories, Inc., Skokie, Ill.

(13) F. I. Carroll, J. D. White, and Monroe E. Wall, *J. Org. Chem.*, **28**, 1236 (1963).

(14) F. Bowers and H. Burkett, *J. Am. Chem. Soc.*, **75**, 1082 (1953).

(15) In the case of the addition to acrylamide and crotononitrile 3 days reflux were required.

(16) The 2-tritylthioethylamine had a smaller R_f than the addition products.

N-(2-Carboxyethyl)-N-2-tritylthioethylamine (IIIh).—To a stirred solution of 10 g. (0.0239 mole) of N-(2-carbethoxyethyl)-N-2-tritylthioethylamine in 50 ml. of dioxane[17] and 10 ml. of water was added 23.91 ml. (0.0239 mole) of 1 *N* sodium hydroxide and the mixture was allowed to stir overnight. The next morning 23.91 ml. (0.0239 mole) of 1 *N* hydrochloric acid was added. On further dilution with water a solid crystallized from solution. Filtration afforded 8.2 g. (90%) of N-(2-carboxyethyl)-N-2-tritylthioethylamine (IIIh), m.p. 184–187° dec. The analytical sample, recrystallized from dioxane[17] and water, had m.p. 186–187° dec.; ν_{max}^{KBr} 3060, 3030, 3020 (aromatic CH), 3000–2500 (broad acid OH), 1640 (acid C=O), and 690 cm.$^{-1}$ (aromatic).

Anal. Calcd. for $C_{24}H_{25}NO_2S$: C, 73.62; H, 6.44. Found: C, 73.28; H, 6.48.

N-(2-Carbohydrazidoethyl)-N-2-tritylthioethylamine (IIIi).—A solution of 16.8 g. (0.04 mole) of N-(2-carbethoxyethyl)-N-2-tritylthioethylamine and 2.8 g. (0.08 mole) of anhydrous hydrazine in 40 ml. of ethanol was kept at 45° overnight. The reaction mixture was concentrated under vacuum. The remaining oil was recrystallized from an ethyl acetate and petroleum ether mixture to afford 14 g. (87%) of N-(2-carbohydrazidoethyl)-N-2-tritylthioethylamine, m.p. 128–129°. An analytical sample, prepared by recrystallization from the same solvent had m.p. 129–130.5°; ν_{max}^{KBr} 3300, 3200 (N—H), 3060, 3030, 3020 (aromatic C—H), 1670, 1635 (hydrazide C=O), and 1590 cm.$^{-1}$ (aromatic). The n.m.r. spectrum (deuteriochloroform) showed a multiplet at δ 2.07–2.83 (CH_2 plus 1NH, 8.5H), a broad peak at 2.97 (NH, 3.2H), and a multiplet at 7.08–7.67 (aromatic, 15.2H).

Anal. Calcd. for $C_{24}H_{27}N_3OS$: C, 71.08; H, 6.71. Found: C, 71.10; H, 6.89.

2-(Substituted alkylamino)ethanethiol *p*-Toluenesulfonate Salts (VI).[18]—To a cold stirred solution of 0.001–0.03 mole of mercuric acetate[19,20] in 10–300 ml. of absolute ethanol was added 0.001–0.03 mole of the N-(substituted alkyl)-N-2-tritylthioethylamine. The mixture was allowed to warm to room temperature and stir for 15 to 30 min.[19] The solution was concentrated under reduced pressure and the remaining residue was extracted with ether. Concentration of the ether afforded a 90–100% yield of triphenylmethylethyl ether, m.p. 79–82°. The analytical sample was prepared by recrystallization from isopropyl alcohol: m.p. 81.5–83°; $\nu_{max}^{CH_2Cl_2}$ 1060 cm.$^{-1}$ (C—O). The n.m.r. spectrum (deuteriochloroform) showed a triplet at δ 0.83 (CH_3, 3H), a quartet at 2.75 (CH_2O, 2H), and a multiplet at 6.72–7.33 (aromatic protons, 15H).

Anal. Calcd. for $C_{21}H_{20}O$: C, 87.46; H, 6.99. Found: C, 87.47; H, 6.97.

The crude mercuric sulfhydryl derivative[21] remaining from the ether extraction was dissolved or suspended in absolute ethanol and hydrogen sulfide was passed through the solution for 2 hr. The mercuric sulfide that formed was separated by filtering the reaction mixture through a filter pad, under a carbon dioxide atmosphere, into a flask containing one equivalent of *p*-toluenesulfonic acid monohydrate[19] in 10–100 ml. of benzene.[22] Concentration of the solution under vacuum afforded the 2-(substituted alkylamino)ethanethiol *p*-toluenesulfonate salts. The results with individual compounds are given in Table II. The infrared and n.m.r. spectra of each compound was consistent with the structures assigned. The purity of the compounds was determined by the N-ethylmaleimide sulfhydryl analysis procedure reported by Alexandria.[23]

Reaction of N-(2-Carbethoxyethyl)-N-2-tritylthioethylamine with Hydrogen Bromide in Acetic Acid.—N-(2-Carbethoxyethyl)-N-2-tritylthioethylamine (0.419 g., 0.001 mole) was dissolved in 4 ml. of 1 *M* hydrogen bromide in acetic acid. After 16 hr. the acetic acid and hydrogen bromide were separated from the products by freeze drying. An N-ethylmaleimide SH analysis of the remaining solid indicated that less than 5% of mercaptan was present. The solid was recrystallized from acetic acid to afford 0.44 g. (88%) of the hydrobromide salt of N-(2-carbethoxyethyl)-N-2-tritylthioethylamine, m.p. 174–176°. The analytical sample was prepared by recrystallization from acetic acid: m.p. 175–177°; ν_{max}^{KBr} 2800–2200 (amine hydrobromide bands), 1725 (ester C=O), and 745 and 700 cm.$^{-1}$ (aromatic).

Anal. Calcd. for $C_{26}H_{30}BrNO_2S$: C, 62.39; H, 6.04. Found: C, 61.90; H, 6.04.

2-Benzylthioethylamine (VII).—An ethanolic solution of sodium ethoxide was prepared by adding 4.6 g. (0.2 g.-atom) of sodium to 125 ml. of absolute ethanol. To this solution was added 12.4 g. (0.1 mole) of benzyl mercaptan and 20.5 g. (0.1 mole) of 2-bromoethylamine hydrobromide and the mixture was refluxed for 1.5 hr. The sodium bromide was separated by filtration and the filtrate was concentrated under reduced pressure. Since some sodium bromide remained in the residue the reaction mixture was taken up in ether and filtered. Concentration of the ether afforded 17.4 g. of crude product. Distillation under reduced pressure afforded 13.94 g. (83.6%) of 2-benzylthioethylamine: b.p. 87–88° at 0.05 mm. (lit.[24] 92–96° at 0.5–0.6 mm.); $n^{25}D$ 1.5738 (lit.[24] $n^{22}D$ 1.5763); $\nu_{max}^{CH_2Cl_2}$ 3340 (NH_2), 3030 (aromatic CH), and 840 cm.$^{-1}$ (aromatic).

N-(2-Carbethoxyethyl)-N-2-benzylthioethylamine (VIII).—To an ice-cooled solution of 16.7 g. (0.1 mole) of 2-benzylthioethylamine in 135 ml. of absolute ethanol was added dropwise 10 g. (0.1 mole) of ethyl acrylate in 75 ml. of absolute ethanol. After 1 hr. the solution was concentrated under reduced pressure to afford 26.2 g. of crude N-(2-carbethoxyethyl)-N-2-benzylthioethylamine. Distillation under reduced pressure afforded 20.7 g. (73.5%): b.p. 140–143° at 0.01 mm., $n^{25}D$ 1.5329, d^{25} 1.0785, $\nu_{max}^{CH_2Cl_2}$ 3310 (broad NH) and 1722 cm.$^{-1}$ (ester C=O). The n.m.r. spectrum (deuteriochloroform) showed a triplet at δ 1.23 (CH_3 of CH_3CH_2O group, 2.8H), a singlet at 1.77 (NH, 0.95H), a multiplet centered at 2.67 ($-SCH_2CH_2NCH_2CH_2C$, 7.6H), a singlet at 3.75 ($ArCH_2S$, 2.0H), a quartet at 4.21 (CH_2 of OCH_2CH_3 group, 1.8H), and a peak centered at 7.45 (aromatic protons, 5H).

Anal. Calcd. for $C_{14}H_{21}NO_2S$: C, 62.88; H, 7.92. Found: C, 62.82; H, 7.90.

The hydrochloride salt was prepared by adding an ethereal solution of hydrogen chloride to an ethereal solution of the amine. The analytical sample was prepared by recrystallization from isopropyl alcohol and ether: m.p. 109.5–112.5°; ν_{max}^{Nujol} 2800–2200 ($>NH_2^+$), 1720 (ester (C=O), and 695 cm.$^{-1}$ (aromatic).

Anal. Calcd. for $C_{14}H_{22}ClNO_2S$: C, 55.38; H, 7.15. Found: C, 55.34; H, 7.30.

N-(2-Carboxyethyl)-N-2-benzylthioethylamine (IX).—To a stirred solution of 5.34 g. (0.02 mole) of N-(2-carbethoxyethyl)-N-2-benzylthioethylamine in 25 ml. of dioxane[17] and 10 ml. of water was added 21.6 ml. (0.0216 mole) of 1 *N* sodium hydroxide and the solution was allowed to stir overnight. The solution was neutralized with 22.7 ml. (0.0216 mole) of 0.952 *N* hydrochloric acid. The solution was concentrated under vacuum and the remaining residue was dried *in vacuo*. The solid was extracted with hot chloroform. Addition of acetone precipitated 4.2 g. (87%) of crystalline N-(2-carboxyethyl)-N-2-benzylthioethylamine, m.p. 124.5–127.5°. The analytical sample was prepared by recrystallization from chloroform: m.p. 126–128°; ν_{max}^{KBr} 1600 ($O=\overset{|}{C}O^-$), and 718 and 698 cm.$^{-1}$ (aromatic).

Anal. Calcd. for $C_{12}H_{17}NO_2S$: C, 60.22; H, 7.16. Found: C, 60.03; H, 7.18.

Preparation of 2-(2-Carboxyethylamino)ethanethiol *p*-Toluenesulfonate Salt from N-(2-Carboxyethyl)-N-2-benzylthioethylamine.—To a solution of 4.75 g. (0.02 mole) of N-(2-carboxyethyl)-N-2-benzylthioethylamine in 60 ml. of liquid ammonia

(17) Purified by the procedure reported in L. F. Fieser, "Experiments in Organic Chemistry," D. C. Heath and Co., Boston, 1957, p. 48.

(18) 2-(2-Carbethoxyethylamino)ethanethiol was isolated as its hydrogen sulfate salt. The tosylate salt was a very low melting solid that could not be purified.

(19) In the case of N-(2-carboxyethyl)-N-2-tritylthioethylamine, 2 moles of mercuric acetate was used for each mole of trityl derivative and the reaction mixture was allowed to stir overnight. The use of 1 mole of mercuric acetate afforded no detritylation.

(20) In the case of N-(2-carbohydrazidoethyl)-N-tritylthioethylamine (IIIi) the mercuric sulfhydryl derivative decomposed readily when prepared by the general procedure. However, the mercuric sulfhydryl derivative could be obtained as a stable ditosylate by adding a solution of 0.002 mole of IIIi and 0.004 moles of *p*-toluenesulfonic acid in ethanol to 0.002 mole of mercuric acetate in ethanol.

(21) The infrared spectrum (KBr) of the mercuric acetate sulfhydryl derivatives showed a peak at 1570–1580 cm.$^{-1}$ ($CH_3\overset{O}{\overset{\|}{C}}—O—$) and each compound showed peaks characteristic of the functional groups present.

(22) The water was removed from the *p*-toluenesulfonic acid monohydrate by azeotropic distillation.

(23) N. M. Alexandria, *Anal. Chem.*, **30**, 1292 (1958).

(24) T. P. Johnston and Anne Gallagher, *J. Org. Chem.*, **28**, 1305 (1963).

under nitrogen and protected from moisture by a sodium hydroxide drying tube was added sodium metal (1.01 g., 0.44 g.-atom) until a permanent blue color remained for 45 min. The excess sodium was decomposed by adding a little ammonium chloride and the ammonia allowed to evaporate under nitrogen. The residue was dissolved in water and made acid with *p*-toluenesulfonic acid monohydrate. The water was separated from the products by freeze drying. The residue was extracted with hot isopropyl alcohol. The addition of ether to the extracts precipitated 5.9 g. of solid that was 67% pure by an N-ethylmaleimide sulfhydryl analysis. A number of recrystallizations from ethanol and ether yielded 2 g. (31.2%) of 2-(2-carboxyethylamino)-ethanethiol *p*-toluenesulfonate salt, m.p. 118–121°, 95% pure by -SH analysis. A mixture melting point with the acid obtained from N-(2-carboxyethyl)-N-2-tritylthioethylamine occurred at 117–120°. The infrared spectra of the two compounds were identical.

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Reactions of Trichloromethanesulfonyl Bromide with Some Hydrocarbons

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Trichloromethanesulfonyl bromide reacts with cyclohexane, cyclopentane, and toluene under the influence of light to yield the expected bromohydrocarbons, chloroform, and sulfur dioxide. The competitive bromination of cyclohexane and toluene strongly suggests that the $Cl_3C\cdot$ radical is involved in hydrogen abstraction from the hydrocarbons. This is in sharp contrast to the previously reported reactions of trichloromethanesulfonyl chloride with hydrocarbons, in which $Cl_3CSO_2\cdot$ is apparently the hydrogen abstractor. Peroxide- or light-induced decomposition of trichloromethanesulfonyl bromide into bromotrichloromethane and sulfur dioxide is proposed to account for the behavior of this material with hydrocarbons.

In a previous report from this laboratory,[1] trichloromethanesulfonyl chloride was found to chlorinate alkanes and alkyl aromatics in reactions induced by benzoyl peroxide or light. Mechanistic studies[2,3] indicated that chloroform, sulfur dioxide, and alkyl halide were formed by the following free-radical chain sequence.

$$R\cdot + Cl_3CSO_2Cl \longrightarrow RCl + Cl_3CSO_2\cdot \quad (1)$$

$$Cl_3CSO_2\cdot + RH \longrightarrow R\cdot + Cl_3CSO_2H \quad (2)$$

$$Cl_3CSO_2H \longrightarrow Cl_3CH + SO_2 \quad (3)$$

The ready decomposition of trichloromethanesulfonyl chloride into the products noted above was observed many years ago.[4]

It was found that the relative reactivities of hydrocarbons toward chlorination by Cl_3SCO_2Cl were different from the relative reactivities toward bromination by bromotrichloromethane, a type of reaction which most likely involves the following chain sequence.[5]

$$R\cdot + BrCCl_3 \longrightarrow RBr + Cl_3C\cdot \quad (4)$$

$$Cl_3C\cdot + RH \longrightarrow R\cdot + Cl_3CH \quad (5)$$

We felt that further support for the proposal that the $Cl_3CSO_2\cdot$ radical functions as the hydrogen abstractor in chlorination of hydrocarbons with Cl_3CSO_2Cl could be obtained by studying the reactions of trichloromethanesulfonyl bromide. However, our investigation shows that the chemistry of trichloromethanesulfonyl bromide differs from that of the previously investigated chloride.

Results and Discussion

In contrast to trichloromethanesulfonyl chloride, which is readily available, the bromide cannot be obtained from commercial sources. Loew prepared the bromide by reaction of bromine with sodium trichloromethanesulfinate.[6] We, however, were unable to reproduce the preparation of this salt, but were able to make the potassium salt unequivocally by reaction between trichloromethanesulfonyl chloride and potassium cyanide in liquid sulfur dioxide. Treatment of an aqueous solution of this salt with bromine gave trichloromethanesulfonyl bromide.

$$Cl_3CSO_2Cl + KCN \xrightarrow[SO_2]{\text{liquid}} Cl_3CSO_2K + CNCl \quad (6)$$

$$Cl_3CSO_2K + Br_2 \longrightarrow Cl_3CSO_2Br + KBr \quad (7)$$

The results of a study of the light-induced reactions of Cl_3CSO_2Br with cyclohexane, cyclopentane, and toluene are shown in Table I. The observation that ring-brominated products were formed when toluene was used as substrate was unexpected. These products may well have resulted from rearrangement of benzyl bromide; indeed, the latter compound was shown to undergo partial rearrangement when subjected to illumination at 110–115°. The products formed with all three hydrocarbons and their distribution can be interpreted in terms of a chain sequence similar to that proposed previously for analogous reactions of Cl_3CSO_2Cl with hydrocarbons. However, comparison of competition reactions between cyclohexane and toluene toward light-induced halogenation by Cl_3CSO_2Br and toward halogenation by Cl_3CSO_2Cl and $BrCCl_3$ would appear to eliminate this chain sequence.

Table II lists the relative reactivity ratios k_c/k_t, where k_c and k_t are the reaction rate constants for hydrogen abstraction from cyclohexane and toluene, respectively. Examination of the data certainly eliminates the possi-

$$X\cdot + C_6H_{12} \xrightarrow{k_c} HX + C_6H_{11}\cdot \quad (8)$$

$$X\cdot + C_6H_5CH_3 \xrightarrow{k_t} HX + C_6H_5CH_2\cdot \quad (9)$$

($X\cdot$ is the hydrogen-abstracting radical)

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