At the end of this treatment, the 2-chlorophenyl silicate was blackened but contained no sludge.

Thermal stability in the presence of metals was investigated by heating with metal strips under dry nitrogen in Pyrex flasks fitted with reflux condensers. Commercial cresyl silicate survived heating with black iron for 140 hr. at 350° substantially unchanged. Under the same conditions, 2-chlorophenyl silicate underwent a fivefold viscosity increase with black iron and a tenfold viscosity increase with cold-rolled steel and stainless steel. In another test at 400° for 50 hr. in the presence of cold-rolled steel, 2-chlorophenyl silicate decomposed to a black, sticky, solid mass while commercial cresyl silicate survived substantially unaffected.

Acknowledgment. We are grateful to the following for experimental assistance: A. D. Berry, G. Billuris, P. S. Flint, D. L. Harms, F. C. Kenyon, Jr., J. R. Ladd, A. J. Quant, J. T. Rossello, R. W. Trevithick, and M. Wasserman. Many of the analytical values and physical properties were obtained from the Materials and Processes Laboratory of the Large Steam Turbine and Generator Department and from the Analytical Chemistry Unit of our Laboratory.

SCHENECTADY, N. Y.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, POLYTECHNIC INSTITUTE OF BROOKLYN]

Preparation of Polymeric Condensation Products Containing Functional Thiol Side Chains. Polyamides[1]

C. G. OVERBERGER AND HERBERT ASCHKENASY[2]

Received April 25, 1960

The purpose of this work was to develop a general method of synthesis for a polyamide containing free sulfhydryl groups. Polyamides from hexamethylene diamine and the acid chlorides of α,α'-dibenzylthioadipic acid, the cyclic disulfide of α,α'-dimercaptoadipic acid, and α,α'-dicarbobenzoxythioadipic acid were prepared by the interfacial polymerization technique. Successful preparation of the polyamide with free sulfhydryl groups was achieved by quantitative removal of the carbobenzoxy group from the polyamide from hexamethylene diamine and α,α'-dicarbobenzoxythioadipic acid.

The importance of the sulfhydryl compounds in biological systems is well known.[3] In addition, their interest as reversible mercaptide-forming reagents as well as their recent applications as radioactive prophylactics has made synthesis of sulfhydryl-containing compounds of practical significance. We have reported[4] the synthesis of a polyurethan containing the sulfhydryl function in a structure of known constitution and environment and in this publication will describe the preparation of a sulfhydryl-containing polyamide.

The synthesis of polyamides requires, in general, exact molecular equivalence of reactants as well as very stringent reaction conditions, temperatures of 250° and above not being uncommon. The two synthetic approaches described, sought in the first instance to use a convenient method for obtaining the desired molecular equivalence, *e.g.*, intermediate salt formation, and in the second to employ a recently published[5] procedure for making high molecular weight polyamides under very mild reaction conditions, *i.e.*, interfacial polycondensation.

Benzylthiomethylsuccinic acid[4] would be expected to form a polymeric salt with a diamine suitable for subsequent polymerization by thermal dehydration. Only oils were obtained with hexamethylene diamine however, and with ethylene diamine a salt containing two acid molecules to one molecule of diamine was obtained. The unavailability of the second carboxyl group for salt formation is at present not understood.

We prepared *meso*-α,α'-dibenzylthioadipic acid by alkali-catalyzed displacement by benzyl mercaptan on *meso*-α,α'-dibromoadipic acid prepared by the method of Zanden[6] and found that it did not give a satisfactorily recrystallizable salt with ethylene diamine. A melting point range of 25° was observed even after five recrystallizations, as well as a small residue of the acid on addition of water.

The use of the *cis* cyclic disulfide of α,α'-dimercaptoadipic acid[7] prepared by Fredga, again did not yield a satisfactorily recrystallizable salt with hexamethylene diamine. Attempted thermal polymerization without recrystallization yielded an insoluble, infusible product. Cross-linking by a base catalyzed rupture of the disulfide bond[8] and/or

---

(1) This is the 20th in a series of papers on new monomers and polymers. For the previous paper in this series, see C. G. Overberger and Herbert Aschkenasy, *J. Am. Chem. Soc.*, in press.

(2) This paper comprises part of the thesis presented by Herbert Aschkenasy in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the graduate school of the Polytechnic Institute of Brooklyn.

(3) E. S. G. Barron, *Advances in Enzymology*, Vol. XI, Interscience Publishers, Inc., N.Y., 1951, pp. 219 *et seq.*

(4) C. G. Overberger and H. Aschkenasy, *J. Am. Chem. Soc.*, in press.

(5) P. W. Morgan and S. L. Kwolek, *J. Chem. Educ.*, **36**, 182 (1959) and previous references.

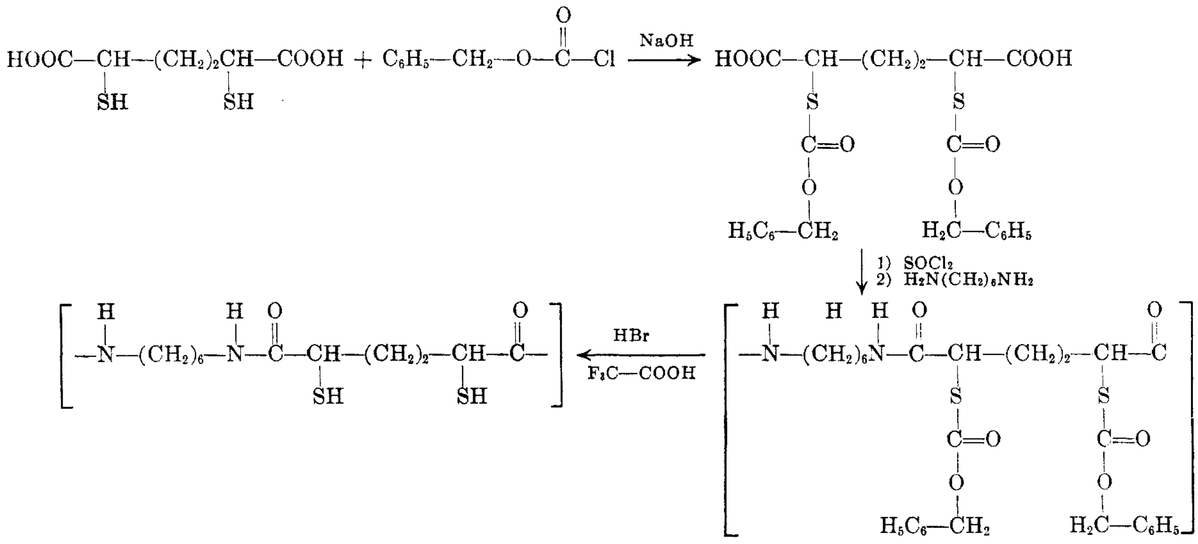
(6) J. M. Zanden, *Rec. trav. chim.*, **63**, 113 (1944).

(7) A. Fredga, *Ber.*, **71B**, 289 (1938).

(8) N. A. Rosenthal and G. Oster, *J. Soc. Cosmetic Chemists*, **5**, 286 (1954).

a disulfide interchange mechanism analogous to the thermal polymerization of lipoic acid[9] is possible here.

Interfacial polycondensation was then considered. This method depended only on the ability to prepare the necessary diacid chlorides. Neither benzylthiomethylsuccinic acid nor carbobenzoxymercaptosuccinic acid gave the desired compounds even by methods yielding the acid halides of related succinic acid derivatives.[10] The corresponding anhydrides were predominantly obtained possibly by sulfur participation in the transition state. Standard methods did, however, convert α,α′-dibenzylthioadipic acid, the *cis* cyclic disulfide of α,α′-dimercaptoadipic acid, and a new acid, α,α′-dicarbobenzoxythioadipic acid to the corresponding acid chlorides. The acid halides were readily converted to their polyamides with hexamethylene diamine, by both a manually stirred and a film-forming interface method.



Neither the polyamide derived from the cyclic disulfide nor the α,α′-dibenzylthioadipic acid could be reductively cleaved to the desired free sulfhydryl compounds, presumably because of their insolubility in the reaction media. The polyamide derived from the α,α′-dicarbobenzoxythioadipic acid did, however, when treated with glacial acetic acid saturated with hydrogen bromide, yield an insoluble material which showed an absence of phenyl absorption in the infrared in what appeared to be a heterogeneous cleavage. A more rapid cleavage where subsequent oxidative coupling of the free thiol residues could be minimized was necessary and trifluoroacetic acid gave the desired results. Analysis indicated that up to 30% decarbobenzoxylation occurred in the trifluoroacetic acid alone on standing at room temperature overnight. When trifluoroacetic acid saturated with hydrogen bromide was employed the reaction was completed in half an hour yielding a base-soluble polyamide. The product was fusible and gave a weak but definitive absorption peak at 2550 cm.$^{-1}$, characteristic of the sulfhydryl function. Elemental analysis showed that 100% decarbobenzoxylation had been effected, a remarkable result for a polymeric reaction.

EXPERIMENTAL[11]

α,α′-Dibenzylthioadipic acid. A general method of Zanden[6], α,α′-dibromoadipic acid was used. To a stirred solution of 15.4 g. (0.05 mole) of the α,α′-dibromoadipic acid in 100 ml. of 1*N* aqueous sodium carbonate, was added dropwise a solution of 12.6 g. (0.1 mole) of benzyl mercaptan, and 5.6 g. (0.1 mole) of potassium hydroxide in 100 ml. of a 50% aqueous ethanol solution. The reaction mixture was warmed on a steam bath for 2 hr. and allowed to stir for 42 additional hours at room temperature. Addition of concd. hydrochloric acid to *p*H 1 yielded a white precipitate, which was recrystallized from a water-ethanol solution, 3.0 g. (20%), m.p. 161–163°. Infrared analysis gave a normal carboxylic acid and phenyl absorption.

This compound had previously been prepared by Fredga[7] by reaction of benzylbromide with α,α′-dimercaptoadipic acid in unspecified yield [m.p. 169° (*meso*); m.p. 130° (*dl* racemate)].

Anal. Calcd. for $C_{20}H_{22}O_4S_2$: C, 61.51; H, 5.68; S, 16.42; neut. equiv. 195. Found: C, 61.39; H, 5.99; S, 16.42; neut. equiv. 197.

Carbobenzoxymercaptosuccinic acid. A solution of 15 g. (0.1 mole) of recrystallized commercial grade mercaptosuccinic acid in 150 ml. of water containing 16 g. (0.4 mole) of sodium hydroxide was treated dropwise with 25 g. (0.15 mole) of carbobenzoxychloride. The solution was stirred at room temperature for 36 hr., extracted with two 50-ml. portions of ether, and acidified with concd. hydrochloric acid to *p*H 1. The resulting oil was extracted with two 100-ml. portions of ether, dried over anhydrous magnesium sulfate, and the ether evaporated. The residual yellow oil was cooled and macerated until it solidified. The solid was recrystallized from

---

(9) R. C. Thomas and L. J. Reed, *J. Am. Chem. Soc.*, **78**, 6148 (1956).

(10) J. Cason and R. D. Smith, *J. Org. Chem.*, **18**, 1201 (1953); W. Petri, *Ber.*, **14**, 1635 (1881); *Org. Synthesis*, **33**, 41 (1953).

(11) All melting points are uncorrected. Polymer melting points were determined on a Fisher-Johns block, all others by the capillary method.

boiling toluene yielding a white solid, 14 g. (56%), m.p. 147–148°. Infrared analysis showed the acid carbonyl at 1715 cm.$^{-1}$ and the carbobenzoxy carbonyl at 1710 cm.$^{-1}$ as well as phenyl absorption.

Anal. Calcd. for $C_{12}H_{12}O_6S$: C, 50.70; H, 4.26; S, 11.27; neut. equiv. 142. Found: C, 50.73; H, 4.39; S, 11.26; neut. equiv. 143.

Carbobenzoxymercaptosuccinic anhydride. Treatment of 2 g. (0.007 mole) of carbobenzoxymercaptosuccinic acid with 10 ml. of purified thionyl chloride at 60° until solution occurred gave a yellow solution from which excess thionyl chloride was removed under reduced pressure. The residue was solidified by cooling and recrystallized from hexane-benzene yielding a white solid, 1.2 g. (66%), m.p. 89–90.5°. Infrared analysis showed anhydride absorption at 1800 cm.$^{-1}$ and 1885 cm.$^{-1}$, carbobenzoxy carbonyl at 1710 cm.$^{-1}$, and phenyl absorption.

Anal. Calcd. for $C_{12}H_{10}O_5S$: C, 54.13; H, 3.78; S, 12.04. Found: C, 54.16; H, 3.98; S, 12.27.

α,α'-Dibenzylthioadipoyl chloride. A large excess of commercial grade thionyl chloride, 30 ml., was added in one portion to 2.6 g. (0.0066 mole) of α,α'-dibenzylthioadipic acid. Gentle warming at 50–60° for 0.5 hr. produced a vigorous evolution of hydrogen chloride and a yellow solution. The solution was allowed to stand at room temperature for 24 hr. and excess thionyl chloride removed under reduced pressure, after which 50 ml. of benzene was added and then removed under reduced pressure. The resulting solid, which could be converted to the starting acid with water, was recrystallized from petroleum ether (b.p. 30–60°), 2.2 g. (77%), m.p. 84.8–86.2°. Infrared analysis showed acid chloride carbonyl at 1778 cm.$^{-1}$, carbobenzoxy carbonyl at 1710 cm.$^{-1}$, and phenyl absorption.

Anal. Calcd. for $C_{20}H_{20}Cl_2O_2S_2$: C, 56.20; H, 4.72; Cl, 16.59; S, 15.00. Found: C, 56.25; H, 4.77; Cl, 16.70; S, 15.02.

α,α'-Dicarbobenzoxythioadipic acid. According to the method of Schotte,[12] α,α'-dimercaptoadipic acid was prepared. A solution of 6.4 g. (0.03 mole) of this acid in 200 ml. of water containing 8.4 g. (0.15 mole) of potassium hydroxide was treated with 15.3 g. (0.08 mole) of carbobenzoxy chloride. The mixture was cooled in an ice bath and stirred for 15 hr. The basic solution was extracted twice with 100-ml. portions of ether and acidified to *p*H 1 with concd. hydrochloric acid. The oil which precipitated could be solidified by cooling. Recrystallization from an acetone-benzene solution gave a white crystalline solid, 5.8 g. (41%), m.p. 180–182°. Infrared analysis showed acid carbonyl at 1715 cm.$^{-1}$, carbobenzoxy carbonyl at 1705 cm.$^{-1}$, and phenyl absorption.

Anal. Calcd. for $C_{22}H_{22}O_8S_2$: C, 55.22. H, 4.63, S, 13.40; neut. equiv. 239. Found: C, 55.06; H, 4.82; S, 13.20; neut. equiv. 236.

α,α'-Dicarbobenzoxythioadipoyl chloride. The diacid chloride was prepared by treatment of 4.8 g. (0.01 mole) of the corresponding acid with an excess (7:1 by weight) of commercial grade thionyl chloride. The mixture was gently refluxed until solution took place (about 0.5 hr.), cooled, and thionyl chloride removed under reduced pressure. The residual oil was dissolved in methylene chloride, filtered, and the methylene chloride evaporated. The oily residue was solidified by cooling and macerating. The solid was dried *in vacuo* for 4 hr. giving 4.9 g. (95%) of crude product. Infrared examination showed a peak at 1789 cm.$^{-1}$ corresponding to an acid halide carbonyl and at 1710 cm.$^{-1}$ corresponding to the carbonyl of the carbobenzoxy group. The material was not satisfactorily recrystallizable, m.p. 77–87°, but was identified by conversion to the diamide.

A mixture of 1 g. (0.0021 mole) of the acid in 5 ml. of thionyl chloride was refluxed until solution took place, cooled to room temperature, and added dropwise to 20 ml. of concd. ammonia cooled in an ice bath. The resulting solid material was filtered and recrystallized from dioxane-water, 0.76 g. (76%), m.p. 215–217°. Infrared analysis gave a normal unsubstituted amide curve with retention of the carbobenzoxy carbonyl at 1710 cm.$^{-1}$ and phenyl absorption.

Anal. Calcd. for $C_{22}H_{24}N_2O_6S_2$: C, 55.44; H, 5.08; N, 5.88; S, 13.46. Found: C, 55.60; H, 5.26; N, 6.01; S, 13.17.

Diacid chloride of cyclic disulfide from α,α'-dimercaptoadipic acid. The corresponding acid may be prepared by oxidation of the corresponding dimercapto acid with iodine–potassium iodide solution or 10% hydrogen peroxide, giving 63–74% of product, m.p. 196–198° (virtually quantitative, 199°).[7]

A mixture of 4.2 g. (0.02 mole) of the acid and an excess of commercial grade thionyl chloride (7:1 by weight) was refluxed until solution occurred (5–6 hr.), cooled, and excess thionyl chloride removed under reduced pressure. The oily residue was dissolved in methylene chloride, filtered, and the solvent evaporated. The residual oil was solidified by cooling and macerating and was dried *in vacuo* for 4 hr., giving 3.7 g. (75%) of crude material, m.p. 62–69°. The material could not be recrystallized satisfactorily. Infrared examination showed strong absorption at 1778 cm.$^{-1}$ indicating acid chloride carbonyl, and the material could be converted with water to a compound identical with that of the starting acid as shown by a mixed melting point determination. Attempts to form derivatives of the acid chloride *via* amide, anilide, and toluide formation did not give satisfactorily recrystallizable solids.

Polyamides. The compounds to be described were prepared by the technique of interfacial polymerization.[5] The two methods used were removal of the product as a continuous film from the interface, and manual or automatic stirring of the reaction mixture followed by isolation of the product by filtration.

A. Polymer from hexamethylene diamine and α,α'-dibenzylthioadipoyl chloride. 1. Stirring method. A solution of 4.27 g. (0.01 mole) of α,α'-dibenzylthioadipoyl chloride in 75 ml. of chloroform was overlaid with 1.85 g. (0.016 mole) of hexamethylene diamine in 75 ml. of water containing 0.8 g. (0.01 mole) of sodium hydroxide. The mixture was stirred for 1 hr. and the product isolated by filtration. The product was dissolved in a small volume of dimethylformamide and precipitated by dropwise addition to a large excess of benzene. The resulting white solid was filtered and dried over phosphorus pentoxide, m.p. 148–150°, [η], 0.32 determined in dimethylformamide at 29.8°.

Anal. Calcd. for $C_{26}H_{34}N_2O_2S_2$: C, 66.34; H, 7.28; N, 5.95; S, 13.62. Found: C, 66.48; H, 7.43; N, 5.82; S, 13.57.

2. *Continuous film method.* A solution of 4.27 g. (0.01 mole) of the acid chloride in 75 ml. of purified carbon tetrachloride was carefully overlaid with a solution containing 7.54 g. (0.065 mole) of hexamethylene diamine and 0.8 g. (0.02 mole) of sodium hydroxide in 75 ml. of water. The film which formed immediately at the interface was separated from the walls of the beaker and withdrawn as a continuous filament. The product was washed with aqueous ethanol and with benzene and dried *in vacuo*. The resulting yellow tinged solid did not dissolve or swell in a variety of solvents and was infusible. It gave an infrared spectrum virtually identical with that of the previously described sample.

B. Polyamide from acid chloride of cyclic disulfide. 1. Stirring method. A solution of 2.45 g. (0.01 mole) of the crude cyclic acid chloride previously described was dissolved in 50 ml. of chloroform and overlaid with a solution containing 1.85 g. (0.016 mole) of hexamethylene diamine and 0.8 g. (0.02 mole) of sodium hydroxide in 50 ml. of water. A voluminous solid formed rapidly and after a few minutes of stirring was isolated by filtration. This material was totally insoluble in a variety of solvents and was infusible. When washed with benzene and dimethylsulfoxide and dried, the product gave an infrared spectrum consistent with the expected structure, but an elemental analysis which was not satisfactory, having low carbon and sulfur.

---

(12) L. Schotte, *Arkiv Kemi*, 9, 377 (1956).

2. *Continuous film method.* A solution of 2.45 g. (0.01 mole) of the acid chloride in 50 ml. of purified carbon tetrachloride was carefully overlaid with a solution of 7.54 g. (0.065 mole) of hexamethylene diamine containing 0.8 g. (0.02 mole) of sodium hydroxide in 50 ml. of water. The film which formed immediately was separated from the walls of the beaker and withdrawn continuously until the reaction was completed which generally coincided with the disappearance of the organic layer. This material was again insoluble and infusible. When washed with aqueous ethanol and benzene and thoroughly dried *in vacuo*, the resulting yellow solid gave an infrared spectrum consistent with the expected structure but an elemental analysis which was not satisfactory, having low carbon and sulfur.

3. *Solution method.* A solution of 2.45 g. (0.01 mole) of the acid chloride in 50 ml. of purified dioxane was rapidly mixed with a solution containing 1.16 g. (0.01 mole) of hexamethylene diamine and 1.12 g. (0.02 mole) of potassium hydroxide in 50 ml. of dioxane. A yellow solid formed almost immediately in a somewhat exothermic reaction. The product was isolated by filtration but proved to be totally insoluble in a variety of solvents and infusible.

4. *Salt formation method.* (*non-interfacial procedure*). A sample of the acid 131.7 mg. (0.64 mole) was dissolved in anhydrous tetrahydrofuran. A solution of hexamethylene diamine dissolved in tetrahydrofuran was added dropwise until no further precipitation occurred. The salt was filtered and dried *in vacuo* to constant weight, yielding a white solid which was completely water soluble, 212 mg. (102%), m.p. 188–194°. The material could not be recrystallized, however, from a variety of solvents. The crude material was heated at 200–205°, 1 mm., for 1 hr. The product was a somewhat yellowish solid which proved to be insoluble and infusible.

C. Polymer from hexamethylene diamine and α,α'*-dicarbobenzoxythioadipoyl chloride.* 1. *Stirring method.* A solution of 2.74 g. (0.0055 mole) of α,α'-dicarbobenzoxythioadipoyl chloride in 50 ml. of methylene chloride (chloroform gave a product of the same physical properties) was poured into a cold solution containing 1.6 g. (0.013 mole) of hexamethylene diamine and 0.67 g. (0.011 mole) of potassium hydroxide in 50 ml. of water. The reaction mixture was stirred for 6 hr. and the product isolated by filtration. The crude material could be separated into two fractions by extraction with dimethylformamide or trifluoroacetic acid. The soluble fraction isolated from the trifluoroacetic acid extract in no case exceeded 25% of total solids, m.p. 118–123°, $[\eta]$, 0.43 determined in dimethylformamide at 29.8°.

Anal. Calcd. for $C_{28}H_{34}N_2O_6S_2$: C, 60.19; H, 6.13; N, 5.02; S, 11.48. Found: C, 56.80; H, 7.04; N, 6.23; S, 11.48.

The dimethylformamide-insoluble fraction could not be dissolved with a variety of solvents and was also infusible. Infrared analysis gave virtually identical spectra for both the soluble and insoluble fractions, showing normal monosubstituted amide links, as well as phenyl and carbobenzoxy carbonyl absorption.

Anal. Calcd. for $C_{28}H_{34}N_2O_6S_2$: C, 60.19; H, 6.13; N, 5.02; S, 11.48. Found: C, 58.87; H, 6.88; N, 7.77; S, 11.74; nonalkaline ash, 1.39.

2. *Continuous film method.* A solution of 3.57 g. (0.007 mole) of the acid chloride in 50 ml. of purified carbon tetrachloride was carefully overlaid with a solution of 5.20 g. (0.045 mole) of hexamethylene diamine containing 0.56 g. (0.014 mole) of sodium hydroxide in 50 ml. of water. The film which formed almost immediately at the interface was separated from the walls of the beaker and pulled from the reaction mixture. The product was washed repeatedly with portions of aqueous ethanol and benzene, and dried *in vacuo*. The resulting light yellow solid could be separated into two fractions with hot dimethylformamide. The soluble fraction was reprecipitated by adding the dimethylformamide solution, dropwise, to a large excess of water giving 0.7 g. (16.6%) of material, m.p. 125–130°, η_{inh}, 0.5 determined in dimethylformamide at 29.8° and a concentration of 5.8 mg./ml. The inherent viscosity showed a slight rise on dilution. The insoluble fraction which could not be dissolved in a variety of solvents was also infusible, but had the correct analysis. Infrared analysis gave a normal amide curve and was very similar to that given by the soluble fraction.

Anal. Calcd. for $C_{28}H_{34}N_2O_6S_2$: C, 60.19; H, 6.13; N, 5.02; S, 11.48. Found: C, 60.42; H, 6.44; N, 5.14; S, 11.43.

Decarbobenzoxylation of polyamide. A 1-g. sample of polyhexamethylene α,α'-dicarbobenzoxy adipamide obtained by the manual stirring method was finely subdivided in a mortar and pestle. The material containing both the soluble and insoluble fractions was then treated with 50 ml. of trifluoroacetic acid, which had been saturated with hydrogen bromide. The polymer, partly dissolved and partly dispersed in this solvent, was stirred by means of a magnetic stirrer at room temperature until the material appeared to agglomerate into large particles of crepe-rubber appearance and jelly-like consistency (in about 0.5 hr.). The polymer was isolated by filtration yielding a yellow solid, m.p. 183–201°.

The polymer was soluble in 10% aqueous sodium hydroxide and gave a strongly positive nitroprusside test for free mercaptan. Infrared analysis showed the presence of a weak sulfhydryl absorption at 2550 cm.$^{-1}$ and retention of the amide link. Elemental analysis indicated 100% decarbobenzoxylation.

Anal. Calcd. for $C_{12}H_{22}N_2O_2S_2$: C, 49.62; H, 7.63; N, 9.65; S, 22.08. Found: C, 49.84; H, 7.21; N, 9.45; S, 22.42.

Acknowledgment. We wish to acknowledge gratefully the support of this work by a grant from the Charles Pfizer Co. and the laboratory assistance of Martin Elsbach and Thomas Reilly.

BROOKLYN 1, N.Y.