31. *Some Aliphatic Thiols and Their Derivatives. Part II.* Thiols Derived from 2 : 2′-Dichlorodiethyl Sulphide and its Analogues. Nickel Complexes from 1 : 5-Dithiols.*

By JOHN HARLEY-MASON.

Reaction of 2 : 2′-dichlorodiethyl sulphide with thiourea, followed by treatment with alkali, gives 2 : 2′-dimercaptodiethyl sulphide which forms a highly crystalline deep red nickel complex; similar complexes are obtained with di-(2-mercaptoethyl)methylamine and 2 : 2′-dimercaptotriethylamine. The structure of these remarkable complexes is discussed.

A dithiol is similarly obtained from 1 : 2-di-(2-chloroethylthio)ethane, but did not give satisfactory complexes.

IN the course of work during 1943—1944 on the development of reagents for the detection and identification of war gases, the reaction of thiourea with 2 : 2′-dichlorodiethyl sulphide (mustard gas) was examined: the bisthiuronium chloride obtained was found to give a deep red precipitate (soluble in chloroform) when treated with alkaline nickel solutions. Since the reaction was sensitive and specific further investigations were made.

Thiuronium salts are readily decomposed by alkali (Arndt, *Ber.*, 1921, **54**, 2236), giving mercaptans, so that it seemed probable that the red material was a nickel complex of 2 : 2′-dimercaptodiethyl sulphide (I), first obtained as one of the products of the action of alkali on ethane-1 : 2-bisthiuronium bromide by Matthias (*Bols. Fac. Fil. cienc. Letras, Univ. Sao Paulo*, 1942, **14**, Quim. No. 1, 75; *Chem. Abs.*, 1946, **40**, 2792). In the present work, (I) was prepared in high yield by the reaction of mustard gas with two mols. of thiourea in boiling ethanol and decomposition of the resulting bisthiuronium chloride with sodium hydroxide. Lead and mercury derivatives of (I) were prepared by Matthias (*loc. cit.*), and similar precipitates insoluble in water and organic solvents were obtained from (I) and salts of copper, cadmium, cobalt, palladium, platinum, and gold. On addition of (I), with shaking, to an ammoniacal nickel sulphate solution, the deep red precipitate, which formed at once, slowly crystallised and, in contradistinction to other metal derivatives, was readily soluble in halogenated solvents such as chloroform, trichloroethylene, ethylene dibromide, and bromoform, giving deep red solutions. Recrystallisation from chloroform gave the complex (IV; X = S) as large garnet-red prisms, insoluble in water and stable to alkali but decomposed by mineral acids and by potassium cyanide solution with regeneration of the dithiol. Very similar complexes (IV; X = MeN and X = EtN) were obtained in the same way from the structurally similar dithiols, di-(2-mercaptoethyl)methylamine (II) and 2 : 2′-dimercaptotriethylamine (III) (for preparation, see Part I, *loc. cit.*). Elementary analysis showed that in all three cases the complexes contained one atom of nickel per molecule of dithiol, but molecular-weight determinations showed that this empirical formula must be doubled. 2 : 2′-Dimercaptodiethyl ether (Backer and Stienstra, *Rec. Trav. chim.*, 1933, **52**, 1037) and 2 : 2′-dimercaptodiethyl sulphoxide (V) (see below), in which it would be expected that the central hetero-atom would be incapable of co-ordination, were found to give entirely different, insoluble, yellowish-brown nickel derivatives, so that in the red complexes (IV) the central sulphur or nitrogen atom must clearly be co-ordinated with the metal. The red colour and solubility in organic solvents suggest that these are non-ionic " square complexes " of 4-covalent nickel (cf. nickel dimethylglyoxime) and on the basis of the above facts the bridged structure (IV) is assigned to them.

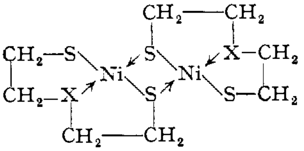
$S(CH_2{\cdot}CH_2{\cdot}SH)_2$ (I) $MeN(CH_2{\cdot}CH_2{\cdot}SH)_2$ (II) $EtN(CH_2{\cdot}CH_2{\cdot}SH)_2$ (III)

An interesting possibility of stereoisomerism then arises. In the case of (IV; X = S), the two nickel and the six sulphur atoms must clearly be in one plane, but, owing to the pyrimidal configuration of 3-covalent sulphur, two possibilities arise: (*a*) the two pairs

---

* Part I, *J.*, 1947, 320.

of ethylene bridges are above the plane, giving a *cis*-form; or (*b*) one pair is above the plane and the other below, giving a *trans*-form. However, repeated fractional crystallisation of the material gave no indication of inhomogeneity, and it is probable that only one form is obtained.

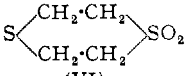


(IV)

Formation of the complex may be used as the basis of a sensitive and specific test for mustard gas and the "nitrogen mustards" corresponding to the dithiols (II) and (III). Contaminated air is aspirated through a 5% solution of thiourea in 2-ethoxyethanol, or alternatively a contaminated article is washed with such a solution. The solution is boiled for two minutes and then poured into an ammoniacal nickel sulphate solution and shaken with chloroform. The appearance of a red colour in the chloroform layer constitutes a positive test. On a test-tube scale, 0·04 mg. of the war gas can be detected visually. All other war gases tested gave negative results.

2 : 2′-Dichlorodiethyl sulphoxide reacted with thiourea less readily than did the sulphide, giving a bisthiuronium chloride which on treatment with alkali gave only white polymeric material. When, however, the decomposition was carried out in the presence of ammoniacal nickel sulphate a nickel derivative was precipitated, forming yellowish plates, insoluble in water and organic solvents. Analysis indicated that it was formed from one molecule of the sulphoxide (V) and one atom of nickel. Decomposition of the nickel derivative with potassium cyanide gave first an oil, giving a strong thiol reaction with sodium nitroprusside, but the oil was rapidly converted into a sparingly soluble amorphous white solid which gave no nitroprusside reaction. It appears therefore that the dithiol (V) is too unstable to be characterised and that the sulphoxide group oxidises the thiol groups with the formation of polymer.

(V) $OS(CH_2{\cdot}CH_2{\cdot}SH)_2$



(VI)

$(CH_2{\cdot}S{\cdot}CH_2{\cdot}CH_2{\cdot}SH)_2$ (VII)

2 : 2′-Dichlorodiethyl sulphone reacted with difficulty with thiourea: however, on long heating of the reactants in 2-ethoxyethanol a bisthiuronium chloride was obtained. Decomposition with alkali again gave mainly white amorphous polymer, but a small amount of 1 : 4-dithian 1 : 1-dioxide (VI) was isolated, presumably arising from intramolecular elimination of hydrogen sulphide from the dithiol at first formed.

1 : 2-Di-(2-chloroethylthio)ethane readily gave a bisthiuronium chloride which with alkali gave 1 : 2-di-(2-mercaptoethylthio)ethane (VII) as a low-melting solid. It was hoped that this dithiol, with two central atoms available for co-ordination, would act as a quadridentate reagent for metals capable of forming "square complexes." Attempts to prepare such complexes were however unsuccessful. Similarly, 2 : 2′ : 2″-trimercaptotriethylamine (Part I, *loc. cit.*), which might be expected to function as a quadridentate reagent for tetrahedral 4-covalent metals, also failed to give satisfactory complexes. It is of interest that 2 : 2′-dimercaptodiethylamine, despite its close relation to (II) and (III), failed to give a complex of type (IV) with nickel. This may possibly be due to a difference in the co-ordinating ability of secondary and tertiary nitrogen.

The action of chlorine on aqueous solutions of *iso*thioureas has been shown by Johnson and Sprague (*J. Amer. Chem. Soc.*, 1936, **58**, 1348) to give sulphonyl chlorides. Treatment of the bisthiuronium chloride from 2 : 2′-dichlorodiethyl sulphide with chlorine at 0° gave a solid bis-sulphonyl chloride, characterised as the diamide and dianilide. The same product was obtained from the corresponding sulphoxide and sulphone, so that evidently oxidation of the central sulphur atom occurred in the first two cases, the product being in all cases (diethyl sulphone)-2 : 2′-bis-sulphonyl chloride.

EXPERIMENTAL

2 : 2′-*Dimercaptodiethyl Sulphide.*—Thiourea (50 g.), redistilled mustard gas (50 g.), and ethanol (150 c.c.) were refluxed for 2 hours. After being kept overnight the product was filtered off and washed with water. (*Diethyl sulphide*)-2 : 2′-*bisthiuronium chloride* formed small prisms, m. p. 116—118° (decomp.) after softening at 108° (Found: N, 18·2. $C_6H_{16}N_4S_3Cl_2$ requires N, 18·0%).

To a solution of the thiuronium salt (30 g.) in water (100 c.c.) a solution of sodium hydroxide (8 g.) in water (20 c.c.) was added. The mixture was heated for 10 minutes on a boiling water-bath, then cooled, and the oily dithiol taken up in ether. After drying (Na_2SO_4) and removal of the solvent, 2 : 2′-dimercaptodiethyl sulphide distilled at 135—137°/18 mm. (11·5 g., 70%) (Found: C, 30·9; H, 6·7. Calc. for $C_4H_{10}S_3$: C, 31·2; H, 6·5%).

Formation of Nickel Complexes.—The dithiol (I) (5 g.) was added dropwise, with vigorous shaking, to a solution of nickel sulphate (12 g.) in water (150 c.c.) and ammonia (*d* 0·88; 25 c.c.). The red precipitate became crystalline when kept and was then collected and recrystallised from chloroform. The *nickel* complex (IV; X = S) formed garnet-red prisms which decomposed without melting when heated [Found: C, 22·9; H, 4·0; Ni, 27·8%; *M* (cryoscopic in ethylene dibromide), 441. $C_8H_{16}S_6Ni_2$ requires C, 22·7; H, 3·8; Ni, 27·9%; *M*, 422].

In the same manner the *nickel* complex (IV; X = MeN) was prepared from di-(2-mercaptodiethyl)methylamine (II) (Found: C, 29·0; H, 5·3; Ni, 28·7. $C_{10}H_{22}N_2S_4Ni_2$ requires C, 28·8; H, 5·3; Ni, 28·4%), and the *nickel* complex (IV; X = EtN) from 2 : 2′-dimercaptotrimethylamine (III) [Found: C, 32·0; H, 6·1; Ni, 27·0%; *M* (cryoscopic in bromoform), 495. $C_{12}H_{26}N_2S_4Ni_2$ requires C, 32·4; H, 5·85; Ni, 26·6%; *M*, 444]. The *nickel* complex, which formed an amorphous light brown powder insoluble in water and organic solvents, was similarly prepared from 2 : 2′-dimercaptodiethyl ether (Found: Ni, 30·1. $C_4H_8OS_2Ni$ requires Ni, 30·2%)

Reaction of 2 : 2′-*Dichlorodiethyl Sulphoxide with Thiourea.*—2 : 2′-Dichlorodiethyl sulphoxide (36 g.) and thiourea (31 g.) were refluxed in ethanol (120 c.c.) for 8 hours. Next morning the product which had crystallised was collected and washed with acetone. (*Diethyl sulphoxide*)-2 : 2′-*bisthiuronium chloride* formed small white plates, m. p. 198° (decomp.) (Found: N, 17·0. $C_6H_{16}ON_4S_3Cl_2$ requires N, 17·1%). A solution of the thiuronium salt (19·6 g.) in water (100 c.c.) was added to a solution of nickel sulphate (16 g.) in water (100 c.c.) and aqueous ammonia (*d* 0·88; 50 c.c.). The mixture was heated on a boiling water-bath, whereupon the product rapidly separated. The material was filtered off hot and washed with water and alcohol. The *nickel* complex of 2 : 2′-dimercaptodiethyl sulphoxide formed bronze-yellow plates, insoluble in water and organic solvents (Found: Ni, 25·8. $C_4H_8OS_3Ni$ requires Ni, 26·5%). The complex (5 g.) was added with stirring to a solution of potassium cyanide (7 g.) in water (30 c.c.), the solid rapidly dissolving with evolution of heat. After filtration from traces of undissolved material the solution was acidified with dilute hydrochloric acid and extracted with peroxide-free ether. After being dried (Na_2SO_4), the solvent was removed, leaving an oil with a " mercaptan " odour and giving an intense nitroprusside reaction. The oil rapidly changed spontaneously into a white amorphous polymeric solid which no longer gave a nitroprusside reaction.

Reaction of 2 : 2′-*Dichlorodiethyl Sulphone with Thiourea.*—2 : 2′-Dichlorodiethyl sulphone (38 g.) and thiourea (31 g.) were heated in 2-ethoxyethanol (100 c.c.) for 8 hours on a boiling water-bath. When the cooled mixture was set aside for 2 days the (*diethyl sulphone*)-2 : 2′-*bisthiuronium chloride*, m. p. 211°, which had separated as small white prisms was collected and washed with acetone (Found: N, 16·2. $C_6H_{16}O_2N_4S_3Cl_2$ requires N, 16·3%).

The thiuronium salt (14 g.) was dissolved in water (100 c.c.) and a solution of sodium hydroxide (3·2 g.) in water (10 c.c.) was added. The *iso*thiourea was at once precipitated as small white plates. The mixture was heated at 100° for 0·5 hour, whereupon the crystalline precipitate slowly changed into white amorphous solid. This was filtered off hot and the filtrate on cooling slowly deposited small colourless prisms of 1 : 4-dithian 1 : 1-dioxide, m. p. 206° after recrystallisation from water (Found: C, 31·5; H, 5·5. Calc. for $C_4H_8O_2S_2$: C, 31·6; H, 5·3%). Alexander and McCombie (*J.*, 1931, 1913) give m. p. 206°.

1 : 2-*Di*-(2-*mercaptoethylthio*)*ethane.*—1 : 2-Di-(2-chloroethylthio)ethane (22 g.) and thiourea (16 g.) were refluxed in ethanol (80 c.c.) for 2 hours. The solvent was distilled off and the white residue dissolved in water (200 c.c.). A solution of sodium hydroxide (8 g.) in water (30 c.c.) was added and the mixture heated for 10 minutes at 100°. On cooling, the oily product solidified

and was filtered off and recrystallised from benzene–light petroleum. 1 : 2-*Di*-(2-*mercapto-ethylthio*)*ethane* formed small white plates, m. p. 46° (Found : C, 33·2; H, 6·7. $C_8H_{14}S_4$ requires C, 33·6; H, 6·5%).

(*Diethyl Sulphone*)-2 : 2′-*bis-sulphonyl Chloride.*—(Diethyl sulphide)-2 : 2′-bisthiuronium chloride (4 g.) was dissolved in water (50 c.c.), and a slow stream of chlorine passed in at 0° until no more precipitate formed. The crude sulphonyl chloride was filtered off, washed with ice-water, and dried in a vacuum. As the material could not be recrystallised satisfactorily it was characterised by conversion into the dianilide by heating it at 100° with an excess of aniline, treating the mixture with dilute hydrochloric acid, and collecting the solid. Recrystallisation from 2-ethoxyethanol gave (*diethyl sulphone*)-2 : 2′-*disulphonanilide* as small plates, m. p. 220—221° (Found : N, 6·6. $C_{16}H_{20}O_6N_2S_3$ requires N, 6·7%). The diamide was also prepared by grinding the sulphonyl chloride with aqueous ammonia (*d* 0·88) and recrystallising the product from water, giving (diethyl sulphone)-2 : 2′-disulphonamide, m. p. 208—210°. The thiuronium salts from diethyl sulphoxide and diethyl sulphone were treated with chlorine as above, and in both cases mixed m. p.s showed that the same dianilide and diamide were obtained.

The greater part of this work was done in No. 2 Anti-Gas Laboratory R.E., during 1944, and it was completed at the Chemical Defence Experimental Establishment, Porton. The author is indebted to the Chief Scientist, Ministry of Supply, for permission to publish these results and to Mr. J. H. R. Slade for much experimental assistance and for the determination of molecular weights.

UNIVERSITY CHEMICAL LABORATORY, CAMBRIDGE. [*Received, October 3rd,* 1951.]