7. *The Structure of Diallyl Disulphide.*

By Frederick Challenger and Douglas Greenwood.

Diallyl disulphide reacts with triphenylphosphine yielding triphenylphosphine sulphide and diallyl monosulphide, with zinc yielding zinc sulphide and diallyl monosulphide, and with phenyl *iso*cyanide, followed by aniline, yielding *s*-diphenylthiourea. These reactions are explained by a free-radical mechanism involving the intermediate compounds $Ph_3P(S \cdot C_3H_5)_2$, $Zn(S \cdot C_3H_5)_2$, and $Ph \cdot N \colon C(S \cdot C_3H_5)_2$ which were, however, not isolated.

An alternative explanation, assuming a branched-chain structure $R_2S \colon S$ for diallyl disulphide, is disproved by a reaction with cysteine whereby cystine and prop-2-ene-1-thiol are obtained in good yield. Dimethyl, diethyl, and di-*p*-nitrophenyl disulphide also react in this way with cysteine. Dimethyl and diethyl disulphide do not react with zinc or triphenylphosphine.

Semmler (*Arch. Pharm.*, 1892, **230**, 434) isolated diallyl disulphide from oil of garlic and found that on distillation with zinc dust it yielded diallyl monosulphide. He recorded no experimental details but we have confirmed his result. To explain this, it could be assumed that diallyl disulphide had a branched-chain structure (I) rather than the normal straight-chain structure (II).

$$\text{(I.)} \quad CH_2 \colon CH \cdot CH_2 \cdot \underset{\overset{\|}{S}}{S} \cdot CH_2 \cdot CH \colon CH_2 \qquad\qquad CH_2 \colon CH \cdot CH_2 \cdot S \cdot S \cdot CH_2 \cdot CH \colon CH_2 \quad \text{(II.)}$$

The preparation of disulphides of type (I) by Backer and Evenhuis (*Rec. Trav. chim.*, 1937, **56**, 129) lends some support to this view : tetrakisbromomethylmethane and sodium or
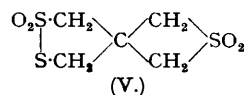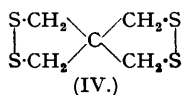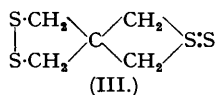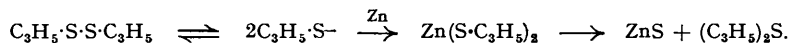

potassium disulphide in alcohol give product (III) instead of the expected (IV); one atom of sulphur was removable by the action of sodium, copper, or sodium sulphide leaving the compound $C_5H_8S_3$, or by oxidation giving sulphuric acid and a disulphone (V) or the derived disulphonic acid $(HO_3S \cdot CH_2)_2 C \overset{CH_2}{\underset{CH_2}{<}} > SO_2$ according to conditions.

Cavallito, Buck, and Suter (*J. Amer. Chem. Soc.*, 1944, **66**, 1952) regarded the naturally occurring antibacterial substance allicin as $CH_2 \colon CH \cdot CH_2 \cdot S \cdot S \cdot CH_2 \cdot CH \colon CH_2$ or

$$CH_2 \colon CH \cdot CH_2 \cdot S \cdot O \cdot S \cdot CH_2 \cdot CH \colon CH_2.$$

Small, Bailey, and Cavallito (*ibid.*, 1947, **69**, 1710) and Stoll and Seebeck (*Helv. Chim. Acta*, 1948, **31**, 189) concluded from a comparison of chemical and antibacterial properties that allicin was also obtained by the direct oxidation of diallyl disulphide with perbenzoic acid or hydrogen peroxide. This favours the structure (II) rather than the branched-chain (I).

It seemed possible that diallyl disulphide could have structure (II) and yet react with zinc as stated by Semmler, if dissociation into free radicals were assumed :

$$C_3H_5 \cdot S \cdot S \cdot C_3H_5 \;\; \rightleftharpoons \;\; 2C_3H_5 \cdot S- \;\; \overset{Zn}{\longrightarrow} \;\; Zn(S \cdot C_3H_5)_2 \;\; \longrightarrow \;\; ZnS + (C_3H_5)_2S.$$

Such a reaction would be analogous with those observed by Schönberg, Rupp, and Gumlich (*Ber.*, 1933, **66**, 1932) with di(thio-α-naphthoyl) disulphide and metallic zinc or silver. We find that *bisallylthiozinc* cannot be isolated from the reaction between zinc and diallyl disulphide, but it has been prepared and found to decompose in the manner shown at temperatures (80—100°) much below those at which the reaction was carried out (120—130°).

It was therefore decided to investigate certain reactions of diallyl disulphide, which should enable a decision to be reached between structures (I) and (II).

We have recently (*Biochem. J.*, 1949, **44**, 87) shown that diallyl disulphide in cultures of the

mould *Scopulariopsis brevicaulis* yields prop-2-ene-1-thiol and methyl allyl sulphide, thus behaving in the same way as saturated alkyl disulphides (Challenger *et al.*, *J.*, 1937, 868 ; 1938, 1872). This favours structure (II). On the alternative structure (I), the formation of hydrogen sulphide and allyl sulphide would be expected, but this was not observed. Moreover, diallyl monosulphide yields no prop-2-ene-1-thiol in cultures of *S. brevicaulis*, but volatilises apparently unchanged, as does also diethyl sulphide (Challenger and North, *J.*, 1934, 70; North, Thesis, Leeds, 1933). The formation of the thiol and methyl allyl sulphide from the disulphide in mould cultures cannot therefore be explained by the further breakdown of diallyl monosulphide formed as an intermediate compound from a disulphide of structure (I).

Schönberg (*Ber.*, 1945, **68**, 162) used triphenylphosphine for the detection of free radicals arising from disulphides by homolytic fission. Later, in a private communication (cf. this vol., pp. 892, 889), Schönberg classified disulphides into two groups, according to their reaction with triphenylphosphine : (1) unreactive, *e.g.*, diethyl and dibenzyl disulphide, and (2) those reacting to give Ph_3PS, probably by way of $Ph_3P(SR)_2$, *e.g.*, di-(*p*-dimethylaminophenyl) and dibenzoyl disulphide.

Some disulphides, *e.g.*, Ph_2S_2, oxidise triphenylphosphine to triphenylphosphine oxide in presence of water, probably by way of the intermediate compound $Ph_3P(SR)_2$ which was not isolated.

$$R_2S_2 \rightleftharpoons 2R\cdot S- \xrightarrow{Ph_3P} Ph_3P(SR)_2 \xrightarrow{H_2O} Ph_3P\colon O + 2R\cdot SH$$
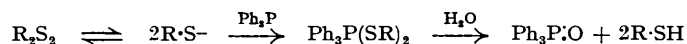
The disulphide was often regenerated from the resulting thiol by the oxygen of the air. The reactions of compounds of class 2 recall the formation of triphenylphosphine sulphide from triphenylphosphine and dithiocyanogen, doubtless through the unstable $Ph_3P(SCN)_2$ (Challenger, Smith, and Paton, *J.*, 1933, 1055).

We find that diallyl disulphide with triphenylphosphine at 80—90° with or without water gives triphenylphosphine sulphide in good yield, and therefore falls into group 2. Diallyl monosulphide was also formed and was characterised in one experiment as the *sulphilimine*.

Schönberg (*loc. cit.*) showed that certain disulphides of group 2 did not react with phenyl *iso*cyanide in conditions where elementary sulphur would form phenyl *iso*thiocyanate. He therefore concluded that Ph_3PS arose from $Ph_3P(SR)_2$ and not from free sulphur formed in solution by dissociation of a disulphide to a monosulphide and sulphur. However, with diallyl disulphide we obtained evidence of the formation of phenyl *iso*thiocyanate, *s*-diphenylthiourea being obtained after reaction with aniline. This appears to favour formula (I); yet the free radicals of diallyl disulphide might be more reactive than those of the disulphides tested by Schönberg, and might react to give $PhN\colon C(S\cdot C_3H_5)_2$ (VI). This could then (*a*) break down directly to allyl monosulphide and phenyl *iso*thiocyanate which, with aniline, would give the thiourea or (*b*) (VI) might itself react with aniline thus :

$$PhN\colon C(S\cdot C_3H_5)_2 + NH_2Ph \longrightarrow (Ph\cdot NH)_2C(S\cdot C_3H_5)_2 \longrightarrow (C_3H_5)_2S + CS(NHPh)_2.$$
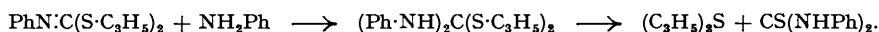
Scheme (*a*) is perhaps more likely because of the ease with which most compounds of the type $X(S\cdot C_3H_5)_2$ (where X is, *e.g.*, a metal or Ph_3P) break down to XS and allyl sulphide. However, if either of the above schemes is correct, it renders this reaction useless for distinguishing between a free-radical mechanism and formation of elementary sulphur.

Triphenylstibine, although less reactive than triphenylphosphine, gives compounds which are more stable than those of triphenylphosphine (Challenger and Wilson, *J.*, 1927, 209). No reaction occurred between triphenylstibine and diallyl disulphide.

The symmetrical structure (II) for diallyl disulphide is supported by the work of Koch (*J.*, 1949, 394) on the ultra-violet absorption spectra of disulphides and has now been established by the reaction of diallyl disulphide with cysteine yielding cystine and prop-2-ene-1-thiol in over 90% yield. If diallyl disulphide had structure (I), it would be impossible to explain this reaction : production of hydrogen sulphide might be expected (no trace of this was detected), and any further reduction could not by any mechanism yield over 50% of the thiol. For structure (II), the reaction appears as a normal reductive fission of a disulphide, accompanied by oxidation of cysteine to cystine. Cysteine seems not to have been used as a reducing agent for simple disulphides, although Harrison (*Biochem. J.*, 1927, **21**, 1408) found that the oxidation of cysteine, by the oxygen of the air and by methylene blue, is catalysed by biscarboxymethyl disulphide; the activity disappeared if the disulphide link were destroyed, *e.g.*, by oxidation with bromine. Bersin and Steudel (*Ber.*, 1938, **71**, 1015) found that cysteine and biscarboxymethyl disulphide come to a 50% equilibrium with cystine and thioglycollic acid in aqueous solution. We found this type of reaction to occur also with dimethyl disulphide which gave methanethiol and

cystine in 97% yield; diethyl and di-*n*-butyl disulphide required heat and gave lower yields, and a slow decomposition of the cysteine yielded hydrogen sulphide (for a similar decomposition of cysteine in aqueous solution see Mörner, *Z. physiol. Chem.*, 1904, **42**, 354, and Routh *J. Biol. Chem.*, 1939, **180**, 297). Di-*p*-nitrophenyl disulphide also yields the thiol and cystine.

Dimethyl and diethyl disulphide did not react with triphenylphosphine (cf. Schönberg, *loc. cit.*). They reacted hardly at all with zinc, even when heated, in contrast to statements that alkyl disulphides yield bisalkylthiozinc (Richter, " Organische Chemie," 11th edn., 1909, Vol. I, p. 162; Houben, " Die Methoden der Organischen Chemie," 1922, Vol. II, p. 365).

ADDENDUM.

It seemed possible that, in a high-boiling solvent and in absence of moisture (see p. 27), triphenylphosphine sulphide might also be formed from the phosphine and diphenyl disulphide. We failed to find any. In mesitylene or in nitrobenzene the phosphine oxide, but no sulphide, was isolated. We then found that in these solvents or in " liquid paraffin," but not in benzene, at the b. p. in presence of air the oxide is formed even in absence of diphenyl disulphide. From the phosphine and diphenyl disulphide in boiling mesitylene in absence of moisture and under nitrogen, neither the oxide nor the sulphide was obtained, although some triphenylphosphine oxide was formed when the reaction mixture was then left in contact with air at room temperature. In a private communication (27th May, 1949) Professor Schönberg states that he has observed independently that " triphenylphosphine reacts with the oxygen of the air at high temperatures, especially in the presence of light."

Schönberg *et al.* (*loc. cit.*) consider that several reactions of disulphides are best explained on the assumption of a homolytic dissociation into free radicals, *e.g.*, the action of metals and of triphenylmethyl giving RS·Metal and R·S·CPh$_3$, and the observation that certain disulphides do not obey Beer's dilution law. Waters (" Free Radicals," Oxford Univ. Press, 1946, pp. 72—73) accepts this free-radical mechanism.

The authors adopted this view in the present paper. A Referee has, however, suggested an alternative explanation of the reaction with triphenylphosphine. Polarisation of R$_2$S$_2$, thus $\overset{+}{RS}\overset{\frown}{}\overset{-}{SR}$, might lead to fission, the positive moiety being captured by the unshared electrons of the phosphorus to give the salt-like product [Ph$_3$$\overset{+}{P}$·SR]$\overset{-}{SR}$. This could then break down to Ph$_3$PS and R$_2$S (allyl sulphide) and with water would yield Ph$_3$PO and RSH. This, it was remarked, would be in accord with the accepted mechanism for the hydrolysis of the *iso*cyanides by acids.

We accept this as an alternative representation of the reaction; the ionisation of a disulphide and the capture of a positive methyl group by the unshared electrons of an arsenic or selenium atom were, in fact, suggested by one of us in earlier discussions of the mechanism of biological methylation (Challenger, Taylor, and Taylor, *J.*, 1942, 49; Challenger, *Chem. and Ind.*, 1942, **61**, 414; *Chem. Reviews*, 1945, **36**, 342). Similar considerations apply to the reaction between phenyl *iso*cyanide and diallyl disulphide.

EXPERIMENTAL.

Diallyl Monosulphide and Scopulariopsis brevicaulis *in Bread Cultures.*—Four 1-l. flasks, each containing 150 g. of bread-crumbs and 25 c.c. of distilled water, were sterilised at 120°, inoculated with spores from a potato–agar subculture of *S. brevicaulis*, and incubated for 6 days at 32° and for 3 days at room temperature. Diallyl monosulphide (0·25 g.), emulsified with 25 c.c. of sterile water, was then added with a sterile pipette to each flask. The flasks were connected in series by means of sterile rubber bungs and glass tubing, and sterile air passed through them, for 18 days, into 2 tubes containing 4% aqueous mercuric cyanide and 5 tubes containing 3% aqueous mercuric chloride. No precipitate formed in either of the cyanide tubes, but a white precipitate was produced in all the chloride tubes during the first 18 days. The white precipitate (3·8 g.) did not melt below 260°, but darkened and sintered above 190°. It was insoluble in the common organic solvents, and gave mercuric oxide with cold sodium hydroxide solution, and the odour of allyl sulphide with 6N-hydrochloric acid. The precipitate was thus the mercurichloride of allyl sulphide which had volatilised unchanged from the cultures.

Diallyl Disulphide.—Our sample of this compound (*Biochem. J.*, 1949, **44**, 90) (Found : C, 49·8; H, 7·23; S, 43·1. Calc. for C$_6$H$_{10}$S$_2$: C, 49·3; H, 6·85; S, 43·8%) apparently contained a trace of the monosulphide. The absence of thiol was shown by shaking with 4% mercuric cyanide solution, no precipitate being formed.

Diallyl Disulphide and Zinc.—5·0 G. of diallyl disulphide and 2·5 g. (slight excess) of zinc dust were mixed, and left at room temperature for 3 days. There was no change in odour or appearance after this time, or after maintaining the mixture at 60° for 2 hours and then at 100° for 2 hours. After 10 hours at 120—130°, the odour of disulphide was almost completely replaced by that of allyl monosulphide. The

oil was then decanted from the zinc dust, and fractionated at 16 mm., giving (i) an almost colourless oil, b. p. 35—45° (2 c.c.), having the odour of allyl monosulphide (b. p. 40°/16 mm.), and (ii) an orange-red oil, b. p. 60—85° (2·5 c.c.), probably mainly unchanged diallyl disulphide (b. p. 78—80°/16 mm.). The first fraction was redistilled at 16 mm., a fraction being collected between 36° and 40°. Two drops of this were shaken with saturated chloramine-τ solution. The precipitate, when separated and recrystallised from ethyl acetate–ligroin (b. p. 40—60°), had m. p. and mixed m. p. with authentic diallyl sulphilimine, 71°.

The zinc dust was only slightly changed in appearance, being slightly darker and coarser than previously. Addition of hydrochloric acid gave hydrogen sulphide, but no odour of a thiol. The product therefore contained zinc sulphide.

Bisallylthiozinc.—A few drops of prop-2-ene-1 thiol, shaken with excess of zinc acetate solution, gave immediately *bisallylthiozinc* as a white precipitate. This was separated after 30 minutes. It sintered from 120° to 200°. It was insoluble in the common organic solvents and was therefore purified by washing it with large quantities of water, alcohol, and ether (Found : Zn, 30·4. $C_6H_{10}S_2Zn$ requires Zn, 30·9%).

When it was refluxed with benzene for 10 minutes, decomposition occurred. The residual pale yellow powder on treatment with dilute hydrochloric acid gave the odour of hydrogen sulphide with only a very slight odour of thiol; it was unmelted below 270°, but showed a colour change at 200—220° characteristic of zinc sulphide.

The same decomposition was observed with dry bisallylthiozinc at 100°. The odour of allyl sulphide was noticed after 15 minutes. The product was extracted with a little alcohol, and the solution added to a saturated solution of chloramine-τ, giving a crystalline precipitate, m. p. 70°. The mixed m. p. with authentic allyl sulphilimine was 71°. The residue, insoluble in alcohol, gave no odour of a thiol with dilute hydrochloric acid.

Allyl Sulphilimine.—13·6 g. of chloramine-τ in about 200 c.c. of water, and 6 g. of diallyl monosulphide were shaken for 20 minutes. The product, which formed within a few seconds, was separated, dried, and recrystallised by addition of light petroleum (b. p. 40—60°) drop by drop to a solution in chloroform. After 3 such recrystallisations, the *sulphilimine* had the constant m. p. 72° (Found : C, 54·8; H, 6·1; N, 5·1. $C_{13}H_{17}O_2NS_2$ requires C, 55·1; H, 6·0; N, 5·4). It is converted into an oil on storage at room temperature for 3—4 days, or rapidly at 100°. At 0° the sulphilimine is stable for 3—4 weeks. No loss in weight is involved. The nature of this change will form the subject of a further communication.

Reaction of Dimethyl and Diethyl Disulphide with Zinc.—Heating dimethyl disulphide (10 hours at 100—110°) or diethyl disulphide (9 hours at 130°) with zinc, yielded no monosulphide, almost all the disulphide being recovered unchanged. Traces of $Zn(SR)_2$ were detected in each reaction by the slight odour of a thiol produced on addition of hydrochloric acid.

Diallyl Disulphide and Triphenylphosphine.—The disulphide (0·3 g.), triphenylphosphine (0·5 g.), and benzene (4 c.c.) were refluxed for 6 hours in the absence of water. On cooling, triphenylphosphine sulphide (0·4 g.) separated (m. p. and mixed m. p. 161—162°). The benzene solution was distilled, with addition of fresh benzene to the residue, until the odour of allyl sulphide had passed entirely into the distillate. This was then shaken for 45 minutes with an aqueous solution of chloramine-τ to form the sulphilimine. Evaporation of the benzene at room temperature left a white solid which, when recrystallised once from chloroform–ligroin, had m. p. and mixed m. p. with allyl sulphilimine, 71°. Repetition of this experiment in toluene at 90° in presence of water again gave triphenylphosphine sulphide, m. p. 162—163° (161—162° on admixture with an authentic specimen, m. p. 161—162°). The m. p. of triphenylphosphine oxide (151°) was depressed to 123°.

Diphenyl Disulphide and Triphenylphosphine.—Triphenylphosphine (1 g.) was heated in boiling nitrobenzene (7 c.c.) for 6 hours. Evaporation then left a tarry residue, which on extraction with ligroin (b. p. 80—100°) for 1 hour and recrystallisation from benzene–ligroin yielded triphenylphosphine oxide (0·3 g.), m. p. 153—154° (mixed m. p. 154°).

The phosphine (0·2 g.) was heated in boiling mesitylene (2 c.c.) for 5 hours with precautions to exclude moisture from the apparatus. Cooling and addition of ligroin (b. p. 40—60°) gave 0·08 g. of the phosphine oxide, m. p. and mixed m. p. 156°.

The phosphine (0·5 g.), diphenyl disulphide (0·42 g.), and mesitylene (5 c.c.) (all dried over P_2O_5; the mesitylene then redistilled) were refluxed for 6 hours in a dried apparatus in a stream of nitrogen previously passed through alkaline pyrogallol, sulphuric acid, and phosphoric oxide. On cooling and addition of ligroin to a portion, no crystals appeared, showing that no phosphine oxide or sulphide had been formed. However, after storage in air in a closed flask for 10 days, addition of ligroin gave 0·12 g. of the phosphine oxide, m. p. 154° (mixed m. p. 155°). Distillation of the solvents in a stream of nitrogen left a red liquid residue, which when kept overnight in air and then treated with ligroin gave a further 0·13 g. of the phosphine oxide. The residue after evaporation of the ligroin slowly deposited diphenyl disulphide, m. p. and mixed m. p. 60°.

Diallyl Disulphide and Phenyl iso*Cyanide* (Experimental conditions were obtained from a private communication from Professor A. Schönberg).—Diallyl disulphide (3 g.), phenyl *iso*cyanide (2 g.; b. p. 64°/20 mm.) and benzene (25 c.c.) were refluxed for 8 hours. Aniline (2 g.) was then added, and refluxing continued for a further 3 hours, a colour change from bluish-green to orange-red being then observed. Orange crystals separated overnight and were removed and washed with cold benzene and ether. After recrystallisation from alcohol, the product (0·65 g.) had m. p. 153° alone and mixed with authentic *s*-diphenylthiourea. The benzene mother-liquor was washed with concentrated hydrochloric acid (to remove aniline and phenyl *iso*cyanide) and with water, dried (Na_2SO_4), and evaporated at 40—50 mm., giving a further quantity of orange solid and unchanged diallyl disulphide.

Diallyl Disulphide and Triphenylstibine.—The disulphide (1·0 g.) and triphenylstibine (2·5 g.) in ligroin (b. p. 80—100°; 50 c.c.) were refluxed for 30 hours. There was no reaction.

When twice these quantities were used without a solvent during 3 hours at 100° and 8 hours at 140°, a viscous liquid slowly formed; no solid product was isolated.

Diallyl Disulphide and Cysteine.—Cysteine hydrochloride (1·0 g.) in water (*ca.* 15 c.c.) was neutralised with 10% sodium hydrogen carbonate solution (*ca.* 5 c.c.), and diallyl disulphide (0·167 g.) added. After

56 hours at room temperature in a stream of nitrogen the reaction was complete. The nitrogen, with the volatile products, passed through 2 tubes containing 4% aqueous mercuric cyanide to absorb thiols, and 3 tubes containing 3% aqueous mercuric chloride to absorb unchanged disulphide. Bisallylthio-mercury (0·358 g.), m. p. and mixed m. p. 72°, was obtained from the first cyanide tube. This represents 0·152 g. (91%) of diallyl disulphide. The white precipitate (0·097 g.) in the mercuric chloride tubes had the properties expected of a mercurated fission product of diallyl disulphide. It gave an odour of a thiol with hydrochloric acid and a precipitate of mercuric oxide with sodium hydroxide solution, and was unmelted below 270° (*Biochem. J.*, 1949, **44**, 89). It represented about 0·016 g. (10%) of diallyl disulphide. Experimentally, 1 g. of diallyl disulphide gives about 6 g. of mercuric chloride derivative.

Cystine (0·25 g.) was removed from the reaction flask. Alone and in admixture with authentic cystine its m. p. (decomp.) was 256—258°. It was equivalent to 0·153 g. or 91·5% of the disulphide used.

Dimethyl Disulphide and Cysteine.—0·078 G. of dimethyl disulphide and excess of cysteine hydrochloride solution (1 g. in *ca.* 15 c.c.), neutralised as before, were left in a stream of nitrogen, as in the previous experiment.

Bismethylthiomercury (0·238 g., 97·5%) was obtained from the first cyanide tube. After one recrystallisation from ethyl acetate, it had m. p. and mixed m. p. 174°. A trace of precipitate in the chloride tubes probably accounted for the remaining 2·5% as unchanged disulphide. Cystine (0·196 g., equivalent to 98% of the disulphide) was recovered.

Diethyl Disulphide and Cysteine.—The reaction was slow. The disulphide (0·074 g.) and cysteine hydrochloride (0·5 g.), neutralised as before, were heated at 100° in nitrogen for 2½ hours. The precipitate in the first cyanide tube contained a trace of mercuric sulphide and was purified by decomposing it with 70% hydrochloric acid, and aspirating the gas again into mercuric cyanide solution, followed by recrystal-lisation from alcohol. The bisethylthiomercury (0·034 g., representing 17% of the disulphide used) melted at 75° (76° on admixture with an authentic specimen). The cystine formed had m. p. and mixed m. p. 258° (decomp.).

Di-n-butyl Disulphide and Cysteine.—The disulphide (0·05 g.), cysteine hydrochloride (1·0 g.), and 3·5% sodium hydrogen carbonate solution (*ca.* 15 c.c.) were heated for 11 hours at 100° in nitrogen. The greenish-black precipitate (0·266 g.) from the mercuric cyanide gave scarcely any thiol with hydrochloric acid, and was insoluble in hot alcohol. It was mainly mercuric sulphide and as the quantity was so large, decomposition of the cysteine was suspected. Cysteine hydrochloride and aqueous sodium hydrogen carbonate evolved hydrogen sulphide slowly at 100°, and mercuric sulphide was gradually precipitated in the mercuric cyanide.

Di-p-nitrophenyl Disulphide and Cysteine.—The disulphide (0·5 g.; m. p. 181—182°; Willgerodt, *Ber.*, 1885, **18**, 331, gives m. p. 180—181°; Fromm and Wittmann, *ibid.*, 1908, **41**, 2264, give m. p. 182°) and cysteine hydrochloride (0·5 g.), neutralised with sodium hydrogen carbonate, were refluxed in 50% aqueous alcohol for 2½ hours, cooled, and poured into excess of dilute hydrochloric acid, thus precipitating the *p*-nitrothiophenol and any unchanged disulphide. The precipitate sintered without complete fusion at 76°. It was dissolved in dilute sodium hydroxide, filtered from a small amount of disulphide, and reprecipitated by dilute hydrochloric acid. When quickly dried, it had m. p. 77° (the recorded m. p. of *p*-nitrothiophenol; Willgerodt, *loc. cit.*; Fromm and Wittmann, *loc. cit.*) but was rapidly re-oxidised to the disulphide.

The cystine was recovered by neutralising the acid solution with sodium hydrogen carbonate. It had m. p. 252° (decomp.) alone or mixed with an authentic cystine.