Oxidation of Organic Sulphides. Part IV. Autoxidation of* cyclo*Hex-2-enyl Methyl Sulphide.*

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*cyclo*Hex-2-enyl methyl sulphide readily absorbs up to *ca.* 0·3 mole of oxygen per mole at 55° to yield a complex mixture. *cyclo*Hexenyl methyl sulphoxide, 6-methylthio*cyclo*hex-2-enone (VIII), *cyclo*hexenone, *cyclo*hexenol, water, and dimethyl disulphide have been identified and estimated approximately quantitatively. A reaction mechanism consistent with these and other experimental data is presented and discussed.

Several new keto-sulphides which were required as reference compounds have been prepared and characterized; the sulphide (VIII) and its 3-methylthio-isomer (III) show marked antioxidant activity.

The autoxidizability of allylic sulphides is characterized by a rapid initial uptake of oxygen which later falls to a negligible rate when only a fraction of a mol. of oxygen has been absorbed (Part III *). One or more of the reaction products must be responsible for this autoinhibition, and this paper describes the first of a series of investigations into what these are and how they act. *cyclo*Hex-2-enyl methyl sulphide (I) was chosen as the first sulphide for detailed study because it is readily obtained pure (in particular, contamination with

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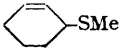
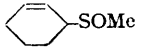
* Part III, *J.*, 1955, 1596.

allylic isomerides is impossible) and because it absorbs more oxygen before reaction ceases than most other sulphides so far examined.

(I) 

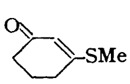
 (II)

When the sulphide (I) was shaken in oxygen at 55°, it absorbed about 0·3 mole of oxygen per mole before further reaction became negligible. The solution was cloudy and contained water droplets. About a quarter of the absorbed oxygen was combined in sulphoxide groups, as estimated by reduction with titanous chloride (Barnard and Hargrave, *Analyt. Chim. Acta*, 1951, **5**, 536).

The reaction mixture was separable by distillation into fractions (i) b. p. 60—70°/14 mm., (ii) b. p. 80—90°/0·1 mm., and (iii) a dark residue involatile at 0·1 mm. Fraction (i) consisted of unchanged sulphide admixed with water, dimethyl disulphide, *cyclo*hex-2-enone, and *cyclo*hex-2-enol. The last two compounds were identified spectroscopically and by the derivatives given with 2 : 4-dinitrophenylhydrazine and α-naphthyl *iso*cyanate, respectively. Fraction (ii) analysed approximately for $C_7H_{11}OS$ and had a sulphoxide content about half that of the nearly isomeric *cyclo*hex-2-enyl methyl sulphoxide (II). Fraction (iii), which also had a substantial sulphoxide content, proved to be mainly the decomposition products formed during distillation (see below) and was not examined in detail.

While the infrared spectrum of fraction (ii) and its reaction with 2 : 4-dinitrophenylhydrazine showed a considerable amount of carbonyl-containing material to be present, attempts at separation by further fractionation proved fruitless. Two other procedures, however, were successful : (*a*) treatment with titanous chloride reduced the sulphoxide to the original sulphide, which could be distilled from the reduced product to leave a heterogeneous keto-sulphide (KS), b. p. 67—70°/0·1 mm.; (*b*) chromatography using silica gel permitted both the sulphoxide (II) and the mixture (KS) to be recovered separately and characterized. Chromatography of the original reaction mixture (after drying) afforded a more thorough, but for sizeable quantities more laborious, overall separation; its application to quantitative estimation of the constituents is described later. Under these mild conditions, the amount of involatile product isolated [fraction (iii) above] was very small.

Composition of the Keto-sulphide (KS).—Elemental analyses and the molecular weight corresponded to the formula $C_7H_{10\cdot7}OS$. Desulphurization with Raney nickel gave *cyclo*hexanol in good yield, thus proving the presence of a cyclic C_6 unit with the oxygen atom attached. The infrared and ultraviolet spectra were complex, but indicated the presence of unconjugated and variously conjugated keto-groups, the simple αβ-unsaturated form being predominant. Weak absorption at 1570 cm.$^{-1}$ suggested the presence of about 5% of a triply conjugated chromophore as occurs in (III), and this was consistent with absorption at 1655 cm.$^{-1}$ attributed to a highly conjugated ketone group. Ultraviolet absorption at 2900—3000 Å was also consistent, but this proved to be non-critical evidence since differently substituted *cyclo*hexenones were found to absorb similarly (see below).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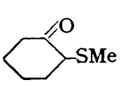
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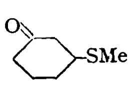
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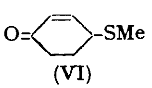
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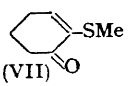
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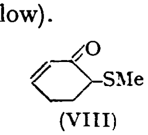
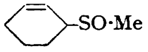
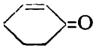
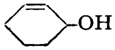

(VIII)

On treatment with 2 : 4-dinitrophenylhydrazine in aqueous hydrochloric acid, a solid derivative, m. p. 168—180°, was obtained in high yield. Non-selective ultraviolet absorption of this product reflected the complexity of the parent ketone. Paper chromatography showed a weak and a strong spot which had R_F values of 0·38 and 0·19, respectively, under the conditions described on p. 2002. The first of these is attributed to the 2 : 4-dinitrophenylhydrazone of a saturated keto-sulphide, since the corresponding derivatives of 2- and 3-methylthio*cyclo*hexanone (IV and V) behave similarly; the second is derived from an unsaturated keto-sulphide, but of uncertain type since the dinitrophenylhydrazones of the differently conjugated 3- and 4-methylthio*cyclo*hex-2-enone (III and VI) have the same R_F value. Fractional crystallization gave a small yield of a derivative of an unidentified saturated keto-sulphide, possibly of 4-methylthio*cyclo*hexanone since it is not (IV) or (V), which were independently synthesized and characterized, while the major constituent consisted of dark red needles, m. p. 235°, having an absorption peak in the near ultraviolet at 3750 Å ($E^{1\%}_{1\,\text{cm.}}$ 821). These spectral features are intermediate to those shown by the corresponding derivatives of the triply conjugated keto-sulphide (III) ($\lambda_{\text{max.}}$ 2650, 3020, 4000 Å; $E^{1\%}_{1\,\text{cm.}}$ 410, 398, 939) and the unconjugated compound (V) ($\lambda_{\text{max.}}$ 3630 Å; $E^{1\%}_{1\,\text{cm.}}$ 743), and hence were associated with a parent αβ-unsaturated ketone structure. The 2 : 4-dinitrophenylhydrazone of *cyclo*hexenone absorbs similarly ($\lambda_{\text{max.}}$ 3750 Å; $E^{1\%}_{1\,\text{cm.}}$ 994), and so does the derivative later prepared from (VI) ($\lambda_{\text{max.}}$ 2500, 3740 Å; $E^{1\%}_{1\,\text{cm.}}$ 552, 880), which is otherwise distinguishable from the unknown. Examination of the corresponding semicarbazones led to the same conclusion.

If the double bond is not involved in more than one displacement from its original position in (I), *i.e.*, oxygen attachment is confined to position 1, 2, 3, or 4 (see Part III, *loc. cit.*), the main constituent of (KS) must be either (VII) or (VIII). Reduction with lithium aluminium hydride gave an alcohol which absorbed far less intensely at 2300 Å than a substituted vinyl sulphide such as would be derived from (VII). Positive identification was finally achieved by the synthesis of (VIII) and direct comparison of the synthetic ketone and its derivatives with the unknown.

Quantitative Estimation of the Products.—The sulphoxide content was determined directly on the oxidized mixture as mentioned above. Dimethyl disulphide was estimated from a separate experiment. The more volatile fraction of the total oxidation mixture was distilled off and reduced with lithium aluminium hydride, and the resulting thiol estimated by the copper acetate method. Water was determined in a number of separate experiments in which it was distilled from the reaction mixture as its benzene azeotrope and then determined by the Karl Fischer procedure. For the remaining products, the reaction mixture was dried, diluted with light petroleum, and passed through a column of silica gel. After removal of the original sulphide and dimethyl disulphide with successive petroleum washings, the column was eluted with petroleum containing 10—50% of ether to remove *cyclo*hexenone, *cyclo*hexenol, and the keto-sulphides. These components could not be separately determined directly in the mixture, but approximate analysis was possible by separating the first two compounds from the third by distillation and then applying spectroscopic and polarographic methods.

Oxygen Balance.—The approximate distribution of the absorbed oxygen is expressed in the following Table, 93% of the oxygen being accounted for :

	H_2O				(KS)	Residue
Proportion of O_2 absorbed (wt. %) ...	25	23	10	8	22	5

Dimethyl disulphide was formed to the extent of 0·12 mole/mole of oxygen absorbed.

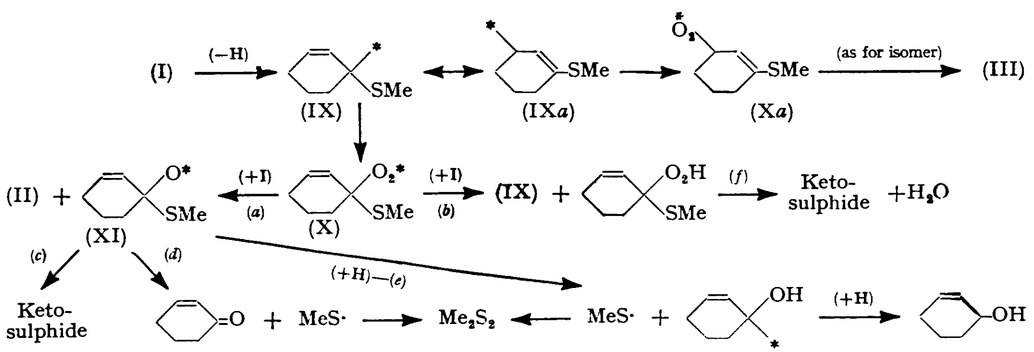
Course of the Reaction.—In view of the complexity of the products and the inference that several alternative or consecutive reactions must be occurring during the oxidation, consideration of the reaction mechanism is limited to developing a reasonable working picture on which to base further experiments.

The general features of the oxidation of allylic sulphides described in Part III lead to two important conclusions. First, the marked catalysis by thermally decomposing azo*iso*butyronitrile and by ultraviolet irradiation and the inhibition by quinol and similar compounds show that the primary attachment of oxygen involves free-radical intermediates. Secondly, the fact that oxygen absorption proceeds initially much faster than with a comparable olefin, coupled with the high reactivity of cinnamyl phenyl sulphide, points to the CH or CH_2 group activated by both the double bond and the sulphur atom being the primary reactive centre. In addition, very little polymeric product is formed (p. 2002), thus showing the unimportance of attack by peroxy-radicals at the double bond and of the following sequence of reactions :

$$RO_2\cdot + C{:}C \longrightarrow RO_2{\cdot}C{\cdot}C\cdot \xrightarrow{O_2} RO_2{\cdot}C{\cdot}C{\cdot}O_2\cdot \xrightarrow{C:C}$$

$$RO_2{\cdot}C{\cdot}C{\cdot}O_2{\cdot}C{\cdot}C\cdot \xrightarrow{O_2} \textit{etc.}$$ (cf. Bateman, *Quart. Rev.*, 1954, **8**, 147).

The annexed scheme is based on these features.

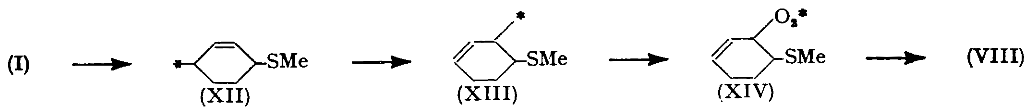


The finding of roughly equal molar proportions of (II), *cyclo*hexenone and *cyclo*hexenol together, keto-sulphide, and water indicates, on this scheme, that reactions (*a*) and (*b*) proceed with equal facility and that reaction (*c*) is negligible. These are not unreasonable consequences.

Hydroperoxides appear to react with allylic sulphides in aprotic solvents, not molecularly as in alcohols to give sulphoxides in quantitative yield, but probably *via* radicals to give only fractional yields of sulphoxides (Barnard, unpublished results; see Parts I and II, *Proc. Roy. Soc.*, 1954, *A*, **224**, 389, 399). Hydrogen abstraction by peroxy-radicals, as invoked in step (*b*), is the fundamental basis of numerous other autoxidations, but the oxygen-transfer process (*a*) has only recently been recognized (Part II). The reactions of (XI) expressed in (*d*) and (*e*) simulate the behaviour of the formally similar *tert.*-alkoxy-radicals derived from di-*tert.*-butyl peroxide and *tert.*-butyl hydroperoxide (see Bell, Raley, Rust, Seubold, and Vaughan, *Discuss. Faraday Soc.*, 1951, **10**, 242). These oxy-radicals show no tendency to oxidize sulphides to sulphoxides in the manner of their peroxy-counterparts (Barnard, unpublished results).

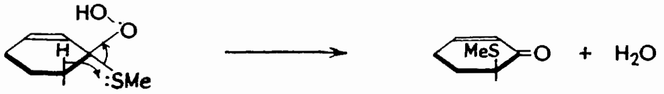
While it is difficult to envisage the transformation of (XI) into a keto-sulphide, the reaction path (IX) ⟶ (IX*a*) ⟶ (X*a*) would be expected to give (III). Although spectroscopic evidence points to the presence of (III) in the keto-sulphide mixture, the amount is so small that neither the liquid ketone nor its crystalline derivatives have been separated and characterized. This is a peculiar feature because 1 : 4-dienes undergo double-bond displacement on autoxidation to give the completely conjugated hydroperoxide : $C{:}C{\cdot}CH{\cdot}C{:}C \longrightarrow C{:}C{\cdot}C{:}C{\cdot}C(O_2H)$ (Bateman, *loc. cit.*), and similar behaviour might have been expected in the present system in view of the considerable conjugation between a double bond and an adjacent sulphur atom (Koch, *J.*, 1949, 387), as shown chemically, for example, in the tendency of allylic sulphides to isomerize into vinylic sulphides on heating (Tarbell and McCall, *J. Amer. Chem. Soc.*, 1952, **74**, 48). Further, whatever the relative importance of the mesomeric structures (IX) and (IX*a*), steric factors would be expected to cause the latter to be the preferred configuration on reaction with other molecules.

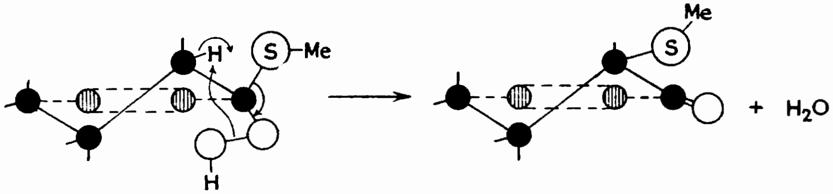
In contrast to the above, a double-bond displacement or an equivalent process is clearly involved in the formation of the main keto-sulphide (VIII). The simplest explanation is that hydrogen abstraction from the sulphide (I) occurs at the non-sulphurated allylic position, followed by reaction of the resulting radical in the isomeric form :



but this seems unlikely for two reasons. First, the increased oxidizability of the *cyclo*hexenyl unit produced by the MeS substituent cannot reasonably be associated with increased reactivity at a methylene group essentially unaffected by the substituent, *i.e.*, it is difficult to believe that the proportion of (XII) to (XI) can be appreciable. Secondly, the ketone derivable directly from (XII), *viz.*, (VI), is definitely absent from the oxidation products, and it is difficult to see why, if (XII) were formed, it should react exclusively as (XIII) [the spectral properties of (VIII) and (VI) suggest steric hindrance between an adjacent oxygen atom and the MeS group].

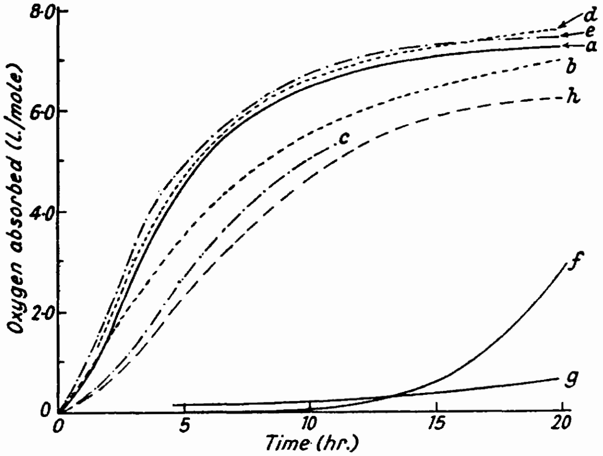
We believe, therefore, that (VIII) is formed in stage (*f*) (p. 1999) and that it results from an internal dehydration which proceeds with migration of the MeS substituent. On the basis of the strained or " half " chair configuration of the *cyclo*hexenyl unit (Raphael and Stenlake, *Chem. and Ind.*, 1953, 1286; Barton *et al.*, *ibid.*, 1954, 21), this is pictured as:





Somewhat similar and unusual bond displacements, which scale models show to be quite feasible sterically, are encountered with *cyclo*hexenyl hydroperoxide itself, *e.g.*, in the acid-catalysed dehydration to *cyclo*pentenaldehyde.

The chain character of the autoxidation, which is revealed by the response to catalyst and inhibitors (Part III), originates in the operation of reactions (*b*) and possibly (*e*) (p. 1999).



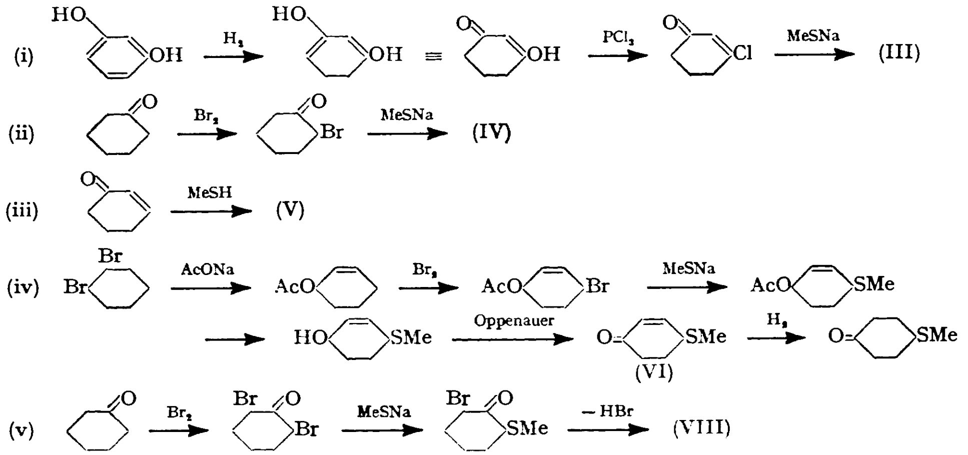
Effect of the reaction products and some keto-sulphides on the autoxidation of cyclo*hexenyl methyl sulphide at* 55°.

a, (I) alone; *b*, (I) + H_2O (11·8% molar); *c*, (I) + (II) (4·5% molar); *d*, (I) + (V) (1·6% molar); *e*, (I) + *cyclo*hexenone (6·3% molar); *f*, (I) + (III) (5·4% molar); *g*, (I) + (VIII) (5·4% molar); *h*, (I) + dimethyl disulphide (3·2% molar).

Influence of the Reaction Products on Autoxidation.—The effect of additions of (II), (VIII), *cyclo*hexenone, water, and dimethyl disulphide on oxygen uptake by the sulphide (I) is shown in the Figure. Only (VIII) has any significant effect [which is closely similar to that caused by (III)], and this keto-sulphide acts as a sufficiently powerful retarder to account without difficulty for the observed autoinhibition. Comparison of the action of (VIII), (III), and (IV) reveals the importance of conjugation as a structural feature conferring inhibitory power on compounds of this type. Although certain saturated keto-sulphides are claimed to be efficient antioxidants for natural fats (Thompson, *Ind. Eng. Chem.*, 1951, **43**, 1638; 1952, **44**, 1659), the inactivity of (IV) in the present system parallels the small effect of 4-ethylthiobutan-2-one on the oxidation of *n*-butyl cinnamyl sulphide (Part III, *loc. cit.*).

Synthesis and Properties of the Keto-sulphides prepared for Comparison.—Although a number of saturated aliphatic keto-sulphides have been prepared by the general method of addition of thiols to αβ-unsaturated ketones (Posner, *Ber.*, 1902, **35**, 809; Ruhemann, *J.*, 1905, **87**, 17, 461; Thompson, *Ind. Eng. Chem.*, 1951, **43**, 1638; U.S.P. 2,492,334), most of the homocyclic compounds considered in this paper are new. Of particular interest are the unsaturated examples where the double bond is conjugated with one or both of the other functional groups.

The syntheses of (III)—(VI) and (VIII) were effected as follows:



Certain characteristic properties of these keto-sulphides and their derivatives are summarized in Table 1.

Table 1.

	Keto-sulphide				2:4-Dinitrophenylhydrazone			Semicarbazone		
Compound	n_D^{20}	ν_{CO} [1] (cm.$^{-1}$)	$\lambda_{max.}$ (Å)	ε [2]	M. p.	$\lambda_{max.}$ (Å)	ε [2]	M. p.	$\lambda_{max.}$ (Å)	ε [2]
(IV)	1·5115	1708	2530 3040 3030	497 315 922 *	137—138°	2540 3630 3500	12,310 22,600 (infl.)	171—172°	2300	14,270
(V)	1·5172	1715	2630 2880	339 45·5	148	3630	24,050	165	2310	13,130
p–O:C_6H_9·SMe	—	—	—	—	145—146	3620	22,800	—	—	—
(VI)	1·5487	1690	—	—	146—147	2500 3740	17,780 28,260	156—160	—	—
(VIII)	1·5608	1690	3000	4,250	234	3750	26,700	234	2650	17,440
(III)	1·5902	1655	2870	20,800	212	2650 3020 4000	14,750 12,850 30,250	207—208	2930	34,030

[1] For neat liquids. [2] In ethanol, except for * in aqueous 2N-NaOH.

Experimental

Microanalyses were carried out under the direction of Dr. W. T. Chambers.

cyclo*Hex-2-enyl Methyl Sulphide.*—3-Bromo*cyclo*hexene (Ziegler *et al.*, *Annalen*, 1942, **551**, 80) was treated with sodium methyl sulphide in ethanol; the *sulphide*, isolated in the usual way and fractionated, had b. p. 64·5°/14 mm., n_D^{20} 1·5210 (Found: C, 65·5; H, 9·4; S, 25·1. $C_7H_{12}S$ requires C, 65·6; H, 9·4; S, 25·0%). It formed trimethylsulphonium iodide on reaction with methyl iodide at room temperature. The derived sulphoxide (Barnard and Hargrave, *Analyt. Chim. Acta*, 1951, **5**, 476) had b. p. 75°/0·1 mm., n_D^{20} 1·5384 (Found: C, 58·1; H, 8·5; S, 22·3. Calc. for $C_7H_{12}OS$: C, 58·3; H, 8·4; S, 22·2%).

To test the effect of the alkyl substituent on oxidizability (see Part III), the following *cyclo*hex-2-enyl sulphides were prepared analogously: *ethyl*, b. p. 76°/14 mm., n_D^{20} 1·5140 (Found:

C, 67·5; H, 9·9; S, 22·7. $C_8H_{14}S$ requires C, 67·5; H, 9·9; S, 22·5%); iso*propyl*, b. p. 84°/14 mm., n_D^{20} 1·5062 (Found: C, 68·8; H, 10·4; S, 20·4. $C_9H_{16}S$ requires C, 69·1; H, 10·3; S, 20·5%); tert.-*butyl*, b. p. 97°/14 mm., n_D^{20} 1·5015 (Found: C, 70·5; H, 10·7; S, 18·4. $C_{10}H_{18}S$ requires C, 70·5; H, 10·7; S, 18·8%); *phenyl*, b. p. 77°/0·1 mm., n_D^{20} 1·5929 (Found: C, 75·4; H, 7·2; S, 16·9. $C_{12}H_{14}S$ requires C, 75·8; H, 7·4; S, 16·8%).

Oxidation Procedure.—The sulphide, kept at 55°, was shaken without solvent in purified oxygen supplied from a constant-temperature and -pressure gas-burette, mercury (which behaves as silicone oil for this sulphide, cf. Part III, *loc. cit.*) being used as the manometric fluid.

Separation of Oxidation Products by Distillation.—The oxidized sulphide (103 g., containing 7·3 g. of oxygen) gave (i) 73 g., b. p. 60—65°/14 mm., n_D^{20} 1·5170, containing unchanged sulphide, water, dimethyl disulphide, *cyclo*hexenol, and *cyclo*hexenone (see below); (ii) 20 g., b. p. 80—90°/0·1 mm., n_D^{20} 1·5435, containing *ca.* 50% of *cyclo*hexenyl methyl sulphoxide; (iii) 7·6 g., undistillable residue, n_D^{20} 1·5744 (Found: C, 57·4; H, 7·2; S, 20·2; sulphoxide content, by $TiCl_3$, 30%). Redistillation of (ii) gave a fraction (15 g.), b. p. 80°/0·1 mm., n_D^{20} 1·5468 (Found: C, 58·6; H, 8·1; S, 21·2; sulphoxide content, by $TiCl_3$, 49·5%). The mutual volatility of the products prevented more refined separation by distillation, but removal of the sulphoxide from faction (ii) was effected as follows. A solution in acetic acid (900 ml.) was added with stirring to titanous chloride solution (2430 ml.; 0·1N) containing concentrated hydrochloric acid (150 ml./l.). After being heated at 70—75° for about 2·5 hr., the solution was cooled, set aside overnight, neutralized (ammonium hydroxide), and then extracted for 48 hr. with purified ether. The ethereal extract gave on fractionation: (*a*) impure *cyclo*hexenyl methyl sulphide (7·0 g.), b. p. 65—67°/14 mm. (Found: S, 22·8%), identified by its infrared spectrum; and (*b*) a ketonic non-sulphoxylic fraction (8·0 g.), b. p. 67—70°/0·1 mm., n_D^{20} 1·5503 (Found: C, 57·9; H, 7·4; S, 24·3%), henceforth designated (KS).

Reduction of a part of the total oxidation mixture with lithium aluminium hydride gave methanethiol (from dimethyl disulphide) which was distilled off, absorbed in alcoholic sodium hydroxide, and identified as 2 : 4-dinitrophenyl methyl sulphide. After several recrystallisations from ethanol this had m. p. 126·5° (Found: C, 39·3; H, 2·8; N, 13·4; S, 14·8. Calc. for $C_7H_6O_4N_2S$: C, 39·3; H, 2·8; N, 13·2; S, 15·0%).

Chromatographic Separation.—Silica gel (200 mesh) was used as adsorbent (decomposition occurred on alumina). All solvents were redistilled immediately before use, the methanol from magnesium methoxide. Oxidized sulphide (11·0 g.) in light petroleum (b. p. <40°; 650 ml.) was passed down the column (45 × 2 cm.), followed by: (1) light petroleum (1250 ml.); (2) light petroleum–10% ether (100 ml.); (3) light petroleum–20% ether (2250 ml.); (4) light petroleum–50% ether (800 ml.); (5) ether (400 ml.); (6) methanol (230 ml.). All eluates were concentrated by carefully evaporating the solvents through a Fenske column. Fraction (1) consisted of the parent sulphide and dimethyl disulphide; (2)—(5) contained *cyclo*hexenol, *cyclo*hexenone, and ketonic sulphides; (6) gave *cyclo*hexenyl methyl sulphoxide, n_D^{20} 1·5374, identified by direct comparison with an authentic specimen (Barnard and Hargrave, *loc. cit.*). Fractions (2)—(5) were combined and fractionated at 0·1 mm. The components volatile at room temperature were *cyclo*hex-2-enol (α-naphthylurethane, m. p. and mixed m. p. with authentic specimen 150—151°) and *cyclo*hex-2-enone (2 : 4-dinitophenylhydrazone, m. p. and mixed m. p. with authentic specimen, 159—160°); the remainder consisted of a fraction virtually identical with (KS), b. p. *ca.* 70°/0·1 mm., and a small non-distillable residue.

Properties and Characterization of (KS).—(*A*) Warming with 2 : 4-dinitrophenylhydrazine in aqueous hydrochloric acid gave a crystalline precipitate, m. p. 168—180°. The heterogeneity of this derivative was clearly shown by paper chromatography (chloroform being used as the stationary phase on acetylated paper), elution by methanol–water (85 : 15) giving two spots, one weak with R_F 0·38 the other strong with R_F 0·19. The first simulates the behaviour of the 2 : 4-dinitrophenylhydrazones of the saturated keto-sulphides (IV) and (V); the second that of the differently conjugated derivatives from (III) and (VI). Fractional crystallization gave a small proportion of red needles (from pyridine–light petroleum), m. p. 148—149° (Found: C, 48·4; H, 4·8; N, 17·2; S, 9·4. $C_{13}H_{16}O_4N_4S$ requires C, 48·2; H, 5·0; N, 17·3; S, 9·9%), having $\lambda_{\max.}$ 3670 Å, $E^{1\%}_{1\,\mathrm{cm.}}$ 714; the parent saturated keto-sulphide has not been identified. The main constituent, later shown to be derived from the compound (VIII), formed dark red needles from pyridine–ethanol or benzene, m. p. 235°, $\lambda_{\max.}$ 3750 Å, $E^{1\%}_{1\,\mathrm{cm.}}$ 787 (Found: C, 48·5; H, 4·4; N, 17·5; S, 9·7. $C_{13}H_{14}O_4N_4S$ requires C, 48·4; H, 4·4; N, 17·4; S, 9·9%).

The *semicarbazone* of the main constituent of (KS) had m. p. 236°, $\lambda_{\max.}$ 2650 Å, $E^{1\%}_{1\,\mathrm{cm.}}$ 865 (Found: C, 48·3; H, 6·5; N, 21·1; S, 16·1. $C_8H_{13}ON_3S$ requires C, 48·2; H, 6·6; N, 21·1; S, 16·1%).

(*B*) The infrared absorption of (KS) indicated the presence of three types of carbonyl grouping: (*a*) an αβ-unsaturated ketone showing strong absorption at 1690 cm.$^{-1}$; (*b*) <5% contained in the more strongly conjugated grouping S–C=C–C=O, absorbing at 1656 cm.$^{-1}$; (*c*) a minor amount of a saturated ketone absorbing at 1708 cm.$^{-1}$. The ultraviolet spectrum showed broad maximal absorption at 2850—3050 Å ($E^{1\%}_{1\,\text{cm.}}$ 290).

(*C*) The material (KS) (1·2 g.) was heated at 75—80° with Raney nickel (catalyst " C "; Hurd and Rudner, *J. Amer. Chem. Soc.*, 1951, **73**, 5157) in ethanol solution (50 ml.) with continuous stirring under a stream of nitrogen for 3 hr. The mixture was filtered, the nickel thoroughly extracted with boiling ethanol, and the combined liquors concentrated to about 15 ml. This solution was shaken in hydrogen over palladium–charcoal: no hydrogen was absorbed. The product was isolated in the usual way and distilled (0·7 g.), n_D^{20} 1·4600 (authentic *cyclo*hexanol, n_D^{20} 1·4643). It readily formed an α-naphthylurethane, m. p. and mixed m. p. with a specimen prepared from *cyclo*hexanol, 125—126°. In a trial experiment, 3-methylthio*cyclo*hex-2-enone (III) gave *cyclo*hexanol in similar yield.

(*D*) Hydrogenation of (KS) over palladium–charcoal (hydrogen absorption, 0·85 mole), and distillation gave a product consisting largely of 2-methylthio*cyclo*hexanone (IV), n_D^{20} 1·5200, and having an infrared spectrum nearly identical with that of a synthetic specimen. This compound was definitely absent before hydrogenation. The orange 2 : 4-dinitrophenylhydrazone could not be obtained pure by crystallization, and had a m. p. several degrees lower than the derivative prepared from the synthetic keto-sulphide.

(*E*) Reduction of (KS) (0·6 g.) with lithium aluminium hydride (0·1 g.) in dry ether (10 ml.), and isolation of the product in the usual way, gave a liquid (0·35 g.), n_D^{20} 1·5650 (Found: C, 56·5; H, 7·7; S, 24·4%). The small amount of (III) originally present appeared to remain unreduced as shown by the non-disappearance of bands at 1655 and 1570 cm.$^{-1}$, but the absence of absorption at 1690 cm.$^{-1}$ (due to unsaturated carbonyl grouping) showed that reduction of the main constituent was complete. The ultraviolet spectrum was consistent with the latter conclusion (weak absorption at 2900 Å), the relatively weak absorption at 2300 Å proving the absence of vinylic sulphide grouping C=C–S. There is very strong absorption in the 3-μ region. The compound is impure 6-methylthio*cyclo*hex-2-enol.

Synthesis of 6-*Methylthio*cyclo*hex*-2-*enone* (VIII) *and its Identification as the Main Component of* (KS).—Methyl sodium sulphide solution prepared from sodium (4·0 g.) and excess of methanethiol was added very slowly with vigorous stirring to 2 : 6-dibromo*cyclo*hexanone (46 g., m. p. 107°; Corey, *J. Amer. Chem. Soc.*, 1953, **75**, 3297) in dry methanol at room temperature. After the addition was complete, the solution was warmed to 50° for 1 hr., then concentrated under reduced pressure, the sodium bromide filtered off, and finally the solvent removed. Attempts to distil the residue led to its decomposition. The crude material was therefore debrominated by treatment with potassium hydroxide (9·0 g.) in ethanol (90 ml.), first at room temperature (3 hr.), then by warming to the b. p. The solution was cooled and filtered, and the solvent removed under reduced pressure. Fractionation of the residue gave 6-*methylthio*cyclo*hex*-2-*enone* (15 g.), b. p. 76—78°/0·1 mm., n_D^{20} 1·5608 (Found: C, 58·9; H, 7·1; S, 22·0. $C_7H_{10}OS$ requires C, 59·1; H, 7·1; S, 22·5%). The 2 : 4-*dinitrophenylhydrazone*, recrystallized from pyridine–ethanol and benzene, formed dark red needles, m. p. 234° (Found: C, 48·3; H, 4·4; N, 17·0; S, 9·7. $C_{13}H_{14}O_4N_4S$ requires C, 48·4; H, 4·4; N, 17·4; S, 10·0%). The *semicarbazone* had m. p. 234° (Found: C, 48·1; H, 6·6; N, 21·1; S, 16·1. $C_8H_{13}ON_3S$ requires C, 48·2; H, 6·6; N, 21·1; S, 16·1%).

The properties of (KS) and (VIII) are compared in Table 2.

TABLE 2.

	KS:		
	Bulk	Main component	(VIII)
n_D^{20}	1·5503	—	1·5608
$\lambda_{\text{max.}}$, $E^{1\%}_{1\,\text{cm.}}$	2850—3050 Å, 290	—	3000 Å, 299
Carbonyl absorption (cm.$^{-1}$)	1690, 1655, 1708	—	1690
2 : 4-Dinitrophenylhydrazone: m. p.	168—180°	235°	234°
2 : 4-Dinitrophenylhydrazone: $\lambda_{\text{max.}}$, $E^{1\%}_{1\,\text{cm.}}$	3700 Å, 719	3750 Å, 821	3750 Å, 829
Semicarbazone: m. p.	219—222°	236°	234°
Semicarbazone: $\lambda_{\text{max.}}$, $E^{1\%}_{1\,\text{cm.}}$	2650 Å, 815	2650 Å, 865	2650 Å, 877

Quantitative Estimation of Oxidation Products.—(A) *Sulphoxide*. This was estimated directly on the total oxidation mixture by Barnard and Hargrave's method (*Analyt. Chim. Acta*, 1951, **5**, 536), and was always within close limits, *viz.*, 23—25% of the oxygen absorbed.

(B) *Water.* This was also estimated on the total oxidation mixture by Karl Fischer's procedure, the usual rigorous precautions to exclude the intrusion of extraneous moisture being observed. The oxidized mixture was washed from the oxidation vessel into a distillation flask with methanol (2—4 ml.) followed by benzene (30—40 ml.). The water–benzene azeotrope was distilled off through a twisted gauze column with a head designed to minimize condensation, and collected in a cooled receiver. The water in the distillate was estimated by electrometric titration with the usual reagents (Fischer, *Z. angew. Chem.*, 1935, **48**, 394). Blank titrations were performed on the solvents. Control experiments with unoxidized sulphide, sulphoxide (dried by azeotropic removal of water with benzene), and a weighed amount of water gave results consistently high by 3·6 mg. after allowance for the solvent blank. Results :

O_2 absorbed (mole/mole)	0·28	0·35	0·34	0·32	0·16	0·16
H_2O (mg.) (corr.)	7·8	11·8	11·0	6·5	5·7	7·3
Absorbed O_2 found as water (wt. %)	18·7	25·6	25·8	18·0	25·1	30·7

(C) *Dimethyl disulphide.* This was estimated (*a*) by reduction to the thiol and (*b*) polarographically. (*a*) Fraction (i) of the total oxidation mixture (p. 2002) in tetrahydrofuran was dried and reduced with excess of lithium aluminium hydride in ether. Careful addition of cold ethanol and 2N-sulphuric acid gave methanethiol, which was estimated by passage into standard cupric acetate solution, the excess of cupric salt being measured iodometrically (Ellis and Barker, *Analyt. Chem.*, 1951, **23**, 1777). Sulphide (5·55 g.) containing oxygen (0·26 mole/mole) gave dimethyl disulphide (0·14 g.). (*b*) Polarographic estimation on the total oxidation mixture was impossible owing to interference by the relatively large amount of sulphoxide. A polarogram of the fraction used in (*a*) in 85% acetone-free methanol–15% water containing 0·1M-lithium chloride at a dropping-mercury cathode gave a wave of height equal to the sum of those due to dimethyl disulphide and *cyclo*hexenone. The wave height, obtained by subtraction of that due to *cyclo*hexenone [see D (*b*)], corresponded to dimethyl disulphide (0·12 g.).

Estimation of the remaining products was carried out on the appropriate fraction from the chromatographic separation described above, the *cyclo*hexenone and *cyclo*hexenol being contained in the more volatile part of the fractions (2)—(5) (p. 2002).

(D) cyclo*Hex-2-enone.* This was estimated (*a*) spectroscopically and (*b*) polarographically. (*a*) Comparison of intensity of absorption at 1688 cm.$^{-1}$ (conjugated carbonyl) with that of the pure ketone gave a content of 0·29 g., representing 10·3% of the total oxygen absorbed. (*b*) Comparison of the wave, given in 85% acetone-free methanol–15% water containing an acid buffer (HCl and NaOAc) with that of the pure ketone gave a *cyclo*hex-2-enone content of 0·28 g., representing 9·8% of the total oxygen absorbed. Polarographic estimation directly on the more volatile part of the total oxidation mixture [fraction (i), p. 2002] gave a value of 8·2% of the total oxygen absorbed.

(E) cyclo*Hex-2-enol.* Estimation of the intensity of the OH stretching frequency in the 3-μ region gave an approximate value of 0·22 g., representing 7·9% of the total oxygen absorbed.

(F) *Keto-sulphide.* Infrared and ultraviolet examination showed this fraction to have an almost identical composition with that of fraction KS, accounting for 22% of the total oxygen absorbed.

(G) *Involatile residue* (0·14 g.) not identified (Found : O, by diff., 15%), corresponding to 4·5% of the total oxygen absorbed.

Syntheses of Keto-sulphides.—(1) 2-*Methylthio*cyclo*hexanone* (IV). Crude 2-bromo*cyclo*hexanone (12·5 g.; b. p. 55—60°/0·1 mm.) (Found : Br, 43·7. Calc. for C_6H_9OBr : Br, 45·1%), prepared by Kötz's method (*Annalen*, 1908, **358**, 194), in ether (20 ml.) was added slowly with stirring to a solution of methyl sodium sulphide (from 1·64 g. of sodium) in methanol (30 ml.) at 0°. After being warmed to room temperature, the mixture was refluxed for a few minutes, and then worked up in the usual way. The required *keto-sulphide* (3 g.) had b. p. 51°/0·1 mm., n_D^{20} 1·5115 (Found : C, 57·5; H, 8·2; S, 21·8. $C_7H_{12}OS$ requires C, 58·3; H, 8·4; S, 22·2%).

(2) 3-*Methylthio*cyclo*hexanone* (V). *cyclo*Hex-2-enone (5·0 g., prepared by oxidation of *cyclo*hexene with chromic anhydride; cf. Whitmore and Pedlow, *J. Amer. Chem. Soc.*, 1941, **63**, 758), piperidine (0·5 g.), and dry benzene (20 ml.) were mixed in a Carius tube into which methanethiol (3·5 ml.) was then distilled. After being sealed, the tube was heated at 55° for 5 hr. Fractionation of the product gave 3-*methylthio*cyclo*hexanone* (V) (4·5 g.), b. p. 55°/0·1 mm., n_D^{20} 1·5172 (Found : C, 58·7; H, 8·5; S, 21·7. $C_7H_{12}OS$ requires C, 58·3; H, 8·4; S, 22·2%).

(3) 4-*Methylthio*cyclo*hex-2-enone* (VI).—1-Acetoxy-4-bromo*cyclo*hex-2-ene (65·7 g.; Ziegler

et al., loc. cit.) in ethanol (100 ml.) was added slowly to a solution of methyl sodium sulphide (from 6·9 g. of sodium) at room temperature. The mixture was refluxed for 30 min., most of the alcohol then distilled off, and 1-acetoxy-4-methylthio*cyclo*hex-2-ene (46 g.), b. p. 67°/0·1 mm., n_D^{20} 1·5375, isolated in the usual manner. Hydrolysis of this compound with sodium hydroxide in ethanol gave 4-*methylthio*cyclo*hex-2-enol* (28 g.), b. p. 65—67°/0·1 mm., n_D^{20} 1·5468 (Found: C, 58·2; H, 8·2; S, 22·1. $C_7H_{12}OS$ requires C, 58·3; H, 8·4; S, 22·2%), which on Oppenauer oxidation and careful fractionation of the product gave 4-*methylthio*cyclo*hex-2-enone* (4·0 g.), b. p. 60°/0·1 mm., n_D^{20} 1·5489 (Found: C, 59·2; H, 7·3; S, 22·6. $C_7H_{10}OS$ requires C, 59·1; H, 7·1; S, 22·5%).

Hydrogenation of this keto-sulphide over palladium–charcoal gave impure 4-methylthio*cyclo*hexanone, which formed an orange-yellow 2 : 4-*dinitrophenylhydrazone* (from light petroleum–ethanol), m. p. 145—146° (Found: C, 48·3; H, 5·2; N, 17·1. $C_{13}H_{16}O_4N_4S$ requires C, 48·2; H, 5·0; N, 17·3%).

(4) 3-*Methylthio*cyclo*hex-2-enone* (III).—Dihydroresorcinol, m. p. 98°, obtained by hydrogenation of resorcinol over Raney nickel (*Org. Synth.*, 1943, **27**, 21), was converted into 3-chloro*cyclo*hex-2-enone (b. p. 78°/14 mm., n_D^{20} 1·5204. Found: Cl, 27·2. Calc. for C_6H_7OCl: C, 55·2; H, 5·4; Cl, 27·2%) by treatment with phosphorus trichloride in chloroform (see Crossley and Haas, *J.*, 1903, **83**, 498). This chloro-compound (8·2 g.) in benzene (10 ml.) was added to a suspension of methyl sodium sulphide in benzene (obtained by saturating methanol containing sodium with methanethiol and then changing the solvent by distillation and simultaneous addition of benzene) at 0° with vigorous stirring. After 1 hr., the mixture was heated to 70—80° for 0·5 hr., cooled, and poured into water. Ether-extraction and subsequent fractionation gave 3-*methylthio*cyclo*hex-2-enone* (5·0 g.), b. p. 75°/0·1 mm., n_D^{20} 1·5902 (Found: C, 59·0; H, 7·0; S, 22·4. $C_7H_{10}OS$ requires C, 59·1; H, 7·1; S, 22·5%).

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