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J. Chem. Soc. (C), 1969

The Vanadium Pentoxide-catalysed Oxidation of Thio-compounds with **Hydrogen Peroxide**

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Sulphides have been oxidised with an anhydrous solution of hydrogen peroxide in tertiary butyl alcohol containing a catalytic amount of vanadium pentoxide to give sulphones and sulphoxides. This method was very useful for the partial oxidation of labile sulphides (e.g. a-chloro-sulphides, an a-acetoxy-sulphide, and thiiran) to sulphoxides of high purity. A reported preparation of 2-hydroxymethylthiiran and the corresponding sulphone has been shown to yield instead 3-hydroxythietan and 3-hydroxythietan 1,1-dioxide.

ALTHOUGH sulphoxides may be prepared from sulphides in a number of ways,¹ many oxidising agents are unsuitable for the reaction since they give unacceptable amounts of sulphone or side reactions take place. We report results obtained with hydrogen peroxide in tertiary butyl alcohol containing a catalytic quantity of vanadium pentoxide. This reagent, first described by Milas² as a means of hydroxylating alkenes, gives excellent results with a number of labile sulphides.

Some of the oxidations carried out with the hydrogen peroxide-tertiary butyl alcohol-vanadium pentoxide system are listed in the Table and several representative procedures are given in the Experimental section. For the oxidation of simple alkyl and aryl sulphides the technique has several advantages. Firstly, oxidation occurs at quite low temperatures and sulphoxides may be isolated from reactions run at $15-20^{\circ}$ (*i.e.* just above the freezing point of the reaction mixture); oxidation to the sulphone normally occurs at ca. 45°. Secondly, vanadium pentoxide, as well as acting as a catalyst, behaves as an indicator. In the presence of hydrogen peroxide the reaction mixture is orange whilst in the absence of peroxide, a pale yellow or green colour is observed. Thus, it is possible to perform the reaction as a titration ensuring that a large excess of oxidant is never present. Finally, the use of anhydrous tertiary butyl alcohol as solvent allows a wide range of waterinsoluble sulphides to be oxidised under homogeneous conditions. No advantage was observed when a desiccant was included in the reaction mixture. The isolation of water-soluble products from this reaction is a simple operation whereas oxidations carried out in an aqueous medium are often complicated by products having a high water solubility. For example, thiiran (VIII) may be oxidised to thiiran 1-oxide (VIIIa) by sodium metaperiodate in aqueous methanol,³ but we found that the reaction gave low nonreproducible yields of (VIIIa). One important factor was undoubtedly the difficulty of isolating the product from aqueous solution. The method described here gave a rapid preparation of thiiran oxide in a yield which was consistently 55-60%of theoretical.

The reactions of this oxidant with labile α -substituted

(a) H. S. Schultz, H. B. Freyermuth, and S. R. Buc, J. Org. Chem., 1963, 28, 1140; (b) N. J. Leonard and C. R. Johnson, J. Org. Chem., 1962, 27, 282; (c) S. Oae, Y. Ohnishi, S. Kozuka, and W. Tagaki, Bull. Chem. Soc. Japan, 1966, 39, 364.
 ^a N. A. Milas, J. Amer. Chem. Soc., 1937, 59, 2342.

sulphides were examined and compared with those of the hydrogen peroxide-aqueous methanol-sodium tungstate system described by Schultz and his co-workers.^{1a} Both systems failed to oxidise dodecylthiomethanol (XII) to the corresponding sulphoxide, didodecyl disulphide being isolated as the main product in each case. Oxid-

$$C_{12}H_{25} \cdot S \cdot CH_{2} \cdot OH \xrightarrow{[0]} (C_{12}H_{25}S \cdot)_{2}$$

$$(XII) \xrightarrow{H_{4}O_{2}-WO_{2}} C_{12}H_{25} \cdot S \cdot CH_{2}O \cdot COMe \xrightarrow{H_{3}O_{3}-V_{2}O_{3}} C_{12}H_{25} \cdot SO \cdot CH_{2}O \cdot COMe$$

$$(VII) \qquad (VIIa)$$

ation of the acetate (VII), however, with the hydrogen peroxide-vanadium pentoxide reaction was more successful and a mixture of the sulphoxide (VIIa) and didodecyl disulphide was produced; the optimum yield of sulphoxide was obtained by rapid addition of (VII) to an ice-cold solution of the oxidant. In contrast, oxidation with hydrogen peroxide-tungstate gave only didodecyl disulphide.

Two recent reports 4,5 have emphasised the difficulty of oxidising a-chloro-sulphides to sulphoxides. To overcome this, novel syntheses of α -chloro-sulphoxides have been developed which involve chlorination of sulphoxides by toluene-p-sulphonyl chloride⁴ or by nitrosyl chloride.⁵ We have found that the *a*-chlorosulphides (V) and (VI) are readily oxidised by one molar equivalent of hydrogen peroxide in the presence of vanadium pentoxide to give the a-chloro-sulphoxides (Va) and (VIa) in good yields. In contrast, the hydrogen peroxide-tungstate system was unsatisfactory for the oxidation of (V) since the reaction mixture became strongly acid and oxidation would not proceed.

The hydrogen peroxide-vanadium pentoxide reagent was least successful when applied to the oxidation of disulphides. With 2 moles of oxidant, thiosulphonates [e.g. (XIb)] were obtained, but only in moderate yields. With 1 mole of oxidant, mixtures of thiosulphinates and thiosulphonates were obtained, with the latter predominating; very small amounts of thiosulphinates could be obtained only after careful column chromatography.

⁸ G. E. Hartzell and J. N. Paige, J. Amer. Chem. Soc., 1966, 88, 2616.

⁴ M. Hojo and Z. Yoshida, J. Amer. Chem. Soc., 1968, 90, 4496. ⁵ R. N. Loeppky and D. C. K. Chang, Tetrahedron Letters, 1968, 5415.

During the course of this work an attempt was made to prepare 2-hydroxymethylthiiran 1-oxide (IXa) from the labile thiiran (IX). Two methods for the preparation of (IX) are known, one ⁶ involving pyrolysis of the ester (XIII) and the other ⁷ involving treatment of 2-chloromethylthiiran (XV) first with potassium acetate in acetic acid and then with alkali. However, the products oxide (IXa), which was characterised as the crystalline N-phenylcarbamate (XIV). Similarly, the thietanol (XVI) was oxidised by the reagent to a crystalline sulphoxide or a crystalline sulphone depending on the amount of oxidant used; the latter was also prepared by Etlis⁹ but was incorrectly formulated as 2-hydroxy-methylthiiran 1,1-dioxide. No attempt was made to





^a With 1 mol. of oxidant. ^b With 2 mol. of oxidant. ^o Yields quoted are not necessarily optimum values and refer to recrystallised products or products purified by distillation to >95% (by g.l.c.). ^d In agreement with literature values. ^e Literature m.p.'s for this compound are variable. The present value was obtained from a distilled sample which had been allowed to solidify, and is in agreement with the literature value (F. G. Bordwell and W. T. Brannen, *J. Amer. Chem. Soc.*, 1964, **86**, 4645). ^f Yield of crude product. ^f Decomposes during distillation.

of the two reactions were found to have different i.r. spectra and their crystalline N-phenylcarbamates had different melting points. This difference is explained by the work of Doyle and his co-workers,⁸ which indicates that nucleophilic displacement of the halogen in 2-chloromethyl thiiran is normally accompanied by ring expansion to give, in the present case, 3-hydroxythietan (XVI).

In the present work, the sulphide (XVI) was prepared by treatment of the thiiran (XV) with aqueous sodium carbonate⁸ and was found to be identical with the product described and incorrectly formulated as (IX) by Etlis and Razuvaev.⁷

Oxidation of 2-hydroxymethylthiiran (IX) with hydrogen peroxide-vanadium pentoxide gave the sulph-

⁶ D. D. Reynolds, D. L. Fields, and D. L. Johnson, J. Org. Chem., 1961, 26, 5130.
⁷ V. S. Etlis and G. A. Razuvaev, Doklady Akad. Nauk

⁷ V. S. Etlis and G. A. Razuvaev, *Doklady Akad. Nauk* S.S.S.R., 1962, **143**, 633 (*Chem. Abs.*, 1962, **57**, 4616).

determine the stereochemistry of either the crystalline N-phenylcarbamate (XIV) or 3-hydroxythietan 1-oxide.

EXPERIMENTAL

Kieselgel G (Merck) was used for t.l.c. and plates were developed with light petroleum-acetone (4:1); chromogenesis was with iodine. Products were chromatographically homogeneous after recrystallisation. G.l.c. was performed at 125—175° on a Pye Argon Chromatograph with a column of Apiezon L on Kieselguhr. Volatile products were >95% pure after distillation.

Hydrogen peroxide-tertiary butyl alcohol solutions were prepared according to the method of Milas and Sussman 10 and always contained *ca*. 6% by weight of peroxide. The

⁸ E. P. Adams, K. N. Ayad, F. P. Doyle, D. O. Holland, W. H. Hunter, J. H. C. Nayler, and A. Queen, *J. Chem. Soc.*, 1960, 2665.
 ⁹ V. S. Etlis, *Zhur. org. Khim.*, 1965, 1, 730 (*Chem. Abs.*, 1965, 63, 5621).

¹⁰ N. A. Milas and S. Sussman, J. Amer. Chem. Soc., 1936, **58**, 1302.

solutions did not deteriorate during refrigeration for several weeks.

Dibenzyl Sulphoxide (Ia) .--- Vanadium pentoxide (10 mg.) was dissolved in the hydrogen peroxide-tertiary butyl alcohol reagent (5.5 ml., 6%) and this solution, after dilution with tertiary butyl alcohol (15 ml.), was added dropwise during 30 min. to a cold (20°), stirred solution of dibenzyl sulphide (2.1 g.) in tertiary butyl alcohol (50 ml.). The stirring was continued until the solution was pale yellow and then tertiary butyl alcohol was removed on a rotary evaporator (30°). The residue was dissolved in chloroform (100 ml.) which was washed several times with water to remove inorganic material, dried (Na₂SO₄), and evaporated to give dibenzyl sulphoxide (1.4 g., 62%), m.p. 135-136° (from ethanol).

Chloromethyl Dodecyl Sulphoxide (Va).-Vanadium pentoxide (0.05 g.) was dissolved in hydrogen peroxide-tertiary butyl alcohol reagent (28.5 ml., 5.9%) and the solution was added in portions (2 ml.) to a solution of chloromethyl dodecyl sulphide 11 (12.2 g.) in tertiary butyl alcohol (100 ml.); a fresh addition was made when the red colour produced by the previous addition had faded. The mixture was stirred for 30 min. after all the reagent had been added and then tertiary butyl alcohol was removed (rotary evaporator); chloroform (100 ml.) was added and the solution was washed with water, dried (Na₂SO₄), and evaporated to give chloromethyl dodecyl sulphoxide (9 g.), m.p. 63—64° (from light petroleum).

Dodecylthiomethanol (XII).-Dodecanethiol (20.2 g.), paraformaldehyde (3.0 g.), and a trace of sodium methoxide were heated under nitrogen at 110° for 1 hr.; the solution was cooled and dodecylthiomethanol separated out. Recrystallised material (14 g.) had m.p. 35° (from acetone) (Found: C, 67.15; H, 11.8. C₁₈H₂₈OS requires C, 67.15; H, 12.15%)

Dodecylsulphinylmethyl Acetate (VIIa).-The alcohol (XII) (13.1 g.) was acetylated by the method of Böhme and Teltz¹² and the product was chromatographed on silica (Hopkin and Williams). Elution with chloroform-light petroleum (1:1) gave dodecylthiomethyl acetate (12 g.).

This material was added dropwise during 2 min. to a well stirred solution of vanadium pentoxide (0.04 g.) in hydrogen peroxide-tertiary butyl alcohol reagent (22.8 ml., 6%) at 0°. When the red colour had disappeared the solution was evaporated to dryness; the residue, taken up in chloroform was then decolourised with charcoal and the solution was evaporated to dryness. The residue was triturated with light petroleum (b.p. 60-80°) to give dodecylthiomethyl acetate (6.2 g.), m.p. 58-60° (from light petroleum).

Thiiran 1-oxide (VIIIa).-To a stirred solution of thiiran (18 g.) in tertiary butyl alcohol (180 ml.) at 20° was added, portionwise, the hydrogen peroxide-tertiary butyl alcohol

¹¹ P. Robson, P. R. H. Speakman, and D. G. Stewart, J. Chem. Soc. (C), 1968, 2180.
 ¹² H. Böhme and H. P. Teltz, Annalen, 1959, 620, 1.

reagent (170 ml., 6%) containing vanadium pentoxide (0.35 g.). When addition was complete the mixture was stirred for a further 30 min. and then tertiary butyl alcohol was removed under reduced pressure. The residue was dissolved in chloroform (100 ml.) and the resulting solution, after decolourisation with charcoal, was distilled. The fraction (13.4 g.) boiling between 35-38°/0.5 mm. consisted of pure thiiran 1-oxide.

S-Methyl methanethiosulphonate (Xb).-Dimethyl disulphide (5 g.) in tertiary butyl alcohol (30 ml.) was treated during 30 min. with hydrogen peroxide-tertiary butyl alcohol (31.1 ml., 5.82%) containing vanadium pentoxide (95 mg.). A second portion of oxidant (31 ml.) was then added rapidly and stirring was continued until the solution was yellow-green. Solvent was removed under reduced pressure and a chloroform solution of the residue was washed with water, dried, and distilled to give the thiosulphonate (2.9 g.), b.p. 116°/15 mm.

2-Hydroxymethylthiiran 1-Oxide (IXa).-Hydroxymethylthiiran (IX) was prepared by the method of Reynolds and his co-workers.⁶ A crystalline N-phenylcarbamate was prepared by warming the alcohol with phenyl isocyanate (1 mol.) at 70° for 20 min.; it had m.p. 96° (ether-light petroleum) (Found: C, 57.45; H, 5.35. C10H11NO2S requires C, 57.4; H, 5.25%). 2-Hydroxymethylthiiran (5.4 g.) was then oxidised with hydrogen peroxide-tertiary butyl alcohol (equimolar proportion) in the presence of vanadium pentoxide. The product (3.8 g.) could not be crystallised. An N-phenylcarbamate (XIV) was prepared by stirring the hydroxymethylthiiran 1-oxide (2.7 g.), phenyl isocyanate (5.35 g.), and dichloromethane (2 ml.) at room temperature for 18 hr. The derivative (1.2 g.) had m.p. 130° (from dichloromethane-light petroleum) (Found: C, 53.25; H, 5.05. C₁₀H₁₁NO₃S requires C, 53.35; H, 4.9%).

3-Hydroxythietan (XVI).-(a) Chloromethylthiiran was treated with sodium carbonate by the literature method.⁸

(b) Chloromethylthiiran was treated with potassium acetate in acetic acid and the acetate was hydrolysed in alkali.7

The two products had identical i.r. spectra and both gave an N-phenylcarbamate, m.p. 118° (carbon tetrachloride), on warming with phenyl isocyanate at 70° for 10 min. (Found: C, 57.2: H, 5.5. C₁₀H₁₁NO₂S requires C, 57.4; H, 5.25%; a mixture of these two derivatives also melted at 118°.

Oxidation of 3-hydroxythietan with an equimolar amount of hydrogen peroxide in tertiary butyl alcohol in the presence of vanadium pentoxide gave a sulphoxide, m.p. 64-67° (tetrahydrofuran) (Found: C, $34\cdot1$; H, $5\cdot75$. $C_3H_6O_2S$ requires C, $34\cdot0$; H, $5\cdot65\%$). With 2 mol. of oxidant, the sulphone, m.p. 99-101° (lit., 7 99-100°) was obtained (Found: C, 29.5; H, 4.75. Calc. for C₃H₆O₃S: C, 29.5; H, **4·8%**).

[9/836 Received, May 19th, 1969]