

Photolysis of Sulphur-containing Nitrones. Support for a Methylene-oxaziridine Radical Intermediate and Formation of New Heterocycles

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The products of photolysis of *N*-diphenylmethylene-1-ethylthioethyl-, -thiolan-2-yl-, -thiacyclohexan-2-yl-, and -1,4-oxathian-3-yl-amine *N*-oxides are described. These products are interpreted as arising from alkylidene-(diphenylmethylene)amine *N*-oxyl radicals of a type previously identified. The nitrones with cyclic *N*-substituents form oxaziridines and new ring-expanded heterocycles, *e.g.* 5,6-dihydro-4*H*-1,2-thiazine from the thiolanyl nitrone. This observation supports the intermediacy of methyleneoxaziridine radicals.

THE nitrone (1) reacts photochemically to form benzophenone and dimethyl disulphide. Product, n.m.r., and e.s.r. evidence has been reported, and the reaction sequence shown in Scheme 1 has been proposed.¹ The novel radical (2) was identified by its e.s.r. spectrum and those of deuteriated derivatives. The intermediate thioimine (4) was identified only from its n.m.r. spectrum and its decomposition product. The intermediate oxaziridine radical (3) was suggested to explain the formation of benzophenone from the radical (2). We now report other photolyses which fully support this reaction scheme.

The ethylthioethyl nitrone (5)² was irradiated in deuteriochloroform, hexadeuteriobenzene, or chlorobenzene at room temperature, and the reactions were followed by n.m.r. spectroscopy. As the SEt and SMe signals

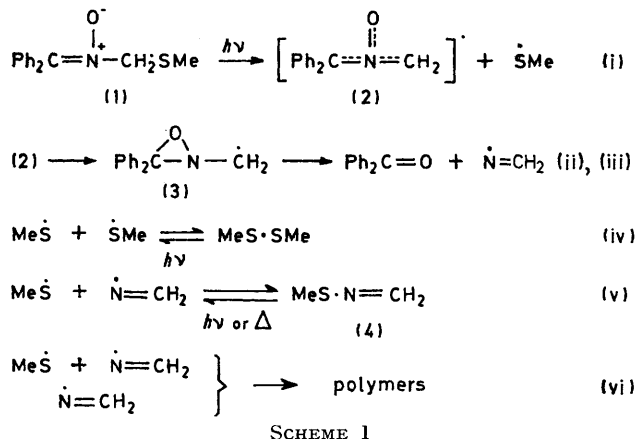
decreased in intensity, benzophenone signals appeared. Also, two new Et signals and two methyl doublets corresponding to CHMe groups appeared, with loss of the methine proton signal from the aliphatic region. Thus far the behaviour was exactly comparable with that of the nitrone (1). The new signals belonged to the two isomers of the imine (6). The overlapping signals of reactant and products could be separated by using the shift reagent Eu(fod)₃; the imine isomers were present in a 2:1 ratio, but which predominated is not known.

Continued irradiation led to loss of the intermediates (6), and formation of diethyl disulphide and a slight

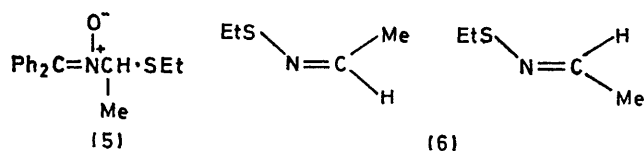
¹ J. C. Evans, E. D. Owen, and D. A. Wilson, *J.C.S. Perkin II*, 1974, 557.

² W. M. Leyshon and D. A. Wilson, preceding paper.

flocculent precipitate, again paralleling the reactions of the nitron (1). One additional sharp singlet was observed, appearing with the disulphide. Comparison of the chemical shift in all three solvents, g.l.c. comparison, and i.r. absorption at $2\ 250\text{ cm}^{-1}$ showed this product to



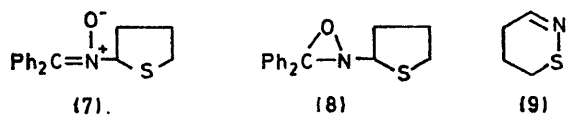
be methyl cyanide. This could have arisen from hydrogen abstraction from the intermediate radical $\text{MeCH}=\dot{\text{N}}$ (cf. Scheme 1), or by elimination of ethanethiol from the imine (6), the thiol then being oxidised to diethyl disulphide by air. A re-examination of the photolysis of the



nitron (1) did not reveal any evidence of formation of HCN.

The nitron (7) ² was irradiated in deuteriochloroform and in hexadeuteriobenzene. N.m.r. spectroscopy clearly showed that benzophenone was being formed, and as the ring NCHS proton signal of the nitron disappeared, a new signal of almost identical shape appeared upfield of it by *ca.* 1 p.p.m. G.l.c. analysis of the solution showed the presence of benzophenone and a more volatile product. Removal of the solvent and crystallisation of the residue gave a solid product. The three products were formed in approximately equal amounts.

Analysis of the solid product indicated it to be an isomer of the starting nitron, and it had a u.v. spectrum consistent with two non-conjugated phenyl rings. It liberated iodine from potassium iodide in propan-2-ol-acetic acid, and was the oxaziridine (8), a structure with



which the n.m.r. spectrum was consistent in showing, in hexadeuteriobenzene, two non-equivalent sets of *ortho*-

³ W. M. Leyshon and D. A. Wilson, following paper.

⁴ D. M. Green, A. G. Long, P. J. May, and A. F. Turner, *J. Chem. Soc.*, 1964, 766.

aromatic protons.² This oxaziridine was unaffected by prolonged irradiation, although it was converted thermally into benzophenone and the same volatile product. However, a detailed kinetic investigation of this thermal reaction³ showed that, under conditions of photolysis, benzophenone and the volatile product could not have been formed from this oxaziridine. Nor did attempted g.l.c. analysis of the oxaziridine (8) give the other two products.

The volatile product was isolated from larger-scale reactions by distillation (thus also converting the oxaziridine into this product) and was shown to be the new heterocycle 5,6-dihydro-4*H*-1,2-thiazine (9). Combined g.l.c.-mass spectrometry on the photolysis solution gave $\text{C}_4\text{H}_7\text{NS}^+$ as the molecular ion, confirmed by accurate mass measurement. The spectroscopic properties (see Experimental section) of this compound led clearly to the structure (9) rather than to any alternatives. For example, the u.v. absorption⁴ and n.m.r. chemical shifts⁵ for the 5,6-dihydro-4*H*-1,3-thiazine system are not those observed for compound (9). However, a chemical confirmation was considered necessary, and one attempt at this gave results interesting in themselves.

Reaction of the compounds (10) ² with mercury(II) chloride in aqueous methyl cyanide⁶ gave 4-oxobutylthiomercury(II) chloride (11), by the reaction shown in Scheme 2. The structure of compound (11) was demonstrated by its n.m.r. spectrum and by mass spectrometry. The presence of three elements with two or more significant isotopes meant that formulae could be assigned to groups of mass spectral peaks by comparison between calculated and observed intensity patterns. The fragmentation pattern (see Experimental section) confirmed the structure but was more extensive than that reported for some alkylmercury(II) chlorides.⁷ The major ion group, HgCl_2^+ , seemed to be a genuine fragment and not impurity, as it remained the base group even after recrystallisation of the compound. The reduced thiazine (9), with mercury(II) chloride, similarly gave a mercury derivative. It was not, however, identical with compound (11), nor could it be proved to be either the corresponding oxime or the cyanide. Similar reaction of the nitron (14) gave the homologue of the derivative (11).

Successful confirmation of structure (9) was achieved by treatment of the volatile product with Raney nickel in ethanol and acetic anhydride, to give *N*-butylacetamide (n.m.r. and g.l.c.-mass spectrometric comparison).

These products of photolysis can be accounted for in terms of Scheme 1, bearing in mind that initial homolysis of the C-S bond would form a diradical rather than two separate radicals. Scheme 3 shows this, and all the products can be derived from the postulated oxaziridine radical (13) and its precursor alkylidene(diphenylmethyl)amine *N*-oxyl radical (12).

The reduced thiazine (9) is the cyclic analogue of the

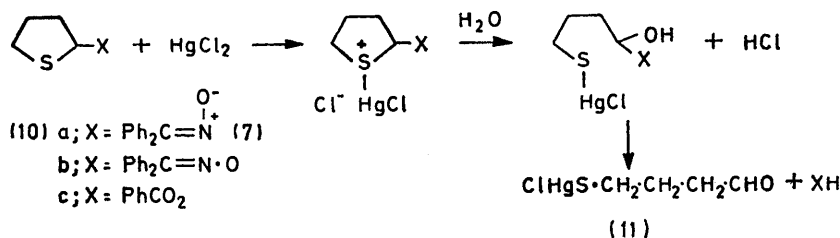
⁵ E. Cherbuliez, B. Baehler, O. Espejo, H. Jindra, B. Willhalm, and J. Rabinowitz, *Helv. Chim. Acta*, 1967, **50**, 331.

⁶ E. J. Corey and D. Crouse, *J. Org. Chem.*, 1968, **33**, 298.

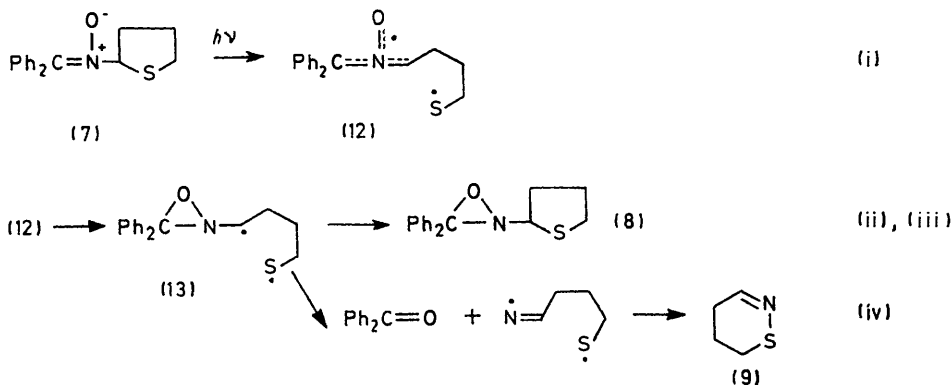
⁷ W. F. Bryant and T. H. Kinstle, *J. Organometallic Chem.*, 1970, **24**, 573.

imines (4) and (6). It is also an aliphatic *S*-alkyl thio-oxime, the first to our knowledge isolated. Although photolysis of nitrones often affords oxaziridines,⁸ we

product formation in photolysis. The mass spectra of the new thio-oxime derivatives (9), (18), and (19) are given in Table 1.



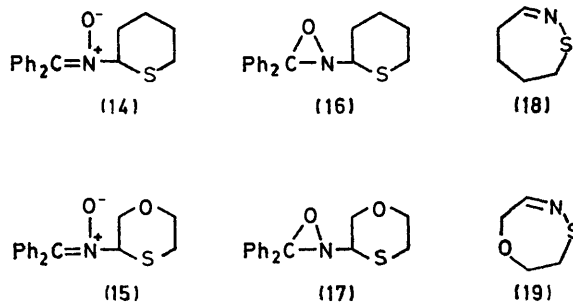
SCHEME 2



SCHEME 3

believe this present case to be distinctive in proceeding by a radical pathway. This mechanism accounts for the difference between the cyclic nitrones (7), (14), and (15) and the acyclic nitrones (1) and (5). The quantum yields for loss of nitron, whether cyclic or acyclic, are the same.[†]

The nitrones² (14) and (15) were similarly photolysed, and gave approximately equal mixtures of benzophenone, oxaziridines (16) and (17), and volatile products. Although not fully characterized there is little doubt that these latter were 4,5,6,7-tetrahydro-1,2-thiazepine (18) and 2,3-dihydro-7*H*-1,4,5-oxathiazepine (19). The oxaziridines (16) and (17) reacted on heating to form benzophenone and the heterocycles (18) and (19), but again a



kinetic study³ of these thermal reactions showed them to be much slower under the photolytic conditions than

[†] Quantum yields, in benzene solutions, for loss of nitrones (1), (5), (7), (14), and (15) are 0.30, 0.24, 0.28, 0.29, and 0.31 respectively (J. R. M. Dales, personal communication).

EXPERIMENTAL

For irradiation experiments an Osram M.E.D. medium-pressure lamp was used with solutions contained in n.m.r.

TABLE I

Mass spectra of 5,6-dihydro-4*H*-1,2-thiazine (9), 4,5,6,7-tetrahydro-1,2-thiazepine (18), and 2,3-dihydro-7*H*-1,4,5-oxathiazepine (19)

Fragment	Relative intensity			Fragment	Relative intensity		
	(9)	(18)	(19) ^a		(9)	(18)	(19) ^a
<i>M</i> + 2	5	5	4	<i>m/e</i> 60 ^c	13	56	100
<i>M</i> ⁺	100	100	76		59	19	25
<i>M</i> - 15	5	3	0		55	15	25
<i>M</i> - (HCN)	11	6	3		54	0	15
<i>M</i> - (CH ₂ N)	86 ^b	35	66		47	56	30
<i>M</i> - (C ₂ H ₄ N)	19	30	0		46	47	24
<i>m/e</i> 61	1	5	32		45	0	34

^a No fragment that contains O, N, or S only has more than two C atoms. ^b C₂H₅S by high resolution (*m/e* 73.0116). ^c CH₃=CHSH⁺ (ref. 9).

tubes. For preparative-scale reactions a Hanovia medium-pressure photochemical reactor with water cooling was employed. Mass spectra were measured with a Varian CH 5D instrument (direct insertion for the solids and combined g.l.c.-mass spectrometry for the volatile compounds).

Photolysis of the Nitron (5).—The reaction was followed by n.m.r. with the results shown in Table 2. N.m.r. data (τ values) are given in Table 3.

Photolysis of the Nitron (7).—The nitron (2 g) in dry benzene or methylene chloride (75 ml) was irradiated for

⁸ K. Koyano, H. Suzuki, Y. Mori, and I. Tanaka, *Bull. Chem. Soc. Japan*, 1970, **43**, 3582, and references therein.

⁹ J. H. Beynon, R. Saunders, and A. E. Williams, 'Mass Spectra of Organic Molecules,' Elsevier, Amsterdam, 1968.

3 h. Solvent was removed at room temperature and the residue was quickly crystallised from carbon tetrachloride to give 3,3-diphenyl-2-(thiolan-2-yl)oxaziridine (8) (500 mg, 25%), m.p. 126—127°, λ_{\max} (Et₂O) 236, 250sh, 259, 265, and 271 nm (ϵ ca. 500), ν_{\max} (CCl₄) 3 050, 2 950, 2 850, 1 500,

TABLE 2

Time (h)	Nitrone (5) (%) ^{a,b}	Ph ₂ C=O (%) ^a	Imine (6) (%) ^b	Et ₂ S ₂ (%) ^b	MeCN (%) ^b
(a) In CDCl ₃					
0	100	0	0	0	0
0.75	70	30	30	0	0
2.5	0	ca. 95	75	25	?
3.5	0	ca. 95	45	30	25
20	0	ca. 100	0	60	40
(b) In C ₆ D ₆					
0	100	0	0	0	0
1.5	70	30	30	0	0
3.5	20	80	40	20	Trace
6	0	ca. 100	0	50	20

^a As fraction of aromatic absorption. ^b As fraction of molecules giving CH₃ absorptions. Where this does not add to 100%, some unassigned CH₃ absorptions were present.

1 450, 1 410, 1 325, and 1 260 cm⁻¹, τ (CDCl₃) 8.4—7.6 (4 H, m), 7.2 (1 H, m), 6.9 (1 H, m), 6.10 (1 H, m), and 2.6 (10 H, m), τ (C₆D₆) 8.6—7.8 (4 H, m), 7.5 (1 H, m), 7.2 (1 H, m), 6.00 (1 H, m), 2.9 (6 H, m), 2.7 (2 H, m), and 2.45 (2 H,

7 H, m), 6.90 (1 H, m), 6.65 (t, 2'-H), 2.9 (6 H, m), 2.6 (2 H, m), and 2.4 (2 H, m), m/e 297 (M^+ , 1%) and 77 (C₆H₅⁺, 100%) (Found: C, 72.3; H, 6.3; N, 4.6. C₁₈H₁₉NOS requires C, 72.7; H, 6.4; N, 4.7%).

Work-up by distillation as above gave 4,5,6,7-tetrahydro-1,2-thiazepine (18) as an oil, τ (CDCl₃) 8.6—7.85 (4 H, m), 7.55 (2 H, m), 7.20 (m, SCH₂), and 2.2 (t, CH=N).

Photolysis of the Nitrone (15).—The oxathianyl nitrone (1 g) was irradiated as above; crystallisation of the residue from ether-chloroform gave 2-(1,4-oxathian-3-yl)-3,3-diphenyloxaziridine (17) (300 mg, 30%), m.p. 182—183°, ν_{\max} (CCl₄) 1 500, 1 450, 1 315, 1 295, and 1 100 cm⁻¹, τ (CDCl₃) 7.6 (1 H, m), 6.9 (1 H, m), 6.6—5.7 (5 H, m), and 2.8 (10 H, m), m/e (electron impact) 103 (C₄H₇SO⁺, 100%), (field desorption) 299 (M^+ , 100%) (Found: C, 68.3; H, 5.7; N, 4.7. C₁₇H₁₇NO₂S requires C, 68.4; H, 5.7; N, 4.7%).

When heated, this product gave benzophenone and a volatile product, presumed to be 2,3-dihydro-7H-1,4,5-oxathiazepine (19) (see Table 1 for mass spectrum).

4-Oxobutylthiomercury(II) Chloride (11).—To a solution of the nitrone (7) (1 g) in water-methyl cyanide (1:3; 35 ml) was added mercury(II) chloride (3 g) in the same solvent (10 ml). The mixture was stirred at room temperature for 2 h. The precipitate was collected, thoroughly washed with water, dried, and crystallised from dimethyl sulphoxide to give the mercury derivative (11) (1 g, 80%), m.p. 175—180°

TABLE 3

In CDCl ₃	Nitrone (5)		Imine (6) ^a		Et ₂ S ₂	CH ₃ CN
	CH ₃ ·CH ₂	CH ₃ ·CH	CH ₂ ·CH ₂	CH ₃		
	8.86t, 7.32q	8.25d, 4.62q	8.60t, 6.92q (8.61t, 6.93q)	8.05d (8.00d)	8.70t, 7.29q	8.01s
In C ₆ D ₆	9.00t, 7.30m	8.30d, 4.73q	8.68t, 7.30q (8.71t, 7.30q)	8.42d (8.36d)	8.90t, 7.60q	9.23s

^a Minor isomer in parentheses.

m), m/e (electron impact) 87 (C₄H₇S⁺ 100%), (field ionisation) 283 (M^+ , 58%) and 182 (Ph₂C=O⁺, 100%) (Found: C, 72.0; H, 6.0; N, 5.0. C₁₇H₁₇NOS requires C, 72.1; H, 6.0; N, 4.9%).

This experiment was repeated, but after removal of the solvent the residue was heated at 100 °C in a stream of nitrogen, and 5,6-dihydro-4H-1,2-thiazine (9) was collected as an oil, λ_{\max} 232 (ϵ 2 300) and 269 nm (3 600), ν_{\max} (film) 3 050, 2 950, 2 905, 2 880, 2 840, 1 605, 1 455, 1 435, 1 425, 1 345, 1 270, 1 245, 1 175, 955, 870, 840, 795, and 670 cm⁻¹ (no NH stretching absorption), τ (CDCl₃) 7.80 (m, CH₂CH₂), 7.00 (ca. t, SCH₂), and 2.15 (t, J 2 Hz, N=CH), τ (C₆D₆) 8.4 (4 H, m), 7.5 (2 H, m), and 2.40 (t, J 2 Hz, N=CH), τ [CDCl₃ + Eu(fod)₃ (0.2 mol. equiv.)] 7.56 (m, 5-H₂), 7.20 (m, 4-H₂), 6.62 (m, 6-H₂), and 1.10 (t, 3-H) (Found: M^+ , 101.0300. C₄H₇NS requires M , 101.0300).

The reduced thiazine (100 mg) in ethanol (1 ml) was added to Raney nickel (1 g). Acetic anhydride (1.5 ml) was added and the mixture was heated under reflux for 1 h. Filtration and evaporation gave crude *N*-butylacetamide, τ (CDCl₃) 9.10 (ca. t, CH₃), 8.56 (m, CH₂·CH₂), 8.03 (s, CH₃·CO), and 6.80 (m, CH₂N), m/e 115 (M^+ , 14%) and 43 (CH₃CO⁺, 100%), identical with an authentic sample.

Photolysis of the Nitrone (14).—The thiacyclohexyl nitrone (2 g) was irradiated as described above, and the residue, when crystallised from chloroform-light petroleum (b.p. 60—80°), gave 3,3-diphenyl-2-(thiacyclohexan-2-yl)oxaziridine (16) (600 mg, 30%), m.p. 134—136°, τ (CDCl₃) 8.7—7.4 (8 H, m), 6.8 (m, 2'-H), and 2.6 (10 H, m), τ (C₆D₆) 9.0—7.7

(decomp.), ν_{\max} (mull) 2 740, 1 730, and 1 715 cm⁻¹, τ ([²H₅]pyridine) 7.95 (2 H, m), 7.40 (t, CH₂·CHO), 6.96 (t, SCH₂), and 0.25 (t, J 1.4 Hz, CHO). The mass spectrum is quoted with the ion intensities for each isotopic cluster added together and normalised to the base cluster, and the mass given is that of the most abundant isotopic fragment ion: 340 (M^+ , 14%), 296 (ClHgSC₂H₃⁺, 41), 283 (ClHgSCH₂⁺, 31), 272 (HgCl₂⁺, 100), 235 (HgSH⁺, 65), 202 (Hg⁺, 74), 103 (SCH₂·CH₂·CH₂·CHO⁺, 90), 94 (ClSC₂H₃⁺, 15), 85 (SC₄H₅⁺, 10), 75 (SC₃H₇⁺, 18), 71 (CH₂·CH₂·CH₂·CO⁺, 48), 60 (SC₂H₄⁺, 21), 59 (SC₂H₃⁺, 15), 57 (CH₂·CH₂·CHO⁺, 24), 47 (HSC₂⁺, 24), 46 (SCH₂⁺, 21), and 45 (HCS⁺, 35) (Found: C, 14.1; H, 2.0. C₄H₇ClHgOS requires C, 14.2; H, 2.3%). Extraction of the filtrate gave benzophenone oxime. The same products were obtained from benzophenone *O*-thiolan-2-yloxime (10b). 2-Benzoyloxythiolan (10c) similarly gave the mercury derivative.

5-Oxopentylthiomercury(II) Chloride.—The nitrone (14), when treated with mercury(II) chloride as above, gave the mercury derivative m.p. 165° (decomp.) from dimethyl sulphoxide, ν_{\max} (mull) 2 720, 1 720, and 1 710 cm⁻¹, τ ([²H₅]pyridine) 8.23 (4 H, m), 7.69 (t, CH₂·CHO), 7.00 (t, SCH₂), and 0.03 (t, CHO), m/e 354 (M^+ , 1%), 272 (HgCl₂⁺, 87%), and 117 (SCH₂·CH₂·CH₂·CHO⁺, 100%).

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