

Photolytic Formation of Nitrile Sulphides from Five-membered Heterocyclic Compounds

By Arne Holm * and Nils Henrik Toubro, Chemical Laboratory II, University of Copenhagen, The H. C. Ørsted Institute, Universitetsparken 5, DK-2100 Copenhagen Ø, Denmark

A number of phenyl-substituted five-membered heterocyclic compounds containing C, N, and S atoms have been examined for the possibility of their photolytic formation of benzonitrile sulphide. The latter is thermally unstable, giving rise to benzonitrile and sulphur, but in neat dimethyl acetylenedicarboxylate the cycloaddition product (20) is formed: this is considered to be strong evidence for photolytic formation of benzonitrile sulphide. The yield of (20) obtained from compounds (1)–(12) was 5–21%, depending on the individual heterocyclic compound. Ready photolytic fragmentation of the heterocyclic compounds with formation of nitrile sulphide apparently takes place when extrusion of a small inorganic fragment (CO, CO₂, COS, CS₂, or N₂, etc.) is possible, a process which appears to be general for this type of compound.

BENZONITRILE sulphide is formed photolytically from the thiaziazole (1), the oxathiazolone (4), and the mesoionic oxathiazole (9).^{1a} Rapid decomposition to benzonitrile takes place at room temperature, but the sulphide may be trapped as a cycloaddition product by carrying out the photolysis in neat dimethyl acetylenedicarboxylate.^{1a,2} The reaction is illustrated in Scheme 1. Compound (20) was isolated in 9, 22, and 9% yield from irradiated (1),^{1a} (4),^{1a} and (9)² respectively. Compound (21) was not detected.^{1a}

We have studied a number of other C, N, and S containing heterocyclic compounds to investigate whether nitrile sulphide formation is a consequence of specific structural or mechanistic features associated with the three compounds mentioned or is a more general type of reaction.

¹ (a) A. Holm, N. Harrit, and N. H. Toubro, *J. Amer. Chem. Soc.*, 1975, **97**, 6197; (b) *ibid.*, *Tetrahedron*, 1976, **32**, 2559.

² H. Gotthardt, *Chem. Ber.*, 1972, **105**, 188.

RESULTS AND DISCUSSION

Compounds (1)–(14), (16), and (18) were irradiated at room temperature in methylene chloride (10⁻³–10⁻⁴M) with light corresponding to the longwave length absorptions. The reactions were monitored by electronic absorption spectroscopy. Under these conditions compounds (1)–(13) and (18) undergo photoconversion in less than 1 h, while the remaining compounds (14)–(17) either undergo photolytic conversion much more slowly or not at all. Compound (15) can, in fact, be used as protection against irradiation.³ Compound (17) is converted slowly giving rise into benzonitrile in 12% yield,⁴ and (14) and (16) were almost unchanged under the conditions mentioned. Compounds (20) and (21) are likewise photostable under the conditions used, an observation which is the basis for the successful

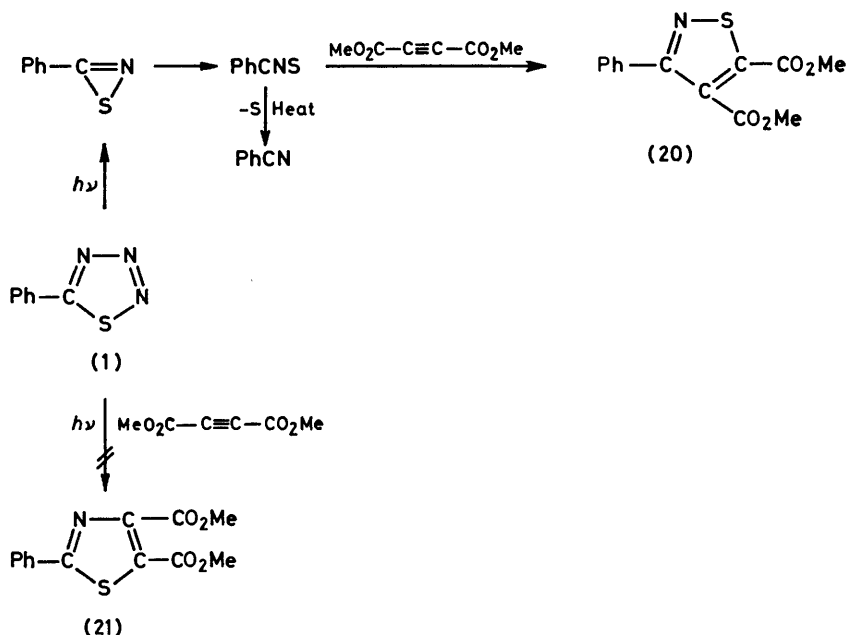
³ Swiss patent 347.977 (*Chem. Abs.*, 1961, **55**, P22,343d).

⁴ T. S. Cantrell and W. S. Haller, *Chem. Comm.*, 1968, 977.

trapping of benzonitrile sulphide. Compound (19) eliminates nitrogen rather than benzonitrile.⁵

In a further series of experiments with slightly more concentrated solutions of compounds (1)—(12) (10^{-2}M)

compounds (13) and (18) were found not to give benzonitrile in significant amounts and their reactions were, therefore, not investigated further. Small amounts of phenyl isothiocyanate are formed from several compounds (as

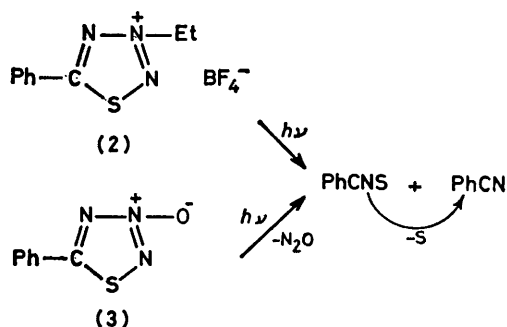


SCHEME 1

the amounts of benzonitrile and phenyl isothiocyanate formed were estimated by g.l.c. Yields and conditions are given in the Table. Compounds (1)—(12) may be divided in two groups according to the amount of benzonitrile formed. The first group contains thiazole and its derivatives* (Schemes 1 and 2), together with other heterocycles (Scheme 3) which all give rise to benzonitrile in high yield. The second group (Scheme 4) embraces those compounds giving rise to relatively

seen from the Table), but it does not seem possible to predict the structural features necessary for its formation. The yield of benzonitrile is in some cases oxygen-dependent (see Table) as discussed elsewhere for com-

Yields of benzonitrile, phenyl isothiocyanate, and the cycloaddition product (20) formed upon irradiation of compounds (1)—(12) in methylene chloride and dimethyl acetylenedicarboxylate respectively under an atmosphere of argon. Yields with air-saturated solutions are given in parentheses



SCHEME 2

small amounts of benzonitrile; they are characterized by fragmentation with the formation of heterocumulenes and other products (*vide infra*). The photolabile com-

* The photochemical reaction (3) is the subject of a closer investigation.⁶

⁵ W. Kirmse and L. Horner, *Annalen*, 1958, **614**, 4; K.-P. Zeller, H. Meier, and E. Müller, *ibid.*, 1972, **766**, 32.

Compound	Benzonitrile	Phenyl isothiocyanate	Compound (20)
(1)	65—76 ¹	4.8—7.6 ¹	(9) ^a
(2)	57	0	8
(3)	66 (65)	0 (3)	21
(4)	26—28 (58)	0	19 ^a
(5)	11 (90)	0 (0)	11
(6)	100 (96)	0 (0)	8
(7)	92 (80)	2 (4)	10
(8)	86 (87)	2 (4)	9
(9)	77 ¹ (21 ¹)	0 (0)	8 ^a
(10)	(21)	(0)	7
(11)	(14)	(0)	12
(12)	(6)	(6)	5

^a The yields obtained here with *ca.* 10^{-2}M solutions of the heterocyclic compounds in neat dimethyl acetylenedicarboxylate (see Experimental section) are almost identical with those obtained previously (preparative t.l.c.) with saturated solutions [compounds (1),¹ (4),¹ and (9)²].

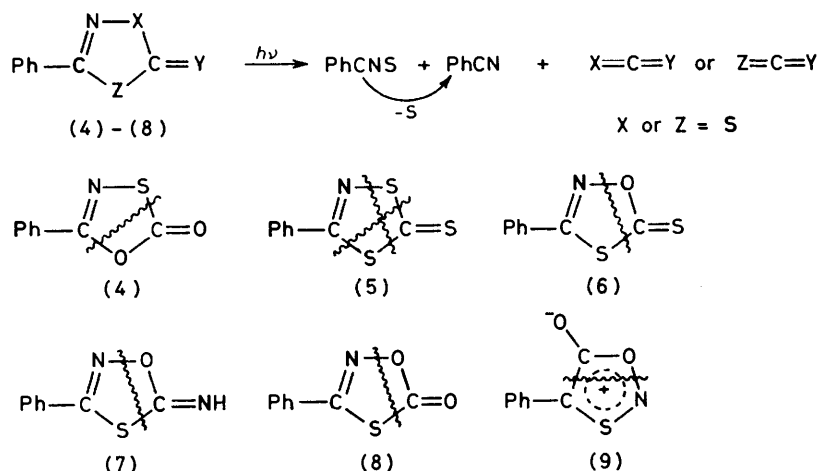
compound (9).¹ The yield of benzonitrile from (1) on the other hand is independent of either the presence or absence of oxygen; this is consistent with product

⁶ J. Skjoldby Petersen, N. Harrit, and A. Holm, to be published.

formation from singlet excited states as previously demonstrated.^{1a}

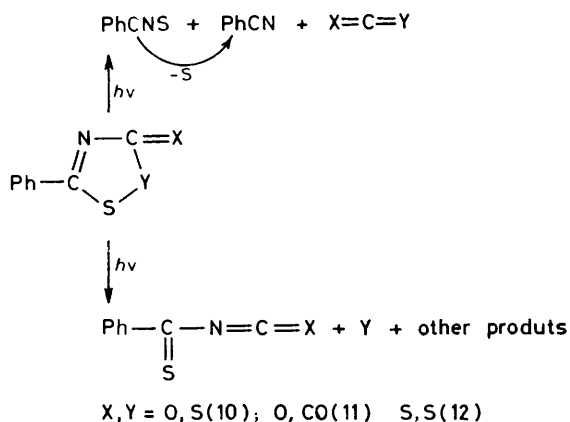
Formation of benzonitrile sulphide was investigated by irradiating the heterocyclic compounds in neat dimethyl acetylenedicarboxylate as described previously.^{1a} Irradiations were performed either through

disregard active sulphur as the source of (20), since no cycloaddition product containing the *p*-tolyl group could be isolated. Further experiments in the present series corroborate this result. Addition of approximately 3 equivalents of sulphur and benzonitrile to (3) in dimethyl acetylenedicarboxylate before photodecom-



SCHEME 3

quartz or Pyrex with light from a medium pressure Hg lamp. The preparative t.l.c. method used previously for analysing for cycloaddition product (20) proved unsatisfactory because of the complexity of the reaction

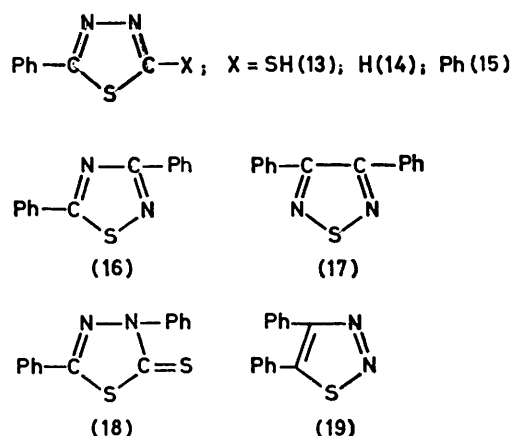


SCHEME 4

mixtures and gas chromatography was, therefore, employed instead. All the heterocycles illustrated in Schemes 1—4 gave rise to a peak in the gas chromatogram identifiable as that of cycloaddition product (20) by combined g.l.c.-m.s. (see Table). The cycloaddition product (21), corresponding to reaction *via* a thioacylnitrene or thiazirine, was in no case observed. Referring to our previous work^{1a} we consider isolation of (20) as providing strong evidence for the photolytic formation of benzonitrile sulphide. Thus, exchange experiments in which *p*-toluonitrile was added to the phenylthiazirazole before irradiation, made it possible to

position did not give rise to increased amounts of (20). Similarly, addition of benzonitrile and 5-(4-chlorophenyl)thiazirazole (the latter acts as a source for active sulphur by photodecomposition) to (3) in dimethyl acetylenedicarboxylate did not affect the yield of (20). Accordingly, we conclude that the cycloaddition product (20) is formed from benzonitrile sulphide.

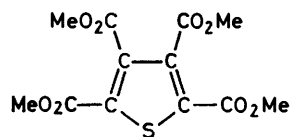
A number of products other than (20) are formed upon irradiation of the various heterocycles in dimethyl acetylenedicarboxylate and more than 20 product peaks are discernible in the gas chromatograms. Since our primary aim was to investigate the possibility of nitrile



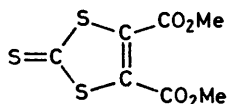
SCHEME 5

sulphide formation no systematic attempt was made to identify the compounds formed. In a few cases, however, some major components were isolated by preparative t.l.c. and characterized: Tetramethyl thiophen-

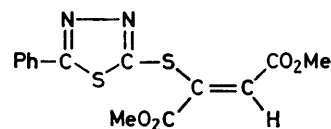
2,3,4,5-tetracarboxylate⁷ (22) was obtained from (4) (7%), (6) (12%), (7) (9%), and (8) (4%). It is probably formed by the action of sulphur on the acetylene.⁸ Compound (23) was isolated in 20% yield from the reaction of (5) with dimethyl acetylenedicarboxylate and may be the result of a diradical reaction requiring C(5)–S(1) bond



(22)



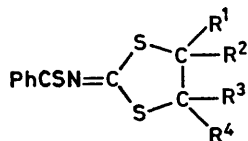
(23)



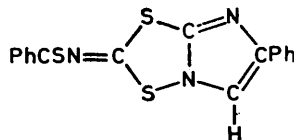
(24)

scission. Compound (23) has previously been obtained by thermal reaction of the same substrates.⁹ A white precipitate formed during photolysis of (13) in dimethyl acetylenedicarboxylate (35% yield) was identified as (24), on the basis of its elemental analysis and i.r., mass, and ¹H n.m.r. spectra. The ¹H n.m.r. substituent shielding coefficients indicate the *trans*-configuration for compound (24) (see Experimental section).

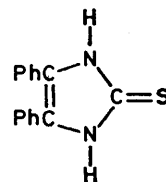
Heterocycles (10)–(12), which as mentioned, give rise only to small amounts of benzonitrile, were irradiated in methylene chloride, the reaction being monitored by electronic absorption spectroscopy. Compounds



(25)



(26)



(27)

(10) and (11) both give rise to a weak absorption at 520 nm which is assigned to thiobenzoyl isocyanate¹⁰ (Scheme 4). In both cases, however, transformation of the isocyanate was observed, probably as a result of the sensitivity of the latter to humidity and heat¹⁰ and possibly also as a result of secondary photolysis. With sufficiently concentrated solutions the characteristic i.r. absorption of the –N=C=O group at 2 215 cm⁻¹ could be observed.¹⁰ Compound (12) gave rise to absorptions at 324 and 560 nm, similarly indicating formation of thiobenzoyl isothiocyanate (Scheme 4). These values compare well with those reported for 2,6-dimethylthiobenzoyl isothiocyanate [λ_{max} 325 (log ϵ 4.1) and 545 nm (log ϵ 2.0)].¹¹ The i.r. absorption of the isocyanate

* The lifetime of benzonitrile sulphide is *ca.* 1 ms at room temperature in ethanol. The resulting low steady-state concentration renders direct photolysis less likely.¹⁵

⁷ A. Michael, *Chem. Ber.*, 1895, **28**, 1633.

⁸ O. P. Strausz, J. Font, E. L. Dedio, P. Kebarle, and H. E. Gunning, *J. Amer. Chem. Soc.*, 1967, **89**, 4805.

⁹ D. Noël, J. Vialle, *Bull. Soc. chim. France*, 1967, 2239.

¹⁰ J. Goerdeler and H. Schenk, *Chem. Ber.*, 1965, **98**, 2954.

¹¹ J. Goerdeler and W. Teller, *Tetrahedron Letters*, 1972, 1513.

group was observed near 2 000 cm⁻¹, in agreement with reported values of 1 980–2 000 cm⁻¹.¹¹

The photochemistry of (12) has previously been studied,¹² but formation of thiobenzoyl isothiocyanate was not reported. In the presence of alkenes compound (25) was formed, whereas irradiation in benzene in the

absence of alkenes gave rise to compounds (26) and (27). Mechanisms for formation of (26) and (27) involving diradicals have been proposed.¹²

Conclusions.—Since nitrile sulphide is formed photochemically from a variety of heterocyclic compounds, all three possible arrangements of the C, N, and S atoms leading to it, individual reaction mechanisms for its formation seem unlikely. An electrocyclic reaction leading to formation of a common intermediate, *i.e.* a thiazirine (Scheme 1), is proposed as discussed in detail elsewhere.¹³

Our observations as a whole allow us to conclude that

ready photo-fragmentation of the investigated heterocyclic compounds takes place when extrusion of a small inorganic molecule such as CO, CO₂, COS, CS₂, N₂O, N₂ or HCNO is possible. This rule is not without exceptions since compound (14), which might be expected to lose HCN, is quite stable under these conditions.

In most cases examined the yield of benzonitrile is considerably greater than that of cycloaddition product (20) (Table), whereas it has previously been reported that thermally generated benzonitrile sulphide may be trapped with up to 90% efficiency with dimethyl acetylenedicarboxylate.¹⁴ This discrepancy is probably due to destruction of benzonitrile sulphide to give benzonitrile under our experimental conditions, either as a result of energy transfer or, less likely,* by direct

¹² R. Okazaki, F. Ishii, K. Okawa, K. Ozawa, N. Inamoto, *J.C.S. Perkin I*, 1975, 270; R. Okazaki, K. Okawa, and N. Inamoto, *Chem. Comm.*, 1971, 843.

¹³ A. Holm, N. Harrit, and I. Trabjerg, *J.C.S. Perkin I*, 1978, 746.

¹⁴ R. K. Howe and J. E. Franz, *J.C.S. Chem. Comm.*, 1973, 524; J. E. Franz and L. L. Black, *Tetrahedron Letters*, 1970, 1381.

¹⁵ A. Holm, J. J. Christiansen, and C. Lohse, *J.C.S. Perkin I*, in the press.

photolysis. Other routes to the formation of benzonitrile are also conceivable, e.g. direct formation from the excited heterocyclic compound.

EXPERIMENTAL

The photolytic reactions were carried out using light from a medium pressure Hg lamp (Hanau Q-700) or from a high-pressure Hg lamp fitted with monochromator typical band width ± 14 nm. Sampleholders were water cooled during photolysis. G.l.c. analyses were carried out on a Pye-Unicam 104 chromatograph, dual FID, in combination with a Varian aerograph 477 electronic integrator, or on a Hewlett-Packard 5840 Gas Chromatograph in combination with a 5840A GC terminal, on a 2 m \times 6 mm column with SE-30 or 10% polypropyleneglycol on Gaschrom Q 100/120 mesh (Applied Science Lab. Inc.) with nitrogen as carrier gas. G.l.c.-m.s. analysis were made with a Finnigan 1015 S/L mass spectrometer directly coupled to the gas chromatograph. Benzyl cyanide was used as internal standard for quantitative measurements of benzonitrile (irradiations of the heterocycles were performed through quartz or Pyrex), and dimethyl 2-phenyl-1,3-thiazole-4,5-dicarboxylate (21) as internal standard for measurements of dimethyl 3-phenyl-1,2-thiazole-4,5-dicarboxylate (20) (irradiations of the heterocycles were performed through quartz). U.v.-visible spectra were obtained on an Unicam SP 800 instrument.

All the investigated compounds have been described previously and were prepared according to the references given below. The longest wavelength absorptions are given in []: 5-phenyl-1,2,3,4-thiatriazole ¹⁶ [(1); 280 nm (log ϵ 4.03) ¹⁷], 3-ethyl-5-phenyl-1,2,3,4-thiatriazolium tetrafluoroborate ¹⁸ [(2) 325 nm, CH₂Cl₂], 5-phenyl-1,2,3,4-thiatriazole 3-oxide ¹⁹ [(3) 320 nm (log ϵ 3.48) ¹⁹], 5-phenyl-2*H*-1,3,4-oxathiazolin-2-one ²⁰ [(4) 269 nm (log ϵ 3.81), EtOH], 5-phenyl-2*H*-1,3,4-dithiazoline-2-thione ^{21,9} [(5) 353 nm (log ϵ 4.19) dioxan ²¹], 4-phenyl-2*H*-1,3,5-oxathiazoline-2-thione ²² [(6) 300 nm, CH₂Cl₂], 4-phenyl-2*H*-1,3,5-oxathiazolin-2-imine ²³ [(7) 272 nm, CH₂Cl₂]; 4-phenyl-2*H*-1,3,5-oxathiazolin-2-one ²⁴ [(8) 255 nm, CH₂Cl₂], 4-phenyl-1,3,2-oxathiazolylio-5-oxide ² [(9) 410 nm (log ϵ

3.95) dioxan ²¹], 5-phenyl-3*H*-1,2,4-dithiazolin-3-one ²⁵ [(10) 350 nm, dioxan ²¹], 5-phenyl-1,4-thiazole-3,4-dione ¹⁰ [(11) 450 nm (log ϵ 1.6) dioxan ¹⁰], 5-phenyl-1,2,4-dithiazoline-3-thione ²⁶ [(12) 428 nm, CH₂Cl₂], 5-phenyl-1,3,4-thiadiazole-2-thiol ²⁷ [(13) 337 nm, CH₂Cl₂], 2-phenyl-1,3,4-thiadiazole ²⁷ [(14) 267 nm, CH₂Cl₂], 3,5-diphenyl-1,2,4-thiadiazole ⁹ [(16) 295sh nm, CH₂Cl₂], 3,5-diphenyl-3*H*-1,3,4-thiadiazole-2-thione ²⁸ [(18); 344 nm, CH₂Cl₂].

Photolysis in Dimethyl Acetylenedicarboxylate.—The heterocyclic compounds, (1)—(12), ca. 1 mg ml⁻¹ for g.l.c. and 25—100 mg ml⁻¹ for p.t.l.c., were irradiated in neat dimethyl acetylenedicarboxylate with light from a high pressure Hg lamp, through quartz under an atmosphere of argon (see Table for g.l.c. results). The elemental analyses of all the compounds mentioned below were in agreement with calculated values. (a) Compound (22) was obtained from (4) (7%), (6) (12%), (7) (9%), and (8) (4%); m.p. 126—127 °C (methanol, lit.,⁷ m.p. 127—128°). (b) The yellow compound (23) was isolated in 20% yield from (5) identified by elemental analysis and i.r. spectroscopy (KBr, 1 742 and 1 721 cm⁻¹ [lit.,²⁹ (KBr) 1 740 and 1 720 cm⁻¹], m.p. 86.0—87.5 °C (lit.,²⁹ m.p. 72—72.5° C), (c) The white precipitate formed during photolysis of (13) [35% yield based on (13)], m.p. 130—131 °C, was submitted to spectral and elemental analysis and identified as compound (24); mass spectrum: *m/e* 336, M⁺ (calc. 336); 305, M⁺ - OCH₃ = C₁₃H₉N₂O₃S₂⁺; 277, C₁₃H₉N₂O₃S₂ - CO = C₁₂H₉N₂O₂S₂⁺; 194, C₁₂H₉N₂O₂S₂ - C₄H₃O₂ = PhC-S-C(SH):N-N⁺; 161, C₈H₆N₂S₂ - SH· = C₈H₅N₂S⁺.

In agreement with the assigned structure the i.r. spectrum (KBr) exhibits two carbonyl bands at 1 720 and 1 710 cm⁻¹, respectively, and the n.m.r. spectrum δ (CDCl₃) shows two singlets (3 H in each case) at 3.70 and 3.84, a singlet (1 H) at 6.92, and aromatic proton resonances (5 H) at 7.3—8.0. From additive substituent coefficients for the chemical shifts of alkene protons ³⁰ δ_{H} *cis* is expected to be 6.05 and δ_{H} *trans* to be 6.94, thus indicating *trans*-addition of (13) to dimethyl acetylenedicarboxylate.

[7/2211 Received, 19th December, 1977]

¹⁶ K. A. Jensen and C. Pedersen, *Acta Chem. Scand.*, 1961, **15**, 1104.

¹⁷ W. Kirmse, *Chem. Ber.*, 1960, **93**, 2353.

¹⁸ A. Holm, K. Schaumburg, N. Dahlberg, C. Christophersen, J. P. Snyder, *J. Org. Chem.*, 1975, **40**, 431.

¹⁹ A. Holm, L. Carlsen, S.-O. Lawesson, and H. Kolind-Andersen, *Tetrahedron*, 1975, **31**, 1783.

²⁰ B.P. 10,79,348/1967 (*Chem. Abs.*, 1968, **68**, 69000w); A. Senning and J. S. Rasmussen, *Acta Chem. Scand.*, 1973, **27**, 2161.

²¹ H. Behringer and D. Deichmann, *Tetrahedron Letters*, 1967, 1013.

²² G.P. 2,059,990 (*Chem. Abs.*, 1972, **77**, 110,567n).

²³ C. Musante, *Gazzetta*, 1938, **68**, 331.

²⁴ Belg. patent 632,072 (*Chem. Abs.*, 1964, **61**, P3119).

²⁵ W. Walter and P. M. Hell, *Annalen*, 1969, **727**, 22.

²⁶ J. W. MacDonald and D. M. McKinnon, *Canad. J. Chem.*, 1967, **45**, 1225.

²⁷ K. A. Jensen and C. Pedersen, *Acta Chem. Scand.*, 1961, **15**, 1124.

²⁸ R. Fusco and C. Musante, *Gazzetta*, 1938, **68**, 665.

²⁹ B. R. O'Connor and F. N. Jones, *J. Org. Chem.*, 1970, **35**, 2002.

³⁰ L. H. Jackman and S. Sternhell, 'Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry,' Pergamon, Oxford, 2nd edn., p. 185.