

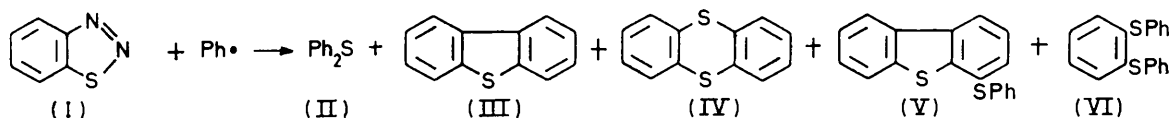
## Reactions of 1,2,3-Benzothiadiazole with Phenyl and with Methyl Radicals<sup>1</sup>

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The reaction of 1,2,3-benzothiadiazole (I) with phenyl radicals, at room temperature, afforded diphenyl sulphide, dibenzothiophen, thianthren, 4-phenylthiodibenzothiophen, and 1,2-bisphenylthiobenzene. Similarly the reaction of (I) with methyl radicals gave thioanisole, thianthren, 4-methylthiodibenzothiophen, and 1-methylthio-2-phenylthiobenzene. A mechanism is proposed which assumes initial attack of phenyl or methyl radical at the sulphur atom of (I) to give *o*-phenylthio- (X) or *o*-methylthio-phenyl radical.

SEVERAL studies have shown that homolytic substitutions at the sulphur atom take place readily with disulphides and thiosulphonates, and less easily with diaryl sulphides.<sup>2</sup> No examples of attack of a radical on a heteroaromatic sulphur atom have been reported. In studies of the phenylation of several sulphur-containing aromatic heterocycles (thiophen,<sup>3</sup> benzo[*b*]thiophen,<sup>4</sup> thiazole,<sup>5</sup> benzo[*b*]thiazole,<sup>6</sup> dibenzothiophen,<sup>7</sup> and two

1,2,3-Benzothiadiazole (I) reacts, in ethyl acetate, with phenyl radicals generated from the decomposition of *N*-nitrosoacetanilide or benzoyl peroxide or from the aprotic diazotization of aniline, to afford diphenyl sulphide (II), dibenzothiophen (III), thianthren (IV), 4-phenylthiodibenzothiophen (V), and 1,2-bisphenylthiobenzene (VI) (see Scheme). Similarly methyl radicals obtained from the decomposition of diacetyl peroxide in



isomeric thienothiophens<sup>8</sup>), compounds derived from the attack on the sulphur atom were not reported. We now describe the first example of such a process.

<sup>1</sup> Preliminary communication, L. Benati, A. Tundo, and G. Zanardi, *J.C.S. Chem. Comm.*, 1972, 590.

<sup>2</sup> K. U. Ingold and B. P. Roberts, 'Free-radical Substitution Reactions,' Wiley-Interscience, New York, 1971, p. 200; W. A. Pryor, 'Mechanisms of Sulfur Reactions,' McGraw-Hill, New York, 1962, ch. 3.

<sup>3</sup> M. Gomberg and W. E. Bachmann, *J. Amer. Chem. Soc.*, 1924, **46**, 2339; N. P. Buu-Hoi and N. Hoan, *Rec. Trav. chim.*, 1950, **69**, 1455; P. A. S. Smith and J. H. Bayer, *J. Amer. Chem. Soc.*, 1951, **73**, 2626; J. Degani, M. Pallotti, and A. Tundo, *Ann. Chim. (Italy)*, 1961, **51**, 434; M. C. Ford and D. Mackay, *J. Chem. Soc.*, 1957, 4620; C. E. Griffin and K. R. Martin, *Chem. Comm.*, 1966, 154; C. M. Camaggi, R. Leardini, M. Tiecco, and A. Tundo, *J. Chem. Soc. (B)*, 1969, 1271; 1970, 1633; C. M. Camaggi, G. De Luca, and A. Tundo, *J.C.S. Perkin II*, 1972, 412, 1594.

ethyl acetate react with (I) to afford thioanisole, thianthren (IV), 4-methylthiodibenzothiophen, and 1-methylthio-2-phenylthiobenzene.

No products derived from attack of phenyl or methyl radicals on the benzene ring of (I) were identified; all the compounds isolated were the result of an interaction

<sup>4</sup> R. Gaertner, *J. Amer. Chem. Soc.*, 1952, **74**, 4950; G. Martelli, P. Spagnolo, M. Tiecco, and A. Tundo, *J.C.S. Perkin I*, 1972, 556.

<sup>5</sup> H. J. Dou, J. C. Poite, G. Vernin, and J. Metzger, *Tetrahedron Letters*, 1969, 779; G. Vernin, H. J. Dou, and J. Metzger, *Bull. Soc. chim. France*, 1972, 1174.

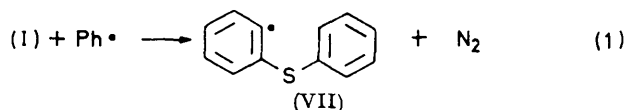
<sup>6</sup> G. Vernin, H. J. Dou, G. Loidan, and J. Metzger, *Bull. Soc. chim. France*, 1970, 2705.

<sup>7</sup> E. B. McCall, A. J. Neale, and T. J. Rawlings, *J. Chem. Soc.*, 1962, 5288.

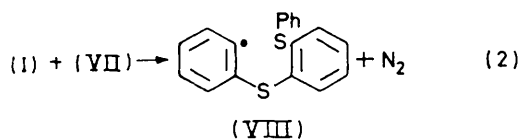
<sup>8</sup> G. Martelli, P. Spagnolo, L. Testaferri, and M. Tiecco, *J.C.S. Perkin I*, 1972, 93.

of the phenyl or methyl radicals and (I) leading to decomposition of the heterocyclic nucleus with loss of nitrogen.

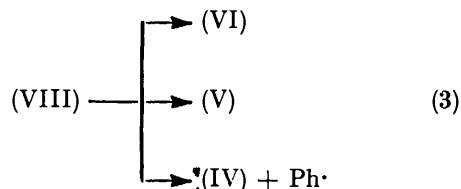
We suggest that the results can be rationalised by assuming that phenyl radicals attack the sulphur atom of (I) to give the *o*-phenylthiophenyl radicals (VII) [reaction (1)] from which the formation of all the reaction products can be explained. In fact, the radical (VII) can give rise to hydrogen abstraction or



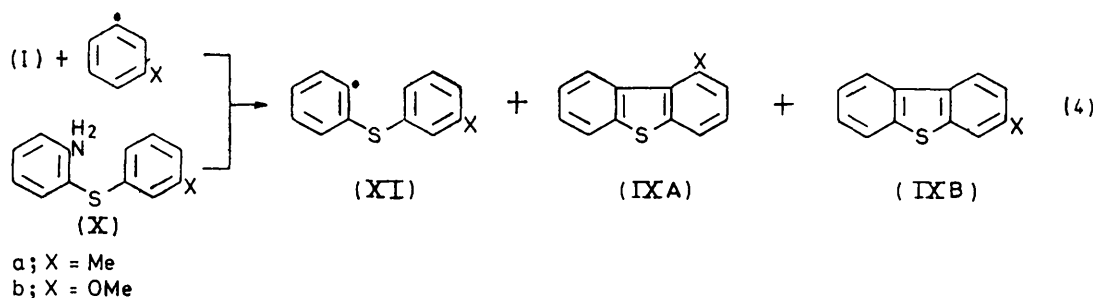
intramolecular aromatic substitution reactions to afford diphenyl sulphide (II) or dibenzothiophen (III), respectively. Moreover, the radical (VII) can also attack the benzothiadiazole at the sulphur atom to afford the substituted phenyl radical (VIII) [reaction (2)].



The radical (VIII) can undergo three kinds of reaction: hydrogen abstraction to afford the bisphenylthiobenzene (VI), intramolecular aromatic substitution to afford 4-phenylthiodibenzothiophen (V), and intramolecular homolytic substitution ( $S_{H^2}$ ) at the sulphur atom of the phenylthio-group linked to the adjacent aromatic nucleus to produce thianthren (IV) and phenyl radicals [reaction (3)]. An analogous mechanism can explain the formation of the products from (I) and methyl radicals.



The foregoing mechanism assumes the intermediacy of the two substituted phenyl radicals (VII) and (VIII);



moreover the radical (VIII) should be formed from (VII). Several independent experiments have been carried out in order to gain indirect support for this interpretation.

When the 1,2,3-benzothiadiazole (I) reacted with *m*-methyl- or *m*-methoxy-phenyl radicals [reaction (4)], besides the expected products, two isomeric methyl- or methoxy-dibenzothiophens (IXA and B) were obtained. The proportions in which the two isomers were formed in the two cases were almost identical with those found in the aprotic diazotisation of the amino-sulphides (Xa and b) (see Table). These results indicate that the two reactions pass through the same intermediate, the *o*-arylthiophenyl radical (XI), analogous to (VII). It is notable that the diazotisation of (Xa) and (Xb) in acidic medium affords the two isomeric dibenzothiophens (IXA and B) in substantially different proportions.

Isomer proportions in the formation of the dibenzothiophens (IXA and B) from different sources

	Isomer proportions (%)			
	X = Me		X = OMe	
	(IXA)	(IXB)	(IXA)	(IXB)
(I) + <i>m</i> -XC <sub>6</sub> H <sub>4</sub> ·	72	28	78	22
(X) + Me[CH <sub>2</sub> ] <sub>4</sub> ONO	68	32	72	28
(X) + HNO <sub>2</sub>	51	49	50	50

Independent experiments carried out on the radical (VIII), generated from the aprotic diazotisation of the amino-bis-sulphide<sup>9</sup> (XII) [reaction (5)] demonstrated that the reactions of this intermediate are in fact those indicated in reaction (3), *i.e.* the production of thianthren (IV), 4-phenylthiodibenzothiophen (V), and the bis-sulphide (VI). In a similar way the diazotisation of 2-aminophenyl 2-methylthiophenylsulphide<sup>9</sup> afforded thianthren (IV), 4-methylthiodibenzothiophen, and 1-methylthio-2-phenylthiobenzene. Finally, the suggested mode of formation of (VIII) [reaction (2)] was demonstrated independently. Producing the *o*-phenylthiophenyl radical (VII) from the aprotic diazotisation of 2-phenylthioaniline in the presence of (I) gave, besides diphenyl sulphide (II) and dibenzothiophen (III), a mixture of the three products (IV)–(VI).

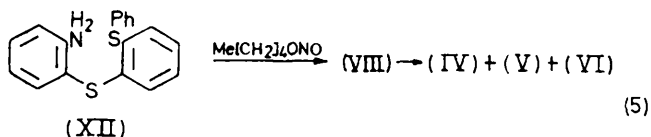
The ratio of (IV) to (V) + (VI) was in this case 87 : 13, which is essentially identical with those found in the diazotisation of the amino-bis-sulphide (XII) (84 : 16) and the reaction of phenyl radicals with 1,2,3-benzothiadiazole (86 : 14).

An alternative route can be envisaged for the form-

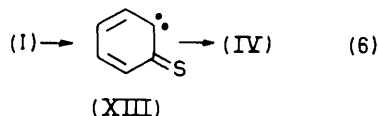
ation of the thianthren (IV), consisting of the dimerisation of the thioxocarbene (XIII) which is known to be

<sup>9</sup> L. Benati, P. C. Montevocchi, A. Tundo, and G. Zanardi, preceding paper.

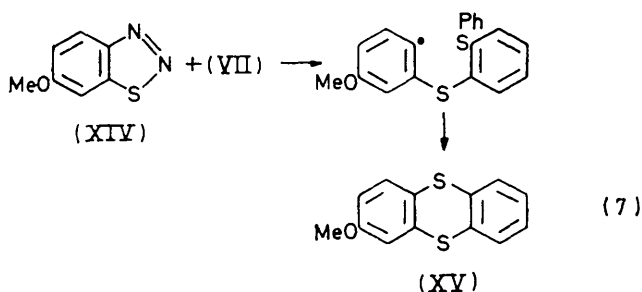
formed from the decomposition of 1,2,3-benzothiadiazole (I) [reaction (6)]. The importance of this reaction can



be evaluated by utilising a substituted 1,2,3-benzothiadiazole, like the 6-methoxy-derivative (XIV). The



reaction of this product with phenyl radicals would be expected to afford 2,7-dimethoxythianthren both from dimerisation of the corresponding thioxocarbene and from the reaction sequences [(1)  $\rightarrow$  (2)  $\rightarrow$  (3)] suggested in the present paper. However if (XIV) is caused to react with *o*-phenylthiophenyl radical (VII), the two processes can be distinguished, because the sequence (2)  $\rightarrow$  (3) would afford 2-methoxythianthren (XV) only [reaction (7)]. From this experiment the



thianthren (XV) was obtained in good yield, and only traces of 2,7-dimethoxythianthren were present. This indicates that dimerisation of (XIII) does not contribute significantly to the formation of thianthren.

#### EXPERIMENTAL

G.l.c. analyses were carried out with a Varian 1440/1 instrument (5% FFAP on a Varaport column). The reaction products were all identified by comparison (mixed m.p. and i.r. and n.m.r. spectra) with authentic samples prepared independently. N.m.r. spectra were recorded with a JEOL 60 MHz instrument and i.r. spectra with a Perkin-Elmer 257 spectrophotometer.

Diphenyl sulphide (II), dibenzothiophen (III), thianthren (IV), and thioanisole were commercial products. 4-Phenylthio- (V) and 4-methylthio-dibenzothiophens,<sup>9</sup> 1,2,3-benzothiadiazole (I),<sup>10</sup> 1,2-bisphenylthiobenzene (VI),<sup>11</sup> diacetyl peroxide,<sup>12</sup> 1-methylthio-2-phenylthiobenzene,<sup>13</sup> 1- and 3-methylthio-dibenzothiophen (IXA and B; X = Me),<sup>14</sup> 2-aminophenyl *m*-tolyl sulphide (Xa),<sup>15</sup> 1-(2-aminophenylthio)-2-phenylthiobenzene (XII),<sup>9</sup> 2-aminophenyl 2-methyl-

thiophenyl sulphide,<sup>9</sup> 2-phenylthioaniline,<sup>16</sup> 6-methoxy-1,2,3-benzothiadiazole (XIV),<sup>17</sup> and 2,7-dimethoxythianthren,<sup>18</sup> were prepared as described in the literature.

**2-Aminophenyl 3-Methoxyphenyl Sulphide (Xb).**—A mixture of *o*-chloronitrobenzene (1.6 g, 0.01 mol) and sodium *m*-methoxybenzenethiolate (1.6 g, 0.01 mol) in ethanol (15 ml) was refluxed for 48 h, then cooled. The 3-methoxyphenyl 2-nitrophenyl sulphide which precipitated was filtered off and crystallised from light petroleum (b.p. 100–120°); yield 2 g, m.p. 123–124° (Found: C, 59.55; H, 4.2; N, 5.45; S, 12.05. C<sub>13</sub>H<sub>11</sub>NO<sub>3</sub>S requires C, 59.75; H, 4.2; N, 5.35; S, 12.25%). This sulphide (1 g) in ethyl ether (30 ml) was reduced over palladium-charcoal. Filtration, evaporation, and distillation gave the amino-sulphide (0.8 g) as an oil, b.p. 198° at 2 mmHg (Found: C, 67.15; H, 5.45; N, 6.2; S, 13.55. C<sub>13</sub>H<sub>13</sub>NOS requires C, 67.55; H, 5.65; N, 6.05; S, 13.85%).

**2-Methoxythianthren (XV).**—Sodium (0.4 g) was dissolved in ethanol (20 ml) and 2-bromothianthren (4.8 g) was added. The mixture, in a steel bomb, was maintained at 250 °C for 48 h. After cooling and filtration, the solvent was evaporated off and the residue was chromatographed on alumina with *n*-pentane as eluant. Unchanged 2-bromothianthren was eluted first, followed by 2-methoxythianthren, m.p. 77–78° (from methanol) (Found: C, 63.2; H, 4.3; S, 25.65. C<sub>13</sub>H<sub>10</sub>OS<sub>2</sub> requires C, 63.4; H, 4.1; S, 26.0%).

**Reactions of 1,2,3-Benzothiadiazole with Aryl and Methyl Radicals.**—(a) *Phenyl radicals.* These experiments were carried out by generating the phenyl radicals in three different ways.

(i) 1,2,3-Benzothiadiazole (2.72 g, 0.02 mol) in ethyl acetate (40 ml) and *N*-nitrosoacetanilide (9.8 g, 0.06 mol) were stirred at room temperature for 24 h in the presence of calcium chloride and sodium carbonate. The mixture was filtered and the solvent evaporated off. The residue was chromatographed on silica gel with *n*-pentane as eluant. The following products were eluted in the order cited: diphenyl sulphide (II), dibenzothiophen (III), thianthren (IV), 1,2-bisphenylthiobenzene (VI), and 4-phenylthiodibenzothiophen (V). Complete separation was not achieved with this first column but the fractions obtained were then further chromatographed under the same conditions.

Direct g.l.c. analysis of the reaction mixture gave the following results (yields are based on 1,2,3-benzothiadiazole consumed): (II), 6%; (III), 6%; (IV), 18%; (VI), 1.5%; (V), 1.5%.

(ii) 1,2,3-Benzothiadiazole (I) (1.4 g, 0.01 mol), aniline (0.9 g, 0.01 mol), ethyl acetate (30 ml), and *n*-pentyl nitrite (1.7 ml, 0.012 mol) were warmed at 40 °C for 5 h. The reaction mixture was directly analysed by g.l.c.; all the products reported in (i) were identified. The ratio of (IV) to (V) + (VI) was 86 : 14.

(iii) 1,2,3-Benzothiadiazole (I) (9.52 g, 0.07 mol), dibenzoyl peroxide (16.4 g, 0.08 mol), and ethyl acetate (150 ml) were refluxed for 72 h. The mixture was analysed by g.l.c.; all the products reported in (i) were identified. Other compounds were present in this case; among them diphenyl disulphide was identified.

(b) *Methyl radicals.* 1,2,3-Benzothiadiazole (I) (2.72 g,

<sup>10</sup> H. Gilman and G. Wilder, *J. Org. Chem.*, 1957, **22**, 523.

<sup>11</sup> H. Gilman and H. S. Broadbend, *J. Amer. Chem. Soc.*, 1964, **86**, 2053.

<sup>12</sup> H. Bourgeois, *Rec. Trav. chim.*, 1912, **31**, 30.

<sup>13</sup> W. H. Poesche, *J. Chem. Soc. (B)*, 1971, 368.

<sup>14</sup> K. Fries and E. Engelbertz, *Annalen*, 1915, **407**, 194.

<sup>9</sup> P. Jacobson and H. Jansen, *Annalen*, 1893, **277**, 219.

<sup>11</sup> J. R. Campbell, *J. Org. Chem.*, 1964, **29**, 1830.

<sup>12</sup> J. R. Slagle and H. J. Shine, *J. Org. Chem.*, 1959, **24**, 107.

<sup>13</sup> N. Marziano and G. Montaudo, *Boll. Sed. Acc. Gioena Sci. Nat. Catania (Italy)*, 1961, [4], 6, n. ro. 239, 160.

0.02 mol), diacetyl peroxide (3.5 g, 0.03 mol), and ethyl acetate (40 ml) were kept at 50° for 12 h. The solvent was then evaporated off and the residue chromatographed on alumina with light petroleum (b.p. 40–70°) as eluant. Several fractions were collected which were again chromatographed on Florisil with n-pentane as eluant. The following products were finally separated and identified; thioanisole, thianthren (IV), 4-methylthiodibenzothiophen, 1-methylthio-2-phenylthiobenzene, and diphenyl disulphide.

(c) *m-Tolyl radicals*. 1,2,3-Benzothiadiazole (2.72 g, 0.02 mol), *N*-nitroso-*m*-methylacetanilide (10.7 g, 0.06 mol), and ethyl acetate (40 ml) were stirred at room temperature for 24 h. The solvent was removed and the residue analysed by g.l.c. 1- and 3-Methylthiodibenzothiophen (IXA and B; X = Me) were present in the ratio 72 : 28, along with other products. The two isomers were separated by column chromatography on silica gel with light petroleum as eluant.

(d) *m-Methoxyphenyl radical*. The reaction was carried out with *N*-nitroso-*m*-methoxyacetanilide under the conditions described for *m*-tolyl radicals. The ratio of 1- to 3-methoxydibenzothiophen, determined by g.l.c., was 78 : 22.

(e) *o-Phenylthiophenyl radicals*. 1,2,3-Benzothiadiazole (1.36 g, 0.01 mol), 2-phenylthioaniline (2.01 g, 0.01 mol), n-pentyl nitrite (1.7 ml, 0.012 mol), and ethyl acetate (40 ml) were kept at 40° for 5 h. The solvent was evaporated off and the residue chromatographed on silica gel with n-pentane as eluant. The products isolated were the same as those obtained from (I) and *N*-nitrosoacetanilide. The ratio of (IV) to (V) + (VI), determined by g.l.c., was 87 : 13.

*Diazotisation of 2-Aminophenyl m-Tolyl Sulphide*.—(i) A mixture of the amino-sulphide (Xa) (3.2 g, 0.015 mol), pentyl nitrite (2.4 g, 0.02 mol), and ethyl acetate (70 ml) was kept at 50 °C for 5 h. The solvent was removed and the residue chromatographed on a silica gel column, with n-pentane as eluant. The following compounds were eluted in the order cited: phenyl *m*-tolyl sulphide, 1-methylthiodibenzothiophen (IXA; X = Me), and 3-methylthiodibenzothiophen (IXB; X = Me). The ratio of (IXA) to (IXB) was 68 : 32.

(ii) The amino-sulphide (3.2 g, 0.015 mol) in dilute sulphuric acid was diazotised at 0–5 °C with sodium nitrite (1.1 g, 0.015 mol). The mixture was extracted with ether and the extract evaporated. The residue was analysed by g.l.c.: 1- and 3-methylthiodibenzothiophen were present in the ratio of 51 : 49.

*Diazotisation of 2-Aminophenyl 3-Methoxyphenyl Sulphide*.

(i) A mixture of the amino-sulphide (Xb) (2.8 g, 0.009 mol), pentyl nitrite (1.3 g, 0.011 mol), and ethyl acetate (70 ml) was kept at 50 °C for 5 h. The solvent was evaporated off and the residue chromatographed on a silica gel column with n-pentane as eluant. The 3-methoxyphenyl phenyl sulphide was eluted first, followed by 1-methoxydibenzothiophen (IXA; X = OMe), m.p. 84–85° (from propan-2-ol) (Found: C, 72.7; H, 4.5; S, 14.95. C<sub>13</sub>H<sub>10</sub>OS requires C, 72.9; H, 4.65; S, 14.95%), and 3-methoxydibenzothiophen (IXB; X = OMe), m.p. 104–105° (from propan-2-ol) (Found: C, 73.0; H, 4.7; S, 14.75%). The ratio of (IXA) to (IXB), determined by g.l.c. of the crude reaction mixture, was 72 : 28. The methoxydibenzothiophens were identified by analyses of their n.m.r. spectra and by desulphuration with Raney nickel in boiling ethanol, which gave 2-methoxy- and 4-methoxy-biphenyl, respectively.

(ii) The diazotisation of (Xb) in dilute sulphuric acid was carried out as described for (Xa). G.l.c. analysis of the reaction mixture indicated that equal amounts of (IXA) and (IXB) were formed.

*Reaction of 6-Methoxy-1,2,3-benzothiadiazole with o-Phenylthiophenyl Radical*.—A mixture of 6-methoxy-1,2,3-benzothiadiazole (XIV) (1.66 g, 0.01 mol), n-pentyl nitrite (1.4 g, 0.012 mol), and 2-phenylthioaniline (2.01 g, 0.01 mol) in ethyl acetate (60 ml) was warmed at 50° for 5 h. The solvent was then removed and the residue was chromatographed on silica gel with light petroleum (b.p. 40–60°) as eluant. Besides other products, 2-methoxythianthren (XV) and 2,7-dimethoxythianthren were obtained; their ratio, determined by g.l.c. analysis, was 9 : 1.

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