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## Studies on 1,2,3-Benzothiadiazoles. Part I. The Nuclear Magnetic Resonance Spectrum of 1,2,3-Benzothiadiazole

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A complete analysis of the nuclear magnetic resonance spectrum of 1.2.3-benzothiadiazole is presented. The results are used to check a recent molecular orbital treatment of the hetero-atom sulphur. A recent deamination procedure has been used for the first time for deuterium labelling.

WE have recorded and completely analysed the highresolution (100 Mc./sec.) nuclear magnetic resonance spectrum of 1,2,3-benzothiadiazole (I) in dilute carbon tetrachloride and deuterochloroform solution. The



spectrum (in deuterochloroform) is shown in the Figure. Its dominant feature is the separation into three wellseparated groups of signals with relative intensity 1:1:2. In the first and second group 12 lines can be distinguished, in the third 13 which are symmetrically disposed around the centre, indicating an AB system. The predicted number of allowed transitions in an ABMX system is  $12 + 12 + 16.^{1}$  Relative intensities and number of lines suggest then that the groups belong to different protons, two of which have different chemical shifts from each other and the other two, while the chemical shifts of the latter must be almost identical. This fortunate fact greatly facilitates the analysis of this system of four non-equivalent mutually coupled spins.

To make an unambiguous assignment of the groups to the individual protons of (I) possible and aid in the evaluation of the spectroscopic parameters we recorded also the spectra of the four monodeutero-1,2,3-benzothiadiazoles. (In the deuterium derivatives the proton signal in the substituted position disappears owing to the different resonance frequencies of proton and deuteron, while the chemical shifts and coupling constants of the remaining protons are not affected by the substitution since the electron distribution does not change.) The spectra are described in Table 1. The intensities of the three groups were equal.

TABLE 1

N.m.r. spectra of monodeutero-1,2,3-benzothiadiazoles (chemical shifts in  $\tau$  units)

1,2,3- Benzo- thia- diazole	x	м	A,B
4-Deutero	_	Sharp signals at 1.900, 1.930, 1.960, 1.995, outer stronger than inner.	Sharp signals at 2:370, 2:390, 2:403, 2:429
5-Deutero	Multiplet cen- tered at 1.403	Sharp signals at 1.896, 1.905, 1.978, 1.986	2 Multiplets cen- tered at 2.342 and 2.426
6-Deutero	Sharp signals at 1·355, 1·364, 1·439, 1·447	Multiplet cen- tered at 1.944	2 Multiplets cen- tered at 2.375 and 2.460
7-Deutero	Sharp signals at 1.353, 1.388, 1.418, 1.448, outer stronger than inner	_	Sharp signals at 2·371, 2·390, 2·403, 2·428

<sup>1</sup> J. A. Pople and T. Schaefer, Mol. Phys., 1960, 3, 551.

It is obvious that the group around  $\tau 1.40$  (860 c./sec.) must be assigned to proton 4, and that around  $\tau 1.94$ (806 c./sec.) to proton 7, since these signals are missing from the spectra of the corresponding deuterium derivatives. Not unexpectedly, the proton next to the nitrogen atom is thus more deshielded than that next to sulphur. Further, proton 5 must resonate at slightly higher field than proton 6, since the centre of 6-deutero-1,2,3-benzothiadiazole ( $\tau 2.417$ ) has a higher  $\tau$ -value than its 5-isomer ( $\tau 2.384$ ).

The line shape (sharp signals or broad unresolved multiplet) confirms this assignment. The broadening can be due to quadrupole relaxation and unresolved in the 7-isomer, on the other hand, are coupled to two protons with similar chemical shifts, and first-order analysis breaks down. Analysis of the patterns would give no new coupling constants; the intensity distributions, however, indicate that at least  $J_{45}$  and  $J_{57}$  and similarly  $J_{67}$  and  $J_{48}$  have the same sign.<sup>2</sup> We have assumed all coupling constants to have the same sign; so far no example of a benzene ring has been found where this is not true.

With the chemical shifts and coupling constants from the deutero-compounds and estimates of  $J_{47}$  and  $J_{56}$ which cannot be obtained from them as first approximations, we have then completely analysed the spectrum



Observed and predicted 100 Mc./sec. n.m.r. spectrum of 1,2,3-benzothiadiazole (in deuterochloroform)

TABLE 2

N.m.r. spectral parameters of 1,2,3-benzothiadiazole

	Chemical shifts $(\tau)$					
Solvent CCl <sub>4</sub> CDCl <sub>2</sub>	$. 1.4362 \pm 0. \\ 1.3897 \pm 0. $	0004 2·4331 0006 2·3860	$\delta_5 \\ \pm 0.0004 \\ + 0.0006$	$\begin{array}{r} \delta_6 \\ 2.3881 \pm 0.0004 \\ 2.3390 \pm 0.0006 \end{array}$	$\frac{\delta_{7}}{1.9551 \pm 0.0004} \\ 1.9197 \pm 0.0006$	line posn. $(\tau)$ 0.00113 0.00121
			Coupling	constants (c./sec.)	_	
Solvent CCl <sub>4</sub> CDCl <sub>3</sub>	$J_{45} = 100000000000000000000000000000000000$	$\begin{array}{c} J_{46} \\ 1 \cdot 19 \pm 0 \cdot 06 \\ 1 \cdot 04 \pm 0 \cdot 08 \end{array}$	$\begin{array}{c} J_{47} \\ 0.73 \pm 0.06 \\ 0.78 \pm 0.08 \end{array}$	$J_{56} = J_{56} = 0.08$ $J_{56} = 0.01$	$\begin{array}{c} J_{57} \\ 1.03 \pm 0.05 \\ 1.00 \pm 0.08 \end{array}$	$\begin{array}{c} J_{67} \\ 8.08 \pm 0.06 \\ 7.88 \pm 0.08 \end{array}$

additional splitting; both effects are important only in protons strongly coupled to the deuterium atom, *i.e.*, ortho-protons. There should then be two broadened signals in both 5- and 6-deutero-1,2,3-benzothiadiazole, belonging to the 4,6- and 5,7-protons, respectively, as is observed.

From the sharp parts of the spectra coupling constants can be extracted. Since in the 6-deutero-compound the 5-proton is coupled to two protons with different chemical shift, first-order analysis applies, and the coupling constants are found to be  $|J_{45}| = 8.35$  and  $|J_{57}| =$ 0.85 c./sec. In the 5-deutero-isomer the 6-proton can be treated similarly and yields  $|J_{67}| = 8.0$  and  $|J_{46}| =$ 0.9 c./sec. The 7-proton in the 4-isomer and the 4-proton of (I), using Ferguson and Marquardt's computer programme.<sup>3</sup> This calculates in its first part energy levels from input chemical shielding and coupling parameters and allowed transitions between them. The second part solves for refined energy levels, by a least-squares procedure, based upon an assignment of the observed transition frequencies which are provided as input data. The third part adjusts the original shielding and coupling parameters in an iterative procedure in such a way as to achieve an optimum match of the newly computed and the refined energy levels. A check on the correctness of the assignment is possible by comparison of the predicted with the observed intensities which have not been used in the analysis.

The final parameters are shown in Table 2; in the <sup>a</sup> R. C. Ferguson and D. W. Marquardt, *J. Chem. Phys.*, 1964, **41**, 2095.

<sup>&</sup>lt;sup>2</sup> J. A. Pople, W. G. Schneider, and H. J. Bernstein, "Highresolution Nuclear Magnetic Resonance," McGraw-Hill Book Co. Inc., New York, 1959, p. 135.

Figure the predicted spectrum (in deuterochloroform) is depicted together with the observed one. The fit of the line positions is excellent; the average deviation can be still lowered if the low intensity transitions (combination lines) are omitted from the analysis. Agreement with the observed intensities is satisfactory. The coupling constants seem reasonable; it is noteworthy that, as in naphthalene, the coupling constant between the two  $\beta$ -positions is smaller than that between adjacent  $\alpha$ - and  $\beta$ -positions, but the difference is much smaller.<sup>4</sup> Particular interest attaches also to the chemical shifts of the 5- and 6-protons, as we shall see later. The solvent shift is of the expected magnitude.

Difficulty was experienced in the preparation of deuterium compounds, as the usual method for introduction of deuterium in specific positions, namely a Grignard reaction with the corresponding bromoderivative followed by hydrolysis with heavy water could not be used, as it breaks the heterocyclic ring. The same is true for reduction of the corresponding diazonium salt with sodium stannite in heavy water.<sup>5</sup> We obtained them by reduction with sodium borodeuteride of the dry diazonium fluoroborates in perdeuteromethanol at low temperature; this reaction, introduced for deamination by Hendrickson,<sup>6</sup> has to our knowledge not been used to prepare labelled compounds. Yields of 50-75% have been reported,<sup>6</sup> but in our case only traces of the desired product were obtained. Substitution of ordinary methanol or dimethylformamide for the expensive perdeuteromethanol led to replacement of the diazonium group by hydrogen, while neither protio- nor deutero-benzothiadiazole could be isolated when heavy water was used as solvent. These observations indicate a radical mechanism for the reaction, with the deuterium atom which replaces the diazonium group coming from the deuteromethanol. The intermediate is presumably an aryl di-imide which, like di-imide and at higher temperatures arylazoalkanes, decomposes homolytically; the phenyl radical formed in the decomposition of benzeneazotriphenylmethane analogously reacts with the solvent rather than with the simultaneously formed triphenylmethyl radical.<sup>7</sup>

In the absence of other contributions to the total screening, a correlation has been shown to exist between the  $\pi$ -charge density on the carbon atom of an aromatic molecule to which a proton is bonded and the chemical shift of this proton. The linear equation  $\delta - \delta_{\text{benzene}} = -10.7(q-1)$  ( $\delta$  = chemical shift in p.p.m., q = charge density) has been suggested.<sup>8</sup> Additional sizeable contributions may come from (i) the magnetic anisotropy of ring hetero-atoms and substituents and (ii)

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ring-current effects. The shift arising from (i) has a  $1/r^3$  dependence and affects significantly only the protons close to the anisotropic centre; it should be minimal at the 5- and 6-positions of (I). The shift due to (ii) should be the same for these two positions, as they are placed symmetrically to either side of the long axis of the molecule. It follows then that the  $\pi$ -charges at the adjacent carbon atoms alone must be responsible for the chemical shifts of the 5- and 6-proton. According to the above equation, the charge densities at the 5- and 6-carbon atoms should differ by between 0.004 and 0.005 electrons.

This fact provides us with a simple check on molecular orbital treatments for sulphur. Owing to the fact that sulphur contributes a 3p-orbital which moreover can be contracted and hybridised with d-orbitals, incorporation of this frequently encountered hetero-atom into conventional molecular orbital schemes is not straightforward. In the Hückel approximation two methods are in use. They give different results whatever the parameters used, and a decision as to which of the two is to be preferred has so far not been possible.<sup>9</sup> Recently two Pariser and Parr calculations on thiophen have been carried out by Sappenfield and Kreevoy<sup>10</sup> and by Solony, Birss, and Greenshield<sup>11</sup> with the object of finding a suitable way in which sulphur can be treated. In both, parameters were adjusted to obtain agreement between the predicted and the observed spectrum. Although this object was achieved in both cases, the assignments differ, emphasising the fact that as there are more disposible parameters than observed transition frequencies more than one way exists in which a match can be obtained.

We have carried out a calculation on (I) using the latter authors' method. Here the sulphur atom is assumed to be non-hybridised, the  $p_z$ -orbital contributing two electrons to the  $\pi$ -system. There is considered to be a one-to-one correspondence between the doubly ionised sulphur and the singly ionised carbon, and the singly ionised sulphur and the neutral carbon atom, the occupation number of the  $p_z$ -orbital being the same in these cases. Pariser and Parr's approximation for the one-centre Coulomb repulsion integral can then be used also for sulphur. The two electrons are assumed to occupy slightly different orbitals, approximated by uniformly charged spheres. The Goeppert-Mayer and Sklar potential is used to evaluate the  $\alpha$ 's, the  $\beta$ 's are assumed, and a single determinant wave-function brought to self-consistency by an iterative process.

We find that this treatment does not give a satisfactory result as judged by our criterion. We obtained for the charge densities at the 5- and 6-position of (I) 1.009 and 0.983 electrons, *i.e.*, a difference about six times that observed.

<sup>&</sup>lt;sup>4</sup> N. Jonathan, S. Gordon, and B. P. Dailey, J. Chem. Phys., 1962, **36**, 2447.

<sup>&</sup>lt;sup>5</sup> Cf. A. P. Best and C. L. Wilson, J. Chem. Soc., 1946, 242.

<sup>&</sup>lt;sup>6</sup> J. B. Hendrickson, J. Amer. Chem. Soc., 1961, **83**, 1251. <sup>7</sup> H. Zollinger, "Azo and Diazo Chemistry," Interscience

Publishers, New York, London, 1961, p. 270. <sup>8</sup> T. Schaefer and W. G. Schneider, *Canad. J. Chem.*, 1963,

**<sup>41</sup>**, 966.

<sup>&</sup>lt;sup>9</sup> J. Koutecky, R. Zahradnik, and J. Paldus, J. Chim. phys., 1959, 56, 455.

<sup>&</sup>lt;sup>10</sup> D. S. Sappenfield and M. Kreevoy, *Tetrahedron*, 1963, **19**, Suppl. 2, 157.

<sup>&</sup>lt;sup>11</sup> N. Solony, F. W. Birss, and J. B. Greenshield, *Canad. Chem.*, 1965, **43**, 1569.

## EXPERIMENTAL

1,2,3-Benzothiadiazole.—This was prepared by diazotisation of commercial o-aminobenzenethiol,<sup>12</sup> isolated by steam-distillation, and purified by vacuum distillation followed by crystallisation from light petroleum (refrigerator), until a sample dissolved in concentrated sulphuric acid without colour formation.<sup>13</sup>

4-Deutero-1,2,3-benzothiadiazole. 4-Amino-1,2,3-benzothiadiazole (0.5 g.) was dissolved in concentrated sulphuric acid (2 ml.), nitrosylsulphuric acid (2 ml. 2M) was added to the magnetically stirred solution at  $ca. 10^{\circ}$ , and after 15 min. the mixture was poured on the minimum of ice necessary to keep the temperature below  $-5^{\circ}$ . Pre-cooled fluoroboric acid (10 ml., 48-50%) was then added, followed by cold ethanol (10 ml.), the precipitate of 4-diazonio-1,2,3benzothiadiazonium fluoroborate immiedately collected in the cold, washed with cold ethanol and ether, and dried over phosphoric oxide at  $0^{\circ}$  (yield 0.62 g., 75%).

The fluoroborate (0.25 g.) was suspended in cold perdeuteromethanol (5 ml.) in a small distillation flask, and sodium borodeuteride (0.04 g.) added in small portions at  $-5^{\circ}$  with magnetic stirring. After 1 hr. the solvent was distilled into an ice-cooled receiver (condenser omitted), the residue dried for 2 hr. in vacuo, and extracted first with hot light petroleum (b. p. 60–68°,  $3 \times 15$  ml.), then benzene (5 ml.). The combined extracts were chromatographed on an aluminium oxide (BDH)-light petroleum column (8  $\times$  1 cm.); the column was eluted with benzenelight petroleum (3:7) until a coloured band had reached the bottom. The eluate was dried on a rotatory evaporator (bath temp. 25°), the residue dissolved in benzene (2 ml.). and the deutero-1,2,3-benzothiadiazole isolated by preparative gas-liquid chromatography (200  $\times$  1 cm. column, 20% Apiezon L on Chromosorp W, 150°, flame ionisation detector) (yield ca. 2%).

5-, 6-, and 7-Deutero-1,2,3-benzothiadiazole.--These were prepared similarly, the recovered perdeuteromethanol being used. More water was added to the solution of the 5-diazonio-1,2,3-benzothiadiazole suphate, as this tended to precipitate.

Nuclear Magnetic Resonance Spectra.-These were recorded with a Varian Associates HR 100 high-resolution spectrometer, operating at a fixed frequency of 100 Mc./sec. The spectra were calibrated by the audio-modulation sideband technique, with tetramethylsilane as internal standard.

The spectra of the parent compound were recorded in

- 12 Cf. P. Jacobson and H. Janssen, Annalen, 1893, 277, 219.
- <sup>13</sup> W. H. Poesche, J. Chem. Soc. (B), 1966, 469.
  <sup>14</sup> J. Hinze and H. H. Jaffe, J. Amer. Chem. Soc., 1962, 84, 545; J. Phys. Chem., 1963, 67, 1505.

Spectral Analysis.—This was carried out with the "Analysis of n.m.r. spectra" programme by Ferguson and Marquardt (IBM share library no. 3165), all the observed transitions being used. It was necessary to reduce the first part of this programme (NMRIT) as its storage requirements exceeded the capacity of the available IBM 7040-1401 computer. This was done by removing the title and reducing the maximum submatrix dimension from 75 to 72. The flexibility of the programme was not impaired by this change, and only the rarely encountered  $A_4B_4C_2$  10 spin case was lost.

Molecular Orbital Calculation.—This was carried out with the programme used by Solony, Birss, and Greenshield for thiophen. A subroutine was added which computed the repulsion integrals and H-matrix elements which previously had to be supplied.

The valence-state ionisation potentials ( $I_{\rm S}=22.91$ ,  $I_{\rm N} = 14.12$ ,  $I_{\rm C} = 11.16$  ev) and electron affinities ( $E_{\rm S} =$ 12·39,  $E_{\rm N} = 1.78$ ,  $E_{\rm C} = 0.03$  ev) were taken from Hinze and Jaffe's Papers,14 the molecular dimensions were assumed to be the same as those reported for 2-methylmercaptobenzothiazole,<sup>15</sup> the effective nuclear charges  $Z_{\rm p}$  (S<sup>++</sup> 5.8, S<sup>+</sup> 5.45, N<sup>+</sup> 3.9, C<sup>+</sup> 3.25) were calculated by Slater's rules, the sphere diameter for C and N was obtained from Pariser and Parr's formula  $4.597/Z_p$ ,<sup>16</sup> that for S from  $7.775/Z_p$  Å.<sup>17</sup> The assumed  $\beta$ 's were  $\beta_{12} = -0.82$ ,  $\beta_{18}=-0.88,\;\beta_{23}=-2.7,\;\beta_{39}=-2.05,\;\text{all others}\;-2.34$ ev. Use of Clementi's effective nuclear charges<sup>18</sup> (S<sup>++</sup> 6·285, S^+ 5·905, N^+ 4·089, C^+ 3·421) had practically no effect on the result, while an increase in  $\bar{\beta}_{CS}$  led to an increase of the charge-density difference.

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- <sup>17</sup> N. Solony, personal communication. <sup>18</sup> E. Clementi and D. L. Raimondi, J. Chem. Phys., 1963, 38, 2686.