Nitroxide Radicals. Part 19.[1] Nuclear Magnetic Resonance Study of [2,2]Paracyclophan-4-yl t-Butyl Nitroxide

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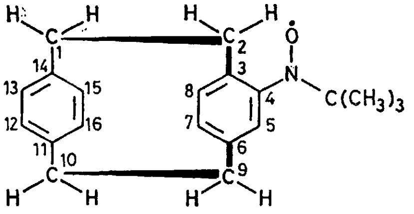
N.m.r. measurements on specifically deuteriated [2,2]paracyclophan-4-yl t-butyl nitroxides and 4,12-[2,2]paracyclophanylene *NN'*-di-t-butyl bisnitroxide give clear assignments of the proton hyperfine coupling constants. There is no substantial interaction of the unpaired electron with transannular protons.

THE fixed framework of [2,2]paracyclophanes, in which the slightly bent aryl rings are held face to face at a distance of *ca.* 3.1 Å, makes them interesting models for studying transannular electronic interactions. Derivatives with radical substituents (nitroxides,[2-5] verdazyls [6]) have been used as intramolecular spin probes to study transannular and direct interactions between the unpaired spin densities on the carbon atoms of the aryl ring bearing the radical substituent and the corresponding ' pseudo gem ' carbons of the other aryl ring. N.m.r. results obtained from 4-verdazyl[2,2]cyclophanes [6] and their deuteriated analogues initiated a restudy of the assignment of the proton hyperfine coupling constants of [2,2]cyclophan-4-yl t-butyl nitroxide,[2,5] and particularly that of the large coupling (+0.77 G) previously ascribed to 15-H. Accordingly, we prepared the deuteriated derivatives (2)—(4) and the biradical (5) by known procedures [2 5] and measured their e.s.r. and n.m.r. spectra.



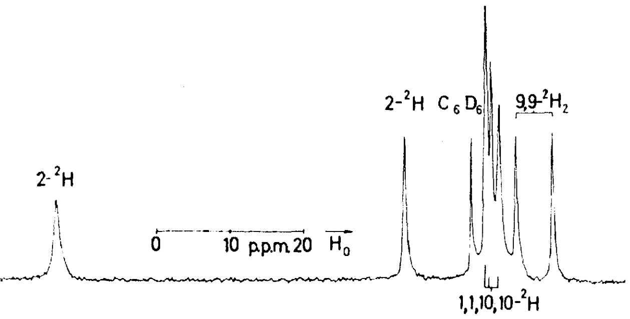
(1)
(2) 1,1,2,2,9,9,10,10-$^2H_8$
(3) 5,7,8,12,13,15,16-$^2H_7$
(4) 2,2,9,9-$^2H_4$,7-OCH_3
(5) 12-$N(\dot{O})C(CH_3)_3$

The e.s.r. spectra of the nitroxides (2)—(4) show three main lines, that due to (2) having numerous ill resolved subsplittings, which could not be analysed. The a_N values (14.8 G) are closer to that of di-t-butyl nitroxide (15.4 G) [7] than to that of phenyl t-butyl nitroxide (12.3 G) [8] indicating considerable steric interactions between the t-butyl NO group and the methylene group in the *ortho*-position as, for example, in *o*-alkylaryl t-butyl nitroxides (13.5 G).[9] The *g* values are in the range expected for nitroxides.[10]

TABLE 1
E.s.r. data of (2)—(4) in benzene

Compound	a_N/G	*g*
(2)	14.78	2.0061
(3)	14.74	2.0061
(4)	14.84	2.0061

N.m.r. paramagnetic shifts of organic free radicals [11,12] render directly the sign and the magnitude of electron–nuclei coupling constants. Small coupling constants below the resolution limits of e.s.r. and ENDOR can frequently be measured. This advantage makes n.m.r. particularly useful for the study of radicals such as (1)—(4), which have many small proton coupling constants. The n.m.r. spectra of nitroxides (2)—(4) are well resolved (see Figure) and exhibit resonance lines for all aliphatic and aromatic protons (D), except those whose signals are obscured by the intense resonance band of the solvent di-t-butyl nitroxide.[13] The resonance



²H N.m.r. spectrum of (2) in di-t-butyl nitroxide

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lines were assigned by comparison of the individual spectra of (1)—(4) and by analogy with n.m.r. data obtained previously for nitroxides [5,14] and verdazyls.[6] The values of the measured paramagnetic shifts are listed in Table 2.

The n.m.r. lines from the 5- and 7-H in the nitroxide aryl ring are shifted to high field yielding a larger negative splitting constant for 5- than for the 7-H as in 2,5-dimethylphenyl t-butyl nitroxide and related *ortho*-substituted aryl nitroxides (for which $a_{o\text{-H}} > a_{m\text{-H}} > a_{p\text{-H}}$).[14] Accordingly, the positive 8-H splitting is slightly larger than the 7-H splitting. The methylene protons (2-,2-,9-,9-H) of the nitroxide aryl system yield two positive and two negative splittings. The positive ones are assigned to 2,2-H_2 (β to positive $\rho_{C\text{-}3}$) and the negative ones to 9,9-H (β to negative $\rho_{C\text{-}6}$). This assignment is strongly supported by results obtained from a verdazyl derivative, in which 2,2-H_2 have been selectively deuteriated.[6] We tentatively attribute the remarkable large positive splitting to the *anti*-2-H with respect to the nitroxide group, for which spin polarisation, hyperconjugation ($\rho_{C\text{-}3}$) and homohyperconjugation [15,16] [in (6), the N–O$^•$ group is considerably twisted out of the aryl plane for steric reasons] reinforce each other.

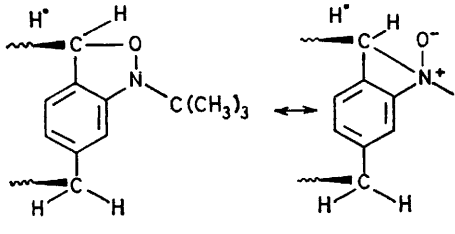
TABLE 2

H and D paramagnetic shifts $\delta_p = (\nu_p - \nu_d)/\nu_d$* and coupling constants $a_{H,D}$ of (2)—(5) in di-t-butyl nitroxide at 300 K

	Assignment	δ_P	a_D/G	a_H/G
(2)	$C(CH_3)_3$	−18.3		−0.25
	1,1,10,10-$^2H_4$	2.2	0.005	0.03 †
		(2 D)		
		1.5	0.003	0.02 †
		0.5	0.001	0.01 †
	2,2-$^2H_4$	60.0	0.125	0.81 †
		14.5	0.030	0.20 †
	5-H	−75.4		−1.02
	7-H	−45.1		−0.61
	8-H	49.5		0 67
	9,9-$^2H_2$	−6.8	−0.014	−0.09 †
		−1.9	−0.004	−0.03 †
	12,13,15,16-H ‡			
(3)	$C(CH_3)_3$	−17.8		−0.24
	1,1,9,9,10,10-$^2H_6$ ‡			
	2,2-H_2	59.5		0.80
		13.0		0.18
	5-^{2}H	−72.3	−0.151	−0.98 †
	7-^{2}H	−42.8	−0.089	−0.58 †
	8-^{2}H	49.4	0.103	0.67 †
	12,13,15,16-$^2H_4$	1.2	0.003	0.02 †
		(3 D)		
		−1.5	−0.003	−0.02 †
(4)	$C(CH_3)_3$	−17.7		−0.24
	1,1,10,10,12,13,15,16-$^2H_8$ ‡			
	2,2-$^2H_2$	49.2	0.103	0.67 †
		10.5	0.022	0.14 †
	5-H	−72.0		−0.97
	OCH_3	4.9		0.07
	8-H	40.5		0.55
	9,9-$^2H_2$	−3.7	−0.008	−0.03 †
		−3.3	−0.007	−0.03 †
(5) §	$C(CH_3)_3$	−16.6		−0.23
	1,1,9,9-H_4			‡
	2,10-H_2	57.5		0.78
	2,10-H_2	16.7		0.23
	5,13-H_2	−75.6		−1.02
	7,15-H_2	−37.7		−0.51
	8,16-H_2	46.1		0.62

* Shift relative to the corresponding H(D) resonance in the parent [2,2]paracyclophane. † Calculated $a_H = 6.51\, a_D$. ‡ These resonances could not be definitely assigned or are covered by the solvent band. § Measured at 220 MHz using a Varian HR 220 spectrometer.

For the protons of the attached 1,4-xylenylene system only small paramagnetic shifts are observed as the spectra of the nitroxide (2) and (3) clearly show. The sizes of these shifts have a considerable relative experimental error, since the position of the diamagnetic reference protons (multiplets not analysed) can only be measured to within ±1 p.p.m.



(6)

The n.m.r. study of the [2,2]paracyclophan-4-yl t-butyl nitroxide reveals no substantial transannular interaction of the unpaired electron delocalised in the nitroxide aryl system with protons of the attached 1,4-xylenylene part and the large splitting (+0.77 G) previously assigned [5] to 15-H is reassigned to one of the 2-H protons. Hence, there is also no substantial direct interaction with 15-H fixed pseudogeminal to the nitroxide nitrogen.

These conclusions were supported by an n.m.r. study of the [2,2]paracyclophanylene *pseudo-para*-bisnitroxide (5). From the limited experimental data available on the n.m.r. spectra of biradicals [17] it appears that proton hyperfine coupling constants in biradicals are related to those of the corresponding protons in the related monoradicals in the following way. For a biradical $\dot{A}-\dot{B}$, the coupling constants of protons in the A moiety are approximately equal to the arithmetic sum of the coupling constants of the corresponding A protons in the monoradicals $\dot{A}-B$ and $A-\dot{B}$ and likewise for the B protons. Since the coupling constants of the protons in the paracyclophanylene bisnitroxide (5) (Table 2) are very similar to those in the monoradical (1) there is clearly little transannular transmission of spin in (1) or in (5). In particular, the similarity of $a_{7\text{-H}}$ (−0.61 G) in the monoradical (1) and $a_{7,15\text{-H}}$ (−0.51 G) in the biradical (5)

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excludes the substantial O–15-H interaction previously suggested.

EXPERIMENTAL

^{1}H N.m.r. spectra were measured using the broad line technique (Bruker Spectrospin HX-90 MHz, 30 Hz modulation, phase sensitive detection, and linear field sweep). ^{2}H Spectra were measured using a Bruker Spectrospin HX-360 MHz intrument.

[1,1,2,2,*9,9,10,10*-$^{2}H_{8}$][2,2]*Paracyclophan*-4-*yl t-Butyl Nitroxide*.—This was prepared from [1,1,2,2,9,9,10,10-$^{2}H_{8}$][2,2]paracyclophane [6] as described in the literature,[3,18] for the undeuteriated compound, m.p. 76—77° (Found: M^{+}, 302.236. $C_{20}H_{16}D_{8}NO$ requires M, 302.235).

[5,7,8,12,13,15,16-$^{2}H_{7}$][2,2]*paracyclophan*-4-*yl t-Butyl Nitroxide*.—This was prepared from [4,5,7,8,12,13,15,16-$^{2}H_{8}$][2,2]paracyclophane [6] as above,[3,18] m.p. 75—76° (Found: M^{+}, 301.234. $C_{20}H_{17}D_{7}NO$ requires M, 301.230).

4-*Bromo*-7-*methoxy*-[2,2,9,9-$^{2}H_{4}$][2,2]*paracyclophane*.—To a solution of 7-methoxy[2,2,9,9-$^{2}H_{4}$][2,2]paracyclophane [6] (2.42 g) in acetic acid (100 ml) at 15 °C bromine (1.60 g) in acetic acid (20 ml) was added dropwise with stirring. The product was precipitated by slowly adding water to the mixture. Crystallisation of the material from ethanol yielded *plates* (2.2 g, 69%), m.p. 164—165° (Found: C, 63.85; H + D, 7.0; Br, 24.6. $C_{17}H_{9}BrD_{8}O$ requires C, 63.7; H + D, 6.6; Br, 25.0%), τ 6.90 (1,1,10,10-H, m), 6.26 (7-OCH_{3}, s), 4.29 (8-H, s), 3.51 (5-H, s), 3.55br (13,16-H_{2}, d), 3.21 (12-H, q, *J* 9, 2 Hz), and 2.87 (15-H, q, *J* 9, 2 Hz).

7-*Methoxy*-[2,2,9,9-$^{2}H_{4}$][2,2]*paracyclophan*-4-*yl t-Butyl Nitroxide*.—To a solution of the above 4-bromo compound (2.1 g) in ether (75 ml) under nitrogen a 0.13M solution (hexane) of butyl-lithium (11.5 ml) was added dropwise with stirring. After stirring for 30 min at room temperature the mixture was cooled to 0°, and then a solution of 2-methyl-2-nitrosopropane (2.0 g) in ether (25 ml) was added during 5 min. The blue solution was heated under reflux for 15 min and after cooling, water (5 ml) was added to the mixture. Evaporation of ether left a brown residue, which was chromatographed on silica gel (light petroleum) to give, upon elution with light petroleum–ether (95 : 5), a red fraction containing a mixture of hydroxylamine and nitroxide (150 mg). This product in benzene (5 ml) was shaken with silver oxide (50 mg) for 30 min. The mixture was then filtered and the filtrate evaporated. Crystallisation of the residue from pentane yielded the *nitroxide* (50 mg) as red needles, m.p. 105—106° (Found: C, 76.8; H + D, 9.7; N, 4.3%; M^{+}, 328.222. $C_{21}H_{22}D_{4}NO_{2}$ requires C, 76.8; H + D, 9.2; N, 4.5%; M, 328.221).

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