

Long-range Deuterium-induced ^{13}C Nuclear Magnetic Resonance Isotope Shifts for Single Assignment and Determination of Deuteriation Site in Cyclodecanone Isotopomers

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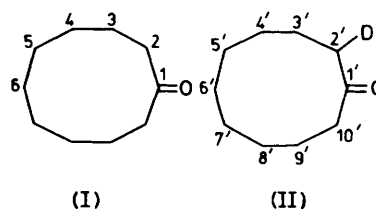
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Summary The incremental ^{13}C chemical shifts observed upon replacement of protons by deuterons in cyclodecanones give line assignments which are not otherwise obtainable; apart from directly bonded carbon, isotope shifts were detected across 2, 3, 4, 5, and 6 bonds.

$[\text{CH}_2]_n \text{CDOH}$ with lead tetra-acetate.³ ^{13}C n.m.r. spectroscopy is the preferred method although unambiguous signal assignment becomes critical for the higher homologues.

SPECIFIC deuteriation has been commonly employed for signal assignment in the ^{13}C n.m.r. spectra of known compounds, usually by exploiting the fact that the carbon atom whose protons are substituted by deuterons gives rise to a greatly attenuated signal.¹ This is a consequence of multiplet formation and a reduction in the dipolar ^{13}C relaxation rate. Only in a few cases, however, has the geminal isotope effect, which typically is *ca.* 0.05–0.10 p.p.m., been used for assignments.² The observation of such subtle effects requires appropriate experimental conditions. Since shifts as small as these can be obscured by concentration effects, it is imperative that the sample contains both isotopomers. Moreover, decoupling has to be optimised and both magnet and digital resolution should be well beyond the shifts to be observed. Under these conditions one- and two-bond, as well as long-range, isotope shifts can be observed.

The present study was undertaken to determine the deuterium labelling site in cycloalkanones formed upon oxidation of the corresponding monolabelled alcohols



This is exemplified by cyclodecanone (I) whose proton noise-decoupled 25 MHz ^{13}C n.m.r. spectrum [Figure (a)] displays three lines within a resonance range as small as 0.5 p.p.m. Whereas C-1, C-2, and C-6 could immediately be designated on the basis of their characteristic chemical shifts and intensities, the assignment of the remaining carbons was unclear. In order to solve this $[2\text{-}^2\text{H}_1]$ cyclodecanone (II) (50% deuteriated) was synthesized as a reference compound. Its proton-decoupled ^{13}C spectrum is displayed in Figure (b). Since the spectrum essentially results from a mixture of the two isotopomers, the isotope shifts can be measured with great accuracy. As expected C-2' gives rise to a triplet resonating at δ 41.65 p.p.m.,

TABLE. Deuterium-induced ^{13}C isotope shifts^a in the deuteriated cyclodecanones (II), (III), and (IV)^b

Isotopomer	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10
(II) ^b	+0.061	-0.364	-0.077	-0.048	-0.025	0	+0.029	+0.028	-0.13	+0.29
(III) ^b	ca. 0	— ^c	< -0.04	-0.056	-0.414	-0.091	— ^c	-0.013	ca. 0	— ^c
(IV) ^b	ca. 0	— ^c	ca. 0	-0.013	-0.084	-0.407	-0.084	-0.013	ca. 0	— ^c

^a In p.p.m. relative to the shift of the prolio compound (a positive sign indicates a displacement to lower field); accuracy: ± 0.006 p.p.m. (0.16 Hz/point digital resolution). ^b (II): $[1\text{-}^2\text{H}_1]$ cyclodecanone; III: $[5\text{-}^2\text{H}_1]$ cyclodecanone; (IV): $[6\text{-}^2\text{H}_1]$ cyclodecanone. ^c Not listed due to ambiguous assignment or overlapping signals.

which is shifted to higher field by 0.364 p.p.m. relative to C-2 in (I). The resonance for C-3, whose assignment follows from its characteristic upfield shift (γ effect exerted by the carbonyl group) is accompanied by a second line at slightly higher field ($\Delta\delta -0.077$). The latter pertains to C-3 in (II) (*i.e.* C-3') and originates from the geminal isotope effect. The broadening is due to unresolved coupling to deuterium ($^2J_{\text{CD}}$). Since the lifetime of the deuterium spin states is comparable in magnitude to the reciprocal of the C-D coupling constant [$T_1^0 \approx (2\pi J)^{-1}$], the multiplet is broadened. Crucial for the differentiation of C-4 and C-5, however, was the vicinal isotope effect observed for C-4 ($\Delta\delta -0.048$). The assignment of this carbon is further corroborated by the presence of vicinal spin-spin coupling to deuterium (typically *ca.* 1 Hz). This manifests itself in the broad shoulder to high field of the line at δ 25.09 p.p.m. The broadened line thus pertains to C-4 of (II), *i.e.* to C-4'. The broadening is again caused by the relatively fast relaxation of the deuterium.

At the resolution observed (*ca.* 0.2 Hz), which was achieved by centring the decoupler at the proton frequency and utilizing a narrow band width for noise modulation, it became possible to resolve long-range isotope shifts. These are much smaller than those for carbons in geminal and vicinal positions. From Figure (b) it is readily recognized that besides those already discussed, further resonances occur near the lines due to C-2, C-3, and C-4, which are assignable to C-10', C-9', and C-8' and are caused by 3-, 4-, and 5-bond isotope shifts, respectively. It is noteworthy that in the case of C-10' and C-8' the observed shifts are positive, *i.e.* the displacement occurs towards lower field, as for the carbonyl carbon, the behaviour of which is well established.⁴ The distinction between C-2 and C-10', or C-4 and C-8', is straightforward on the basis of their relative intensities. Also the line assignable to C-5 is accompanied by two lower intensity resonances that belong to C-5' and C-7', consistent with a 4- and 6-bond isotope effect, respectively. Only C-6 exhibits no resolved splittings

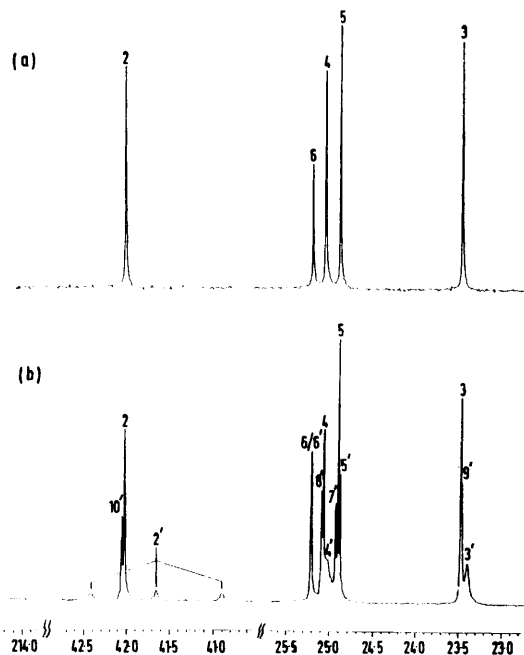


FIGURE. 25.2 MHz proton noise-decoupled ^{13}C n.m.r. spectra (XL-100), recorded at a digital resolution of 0.15 Hz and proton irradiation at δ_{H} 1.0 (noise bandwidth: 500 Hz); (a) cyclo-decanone; (b) $[2\text{-}^2\text{H}_1]$ cyclo-decanone, 50% deuteriated.

although the line is significantly broadened. The isotope shifts for the isotopomer (II) are listed in the Table, along with those for the unknown cyclodecanone species, obtained in the lead tetra-acetate oxidation of $[1\text{-}^2\text{H}_1]$ cyclodecanol, which proved to be a mixture of $[^2\text{H}_1]$ cyclodecanones labelled at C-5 and C-6.

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⁴ G. E. Maciel, P. D. Ellis, and D. C. Hofer, *J. Phys. Chem.*, 1967, **71**, 2160.