Conformational Free Energy Difference (—$\Delta G°$ value) of the Methyl Group in Methylcyclohexane: an Accurate Determination by the Direct, Low-temperature Nuclear Magnetic Resonance Method

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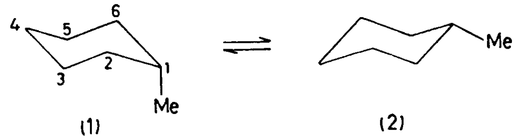
Summary The low-temperature pulse Fourier transform ^{13}C n.m.r. spectrum of methylcyclohexane, enriched with ^{13}C in the methyl substituent, shows that the ratio of major conformation (methyl equatorial) to minor conformation (methyl axial) is 164 : 1 (0·6% methyl axial), corresponding to a conformational free energy difference at 172 K of $1{\cdot}74 \pm 0{\cdot}06$ kcal mol^{-1} ($7{\cdot}30 \pm 0{\cdot}25$ kJ mol^{-1}).

THE conformational free energy difference (—$\Delta G°$ value) of the methyl group is one of the cornerstones of the quantitative conformational analysis of cyclohexanes; it has been determined often,[1] but only once[2] by the 'direct' method from methylcyclohexane (**1** $\rightleftharpoons$ **2**) in which the proportion of minor conformation (**1**), with axial methyl, is estimated under conditions of slow exchange. In the



(1) (2)

^{13}C n.m.r. experiment of Anet *et al.*[2] (**1**) was clearly identified, but the derived $-\Delta G°$ value (1·6 kcal mol^{-1}) was limited in accuracy by the high noise level of the continuous wave spectrum. We briefly report a $-\Delta G°$ value of greater accuracy, determined by spectroscopic examination of methylcyclohexane, enriched with ^{13}C at the methyl carbon, using pulse Fourier transform ^{13}C n.m.r. spectroscopy.

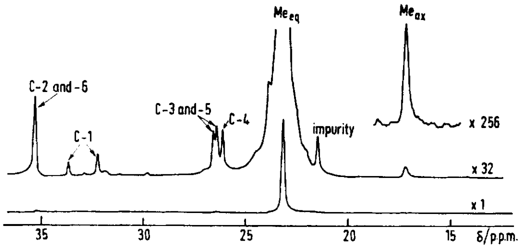


Figure The ^{13}C n.m.r. spectrum of [*Me*-^{13}C]methylcyclohexane at 172 K in CFCl$_3$–CDCl$_3$, measured at 25·15 MHz with a JEOL P.S. 100 spectrometer, JEOL pulse programmer, and NICOLET 1085 computer. The free induction delays were sampled over 2500 Hz using 8192 data points. The pulse width was 4 μs (30° tip) and the repetition time was 4 s.

[*M*e–^{13}C]Methylcyclohexane† was synthesised in 47% overall yield from ^{13}C-enriched methyl iodide (2 g, 91·0 ^{13}C atom %) and cyclohexanone by a classical route through 1-methylcyclohexan-1-ol and 1-methylcyclohex-1-ene. The noise-decoupled ^{13}C spectrum, recorded at 172 K in CFCl$_3$–CDCl$_3$ (90 : 10 v/v) showed signals for the enriched methyl carbon at δ 23·47 (methyl equatorial) and 17·43 (methyl axial) (Figure). In addition, the natural abundance ^{13}C carbon atoms of (**2**) gave signals at δ 33·2 [C–1, d, ^1J (^{13}C–^{13}C) 36·0 Hz], 35·5 (C–2 and –6, s), 26·7 [C–3 and –5, d, ^3J(^{13}C–^{13}C) 4·3 Hz], and 26·4 (C–4, s) p.p.m.

The ratio [**2**]/[**1**] was found to be 165·2 by instrumental integration, and to be 163·2 by hand planimetry. The ^{13}C spin–lattice relaxation time (T_1) values for equatorial and axial methyl carbon nuclei may differ, but are both expected to be < 1 s at 172 K (*cf.* ref. 3). Consequently, with a pulse angle of 30° and a pulse repetition time of 4 s, the relative signal areas should be an accurate measure of the corresponding molecular proportions.

The equilibrium constant of 164·2 ± 7 (ref. 2. gave *ca.* 100), taken in conjunction with the sample temperature of 172 ± 4 K, leads to a $-\Delta G°_{172}$ value, for methyl in methylcyclohexane, of 1·74 ± 0·06 kcal mol^{-1}, the present accepted value[4] being 1·7 kcal mol^{-1}.

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† >99% pure by g.l.c., the identified impurities being cyclohexanone (<0·5%) and 1-methylcyclohex-1-ene (<0·5%).

[1] *Cf.* E. W. Garbisch, Jr., B. L. Hawkins, and K. D. Mackay, in 'Conformational Analysis: Scope and Present Limitations', G. Chiurdoglu, Academic Press, New York, 1971, p. 93; E. L. Eliel and T. J. Brett, *J. Amer. Chem. Soc.*, 1965, **87**, 5039.
[2] F. A. L. Anet, C. N. Bradley, and G. W. Buchanan, *J. Amer. Chem. Soc.*, 1971, **93**, 258.
[3] H. Booth and M. L. Jozefowicz, *J.C.S. Perkin II*, in the press.
[4] *Cf.* J. A. Hirsch, *Topics Stereochem.*, 1967, **1**, 199.