Tetrahedron Letters,Vol.24,No.42,pp 4555-4558,1983 0040-4039/83 $3.00 +.00
Printed in Great Britain

HIGH RESOLUTION ^{13}C NMR SPECTROSCOPY OF OXYGENATED HEXALIN, OCTALIN AND DECALIN DERIVATIVES IN SOLUTION AND THE SOLID STATE: CONFORMATIONAL ANALYSIS AND CRYSTAL LATTICE EFFECTS

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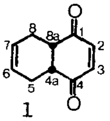
Abstract. The high resolution, proton-decoupled ^{13}C NMR spectra of several oxygenated hexalin, octalin and decalin derivatives have been obtained in solution and in the solid state (cross polarization, magic angle spinning). The results are used to deduce both the static (solid state) and dynamic (solution) conformational properties of these systems, and it is demonstrated that the solid state spectra provide information on the number of independent molecules in the crystallographic asymmetric unit.

In a previous publication[1] we demonstrated that high resolution solid state ^{13}C NMR spectroscopy[2] can be used for the conformational analysis of derivatives of the oxygenated cis-hexalin system **1**. In this communication we (1) extend the method to the corresponding octalin and decalin systems, (2) compare the solid state spectra with the solution spectra both above and below the coalescence temperatures, (3) calculate the free energies of activation for the conformational interconversions in solution, and (4) demonstrate that solid state ^{13}C NMR can be used to indicate the number of independent molecules in the crystallographic asymmetric unit. Spectra are reported for compound **1** itself[3] and for its reduction products **2**, **3** and **4** as well as for the trans isomer **5** and cyclohexane-1,4-dione (**6**).[4] Table I summarizes the data for compounds **2**, **3** and **5**.



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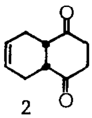

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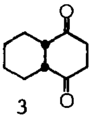

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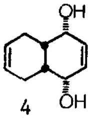

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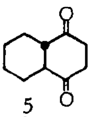

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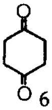

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The data clearly indicate that compounds **2** and **3** crystallize in conformations in which nominally equivalent carbon atoms are magnetically non-equivalent, whereas in solution, an average plane of symmetry is achieved through rapid conformational isomerization. The enantiomeric conformations 2a and 2b (below) fulfill these requirements for compound 2; an analogous pair of conformers can be drawn for compound 3. The ketone-containing ring of compounds 2 and 3 is assumed to exist preferentially in a twist-boat conformation in analogy with cyclohexane 1,4-dione.[5] The X-ray crystal structure of cyclohexane-1,4-dione itself reveals a slight distortion from perfect C_2 symmetry,[6] and this is clearly evident from its solid state spectrum which shows two well resolved carbonyl resonances at 212.4 and 214.9 ppm as well as a multiplet centered at 36 ppm due to the four magnetically non-equivalent methylene carbons. In contrast, trans-decalin-1,4-dione (5) exhibits only singlets, both in solution and the solid state, indicating in the latter medium, a conformation with essentially perfect C_2 symmetry. The twist-boat/chair conformation shown below seems most likely, but a chair/chair conformation also fits the data. X-ray studies on this point are planned.

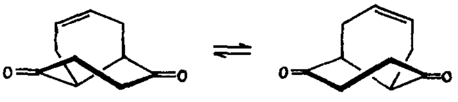

2a 2b

Table I. ^{13}C NMR Chemical Shift Data for Compounds 2, 3 and 5[a]

Carbon Atom	2 Solution	2 Solid	3 Solution	3 Solid	5 Solution	5 Solid
C(1,4)	209.1	212.7 213.4	210.2	212.7 213.5	209.2	211.2
C(2,3)	35.9	33.7 38.3	36.5	34.9 37.1	36.8	36.3
C(4a,8a)	44.9	43.9 44.4	48.2	46.5 49.4	49.9	48.0
C(5,8)	23.6	22.0 25.8	23.5	22.2 25.1	24.8	26.6
C(6,7)	124.5	125.5 127.1	25.9	25.4 27.6	26.5	27.6

[a] The solid state spectra were obtained at room temperature on a Bruker CXP-200 FT NMR spectrometer, and the solution spectra were measured at the same temperature on a Bruker WH-400 FT instrument. The chemical shifts are given in ppm relative to TMS. Assignments are based on SFORD splitting patterns. The C(5,8) and C(6,7) assignments for compounds 3 and 5 are tentative and may be reversed.

In the case of compound 1, carbon atoms which appear as singlets in solution give rise to *four lines* rather than the expected two lines in the solid state (Figure 1). This can be attributed to the fact that the crystallographic asymmetric unit of compound 1 contains two independent molecules,[7] each of which contributes two lines. A similar effect is noted for diol 4 and its 6,7-dimethyl derivative, both of which also crystallize with

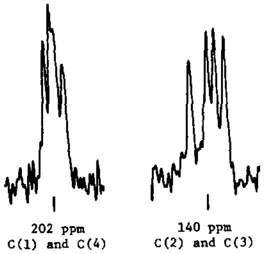
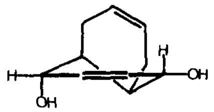


Figure 1. Partial solid state spectrum of compound 1.

two independent molecules per asymmetric unit.[8] Cooling solutions of compounds 1 and 2 to -90°C has no effect on their NMR spectra. However, when solutions of diol 4 are cooled, the room temperature spectrum, which consists of singlets at 130.2, 127.9, 69.0, 35.0 and 25.4 ppm, is replaced by a series of doublets at essentially the same chemical shifts.[9] This can be attributed to the static spectrum of the half-chair/half-chair conformation of this compound,[8] and further indicates that the four line pattern observed for each pair of "equivalent" carbons of 4 in the solid state is due to two independent molecules in the asymmetric unit.



half-chair/half-chair 4

Ene-diones with methyl substituents at C(4a) and C(8a) also have coalescence temperatures between 25°C and -90°C, and the temperature-dependent spectra can be used to calculate the conformational free energies of activation. Figure 2 shows the C(4a)/C(8a) methyl signal pattern of ene-dione 7 as a function of temperature. The coalescence temperature is -58°C, and making use of the relationship $\Delta G^{\ddagger} = 19.14\ T_c(9.97 + \log T_c/\delta\nu)$ (J mole^{-1}),[10] in which $\delta\nu$ is the chemical shift difference between the signals in the slow exchange limit, an energy barrier of $\Delta G^{\ddagger}_{215} = 38.5$ kJ mole^{-1} (9.2 kcal mole^{-1}) may be calculated. The 6,7-dimethyl derivative of 7 has similarly been determined to have a ring inversion $\Delta G^{\ddagger}_{203} = 36.3$ kJ mole^{-1} (8.7 kcal mole^{-1}). These barriers, which are of interest with respect to the conformation-controlled solution photochemistry of these and related compounds,[11] are well below that of 9,10-dimethyl-cis-decalin ($\Delta G^{\ddagger}_{298} = 15.2$ kcal mole^{-1}).[12] This is consistent with the diminution of cyclohexane inversion barriers which accompanies the introduction of sp^2-hybridized carbon atoms.

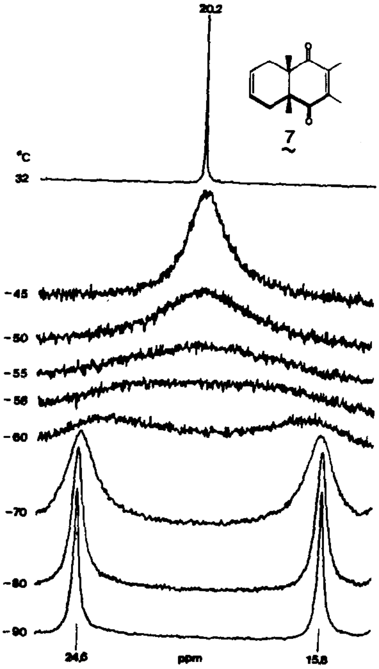


Figure 2. Temperature-dependent spectrum of compound 7 in CD_2Cl_2.

Acknowledgement. We thank the Natural Sciences and Engineering Research Council of Canada for financial support and Dr. A. Naito for many helpful discussions.

1. C.A. McDowell, A. Naito, J.R. Scheffer and Y-F. Wong, *Tetrahedron Lett.*, *22*, 4779 (1981).
2. For recent reviews and leading references, see (a) C.S. Yannoni, *Acc. Chem. Res.*, *15*, 201 (1982); (b) J.R. Lyerla, C.S. Yannoni and C.A. Fyfe, *Acc. Chem. Res.*, *15*, 208 (1982); (c) L.B. Alemany, D.M. Grant, R.J. Pugmire, T.D. Alger and K.W. Zilm, *J. Am. Chem. Soc.*, *105*, 2133 and 2142 (1983).
3. E.E. van Tamelen, M. Shamma, A.W. Burgstahler, J. Wolinsky, R. Tamm and P.E. Aldrich, *J. Am. Chem. Soc.*, *91*, 7315 (1969.
4. Compound **2** was prepared by zinc-acetic acid reduction of **1** by the method of van Tamelen, et. al.[3] Catalytic hydrogenation of **2** afforded **3**, and base-catalyzed epimerization of **3** gave **5**. Compounds **2**, **3** and **5** were first prepared by K. Alder and G. Stein, *Ann*, *501*, 247 (1933). Diol **4** was prepared by sodium borohydride reduction of **1** in the presence of cerium trichloride, *cf.*, J-L. Luche, *J. Am. Chem. Soc.*, *100*, 2226 (1978). Details will be reported in a full paper.
5. Review: G.M. Kellie and F.G. Riddell, *Topics Stereochem.*, *8*, 225 (1974).
6. (a) A. Mossel and C. Romers, *Acta Cryst.*, *17*, 1217 (1964); (b) P. Groth and O. Hassel, *Acta Chem. Scand.*, *18*, 923 (1964).
7. S.E.V. Phillips and J. Trotter, *Acta Cryst.*, *B33*, 996 (1977).
8. Compound **4**: S. Ariel and J. Trotter, *Acta Cryst.*, submitted for publication. 6,7-Dimethyl-**4**: A.S. Secco and J. Trotter, *Acta Cryst.*, *C39*, 125 (1983).
9. In acetone-d_6 at -90°C, δ ppm (128.5 and 132.4), (127.3, fortuitous singlet), (66.0 and 69.8), (34.4 and 36.3), and (22.2 and 28.5). Similar results were obtained for the 6,7-dimethyl derivative of **4**.
10. H. Günther, "NMR Spectroscopy - An Introduction," John Wiley and Sons, New York, 1980, pp 238-244.
11. (a) J.R. Scheffer, K.S. Bhandari, R.E. Gayler and R.A. Wostradowski, *J. Am. Chem. Soc.*, *97*, 2178 (1975); (b) J.R. Scheffer, B.M. Jennings and J.P. Louwerens, *J. Am. Chem. Soc.*, *98*, 7040 (1976).
12. L.M. Browne, R.E. Klink and J.B. Stothers, *Can. J. Chem.*, *57*, 803 (1979).

(Received in USA 27 June 1983)