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STEREOCHEMICAL DYNAMICS OF CROWN ETHERS: RING INVERSION IN ISOMERIC DICYCLOHEXANO-18-CROWN-6 SYSTEMS AS STUDIED BY ^{13}C MAGNETIC RESONANCE AT LOW TEMPERATURE

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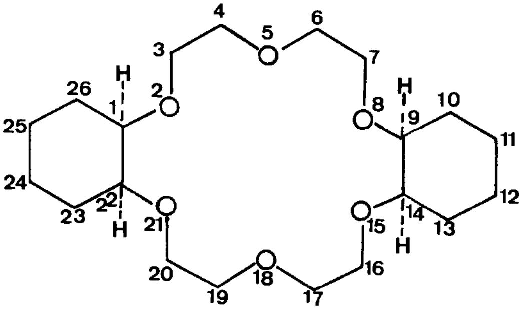
Abstract: From ^{13}C NMR coalescence temperature measurements, free energies of activation for degenerate ring reversal in two configurationally isomeric dicyclohexano-18-crown-6 ethers have been determined to be ca. 10.2 kcal/mole, with higher barriers for the 1:1 complexes with potassium phenoxide.

Despite the large volume of published work$^{(1)}$ regarding the stereochemistry of 18-crown-6 and its derivatives, no reports of ring inversion barrier determinations in these materials have appeared. Herein we present results of ^{13}C NMR studies of two isomers of the title crown ether, specifically the cis-syn-cis isomer 1 and the cis-anti-cis isomer 2 (below)$^{(2)}$ which permit calculation of these barriers. The influence of complexation of 1 and 2 with K $^{+}$ on these parameters also has been examined.



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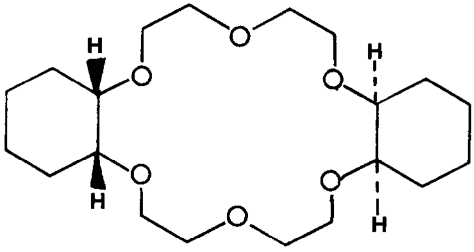

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At 298 K in a variety of solvents, the ^{13}C spectra$^{(4)}$ of 1 and 2 show 5 resonances, indicative of fast ring inversion on the NMR timescale. Upon cooling, the resonances for

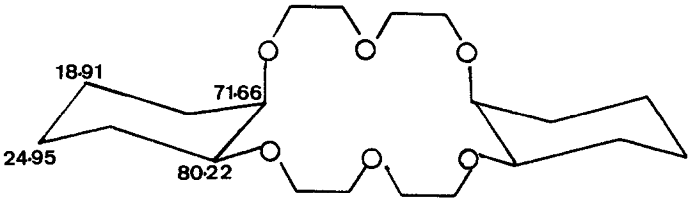
C-1,9,14,22, and C-11,12,24,25 each separate into two lines of equal intensity, giving "slow exchange" spectra at 198 K. From coalescence temperatures (T_c) and the chemical shift differences, one can use the Eyring equation to calculate $\Delta G^{\neq}$, the free energy of activation for ring reversal. Data are summarized in Table 1. Chemical shift differences between separate conformers for the other three carbon types of 1 and 2 are not sufficiently large at 198 K to permit detection of the separate forms.

Table 1

Compd	Solvent	Carbon(5)	δ_c(at 298K)	δ_c(198K)	T_c(K)	$\Delta G^{\neq}$(Kcal/mol)
1	CD_2Cl_2	1,9,14,22	77.59	80.22 71.66	233.0	10.3
1	MeOD	1,9,14,22	78.74	81.32 74.44	228.0	10.2
1	CD_2Cl_2	11,12,24,25	22.47	24.95 18.91	230.0	10.4
1	MeOD	11,12,24,25	23.04	25.46 20.15	218.0	9.9
1	CD_2Cl_2	3,7,16,20	68.43			
1	MeOD	3,7,16,20	69.17			
1	CD_2Cl_2	4,6,17,19	71.20			
1	MeOD	4,6,17,19	71.99			
1	CD_2Cl_2	10,13,23,26	27.92			
1	MeOD	10,13,23,26	28.56			
2	CD_2Cl_2	1,9,14,22	77.44	79.61 72.43	228.0	10.2
2	MeOD	1,9,14,22	78.53	80.73 73.83	228.0	10.2
2	CD_2Cl_2	11,12,24,25	22.48	24.75 19.41	230.0	10.4
2	MeOD	11,12,24,25	23.04	25.35 20.18	223.0	10.1
2	$CDCl_2$	3,7,16,20	68.19			
2	MeOD	3,7,16,20	69.03			
2	CD_2Cl_2	4,6,17,19	70.82			
2	MeOD	4,6,17,19	71.56			
2	CD_2Cl_2	10,13,23,26	27.98			
2	MeOD	10,13,23,26	28.54			

Both 1 and 2 are expected to undergo degenerate inversions of their 18-membered rings which necessarily involve inversion of their 6-membered rings(1). The observed free energies of activation for 1 (10.2 ± .2 Kcal/mol) and for 2 (10.2 ± .1 Kcal/mol) are, perhaps not surprisingly within 0.5-0.8 Kcal/mol of ring reversal barriers for *cis*-1,2-disubstituted cyclohexanes(7).

The individual ^{13}C shifts for C-1,9 *vs* C-14,22 and C-11,25 *vs* C-12,24 of 1 when ring inversion is slow on the NMR timescale can be assigned by consideration of the known(8) substituent effects of axial vs equatorial OR groups on the ^{13}C shifts of individual cyclohexane conformers. Accordingly we assign the resonances (for 1 in CD_2Cl_2 at 198 K) for example, as indicated below.



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We also have examined the 1:1 complexes of 1 and 2 with K^+ (as Koø) in MeOD solutions as a function of temperature. The results are summarized in Table 2. As expected for ring inversion, again equal populations of conformers were observed and coalescence phenomena were noted for 4 out of the 5 possible sites, thus allowing calculation of the free energies of activation.

Table 2

Complex	Carbon	δ_c(at 298 K)	δ_c(at 183 K)	T_c(K)	$\Delta G^{\neq}$(Kcal/mol)
1 + Koø	1,9,14,22	78.83	81.58 76.06	245.0	11.1
1 + Koø	11,12,24,25	22.64	25.21 19.79	242.0	11.0
1 + Koø	3,7,16,20	67.99	68.04 67.24	223.0	10.9
1 + Koø	4,6,17,19	71.68			
1 + Koø	10,13,23,26	27.10	26.67 26.11	223.0	11.1
2 + Koø	1,9,14,22	79.42	81.53 76.55	253.0	11.5
2 + Koø	11,12,24,25	22.44	26.70 19.45	260.0	11.7
2 + Koø	3,7,16,20	67.43	67.69 66.12	237.0	11.4
2 + Koø	4,6,17,19	71.43	71.49 70.78	232.0	11.5
2 + Koø	10,13,23,26	26.50			

The activation parameters for the complexation-decomplexation of K^+ with 1 and 2 are as yet undetermined. It appears however that this process is rapid relative to the rate of ring reversal in these materials since phenoxide carbon resonances remain unchanged from sharp singlets at all temperatures. A ^{39}K T_1 study as a function of temperature is in progress to quantify the complexation rates.

Comparison of data in Table 2 with those in Table 1 indicates a measurable increase in the free energy of activation for ring inversion upon complexation with 1 equivalent of potassium phenoxide. For 1 + Koø, $\Delta G^{\neq}$ = 11.0 ± 0.1 Kcal/mole, while for 2 + Koø, $\Delta G^{\neq}$ = 11.5 ± 0.1 Kcal/mole.

One might expect some increase in the ring inversion barriers when K^+ is present, since presumably there is an ideal complexation geometry which must be disrupted during the process of ring inversion. Electrostatic interactions between the oxygen lone pairs and the cation in the cavity should stabilize the preferred conformations relative to the case of free 1 and 2. These stabilizing interactions are probably less important in the transition states for ring reversal, thus leading to increases in the barriers for the Koø complexes.

Finally, it should be noted that 1 and 2, but not the Koø complexes, both show evidence of a second non-degenerate temperature dependent phenomenon near 173 K in CD_2Cl_2 and MeOD solution. The non-degeneracy indicates that this process is distinct from the presently studied ring reversal phenomenon. The problem is presently under study using higher field instruments and results will be presented in the near future.

References and Notes

1. A.C. Coxon, D.A. Laidler, R.B. Pettman and J.F. Stoddart. J. Am. Chem. Soc. 100 8260 (1978) and references therein.
2. The commercial mixture of 1 and 2 was separated by published techniques(3). For 1, mp = 61-63 and for 2, mp = 69-70°C.
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4. Spectra were recorded using a Varian XL-200 NMR spectrometer at 50.3 MHz under conditions of complete ^1H noise decoupling. Samples were 0.4 M, contained in 10 mm tubes. Typical sweep width was 10,000 Hz, acquisition time 1.6 seconds with 32 K data points. Pulse repetition rate was 2.0 seconds, with 45° observe pulses. Temperatures are accurate to ± 2.0 K. Adequate signal to noise ratios were obtained after 200-300 spectral accumulations. Chemical shifts are relative to internal TMS. Uncertainties in $\Delta G^{\neq}$ are standard deviations.
5. The numbering scheme follows that used previously(6).
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