The reaction proceeded for 4.5 min, at which time methanol (4 drops) and water (20 mL) were added. This was extracted with chloroform, the extract was dried (sodium sulfate), and the solvent was removed in vacuo to yield the crude product. Recrystallization from methanol yielded **1c**; mp 161–163 °C; IR (KBr) 2192, 2092 (C–D), 1734, 1719, 1701 (C=O); NMR ($CDCl_3$) 3.09 (s, 2, CH_2, C-4), 0.96 ppm (s, 3, CH_3, C-18); mass spectrum, *m/e* 288 (M^+); 5% D_1, 95% D_2.

(4*R*)-5,10-Secoestr-4,5-diene-3,10,17-trione-7,7-d_2 (3c). 5,10-Secoestr-5-yne-3,10,17-trione-7,7-d_2 (**1c**, 200 mg) was stirred with triethylamine (0.5 mL) in dioxane (15 mL) at room temperature for 1 h. The solution was evaporated to dryness, and the residue was chromatographed on dry-column silica gel with elution by 5:1 hexane/acetone. Pure 4*R* allenic ketone **3c** eluted first followed by a mixture of 4*R* and 4*S* allenic ketones. The mixed fractions were further purified by high-pressure LC (μ-Porasil, 90% 3:1 hexane–ethylene dichloride, 10% acetonitrile; flow rate 2 mL/min). The 4*R* allenic ketone **3c** was recrystallized from hexane/acetone to give a white solid: 61 mg; mp 143–145 °C; IR (KBr) 2108 (C–D stretch), 1954 (allene), 1742, 1707, 1670 cm^{-1} (C=O); NMR ($CDCl_3$) 5.58 (H-4, dd, $J_{4,6\beta}$ = 6, $J_{4,2e}$ = 1.8 Hz), 2.32 (H-6β, d, $J_{6\beta,4}$ = 6 Hz), 0.98 ppm (s, 3, CH_3, C-18); mass spectrum, *m/e* 288 (M^+); 5% D_1, 95% D_2.

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Registry No. **1a**, 26012-92-0; **1b**, 73872-33-0; **1c**, 73872-39-6; **2a**, 41033-64-1; **2b**, 73872-34-1; **2c**, 73891-26-6; **3a**, 60398-18-7; **3b**, 73872-35-2; **3c**, 73872-36-3; **4**, 734-32-7; **5a**, 57215-01-7; **5c**, 73891-27-7; **6a**, 57215-06-2; **6b**, 73872-37-4; **6c**, 73872-38-5.

Variable-Temperature Fluorine-19 Nuclear Magnetic Resonance Spectra of Fluorocyclooctane

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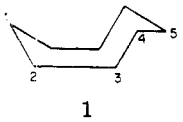
Two conformational processes have been observed for fluorocyclooctane by variable-temperature, proton-decoupled fluorine NMR. The observations are in good agreement with predictions by molecular mechanics of ring inversion and pseudorotation among nonequivalent boat–chairs.

The conformational preferences of cyclooctane and its derivatives have been and still are of considerable interest.[1] Experimentally, variable-temperature NMR of suitably substituted derivatives has been the major approach, while molecular mechanics calculations have provided a theoretical basis for understanding the observations. Anet's group[2] has focused on massively deuterated species with one or two strategically remaining protons. Roberts' group[3] has used *gem*-difluoride groups to take advantage of the larger chemical shift differences expected for nonequivalent fluorines. Calculations of strain energies for various conformations and possible interconversion itineraries have been made with molecular mechanics techniques by several groups.[4-6] All workers now agree that the major conformation of the parent molecule is the boat–chair **1** and that two processes, a low-temperature pseudorotation and a high-temperature ring inversion, are necessary to exchange all positions in **1**.



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Anet has also observed a second species using ^{13}C NMR.[7] At −75 °C this species was 1.9 kcal/mol less stable than the boat–chair species and separated from it by a 10.5-kcal/mol energy barrier. Perfluorocyclooctane[3,8] has two energetically similar conformations which equilibrate in the same temperature range as the fully hydrogenated species. Difluorocyclooctane exists as two differently substituted boat–chairs with no other conformation detected (though the limit is not as good as for C_8H_{16} because proton decoupling was not used).[3]

Table I. Observed Thermodynamic Parameters for Conformational Processes in Fluorocyclooctane

	T_c, °C	$\Delta G^{\ddagger}$, kcal/mol	$\Delta H^{\ddagger}$, kcal/mol	$\Delta S^{\ddagger}$, eu	log $A^{\ddagger}$	$\Delta E^{\ddagger}$, kcal
boat–chair inversion	−81	8.1	8.3	+1	13	8.7
boat–chair pseudorotation	−142	5.5	3.8	−13	10	4.2

A single fluorine atom is a little larger than a hydrogen atom as judged by the 0.2-kcal/mol difference in the energy between axial and equatorial fluorocyclohexane.[9] Fluoropropane actually prefers the gauche conformation by 0.2 kcal/mol,[10] in contrast to the trans orientation for *n*-butane, suggesting that some fluorine–hydrogen interactions can be attractive. This experimental observation is reproduced by molecular mechanics calculations.

Within the paradigm of the boat–chair hypothesis, ten nonequivalent conformations of a monosubstituted cyclooctane are separated on two independent pseudorotation itineraries by eight nonequivalent twist-boat–chairs. We report here the variable-temperature, proton-decoupled, fluorine NMR spectra of fluorocyclooctane.

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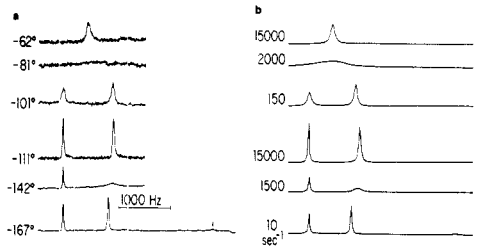

Figure 1. Variable-temperature NMR spectra of fluorocyclooctane: (a) observed, T, °C; (b) calculated, τ, s.

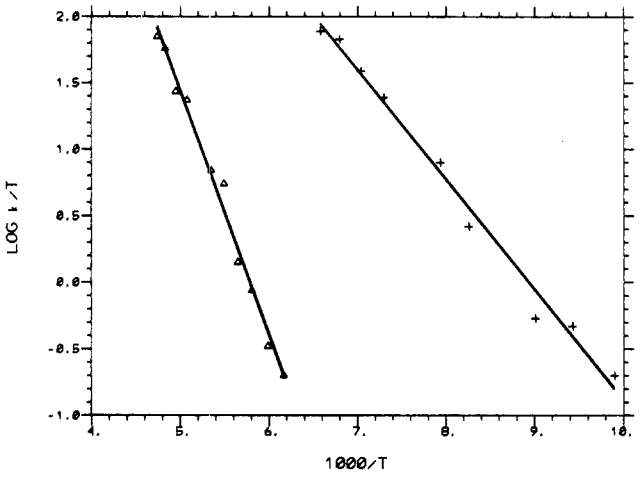

Figure 2. Eyring plot for fluorocyclooctane. Conformational processes: Δ, inversion; +, pseudorotation.

Results

A representative sample of the proton-decoupled fluorine NMR spectra of fluorocyclooctane in propene is given in Figure 1a. The high-temperature singlet at δ −158.2 broadens, coalesces at −80 °C, and reappears as two singlets at δ −153.3 and −162.8 at −100 °C in the ratio 43:57. Below −120 °C, the peak at δ-163 broadens, coalesces at −145 °C, and below −170 °C reappears as two singlets at δ −159.2 and −179.1 in the ratio 90:10. The peak at δ −153 does not broaden in this temperature range but shifts slightly to −150.6 ppm.

The spectral changes were visually matched with spectra calculated for the mutual exchange of two species with differing populations.[11] A representative selection of calculated spectra is shown in Figure 1b. The thermodynamic parameters obtained by Arrhenius and Eyring equation[12] treatment of the temperature variation of the exchange rates are given in Table I, and the Eyring treatment of the data is presented in Figure 2. Both pseudorotation and ring-inversion free energies are consistent with other cyclooctane derivatives.[1] The large entropy for the pseudorotation process is most likely an inaccuracy resulting from the difficulty in controlling and measuring temperatures at the extreme limit of our spectrometer system.

Calculations

The relative energies of the various conformations of fluorocyclooctane were calculated by molecular mechanics using Allinger's parameters.[5] The basic ring geometry was initially minimized without the fluorine substituent. For many of the less stable conformations, symmetry restrictions were incorporated to prevent the program from seeking more stable conformations. The results are compared to Hendrickson's calculations for the same cyclooctane conformations in Table II.

Table II. Molecular Mechanics Calculations of the Stability of Cyclooctane Conformations

conformation	rel enthalpy, kcal/mol this work	Hendrickson[4]
boat-chair	0	0
twist boat-chair‡	1.5	2.0
chair‡	7.4	8.3
twist chair‡	8.2	8.7
twist boat	3.2	0.9
boat-boat‡	4.5	1.4
boat‡	10.0	10.3
twist boat-chair	0.8	1.7
chair-chair‡	3.1	1.9
crown	1.6	2.8

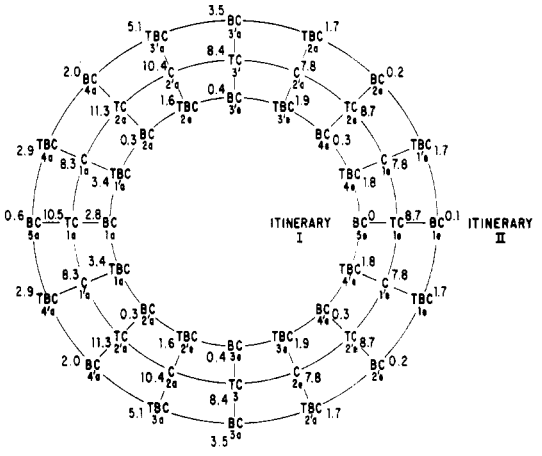

Figure 3. Interconversion of fluorocyclooctane boat–chair conformations: along circumference, pseudorotation; axially, ring inversion.

While both Allinger's parameters[5] and Hendrickson[4] predict that the boat–chair should be the most stable conformation, there are many discrepancies in the ordering within the various conformational families. It would seem prudent not to use these calculations to predict the relative stabilities of high-energy forms in the absence of other evidence. Next the fluorine was added, and *only* its position was varied: the ring was held constant. These calculations predict that seven out of the ten boat–chair conformers should be significantly populated but that the barriers to interconverting many of them are quite low. The energies of the boat–chair family of conformations are given in Figure 3. In general, fluorine has a smaller effect than methyl and in some cases fluorine stabilizes high-energy conformations relative to the parent hydrocarbon. Methyl is always destabilizing.

Assignments

We interpret the −170 °C resonance at δ −151 as the average of the four populated species in pseudorotation itinerary I, 5e, 4e, 2a, and 3e. The peak at δ −159 represents the rapid averaging of conformers 1e and 2e in pseudorotation itinerary II, while the weak high-field peak at δ −179 represents the static shift of conformer 5a which is separated from the other stable forms by the 5.1-kcal/mol energy barrier of TBC-3a. The molecular mechanics calculations predict a population ratio for the two pseudorotation itineraries of 61:39 vs. the 57:43 ratio observed and a barrier to inversion of 7.8 kcal/mol vs. the

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(12) The kinetic data were analyzed by using the computer program ARH2 supplied by Professor J. D. Roberts.

8.1-kcal/mol observed value (we will use ΔG values as being more accurate even though ΔH should be used). For the low-temperature process, the molecular mechanics calculations predict a population ratio of 4:96 vs. the 10:90 observed ratio and a barrier of 5.1 kcal vs. the 5.5-kcal observed value.

Molecular mechanics appears to be a useful tool in assessing conformational possibilities in monofluorosubstituted hydrocarbons.

Experimental Section

General Methods. NMR spectra were obtained on a Varian XL-100 spectrometer operating at 94.1 MHz. Proton-noise decoupling was used. Spectra were run on the 5000-Hz sweep at a sweep rate of 20 Hz/s. Temperatures were measured by replacing the sample with a Doric digital thermometer. Chemical shifts were measured relative to internal CHF_2Cl and converted to the δ scale ($CFCl_3$) by adding −71.7 ppm.

Fluorocyclooctane. A stable, HF-free sample of fluorocyclooctane was prepared by adding a solution of 5.12 g (0.04 mol) of cyclooctanol in 4 mL of CCl_3F to a stirred solution of 5 mL (0.04 mol) of (diethylamino)sulfur trifluoride (DAST)[13] in 40 mL of CCl_3F cooled to −78 °C. The reaction mixture was warmed to 0 °C and poured into water. The organic layer was separated, washed with water, 5% $NaHCO_3$, and water again, and dried ($MgSO_4$). Distillation gave 4.5 g of a colorless liquid composed of 80% fluorocyclooctane and 20% cyclooctene (by ^1H NMR and GLC analysis); bp <25 °C (0.8 mm).

A sample of fluorocyclooctane was also prepared (without isolation) in propene solution by reaction of DAST with cyclooctanol in propene at −78 °C. However, solutions prepared in this manner must be kept cold and used immediately because the HF present causes an autocatalytic decomposition of the fluorocyclooctane.

Acknowledgment. The fluorine NMR spectra were obtained by Wendy John.

Registry No. Fluorocyclooctane, 53731-16-1; cyclooctanol, 696-71-9.

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Synthesis and ^3H NMR Analysis of [1,4-$^3H_2$]Benzene: A Natural Source of Tritiated Phenylium Cations

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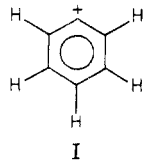
Multicurie amounts of [^3H_x]benzene (x = 1, 2) were prepared by ^3H_2O decomposition of 1,4-phenylenebis[bromomagnesium]. After purification, the radio gas chromatographic analysis of the [^3H_x]benzene fraction revealed less than 0.1% radioactive impurities (mostly [^3H]bromobenzene). Isotopic analysis by ^3H NMR spectroscopy showed that the major component (56 mol %) of the [^3H_x]benzene mixture is [1,4-$^3H_2$]benzene (overall yield ca. 23%), the remainder being mainly [^3H]benzene. An interesting long-range inverse heavy-isotope effect on the ^3H NMR chemical shifts of the two radioactive products has been observed and its possible cause considered.

Introduction

Although there are many well-established solvolytic methods for generating carbocations, to date dediazoniation of benzenediazonium ion salts is the only route for the production of phenylium ions (I) in solution.[1]



I

This limitation is one of the main reasons for the long time span between Waters' original proposal[2] for the existence of I and the very recent systematic solution[3] and gas-phase[4] studies that have gathered persuasive evidence for the occurrence of I and that have provided information on its nature.[5]

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