mmHg) (lit.[11b] bp (for (±)-**4a**) 100 °C (bath) (10 mmHg)); $[\alpha]^{25}_D$ −0.42° (*c* 1.9); IR and NMR as for (±)-**4a** above] and (1*S*,3*S*)-*trans*-3-*tert*-butylcyclohexanecarboxylic acid ((+)-**4b**, 30 mg, 46% yield, 4% ee) [mp 117–118 °C (lit.[15] mp (for (+)-**4a**) 119–120 °C); $[\alpha]^{25}_D$ +0.33° (*c* 4.0); IR 3300–2570, 1697 cm^{-1}; ^1H NMR δ 0.88 (9 H, s), 0.90–2.46 (9 H, m), 2.63–2.97 (1 H, m), 9.27 (1 H, br s)].

Absolute Configuration Determinations. All correlations were to (+)-(1*S*,3*R*)- and (−)-(1*R*,3*S*)-**3b**.[7] Methyl *cis*-3-*tert*-butylcyclohexanecarboxylate ((+)-**3a**, 80 mg, 0.40 mmol) was hydrolyzed with KOH to give (+)-(1*S*,3*R*)-*cis*-3-*tert*-butylcyclohexanecarboxylic acid (**3b**, 52 mg, 70% yield): mp 90–92 °C (lit.[14] mp (for (±)-**3b**) 94.5–95 °C); $[\alpha]^{25}_D$ +1.0° (*c* 4.0) (lit.[7] $[\alpha]^{25}_D$ +21.1° (*c* 1.6).

trans-3-*tert*-Butylcyclohexanecarboxylic acid ((+)-**4b**, 60 mg, 0.3 mmol) in ethylene glycol (10 mL) was epimerized with KOH (1.0 g, 17.9 mmol) under reflux for 14 h. Workup with diethyl ether extraction of the acidified mixture gave (−)-(1*R*,3*S*)-**3b** (50 mg, 83% yield): mp 89–91 °C; $[\alpha]^{25}_D$ −0.29° (*c* 3.8) (lit.[7] $[\alpha]^{25}_D$ −19.1° (*c* 1.6).

Methyl *trans*-*tert*-butylcyclohexanecarboxylate ((−)-**4a**, 20 mg, 0.1 mmol) was hydrolyzed and epimerized as for (+)-**4b** above to give (+)-(1*S*,3*R*)-**3b** (15 mg, 80% yield): mp 90–93 °C; $[\alpha]^{25}_D$ +0.54° (*c* 1.3).

Enantiomeric Excess Determinations. These were performed on the (*S*)-1-phenylethanamides of the trans acids (+)- and (−)-**3b** obtained directly from the enzyme reactions or from the absolute configuration determinations. The ee's (Table II) were determined from integrations of the diastereomeric *tert*-butyl proton peaks or, better, from GLC analysis, using the amide from (+)-**3b** as the reference standard, and are accurate to ≤±2%. The reference amide (1*R*/*S*,3*S*/*R*,1′*S*)-*N*-(1′-phenylethyl)-*cis*-3-*tert*-butylcyclohexancarboxamide, prepared by the method of Heathcock and co-workers[6] in quantitative yield, had the following properties: mp 126–128 °C; IR 3270, 1637 cm^{-1}; ^1H NMR (200 MHz) δ 0.84 and 0.85 (9 H, two s, 1:1), 0.93, 2.27 (10 H, m), 1.46 (3 H, d, *J* = 6.9 Hz), 5.06–5.21 (1 H, m), 5.66–5.70 (1 H, br s), 7.07–7.33 (5 H, m); GLC (DB wax capillary column, 220 °C) retention times 26.11 (49.02%), 26.91 (50.98%) min.

Acknowledgment. The support of the Natural Sciences and Engineering Research Council of Canada and the awards (to L.K.P.L.) of a Gollop Memorial and a University of Toronto Open Scholarship are gratefully acknowledged.

(15) van Bekkum, H.; van de Graaf, B.; van Minnen-Pathius, G.; Peters, J. A.; Wepster, B. M. *Recl. Trav. Chim. Pays-Bas* **1970**, *89*, 521.

Direct Synthesis of Spiro[5.5]undeca-1,4,7-trienones from Phenols via a Quinone Methide Intermediate

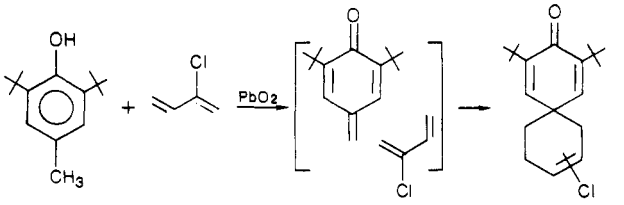
Jerry M. Roper* and Charles R. Everly

Ethyl Corporation, Research and Development, Ethyl Technical Center, P.O. Box 14799, Baton Rouge, Louisiana 70898

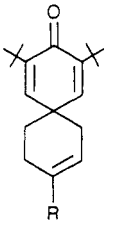
Received January 12, 1987

Spiro ketones, such as 2,4-dialkylspiro[5.5]undeca-1,4,7-trien-3-ones, are rather unusual compounds which are reported only infrequently in the literature. An intriguing feature of these molecules is their ability to undergo a dienone–phenol rearrangement and thereby yield a fused ring system. Reported herein is a significant improvement in the synthesis of dienones, specifically spiroundecatrienones.

In 1958 Hatchard[1a] synthesized 2,4-di-*tert*-butyl-8(or 9)-chlorospiro[5.5]undeca-1,4,7-trien-3-one (**1**) by treating 4-methyl-2,6-di-*tert*-butylphenol with lead dioxide in the presence of chloroprene. Hatchard suggested a radical mechanism for the formation of spiro ketone **1**. It was not until McClure's report[1b] in 1962 that this reaction was recognized as proceeding via entrapment of a quinone methide intermediate to give a [4 + 2] cycloadduct. McClure prepared compounds **1**, **2a**, and **2b** in yields of 93%, 10%, and 44%, respectively. Subsequently, only

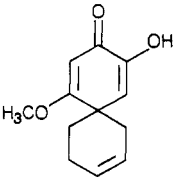


1

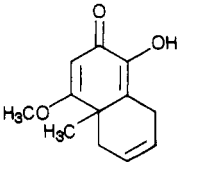


2a, R = H
b, R = CH_3

a few isolated reports[1c-g] of spiroundecatrienone synthesis via cycloaddition have appeared in the literature. These reports include an unexpected spiro ketone synthesis discovered by Danishefsky[1e,f] while studying Diels–Alder reactions of *o*-benzoquinones. Under certain circumstances, spiroundecatrienone **3** was formed and not the expected fused ring product **4**. All the references cited



3



4

herein rely upon a *p*-alkyl-substituted phenol as starting substrate. Generally, these para-alkylated phenols require a labile benzyl substituent in order to generate a reactive quinone methide dienophile. This paper reports a synthetic method which avoids this requirement by utilizing phenols as starting substrates for spiroundecatrienone synthesis.

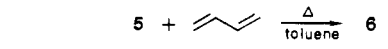
Results and Discussion

A series of observations lead to the conclusion that spiroundecatrienones could be prepared directly from 2,6-dialkylphenols and thereby avoid the necessity of first preparing and then isolating a para-substituted phenol possessing a leaving group at the benzylic position. Initially spiro ketone **6a** was prepared by treating **5a** with methyl iodide to give (4-hydroxy-3,5-di-*tert*-butylbenzyl)trimethylammonium iodide. Heating this quater-

(1) (a) Hatchard, W. R. *J. Am. Chem. Soc.* **1958**, *80*, 3640. (b) McClure, J. D. *J. Org. Chem.* **1962**, *27*, 2365. (c) Starnes, W. H., Jr.; Lauff, J. J. *Ibid.* **1970**, *35*, 1978. (d) Sheppard, W. S. *Ibid.* **1968**, *33*, 3297. (e) Danishefsky, S.; Schuda, P. F.; Caruthers, W. *Ibid.* **1977**, *42*, 2178. (g) Hutchins, R. O.; Zipkin, R. E.; Natale, N. R.; Taffer, I. M. *Synthesis* **1980**, 1035.

0022-3263/88/1953-2639$01.50/0

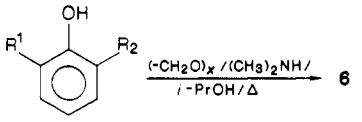
Table I. Spiro Ketones Synthesized by Thermal Fragmentation of a Mannich Base



R^1, R^2	5 (g/mmol)	1,3-butadiene (g/mmol)	toluene (g)	reactn temp (°C)	reactn time (h)	purification	% yield of 6
a *t*-Bu, *t*-Bu	10.52/40	4.3/80	90	205	10	recry[c]	94[a]
b *t*-Bu, CH_3[d]	8.76/40	4.3/80	81	205	10	distill	83[a]
c CH_3, CH_3	0.90/5	1.08/20	40	190–205	6	distill	78[b]

[a] Isolated yield. [b] GC yield. [c] 80% ethanol. [d] Dissymmetric molecule, enantiomers are possible; no attempt to separate enantiomeric pair was made.

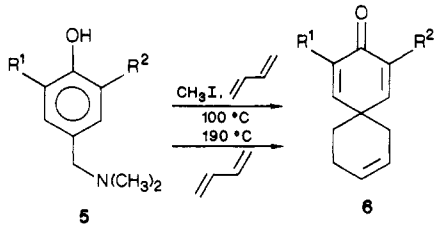
Table II. Spiro Ketones Synthesized Directly from 2,6-Dialkylphenols

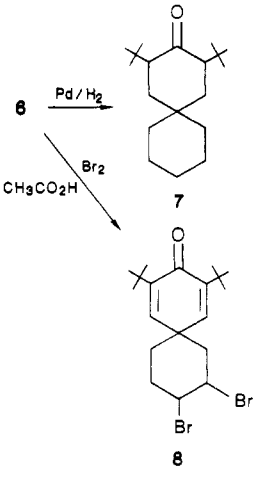


R^1, R^2	2,6-dialkyl-phenol (g/mmol)	1,3-butadiene (g/mmol)	paraformaldehyde (g/mmol)	40% DMA (g/mmol)	isopropyl alcohol, g	temp (°C)	time (h)	purification	6, %
a *t*-Bu, *t*-Bu	10.3/50	10/185	1.65/55	0.56/5	100	190–200	5	recry[b]	53[a]
d *i*-Pr, *i*-Pr	8.9/50	11.5/210	2.25/75	13.38/75	100	190–200	5	distill	82[a]

[a] Isolated yield. [b] 80% ethanol.

nary salt to 100 °C resulted in fragmentation to the quinone methide dienophile which in the presence of 1,3-butadiene was trapped as **6a**. Product identification by



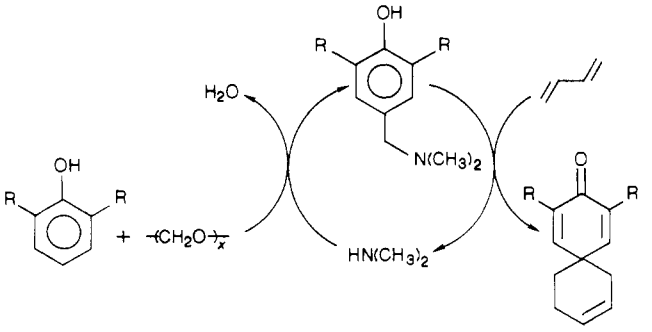


a, $R^1, R^2 = t$-Bu; **b**, $R^1 = t$-Bu, $R^2 = CH_3$; **c**, $R^1, R^2 = CH_3$

NMR was straightforward. Vinyl signals at δ 5.77 along with the shifting of aromatic signals at δ 6.68 and the appearance of coupled aliphatic protons clearly indicated formation of spiroundecatrienone **6a**. A 272 mass unit parent ion peak and conjugated carbonyl stretching frequency at 1635 cm^{-1} confirmed the structure. Bromination and hydrogenation of spiroundecatrienone **6a** to dibromo **8** and saturated spiro ketone **7**, respectively, provided further characterization.

Elevation of the reaction temperature from 100 °C to approximately 190 °C precluded the need to form the quaternary salt of Mannich base **5a**. Thermal fragmentation of this Mannich base to the quinone methide dienophile proceeded smoothly, giving spiro ketone yields as high as 94%. Table I lists various *N*,*N*-dimethyl-4-(aminomethyl)-2,6-dialkylphenols which underwent [4 + 2] cycloaddition. Interestingly, 4-(methoxymethyl)- or 4-(hydroxymethyl)-2,6-di-*tert*-butylphenol did not give the expected spiroundecatrienone product at these elevated temperatures.

Scheme I

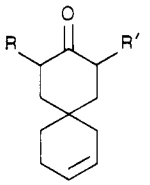


Since the quinone methide dienophile could be generated thermally from a Mannich base, it followed that in situ formation of the Mannich base at elevated temperature in the presence of 1,3-butadiene should give a direct synthesis of spiroundecatrienones from 2,6-disubstituted-phenols. Indeed, that is the case. A mixture of 2,6-di-*tert*-butylphenol, paraformaldehyde, 1,3-butadiene, and a catalytic amount of dimethylamine in isopropyl alcohol heated to 190 °C afforded an 82% yield of spiro ketone **6a**, where R equals *tert*-butyl groups. Scheme I illustrates the catalytic role of dimethylamine. Table II presents 2,6-dialkylphenols utilized in the direct synthesis of spiroundecatrienones. Thus a direct method of spiroundecatrienone synthesis based on 2,6-disubstituted-phenols was developed.

Experimental Section

Melting points were determined on a Thomas-Hoover Unimelt and are uncorrected. ^1H NMR spectra were taken on a Varian EM-390 spectrometer and ^{13}C NMR were recorded on a Nicholet NT-360 spectrometer. Infrared spectra were recorded on either

Table III. Physical Properties of Spiro Ketones



R, R′	mp (°C) (lit. mp)	bp (°C)	NMR ($CDCl_3$)	IR (cm^{-1})	exact mass calcd/found
a *t*-Bu, *t*-Bu	(75–76)[1b]		1.23 (s, 18H), 1.58 (t, 2 H, J = 9.5 Hz), 1.94–2.28 (bm, 4 H), 5.80 (brm, 2 H), 6.69 (s, 2 H)	(KBr) 2950, 1655, 1634, 1924, 1482, 1458, 1364, 1249, 940, 658	272.2133 272.2143
b *t*-Bu, CH_3		85–89/0.06 mmHg	1.22 (s, 9 H), 1.60 (t, 2 H, J = 10 Hz), 1.90 (s, 3 H), 2.02 (bm, 2 H), 2.18 (bm, 2 H), 5.79 (m, 2 H), 6.71 (s, 2 H)	(neat) 2975, 1677, 1645, 1495, 1459, 1445, 1380, 1370, 661	230.165 230.1664
c CH_3, CH_3		85–86/0.13 mmHg	1.62 (t, 2 H, J = 10 Hz), 1.90 (s, 6 H), 2.06 (bm, 2 H), 2.20 (bm, 2 H), 5.80 (m, 2 H), 6.77 (s, 2 H)	(neat) 2920, 1668, 1635, 1452, 1440, 1376, 1209, 912, 736, 660	
d *i*-Pr, *i*-Pr	48.5–49.5	95–96/0.10 mmHg	1.05 (d, 12 H, J = 10.5 Hz), 1.60 (t, 2 H, J = 10 Hz), 2.02 (bm, 2 H), 2.20 (bm, 2 H), 3.02 (sept, 2 H), 5.81 (m, 2 H), 6.65 (s, 2 H)	(KBr) 2975, 1673, 1648, 1471, 1392, 1223, 940, 668	244.1821 244.1819

a Perkin-Elmer 683 or a Nicholet 7199 Fourier transform spectrophotometer. Mass spectra were obtained on a Finnigan 4000 Series GC/MS or a Kratos MS50 located at the Midwest Center for Mass Spectrometry in Lincoln, NE. Pressure vessels employed were a 316 stainless steel 300-mL Parr autoclave and a glass 250-mL Fischer–Porter bottle. *N,N*-Dimethyl-4-(aminomethyl)-2,6-di-*tert*-butylphenol, a product of Ethyl Corporation, was recrystallized from ethanol–water before use.

General Procedure. Synthesis of *N,N*-Dimethyl-4-(aminomethyl)-2,6-dialkylphenols. Paraformaldehyde (60 mmol) was slurried into isopropyl alcohol (80 g) containing 2,6-dialkylphenol (50 mmol). This slurry was chilled in an ice bath, and then an isopropyl alcohol solution (10 g) of dimethylamine (40% aqueous solution, 60 mmol of amine) was added dropwise under a nitrogen atmosphere. The resultant solution was allowed to warm to room temperature and finally refluxed for ca. 4 h. After cooling, the reaction mixture was concentrated in vacuo to afford a solid which was recrystallized from alcohol–water to give the following Mannich bases. *N,N*-dimethyl-4-(aminomethyl)-2,6-dimethylphenol,[3] as colorless crystals, 97% yield (mp 115–117 °C). ^1H NMR ($CDCl_3$): δ 1.20 (s, CH_3, 6H), 1.22 (s, $N(CH_3)_2$, 6 H), 3.31 (s, benzyl H, 2 H), 4.97 (br s, OH, 1 H), 6.90 (s, Ar H, 2 H). *N,N*-Dimethyl-4-(aminomethyl)-2-methyl-6-*tert*-butylphenol,[5] as near colorless crystals, 96% (mp 117–118 °C). ^1H NMR ($CDCl_3$): δ 1.33 (s, *t*-Bu H, 9 H), 2.09 (s, CH_3, 3 H), 2.18 (s, $N(CH_3)_2$, 6 H), 3.27 (s, benzyl H, 2 H), 6.88 (d, Ar H, J = 1.0 Hz, 1 H), 7.00 (d, Ar H, J = 1.0 Hz, 1 H).

2,4-Di-*tert*-butylspiro[5.5]undeca-1,4,7-trien-3-one. Method A. Thermal Fragmentation of Quaternary Ammonium Salts of a Mannich Base.[4] To an ethyl acetate solution (120 g) of *N,N*-dimethyl-4-(aminomethyl)-2,6-di-*tert*-butylphenol (4.12 g, 20 mmol) contained in a glass pressure vessel was added iodomethane (1.24 mL, 20 mmol) dropwise. A flocculent slurry resulted. 1,3-Butadiene (5.4 g, 100 mmol) was introduced; the vessel was sealed and heated to 100–120 °C for 18 h. After cooling, the reaction slurry was filtered to remove iodide salts. Filtrate was concentrated in vacuo to afford a brown solid which was crystallized from 80% ethanol to give 2,4-di-*tert*-butylspiro-[5.5]undeca-1,4,7-trien-3-one as colorless crystals: 5.3 g, 98%; see Table III for physical properties.

Method B. Thermal Fragmentation of a Mannich Base.[5] A toluene solution (90 g) of *N,N*-dimethyl-4-(aminomethyl)-2,6-dialkylphenol (40 mmol) was charged in a stainless steel pressure vessel, which was sealed and evacuated. 1,3-Butadiene (4.3 g, 80 mmol) was introduced into the vessel, which was resealed and heated to ca. 205 °C for 10 h. After cooling, the reaction mixture was washed with the following: (a) 2 N hydrochloric acid (1 × 50 mL), (b) water (1 × 50 mL), and (c) brine (1 × 50 mL); then the toluene solution was dried over anhydrous magnesium sulfate and concentrated in vacuo to afford a brown residue; for purification procedures see Table I and for physical properties see Table III.

Method C. Direct Synthesis from 2,6-Dialkylphenol.[6] A mixture of paraformaldehyde (60 mL), 2,6-dialkylphenol (50 mmol), and dimethylamine (40% aqueous solution, 25 mmol of amine) in isopropyl alcohol (81 g) was charged to a stainless steel pressure vessel which was sealed and evacuated. 1,3-Butadiene (5.4 g, 100 mmol) was introduced into the vessel which was resealed and then heated to ca. 200 °C for 6–7 h. After cooling, the solvent was evaporated to afford a black oily residue which was dissolved in diethyl ether (150 mL). The ether solution was washed with 2 N hydrochloric acid (1 × 75 mL), dried over anhydrous magnesium sulfate, and concentrated in vacuo to give a crude oil; for purification procedures see Table II and for physical properties see Table III.

2,4-Di-*tert*-butylspiro[5.5]undecan-3-one (7). 2,4-Di-*tert*-butylspiro[5.5]undeca-1,4,7-trien-3-one (2.72 g, 10 mmol) was suspended in absolute ethanol (45 mL) and treated with 5% palladium on charcoal (0.54 g, 0.25 mmol, of Pd). This mixture was charged in a hydrogenation vessel and shaken for 2 h at room temperature. Standard workup afforded an oil which was crystallized from ethanol–water to afford 2,4-di-*tert*-butylspiro-[5.5]undecan-3-one as pale yellow crystals, 2.67 g, 96%, mp 52–53 °C (lit.[1b] mp 53–54 °C). ^1H NMR ($CDCl_3$): δ 1.05 (s, *t*-Bu H, 9 H), 1.28 (s, *t*-Bu H, 9 H), 1.32 (m, alkyl H, 14 H).

7,8-Dibromo-2,4-di-*tert*-butylspiro[5.5]undeca-1,4-dien-3-one (8). 2,4-Di-*tert*-butylspiro[5.5]undeca-1,4,7-trien-3-one (1.09 g, 4 mmol) was suspended in glactial acetic acid and the suspension was cooled to 15 °C. Bromine (2.4 g, 15 mmol) was then added dropwise. The mixture was allowed to warm to room temperature and was stirred for 1 h. The resultant yellow slurry was filtered to collect a yellow solid which was recrystallized from petroleum ether (60–90 °C) to give dibromospiro 8 as pale yellow crystals: 1.0 g, 58%, mp 107–109 °C. ^1H NMR ($CDCl_3$): δ 1.21 (s, *t*-Bu H, 9 H), 1.25 (s, *t*-Bu H, 9 H), 1.69 (m, CH_2, 2 H), 1.98–2.72 (m, CH_2CHBr, 4 H), 4.39 (m, CHBr, 2 H), 6.67 (d, vinyl H, J = 1.0 Hz, 1 H), 6.80 (d, vinyl H, J = 1.0 Hz, 1 H). Exact mass calcd 432.0479, found 432.0618.

Acknowledgment. We gratefully acknowledge Dr. Vernon O. Brandt for his assistance with mass spectral data and Drs. G. P. Stahly and Richard D. Gandour for helpful discussions.

(2) (a) Burnell, R. H.; Taylor, W. I. *J. Chem. Soc.* **1954**, 3486. (b) Von Farges, G.; Dreiding, A. S. *Helv. Chim. Acta* **1966**, *49*, 552.

(3) (a) Roth, B.; Strelitz, J. Z.; Rauckman, B. S. *J. Med. Chem.* **1980**, *23*, 379. (b) Roth, B.; Aig, E.; Kane, K.; Rauckman, B. S. *Ibid.* **1980**, *23*, 535.

(4) Roper, J. M. U.S. Pat. 4 480 133, 1984.

(5) Roper, J. M. U.S. Pat. 4 562 294, 1985.

(6) Roper, J. M. U.S. Pat. 4 562 293, 1985.

Registry No. **5a**, 88-27-7; **5b**, 13086-92-5; **5c**, 42900-95-8; **6a**, 94817-72-8; **6b**, 102392-51-8; **6c**, 94817-75-1; **6d**, 102392-50-7; **7**, 95423-30-6; **8**, 114199-90-5; 2,6-dimethylphenol, 576-26-1; 2-methyl-6-*tert*-butylphenol, 2219-82-1; 1,3-butadiene, 106-99-0; 2,6-di-*tert*-butylphenol, 128-39-2; 2,6-diisopropylphenol, 2078-54-8.

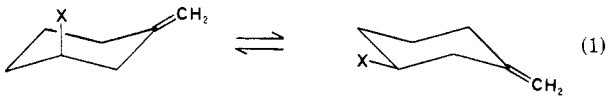
A Comparison of the Through-Space, Dipolar Repulsion of Alkenic and Allenic Groups

Joseph B. Lambert,*[1] Dale E. Marko, and Erik C. Chelius

Department of Chemistry, Northwestern University, Evanston, Illinois 60208

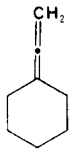
Received October 6, 1987

The double bond exerts a repulsive dipolar interaction with polar groups across a six-membered ring. We have documented this phenomenon in 3-substituted *exo*-methylenecyclohexanes (eq 1), in which there is less axial

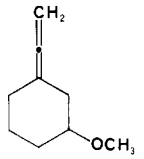


(1)

conformer for polar X groups (OH, OCH_3, SCH_3) in low polarity solvents than there is in the corresponding monosubstituted cyclohexanes.[2] These observations have provided a superb opportunity for studying the dipolar interactions of double bonds, because the equilibrium of eq 1 is extremely sensitive to these effects. There have been no such studies of the cumulated double bond (the allenic functionality). Consequently, we have prepared ethenylidenecyclohexane (**1**) and its 3-methoxy derivative (**2**) and have explored the conformational properties of the

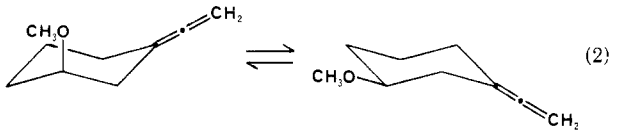


1



2

ethenylidene group by low-temperature NMR experiments. The barrier to ring reversal in **1** provides information about deformation of the six-membered ring by the ethenylidene group. The axial–equatorial equilibrium constant in **2** (eq 2) provides information about the dipolar repulsion be-



(2)

tween the ethenylidene and methoxy groups. We report herein the synthesis and conformational analysis of **1** and **2**.

Results

exo-Methylenecyclohexane was converted to ethenylidenecyclohexane (**1**) by treatment with carbon tetrabromide and, sequentially, 2 equiv of methyllithium.[3] Reaction of CBr_4 with the first equivalent of CH_3Li resulted in addition of dibromocarbene to the double bond to form the dibromocyclopropane. The second equilvalent of CH_3Li removed the two bromine atoms to form a carbene that rearranged to the ethenylidene product **1**. Treatment of 3-methoxy-1-methylenecyclohexane[2] in the same fashion with CBr_4 and CH_3Li produced 3-methoxy-1-ethenylidenecyclohexane (**2**).

The ^1H NMR spectrum of ethenylidenecyclohexane (**1**) was measured as a function of temperature at 500 MHz.[3] Measurements were carried out in CF_2Cl_2, a nearly nonpolar solvent that minimizes solute–solvent interactions. At room temperature, the C2 and C6 resonances occurred at δ 2.28 the C3 and C5 resonances at δ 1.74, and the C4 resonances at δ 1.68. The latter two resonance groups overlapped at lower temperatures. The two broad peaks at 193 K passed through decoalescence at 180 K, from slowing of ring reversal, and produced two peaks apiece at 153 K for the separate axial and equatorial protons. From k_C at coalescence ($\pi\Delta\nu/\sqrt{2}$, in which $\Delta\nu$ is the slow exchange shift difference), the free energy of activation for ring reversal was calculated to be 8.3 kcal/mol, compared with 8.4 kcal/mol for *exo*-methylenecyclohexane.[4]

The proton geminal to methoxyl (3H) provides the best probe for the conformational equilibrium of 3-methoxy-1-ethenylidenecyclohexane (eq 2), since its resonance is well removed from the other ring proton resonances. Lowering the temperature should result in slowing of ring reversal and doubling of the 3H signal. Unfortunately, the 3H resonance is only slightly upfield of the methoxy resonance. The resonance, however, may be followed through its low-temperature decoalescence into two peaks, one above and the other below the methoxy resonance.[3] Direct integration of these peaks yielded a free energy difference of 0.45 kcal/mol at 143 K.

Discussion

The barriers to ring reversal are essentially equal in *exo*-methylenecyclohexane[4] and ethenylidenecyclohexane (**1**), 8.3–8.4 kcal/mol. This result suggests that deformations of the six-membered ring by the alkenic and allenic exocyclic unsaturations are the same. Therefore, any differences in substituent preferences for the axial and equatorial positions should not be attributed to changes in the shape of the ring.

In the parent saturated system, methoxycyclohexane, the axial/equatorial free energy difference is 0.55 kcal/mol in CS_2.[5] Introduction of the *exo*-methylene group raises the equatorial preference to 0.80 kcal/mol in the nonpolar solvent CF_2Cl_2.[2] We have attributed this change to the presence of a significant intramolecular dipolar repulsion between the *exo*-methylene double bond and the axial 3-methoxy group. When *exo*-methylene (CH_2=) is replaced with isopropylidene (Me_2C=), the free energy difference drops to 0.19 kcal/mol.[6] The tetrasubstituted double bond in the isopropylidene system has little or no dipole, so that electrostatic repulsion with the axial 3-methoxy group is negligible and more axial methoxy is present.

The free energy difference for 3-methoxy-1-ethenylidenecyclohexane (**2**) is 0.45 kcal/mol. Thus the dipolar repulsion of the allenic group is substantially less

(1) Supported by the National Science Foundation (Grants CHE83-12285 and CHE86-09899) and the donors of the Petroleum Research Fund, administered by the American Chemical Society. Low-temperature NMR spectra were taken at the Regional NMR Facility at Yale University, sponsored by the National Science Foundation (Grant CHE79-16210).

(2) Lambert, J. B.; Clikeman, R. R. *J. Am. Chem. Soc.* **1976**, *98*, 4203–4211. Lambert, J. B.; Taba, K. M. *J. Org. Chem.* **1980**, *45*, 452–455.

(3) Details may be found in D. E. Marko, Ph.D. Dissertation, Northwestern University, Evanston, IL, 1987.

(4) Gerig, J. T.; Rimerman, R. L. *J. Am. Chem. Soc.* **1970**, *92*, 1219–1224.

(5) Jensen, F.; Bushweller, C. H.; Beck, B. H. *J. Am. Chem. Soc.* **1969**, *91*, 344–351.

(6) Lambert, J. B.; Taba, K. M. *J. Am. Chem. Soc.* **1981**, *103*, 5828–5832.

0022-3263/88/1953-2642$01.50/0