1986 *J. Org. Chem.* 1991, *56*, 1986-1989

Articles

Cleavage vs Rearrangement Ratios and Secondary Deuterium Kinetic Isotope Effects in the Thermolysis of Conformationally Fixed Cisoid Vinylcyclobutanes

Joseph J. Gajewski* and Gitendra C. Paul

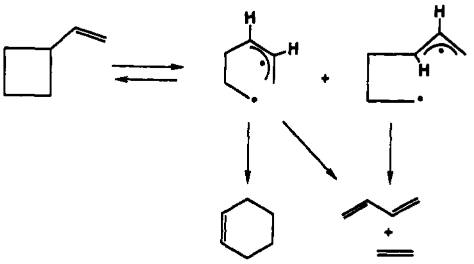
Department of Chemistry, Indiana University, Bloomington, Indiana 47405

Received September 25, 1990

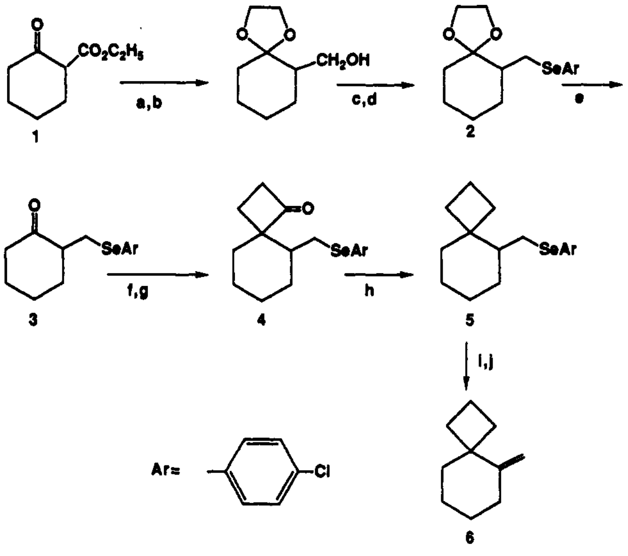
The first-order rate constants for the thermally induced retro 2 + 2 cleavage and rearrangement of 5-methylenespiro[3.5]nonane occur in a 1:2 ratio. In contrast, a 2:1 ratio of these rate constants is usual from conformationally unbiased vinylcyclobutanes. Comparison of the activation parameters suggests that the rearrangement in unbiased systems results from an unfavorable entropy of activation which suggests that the rearrangement is concerted. For the rearrangement of 5-methylenespiro[3.4]octane, the secondary deuterium kinetic isotope effect at the exo-methylene carbon (k^H/k^{D_2}) is 1.086 ± 0.023. This is also consistent with concert in the rearrangement where *exo*-methylene rotation contributes to the reaction coordinate. The secondary KIE for cleavage of 5-methylenespiro[3.4]octane is 1.025 ± 0.027.

The first-order thermolysis of unrestricted vinyl cyclobutanes gives retro 2 + 2 cleavage products and cyclohexenes via a 1,3-shift of carbon in ratios typically greater than two (2).[1a-c] There is evidence for reversible bond fission with (2-alkylvinyl)cyclobutanes since geometric isomerization occurs at about the same rate as cleavage. Whether or not a freely rotating biradical is involved is unclear in the hydrocarbon cases, although a study by Doering and Mastrocola on the (2-cyanovinyl)cyclobutanes reveals some nonrandom behavior in the geometric isomerization.[1d]

The question of rearrangement vs cleavage would appear to be a function of the geometry of the species generated upon initial fission of the cyclobutane allylic bond. In the extreme if biradicals are formed, there are two geometric isomers, and only the cisoid form can close to a cyclohexene.



Scheme I[a]



[a] (a) Ethylene glycol, p-TsOH·H_2O, reflux; (b) $LiAlH_4$, Et_2O; (c) MsCl, Et_3N, Et_2O, 25 °C; (d) 4,4′-dichlorodiphenyl diselenide, $NaBH_4$, EtOH, reflux; (e) acetone, BF_3·Et_2O, reflux; (f) lithiocyclopropyl phenyl sulfide, THF, −78 °C; (g) p-TsOH·H_2O, PhH, reflux; (h) H_2N·NH_2·H_2O, K_2CO_3, ethylene glycol, Δ; (i) MCPBA, THF, −10 °C; (j) CCl_4, Et_2NH, reflux.

Therefore, in the vinylcyclobutane rearrangement, it is necessary to establish the extent of cleavage that occurs from the cisoid species. In geometrically restricted vinylcyclobutanes, using as the most studied example bicyclo[3.2.0]hept-2-ene, the rate of cleavage is equal to or less than half the rate of the 1,3 shift.[2] Further, 1,3-shift in bicyclo[3.2.0]hept-2-ene occurs with roughly 72% inversion and 28% retention at the migrating carbon, suggesting some degree of concert in the rearrangement. Since it was extremely difficult to determine the cleavage to rearrangement ratio in bicyclo[3.2.0]hept-2-ene because the 1,3-shift product, norbornene, readily undergoes the retro-Diels–Alder reaction to give the same products as the retro 2 + 2 from reactant, it appeared appropriate to examine the question in a conformationally restricted system whose products would be stable. To this end, 5-methylene spiro[3.5]nonane and 5-methylenespiro[3.4]octane, which are vinylcyclobutanes that cannot ring open to transoid allylic species, were prepared and pyrolyzed. Further, this system allows deuterium labeling at the *exo*-methylene to examine kinetic isotope effects.

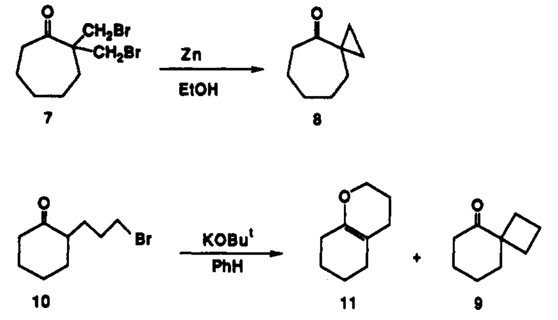
---

(1) (a) For a review, see: Gajewski, J. J. *Hydrocarbon Thermal Isomerizations*; Academic Press: New York, 1980. (b) Frey, H. M.; Pottinger, R. *J. Chem. Soc., Faraday Trans.* **1978**, 1827. (c) For recent work, see: Getty, S. J.; Berson, J. A. *J. Am. Chem. Soc.* **1990**, *112*, 1652. Gajewski, J. J.; Paul, G. C. *J. Org. Chem.* **1990**, *55*, 4575. (d) Doering, W. von E.; Mastrocola, A. R. *Tetrahedron* **1981**, *37*, C329.

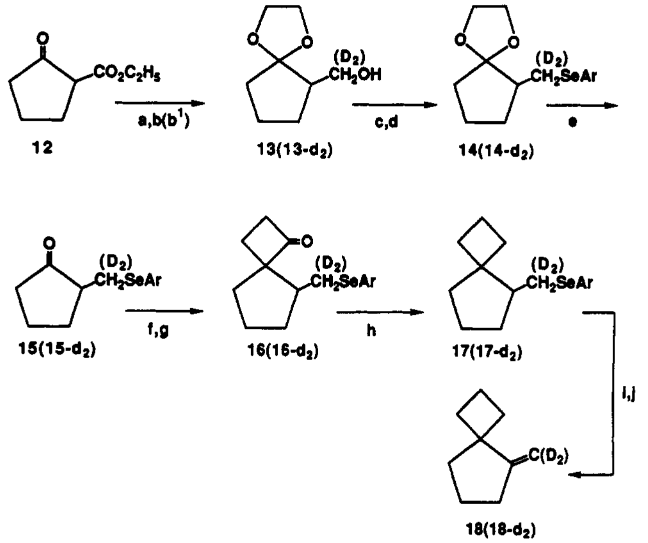
(2) (a) Baldwin, J. E.; Belfield, K. D. *J. Phys. Org. Chem.* **1989**, *2*, 455; *J. Am. Chem. Soc.* **1988**, *110*, 296. (b) Klarner, F.-G.; Drewes, R.; Hasselmann, D. *Ibid.* **1988**, *110*, 297.

0022-3263/91/1956-1986$02.50/0

Scheme II



Scheme III^{a,b}



[a] See footnote *a*, Scheme I. [b] (b¹) $LiAlD_4$.

Results

5-Methylenespiro[3.5]nonane, **6**, was prepared from (2-carboethoxy)cyclohexanone, **1**, using the reaction sequence of Scheme I.

Alternative routes to **6** via ketone **9** were frustrated by the difficulty in obtaining **9**. Thus, while zinc dust debromination of **7** has been reported to give **9**,[3] contradicting an earlier report that **8** is the product of debromination,[4] we found, not unreasonably, that the debromination product is indeed **8** as reported earlier by Conia (Scheme II).[4] Further, treatment of bromo ketone **10** with potassium *tert*-butoxide in refluxing benzene gave enol ether **11** as a major product along with ~2–3% of spiroketone **9** as was reported earlier by Etheredge (Scheme II).[5]

5-Methylenespiro[3.4]octane, **18**, was prepared by the same sequence of reactions used for the synthesis of **6** (Scheme III). 5-(Dideuteriomethylene)spiro[3.4]octane, **18-*d*₂**, was also prepared in a similar fashion with the replacement of $LiAlH_4$ by $LiAlD_4$.

Pyrolysis of **6** in a well-conditioned static reactor at temperatures from 269.7–310.0 °C gave 1,2-dimethylenecyclohexane (**19**), Δ-1,6-octalin (**20**), and 2-propyl-3-methylenecyclohexene (**21**) in ratios roughly 1:2:0.4. The first-order rate constants and activation parameters from a weighted least-squares analysis, for the three reactions of Scheme IV, namely, cleavage, 1,3 shift, and hydrogen shift, respectively, are given in Table I.

Scheme IV

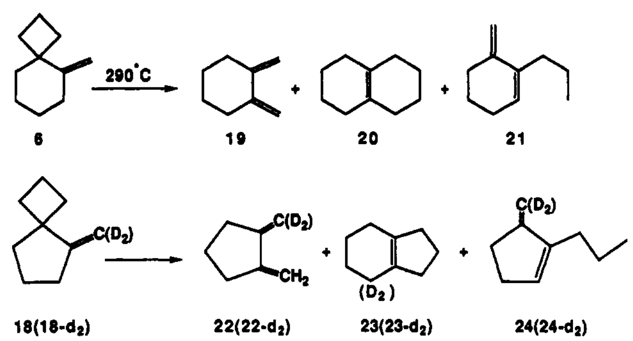


Table I. Kinetics of Thermal Reaction of 6[a]

temp, °C	10^5k_{overall}, s^{-1}	$k_{\text{clv}} \times 10^5$, s^{-1}	$k_{1,3} \times 10^5$, s^{-1}	$k_{\sim\text{H}} \times 10^5$, s^{-1}
310.0	14.698 ± 0.076	4.534	8.441	1.723
290.0	3.087 ± 0.064	0.936	1.772	0.379
269.7	0.573 ± 0.003	0.167	0.332	0.074

[a] $\log k_{\text{overall}}$ (s^{-1}) = 15.24 ± 0.034 − ((50895.6 ± 91.2)/ϕT). $\log k_{\text{clv}}$ (s^{-1}) = 14.96 ± 0.010 − ((51513.29 ± 23.26)/ϕT). $\log k_{1,3}$ (s^{-1}) = 14.99 ± 0.056 − ((50885.59 ± 148.09)/ϕT). $\log k_{\sim\text{H}}$(s^{-1}) = 13.74 ± 0.034 − ((49377.29 ± 90.78/ϕT). $\phi = 2.303R$.

Table II. Kinetics of Thermal Reaction of Compound 18 and 18-*d*₂ at 290.0 °C[a]

compd	10^4k_{overall}, s^{-1}	$k_{\text{clv}} \times 10^4$, s^{-1}	$k_{1,3} \times 10^4$, s^{-1}	$k_{\sim\text{H}} \times 10^4$, s^{-1}
18	1.889 ± 0.003	0.6483 ± 0.0095	1.159 ± 0.009	0.0848
18-d_2	1.779 ± 0.033	0.6324 ± 0.0139	1.067 ± 0.021	0.0840

[a] Overall, $k^{\text{H}}/k^{\text{D}}{}_2$ = 1.062 ± 0.020; cleavage, $k^{\text{H}}/k^{\text{D}}{}_2$ = 1.025 ± 0.027; 1,3 shift, $k^{\text{H}}/k^{\text{D}}{}_2$ = 1.086 ± 0.023.

Pyrolysis of **18** under conditions similar to those for pyrolysis of **6** gave the same types of products in similar ratios. However, the overall rate of the reactions of **18** is roughly 6 times faster than those of **6**. The kinetic data is given in Table II.

In an effort to examine the extent of bonding at the *exo*-methylene carbon of **18**, through an examination of secondary deuterium kinetic isotope effects, **18-*d*₂** was pyrolyzed under identical conditions. The kinetic data is also given in Table II.

Discussion

As anticipated, the thermal behavior of the conformationally biased vinylcyclobutanes **6** and **18** lead to more rearrangement and less retro 2 + 2 cleavage. The ratio is increased by a factor of roughly 4 relative to other conformationally unbiased vinylcyclobutanes.[1] This suggests that in the ring opening of simple vinylcyclobutanes, the ratio of transoid to cisoid pathways is roughly 7.5 at 290 °C which corresponds to roughly 2 kcal/mol in favor of the transoid pathway in the unbiased cases.

It should be noted that the cleavage reaction of **6** has activation parameters very similar to that for the parent vinylcyclobutane,[1b] but the preexponential term for 1,3-shift is higher than that in the parent case by 1.1 log units. This suggests that the 1,3-shift in the parent case is retarded by a relatively unfavorable entropy of activation which must be a reflection of the difficulty in forming the cisoid species necessary for rearrangement. It is surprising that the higher potential energy for formation of cisoid species is not a result of enthalpic differences. This suggests that the rearrangement is a concerted process requiring a specific geometry for the vinyl group in the transition state. The normal secondary deuterium kinetic

---

[3] Slobodin, Ya. M.; Tsukshverdt, T. V.; Varen'e, G. V.; Khachaturov, A. S.; Volodina, V. F. *Zh. Org. Khim.* **1972**, *8*, 1764; *Engl. Transl.* **1972**, 1806.

[4] Leriverend, P.; Conia, J. M. *Bull. Soc. Chim. Fr.* **1966**, 121.

[5] Etheredge, S. J. *J. Org. Chem.* **1966**, *31*, 1990.

isotope effect at the terminal methylene in the rearrangement of 18 is reminiscent of that found with the vinylcyclopropane rearrangement which has been interpreted in terms of *exo*-methylene rotation as part of the reaction coordinate in a concerted process.[6] Predominant suprafacial-inversion stereochemistry in the vinylcyclobutane rearrangement of bicyclo[*n*.2.0]*n*-enes and of bicyclo[2.1.1]heptene has been demonstrated in the 1960s by Berson,[7] and by Roth,[8] respectively, in systems where steric effects do not prevent this stereomode. The recent work of Baldwin and of Klarner with the parent [3.2.0] system reveals similar behavior.[2] There has been concern that the stereochemistry is a result of steric effects guiding a nonconcerted ring opening followed by fast least motion closure.[1a] However, the observation of a kinetic isotope effect at the *exo*-methylene carbon reported in this work suggests concert in the vinylcyclobutane rearrangement.

Finally, it is interesting to note that the 6-fold rate increase in the reactions of 18 relative to 6 is not unlike the rate difference found for the solvolysis of cyclopentyl halides relative to cyclohexyl halides and may have similar origins, namely ground-state destabilization of the cyclopentyl system by eclipsing interactions.

Experimental Section

^{1}H NMR spectra were recorded on a Nicolet Model NT-360 spectrometer (360 MHz) unless otherwise indicated. All chemical shifts were reported as parts per million (δ scale) from TMS and were taken in $CDCl_3$ solution. Mass spectra (MS) were obtained on a Kratos MS-80 spectrometer. IR spectra were recorded on a Mattson 4020 Galaxy Series FT-IR spectrometer. Gas chromatographic (GC) analyses were performed on a Varian 3700 gas chromatograph equipped with a flame-ionization detector and Varian Model 4270 electronic integrator.

5-[[(*p*-Chlorophenyl)selenyl]methyl]spiro[3.5]nonane (5). Spiroketone 4[9] (3.0 g, 8.78 mmol) was heated in the presence of hydrazine hydrate (85% in H_2O, 4.5 mL), K_2CO_3 (2.8 g), and diethylene glycol (6 mL) at ~150 °C for 3 h and then at ~200 °C for 5 h.[10] The cooled reaction mixture was treated with 10% HCl and brine before drying. The solvent was removed under aspirator vacuum. The crude product revealed one major spot on TLC. Purification was achieved by passage through a short silica gel column (3% EtOAc in hexanes) to give 2.61 g (90% yield) of a light yellow liquid which is assigned structure 5: ^{1}H NMR 7.50–7.18 (m, 4 H), 3.17–3.07 (bd, 1 H), 2.80 (bt, 1 H), 1.95–1.20 (m, 15 H); CIHRMS for $C_{16}H_{21}ClSe$ (M + 1) found 328.0501, calcd 328.0496.

5-Methylenespiro[3.5]nonane (6). The selenide 5 was converted to methylenespirononane 6 by treating with MCPBA in CCl_4 containing Et_2NH according to literature procedures.[9] Volatiles were removed under aspirator vacuum. Distillation under vacuum led to water white 6 (bp 30–32 °C at 6–7 Torr) in 62% yield. ^{1}H NMR (400 MHz): 4.65 (m, 1 H), 4.60 (bd, 1 H), 2.14–2.02 (m, 4 H), 1.95–1.80 (m, 1 H), 1.80–1.70 (m, 3 H), 1.68–1.58 (m, 2 H), 1.58–1.50 (m, 2 H), 1.50–1.42 (m, 2 H). ^{13}C NMR: 155.60, 103.40, 45.57, 39.62, 32.69, 30.99, 28.49, 22.97, 15.19. CIHRMS for $C_{10}H_{16}$: found 136.1253, calcd 136.1252.

5-Methylenespiro[3.4]octanes (18 and 18-d_2). The syntheses of 18 and 18-d_2 follow the same general procedures as has been described in the synthesis of compound 6. The reduction of ester protected ketone 12 with $LiAlD_4$ led to dideuterated alcohol 13-d_2 (~100% deuterium incorporation). The formation of 16 and 16-d_2 from 15 and 15-d_2, respectively, occurred with poor yields (~15–16%). The yields of other compounds were comparable to those of six-membered ring compounds. The spectral data of all previously unknown compounds are as follows.

13-d_2: ^{1}H NMR 4.01–3.83 (m, 4 H), 2.58 (s, 1 H), 2.13 (bt, J = 7.9–8.6 Hz, 1 H), 1.90–1.50 (m, 6 H); CIHMRS for $C_8H_{12}D_2O_3$ (M + 1) found 161.1152, calcd 161.1146.

14: ^{1}H NMR 7.50–7.19 (m, 4 H), 3.98–3.86 (m, 4 H), 3.10 (dd, J = 12.2, 3.96 Hz, 1 H), 2.78 (dd, J = 12.2, 8.64 Hz, 1 H), 2.30–2.20 (m, 1 H), 2.05–1.96 (m, 1 H), 1.81–1.75 (m, 2 H), 1.74–1.55 (m, 2 H), 1.54–1.42 (m, 1 H); CIHRMS for $C_{14}H_{17}ClO_2Se$ found 332.0081, calcd 332.0082.

14-d_2: ^{1}H NMR 7.43–7.30 (m, 2 H), 7.24–7.18 (m, 2 H), 3.98–3.86 (m, 4 H), 2.24 (bt, J = 8.6–9.0 Hz, 1 H), 2.05–1.95 (m, (9 lines), 1 H), 1.81–1.76 (m, 2 H), 1.75–1.56 (m, 2 H), 1.54–1.44 (m, 1 H); CIHRMS for $C_{14}H_{15}D_2ClO_2Se$ found 334.0209, calcd 334.0207.

15: ^{1}H NMR 7.46–7.40 (m, 2 H), 7.25–7.20 (m, 2 H), 3.34 (dd, J = 12.2, 3.96 Hz, 1 H), 2.80 (dd, J = 12.2, 8.64 Hz, 1 H), 2.42–2.22 (m, 3 H), 2.20–1.98 (m, 2 H), 1.85–1.60 (m, 2 H); CIHRMS for $C_{12}H_{13}ClOSe$ found 287.9833, calcd 287.9819.

15-d_2: ^{1}H NMR 7.45–7.40 (m, 2 H), 7.25–7.20 (m, 2 H), 2.42–2.22 (m, 3 H), 2.20–2.08 (m, 1 H), 2.08–1.96 (m, 1 H), 1.85–1.60 (m, 2 H).

16: ^{1}H NMR 7.45–7.36 (m, 2 H), 7.25–7.20 (m, 2 H), 3.15–3.00 (m, 1 H), 3.00–2.88 (m, 2 H), 2.88–2.78 (m, 1 H), 2.49–2.31 (m, 1 H), 2.25–2.10 (m, 1 H), 2.10–1.86 (m, 3 H), 1.86–1.57 (m, 4 H); IR 1780 cm^{-1} (C=O); HRMS for $C_{15}H_{17}ClOSe$ found 328.0118, calcd 328.0133.

16-d_2: ^{1}H NMR 7.42–7.34 (m, 2 H), 7.25–7.18 (m, 2 H), 3.14–3.00 (m, 1 H), 3.00–2.86 (m, 1 H), 2.42–2.30 (t, 1 H), 2.24–2.10 (m, 1 H), 2.10–1.90 (m, 2 H), 1.85–1.54 (m, 5 H); IR 1771 cm^{-1} (C=O).

17: ^{1}H NMR 7.46–7.36 (m, 2 H), 7.25–7.16 (m, 2 H), 3.16 (dd, J = 11.2, 3.6 Hz, 1 H), 2.62 (t, J = 10.8 Hz, 1 H), 2.10–1.54 (m, 13 H); HRMS for $C_{15}H_{19}ClSe$ found 314.0328, calcd 314.0341.

17-d_2: ^{1}H NMR 7.46–7.35 (m, 2 H), 7.26–7.16 (m, 2 H), 2.10–1.50 (m, 13 H); HRMS for $C_{15}H_{17}D_2ClSe$ found 316.0473, calcd 316.0466.

18: ^{1}H NMR 4.98 (bs, 1 H), 4.87 (bs, 1 H), 2.33–2.27 (tt, J = 7.2, 2.2 Hz, 2 H), 2.09–2.00 (m, 2 H), 1.92–1.80 (m, 4 H), 1.76 (t, J = 7.0 Hz, 2 H), 1.56 (pent, J = 7.0 Hz, 2 H); ^{13}C NMR 160.33, 102.80, 49.37, 40.56, 34.53, 32.53, 22.35, 15.77; HRMS for C_9H_{14} found 122.1097, calcd 122.1096.

18-d_2: ^{1}H NMR 2.30 (t, J = 7.2 Hz, 2 H), 2.09–2.00 (m, 2 H), 1.98–1.81 (m, 4 H), 1.76 (t, J = 7.0 Hz, 2 H), 1.56 (pent, J = 7.0 Hz, 2 H); ^{13}C NMR 160.12, 102.26, 49.31, 40.56, 34.53, 32.50, 22.35, 15.76; HRMS for $C_9H_{12}D_2$ found 124.1204, calcd 124.1221.

Kinetic Studies. Pyrolyses were carried out in a 2-L Pyrex bulb submerged in a molten salt bath containing a 10:7 mixture of KNO_3 and $NaNO_2$, respectively.[6] The temperature of the bath was maintained within ±0.1 °C.

For kinetic studies 2–3 μL of 6 were loaded into the bulb and pyrolyzed for different periods of time at each temperature. The pyrolysate was diluted with acetone and analyzed by capillary GC. The response factor of 1,2-dimethylenecyclohexane relative to 6 was determined separately. The response factors of products isomeric to reactant were assumed unity. At each temperature, overall rate constants were determined from a least-square analysis of the appropriate first-order plot. The individual rate constants, k_{dv}, $k_{1,3}$, and $k_{\sim\mathrm{H}}$ were determined by multiplying the overall rate constants by the mole fraction of the products. The overall rate constants for the decomposition of 6 at various temperatures and the individual rate constants of products in the decomposition of 6 are given in Table I.

A least-squares analysis of the results presented in Table I yielding the Arrhenius equations is also tabulated. Kinetic results in the decomposition of 18 and 18-d_2 appeared in Table II.

Product Identification. For product identification a 150-μL sample of 6 was pyrolyzed to almost complete conversion. The components in the pyrolysate were separated by preparative GC on a 12-ft 20% OV 101 on chromosorb P column. These compounds were identified by ^{1}H NMR and ^{13}C NMR and mass spectral analyses. NMR spectra of compounds 19[11] and 20[12,13]

---

[6] Gajewski, J. J.; Squicciarini, M. P. *J. Am. Chem. Soc.* **1989**, *111*, 6717.

[7] (a) Berson, J. A.; Nelson, G. L. *J. Am. Chem. Soc.* **1967**, *89*, 5503. (b) Berson, J. A. *Acct. Chem. Res.* **1972**, *5*, 406.

[8] Roth, W. R.; Friedrich, A. *Tetrahedron Lett.* **1969**, 2607.

[9] Gadwood, R. C.; Lett, R. M. *J. Org. Chem.* **1982**, *47*, 2268.

[10] Paquette, L. A.; Roberts, R. A.; Drtina, G. J. *J. Am. Chem. Soc.* **1984**, *106*, 6690.

[11] van Straten, J. W.; van Norden, J. J.; van Schaik, T. A. M.; Franke, G. Th.; de Wolf, W. H.; Bickelhaupt, F. *Recl. Trav. Chim. Pay-Bas* **1978**, *97*, 105.

[12] Becker, K. B. *Helv. Chim. Acta* **1977**, *60*, 68.

J. Org. Chem. 1991, *56*, 1989–1993

matched literature values.

^{1}H NMR of **21**: 5.66 (m, 1 H), 4.89 (bs, 1 H), 4.74 (bs, 1 H), 2.34 (m, 2 H), 2.15 (m, 4 H), 1.68 (pent, J = 6.0 Hz, 2 H), 1.47 (sext, J = 7.5 Hz, 2 H), 0.90 (t, J = 7.5 Hz, 3 H). ^{13}C NMR: 143.77, 136.70, 127.34, 107.27, 35.19, 32.98, 26.46, 23.57, 21.85, 14.24. CIHRMS for $C_{10}H_{16}$: found 136.1243, calcd 136.1252.

Samples of **18** and **18-d_2** were pyrolyzed to nearly complete conversion and analyzed by ^{1}H NMR and GCMS analyses. ^{1}H NMR of **22**[11] matched literature values. The 360-MHz ^{1}H NMR spectrum of **23** is 2.22 (t, 4 H), 1.93 (bs, 4 H), 1.80 (pent, 2 H), 1.63–1.57 (m, 4 H), which is consistent with the lower field spectrum previously reported.[13] Hydrogen shift products **24** (and **24-d_2**) were identified by only GCMS. In analogy with **21**, structures **24** and **24-d_2** were assigned.

Acknowledgment. We thank the Department of Energy for support of this work.

Supplementary Material Available: ^{1}H NMR spectra of all new compounds (along with some ^{13}C NMR spectra) (18 pages). Ordering information is given on any current masthead page.

---

(13) Benkeser, R. A.; Belmonte, F. G.; Kang, J. *J. Org. Chem.* 1983, *48*, 2796.

Carbon Acidity. 79. Acidity of Enolate Equivalent Compounds: Oxime Ethers

James C. Ciula and Andrew Streitwieser*

Department of Chemistry, University of California, Berkeley, California 94720

Received September 7, 1990

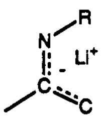
A series of benzylic oxime ethers were synthesized ($CH_3ON{=}C(CH_2Ar)_2$, Ar = phenyl (**1**), 4-biphenylyl (**2**), 1-naphthyl (**3**)), and the equilibrium ion pair acidities in THF were determined. The lithium ion pair acidity of **1** was found to be approximately 5 pK units lower than the corresponding cesium ion pair acidity. The oxime ethers are approximately 10 orders of magnitude less acidic than their corresponding ketones for cesium ion pairs. Thermodynamic parameters for the equilibrium acidities were measured and are consistent for contact ion pair monomers being the important species in solution. An aggregation study also indicates that these cesium oxime ether enolates exist mainly as ion pair monomers. The role of the gegenion in the stability of oxime ether anions is discussed.

The use of carbanion intermediates for the formation of carbon–carbon bonds is an important method in synthetic chemistry. A common source of these intermediates comes from the removal of the α-proton of a carbonyl compound by either a lithium amide or alkyllithium compound to produce an enolate ion. Much work have been dedicated to the chemistry of the enolate ion.[1] Recently, the use of carbonyl derivatives has attracted a great deal of attention for their uses as "enolate equivalents" in organic synthesis. The most important classes of these derivatives are the imines,[2] hydrazones,[3] and oxime ethers.[4,5] An interesting and useful aspect of these "enolate equivalents" is their preference for producing the syn configuration at the CCNR (R = R′, OH, OR′, NR′$_2$) partial double bonds.[5,6] This fact results in reactions of these anions being both highly regioselective and stereoselective.[7]

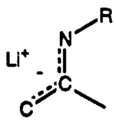
Table I. Spectrophotometric Data for Oxime Ether Anions in Tetrahydrofuran at −20 °C

O-methyloxime ether of	Cs$^+$ salt λ_{max}[a] (ϵ)	Li$^+$ salt λ_{max}[a]
1,3-diphenylacetone (1)	398 (24100)	373[b]
1,3-di(4-biphenylyl)acetone (2)	473 (37800)	450[b]
1,3-di(1-naphthyl)acetone (3)	505 (15000)	*c*

[a] In nanometers. [b] Li$^+$ salt is not stable at these conditions so that an extinction coefficient could not be determined. [c] No absorbance from the Li$^+$ salt could be detected.



syn



anti

Although many studies on the reactivity and regiochemistry of these intermediates have been done,[8] relatively few physical studies are available discussing their acid–base behavior or the actual species that are involved in the reactions. Since these reactions are usually carried

---

(1) House, H. O. *Modern Synthetic Techniques*, 2nd ed.; Benjamin-Cummings Publishing Company: Menlo Park, CA 1972.

(2) Reviews: Wittig, G.; Reiff, H. *Angew. Chem.* 1968, *80*, 8. Whitesell, J. K.; Whitesell, M. A. *Synthesis* 1983, 517. Bergbreiter, D. E.; Newcomb, M. *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: New York, 1983; Vol. 2, p 243.

(3) Review: Enders, D. *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: Orlando, FL, 1984; Part B, Vol. 3, p 275.

(4) Spencer, T. A.; Leong, C. W. *Tetrahedron Lett.* 1975, *45*, 3889.

(5) Fraser, R. R.; Dhawan, K. I. *J. Chem. Soc., Chem. Commun.* 1976, 674. Gawley, R. E.; Termine, E. J.; Aube, J. *Tetrahedron Lett.* 1980, *21*, 3115. Ikeda, K.; Yoshinaga, Y.; Achiva, K.; Sekiya, M. *Chem. Lett.* 1984, *3*, 369. Shatzmiller, S.; Lidor, R. *Synthesis* 1983, 590.

(6) Philips, J. C.; Perianayagam, C. *Tetrahedron Lett.* 1975, *38*, 3263. Kofron, W. G.; Yeh, M.-K. *J. Org. Chem.* 1976, *41*, 439. Jung, M. E.; Blair, P. A.; Lowe, J. A. *Tetrahedron Lett.* 1976, *18*, 1439. Lyle, R. E.; Saavedra, J. E.; Lyle, G. G.; Fribush, H. M.; Marshall, J. L.; Lijinslij, W.; Singer, G. M. *Tetrahedron Lett.* 1976, *49*, 4431. Gawley, R. E.; Nagy, T. *Tetrahedron Lett.* 1984, *25*, 263. Lidor, R.; Shatzmiller, S. *J. Am. Chem. Soc.* 1981, *103*, 5916.

(7) Collum, D. B.; Kahne, D.; Gut, S. A.; DePue, R. T.; Mohamadi, F.; Wanat, R. A. *J. Am. Chem. Soc.* 1984 *106*, 4865. Ludwig, J. W.; Newcomb, M.; Bergbreiter, D. E. *J. Org. Chem.* 1980, *45*, 4666. Bergbreiter, D. E.; Newcomb, M. *Tetrahedron Lett.* 1979, 4145.

(8) Corey, E. J.; Enders, D. *Tetrahedron Lett.* 1976, 11. Corey, E. J.; Enders, D.; Bock, M. G. *Tetrahedron Lett.* 1976, 7. Corey, E. J.; Knapp, S. *Tetrahedron Lett.* 1976, 4687. Enders, D.; Weuster, P. *Tetrahedron Lett.* 1978, 2853. Corey, E. J.; Enders, D. *Chem. Ber.* 1978, *111*, 1362.

0022-3263/91/1956-1989$02.50/0