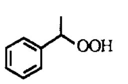

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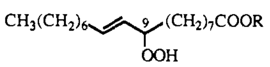

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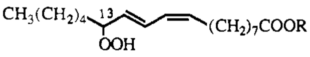

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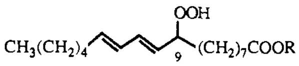

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examined, the readily formed perketals were stable to chromatography under appropriate conditions, and the perketal protecting group could be removed with acetic acid/THF/water. Although the perketals are completely stable to normal-phase chromatography, some decomposition occasionally occurs in reverse-phase solvents such as acetonitrile/water or methanol/water unless 0.01% Et_3N is added.

Separation of the menthol derivatives **3a** was acceptable on analytical reverse-phase columns but troublesome on a preparative scale. In contrast to the menthol auxiliary, the diastereomeric perketals **3b** derived from (−)-phenylcyclohexanol generally gave base line separation on normal or reverse-phase chromatography, and hundreds of mg quantities of the diastereomers could be isolated with isomeric purities of 96% or better.[18] After recovery of hydroperoxides **4–7** from the perketal by hydrolysis with acetic acid/THF/water, the optical purity of the hydroperoxide was assayed by rederivatization with **2b** and analytical chromatography or by comparison of the specific rotation of the resolved enantiomers with a known natural product.[19] For **4** and **6**, reduction of the hydroperoxide to the corresponding alcohol and conversion of the alcohol to its Mosher ester followed by spectroscopic or chromatographic analysis was used to confirm the purity of the hydroperoxides.[20] No evidence for racemization during deprotection was observed. Properties of the perketals and resolved isomers are presented in Table I.

The hydroperoxides **5** and **6** are of particular interest. The fatty acid alcohol ($[\alpha]_D = -2.14°$ in EtOH, methyl ester) derived from **5** has recently been obtained from the timothy plant fungus *Epichloe typhina*.[21] Enzymatic formation of **5** is unexpected since all known lipoxygenase enzymes require at least diene substrates for activity. The hydroperoxide **5** resulting from the initially eluting perketal could be resolved to 99% ee and the derived alcohol (R = Me) had $[\alpha]_D = -4.6°$ (EtOH), indicating that the material isolated from *Epichloe typhina* is not optically pure. The *S* enantiomer of hydroperoxide **6** (R = H), a natural product resulting from the action of soybean lipoxygenase on linoleic acid,[3] could be prepared in one pot from the corresponding perketal by LiOH hydrolysis of the methyl ester followed by acidification to give the deprotected free acid hydroperoxide which was identical with the lipoxygenase product in every respect.

The use of chiral perketal derivatives to resolve hydroperoxides may have widespread application. We have yet to study a hydroperoxide (seven total) that could not be resolved by chromatography of one of the perketal derivatives.

Principal Component Self-Modeling Analysis Applied to Conformational Equilibration of 1,3-Butadiene Vapor. UV Spectra and Thermodynamic Parameters of the Two Conformers

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1,3-Butadiene exists as a mixture of two conformations separated by a small energy barrier.[1] The more stable is planar *s-trans*-1,3-butadiene, while the less stable *s-cis*-1,3-butadiene, planar or twisted, has been the topic of many recent experimental[2] and theoretical[3] investigations. The UV absorption spectrum of the minor conformer in an Ar matrix at 20 K was estimated by subtraction of the spectrum of the s-trans conformer from a spectrum obtained by irradiation of 1,3-butadiene at 214 nm, assuming that only the s-trans conformer absorbs at 200 nm.[4] A Gaussian shape spectrum resulted with λ_{max} significantly red shifted from that of the s-trans conformer, 226 and 212 nm, respectively, leading to a preference for the planar s-cis geometry.[4]

In this paper we report the resolution of UV absorption spectrothermal matrices of 1,3-butadiene vapor by using our modified principal component analysis (PCA)-self modeling (SM) method.[5]

Two sets of 90 UV spectra were measured in the 5.0 to 93.0 °C temperature range with a Perkin Elmer λ5 spectrophotometer interfaced to a PC's Limited 80286/87 (12 MHz) microcomputer. Spectral set A, consisting of spectra in the 250–226 nm range in 0.2-nm increment, was obtained with a high 1,3-butadiene partial pressure (air was not excluded). The second set **B**, consisting of spectra in the 246–196 nm range in 0.4-nm increments, was obtained with a lower partial pressure of 1,3-butadiene vapor. PCA treatment of matrix A gave eigenvalues corresponding to a two-component system. The coefficients (α_i, β_i) for the experimental spectra adhered closely to the normalization line, Figure 1. A narrow range of pure component coefficients for the s-trans conformer was found readily because only the minor conformer contributes significantly at the high λ part of the spectrum. Minor conformer coefficients were determined by applying the constraint that they correspond to the best fit of the fractional contributions to the van't Hoff equation

$$\ln \frac{\chi_{\text{s-cis}}}{\chi_{\text{s-trans}}} = -\frac{\Delta H}{RT} + \frac{\Delta S}{R} + \ln \frac{\Sigma\epsilon_{\text{s-cis}}}{\Sigma\epsilon_{\text{s-trans}}} \qquad (1)$$

where ΔH and ΔS are enthalpy and entropy differences for the s-trans $\rightleftarrows$ s-cis equilibrium and $\Sigma\epsilon_{\text{s-cis}}$ and $\Sigma\epsilon_{\text{s-trans}}$ are sums of absorptivity coefficients over the λ range monitored. Plots of standard deviation of fit, σ (Figure 1) versus combination coefficient β, show a minimum defining the optimum β value (for a given β, α is defined by the normalization equation). The van't Hoff plot corresponding to this limit gives $\Delta H = 2.950 \pm 0.002$ kcal/mol, Figure 2. Since the limit for the s-cis conformer depends on the pure component coefficients selected for the s-trans conformer, region R on normalization line, we estimate that a more realistic uncertainty range for ΔH is ±0.15 kcal/mol. Our value falls within the range, 2.3–3.3 kcal/mol, from previous determinations.[1c,6]

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(18) The 96% figure and the purities quoted in Table I are drawn from preparative (150–750 mg) resolutions. Chromatographic conditions: Rainin 21 mm × 25 cm C18 Dynamax (8μ), 15–50 mg/injection, 9 mL/min. Perketal **4**: 950/50/0.1 $CH_3CN/H_2O/Et_3N$, 21.2, 23.2 min (α = 1.15). **5**: 0.01% Et_3N/MeOH, 33.0, 34.2 min (α = 1.05). **6**: CH_3CN, 51.3, 55.7 min (α = 1.1). **7**: CH_3CN, 58.72, 64.45 (α = 1.11). Recovery of perketals was 60–90%. It should be noted that base line (100%) separations are often achieved during analytical separations by using two Altex Ultrasphere 4.6 mm × 25 cm C-18 columns in series.

(19) Perketals were deprotected in 4:2:1 $THF/HOAC/H_2O$ in the presence of 0.1% butylated hydroxytoluene (BHT) within 4–8 h at room temperature. Hydroperoxide **4** was extracted from water with ether; **5–7** were isolated by removal of solvent in vacuo. The hydroperoxides were separated from hydrolyzed auxiliary by flash chromatography on 230–400 mesh silica in ether/petroleum ether and concentrated in the presence of 0.1% BHT.

(20) Dale, J. A.; Dull, D. L.; Mosher, H. S. *J. Org. Chem.* **1969**, *34*, 2543–2549.

(21) (a) Koshino, H.; Togiya, S.; Yoshihara, T.; Sakamura, S.; Shimanuki, T.; Sato, T.; Tajimi, A. *Tetrahedron Lett.* **1987**, *28*, 73. (b) See, also: Phillips, N. J.; Lynn, D. G.; Lynn, W. S. Ninth Cotton Dust Research Conference Proceedings, National Cotton Dust Council, Memphis, TN, 1985, 91.

(1) (a) Hückel, E. *Z. Phys.* **1932**, *76*, 630. (b) Mulliken, R. S. *Rev. Mod. Phys.* **1942**, *14*, 265. (c) Aston, J. G.; Szasz, G.; Woolley, H. W.; Brickwedde, F. G. *J. Chem. Phys.* **1946**, *14*, 67. (d) Bock, C. W.; George, P.; Trachtman, M.; Zanger, M. *J. Chem. Soc., Perkin Trans. 2* **1979**, 26. (e) Bock, C. W.; George, P.; Trachtman, M. *Theor. Chim. Acta* **1984**, *64*, 293.

(2) Fisher, J. J.; Michl, J. *J. Am. Chem. Soc.* **1987**, *109*, 1056 and references cited.

(3) (a) Breulet, J.; Lee, T. J.; Schaefer, H. F. *J. Am. Chem. Soc.* **1984**, *106*, 6250. (b) Feller, D.; Davidson, E. R. *Theor. Chim. Acta* **1985**, *68*, 57.

(4) Squillacote, M. E.; Sheridan, R. S.; Chapman, O. L.; Anet, F. A. L. *J. Am. Chem. Soc.* **1979**, *101*, 3657.

(5) (a) Lawton, W. H.; Sylvestre, E. A. *Technometrics* **1971**, *13*, 617. (b) Sun, Y.-P.; Sears, D. F., Jr.; Saltiel, J. *Anal. Chem.* **1987**, *59*, 2515.

0002-7863/88/1510-6277$01.50/0

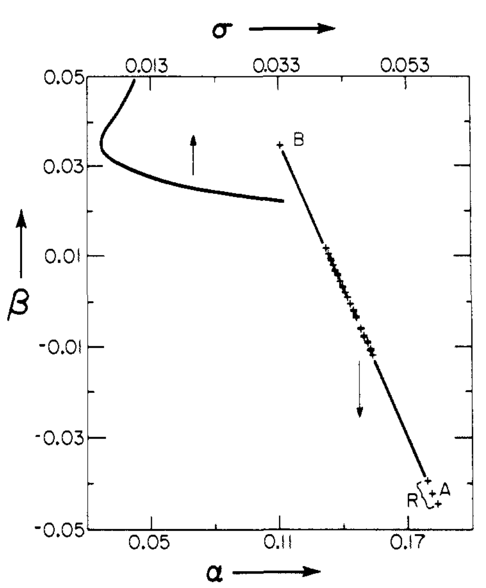

Figure 1. α,β plot for A spectral matrix; the normalization line of $\bar{V}_\alpha$ and $\bar{V}_\beta$ is drawn through the points.[5] Inset shows σ versus β for van't Hoff fit based on point A for the s-trans combination coefficients.

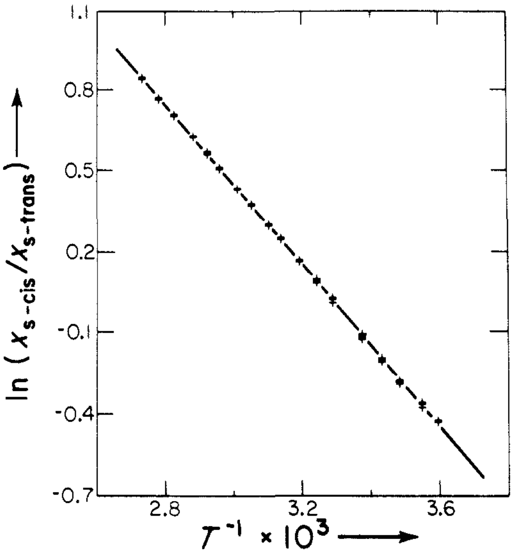

Figure 2. van't Hoff plot of the fractional contributions for matrix A, linear correlation coefficient $r = 0.9999$.

A narrow range of acceptable combination coefficients for the s-trans conformer is also found easily for the **B** matrix.[7] However, in this case, the small contribution of the minor conformer in the spectra makes the van't Hoff plot extremely sensitive to small errors and the plot of σ versus β shows no clear minimum. Accordingly, s-cis conformer combination coefficients were selected so that the van't Hoff plot gave the predetermined $\Delta H = 2.95$ kcal/mol value. Strikingly similar normalized pure component spectra resulted, Figure 3, with the spectrum of the s-cis conformer shifted 3 nm to the red of the s-trans spectrum [s-trans: 215.4 nm, 208.8 nm (max), 203.6 nm, 198.2 nm (sh); s-cis: 218.5 nm, 212.0 nm (max), 206.5 nm, 201.0 nm]. Except for a 3-nm blue-shift and a better resolved vibronic progression, our s-trans spectrum agrees with the spectrum obtained at 20 K. In contrast, our s-cis spectrum bears no similarity to the spectrum assigned to it in the Ar matrix at 20 K.[4] Our solution could be affected by nonlinear changes due to temperature broadening of the spectra of the individual conformers.[8] To test this possibility, calculated amounts of the s-trans spectrum (based on fractional contributions) were subtracted from the experimental spectra for 25 °C and 93 °C. The resultant difference spectra after normalization were indistinguishable from the s-cis spectrum in Figure 3. However, if the temperature dependence of spectral broadening of the s-trans spectrum fortuitously coincides with the temperature dependence of equilibrium s-cis rotamer content, features due to spectral broadening will be included in our pure component s-cis spectrum and may give the impression of vibronic structure.

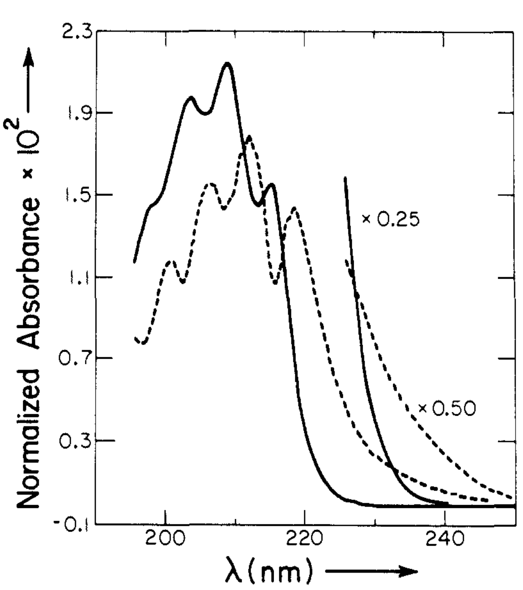

Figure 3. Resolved *s-trans*- (—) and *s-cis*-1,3-butadiene (- - -) absorption spectra from matrices A and **B**.

A rather approximate $\Delta S = 3.27 \pm 0.45$ gibbs/mol was obtained from the van't Hoff plot for matrix A by adjusting the absorptivity coefficient term so that $(\epsilon_{\text{s-cis}}/\epsilon_{\text{s-trans}}) = 0.5$ at the respective $\lambda_{\max}$ of the two conformers. Together with $\Delta H = 2.95$ kcal/mol this ΔS value predicts that the equilibrium composition of the minor conformer is 3.4% at 25 °C in good agreement with previous estimates. Though our results suggest a large positive ΔS value consistent with a twisted geometry or a planar geometry with a very shallow minimum for the s-cis conformer, we hesitate to draw this structural conclusion because, due to the narrow accessible temperature range, the uncertainty in ΔS is large.

The temperature dependence (298–621 K) of 1,3-butadiene apparent absorptivity coefficients was measured by Mui and Grunwald in the 237–249-nm λ region.[9] Using the s-cis spectrum of Squillacote et al.[4] as a guide, all absorption in this region was assigned to the c-cis conformer, and spectral changes were attributed to the temperature dependence of the absorptivity coefficients of this conformer.[8,9] Our results with matrix A show that this treatment neglects significant contribution of s-trans conformer absorption whose decrease with increasing T leads to the mistaken impression of broadening. PCA-SM treatment of the reported ϵ's (including data at 298 K) leads to a very satisfactory two-component solution which gives pure component spectra in the 237–249-nm region in agreement with those obtained from our matrix A.

This work is being extended to other 1,3-dienes. We expect that the use of higher temperatures will lead to better defined thermodynamic parameters.

Acknowledgment. This research was supported by NSF Grant CHE 87-13093.

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(6) (a) Sverdlov, L. M.; Bolotina, E. N. *Russ. J. Phys. Chem.* (*Engl. Transl.*) **1962**, *36*, 1502. (b) Carreira, L. A. *J. Chem. Phys.* **1975**, *62*, 3851. (c) Durig, J. R.; Bucy, W. E.; Cole, A. R. H. *Can. J. Phys.* **1975**, *53*, 1832. (d) Compton, D. A. C.; George, W. O.; Maddams, W. F. *J. Chem. Soc., Perkin Trans. 2* **1976**, 1666.

(7) The spectra in matrix B were multiplied by a step function which favors the red portion of each spectrum thus increasing the apparent fractional contribution of the s-cis conformer. Resolved spectra were corrected by using the same step function in reverse. While improving slightly the appearance of the s-cis spectrum, essentially the same results were obtained without applying the step function.

(8) Grunwald, E. *J. Phys. Chem.* **1981**, *85*, 3409.

(9) Mui, P. W.; Grunwald, E. *J. Am. Chem. Soc.* **1982**, *104*, 6562.