Acknowledgment. The author wishes to thank Professor F. Cramer for helpful discussions and generous support of this work, and Miss G. Moebus and Mr. G. Sievers for skillful technical assistance.

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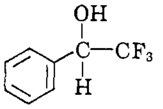
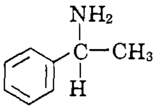
The Nonequivalence of Physical Properties of Enantiomers in Optically Active Solvents. Differences in Proton Magnetic Resonance Spectra. II

Sir:

We have recently reported[1] that the fluorine nmr spectra of the enantiomers of trifluoromethylphenylcarbinol (I) are dissimilar when optically active α-phenethylamine (II) is used as solvent. We now wish to report the first examples of nonequivalence of the proton magnetic resonance spectra of enantiomers in an optically active solvent.


I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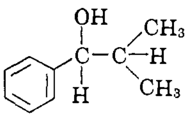
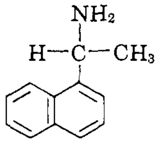

III


IV

In fluorotrichloromethane, the resonance of the carbinyl proton in racemic phenylisopropylcarbinol (III) appears as a doublet[2] ($|J_{H-H}| = 6.8$ cps) at 4.1 ppm from internal tetramethylsilane. When d-α-(1-naphthyl)ethylamine (IV) ($[\alpha]^{27}D$ +75.6° (neat), lit.[3] for the *levo* isomer $[\alpha]^{25}D$ −80.8° (neat)) is used as the solvent, the carbinyl proton resonances of the enantiomers have different chemical shifts and give rise to two equally intense sets of doublets ($|J_{H-H}| = 6.3$ cps).[4] At 60 Mc the sets are separated by 1.6 cps; at 100 Mc the separation is 2.5 cps.[5] The increased separation at the higher frequency rules out the possibility that the increased multiplicity arises from some unusual solvent effect causing long-range coupling which is not observed when fluorotrichloromethane is used as solvent. Further indication that the increased multiplicity has been correctly interpreted arises from the observation that replacement of the optically active amine with racemic amine causes the two sets of doublets to coalesce. This indicates that any given carbinol molecule is solvated by both optical forms of the amine solvent during the time required for nmr measurement. Because of this fast exchange, both carbinol enantiomers are in identical average magnetic environments and no longer have dissimilar spectra. An important consequence of this fast exchange is that *the solvent need not be completely optically pure* in order for one to observe spectral nonequivalence of enantiomeric solutes. The magnitude of the observed nonequivalence will simply be proportional to the optical purity of the solvent in cases where such fast exchange obtains.

The chemical shifts of the enantiomeric carbinyl proton resonances are unequally affected by changes in temperature, ratio of amine to carbinol, and extent of dilution with optically inactive solvents. Hence, the separation between the sets of carbinyl proton resonances is affected by the choice of experimental conditions as well as by the operating frequency of the spectrometer.[6]

Under similar conditions, proton spectral nonequivalence of the enantiomers of trifluoromethylphenylcarbinol, methyl-2-naphthylcarbinol, and methyl-o-fluorophenylcarbinol has also been noted. The ability to observe pmr spectral nonequivalence greatly enhances the scope of our previously reported nmr method for optical purity determination.[1] In all cases cited, the extent of nonequivalence is great enough to allow 60-Mc nmr optical purity determinations to be made. The use of higher frequency nmr spectrometers will facilitate these determinations.

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[1] W. H. Pirkle, *J. Am. Chem. Soc.*, **88**, 1837 (1966).

[2] The absence of observable coupling between the carbinyl and hydroxyl protons suggests that the hydroxyl protons are undergoing rapid intermolecular exchange.

[3] E. Samuelsson, *Svensk. Kem. Tidskr.*, **34**, 7 (1922).

[4] It has proven advantageous to use fluorotrichloromethane as a diluent in order to obtain better resolution through diminished viscosity and to shift the carbinyl proton resonances from underneath the methine proton resonance of the solvent amine.

[5] The 100-Mc spectra were obtained by Dr. N. Bhacca of Varian Associates. The 60-Mc spectra were determined by means of a Varian A56/60A spectrometer.

[6] The effect of these parameters upon the extent of enantiomeric spectral nonequivalence is being studied in order to gain a better understanding of the origin of the phenomenon.

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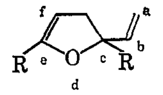
Thermal Rearrangement of 2,5-Dimethyl-2-vinyl-2,3-dihydrofuran to 4-Methyl-4-cycloheptenone

Sir:

Inherent in the simple 2-vinyl-2,3-dihydrofuran structure is the rearrangement-prone bisallylic system of an allyl vinyl ether (I, atoms a–f). Such furan derivatives have been observed to undergo a variety of rearrangements depending on the conditions imposed and the location and nature of substituents on the basic structure, I; thus, acylcyclopentenes,[1] 1-acyl-2-vinylcyclopropanes,[2] and acyclic dienic carbonyl compounds[3] have been reported as products.



I, R = H
II, R = CH_3

In our continuing interest in Claisen and Cope rearrangements and with a view to exploring the geometric

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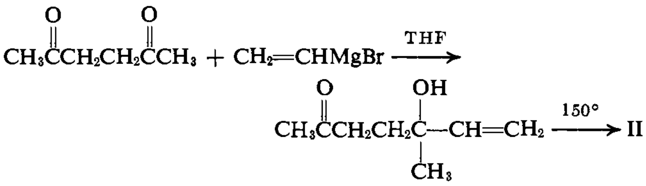
[1] J. Wiemann and S. T. Thuan, *Compt. Rend.*, **241**, 503 (1955); *Bull. Soc. Chim. France*, 199 (1958).

[2] J. Wiemann, N. Thoai, and F. Weisbuch, *ibid.*, 2187 (1964).

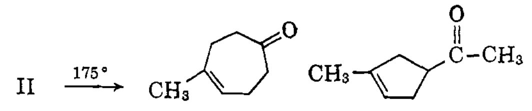
[3] J. Wiemann, P. Casals, and N. Lefebvre, *ibid.*, 310 (1962); N. Thoai, *ibid.*, 225 (1964).

restrictions of such electron reorganizations, we have investigated the thermal behavior of an example of this type, 2,5-dimethyl-2-vinyl-2,3-dihydrofuran (II). II was prepared by treatment of 2,5-hexanedione with 1 equiv of vinylmagnesium bromide in tetrahydrofuran followed by cyclodehydration of the monoaddition product. The latter process occurred smoothly at 150° on a glpc column of SE-30 on Gas-Chrom P. The structure of II, purified by glpc recycling, follows unequivocally from its spectral properties. The mass spectrum shows a parent ion peak of m/e 124. The infrared spectrum reveals vinylic hydrogen absorptions at 3100, 985, 975, 945, and 920 cm^{-1}, a very intense double bond stretching band at 1680 cm^{-1}, typical of vinyl ethers, and a weak band at 1645 cm^{-1} due to the side-chain double bond. Strong bands associated with carbon–oxygen stretching vibrations are found at 1185 and 1270 cm^{-1}. The nmr spectrum (in $CDCl_3$) shows a typical ABX pattern for the three protons of the vinyl side chain with δ values of 6.02, 5.18, and 5.00 ppm, and J_t = 17, J_c = 10, and J_{gem} = 2 cps. The olefinic hydrogen at C-4 appears as a complex multiplet of area 1 at δ = 4.40 ppm. A broad signal of area two showing complex splitting at δ = 2.49 ppm is assigned to the C-3 methylene protons while a three-proton signal at δ = 1.77 ppm, broadened by fine splitting, is that of the allylic methyl hydrogens at C-5. The proton signal of the 2-methyl group appears as a singlet of area 3 at δ = 1.40 ppm.



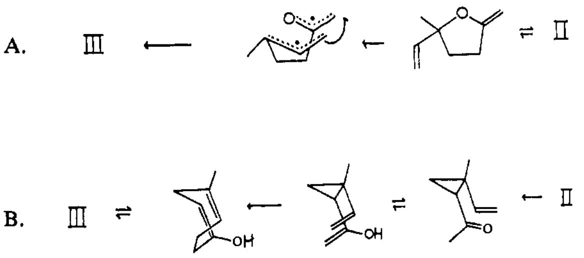
$$CH_3\overset{O}{\overset{\|}{C}}CH_2CH_2\overset{O}{\overset{\|}{C}}CH_3 + CH_2{=}CHMgBr \xrightarrow{THF} CH_3\overset{O}{\overset{\|}{C}}CH_2CH_2\underset{CH_3}{\overset{OH}{C}}{-}CH{=}CH_2 \xrightarrow{150°} II$$

When II is heated, neat or in n-decane, at 175° for 24 hr, it rearranges in nearly quantitative yield to a single product, 4-methyl-4-cycloheptenone (III). The structure of III is based on the following evidence. Its mass spectrum shows a parent ion peak of m/e 124 and, significantly, no peak of m/e 43 indicative of an acetyl fragment anticipated for the "normal" Claisen rearrangement product 1-methyl-4-acetylcyclopentene (IV). The infrared spectrum of III reveals a strong carbonyl band at 1705 cm^{-1} and weak double bond absorption at 1670 cm^{-1}. The nonconjugated nature of the double bond and the carbonyl function is confirmed by the ultraviolet spectrum, λ_{max}^{EtOH} 280 mμ (ϵ 27); $\lambda_{max}^{cyclohexane}$ 282 mμ (ϵ 22). The nmr spectrum (in benzene) shows signals at δ = 5.46 ppm, area 1, broad multiplet with fine splitting (C=CH); δ = 1.65 ppm, area 3, complex multiplet with fine splitting ($C{=}CCH_3$); and two groups of four protons each, centered at $\delta \sim$ 2.5 and $\sim$2.0 ppm, assigned to the α-methylene protons and the allylic methylene protons, respectively. The location of the double bond at the 4 position and the assignment of the two groups of methylene protons are supported by the nmr spectrum of III-d_4, prepared by base-catalyzed deuterium exchange. In the spectrum of III-d_4 the multiplet at δ = 2.5 ppm has disappeared and the signals of the four allylic methylene protons show a much simplified pattern at δ = 1.9 ppm. Finally, catalytic reduction of III with 1 equiv of hydrogen yields 4-methylcycloheptanone, identical in all respects with an authentic sample.[4]



III IV

The unidirectional and heretofore unobserved rearrangement of II to III has important mechanistic and synthetic implications. It appears that the geometric restraint imposed on the bisallylic system, I, by methylene bridging of the third (c) and sixth (f) atoms provides a barrier of such magnitude to the usually facile Claisen rearrangement that another, energetically less demanding, route is traversed.[5] Two possible sequences are suggested: (A) rearrangement of the dihydrofuran system to *cis*-1-acetyl-2-vinylcyclopropane followed by enolization toward the methyl group and rapid thermal reorganization of the very labile *cis*-divinylcyclopropane system;[8] (B) isomerization of II to the *exo*-methylene derivative with subsequent rearrangement of the new (and less constrained) allyl vinyl ether system. Experiments designed to distinguish these possibilities and to explore the generality of the rearrangement are in progress.



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[4] Synthesized by the method of C. Djerassi, *et al.*, *J. Am. Chem. Soc.*, **85**, 949 (1963).

[5] Formally, II may be viewed as a tetraalkylated allyl vinyl ether with c,c,e,f substitution of the bisallylic system I. Closely analogous acyclic systems[6] and allylic aryl ethers,[7] differentiable from II only by the absence of geometric restraint imposed by the methylene bridge, invariably show the characteristic of a facile, concerted, thermal reorganization with ultimate bonding of the a and f atoms through a six-atom transition state. To our knowledge, there is no case on record in which the alternative four-atom complex (leading to bonding of the c and f atoms) is preferred when the geometry of the system permits the achievement of both.

[6] L. Stein and G. W. Murphy, *J. Am. Chem. Soc.*, 74, 1041 (1952); A. W. Burgstahler, *ibid.*, **82**, 4681 (1960); Y. Pocker, *Proc. Chem. Soc.*, 141 (1961); H. M. Frey and B. M. Pope, *J. Chem. Soc., Sec. B*, 209 (1966).

[7] Reviews by D. S. Tarbell, *Org. Reactions*, **2**, 1 (1944), and S. J. Rhoads in "Molecular Rearrangements," Vol. I, P. deMayo, Ed., Interscience Publishers, Inc., New York, N. Y., 1963, Chapter 11.

[8] E. Vogel, *Angew. Chem.*, **72**, 21 (1960); E. Vogel, K. H. Ott, and K. Gajek, *Ann.*, **644**, 172 (1961); W. von E. Doering and W. R. Roth, *Tetrahedron*, **19**, 715 (1963).

[9] National Science Foundation Summer Fellow, 1966.

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Electron Transfer by Remote Attack in Substituted Pyridine Bridging Ligands

Sir:

Electron transfer by remote attack at a bridging group has been suggested as a pathway for the reduction