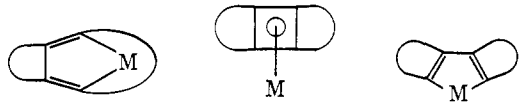
One other noticeable feature of the molecular structure is the disorder of the methylene groups. This appears in Figure 1 as unusually elongated thermal ellipsoids for the eight methylene carbons, particularly the four central ones (C_{12}, C_{13}, C_{16}, C_{17}). This effect is best explained in terms of a 1:1 statistical disorder involving a superposition of the two stable half-chair conformers Va and Vb (as in cyclohexene[11]) of each of

Va Vb

the six-membered rings. Attempts at resolving the disorder problem by using equally populated half-carbon atoms in the least-squares refinement were not entirely successful.

The most remarkable feature of this structure determination is the unexpected[12] finding that a gross skeletal rearrangement of the starting diyne (from a 12-membered ring to a bicyclohexenyl-type framework) has occurred upon complexation. This reaction probably occurs *via* the formation of a metallocycle of type VI first, which then rearranges to the observed type VIII metallocycle. One can speculate about the possible



VI VII VIII

intermediacy of a cyclobutadiene-type species VII in the VI to VIII rearrangement process. The isolation[1b] of trace amounts of III from the reaction mixture indicates that, at the very least, the formation of cyclobutadiene complexes is possible in this system. While there is ample evidence for a VI-to-VII type process from previous studies on related systems,[13] the VII-to-VIII type conversion (which may very well involve participation by the second iron atom) is, as far as we know, unknown.

Irrespective of whether VII is a true intermediate or not, our result suggests that metallocyclic intermediates may play a prominent part in the mechanism of tungsten-catalyzed alkyne disproportionation reactions[14] (eq 1) and also suggests that the $Fe(CO)_5$ system may

$$R_1C{\equiv}CR_1 + R_2C{\equiv}CR_2 \rightleftharpoons 2R_1C{\equiv}CR_2 \qquad (1)$$

in fact be one where such processes might take place. We would like to point out that other metallocycles (saturated analogs of VIII) have been implicated as intermediates in olefin disproportionation[15] and other skeletal rearrangement reactions. Very recently one such intermediate was isolated and structurally characterized.[16]

(11) F. A. L. Anet and M. Z. Haq, *J. Amer. Chem. Soc.*, **87**, 3147 (1965).

(12) The original formulation (II) for the compound was, on the basis of chemical intuition and the known spectral data, certainly the most logical choice.

(13) (a) H. Yamazaki and N. Hagihara, *J. Organometal. Chem.*, **7**, P22 (1967); (b) W. Hübel in "Organic Syntheses via Metal Carbonyls," Vol. I, I. Wender and P. Pino, Ed., Interscience-Wiley, New York, N. Y., 1968, pp 294, 330.

(14) F. Pennella, R. L. Banks, and G. C. Bailey, *Chem. Commun.*, 1548 (1968).

(15) R. H. Grubbs and T. K. Brunck, *J. Amer. Chem. Soc.*, **94**, 2538 (1972).

(16) A. R. Fraser, P. H. Bird, S. A. Bezman, J. R. Shapley, R. White, and J. A. Osborn, *J. Amer. Chem. Soc.*, **95**, 597 (1973).

Acknowledgment. We thank Professor R. B. King of the University of Georgia for the crystals used in this work. Partial financial support was provided by the National Institutes of Health, and computer time was provided by the Computer Center of the University of Southern California. The diffractometer was purchased through a grant from the National Science Foundation.

Supplementary Material Available. A listing of the final atomic parameters will appear following these pages in the microfilm edition of this volume of the journal. Photocopies of the supplementary material from this paper only or microfiche (105 × 148 mm, 20× reduction, negatives) containing all of the supplementary material for the papers in this issue may be obtained from the Journals Department. American Chemical Society, 1155 16th St., N.W., Washington, D. C. 20036. Remit check or money order for $3.00 for photocopy or $2.00 for microfiche, referring to code number JACS-73-5068.

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Received April 6, 1973

Configurationally Isomeric Iminoxy Radicals. Intermediates in the Rearrangements of Nitrones to *O*-Alkyl Oximes[1]

Sir:

Previous investigations[2,3] of the thermal rearrangement of *N*-benzhydryl-α,α-diphenylnitrone (**1**) to benzophenone *O*-benzhydryloxime (**2**) provide evidence for a homolytic cleavage to iminoxy and benzhydryl radicals with subsequent recombination at oxygen.[4] We now report evidence which indicates that geometrically isomeric diaryliminoxy radicals (*Z*)-**4** and (*E*)-**4** undergo syn–anti isomerization five or six orders of magnitude faster than the corresponding oxime anions.

A study of the geometric course of the N to O rearrangements of syn–anti isomeric nitrones ((*Z*)-**3** and (*E*)-**3**) offered an opportunity to estimate the rates of geometric isomerization of iminoxy radicals in the absence of such potential isomerization catalysts as acids and oxidizing agents.[5]

The minimum number of processes which were anticipated for these nitrone decompositions is shown in Scheme I. Retention of configuration in product formation would be expected in the case $[(C_6H_5)_2\dot{C}H]k_d \gg k_3$ or k_4. Retention would also be anticipated if the N to O rearrangement was concerted (*i.e.*, *via* a quasi three-membered ring transition state).[6] The two *O*-

(1) A preliminary account of this study was presented at the 165th National Meeting of the American Chemical Society, Dallas, Tex., April 1973, Abstract ORGN-99.

(2) E. J. Grubbs, J. A. Villarreal, J. D. McCullough, Jr., and J. S. Vincent, *J. Amer. Chem. Soc.*, **89**, 2234 (1967).

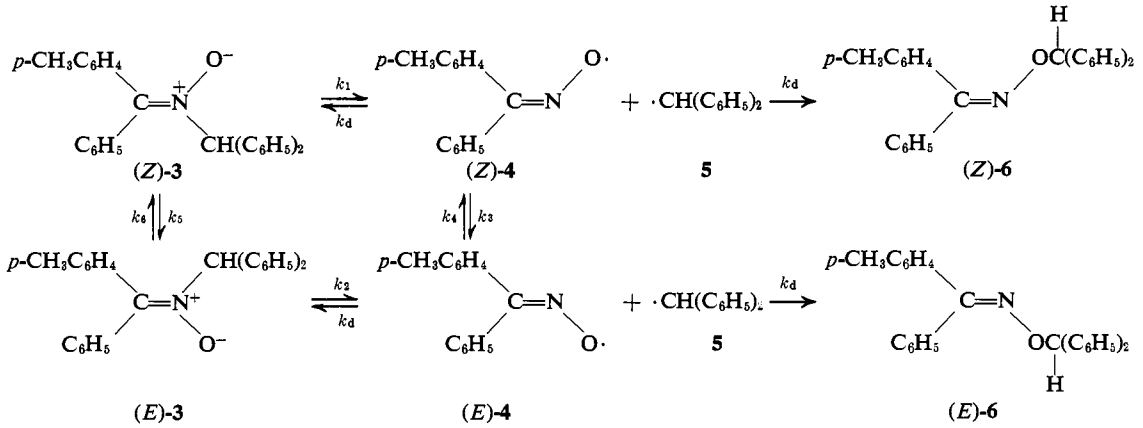
(3) J. S. Vincent and E. J. Grubbs, *ibid.*, **91**, 2022 (1969).

(4) See also D. G. Morris, *Chem. Commun.*, 221 (1971) for CIDNP evidence for caged radicals in the thermal N to O rearrangement of the nitrone derived from fluorenone oxime.

(5) See B. C. Gilbert and R. O. C. Norman, *J. Chem. Soc. B*, **86**, 722 (1966); 123 (1968) (and references therein) for reports of the generation of mixtures of geometrically equilibrating iminoxy radicals from oxidations of isomerically pure oximes.

(6) A. C. Cope and A. C. Haven, Jr., *J. Amer. Chem. Soc.*, **72**, 4896 (1950).

Scheme I



benzhydryloximes, (*Z*)-**6** and (*E*)-**6**, were prepared by the alkylations of the geometrically pure oxime anions employing benzhydryl bromide in acetone.[7] They were shown to be stable toward decomposition and configurational isomerization under the conditions of the nitrone decompositions. A mixture of the nitrones (*Z*)-**3** and (*E*)-**3** (prepared by the reaction of *p*-tolylphenylketimine with *N*-benzhydrylhydroxylamine) was resolved into pure isomers by fractional crystallization. Configurational assignments were determined by an nmr method previously described.[8]

Because the nitrone geometric isomerization proved to be competitive with the rate for the N to O rearrangement, analyses of the geometric compositions of the products (*O*-benzhydryl ethers) had to be extrapolated back to "zero per cent decomposition" (corresponding to product formation from a geometrically pure nitrone). These extrapolations lead to the following results. Under the conditions of these studies (144°, *tert*-butyl alcohol solvent, initial concentrations of nitrones $\sim 4.0 \times 10^{-2}$ *M*) pure (*Z*)-**3** leads to a mixture of *O*-benzhydryl ethers in a ratio (*Z*)-**6**/(*E*)-**6** of 72/28. The corresponding ratio (*E*)-**6**/(*Z*)-**6** formed from pure (*E*)-**3** is 62/38. Kinetic data for the decompositions of the two nitrones were also analyzed at early stages of the N to O rearrangements, prior to significant geometric ((*Z*)-**3** $\rightleftharpoons$ (*E*)-**3**) equilibration. In this way the following observed first-order rate constants were determined: for (*Z*)-**3**, $k_{obsd} = 1.4 \times 10^{-5}$ sec^{-1}; for (*E*)-**3**, $k_{obsd} = 1.0 \times 10^{-5}$ sec^{-1}.[9]

Two observations regarding the above stereochemical results are noteworthy. First, at very early stages of the rearrangements (as measured by consumption of nitrone) when the starting nitrone has undergone little configurational isomerization, the *O*-benzhydryloximes are formed with extensive configurational isomerization.[10] This is inconsistent with a concerted mechanism[6] and indicates that the products are formed largely from intermediates (iminoxy radicals) that do not maintain their geometric configuration. The second important point is that the products are not being formed by the reaction of benzhydryl radicals with iminoxy radicals which have achieved and are maintaining a state of equilibrium.

Employing Scheme I, the above stereochemical data and the measured rates of the N to O rearrangements of (*Z*)-**3** and (*E*)-**3** may be used to estimate the rate constants for iminoxy radical geometric isomerization, k_3 and k_4. In the following analysis it has been assumed that all processes involving radical–radical combinations are diffusion controlled with an estimated value of the rate constants, k_d, of 10^9.[11] Referring to Scheme I, the "steady state" concentrations of iminoxy radicals (*Z*)-**4** and (*E*)-**4** and benzhydryl radicals **5** may be calculated at early stages of the reaction as follows. The rate of disappearance of nitrone (*E*)-**3** determined spectrophotometrically is equal to the rate of product formation, *i.e.* $k_{obsd}[(E)\text{-}3] = \{[(E)\text{-}4] + [(Z)\text{-}4]\}[5]k_d$. Furthermore, since *O*-benzhydryloxime formation is nearly quantitative $[(E)\text{-}4] + [(Z)\text{-}4] = [5]$. The values of k_{obsd} and initial $[(E)\text{-}3]$ (3.6×10^{-3} *M*) are known and k_d is the assumed diffusion-controlled rate constant. This leads to a value of $[5] = [(E)\text{-}4] + [(Z)\text{-}4] = 6.02 \times 10^{-9}$ *M*. Again for the decomposition of pure (*E*)-**3**, the ratio ((*E*)-**6**/(*Z*)-**6**) of products formed at the initial stages of the reaction (experimentally 1.63) equals the ratio of initial "steady state" concentrations of the iminoxy radicals, $[(E)\text{-}4]/[(Z)\text{-}4]$. Thus, $[(E)\text{-}4]_{init} = 3.7 \times 10^{-9}$ *M* and $[(Z)\text{-}4]_{init} = 2.3 \times 10^{-9}$ *M*. The steady state approximation for $[(E)\text{-}4]_{init}$ leads to the following

$$k_2[(E)\text{-}3] + k_3[(Z)\text{-}4] = 2k_d[5][(E)\text{-}4] + k_4[(E)\text{-}4] \quad (1)$$

Since $k_2 = 2k_{obsd}$ in this scheme, all quantities in eq 1 are known except k_3 and k_4. A value of $k_3/k_4 = 0.7$ can be deduced from the initial first-order rate constants for decomposition of (*Z*)-**3** and for (*E*)-**3** (1.4×10^{-5} and 1.0×10^{-5} sec^{-1}, respectively) and our experimental observation that the ground-state free energies of the two nitrones are identical within experimental error. When this ratio is combined with the other known quantities in eq 1, the rate constants $k_3 = 9$ sec^{-1} and $k_4 = 13$ sec^{-1}

(7) Satisfactory elemental analyses were obtained for all new compounds prepared in the course of this study. Spectra were in accord with the assigned structures. Geometric purities of isomeric *O*-benzhydryloximes could be determined by pmr integrations of the CH_3 singlets (2.38 ppm for (*Z*)-**6** and 2.29 ppm for (*E*)-**6** in $CDCl_3$).

(8) E. J. Grubbs, R. J. Milligan, and M. H. Goodrow, *J. Org. Chem.*, **36**, 1780 (1971).

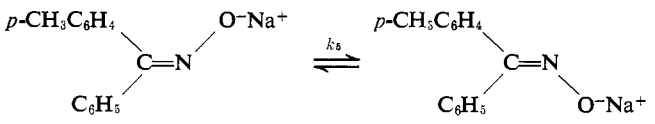
(9) Rates were determined in *tert*-butyl alcohol at 144° spectrophotometrically (uv).

(10) For example, at 5% decomposition of (*Z*)-**3**, recovered nitrone is 90% (*Z*)-**3** and 10% (*E*)-**3**, whereas the ratio (*Z*)-**6**/(*E*)-**6** at this stage of the reaction is 70/30. Similarly, at 6% decomposition of (*E*)-**3**, the recovered nitrone is 90% (*E*)-**3** and 10% (*Z*)-**3**, while the ratio (*E*)-**6**/(*Z*)-**6** at this stage of the reaction is 60/40.

(11) Evidence has been obtained from crossover studies employing **1** and its tetradeuterated (in the para positions) analog that in *tert*-butyl alcohol the rate constants (at least for intermolecular reaction) for benzhydryl radical combination with iminoxy radicals at oxygen and nitrogen are approximately equal.[12]

(12) J. A. Villarreal and E. J. Grubbs, unpublished data.

are obtained.[13] It has been pointed out previously that the range of rates of geometric isomerization of imine derivatives is a remarkable 16 powers of 10 or more.[14] We now report another dramatic demonstration of the sensitivity of these interconversion rates toward structural changes in the group singly bound to nitrogen. We have recently determined the rate constant for the *Z* to *E* isomerization of sodium *p*-methylbenzophenone oximate in methanol at 144°.[15] The value for k_5 is



3.1×10^{-5} sec^{-1} (the equilibrium constant under these conditions is 0.64). Thus under comparable[16] conditions *the iminoxy radical undergoes geometric isomerization approximately 5 or 6 powers of 10 faster than the corresponding oximate.* If one assumes a lateral shift mechanism for both isomerizations, a partial source of this difference in rates may be the difference in nonbonding electron promotional energies for the $sp^2 \rightarrow 2p$ processes during passage through the respective linear (C–N–O) transition states. Various calculated contributions to differences in energy barriers for the iminoxy radical and oxime anion interconversions will be considered in a later publication.

Acknowledgments. This investigation was supported by the National Cancer Institute, National Institutes of Health, U. S. Public Health Service (Grant No. CA-10741-04).

(13) The accuracy of these rate constants is limited primarily by two factors. The magnitude of the diffusion-controlled rate constant, k_d, used is clearly an estimate. However, an order of magnitude error in this estimate leads to iminoxy radical syn–anti interconversion rate constants which differ from k_3 and k_4 by only a factor of 3. A second uncertainty arises from the question as to whether caged iminoxy–benzhydryl radical pairs recombine with a higher degree of stereochemical retention than do free iminoxy and benzhydryl radicals. We have recently shown that approximately 20% of **2** formed from **1** under conditions of the above stereochemical study is formed *via* a caged process.[12] The errors in k_3 and k_4 which could result from such a highly stereospecific caged process can be estimated. In the limiting case, the caged (or less likely concerted) process could be considered as competing with Scheme I and yielding *O*-benzhydryloxime with 100% geometric retention. If data used in obtaining k_3 and k_4 above are corrected for the contribution of this process to rates and stereochemistry of product formation, the revised k_3 and k_4 values are larger by a factor of approximately two.

(14) D. Y. Curtin, E. J. Grubbs, and C. G. McCarty, *J. Amer. Chem. Soc.*, **88**, 2775 (1966); see also G. E. Hall, W. J. Middleton, and J. D. Roberts (*ibid.*, **93**, 4778 (1971)) for additional references to studies of rates and mechanisms of syn–anti isomerizations of imine derivatives.

(15) D. R. Parker and E. J. Grubbs, unpublished data.

(16) It is unlikely that solvent differences can account for more than a small percentage of this difference in rates.

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Aryldiazirines. Potential Reagents for Photolabeling of Biological Receptor Sites

Sir:

Since the photochemical generation of a reactive intermediate as a novel approach to the labeling of biological macromolecules was put forward by Westheimer and his group,[1] this technique has been limited to the use of α-keto diazo compounds and of aryl azides as carbene and nitrene precursors, respectively.[2] The carbenes have had to be derived from α-keto diazo compounds because of the chemical instability of the diazo compounds themselves, but the susceptibility of the resulting α-keto carbenes to Wolff-type rearrangements has seriously limited the utility of these materials. Further, it appears that aryl nitrenes are not always as reactive as one would like.[2] What is required is a chemically stable carbene[3] precursor that will photolyze smoothly at wavelengths clear of protein absorption. We report here the synthesis and photolysis of several 3-aryl-3*H*-diazirines. These materials have a chemical stability and photochemical lability that augur well for their use as precursors of carbene labeling reagents.

The only 3-aryl-3*H*-diazirine in the literature is the *p*-nitrophenyl compound, which was prepared by a route using difluoramine.[4] 2,4,6-Triaryl-1,3,5-triazabicyclo[3.1.0]hexanes can be made from aryl aldehydes, chloramine, and ammonia in methanol at −10°. In contrast to the alkyl compounds,[5] oxidative cleavage of the aryl derivatives with acid dichromate gives very poor yields of diazirines, presumably owing to the rapid acid hydrolysis of the intermediate aryl diaziridines. However, the diaziridines can be trapped by oxidation to the diazirine if yellow mercuric oxide is added to the reaction mixture immediately after precipitation of the triazabicyclohexane has begun. In this way, 3-(*p*-tolyl)- (**1**) and 3-(*p*-anisyl)-3*H*-diazirine and the water-soluble *p*-diazirinophenoxyacetic acid (**2**) were prepared (in 2–4% yield). The low yields are offset to some extent by the simplicity of the method, preparative thin-layer chromatography of the reaction mixture giving the diazirine directly. The parent 3-phenyl-3*H*-diazirine (**3**) was prepared in 48% yield by cleavage of the corresponding bicyclohexane with *tert*-butyl hypochlorite in methanol at 0° (**1**, oil; ir ($CHCl_3$) 1600 cm^{-1}; pmr (CCl_4) τ 8.12 (S, 1 H); uv 368 (ϵ 311), 272 (ϵ 319) nm; **2**, yellow crystals; ir (mull) 1610 cm^{-1}; pmr (CD_3OD) τ 7.90 (S, 1 H); uv 378 (ϵ 300), 269 (ϵ 1607) nm; **3**, oil; ir ($CHCl_3$) 1580 cm^{-1}; pmr (CCl_4) τ 8.24 (S, 1 H); uv 362 (ϵ 299), 265 (ϵ 331) nm). The mass spectra showed $M^+ - 28$ peaks characteristic of loss of nitrogen from the molecular ion. No detectable amounts of diazirine could be obtained from the *tert*-butyl hypochlorite cleavage of the *p*-tolyl- or of the *p*-anisyltriazabicyclohexane. The mechanism of this cleavage probably involves initial N-chlorination followed by participation of a lone pair of one of the diaziridine nitrogen atoms in the loss of chloride ion. The resultant cation may then break down to give products other than the diazirine, derived from the aryl carbonium ion (formed by opening the three-membered ring) which can be stabilized by the presence of an electron-releasing group.

The photochemical interconversion of diazirines and diazo compounds is known for diazirine itself[6] and

(1) A. Singh, E. R. Thornton, and F. H. Westheimer, *J. Biol. Chem.*, **237**, PC 3006(1962); J. Shafer, P. Baronowsky, R. Laursen, F. Finn, and F. H. Westheimer, *ibid.*, **241**, 421 (1966).

(2) J. R. Knowles, *Accounts Chem. Res.*, **5**, 155 (1972).

(3) Preferably an aryl carbene; alkyl carbenes rearrange to the olefin.

(4) W. A. Graham, *J. Amer. Chem. Soc.*, **88**, 4677 (1966).

(5) E. Schmitz, *Chem. Ber.*, **95**, 690 (1962).

(6) M. J. Amrich and J. A. Bell, *J. Amer. Chem. Soc.*, **86**, 292(1964).