The presence of the water molecule is clearly noted in the ^1H NMR spectrum and confirmed by the microanalysis. It is assumed to be present only to give maximum steric and electrostatic stability to the complex. No attempt was made to remove the water. When the ^1H NMR sample is exchanged with D_2O, the spectrum reverts to that of the triol, which can be recovered from the chloroform solution.

The complex **2** could also be formed by addition of potassium acetate to the free triol. No complex formation could be detected between sodium acetate and the triol. It should be noted that there are only seven oxygens as possible ligands in this complex. The mole of water would seem to be necessary, although this has not been definitively shown. The acetate ion apparently functions similarly to the intramolecular carboxyl group in some ionophorous antibiotics.[9-10]

Experimental Section

Preparation of the Complex 2 by Hydrolysis. The acetate **1** (5 g, mp 107–108°) was treated with 1 equiv of potassium hydroxide in 1:1 MeOH–H_2O (30 ml) at room temperature overnight. The solvents were removed under vacuum, $CHCl_3$ was added, and the solution was filtered. Removal of the $CHCl_3$ under vacuum gave an oil which could be crystallized by dissolving in a minimum volume of MeOH, adding five volumes of ether, and cooling. The complex separated slowly as flocculent, white crystals, mp 53–56° (2 g). Addition of a larger volume of ether caused separation of potassium acetate. The complex could be recrystallized from $CHCl_3$–ether, mp 56–58°. The free triol could be obtained from the first mother liquors and had mp 98–99°.

The complex **2** has ^1H NMR ($CDCl_3$) δ 4.91, s (5 H), 3.65, m (4 H), 1.92, broad s (7 H), 1.24, s (3 H), 1.13, s (3 H), and 1.08, s (3 H). D_2O exchange causes decomposition of the complex as shown by removal of the absorption at δ 4.91, decrease of the integration for the peak at δ 1.92 to four protons, and reversion of the spectrum to that of the triol: δ 3.8, sharpened multiplet (4 H), 1.4–2.4, multiplet (4 H), 1.27, s (3 H), 1.18, s (3 H), and 1.09, s (3 H). Titration of the complex gave a pK_a of 4.55 and a mol wt of 322. The calculated mol wt is 320. Combustion Anal. Calcd for $C_{12}H_{25}KO_7$: C, 44.98; H, 7.86. Found: C, 45.04; H, 7.67. Atomic Absorption Anal. Calcd: K, 12.2. Found: K, 11.7.

Formation of the Complex 2 from the Triol. The parent triol (5.01 g, 25 mmol), potassium acetate (2.45 g, 25 mmol), and water (0.45 ml) were stirred in MeOH (50 ml) until everything went into solution (about 20 min). The solvent was removed under vacuum, MeOH (10 ml) was added, and after filtration, ether (50 ml) was added. The solution was cooled for 24 hr at −25°, and white crystals (2.5 g) were collected, mp 55–57°.

Acknowledgments. I thank Professor Jack Baldwin for his valuable suggestions and Messrs. G. M. Maciak and R. L. Wilson for analytical measurements.

Registry No.—**1**, 4031-49-6; **2**, 56050-93-2; potassium hydroxide, 1310-58-3; *cis*-tetrahydro-α^2-(hydroxymethyl)-2α,α^5,α^5-trimethyl-2β,5β-furandimethanol, 4031-50-9; potassium acetate, 127-08-2.

References and Notes

(1) C. J. Pedersen, *J. Am. Chem. Soc.*, **89**, 7017 (1967); **92**, 391 (1970).
(2) J. J. Christensen, J. O. Hill, and R. M. Izatt, *Science*, **174**, 459 (1971).
(3) C. J. Pedersen and H. K. Frensdorff, *Angew. Chem., Int. Ed. Engl.*, **11**, 16 (1972).
(4) C. D. Hurd, *J. Org. Chem.*, **39**, 3144 (1974).
(5) N. P. Marullo and R. A. Lloyd, *J. Am. Chem. Soc.*, **88**, 1076 (1966).
(6) T. C. Shields, *Chem. Commun.*, 832 (1968).
(7) W. Hewertson, B. T. Kilbourn, and R. H. B. Mais, *Chem. Commun.*, 952 (1970).
(8) A. Agtarap, J. W. Chamberlin, M. Pinkerton, and L. Steinrauf, *J. Am. Chem. Soc.*, **89**, 5737 (1967).
(9) L. K. Steinrauf, M. Pinkerton, and J. W. Chamberlin, *Biochem. Biophys. Res. Commun.*, **33**, 29 (1968).
(10) N. D. Jones, M. O. Chaney, J. W. Chamberlin, R. L. Hamill, and S. Chen, *J. Am. Chem. Soc.*, **95**, 3400 (1973).
(11) J. D. Dunitz, M. Dobler, P. Seiler, and R. P. Phizackerley, *Acta Crystallogr., Sect. B*, **30**, 2733 (1974).
(12) J. M. Lehn, "Structure and Bonding", Vol. 16, Springer-Verlag New York, New York, N.Y., 1973, pp 1–69; M. R. Truter, *ibid.*, pp 71–111.
(13) E. Klein and W. Rojahn, *Tetrahedron*, **21**, 2353 (1965).

The Carbon–Nitrogen Rotational Barrier as a Stereochemical Probe of Benzamidoximes

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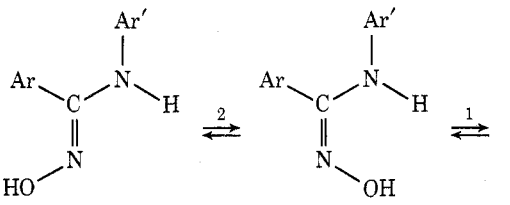
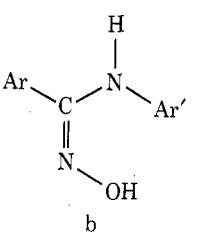
Received February 24, 1975

The stereochemistry of benzamidoximes has been recently investigated by electric dipole moment measurements and NMR spectroscopy.[1] The results of these two independent experimental approaches were complementary and conclusive enough to support the existence of the amino oxime tautomeric structure as well as the *Z* configuration on the C=N bond (structure a and b). However, a further point which remained to be clarified concerns the nature of the two isomers observed in the NMR spectra of some compounds. In principle the two species could derive either from restricted rotation around the amidic bond (equilibrium 1) which creates a barrier for the a ⇄ b transformation, or from inversion around the oximino bond (equilibrium 2); it has been already suggested that the first model should apply.[1]





In order to provide further evidence in favor of this interpretation, we have measured the activation parameters for the reversible conversion of these isomers, since it was thought that a quantitative estimate of the energy involved in this process could discriminate between the two possibilities. In fact it is well known that the rotational barriers around the amidic bond amount[2] to 15–24 kcal mol^{-1} in different environments, whereas the inversion of the carbon-nitrogen double bond of oximes[3] and related compounds[4] should require a much larger energy since syn–anti thermal isomerization is difficult and isomers can be separated.[5]

Among the compounds previously examined,[1] those bearing ortho methyl groups in Ar gave NMR spectra indicating the presence of two isomers whereas only one species was observed for Ar = Ar′ = Ph. We have therefore selected compounds **1** (Ar = 3,5-Cl_2-2,4,6-Me_3C_6; Ar′ = Ph) and **2** (Ar = 2-MeC_6H_4; Ar′ = Ph) and their NMR spectra were recorded at various temperatures. Ortho-methyl substituted benzamidoximes were suitable for a line-shape study since, owing to the lacking of exchange at room temperature, the methyl groups give enough separated sharp singlets. The same nonequivalence was observed also for the amidic and hydroxylic protons, which, however, were less reliable for this study since they can be involved in intra- and intermolecular exchange phenomena. The signals of

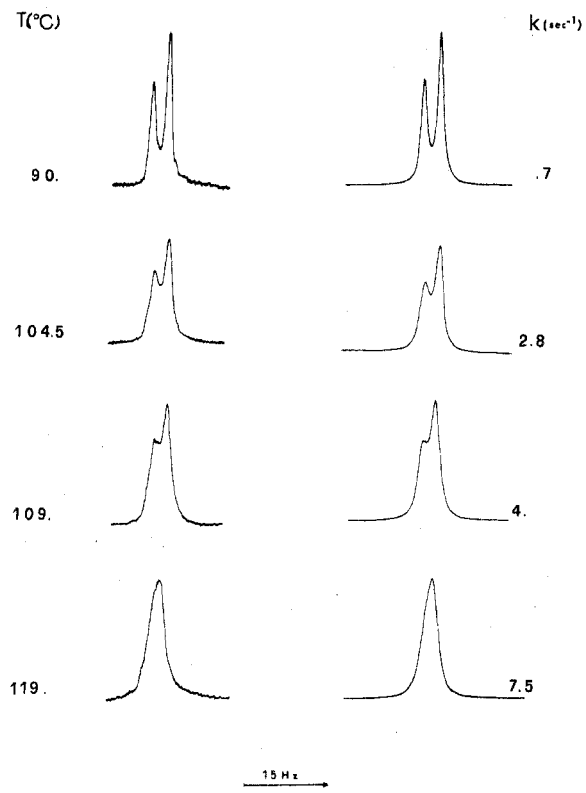


Figure 1. Experimental (left) and simulated (right) 60-MHz spectra of 1 at various temperatures.

the ortho-methyl groups of 1 (Figure 1), which show unequal intensities owing to the different amounts of the two isomers, begin to broaden at about 90° and coalesce into a single line at about 110°. In Figure 1 are also reported for comparison some of the experimental and calculated methyl signals of **1**, the latter being obtained by the DNMR computer program[6] assuming appropriate rate constants. The thermodynamic parameters evaluated from the Eyring and Arrhenius equations[7] are collected in Table I. The activation entropies very close to zero are consistent with both rotational and syn–anti isomerization processes;[3] on the other hand, the relatively low values of the activation energies give evidence in favor of the existence of equilibrium 1 rather than 2. As the *Z* configuration on the C=N has been previously established,[1] it may be inferred from steric considerations that a is the preferred conformer whereas b can be observed when the size of Ar is increased by introducing one or two ortho-methyl groups. This fact forces Ar′ in the conformation b to an extent which is proportional to the ortho substitution (10 and 40% for **2** and **1**, respectively). If the opposite situation would apply (b more stable than a) it is difficult for us to find conceivable reasons to explain the above change of isomer ratio. Furthermore, it may be observed that conformation a, where H faces the OH group,[8] is expected to be sterically more favored than b. This is supported by the observation that substitution of the amidic hydrogen in PhC(NHPh)=NOH with a methyl group [**3**, PhC(NMePh)=NOH] induces the formation of the second isomer in a relatively lower amount (30%), owing to the increased steric interaction between Me and OH which destabilizes isomer a. Unfortunately, the activation parameters could not be measured in this case, since the two methyl signals, which are well separated at room temperature, become incidentally equivalent before any broadening is observed.

Table I
Activation Parameters[a] for the C–N Rotation in Benzamidoximes 1 and 2 in Me_2SO-d_6

Amidoxime	E_a, kcal/mol	$\Delta H^{\ddagger}$, kcal/mol	$\Delta S^{\ddagger}$, eu	$\Delta F^{\ddagger}$, kcal/mol
1	21.9 ± 0.7	21.1 ± 0.7	−1.1 ± 1.8	21.54 ± 0.04
2	21.8 ± 0.5	21.1 ± 0.5	3.4 ± 1.3	19.91 ± 0.05

[a] The data refer to the forward process a → b, where a and b are the more and less stable isomers, respectively. $\Delta F^{\ddagger}$ values are the average from values calculated at ten different temperatures.

Experimental Section

The variable-temperature NMR spectra were recorded in Me_2SO-d_6 by a 60-MHz instrument. Temperatures were determined before and after each measurement by a suitable thermometer placed inside the NMR probe. Spectra were simulated (see Figure 1) by the DNMR program[6] run on a CDC 6600 computer.

Benzamidoximes **3–5** were prepared by addition of the proper amine to benzonitrile *N*-oxide as described[1] for compounds **1** and **2**. The products were separated from the excess of amine and diphenylfurazan *N*-oxide by chromatography on a silica gel column [eluents, benzene and then ethyl ehter for **4** and **5**; eluent, benzene-ethyl ether (95:5) for **3**] and after crystallization from proper solvent were analytically pure and gave ir spectra (CCl_4–C_2Cl_4–CS_2) showing characteristic bands at 3600 (OH), 3400 (NH) (absent in **3**), ca. 3300 broad (OH), and 1630 cm^{-1} (C=N). ***N*-Methylphenylbenzamide oxime (3)** had mp 110° (from benzene–petroleum ether); NMR (Me_2SO-d_6) δ 10.8 (s, 1, OH), 7.5–6.3 (m, 10, aromatic protons), 3.2 and 3.1 (s, 3, Me). Anal. Calcd for $C_{14}H_{14}N_2O$: C, 74.31; H, 6.24; N, 12.38. Found: C, 74.35; H, 6.27; N, 12.49. ***N*-*o*-Tolylbenzamide Oxime (4)** had mp 148–149° (from benzene-petroleum ether); NMR (CS_2) δ 10–8 (very broad, 1, OH), 7.5–6.0 (m, 10, NH and aromatic protons), 2.25 (s, 3, Me). Anal. Calcd for $C_{14}H_{14}N_2O$: C, 74.31; H, 6.24; N, 12.38. Found: C, 74.26; H, 6.20; N, 12.35. ***N*-Mesitylbenzamide oxime (5)** had mp 184–185° (from ethanol); NMR (CS_2) δ 9.5–8.0 (very broad, 1, OH), 7.0 (s, 5, aromatic protons), 6.5 (s, 2, aromatic protons), 2.0 (s, 6, ortho Me), 2.05 (s, 3, para Me), the NH signal was between the two aromatic proton signals. Anal. Calcd for $C_{16}H_{18}N_2O$: C, 75.56; H, 7.13; N, 11.02. Found: C, 75.65; H, 7.14; N, 11.10.

Registry No.—**1**, 56050-94-3; **2**, 56050-95-4; **3**, 56050-96-5; **4**, 56050-97-6; **5**, 56050-98-7; benzonitrile *N*-oxide, 873-67-6; *N*-methylbenzenamine, 100-61-8; 2-methylbenzenamine, 95-53-4; 2,4,6-trimethylbenzenamine, 88-05-1.

References and Notes

(1) O. Exner, V. Jehlička, A. Dondoni, and A. C. Boicelli, *J. Chem. Soc., Perkin Trans. 2*, 567 (1974).
(2) R. C. Neuman, Jr., and V. Jonas, *J. Org. Chem.*, **39**, 925, 929 (1974), and references cited therein; H.-O. Kalinowski and H. Kessler, *Top. Stereochem.*, **7**, 295 (1973).
(3) C. G. McCarty in "The Chemistry of the Carbon-Nitrogen Double Bond", S. Patai, Ed., Interscience, New York, N.Y., 1969, p 363.
(4) O. Exner, V. Jehlička, A. Relser, *Collect. Czech. Chem. Commun.*, **24**, 3207 (1959); J. E. Johnson, J. R. Springfield, J. S. Hwang, L. J. Hayes, W. C. Cunningham, and D. L. McClaugherty, *J. Org. Chem.*, **36**, . 284 (1971); A. Battaglia, A. Dondoni, and O. Exner, *J. Chem. Soc., Perkin Trans. 2*, 1911 (1972).
(5) The thermal syn–anti isomerization of oximes is usually very slow and $\Delta F^{\ddagger}$ values are too high to be measured before considerable decomposition takes place. However, a $\Delta F^{\ddagger}$ value as low as 32 kcal/mol is reported for a typical case: E. G. Vassian and R. K. Murmann, *J. Org. Chem.*, **27**, 4309 (1962). In principle, it is possible that the barrier to syn–anti isomerization of oximes may be lowered by a heteroatom bonded to the azomethine carbon in place of a carbon of an alkyl or aryl group, as observed for other compounds containing the C=N double bond (ref 3, p 404). However, the existence of stable syn and anti isomers at room temperature even for this type of oximes, such as ethyl benzohydroximates [I. K. Larsen and O. Exner, *Chem. Commun.*, 254 (1970)], seems to indicate that the interconversion energy is still much higher than 30 kcal/mol. Furthermore, also the well-established amino oxime form of amidoximes[1] makes it unlikely that a partial single bond character of the C=N bond may lower the energy of the syn–anti isomerization to the observed values.
(6) G. Binsch, "Quantum Chemistry Program Exchange", Indiana University, Programs 140 and 165; *J. Am. Chem. Soc.*, **91**, 1304 (1969).
(7) S. Glasstone, K. J. Laidler, and H. Eyring, "The Theory of Rate Processes", McGraw-Hill, New York, N.Y., 1941, Chapter 6.
(8) When ortho methyl groups are in Ar′ [**4**, PhC(NHC$_6$H$_4$-Me-2)=NOH; **5**, PhC(NHMes)=NOH], a single methyl signal is observed. In principle this could be due either to a fast rotation around the carbon–nitrogen bond or to the presence of only one isomer. In view of the high activation energies measured for compounds **1** and **2**, the second hypothesis seems more likely, but we cannot assign the structure of the conformer in these cases.