

3.84-4.50 (m, CHOH), 1.46 (s, CH₃). Anal. Calcd for C₈H₁₂Cl₂O: C, 49.25; H, 6.20; Cl, 36.35. Found: C, 49.05; H, 6.18; Cl, 36.51.

Reduction of endo alcohol **5a** with Li/NH₃⁵ gave endo-6-methylbicyclo[4.1.0]heptan-2-ol (**5b**), which had an NMR spectrum identical with that published.⁷

exo-8,8-Dichlorobicyclo[5.1.0]octan-2-ol (7a). Reaction of 2-cycloheptenol (20 mmol) with dichlorocarbene by the general procedure gave 1.54 g (40%) of exo alcohol **7a** as a solid. Recrystallization from hexane gave material with mp 75-75.5 °C (lit.⁴ mp 74.5-75.5 °C); NMR (CDCl₃) δ 3.44-3.86 (m, CHOH).

Reduction of exo alcohol **7a** with Li/NH₃⁵ gave exo-bicyclo[5.1.0]octan-2-ol (**7b**), which had an NMR spectrum identical with that published.⁴

exo-9,9-Dichlorobicyclo[6.1.0]nonan-2-ol (8a). Reaction of 2-cyclooctenol (20 mmol) with dichlorocarbene by the general procedure gave exo alcohol **8a**. Recrystallization from hexane gave 3.10 g (74%) of white solid: mp 87-88 °C (lit.⁴ mp 87.5-89 °C); NMR (CDCl₃) δ 3.34-3.84 (m, CHOH).

Reduction of exo alcohol **8a** with Li/NH₃⁵ gave exo-bicyclo[6.1.0]nonan-2-ol (**8b**), which had an NMR spectrum identical with that published.⁴

Registry No. **1a**, 73378-12-8; **1b**, 7432-49-7; **2a**, 31022-86-3; **2b**, 31022-87-4; **3a**, 73378-13-9; **3b**, 41299-39-2; **4a**, 73378-14-0; **5a**, 73378-15-1; **5b**, 13388-57-3; **6a**, 73378-16-2; **7a**, 31022-91-0; **7b**, 6142-49-0; **8a**, 31022-98-7; **8b**, 29783-12-8; 2-cyclohexenol, 822-67-3; dichlorocarbene, 75-09-2; 3-methyl-1-cyclopentenol, 3718-59-0; 3-methyl-2-cyclohexenol, 21378-21-2; 2-cycloheptenol, 4096-38-2; 2-cyclooctenol, 3212-75-7.

Restricted Rotation in Pentaarylpyridines. Steric Requirement of the Nitrogen Lone Pair

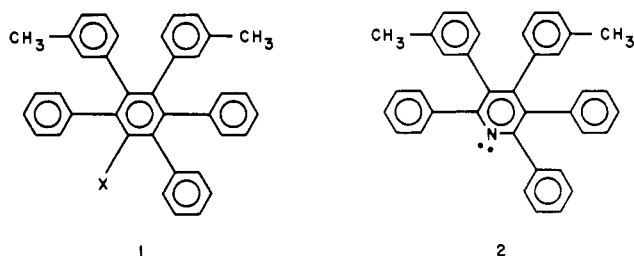
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A perennial unresolved stereochemical question concerns the steric "size" of the nonbonding pair of electrons on nitrogen.¹ One very useful measure of the steric requirement of a group has been the *A* value, or $-\Delta G^\circ$ for the axial-equatorial equilibrium in cyclohexane derivatives.² As a result, many attempts to measure $-\Delta G^\circ$ for the lone pair in piperidine have been made. However, there is not as yet complete agreement as to whether this molecule is most stable with the nitrogen lone pair in the axial or in the equatorial position.³

We have recently shown⁶ that substituted penta-phenylbenzenes such as those represented by **1** exist in a



(1) For a short review of this problem, see: le Noble, W. J. "Highlights of Organic Chemistry"; Marcel Dekker: New York, 1974; pp 231-3.

(2) For reviews, see: Eliel, E. L. *J. Chem. Educ.* **1960**, *37*, 126; *Angew. Chem., Int. Ed. Engl.* **1965**, *4*, 761.

(3) For reviews presenting differing viewpoints in this controversy, see ref 4 and 5.

(4) Lambert, J. B.; Featherman, S. I. *Chem. Rev.* **1975**, *75*, 611.

(5) Blackburne, I. D.; Katritzky, A. R.; Takeuchi, Y. *Acc. Chem. Res.* **1975**, *8*, 300.

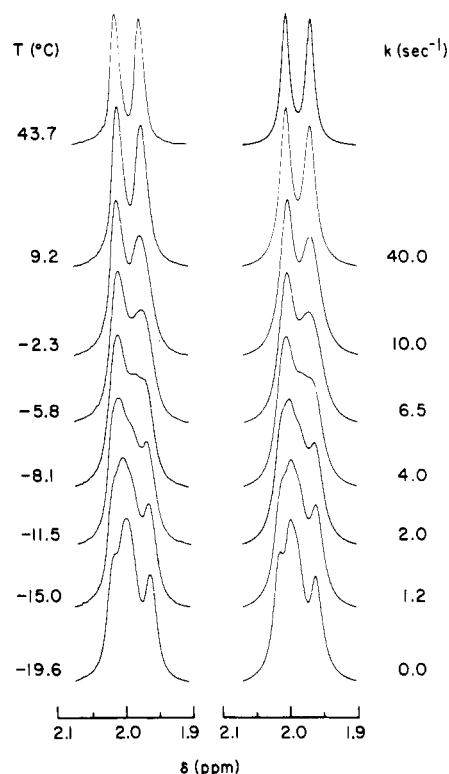


Figure 1. Experimental (left) and calculated (right) 100-MHz ¹H NMR spectra for **2** in chloroform-*d* solution at selected temperatures.

perpendicular conformation with the five peripheral aryl rings approximately at right angles to the plane of the central ring on the NMR time scale. These molecules display restricted rotation about the bonds joining the central ring and the peripheral rings bearing meta methyl groups. Results for a variety of substituents X revealed that substantial steric buttressing effects are transmitted from X to the vicinity of the rotating rings. The free energies of activation for rotation (ΔG^\ddagger_{293}) ranged from 15.5 to 18.7 kcal/mol and were linearly related to $-\Delta G^\circ$ for the same substituent X in the axial-equatorial cyclohexane equilibrium (eq 1). This relationship suggests that steric

$$\Delta G^\ddagger_{293} = 0.60(-\Delta G^\circ) + 15.4 \quad (1)$$

buttressing interactions in the pentaarylbenzenes are similar in their general nature to steric effects in the cyclohexanes and that values for $-\Delta G^\circ$ may be estimated from energy barriers in the pentaarylbenzene system.⁶

It has been known for some time⁷ that pentaphenylpyridine can be prepared by a route similar to that employed for pentaphenylbenzenes.⁶ Because pentaphenylpyridine in both its free base and protonated forms closely resembles the pentaarylbenzenes such as **1** in stereochemistry and steric properties, a properly substituted pentaarylpyridine would appear to be an ideal molecule in which to compare the steric requirements of hydrogen and the nitrogen lone pair.

Pentaarylpyridine **2** (mp 208.5-210 °C) was prepared by heating 3,4-bis(3-methylphenyl)-2,5-diphenylcyclopentadienone^{8,9} with an excess of benzonitrile at 380 °C for 18 h in a sealed tube. Purification of the product was

(6) Patton, A.; Dirks, J. W.; Gust, D. *J. Org. Chem.* **1979**, *44*, 4749.

(7) Dilthey, W.; Schommer, W.; Hoschen, W.; Dierichs, H. *Chem. Ber.* **1935**, *68*, 1159.

(8) Ogliaruso, M. A.; Romanelli, M. G.; Becker, E. I. *Chem. Rev.* **1965**, *65*, 261.

(9) Gust, D. *J. Am. Chem. Soc.* **1977**, *99*, 6980.

achieved by fractional crystallization followed by sublimation. ^1H NMR spectra and elemental analyses were consistent with the proposed structure.

The 100-MHz ^1H NMR spectra of the aromatic methyl region of **2** at various temperatures are shown in Figure 1. At -19.6°C , four resonances at δ 1.96, 2.00, 2.01, and 2.03 with approximately equal intensities were observed. This spectrum is consistent with a perpendicular conformation for **2** in which rotation of the peripheral rings bearing meta methyl substituents is slow on the NMR time scale. The molecule exists as two diastereomeric *dl* pairs. In one of these pairs, the two constitutionally heterotopic methyl groups are on the same side of the plane of the central ring, whereas in the other, these two methyl groups are on opposite sides of this plane. The diastereomers are present in essentially equal amounts.

When the sample was warmed in the NMR spectrometer, the resonances broadened and coalesced pairwise to two resonances (Figure 1). This coalescence behavior signifies isomerization by rotation about the bonds joining the central and peripheral rings. Similar behavior was observed previously in the pentaarylbenzene series.⁶ Line-shape analysis carried out as described previously⁶ (Figure 1) yielded a free energy of activation for rotation of $\Delta G^*_{265} = 14.7$ kcal/mol for **2**.

Treatment of a chloroform-*d* solution of **2** with trifluoroacetic acid produced the corresponding pyridinium ion (**3**). Although a 1:1 molar ratio of acid to **2** yielded complete conversion to the ion as monitored by ^1H NMR spectroscopy, a fivefold excess of acid was employed for variable-temperature NMR studies. At -19.6°C the 100-MHz ^1H NMR spectrum of **3** also featured four resonances of approximately equal intensities at δ 2.03, 2.05, 2.06, and 2.07 which coalesced pairwise upon warming the sample. Line-shape analysis similar to that employed for **2** yielded $\Delta G^*_{265} = 15.4$ kcal/mol for rotation.

For the interpretation of these results, it is instructive to compare **3** with the corresponding pentaphenylbenzene derivative (1, X = H). The overall structures of the two molecules are similar, and it seems reasonable to assume that steric hindrance in the region of the rotating 3-methylphenyl rings will be quantitatively similar for the two species in spite of the small differences in bond lengths and angles which necessarily exist. In addition, **3** is a charged species, whereas the pentaarylbenzene is neutral. Although the effects of such a charge on rotational barriers for **3** are difficult to estimate intuitively, it has been found that electronic effects upon rotational barriers in hexaarylbenzenes are generally small.^{6,9,10} Hence, it seemed likely that the pentaarylbenzene series would serve as a good model for the pentaarylpyridines and that the linear relationship of $-\Delta G^\circ$ and the rotational barrier found for the pentaarylbenzenes could be applied to **2** and **3**. In fact, substitution of ΔG^*_{265} for **3** into eq 1 yields $-\Delta G^\circ = 0$ for **3**.¹¹ This is, indeed, the *A* value for hydrogen. The simplest explanation of this result is that, as expected, the linear relationship found for pentaarylbenzenes is also valid for the closely related pentaarylpyridines.

The variable-temperature NMR results show that the free energy of activation for rotation of an aryl ring of **2**, where nitrogen bears a lone pair, is 0.7 kcal/mol lower than

the corresponding barrier for **3**, where nitrogen bears a hydrogen atom. The above comparison with the pentaarylbenzene series suggests that this difference is mainly steric in origin. Thus in pentaarylpyridines the lone pair on nitrogen has a smaller steric requirement than does hydrogen.

If the free energy of activation for rotation found for **2** is substituted into eq 1, a $-\Delta G^\circ$ of -1.2 kcal/mol is calculated.¹⁴ This "A value" for the nitrogen lone pair cannot necessarily be applied to the piperidine equilibrium because the hybridization at nitrogen in **2** and in piperidine is different and because the position of the axial-equatorial equilibrium in piperidine is evidently affected by many factors, including the solvent.³ However, the results presented here do provide an answer to the more general question of the steric requirement of the nitrogen lone pair.¹⁶

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Registry No. **2**, 73496-15-8; **3**, 73496-16-9; 3,4-bis(3-methylphenyl)-2,5-diphenylcyclopentadienone, 64897-54-7; benzonitrile, 100-47-0.

(14) Because this $-\Delta G^\circ$ value is obtained by an extrapolation of eq 1, it is possible that it represents a steric requirement which is negligible. In this connection, it has been suggested that in piperidine systems the "size" of the lone pair need not be considered.¹⁵

(15) Allinger, N.; Hirsch, J. A.; Miller, M. A. *Tetrahedron Lett.* **1967**, 3729.

(16) It is well-known that the relative "size" of a group depends upon the type of steric interaction being observed. The pentaphenylpyridine and -cyclohexane systems both feature a "side-by-side" type of interaction. In a quite different type of steric interaction, an sp^2 -hybridized nitrogen atom bearing a lone pair has been found to have a smaller steric requirement than an sp^2 -hybridized carbon bearing a hydrogen atom.¹⁷

(17) Fujita, S.; Hirano, S.; Nozaki, H. *Tetrahedron Lett.* **1972**, 403.

Heterocyclization with Cyano and Sulfonyl Epoxides. Preparation of Quinoxalines and Tetrahydroquinoxalines^{1a}

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Continuing interest in our laboratories in new and versatile methods for the construction of heterocycles has led us to explore the concept of utilizing α -substituted epoxides as bifunctional two-carbon synthons. Condensation with a suitably constructed reagent possessing two nucleophilic centers should lead to heterocycles according to Scheme I. We describe in the present paper a novel heterocyclization procedure which involves the reaction of α -sulfonyl or α -cyano epoxides with *o*-phenylenediamines to give quinoxaline derivatives.²

The requisite α -substituted epoxides were prepared by the Darzens condensation utilizing phase-transfer catalysis under conditions analogous to those described by Makosza and co-workers.³ Thus, condensation of chloromethyl

(10) Gust, D.; Patton, A. *J. Am. Chem. Soc.* **1978**, *100*, 8175.

(11) The free energies of activation for **2** and **3** at 265 K, which is near the coalescence temperatures, have been used in eq 1 rather than those at 293 K because values of ΔH^\ddagger and ΔS^\ddagger as derived from DNMR studies are notoriously inaccurate.^{12,13} Entropies of activation for similar isomerizations in the closely related hexaarylbenzene system are small.¹⁰

(12) Binsch, G. *Top. Stereochem.* **1968**, *3*, 97.

(13) Drakenberg, T.; Carter, R. E. *Org. Magn. Reson.* **1975**, *7*, 307.

(1) (a) Presented in part at the 178th National Meeting of the American Chemical Society, Washington, D.C., Sept 10-14, 1979, Abstract No. ORGN-050. (b) Smith Kline and French Laboratories, Philadelphia, PA 19101. (c) Recipient of the Cyanamid Educational Award, 1977-1979.

(2) For recent reviews on the synthesis of quinoxalines, see (a) G. W. H. Cheeseman and R. F. Cookson, *Chem. Heterocycl. Compd.*, **35** (1979). (b) G. W. H. Cheeseman and E. S. G. Werstiuk, *Adv. Heterocycl. Chem.*, **22**, 367-431 (1978).