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

The 100-MHz ^{1}H 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 previously[6] (Figure 1) yielded a free energy of activation for rotation of $\Delta G^{\ddagger}_{265}$ = 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 ^{1}H NMR spectroscopy, a fivefold excess of acid was employed for variable-temperature NMR studies. At −19.6 °C the 100-MHz ^{1}H 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 $\Delta G^{\ddagger}_{265}$ = 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 $-\Delta G°$ and the rotational barrier found for the pentaarylbenzenes could be applied to **2** and **3**. In fact, substitution of $\Delta G^{\ddagger}_{265}$ for **3** into eq 1 yields $-\Delta G°$ = 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 $-\Delta G°$ 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]

Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this research.

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.

(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 $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ 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.

(14) Because this $-\Delta G°$ 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

(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).

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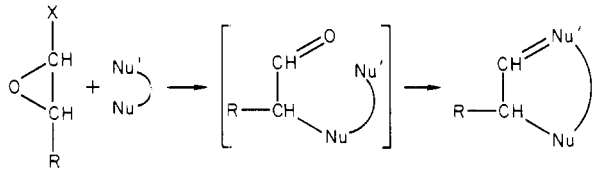
Scheme I



Scheme II

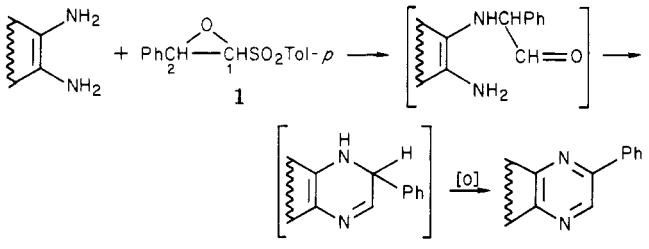
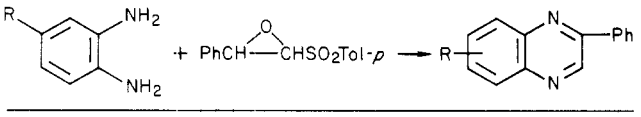


Table I. Synthesis of 2-Phenylquinoxalines



compd	R	time, h	yield, %[a]	solvent	mp, °C (lit. mp, °C)
3a	H	3	66	DMF	77-78 (78)[b]
3b	$(CH_3)_2$[c]	3	45	EtOH	127.5-128.5 (128-129)[d]
3c	CH_3[e]	3	31	EtOH	133-134 (135)[b]
3d	Cl[f]	18	66	EtOH	130-132 (130-131)[g]

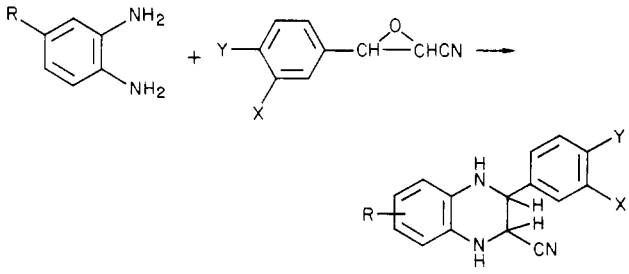
[a] Yields reported are those of isolated purified products and have not been optimized. Spectral data obtained for these compounds are consistent with assigned structures. [b] Reference 5. [c] 6,7-Dimethyl. [d] Reference 18. [e] Although presumably both the 6 and 7 isomers were formed, only the former was isolated. [f] 7-Chloro. [g] Reference 19.

p-tolyl sulfone with benzaldehyde in a two-phase system in the presence of triethylbenzylammonium chloride gave 1-(*p*-tolylsulfonyl)-2-phenyloxirane (**1**).[3a] Similarly, condensation of chloroacetonitrile with various benzaldehydes under the same conditions gave 1-cyano-2-aryloxiranes (**2**)[3b,4] as diastereomeric mixtures.

We have found that condensation of **1** with *o*-phenylenediamines leads directly to 2-phenylquinoxaline derivatives. For example, portionwise addition of **1** to a DMF solution of *o*-phenylenediamine at 90 °C under nitrogen, followed by heating for 3 h, gave 2-phenylquinoxaline (**3a**)[5] in 66% yield (see Table I).

A plausible reaction pathway for this quinoxaline synthesis is outlined in Scheme II and is consistent with previous observations that nucleophilic attack on α-sulfonyl epoxides occurs at C-2. For example, α-arylsulfonyl epoxides react with magnesium bromide to give α-bromo carbonyl compounds,[6a] with sodium thiophenoxide to give α-phenyl thioaldehydes,[6b] with *N*-methylaniline to give 2-arylindoles,[6c] and with sodium azide to give α-azido aldehydes.[6d] The intermediate α-arylamino aldehyde generated in the present instance (see Scheme II) presumably cyclizes to a dihydroquinoxaline, which then undergoes air oxidation to give the observed fully aromatic product.

Table II. Synthesis of 2-Aryl-3-cyano-1,2,3,4-tetrahydroquinoxalines



compd	R	X	Y	time, h	yield, %[a]	mp, °C
4a	H	H	H	3	92	174-175
4b	$(CH_3)_2$[b]	H	H	3	72	188-189
4c	CH_3[c]	H	H	3	42	137-145
4d	Cl[d]	H	H	18	54	136-138
4e	NO_2[d]	H	H	18	74	211-212
4f	H	NO_2	H	3	94	171-172
4g	$(CH_3)_2$[b]	NO_2	H	3	74	171.5-173.5
4h	CH_3[c]	NO_2	H	3	68	172-180
4i	Cl[d]	NO_2	H	18	73	220
4j	NO_2[d]	NO_2	H	18	46	148-150
4k	H	H	OCH_3	3	91	148-150
4l	$(CH_3)_2$[b]	H	OCH_3	3	32	134
4m	CH_3[c]	H	OCH_3	3	30	150-158

[a] Yields reported are those of isolated purified products and have not been optimized. Spectral and microanalytical data obtained for these compounds are consistent with their assigned structures. [b] 6,7-Dimethyl. [c] Obtained as a mixture of 6 and 7 isomers (NMR) not separable by TLC. [d] The regiochemistry of these products has not been determined.

We have isolated a small amount of 3-phenyl-2-(*p*-tolylsulfonyl)-1,2,3,4-tetrahydroquinoxaline as a byproduct in the reaction of *o*-phenylenediamine with 1-(*p*-tolylsulfonyl)-2-phenyloxirane (**1**). This byproduct might conceivably have arisen by addition of *p*-tolylsulfinic acid to an intermediate dihydroquinoxaline; however, when it was subjected to the reaction conditions (refluxing ethanol or hot DMF), it remained unaltered. Since this compound is thus not an intermediate in the conversion of **1** to 2-phenylquinoxaline, it seems reasonable to assume that it arose by alternate initial nucleophilic attack at C-1. This duality of mechanisms may be responsible in part for the moderate yields of quinoxaline derivatives obtained from this α-sulfonyl epoxide.

Extrapolation of this heterocyclization concept to 1-cyano-2-aryloxiranes (**2**) afforded 3-aryl-2-cyano-1,2,3,4-tetrahydroquinoxalines (**4a–m**) (see Table II). Surprisingly, only one of the two possible diastereomeric tetrahydroquinoxalines was obtained; it was tentatively identified as the trans isomer. This structural assignment is based on a consideration of its mechanism of formation (vide infra), as well as a comparison of the observed vicinal coupling constant of **4a** with those reported for *cis*- and *trans*-2,3-dimethyl-1,2,3,4-tetrahydroquinoxaline. For the cis isomer, J_{AB} was reported to be 2.7 Hz, while J_{AB} for the trans isomer was reported to be 7.0 Hz.[7] **4a** exhibits J_{AB}

(3) (a) A. Jonczyk, K. Banko, and M. Makosza, *J. Org. Chem.*, **40**, 266 (1975); (b) A. Jonczyk, M. Fedorynski, and M. Makosza, *Tetrahedron Lett.*, 2395 (1972).

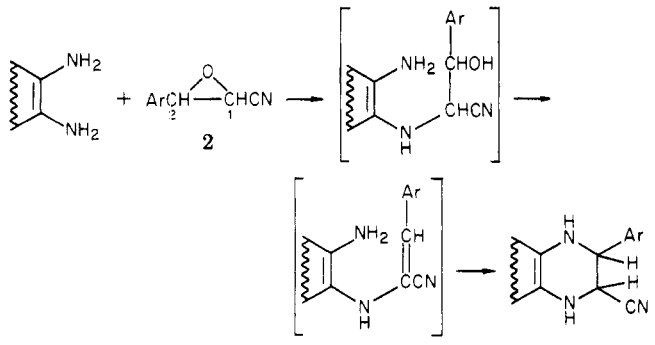
(4) Satisfactory microanalytical and spectral data were obtained for all new compounds prepared in this study and are available as supplementary material.

(5) (a) O. Hinsberg, *Justus Liebigs Ann. Chem.*, **292**, 245 (1896); (b) A. Dornow and W. Sassenberg, *ibid.*, **594**, 185 (1955).

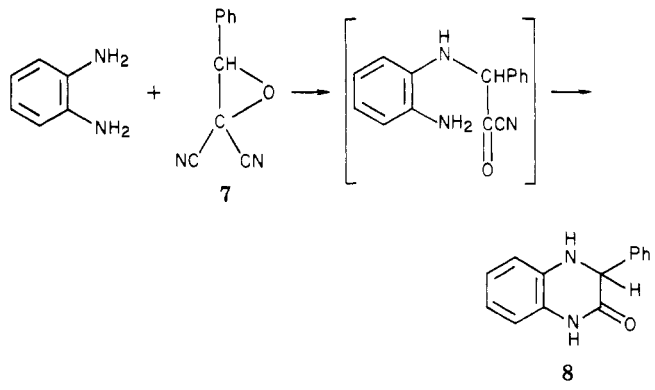
(6) (a) F. de Reinach-Hirtzbach and T. Durst, *Tetrahedron Lett.*, 3677 (1976); (b) T. Durst, K.-C. Tin, F. de Reinach-Hirtzbach, J. M. Decesare, and M. D. Ryan, *Can. J. Chem.*, **57**, 258 (1979); (c) L. Thijs, A. Houwen-Claasen, and B. Zwanenburg, *Phosphorus Sulfur*, **6**, 303 (1979); (d) A. D. Barone, D. L. Snitman, and D. S. Watt, *J. Org. Chem.*, **43**, 2066 (1978).

(7) R. Aguilera, J.-C. Duplan, and C. Nofre, *Bull. Soc. Chim. Fr.*, 4491 (1968).

Scheme III



Scheme IV



= 4.0 Hz. In view of the known effect of electron-withdrawing groups in reducing vicinal coupling constants,[8] we feel the value of J_{AB} in **4a** is consistent with the trans assignment.

These tetrahydro derivatives are convenient precursors to 3-aryl-2-cyanoquinoxalines by dehydrogenation; indeed, 2-cyano-3-phenyl-1,2,3,4-tetrahydroquinoxaline (**4a**) was smoothly converted to 2-cyano-3-phenylquinoxaline (**5**)[9] by heating in ethanol in the presence of mercuric oxide. By contrast, the use of activated manganese dioxide in toluene at 100 °C resulted in aromatization with concomitant hydrolysis[10] of the nitrile functionality to give 2-carboxamido-3-phenylquinoxaline (**6**).[11]

Although a mechanism analogous to that described in Scheme II can be envisioned for the above tetrahydroquinoxaline synthesis from 1-cyano-2-aryloxiranes (cyanide addition to the intermediate dihydroquinoxaline, rather than air oxidation), an alternate mechanism involves nucleophilic attack at C-1, rather than at C-2, as depicted in Scheme III.[12] Dehydration of the initially formed benzylic alcohol would then be followed by intramolecular conjugate addition to give the observed product. Such a ring opening of α-cyano epoxides would thus be analogous to the known reaction of 2-arylglycidic esters with nitrogen nucleophiles (i.e., attack at C-1).[13,14]

It should be noted that an additional cyano group at C-1 in α-cyano epoxides can lead to exclusive ring opening at C-2. Thus, 1,1-dicyano-2-phenyloxirane (**7**)[15] (prepared by epoxidation of 2,2-dicyanostyrene) condensed with *o*-phenylenediamine to give 3-phenyl-1,2,3,4-tetrahydroquinoxaline-2-one (**8**)[16,17] (see Scheme IV).

In summary, a new heterocyclization method is described which involves the reaction of 1-(*p*-tolylsulfonyl)-2-phenyloxirane with *o*-phenylenediamines to give 2-phenylquinoxalines. An extension of this concept to the use of 1-cyano-2-aryloxiranes leads to 3-aryl-2-cyano-1,2,3,4-tetrahydroquinoxalines. Applications of these reactions to the synthesis of pyrrolopyrimidines and pteridines are currently under exploration.

Experimental Section

Infrared spectra were recorded on a Perkin-Elmer Model 237-B spectrophotometer. Proton nuclear magnetic resonance spectra were obtained on a Varian A-60A or XL-100 spectrophotometer, while ^{13}C nuclear magnetic resonance spectra were determined with the latter instrument; tetramethylsilane was used as the internal standard in the indicated solvents. Melting points, which are uncorrected, were determined on a Thomas-Hoover capillary apparatus. Microanalyses were performed at Hoffmann-La Roche, Inc., Nutley, NJ, or Eli Lilly and Co., Indianapolis, IN.

2-Phenylquinoxaline (3a). To a stirred solution of 1.18 g (10.9 mmol) of *o*-phenylenediamine and 15 mL of anhydrous DMF under a nitrogen atmosphere was added portionwise 2.0 g (7.3 mmol) of **1**. The reaction mixture was heated at 90 °C for 3 h, poured into water, and heated until the resulting oil crystallized. The solid was collected and recrystallized from DMF to give 1.0 g (66%) of **3a** as a yellow solid.

In one experiment, a small amount (13%) of 3-phenyl-2-(*p*-tolylsulfonyl)-1,2,3,4-tetrahydroquinoxaline was obtained as a byproduct: white solid; mp 143–144 °C (EtOH); ^1H NMR ($CDCl_3/Me_2SO$-d_6) δ 7.60 and 7.28 (AB q, 4 H, Ar H, J = 9 Hz), 7.32 (s, 5 H, Ar H), 6.68–6.48 (m, 4 H, Ar H), 5.18–4.97 (m, 4 H, NHCHCHNH), 2.40 (s, 3 H, CH_3).

Anal. Calcd for $C_{21}H_{20}N_2O_2S$: C, 69.20; H, 5.53; N, 7.69; S, 8.80. Found: C, 69.22, H, 5.72; N, 7.72; S, 8.84.

6,7-Dimethyl-2-phenylquinoxaline (3b). To a stirred solution of 450 mg (3.3 mmol) of 4,5-dimethyl-*o*-phenylenediamine and 10 mL of absolute EtOH under a nitrogen atmosphere at reflux temperature was added portionwise 1.30 g (4.7 mmol) of **1**. The reaction mixture was stirred at this temperature for 3 h and allowed to cool gradually to ambient temperature. The resulting precipitate was collected and recrystallized from aqueous EtOH to provide 350 mg (45%) of **3b** as a tan solid.

3c and **3d** were prepared analogously.

2-Cyano-3-phenyl-1,2,3,4-tetrahydroquinoxaline (4a). A solution of 500 mg (4.6 mmol) of *o*-phenylenediamine, 730 mg (5.0 mmol) of 1-cyano-2-phenyloxirane, and 10 mL of absolute EtOH was stirred at reflux temperature under a nitrogen atmosphere for 3 h. The reaction mixture was allowed to cool to ambient temperature, and the resulting precipitate was collected and recrystallized from aqueous EtOH to afford 1.0 g (92%) of **4a** as a pale yellow solid: IR (KBr) 3400, 3360, 2220, 1590, 1480 cm^{-1}; ^1H NMR ($CDCl_3/Me_2SO$-d_6) δ 7.30 (s, 5 H, Ar H), 6.73–6.55 (m, 4 H, Ar H), 5.67–5.22 (m, 2 H, 2 NH), 4.82–4.63 and 4.43–4.27

(8) R. J. Abraham and P. Loftus, "Proton and Carbon-13 NMR Spectroscopy", Heyden and Son, Ltd., London, 1978, pp 42–6.
(9) E. Hayashi and C. Iijima, *Yakagaku Zasshi*, **82**, 1093 (1962); *Chem. Abstr.*, **58**, 4551f (1963).
(10) For other examples of the conversion of nitriles to amides with activated MnO_2, see M. J. Cook, E. J. Forbes, and G. M. Khan, *Chem. Commun.*, 121 (1966).
(11) E. Hayashi and C. Iijima, *Yakagaku Zasshi*, **84**, 156 (1964); *Chem. Abstr.*, **61**, 3108c (1964).
(12) Durst[6a] has observed that the reaction of α-cyano epoxides with $MgBr_2$ gave α-bromo-β-hydroxy nitriles.
(13) A. Rosowsky, *Chem. Heterocycl. Compd.*, **19**, 323–4 (1964); (b) S. Winstein and R. B. Henderson, *Heterocycl. Compd.*, **1**, 35–6 (1950); (c) R. E. Parker and N. S. Isaacs, *Chem. Rev.*, **59**, 737 (1959).
(14) For an exception to this mode of ring opening of glycidic esters by nitrogen nucleophiles, however, see A. Elker, J. Lehmann, and F. Zymalkowski, *Arch. Pharm.*, **312**, 26 (1979).
(15) J. J. Pommeret and A. Robert, *Tetrahedron*, **27**, 2977 (1971).
(16) A. Marxer, U. Salzmann, and F. Hofer, *Helv. Chim. Acta*, **54**, 2509 (1971).
(17) The condensation of 1,1-dicyano-2-aryloxiranes with thiourea and with thioamides to give thiazole derivatives has been reported: M. Ferrey, A. Robert, and A. Foucaud, *C. R. Hebd. Seances Acad. Sci., Ser. C*, **277**, 1153 (1973); M. Baudy and A. Robert, *J. Chem. Soc., Chem. Commun.*, 23 (1976). A related procedure has been reported for the preparation of 3-(trifluoromethyl)-2(1*H*)-quinoxalone from hexafluoropropylene oxide and *o*-phenylenediamine: N. Ishikawa and S. Sasaki, *Bull. Chem. Soc. Jpn.*, **50**, 2164 (1977). See also J. E. Nottke, U.S. Patent 3 928 350 (1975); *Chem. Abstr.*, **84**, 105652 (1976).
(18) V. M. Berezvski and A. M. Yurkevich, *Zh. Obshch. Khim.*, **31**, 3775 (1961).
(19) S. N. Bannore and J. L. Bose, *Indian J. Chem.*, 11, 631 (1973).

(2 m, 2 H, ArCHCHCN); (100 MHz, $CDCl_3/Me_2SO$-d_6/D_2O) δ 4.70 and 4.32 (AB q, 2 H, ArCHCHCN, J = 4.0 Hz); ^{13}C NMR ($CDCl_3/Me_2SO$-d_6) 141.4, 132.4, 129.3, 127.8, 127.1, 126.4, 119.5, 119.3, 116.9, 114.5, 113.2, 55.23, 46.1 ppm.

Anal. Calcd for $C_{15}H_{13}N_3$: C, 76.57; H, 5.57; N, 17.86. Found: C, 76.74; H, 5.54; N, 17.73.

Tetrahydroquinoxalines **4b–m** were prepared analogously.

2-Cyano-3-phenylquinoxaline (5). A suspension of 1.0 g (4.3 mmol) of **4a**, 1.75 g (8.1 mmol) of mercuric oxide, and 100 mL of absolute EtOH was stirred at reflux temperature for 1.25 h. The reaction mixture was cooled and filtered through Celite. The filtrate was concentrated in vacuo to give a reddish brown oil which was chromatographed first on silica gel ($CHCl_3$) and then on alumina (hexanes/$CHCl_3$ 1:1) to afford 630 mg (64%) of **5** as colorless plates: mp 160–163 °C (lit.[9] mp 163 °C); ^1H NMR (Me_2SO-d_6) δ 8.50–7.42 (m, Ar H).

2-Carboxamido-3-phenylquinoxaline (6). A mixture of 7.0 g (29.8 mmol) of **4a**, 7 g (80.5 mmol) of activated MnO_2, and 500 mL of toluene was stirred at 100 °C under a nitrogen atmosphere for 36 h. The reaction mixture was allowed to cool to ambient temperature, diluted with $CHCl_3$, and filtered through Celite. The filtrate was concentrated under reduced pressure to afford a colorless solid which was recrystallized from aqueous EtOH: yield 6.1 g (82%); mp 198–199 °C (lit.[11] mp 198–199 °C); IR (KBr) 3360, 3175, 1655 cm^{-1}; ^1H NMR ($CDCl_3/Me_2SO$-d_6) δ 8.10–7.20 (m, Ar H).

3-Phenyl-1,2,3,4-tetrahydroquinoxalin-2-one (8). A solution of 900 mg (5.3 mmol) of 1,1-dicyano-2-phenyloxirane,[15] 350 mg (3.1 mmol) of *o*-phenylenediamine, and 10 mL of absolute EtOH was stirred at reflux temperature under a nitrogen atmosphere for 4 h. The reaction mixture was cooled, and the resulting precipitate was collected and recrystallized from EtOH to provide 420 mg (60%) of **8** as a dark red solid: mp 196–197 °C (lit.[16] mp 201–203 °C); IR (KBr) 3300, 1660, 1595, 1500 cm^{-1}; ^1H NMR ($CDCl_3/Me_2SO$-d_6) δ 7.37–7.17 (m, 5 H, Ar H), 6.80–6.58 (m, 4 H, Ar H), 6.32–6.18 (m, 2 H, 2 NH), 4.45 (m, 1 H, PhCHN).

Anal. Calcd for $C_{14}H_{12}N_2O$: C, 74.99; H, 5.38; N, 12.49. Found: C, 74.77; H, 5.23; N, 12.35.

Registry No. 1, 54607-00-0; *cis*-**2a**, 33984-96-2; *trans*-**2a**, 33984-95-1; *cis*-**2f**, 73377-89-6; *trans*-**2f**, 73377-90-9; *cis*-**2k**, 33984-92-8; *trans*-**2k**, 33984-91-7; **3a**, 25855-20-3; **3b**, 71897-07-9; **3c**, 25187-18-2; **3d**, 49634-78-8; **4a**, 73377-91-0; **4b**, 73377-92-1; **4c**, 6-methyl derivative, 73377-93-2; **4c**, 7-methyl derivative, 73378-01-5; **4d**, 73378-32-2; **4e**, 73378-31-1; **4f**, 73377-94-3; **4g**, 73377-95-4; **4h**, 6-methyl derivative, 73377-96-5; **4h**, 7-methyl derivative, 73378-02-6; **4i**, 73378-30-0; **4j**, 73378-29-7; **4k**, 73377-97-6; **4l**, 73384-19-7; **4m**, 6-methyl derivative, 73377-98-7; **4m**, 7-methyl derivative, 73378-03-7; **5**, 59393-45-2; **6**, 73377-99-8; **7**, 33512-02-6; **8**, 23465-73-8; *o*-phenylenediamine, 95-54-5; 3-phenyl-2-(*p*-tolylsulfonyl)-1,2,3,4-tetrahydroquinoxaline, 73378-00-4; 4,5-dimethyl-*o*-phenylenediamine, 3171-45-7; 4-methyl-*o*-phenylenediamine, 496-72-0; 4-chloro-*o*-phenylenediamine, 95-83-0; 4-nitro-*o*-phenylenediamine, 99-56-9.

Supplementary Material Available: NMR and IR spectra and analytical data for quinoxalines and tetrahydroquinoxalines (6 pages). Ordering information is given on any current masthead page.

Conversion of Primary Amines into Nitrate Esters

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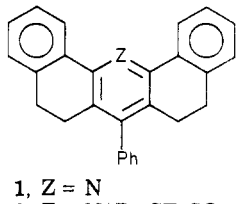
Two classical methods have been used for the preparation of nitrate esters: nitric acid esterification of the appropriate alcohol and treatment of alkyl halides with silver nitrate.[1] Recently, increased interest in these compounds has resulted in improvements in the direct esterification[2,3] and the use of mercury(I) nitrate in the preparation from alkyl halides.[4]

A general method for the conversion of amines into nitrate esters was lacking until recently. In 1970-1971, Wudl published two preliminary communications[5,6] on the conversion of amines into nitrate esters: one involved preliminary silylation[5] and the other reported four examples of which two gave yields of only 20%. No further details of this work have appeared; however, Barton and Narang[7] have shown that in the presence of excess amidine base at −78 °C, N_2O_4 can convert primary or secondary alkyl primary amines into the corresponding alkyl nitrates in good yield; the reaction proceeds with predominant retention of configuration.

We have shown[8] that the conversion of primary amines into pyridinium salts by pyryliums can be utilized as the first step in a general two-stage transformation of amino into other functionality. The displacement of the pyridinium N substituent can be carried out either by the gegen anion or by an added nucleophile. We now extend both these procedures to give nitrate esters.

Nitrate Esters by Thermolysis. 1,3,5-Triphenylpent-2-ene-1,5-dione[9] is converted by nitric acid into 2,4,6-triphenylpyrylium nitrate[10] (70%) which reacts readily with a series of alkyl- and benzylamines to give the corresponding 1-substituted 2,4,6-triphenylpyridinium nitrates (Table I); the structures of these salts are supported by their spectral features.[11] On thermolysis of these salts (Table I), using triphenylpyridine where necessary as flux, at 180–230 °C under reduced pressure, the alkyl nitrate distilled over with purity >97% as shown by ^1H and ^{13}C NMR.[11] The yields averaged 77% for the first step and 66% for the second step.

Formation of Nitrate Esters in Solution. Although mononitrates are thermally rather stable in the absence of impurities such as nitrites and nitric acid,[1] the preceding method is clearly not suitable for large-scale work or for the preparation of high molecular weight nitrates or polynitrates. Hence we sought a method in solution. 5,6,8,9-Tetrahydro-7-phenyldibenzo[*c*,*h*]acridine (1) is a



1, Z = N
2, Z = N^+R, $CF_3SO_3^-$

far better leaving group than 2,4,6-triphenylpyridine.[12] We

(1) R. Boschan, R. T. Merrow, and R. W. van Dolah, *Chem. Rev.*, **55**, 485 (1955).
(2) C. D. Marken, C. E. Kristofferson, M. M. Rolond, A. P. Manzara, and M. W. Barnes, *Synthesis*, 484 (1977).
(3) G. A. Olah, S. C. Narang, R. L. Pearson, and C. A. Cupas, *Synthesis*, 452 (1978).
(4) A. McKillop and M. E. Ford, *Tetrahedron*, **30**, 2467 (1974).
(5) F. Wudl and T. B. K. Lee, *J. Chem. Soc. D*, 490 (1970).
(6) F. Wudl and T. B. K. Lee, *J. Am. Chem. Soc.*, **93**, 271 (1971).
(7) D. H. R. Barton and S. C. Narang, *J. Chem. Soc., Perkin Trans. 1*, 1114 (1977).
(8) A. R. Katritzky, *Tetrahedron Reports*, in press.
(9) R. Lombard and J. P. Stephan, *Bull. Soc. Chim. Fr.*, 1458 (1958).
(10) C. Gastaldi, *Gazz. Chim. Ital.*, **2**, 289 (1921).
(11) See paragraph on Supplementary Material at end of paper.
(12) A. R. Katritzky and S. S. Thind, *J. Chem. Soc., Perkin Trans. 1*, in press.

0022-3263/80/1945-2515$01.00/0