7018 *J. Org. Chem.* **1996,** *61,* 7018−7021

Atropisomers of Cofacial Heteroaromatic Rings with Two Positive Charges. Derivatives of 1,8-Di(3′-pyridyl)naphthalene

John A. Zoltewicz* and Nobert M. Maier

Department of Chemistry, University of Florida, Gainesville, Florida 32611-7200

Walter M. F. Fabian

Institut für Organische Chemie, Karl-Franzens Universität, A-8010 Graz, Austria

Received May 16, 1996[⊗]

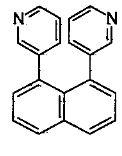
The two nitrogen atoms in 1,8-di(3′-pyridyl)naphthalene were quaternized by the addition of either benzyl or methyl groups to give dications; the latter was oxidatively converted to the di(6′-pyridone). N-Oxidation gave the mono- and di-*N*-oxides. All these compounds in DMSO-d_6 show *anti*−*syn* atropisomerism at ambient temperatures by ^{1}H NMR analysis; similar amounts of both diastereomers are present.

The noncovalent interaction between π-stacked aromatic rings is due predominantly to Coulombic or electrostatic attraction and not to van der Waals or charge transfer forces.[1−6] Such binding interactions play an important role in chemistry and in biology. Many substrates which intercalate cofacially into nucleic acids are positively charged.[7]

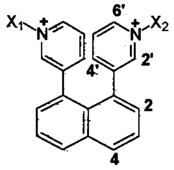
We report the facile synthesis of compounds with two positively charged cofacial pyridinium rings as well as uncharged highly dipolar di-*N*-oxide and dipyridone derivatives held in close proximity by a naphthalene frame. These compounds show *anti*−*syn* atropisomerism at ambient temperatures. Our unique compounds are unlike most other well-known structurally simple naphthalene-based cofacial ring systems which are neutral and modestly polar[8−15] and not usually present as distinct *anti*−*syn* diastereomers detectable by NMR analysis at ambient temperatures. Our compounds have not only π-electronic interactions between the cofacial rings but also the new feature of charge-charge repulsion in the dications. Another cofacial naphthalene-based system is known where just one of the rings is a positively charged tropylium ion.[16]

Results

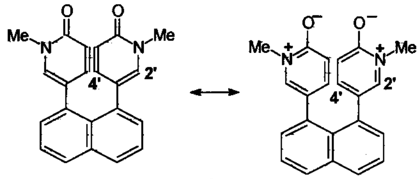
Syntheses. 1,8-Di(3′-pyridyl)naphthalene (**1**) was prepared in high yield by Suzuki coupling[18] from the 1,8-dibromonaphthalene[14] and diethyl(3-pyridyl)borane in the presence of Pd(PPh$_3$)$_4$.[17] Mono- and then diquaternization of **1** by MeI in DMSO or MeOTs in nitromethane to give **2a** readily took place in a few hours at room temperature, indicating no major energy barrier to the juxtaposition of the two positive charges. We were not able to separate the mono- and dimethylated materials, and so only the dimethyl salt was prepared using excess alkylating agent. Benzyl bromide in nitromethane at room temperature gave dibenzyl dication **2b**. Free base **1** also was readily N-oxidized with *m*-chloroperbenzoic acid to the mono- (**2c**) and di-*N*-oxides (**2d**). *N*-Methyl dication **2a** was readily oxidized with alkaline ferricyanide to dipyridone **3**.



1



2a, $X_1 = X_2$ = Methyl
2b, $X_1 = X_2$ = Benzyl
2c, $X_1 = O^-$, X_2 = Lone pair
2d, $X_1 = X_2 = O^-$
2e, $X_1 = X_2$ = D



3

Three isomeric pyridones are possible from the oxidation of **2a** by way of the formation of pseudobase intermediates: those resulting from the addition of hydroxide ion to the two α (H2′ and H6′) and one γ (H4′) positions followed by ferricyanide oxidation to a pyridone.[19−21] The

---

[⊗] Abstract published in *Advance ACS Abstracts,* September 1, 1996.

(1) Hunter, C. A.; Sanders, J. K. M. *J. Am. Chem. Soc.* **1990**, *112*, 5525.

(2) Hunter, C. A. *Angew. Chem., Int. Ed. Engl.* **1993**, *32*, 1584.

(3) Cozzi, F.; Cinquini, M.; Annunziata, R.; Dwyer, T.; Siegel, J. *J. Am. Chem. Soc.* **1992**, *114*, 5729.

(4) Cozzi, F.; Cinquini, M.; Annunziata, R.; Siegel, J. S. *J. Am. Chem. Soc.* **1993**, *115*, 5330.

(5) Cozzi, F.; Ponzini, F.; Annuziata, R.; Cinquini, M.; Siegel, J. S. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 1019.

(6) Williams, V. E.; Lemieux, R. P.; Thatcher, G. R. J. *J. Org. Chem.* **1996**, *61*, 1927.

(7) Zimmerman, H. W. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 115.

(8) House, H. O.; Koepsell, D. G.; Campbell, W. J. *J. Org. Chem.* **1972**, *37*, 1003.

(9) House, H. O.; Campbell, W. J.; Gall, M. *J. Org. Chem.* **1970**, *35*, 1815.

(10) Clough, R. L.; Kung, W. J.; Marsh, R. E.; Roberts, J. D. *J. Org. Chem.* **1976**, *41*, 3603.

(11) Clough, R. L.; Roberts, J. D. *J. Am. Chem. Soc.* **1976**, *98*, 1018.

(12) Cosmo, R.; Sternhell, S. *Aust. J. Chem.* **1987**, *40*, 1107.

(13) Nagawa, Y.; Honda, K.; Nakanishi, H. *Magn. Reson. Chem.* **1996**, *34*, 78.

(14) Kuroda, M.; Nakayama, J.; Hoshino, M.; Furusho, N.; Kawata, T.; Ohba, S. *Tetrahedron* **1993**, *49*, 3735.

(15) Nugent, H. M.; Rosenblum, M. *J. Am. Chem. Soc.* **1993**, *115*, 3848.

(16) Komatsu, K.; Tsuji, R.; Inoue, Y.; Takeuchi, K. *Tetrahedron Lett.* **1993**, *34*, 99.

(17) Zoltewicz, J. A.; Maier, N. M.; Fabian, W. M. F. *Tetrahedron* **1996**, *52*, 8703.

(18) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457.

(19) Bunting, J. W.; Stefanidis, D. *J. Org. Chem.* **1986**, *51*, 2068.

(20) Bunting, J. W.; Stefanidis, D. *J. Org. Chem.* **1986**, *51*, 2060.

S0022-3263(96)00906-1 CCC: $12.00

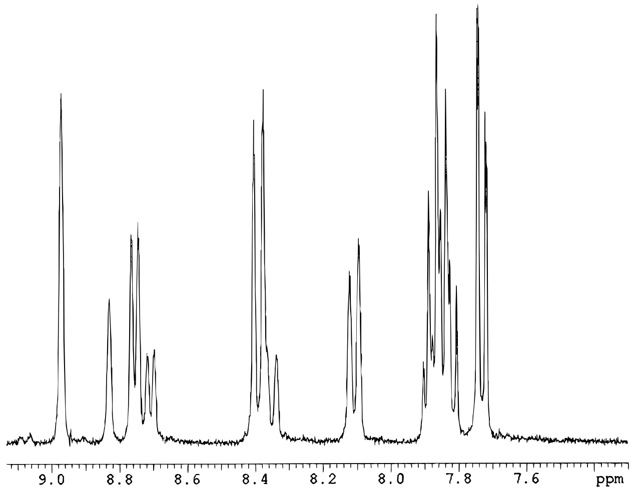


Figure 1. ^{1}H NMR spectrum of dimethyl diiodide **2a** in DMSO-d_6 at 20 °C. The peak assignments based on a COSY analysis are as follows, where A indicates the *anti* and S the *syn* diastereomer: δ 8.97, H2′(A); 8.83, H2′(S); 8.75, H6′(A); 8.70, H6′(S), 8.38, H4 + H5; 8.34, H4′(S); 8.10, H4′(A); 7.85, m; 7.72, H2 + H7. The signals for the *N*-methyl protons at δ 4.29 (A) and 4.26 (S) are not shown.

simplicity of the proton spectrum of **3** in DMSO-d_6 indicated that each ring had oxidized to a common structure; the spectrum did not show a triplet signal for H5′ and the 2′-pyridone isomer therefore was eliminated. An NOE difference experiment in which the *N*-methyl protons were irradiated caused only the broadened singlet at δ 7.1 for H2′ to be enhanced (12%), thereby favoring the 6′-pyridone and eliminating the 4′ isomer, the latter expected to show enhanced signals for both H2′ and H6′.

Proton Spectra of DMSO-d_6 Solutions. All these materials, including neutral **1**[17] and its deuteriated dication **2e** in acidic solution, demonstrated *anti*–*syn* atropisomerism due to restricted rotation about the pyridine–naphthalene bond at ambient temperatures. The dominant diastereomer was assigned the *anti* conformation. The pyridine but not the naphthalene ring clearly showed two sets of protons for all materials except di-*N*-oxide **2d** where signal overlap was severe in the complex spectrum (DMSO-d_6 and methanol-d_4). However, on heating **2d** at 70 °C, a simple spectrum containing seven multiplets was observed consistent with rapid rotation and isomerization to yield a population weighted averaged spectrum of the two diastereomers. Separate *N*-methyl groups were apparent in the proton NMR spectrum for the two isomeric forms of **2a**, Figure 1 (methyl signals not shown), but not for the methyl units in dipyridone **3**. Individual methylene protons of dibenzyl **2b** appeared as a degenerate singlet for the *anti* and a diastereotopic pair of doublets for the *syn* conformation at 20 °C, Figure 2. The pyridyl protons of **2a** demonstrated some broadening even at 100 °C, and the methylene and ring protons of dibenzyl **2b** each merged at about 75 °C, indicating a sizeable energy barrier for rotation to interconvert the diastereomers. An unusual feature of **2b** is the abnormally high field position of pyridine H5′, appearing at δ 6.7, suggesting shielding by the phenyl ring.

***Anti*–*Syn* Ratios.** The values of the ratios did not change with time, indicating a system at equilibrium. The *anti*–*syn* ratio at 20 °C is 1.4 for **1**,[17] 2.2 for **2a**, 6.6 for **2b**, 1.2 for **2c**, and 1.7 for **3**, all in DMSO-d_6, and 1.8 for **2e** in D_2O–trifluoroacetic acid. The value for **2a** in D_2O was about 3 and for **3** in $CDCl_3$ at −20 °C it was 4.0 with the methyl protons now showing two separate signals. Such obvious atropisomerism has not usually been observed with simple cofacial arene derivatives of naphthalene.

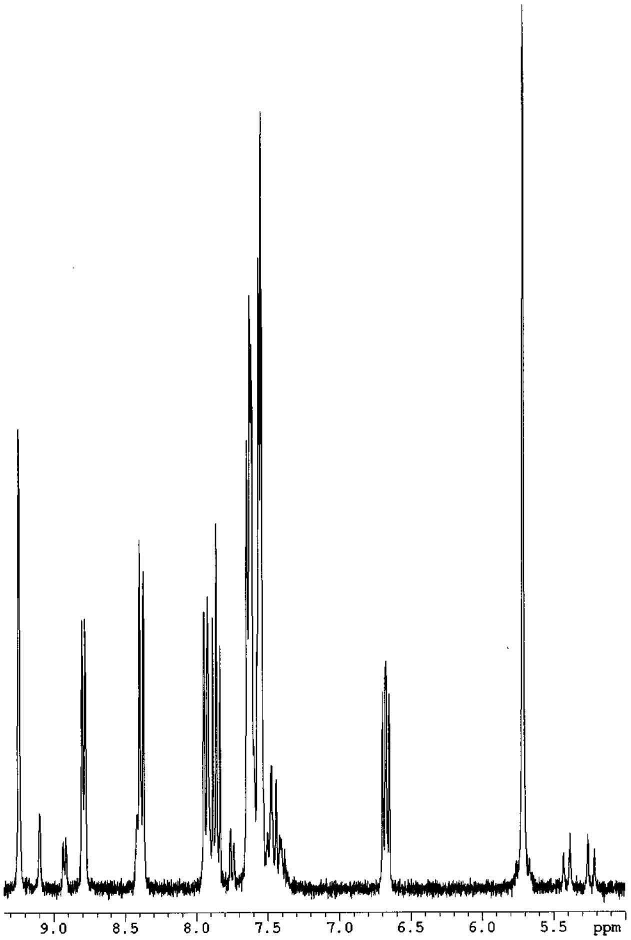
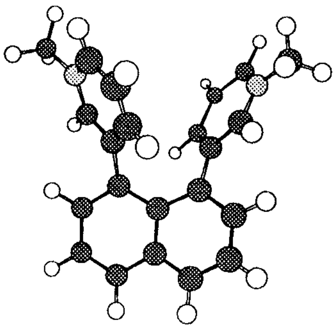
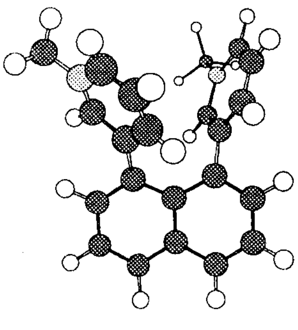


Figure 2. ^{1}H NMR spectrum of dibenzyl diperchlorate **2b** in DMSO-d_6 at 20 °C. The peak assignments based on a COSY analysis are as follows, where A indicates the *anti* and S the *syn* diastereomer: δ 9.25, H2′(A); 9.10, H2′(S), 8.92, H6′(S); 8.80, H6′(A); 8.38, H4 + H5; 7.94, H4′(A); 7.86, H3 + H6; 7.77, H4′(S); 7.6, (H2 + H7 + Ph); 7.4, H5′(S); 6.65, H5′(A); 5.72 CH_2(A); 5.32, CH_2(S).



2a (*anti*)



2a (*syn*)

Discussion

The computed (AM1 and PM3) ground states for all the derivatives of **2** have the *peri* carbon atoms of the

---

(21) Weber, H. *Adv. Heterocycl. Chem.* **1987**, *41*, 275.

naphthalene ring lying above and below the main plane of this ring with the pyridine rings splayed apart in order to increase their separation with increasing distance from the point of bonding. For the *anti* form of **2a**, for example, the distance increases from 3.14 to 5.51 Å on going along the rotational axis from C3′ to C6′. The pyridine rings are twisted with respect to the naphthalene plane, the amount depending on the substituents on the nitrogen atoms. In both diastereomers the centers of the pyridyl rings are offset and the rings are canted outward so as to increase the separation between the nitrogen atoms; in the case of *anti* **2a** this distance is 5.71 Å (AM1). The computed *anti* and *syn* geometries of **2a** are shown in the structures with a three-dimensional perspective. This model is consistent with X-ray structures of similar arene–naphthalenes[8,10,22] and a typical benzene ring with a "thickness" of about 3.4 Å.[1]

With the exception of dibenzyl **2b**, the *anti*–*syn* ratio for all the other forms is about the same with only a modest preference for the *anti* conformation. We offer the following rationalization for the value of this ratio being so close to 1. For simplicity we consider the positive charges to be localized on the nitrogen atoms. According to an electrostatic model,[1,2] eq 1, the difference between the energies of the *anti* and *syn* ions is determined by $(1/\epsilon d_{\text{anti}} - 1/\epsilon d_{\text{syn}})$ where ϵ is the dielectric constant, d is the distance (Å) between the charges (q) in a diastereomer, RT has its usual meaning, and 332 is the conversion factor to provide energy in units of kcal/mol. The computed distance between these heteroatoms in **2a**, for example, in the *syn* conformation, 5.34 (AM1) or 5.59 Å (PM3), is only slightly smaller than that in the *anti* isomer, 5.71 (AM1) or 5.80 Å (PM3), and so it is reasonable that the ground state energies and populations are similar. The value for ϵ must be on the order of about 5 (PM3) to 10 (AM1) in order to be consistent with an experimental ratio of 2 when considering a simple model in which a unit charge is place on each nitrogen atom. A more elaborate model would recognize that charge is dispersed around each ring.

$$\Delta E = -RT \ln[anti]/[syn] = 332 q_1 q_2 (1/\epsilon d_{\text{anti}} - 1/\epsilon d_{\text{syn}}) \quad (1)$$

In the case of dibenzyl dication **2b** another computational approach was applied on the basis of a conformational search by SYBYL with the TRIPOS force field[23] and a random search technique.[24,25] The lowest energy conformation of the *anti* diastereomer was estimated to have an energy of 17.58 and the *syn* form 18.80 kcal/mol, thereby giving an energy difference of 1.22 kcal/mol and a calculated *anti*–*syn* ratio of 8.2. The observed value is 6.6. The favored conformation for the *anti* form has the phenyl group in a T-shaped geometry with respect to the pyridyl ring to which it is bonded; the phenyl ring also is directed toward the naphthalene portion. Steric hindrance involving the benzyl group in the *syn* isomer may cause it to be disfavored.

The estimated dipole moments of di-*N*-oxide **2d** in DMSO are quite large: *syn*, 9.8μ (AM1) or 9.2μ (PM3), and *anti*, 6.9μ (AM1) or 6.5μ (PM3)). The *anti*–*syn* ratio is estimated to be 11 (AM1) or 6.6 (PM3), and the barrier to rotation from the lower energy *anti* to the transition state is 14.0 (AM1) or 13.5 kcal/mol (PM3). The rotational barrier is not much different from the 12.6 (AM1) or 12.4 kcal/mol (PM3) calculated for a simple unsubstituted 1,8-diphenyl system.

For dipyridone **3** in DMSO again the dipole moments are large: *syn*, 8.3μ (AM1) or 8.0μ (PM3), and *anti*, 8.0μ (AM1) or 6.0μ (PM3). The *anti*–*syn* ratio is estimated to be 2.5 compared with the experimental value of 1.7 and the rotational barrier is 11.0 (AM1) or 10.2 (PM3) kcal/mol.

The computations indicate that the pyridine rings adopt a T-shaped edge-to-face geometry in a transition state during rotation. The substituted nitrogen atom of one ring is directed away from the plane of the adjacent pyridine ring. Only one pyridyl hydrogen atom, H4′, is directed toward the second ring because the rings are splayed apart. Eclipsing of the pyridine H2′ and naphthalene H2 positions is only partial. Rotation of 180° about the bond between the pyridine and naphthalene rings leads to the interconversion and equilibration of the racemic *anti* and *meso syn* diastereomers, eq 2.

$$anti(\mathrm{R,R}) \rightleftarrows syn(\mathrm{R,S}) \rightleftarrows anti(\mathrm{S,S}) \quad (2)$$

Conclusions. Charged and polar groups may be added to **2** with ease to give mixtures of *anti* and *syn* diastereomers that may be examined at ambient temperatures by NMR spectroscopy, thereby making **2** and its derivatives attractive model compounds to study large electrostatic effects on the interactions between aromatic rings. The *N*-oxide and pyridone derivatives may be expected to serve as useful synthons for the preparation of still more elaborate rings.[26]

Experimental Section

The following NMR data report chemical shifts for the *anti* and *syn* mixtures of diastereomers at a probe temperature of about 20 °C unless another temperature is indicated. Coupling constants, *J*, are in hertz. Multiplets do not necessarily give integers for the numbers of protons on integration because they may consist of fractional numbers of protons due to the presence of mixtures of *syn* and *anti* forms present in unequal amounts. The spectra were recorded on a 300 MHz instrument.

1,8-Bis(1′-methylpyridin-1′-ium-3′-yl)naphthalene Ditosylate (2a). A solution of 300 mg (1.06 mmol) of 1,8-di(3′-pyridyl)naphthalene[17] and 450 mg (2.25 mmol) of methyl *p*-toluenesulfonate in 5 mL of nitromethane was allowed to stand for 14 h at rt. The solvent was evaporated in vacuo. The residue was dissolved in a minimum volume of MeOH, and the solution was made cloudy with ether. Crystallization at 0 °C overnight and drying at 100 °C in vacuo gave a colorless solid (465 mg, 71 mmol, 67%), mp >220 °C. Anal. Calcd for $C_{36}H_{34}N_2O_6S_2$: C, 66.04; H, 5.23; N, 4.28. Found: C, 65.84; H, 5.14, N, 4.05. ^{1}H NMR (DMSO-d_6): δ 8.94 (s), 8.81 (s), 8.73 (d, $J = 6$), 8.68 (d, $J = 6$), 8.39 (d, $J = 8.4$), 8.35 (d, $J = 8.1$), 8.11 (d, $J = 7.8$), 7.85 (m), 7.70 (dd, $J = 1.2$ and 7.2), 7.45 (4H, d, $J = 8.1$), 7.09 (4H, d, $J = 8.1$), 4.29 (s), 4.26 (s), 2.27(6H, s).

1,8-Bis(1′-benzylpyridin-1′-ium-3′-yl)naphthalene Diperchlorate (2b). A solution of 100 mg (0.36 mmol) of 1,8-di(3′-pyridyl)naphthalene[17] and 300 mg (1.8 mmol) of benzyl bromide in 1 mL of nitromethane was allowed to stand for 30 h at rt. The solvent was evaporated, and the oily residue was stirred with ether. The yellowish solid was washed with ether,

---

[22] Evard, P. G.; Piret, P.; Van Meersche, M. *Acta Crystallogr., Sect. B* **1972**, *28*, 497.

[23] Clark, M.; Cramer, R. D.; Opdenbosch, N. v. *J. Comput. Chem.* **1989**, *10*, 982.

[24] Chang, G.; Guida, W. C.; Still, W. C. *J. Am. Chem. Soc.* **1989**, *111*, 4739.

[25] Saunders, M.; Houk, K. N.; Wu, Y.-D.; Still, W. C.; Lipton, M.; Chang, G.; Guida, W. C. *J. Am. Chem. Soc.* **1990**, *112,* 1419.

[26] Zoltewicz, J. A.; Cruskie, M. P., Jr.; Dill, C. D. *Tetrahedron* **1996**, *52*, 4239.

dried in vacuo, and dissolved in MeOH/acetone (1/10, 10 mL) containing 10 drops of 70% $HClO_4$. The solution was concentrated at rt using a stream of nitrogen. The solid was recrystallized three times from acetone and dried in vacuo at 100 °C to give off-white crystals (130 mg, 0.196 mmol, 54%), mp 193−198 °C dec. Anal. Calcd for $C_{34}H_{28}N_2Cl_2O_8$: C, 61.55; H, 4.25; N, 4.22. Found: C, 61.67; H, 4.22; N, 4.13. ^{1}H NMR (DMSO-d_6 at 75 °C): δ 9.27 (2H, s), 8.88 (2H, br), 8.35 (2H, d, $J = 7.8$), 8.02 (2H, br), 7.80 (2H, t, $J = 7.8$), 7.5 (12H, m), 7.01 (2H, br), 5.84 (4H, s).

1,8-Di(3′-pyridyl)naphthalene 1′-Oxide Hemihydrate (2c). To a stirred ice-cold solution of 300 mg (1.06 mmol) of 1,8-di(3′-pyridyl)naphthalene[17] in 25 mL of $CHCl_3$ was added dropwise 300 mg of *m*-chloroperbenzoic acid (71%, 1.24 mmol) in 15 mL of $CHCl_3$. Stirring was continued for 14 h at rt. After removal of the solvent, the yellow oil was purified chromatographically on neutral alumina using MeOH/ethyl acetate (1/1) to give a yellow solid (180 mg, 0.59 mmol, 55%). An analytical sample was recrystallized from ethyl acetate, mp 168−170 °C dec. Anal. Calcd for $C_{20}H_{14}N_2O{\cdot}0.5H_2O$: C, 78.16; H, 4.92; N, 9.11. Found: C, 78.08; H, 4.56, N, 9.07. ^{1}H NMR (DMSO-d_6): δ 8.34 (d, $J = 1$), 8.27 (m), 8.17 (m), 7.95 (m), 7.81 (dt, $J = 1.5$ and 6.3), 7.67 (m), 7.57 (d, $J = 6.9$), 7.47 (dd, $J = 1.5$ and 6.0), 7.35 (d, $J = 8.1$), 7.15 (dd, $J = 5.5$ and 7.5), 7.07 (dd, $J = 4.8$ and 7.5), 6.84 (m).

1,8-Di(3′-pyridyl)naphthalene 1′,1′′-Dioxide Hemihydrate (2d). To 300 mg (1.06 mmol) of 1,8-di(3′-pyridyl)naphthalene[17] in 5 mL of $CHCl_3$ was added 1.00 g of *m*-chloroperbenzoic acid (71%, 4.11 mmol), and the clear solution was allowed to stand 14 h at rt. The solvent was evaporated under reduced pressure, and the oily residue was purified by column chromatography on neutral alumina using MeOH/ethyl acetate (8/2). Drying at 100 °C in vacuo gave a yellow solid (230 mg, 7.11 mmol, 67%), mp 223−228 °C dec. Anal. Calcd for $C_{20}H_{14}N_2O_2{\cdot}0.5H_2O$: C, 74.29; H, 4.67; N, 8.66. Found: C, 74.39 ; H, 4.40; N, 8.50. ^{1}H NMR (DMSO-d_6 at 70 °C): δ 8.18 (2H, d, $J = 8.4$), 7.95 (2H, s), 7.90 (2H, d, $J = 6.3$), 7.66 (2H, t, $J = 8$), 7.48 (2H, d, $J = 7.2$), 7.15 (2H, t, $J = 6.9$), 6.98 (2H, d, $J = 7.2$).

1,8-Di(pyridin-1′-ium-3′-yl)naphthalene (2e). 1,8-Di(3′-pyridyl)naphthalene[17] was added to D_2O containing trifluoroacetic acid. ^{1}H NMR: δ 8.8 (s), 8.62 (s), 8.59 (d, $J = 5.7$), 8.55 (d, $J = 5.4$), 8.38 (d, $J = 5.1$), 8.30 (d, $J = 8.1$), 8.14 (d, $J = 8$), 7.88 (dd, $J = 5$ and 6.0), 7.80 (t, $J = 7.6$), 7.74 (dd, $J = 5$ and 6.0); 8.63 (d, $J = 7.2$).

1,8-Bis(1′-methyl-6′-pyridon-3′-yl)naphthalene (3). To 250 mg (0.38 mmol) of dimethyl **2a** was added in portions a saturated solution of $K_3Fe(CN)_6$ in 10 mL of H_2O containing 1 mL of 50% NaOH. The reddish brown solution was stirred at rt for 14 h. The heterogenous mixture was extracted with chloroform (3 × 30 mL), dried ($MgSO_4$), and concentrated. The yellowish crystalline residue was purified by column chromatography on neutral alumina using MeOH in ethyl acetate (10−50). Drying in vacuo at 100 °C gave a white solid (76 mg, 0.22 mmol, 58%); an analytical sample was recrystallized from ethanol, mp >220 °C. Anal. Calcd for $C_{22}H_{18}N_2O_2$: C, 77.17; H, 5.30; N, 8.18; Found: C, 77.25; H, 5.28; N, 8.18. ^{1}H NMR (DMSO-d_6) δ 8.05 (d, $J = 8.1$), 7.59 (t, $J = 7.8$), 7.45 (m), 7.12 (d, $J = 8.7$), 6.71 (d, $J = 9.0$), 6.11 (d, $J = 9.0$), 6.05 (d, $J = 9.3$), 3.33 (6H, s). ($CDCl_3$ at −20 °C) δ 7.94 (dd, $J = 1$ and 4.8), 7.57 (t, $J = 8$), 7.39 (m), 7.21 (d, $J = 2.4$), 7.15 (dd, $J = 2.4$ and 9.3), 7.05 (d, $J = 2$), 6.94 (dd, $J = 2.4$ and 9.3), 6.41 (d, $J = 9.3$), 6.27 (d, $J = 9.0$), 3.54 (s), 3.50 (s).

Semiempirical Computations. All calculations were performed using AM1[27] and PM3[28] and the VAMP[29] program on isolated molecules in the gas phase as well as in DMSO where the solvent effect was approximated by the self-consistent reaction field (SCRF) model. The pyridyl torsion angle was used as a reaction coordinate while all other geometrical parameters refined by gradient norm minimization were optimized and verified as transition states by force constant calculations. Coordinate calculations started from both the *syn* and *anti* minima.

SYBYL−TRIPOS Computations. For dibenzyl dication **2b** four structures were employed, starting with two *anti* and two *syn* conformations using SYBYL 6.2 with the TRIPOS force field[23] with electrostatics included by Gasteiger−Hückel charges using a random search technique.[24,25] Each of the four starting structures led to approximately 30 conformations, many of which were the same. The lowest energy conformation was obtained from both the *syn* and the *anti* diastereomer.

JO960906G

---

(27) Dewar, M. J. S.; Zoebisch, E. G.; Healey, E. F.; Stewart, J. J. P. *J. Am. Chem. Soc.* **1985**, *107*, 3902.

(28) Stewart, J. J. P. *J. Comput. Chem.* **1989**, *10*, 209.

(29) Clark, T. Ver. 4.40, 1992, Erlangen, Germany.