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Azinium Azolate Inner Salts: Synthesis and Structural Studies

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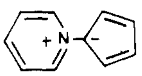
Ten mesomeric betaines of the pyridinium azolate class have been prepared from the corresponding pyridinium azole salts. Theoretical calculations (MNDO), experimental dipole moments (10 to 19 D), ^{1}H and ^{13}C NMR spectra, and the X-ray structure of pyridinium benzimidazolate inner salts **3** and **17** have been used to determine the electronic and molecular structure of these compounds.

Conjugated heterocyclic N-ylides isoconjugated with odd nonalternant hydrocarbon anions are scarcely known.[2] *N*-Pyridinium cyclopentadienide (**1**) is a typical example of this class of mesomeric betaines. Up to now, only a few aza analogues of **1**, the inner salts of azinium azolate **2**, are known.[3] The first example **3** of such structures was described by Boyd in 1966.[4] Other pyridinium benzimidazolates have been prepared by Lindberg et al.,[5] Figala et al.,[5] Postovskii et al.,[6] and Dorofeenko et al.,[7] who also prepared the pyridinium tetrazolate **4**.



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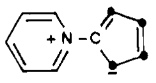
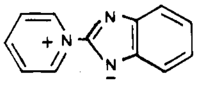


2

●=CR or N



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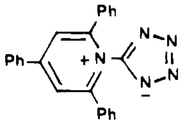
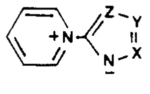


4

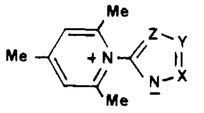
The prospective interest of this rather neglected class of heterocyclic mesomeric betaines **2** prompted us to investigate them. We have now initiated such a study by preparing closely related members of pyridinium azolate inner salts. Theoretical calculations have been carried out and their physicochemical properties are discussed on the basis of spectroscopic data, experimental dipole moments, and two X-ray structure determinations.

Results and Discussion

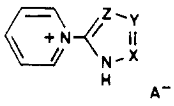
MNDO Calculations. Theoretical calculations have been performed for seven pyridinium azolate inner salts **3** and **5-10** within the MNDO approximation.[8] A fixed geometry has been selected for both rings,[9] and the interannular bond has been taken to be 1.48 Å. The results of the calculations are collected in Table I.



5, 7, 9, 10



6 , 8



11 - 13

5, 6, 11 X = Y = CH ; Z = N
7, 8 X = N ; Y = Z = CH
9, 12 X = Z = N ; Y = CH
10, 13 X = Y = Z = N

The variation of energy as a function of the conformation around the interannular C–N bond (θ angle defined as $\theta = 0°$ for the coplanar conformation) shows that the preferred structure of these betaines depends on the substituents on the pyridinium ring as well as on the nature of the azolate ring. Unsubstituted pyridinium derivatives **3**, **5**, **9**, and **10** are found to be more stable as coplanar structures, except for the pyridinium pyrazolate **7**, which is twisted 35.5°, as a result of the interaction of the hydrogen atoms ortho to the central bond in the planar conformation. In all cases, their energy barriers for free rotation around the interannular bond are low. On the other hand, 2,4,6-trimethylpyridinium derivatives **6** and **8** have perpendicular rings in the most stable conformation with highly destabilized planar transition states. Presumably, the 2,4,6-triphenylpyridinium derivatives (see below) have also orthogonal conformations.

The central C–N bond has a high single-bond character (Wiberg index $\simeq$ 0.9). The electronic structure of pyridinium azolate inner salts is well reflected by their calculated dipole moments which are unusually high, the largest known values for organic molecules excluding polymers (natural or synthetic).

Finally, MNDO calculations of three *N*-azolylpyridinium salts **11**, **12**, and **13** are listed in Table II.

Synthesis. The syntheses of ten pyridinium azolate inner salts **3**, **4**, and **14–21** were performed by deprotonation of the corresponding *N*-azolylpyridinium salts, using

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[1] (a) Universidad de Barcelona. (b) Instituto de Quimica Médica. (c) Université Paul Sabatier. (d) Instituto de Ciencia de Materiales.

[2] Ollis, W. D.; Stanforth, S. P.; Ramsden, C. A. *Tetrahedron* **1985**, *41*, 2234.

[3] Alcalde, E.; Dinarés, I.; Fayet, J.-P.; Vertut, M.-C.; Elguero, J. *J. Chem. Soc., Chem. Commun.* **1986**, *734* and references cited therein.

[4] Boyd, C. V. *Tetrahedron Lett.* **1966**, 3369.

[5] (a) Ankner, K. F.; Brandström, A. E.; Lindberg, P. L.; Nordberg, M. P.; Wallmark, B. E. Patent 181 846, 1986. (b) Figala, V.; Klemm, K.; Kohl, B.; Krüger, V. Rainer, G.; Schaefer, H.; Senn-Bilfinger, J.; Sturm, E. *J. Chem. Soc., Chem. Commun.* **1986**, 125.

[6] Postovskii, I. Y.; Mamaev, V. P.; Mokrushina, G. A.; Zuguliaeva, O. A.; Kosareva, A. *Khim. Geterotsikl. Soedin.* **1975**, 987.

[7] Zvezdina, E. A.; Zhdanova, M. P.; Bren', V. A.; Dorofeenko, G. N. *Khim. Geterotsikl. Soedin.* **1978**, 944.

[8] Dewar, M. J. S.; Thiel, W. *J. Am. Chem. Soc.* **1977**, *99*, 4899.

[9] *Tables of Interatomic Distances and Configuration in Molecules and Ions*; Sutton, L., Ed.; The Chemical Society: London, 1965.

0022-3263/87/1952-5009$01.50/0

Table I. Heat of Formation, Total Energy, Energy Barriers, Dipolar Moments, and Wiberg Index of Pyridinium Azolate Inner Salts

		θ_{min}					θ = 0°			θ = 30°			θ = 60°			θ = 90°		
no.	θ_{min}, deg	$\Delta H_f{}^a$	$E_T{}^b$	$\Delta E^{\ddagger\,a}$	μ^c	$i_W{}^d$	$\Delta H_f{}^a$	$E_T{}^b$	μ^c	$\Delta H_f{}^a$	$E_T{}^b$	μ^c	$\Delta H_f{}^a$	$E_T{}^b$	μ^c	$\Delta H_f{}^a$	$E_T{}^b$	μ^c
3	0	567.73	-2278.9815	11.21	11.06	0.9311				568.65	-2278.9710	11.37				578.94	-2278.8653	12.67
5	0	476.64	-1739.9504	18.12	8.19	0.9613				479.19	-1739.9243	8.58	488.06	-1739.8324	9.66	494.76	-1739.7628	10.49
6	90	429.24	-2209.1683	108.32	10.15	0.8807	537.56	-2208.0455	7.66	493.92	-2208.4979	8.24	441.75	-2209.0384	9.41			
7	37.5	531.83	-1739.3786	5.40	11.72	0.9141	534.76	-1739.3481	11.23	532.12	-1739.3756	11.55	533.88	-1739.3572	12.34	537.23	-1739.3226	12.85
8	90	468.77	-2208.7277	349.36	12.52	0.8678	821.11	-2205.1070	10.57	590.82	-2207.4935	11.16	488.98	-2208.5489	12.04			
9	0	514.80	-1804.9597	9.66	11.19	0.9292				515.80	-1804.9494	11.44	520.61	-1804.8996	12.06	524.46	-1804.8597	12.44
10	0	588.98	-1869.5957	5.15	13.84	0.9167				589.02	-1869.5950	14.01	591.62	-1869.5681	14.41	594.13	-1869.5420	14.64

[a] In kJ/mol. [b] In eV; 1 eV = 1.6021 × 10^{-19} J. [c] In debye; 1 D = 3.34 × 10^{-30} C m. [d] Wiberg index.

Table II. MNDO Calculations of *N*-Azolylpyridinium Salts 11-13

		θ_{min}		
no.	θ_{min}, deg	$\Delta H_f{}^a$	$E_T{}^b$	$i_W{}^c$
11	0	1020.98	-1748.4745	0.9255
12	0	1113.53	-1812.9203	0.9206
13	0	1235.37	-1877.0619	0.9460

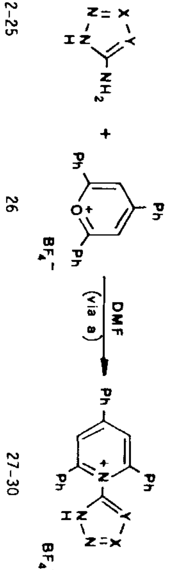
[a] In kJ/mol. [b] In eV; 1 eV = 1.0621 × 10^{-19} *J*. [c] Wiberg index.

Table III. Physical Data of *N*-Azolylpyridinium Salts

no.[a]	azolyl	R	reactn time (h)	yield[b] (%)	mp, °C[c] (solvent)
27	5-methyl-1*H*-pyrazol-3-yl	C_6H_5	1	30	253-254 (*d*)
28	1*H*-1,2,4-triazol-3(5)-yl	C_6H_5	1	65	254-256 (*d*)
29	1*H*-tetrazol-5-yl	C_6H_5	1	49	210-211 (*e*)
30	3(5)-amino-1*H*-1,2,4-triazol-5(3)-yl	C_6H_5	2	78	244-246 (*f*)
33	1*H*-benzimidazol-2-yl	C_6H_5	1	47	236-237 (*f*)
34	5,6-dimethyl-1*H*-benzimidazol-2-yl	C_6H_5	1.5	39	281-282 (*f*)
39	1*H*-benzimidazol-2-yl	H	1	87	229-230 (*g*)
40	5,6-dimethyl-1*H*-benzimidazol-2-yl	H	2	83	254-255 (*g*)
43	4-(1*H*-benzimidazol-2-yl)phenyl	C_6H_5	24	70	253-254 (*h*)
44	4-(5,6-dimethyl-1*H*-benzimidazol-2-yl)phenyl	C_6H_5	27	53	257-258 (*h*)

[a] Satisfactory analytical data (±0.4% for C, H, N) were obtained for all new compounds. [b] Yields were not optimized. [c] Some salts have already been described as perchlorates of **28**, mp 253-254 °C (ref 7); **29**, mp 222 °C (ref 7); **33**, mp 255 °C (ref 7); **39**, mp 232-233 °C (ref 4). [d] 2-Propanol. [e] Ethanol/tetrafluoroboric acid. [f] Absolute ethanol. [g] Ethanol/water/hydrogen chloride. [h] Ethanol.

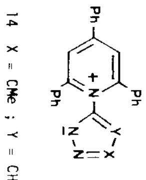
Scheme I



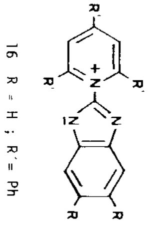
22-25 26 27-30

22 , 27 X=CMe , Y=CH
23 , 28 X=CH , Y=N
24 , 29 X=Y=N
25 , 30 X=CNH$_2$, Y=N

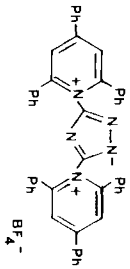
different procedures (see later). The method of choice was found to be the use of an anionic (hydroxide form) ion-exchange resin which now allows a facile entry into this class of mesomeric betaines.



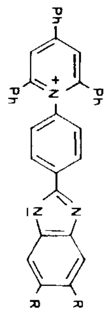
14 X = CMe ; Y = CH
15 X = CH ; Y = N
4 X = Y = N



16 R = H ; R' = Ph
17 R = Me ; R' = Ph
3 R = R' = H
18 R = Me ; R' = H

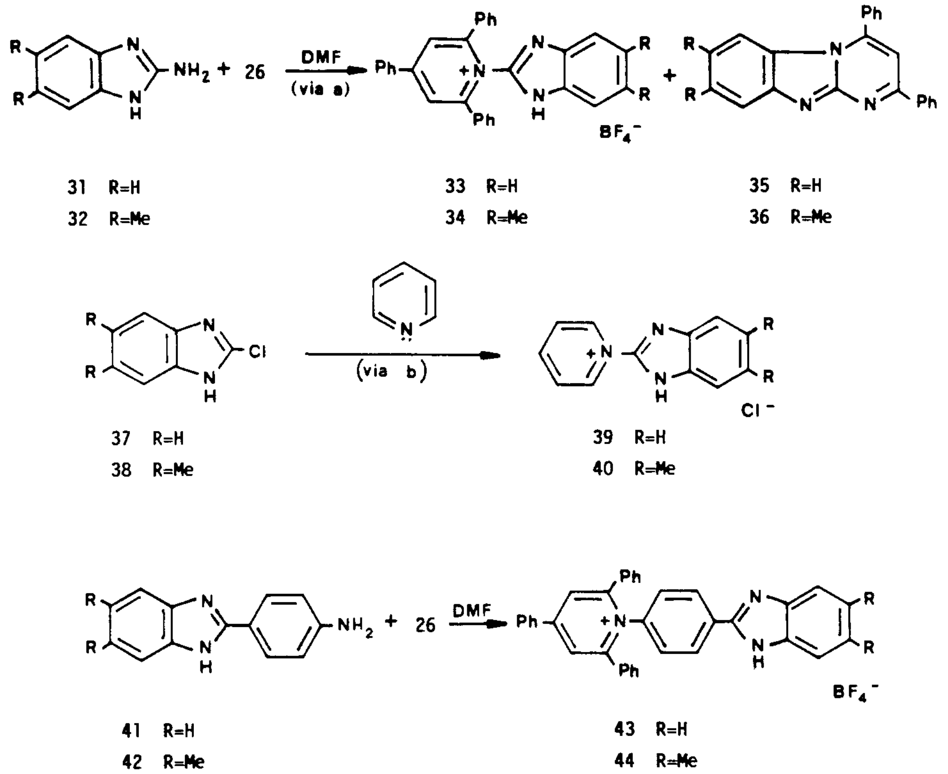


19



20 R = H
21 R = Me

Scheme II



Substituted N-azolylpyridinium salts were obtained via two general synthetic methods for the preparation of pyridinium salts: by reaction of C-aminoazoles with triphenylpyrylium tetrafluoroborate or by reaction of 2-chlorobenzimidazoles with pyridine.

The reaction of primary amines with pyrylium salts to give pyridinium compounds is a well-known procedure.[10a] However, only a few examples of the preparation of N-heteroaryl substituted pyridinium salts from C-aminoazoles have been described.[10b] Reaction of C-aminoazoles **22–25** with **26** in dimethylformamide afforded the corresponding N-azolyl-2,4,6-triphenylpyridinium tetrafluoroborates **27–30** (Scheme I).

When 2-aminobenzimidazoles **31** and **32** reacted with the pyrylium salt **26** the reaction proceeded primarily with formation of the salts **33** and **34**, while 1,3-diphenylbenzimidazo[1,2-*a*]pyrimidines **35** and **36** were formed as secondary products (Scheme II). Alternatively, displacement of the chlorine atom in **37** and **38** by pyridine itself afforded the N-benzimidazolylpyridinium chlorides **39** and **40**. Reaction of the amino derivatives **41** and **42** with the pyrylium salt **26** produced the desired pyridinium salts **43** and **44** (Scheme II). The physical properties of the substituted N-azolylpyridinium salts are found in Table III.

Transformation of N-azolylpyridinium salts **27–30**, **33**, **34**, **39**, **40**, **43**, and **44** into the corresponding mesomeric betaines **3**, **4**, and **14–21** has been achieved by different procedures. The optimal conditions for this transformation were uncovered through an investigation probing a variety of methods. As pointed out above highest yields of mesomeric betaines were obtained when a strong base anion-exchange resin was used. It is noteworthy that under Dorofeenko's conditions[7] N-1H-tetrazol-5-yl-2,4,6-triphenylpyridinium tetrafluoroborate (**29**) was not transformed into the pyridinium tetrazolate **4** and the starting salt **29** was recovered unchanged (see Experimental Section). Concerning 2-(2,4,6-triphenylpyridinio)benzimidazolate (**16**), the product has been described by Dorofeenko[7] with a melting point 149–150 °C which correspond to a mixture of the betaine **16** and the starting salt **33** ($X = ClO_4^-$) (see later and Experimental Section).

Finally, when N-(5-amino-1H-1,2,4-triazol-3-yl)-2,4,6-triphenylpyridinium tetrafluoroborate (**30**) reacted with **26** in dimethylformamide, the betaine **19** was formed. The physical data of pyridinium azolate inner salts are listed in Table IV.

Table IV. Physical Data of Pyridinium Azolate Inner Salts

no.[a]	azolate	R	method[b] (yield, %)	mp (°C)[c] (solvent)
14	5-methyl-3-pyrazolate	C_6H_5	A (94)	78–79 (*e*)
15	3(5)-1,2,4-triazolate	C_6H_5	A (99)	255–256 (*f*)
4	5-tetrazolate	C_6H_5	A (90)	273–275 (*e*)
16	2-benzimidazolate	C_6H_5	A (98)	255–257 (*f*)
17	5,6-dimethyl-2-benzimidazolate	C_6H_5	A (97)	229–231 (*d*)
3	2-benzimidazolate	H	A (96), B (99)	269–270 (*d*)
18	5,6-dimethyl-2-benzimidazolate	H	A (95), B (99)	230–231 (*g*)
19	3(5)-(2,4,6-triphenyl-1-pyridinio-5(3)-1,2,4-triazolate tetrafluoroborate	C_6H_5	(64)	279–281 (*h*)
20	2-(*p*-phenylene)benzimidazolate	C_6H_5	A (98)	226–227 (*d*)
21	5,6-dimethyl-2-(*p*-phenylene)benzimidazolate	C_6H_5	A (97)	255–256 (*d*)

[a] Satisfactory analytical data (±0.4% for C, H, N) were obtained for all compounds. [b] Yields were not optimized. [c] Some mesomeric betaines have been described: **3**, mp 260 °C (ref 4); **4**, mp 274–275 °C (ref 7); **17**, mp 149–150 °C (ref 7). [d] 70% ethanol. [e] Chloroform. [f] Benzene. [g] 50% ethanol. [h] Absolute ethanol.

Structural Assignments. All the compounds described gave satisfactory elemental analyses.[11] Infrared

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(10) (a) Balaban, A. T.; Dinculescu, A.; Dorofeenko, G. N.; Fisher, G. W.; Koblik, A. V.; Mezheritskii, V. V. *Adv. Heterocycl. Chem.* **1982**, 114–127; (b) 117–118.

(11) For the pyridinium azolate inner salts described in this work, the amount of water was also determinated by termogravimetry.

spectra (IR) of the substituted *N*-azolylpyridinium tetrafluoroborates showed absorptions in the range of 3500–3340 cm^{-1} (ν_{NH}) and 1100–1000 cm^{-1} ($\nu_{BF_4^-}$); the hydrochlorides absorb in the 2550–2490-cm^{-1} region. In the infrared spectra (IR) of the pyridinium azolate inner salts the above mentioned bands were absent.

The ^{1}H and selected ^{13}C NMR parameters of *N*-azolylpyridinium salts are given in Tables V and VI.

In the ^{1}H NMR spectra, the signals corresponding to the phenyl rings of the triphenylpyridinium group appear as multiplets which means that phenyl groups are not orthogonal with the pyridinium ring.[12]

The 2,4,6-triphenylpyridinium substituent produces a deshielding effect due to its electron-withdrawing nature, observable on the H-3′ proton of **28**, and a shielding effect due to the phenyl groups in positions 2 and 6, which depends on the torsional angle between phenyl and pyridinium rings (steric effects). On the whole, both effects cancel for H-4′ of compound **27** as well as for benzimidazole derivatives **33** and **34**. On the other hand, the pyridinium group exerts a deshielding effect in the *N*-benzimidazolylpyridinium salts **39** and **40**.

In the ^{13}C NMR spectra the chemical shifts have been assigned by comparison with data from other *N*-arylpyridinium salts,[12a] pyrazoles,[13] 1,2,4-triazoles,[14,15] and benzimidazoles.[16] It is noteworthy that the chemical shifts corresponding to the benzimidazolyl carbon atoms (mainly C-2) were quite similar to the parent benzimidazoles and the deshielding effect of 2,4,6-triphenylpyridinium and pyridinium groups were not detected as was the case for *N*-arylpyridinium salts.[12a] The unusual behavior of the C-2 in some 2-substituted benzimidazoles has been indicated previously.[17,18] Moreover, in the *N*-benzimidazolylpyridinium salts **33**, **34**, **39**, and **40**, the signals of $C_{3a,7a}$ and $C_{4,7}$ are broadened due to a slow exchange of the NH proton at room temperature in the benzimidazole ring, in agreement with the fact that the proton exchange between the two nitrogen atoms is easier to observe in a benzimidazole system than in other heteroaromatic rings.[16] The asymmetric pyrazole **27** has been assigned as the 5-methyl tautomer via two-bond heteronuclear selective NOE difference[19] and by the chemical shift of C-Me at 10.4 ppm characteristic of 5-methylpyrazoles.[13]

It has been shown[20,21] that for proton spectra, where electron density plays an important role, the CH protons of the azole ring were more shielded in the anion than in the neutral molecule. The dipolar structure of the mesomeric betaines **3**, **4**, and **14–21** is well reflected by ^{1}H NMR,[22] the chemical shifts of the CH protons in the azolate group are shifted upfield, and those of the α and γ position in the pyridinium ring for unsubstituted pyridinium compounds **3** and **18** are shifted downfield with respect to the corresponding *N*-azolylpyridinium salts (see Tables V and VII). As can be seen from ^{13}C NMR values of the pyridinium azolate inner salts (Table VIII), deprotonation of the azole ring causes a shift effect in excellent agreement with data reported for anionic species in the azole series.[18,20,23–25]

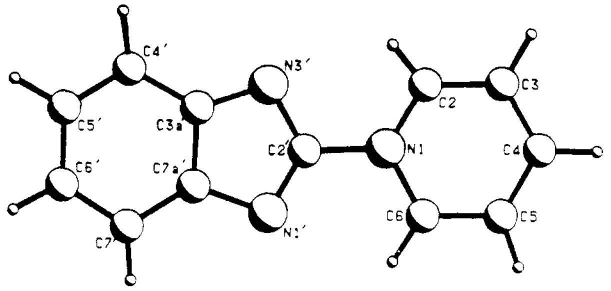

Figure 1. Computer-generated perspective drawing of **3** with the atom numbering[26] used in the crystal structure analysis.

Table IX. Dipole Moments in Dioxane at 25 °C for Benzimidazolate Pyridinium Inner Salts

no.	α	β	R_{MD}	P_{200}	μ_{exp}	μ_{calcd}[a]
3	68.0	0	58.4	2241.8	10.33	11.06
18	102.5	−0.40	67.7	3807.3	13.52	*b*
16	51.0	−0.35	133.5	3634.4	13.08	*b*
17	97.0	−0.40	142.8	7290.7	18.70	*b*

[a] MNDO. [b] Not calculated owing to the large molecular sizes involved.

The experimental dipole moment values extrapolated to infinite dilution in dioxane of the anhydrous mesomeric betaines **3**, **16**, **17**, and **18** are in the range of 10.3 to 18.7 D; the results are given in Table IX. The planar mesomeric betaines **3** and **18** are strongly associated when the weight fraction is greater than 0.0002, and their dipole moments tend to zero when concentration increases, indicating a head-to-tail orientation to form a nonplanar dimer (see later). On the contrary, the hindred perpendicular mesomeric betaines **16** and **17** do not associate at these concentrations.

The dipole moment was calculated to be 11.06 D for the betaine **3**, in good agreement with the experimentally determined value which lends credence to the MNDO calculations. For experimentally studied betaines **16** and **17**, the calculations were precluded due to the larger number of orbitals.

In order to increase the unusually high dipole moment of 18.70 D for betaine **17**, two compounds, **20** and **21**, have been synthesized. Unfortunately, the experimental dipole moments could not be measured due to the low solubility of these betaines.

Both energy calculations and the agreement of the experimental dipole moment with the calculated one indicates that unsubstituted 2-pyridiniobenzimidazolate (**3**) is planar. However, the 2,4,6-trisubstituted pyridinium benzimidazolate betaines are hindered molecules with

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(12) (a) Claramunt, R. M.; Elguero, J. *Collect. Czech. Chem. Commun.* **1981**, *71*, 598. (b) Ritchie, G. L. D.; Urbancich, J. *J. Mol. Struct.* **1982**, *78*, 279.

(13) Elguero, J. In *Comprehensive Heterocyclic Chemistry*; Katritzky, A. R., Rees, C. W., Eds.; Pergamon Press: Oxford, 1984; Vol. 5, p 167.

(14) Elguero, J.; Marzin, C.; Roberts, J. D. *J. Org. Chem.* **1974**, *39*, 357.

(15) Winkler, T.; Kristinsson, H. *Helv. Chim. Acta* **1983**, *66*, 694.

(16) Fruchier, A.; Pappalardo, L.; Elguero, J. *Anal. Quim.* **1980**, *76*, 79 and references cited therein.

(17) (a) Mathias, L. J.; Overberger, C. G. *J. Org. Chem.* **1978**, *43*, 3526 and references cited therein. (b) Gründemann, E.; Graubaum, H.; Martin, D.; Schiewald, E. *Magn. Reson. Chem.* **1986**, *24*, 21.

(18) Lopyrev, V. A.; Larina, L. I.; Vacul'skaya, T. I.; Larin, M. F.; Nefedova, O. B.; Schibadonova, E. F.; Voronkov, M. G. *Org. Magn. Reson.* **1981**, *15*, 219.

(19) Sanchez-Ferrando, F. *Magn. Reson. Chem.* **1985**, *23*, 185.

(20) Butler, R. N.; McEvoy, T. M. *Proc. R. Irish Acad.* **1977**, *77B*, 359.

(21) Barlin, G. B.; Batterham, T. J. *J. Chem. Soc.* **1967**, 516.

(22) The pyridinium azolate inner salts re-formed the *N*-azolylpyridinium salts with acids: ^{1}H NMR spectra of the mesomeric betaines were measured in $(CD_3)_2SO$ with 10% TFAA and the chemicals shifts were similar to those observed for their corresponding *N*-azolylpyridinium salts.

(23) ^{13}C NMR of 1,2,4-triazole [$(CD_3)_2SO$]: δ 147.2 (C-3, C-5); [$(CD_3)_2SO$ with an excess of sodium hydride] δ 147.6 (C-3, C-5).

(24) Pugmire, R. J.; Grant, D. M. *J. Am. Chem. Soc.* **1968**, *90*, 4232.

(25) Pugmire, R. J.; Grant, D. M. *J. Am. Chem. Soc.* **1971**, 93, 1880.

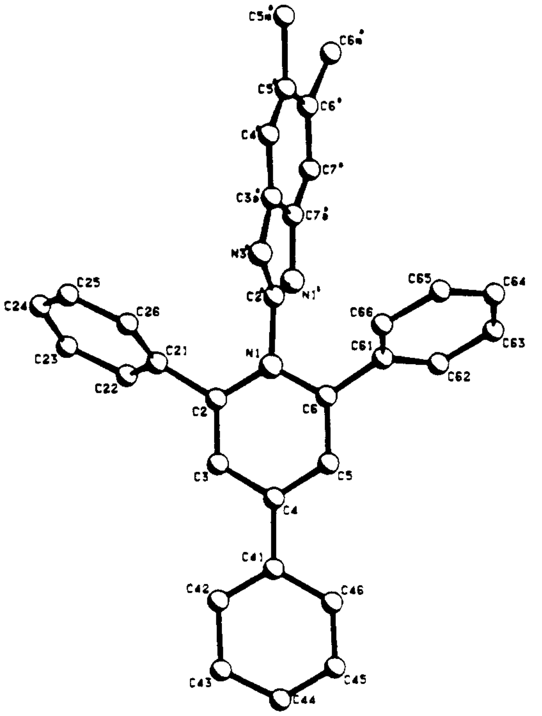

Figure 2. Computer-generated perspective drawing of **17** with the atom numbering[26] used in the crystal structure analysis.

perpendicular conformation (see Tables I and IX).

In order to verify this conclusion, X-ray diffraction analyses were performed on two selected representative mesomeric betaines: with an unsubstituted pyridinium group (**3**) and with a 2,4,6-trisubstituted pyridinium ring (**17**). A perspective diagram of each of the two selected compounds is given in Figures 1 and 2 (note that the atom numbering for the crystal structure is the same to that for the NMR assignments).[26]

Figure 1 shows that the molecule **3** is planar, the angle between the mean plane of imidazole ring (rms disatnce 0.03 Å) and the mean plane of pyridine ring (rms distance 0.01 Å) is 1.9°. The N(1)–C(2′) bond length is 1.450 Å, close to the value reported[3,27] for a 2,3,4-trisubstituted pyridinium benzimidazolate inner salt. Neither the pyridinium ring nor the benzimidazole ring is symmetrical, but the small differences between related bonds are due to the packing and the mean values close to those described for related heterocycles.[27-30] Selected bond lengths (Å) for compound **3**: C(2)–N(1), 1.33; C(6)–N(1), 1.38; C-(2′)–N(1), 1.45; C(3)–C(2), 1.37; C(4)–C(3), 1.37; C(5)–C(4), 1.38; C(6)–C(5), 1.39; C(2′)–N(1′), 1.30; C(7′a)–N(1′), 1.42; N(3′)–C(2′), 1.35; C(3′a)–N(3′), 1,33; C(4′)–C(3′a), 1.42; C(7′a)–C(3′a), 1.42; C(5′)–C(4′), 1,36; C(6′)–C(5′), 1.39; C(7′)–C(6′), 1.38; C(7′a)–C(7′), 1.39. Bond distance mean values (Å), compound **3**: C(2)–N(1) and C(6)–N(1), 1.36; C(2′)–N(1), 1.45; C(3)–C(2) and C(6)–C(5); 1.38; C(4)–C(3) and C(5)–C(4), 1.37; C(2′)–N(1′) and N(3′)–C(2′), 1.33; C(7′a)–N(1′) and C(3′a)–N(3′), 1.38; C(4′)–C(3′a) and C-(7′a)–C(7′), 1.40; C(5′)–C(4′) and C(7′)–C(6′), 1.37; C-(6′)–C(5′), 1.39.

In the case of compound **17** the X-ray structure[31,32] (see Figure 2 for a drawing of the final model) shows that the torsional angle between the weighted least-squares planes of the rings is 84.4°, a quasi-perpendicular conformation in accordance with MNDO calculations, and the interannular bond length N(1)–C(2′) is 1.49 Å. Selected bond lengths (Å) for compound **17**: C(2)–N(1), 1.36; C(6)–N(1), 1.37; C(2′)–N(1), 1.49; C(3)–C(2), 1.39; C(4)–C(3), 1.40; C(5)–C(4), 1.41; C(6)–C(5), 1.40; C(2′)–N(1′), 1.43; C-(7′a)–N(1′), 1.40; N(3′)–C(2′), 1.33; C(3′a)–N(3′), 1.39; C(4′)–C(3′a), 1.38; C(7′a)–C(3′a), 1.44; C(5′)–C(4′), 1.39; C(6′)–C(5′), 1.41; C(7′)–C(6′), 1.36; C(7′a)–C(7′), 1.37.

As mentioned before, for compound **3** we have postulated the formation of nonpolar dimers to explain the decrease of its experimental dipole moment when the concentration increases. The head-to-tail orientation has been further confirmed by X-ray analysis. Selected intermolecular contacts of compound **3** are drawn in Figure 3, ranging from 3.29 Å to 3.62 Å (shortest contacts are C(7′)···C(6) [$-1 + x, y, z$] 3,29 Å and C(5)···N(1′) [$^1/_2 + x, {}^1/_2 - y, -z$] 3.29 Å).

Experimental Section

General Methods. All melting points were determined on a CTP-MP 300 hot-plate melting point apparatus and are uncorrected. IR spectra were obtained as KBr disks on a Perkin-Elmer 1430 spectrophotometer. ^{1}H NMR spectra were recorded on one of the following spectrometers: Bruker AM-100, Varian XL-200. ^{13}C NMR spectra were run on a Bruker AM-100 spectrometer. NMR spectra were taken in $(CD_3)_2SO$, and chemical shifts are expressed in parts per million (δ) relative to internal Me_4Si. TLC was performed on SiO_2 (silica gel 60 F_{250}, Merck), in the following solvent systems: A, methanol–diethyl ether (8:2), B, diethyl ether–methanol (9.5:0.5) as developing solvent; and the spots were located with UV light. Ion-exchange chromatography was carried out on an anionic (OH^- form) ion-exchange resin (Amberlite IRA-401). If necessary the compounds were dried by heating overnight at 110 °C in a vacuum oven. Microanalysis were performed on a Carlo Erba 1106 analyzer by Instituto de Quimica Bio-Orgânica, Barcelona.

Materials. The aminoazoles **23**, **24**, **25**, **31**, and **32** are commercially available. 3(5)-Amino-5(3)-methylpyrazole,[33] 2,4,6-triphenylpyrylium tetrafluoroborate,[34] 2-chlorobenzimidazole,[35] and 2-chloro-5,6-dimethylbenzimidazole[36] were prepared as in the literature.

Preparation of *N*-Azolyl-2,4,6-triphenylpyridinium Tetrafluoroborates 27–30. A solution of the aminoazole **22**, **23**, **24** or **25** (6 mmol) in 4 mL of anhydrous DMF and the pyrylium salt **26** (1.98 g, 5 mmol) were refluxed under stirring for the time specified in Table III. After cooling, diethyl ether (20 mL) was added to give a yellow solid for compound **29** or an oily products **27**, **28**, and **30**. The solutions were decanted from the oily residues which were then triturated thoroughly with water. The yellow triturates were filtered, washed with water, and recrystallized (see Table III).

Reaction of 2-Aminobenzimidazole 31 or 32 with 2,4,6-Triphenylpyrylium Tetrafluoroborate (26). To a solution of 2-aminobenzimidazole **31** or **32** (13 mmol) in 7 mL of anhydrous DMF was added the pyrylium salt **26** (4.40 g, 11 mmol). The

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(26) To facilitate comparison of spectroscopic and X-ray data, the numbering system for NMR assignments of the pyridinium azolate inner salts in this paper is not the same as the IUPAC numbering system.

(27) Senn-Bilfinger, J.; Byk-Gulden Pharmazeutica, Konstanz, private communication.

(28) Smith, K. Aa; Waterman, K. C.; Streitweiser, A., Jr. *J. Org. Chem.* **1985**, *50*, 3360.

(29) Camerman, A.; Jensen, L. H.; Balaban, A. T. *Acta Crystallogr., Sect. B* **1969**, *b25*, 2623.

(30) Quick, A.; Williams, D. J. *Can. J. Chem.* **1976**, *54*, 2482.

(31) The crystals of **17** for X-ray diffraction analysis were grown from 70% ethanol and the sample was submitted as an orange needle crystals with wide core.

(32) Compound **17** formed a dihydrate (see Table IV) and the two water molecules were disordered. In spite of not knowing the occupancy factors for the two water molecules, the bond distances[27] of the pyridinium benzimidazolate inner salt **17** were in agreement with a quasi-symmetrical structure.

(33) Alcalde, E.; Mendoza, J.; Garcia-Marquina, J. M.; Almera, C.; Elguero, J. *J. Heterocycl. Chem.* **1974**, *11*, 423.

(34) Dimroth, K.; Reichardt, C.; Vogel, K. *Org. Synth.* **1969**, *49*, 121.

(35) Harrison, D.; Ralph, J. T.; Smith, A. C. B. *J. Chem. Soc.* **1963**, 2930.

(36) Bednyagina, N. P.; Tyurenkova, G. N.; Panov, I. V. *Zh. Obshch. Khim.* **1964**, *34*, 1585.

reaction mixture was refluxed under stirring for the time specified in Table III. On standing at room temperature, yellow crystals of benzimidazo[1,2-*a*]pyrimidine **35** or **36** slowly precipitated. Compound **35** was filtered and washed with diethyl ether: yield 0.55 g (16%); mp 308–310 °C (lit.[37] mp 311 °C); ^{1}H NMR (80% DMSO-d_6–20% TFAA) δ 8.30 (s, 1 H, H_3), 8.30–8.55 (m, 1 H, H_6), 7.20–7.45 (m, 1 H, H_7), 6.62–6.80 (m, 1 H, H_8), 8.30–8.55 (m, 1 H, H_9), 7.50–7.70 (m, 10 H, Ph).

Compound **36** was filtered and washed with diethyl ether: yield 0.52 g (13%); mp 260–262 °C; ^{1}H NMR (80% DMSO-d_6–20% TFAA) δ 8.25 (s, 1 H, H_3), 8.40–8.60 (m, 1 H, H_6), 2.15 and 2.44 (s, 6 H, CH_3), 8.46–8.60 (m, 1 H, H_9), 7.55–8.0 (m, 10 H, Ph). Anal. Calcd for $C_{24}H_{19}N_3$: C, 82.5; H, 5.4; N, 12.2. Found: C, 82.2; H, 5.4; N, 11.9.

To the dimethylformamide solution was added diethyl ether (20 mL); the solution was decanted from the oily product which was then triturated with water. The crude product **33** or **34** was filtered, washed with water, and the recrystallized (see Table III).

Reaction of 2-Chlorobenzimidazoles 37 and 38 with Pyridine. A stirred solution of 2-chlorobenzimidazole **37** or **38** (3.3 mmol) in 3 mL of anhydrous pyridine was heated at 130 °C for the time specified in Table III. The mixture was cooled, and the resultant was filtered, washed with 5 × 10 mL portions of diethyl ether, and recrystallized (Table III).

2-(4-Aminophenyl)benzimidazole (41). A stirred suspension of *o*-phenylenediamine (2.77 g, 25 mmol) and 4-aminobenzoic acid (3.72 g, 27 mmol) in polyphosphoric acid (40 g) under a nitrogen atmosphere was heated at 195 °C for 4 h. The cooled mixture was poured into water and the resulting solution was treated with solid potassium carbonate to reach pH 8. The precipitated product was filtered and recrystallized from 70% ethanol to provide 3.94 g (75% yield) of **41**: mp 238–240 °C (lit.[38] mp 240–241 °C; ^{1}H NMR (DMSO-d_6) δ 7.13 (m, 2 H, $H_{5,6}$), 7.36 (m, 2 H, $H_{4,7}$), 5.6 (b, 2 H, NH_2), 12.4 (b, NH), 7.96 (m, 2 H, $H_{2',6'}$), 6.75 (m, 2 H, $H_{3',5'}$).

2-(4-Aminophenyl)-5,6-dimethylbenzimidazole (42). A suspension of 4,5-dimethyl-*o*-phenylenediamine (7.0 g, 52 mmol) and 4-aminobenzoic acid (7.44 g, 55 mmol) in polyphosphoric acid (40 g) under a nitrogen atmosphere was stirred and heated at 195 °C for 4 h.

Workup as described above provided 11.61 g (95%) of white crystals of compound **42**: mp 199–200 °C; ^{1}H NMR (DMSO-d_6) δ 7.32 (s, 2 H, $H_{4,7}$), 2.32 (s, 6 H, CH_3), 7.0 (b, 2 H, NH_2), 12.0 (b, NH), 7.95 (m, 2 H, $H_{2',6'}$), 6.76 (m, 2 H, $H_{3',5'}$). Anal. Calcd for $C_{15}H_{15}N_3\cdot{}^1/_2H_2O$: C, 73.2; H, 6.5; N, 17.0. Found: C, 73.05; H, 6.45; N, 17.0.

Preparation of 1-[4-(2-Benzimidazolyl)phenyl]-2,4,6-triphenylpyridinium Tetrafluoroborates 43 and 44. A solution of the 2-(4-aminophenyl)benzimidazole (**41** or **42**; 9.28 mmol) and the pyrylium salt **26** (3.34 g, 8.44 mmol) in 50 mL of ethanol and 1 mL of glacial acetic acid was stirred and refluxed for the time specified in Table III. After cooling, the precipitate was filtered, washed with 3 × 5 mL portions of ethanol and diethyl ether, and then recrystallized (see Table III).

Procedures for Pyridinium Azolate Inner Salts (Table IV). Method A. A column packed with anion-exchange Amberlite resin IRA-401 was used, and the chloride-form resin was converted to the hydroxide form. The resin (4 g) was washed with aqueous 10% NaOH (250 mL) until it was free of halide ion ($AgNO_3$–HNO_3 test), with water until the eluant was no longer alkaline (pH 7), and then with 70% ethanol (20 mL).

A solution of *N*-azolylpyridinium salt **27–30**, **33**, **34**, **39**, **40**, **43**, or **44** (1 mmol) in 70% ethanol (50 mL) was passed through the column. The neutral, yellow to orange eluates were concentrated on rotary evaporator at 45 °C to give colored solids, which were recrystallized (Table IV).

The yellow eluate of pyridinium pyrazolate **14** was extracted with 10 × 25 mL portions of dichloromethane and the combined extracts were concentrated on a rotary evaporator at 25 °C. The residual brown oil solidified as a brown powder (Table IV).

Method B. A solution of the *N*-benzimidazolylpyridinium chlorohydrates **39** or **40** in 100 mL of water was neutralized with concentrated NH_4OH to pH 8 and the bright yellow solid was collected, washed with water, and recrystallized (Table IV).

2-(2,4,6-Triphenyl-1-pyridinio)benzimidazolate (16). A mixture of *N*-(1*H*-benzimidazol-2-yl)-2,4,6-triphenylpyridinium tetrafluoroborate (**33**) and an equivalent amount of methanolic KOH was refluxed for 30 min.[7] The mixture was cooled, and the potassium tetrafluoroborate was removed by filtration. The filtrate was evaporated to dryness, and the residue was recrystallized from benzene to give an orange-red solid; mp 256–257 °C (lit.[7] mp 149–150 °C).

To a solution of compound **33** (0.5 g, 0.97 mmol) in pyridine (1 mL) was added 5 mL of water. The crude product was filtered, washed with water (12 × 1 mL), and dried to provide 0.42 g of an orange-red solid; mp 145–147 °C. By means of ^{1}H and ^{13}C NMR, this solid was a mixture of the salt **33** and its betaine **16**. Recrystallization from benzene afforded 0.37 g (90%) of the betaine 16; mp 256–257 °C (see Table IV).

Selected ^{13}C NMR chemical shifts ($CDCl_3$) of the *N*-benzymidazolylpyridinium tetrafluoroborate **33**, the mesomeric betaine **16**, and the orange-red solid of mp 145–147 °C are given below.

Compound **33**: δ 157.9 (C-2, C-6), 159.3 (C-4), 125.3 (C-3, C-5), 140.6 (C-2′), 139.7 (C-3a′, C-7a′, broad), 120.0 (C-4′, C-7′, broad), 123.3 (C-5′, C-6′, broad).

Compound **16**: δ 157.8 (C-2, C-6), 156.0 (C-4), 124.3 (C-3, C-5), 150.8 (C-2′), 144.5 (C-3a′, C7a′), 117.3 (C-4′, C-7′), 119.1 (C-5′, C-6′).

Solid: mp 145–147 °C: δ 157.6 (C-2, C-6), 157.4 (C-4), 124.7 (C-3, C-5), 146.4 (C-2′), 140.8 (C-3a′, C-7a′), 116.7 (C-4′, C-7′), 121.2 (C-5′, C-6′).

Attempted Preparation of Pyridinium Tetrazolate Inner Salt 15. The experimental procedure by Dorofeenko et al.[7] was followed. A suspension of *N*-(1*H*-tetrazol-5-yl)-2,4,6-triphenylpyridinium tetrafluoroborate (**29**) was refluxed briefly in water. After cooling, only white crystals of compound **29** precipitated.

Preparation of Mesomeric Betaine 19. A solution of *N*-[3(5)-amino-1*H*-1,2,4-triazol-5(3)-yl]-2,4,6-triphenylpyridinium tetrafluoroborate (**30**) (2 g, 4.2 mmol) and the pyrylium salt **26** (1.4 g, 3.5 mmol) in 6 mL of DMF was stirred under reflux for 8 h and then cooled and treated with ethyl ether (20 mL) to give an oil that solidified on trituration with water. The yellow precipitate was recrystallized (Table IV).

Dipole Moment Measurements. The electrical dipole moments were measured in dioxane at 25 °C. The Halverstadt and Kumler extrapolation method[39] was used for calculation of total polarization.

Single-Crystal X-ray Structure Determination of Compounds 3 and 17. The determination of the unit cell parameters and the collection of the intensity data were performed on an Enraf-Nonius CAD-4 Diffractometer at 21 °C. Crystallographic data for **3** (**17**): M_r 195 (451.3); space group, $P2_12_12_1$ ($P2_1/n$); a (Å), 5.808 (2) [12.984 (4)]; b (Å), 11.170 (1) [16.537 (3)]; c (Å), 14.442 (2) [13.425 (3)]; α (deg), 90 (90); β (deg), 90 [99.91 (2)]; γ (deg), 90 (90); V (Å^3), 936.9 (5) [839.4 (7)]; Z, 4 (4); D_c (g/cm^3), 1.38 (1.14); size (mm), 0.70 × 0.30 × 0.55 (0.32 × 0.20 × 0.45); $F(000)$, 408 (1032). Data collection: radiation, Mo K_α [Mo K_α (λ = 0.71069 Å)]; number of collected reflections, 1638 (8923); number of unique reflections, 1429 (8.263); number of observed reflections, 766 [2.120 ($I > 2(I)$)]; data collection range (2θ), 2–60° (2–60°); scan technique, $\omega/2\theta$ ($w/2\theta$); range of hkl, (0–8; 0–15; 0–20) [−18–18; 0–23; 0–18]; standard reflection decay (%), 0.9 (0.83). Structure refinement: number of refined parameters, 164 (354); R, 0.057 (0.11); R_w 0.065 (0.12); ω, $1/(\sigma^2(F) + 0.0087484F^2)$ [$1/(\sigma^2(F) + 0.001466F^2)$]; maximum final ΔF peak (e Å^{-3}), 0.21 (0.51); minimum final ΔF peak (e Å^{-3}), 0.30 (0.35).

The structures were solved by direct methods (MULTAM-11/84 program)[40] and the observed reflections were used in least-squares refinements (SHELX-76 program).[41] Scattering factors for non-

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[37] Zvezdina, E. A.; Zhdanova, M. P.; Bren', V. A.; Dorofeenko, G. N. *Khim. Geterotsikl. Soedin.* **1975**, 1180.

[38] Schel'tsyn, V. K.; Kaminskii, A. Ya.; Shapiroskaya, T. P.; Vaisman, I. L.; Andrianov, V. F.; Gitis, S. S. *Khim. Geterotsikl. Soedin.* **1973**, 115.

[39] Mauret, P.; Fayet, J.-P.; Fabre, M. *Bull. Soc. Chim. Fr.* **1975**, 1675 and references cited therein.

[40] Main, P.; Germain, G.; Woolfson, M. M. MULTAN 11/84: A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data, Universities of York, England, and Louvain, Belgium, 1984.

hydrogen atoms were taken from the International Tables for X-Ray Crystallography.[42] Hydrogen atoms scattering factors were those of Stewart, Davison, and Simpson.[43] Computer-generated perspective drawings were obtained by using a PLUTO 78 program.[44]

Bond angles, additional bond lengths, and the final values of positional and thermal parameters are given in the supplementary material.

Acknowledgment. We extend our special thanks to Dr. Jordi Frigola, Department of Medicinal Chemistry, Laboratorios Dr. Esteve, S. A., Barcelona, for the helpful discussions and for recording the ^{13}C NMR spectra. Thermogravimetry experiments were kindly determined by Dr. José Luis Serrano, Facultad de Quimica, Universidad de Zaragoza. We are indebted to the Ministerio de Educación y Ciencia for a postgraduate scholarship to I.D.

Registry No. **3**, 105958-17-6; **4**, 67766-29-4; **5**, 109929-49-9; **6**, 105958-19-8; **7**, 105958-20-1; **8**, 105958-21-2; **9**, 105958-22-3; **10**, 105958-23-4; **11** (ion 1+), 109929-50-2; **12** (ion 1+), 109959-83-3; **13** (ion 1+), 109929-51-3; **14**, 105958-24-5; **15**, 105958-25-6; **16**, 67766-30-7; **17**, 105958-26-7; **18**, 105958-28-9; **19**, 109959-82-2; **20**, 109929-47-7; **21**, 109929-48-8; **22**, 31230-17-8; **23**, 61-82-5; **24**, 4418-61-5; **25**, 1455-77-2; **26**, 448-61-3; **27**, 105958-31-4; **28**, 105958-32-5; **29**, 89419-81-8; **30**, 109929-40-0; **31**, 934-32-7; **32**, 29096-75-1; **33**, 105958-33-6; **34**, 105958-35-8; **35**, 107553-43-5; **36**, 109929-41-1; **37**, 4857-06-1; **38**, 39791-96-3; **39**, 21539-80-0; **40**, 105958-29-0; **41**, 2963-77-1; **42**, 109929-42-2; **43**, 109929-44-4; **44**, 109929-46-6.

Supplementary Material Available: ^{1}H NMR data of *N*-azolylpyridinium salts (Table V); ^{13}C NMR data of *N*-azolylpyridinium salts (Table VI); ^{1}H NMR data of pyridinium azolate inner salts (Table VII); ^{13}C NMR data of pyridinium azolate inner salts (Table VIII); unit cell perspective view showing selected intermolecular contacts for compound **3** (Figure 3); elemental analysis for all the *N*-azolylpyridinium salts and the pyridinium azolate inner salts synthesized (Table X); total charges at $\theta_{\min}$ for **3**, **5**–**10** (Table XI); plot of the total energy vs. torsional angle θ in compound **7** (Figure 4); crystallographic data for the pyridinium benzimidazolate inner salts **3** and **17**, the final values of positional parameters (Table XII and XIII), thermal parameters (Table XIV and XV), and bond distances and angles (Table XVI and XVII) (15 pages). Ordering information is given on any current masthead page. Structure factors tables are available from the authors.

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(41) Sheldrick G. M. SHELX 76: Program for Crystal Structure Determination, University of Cambridge, England, 1976.

(42) *International Tables for X-Ray Crystallography*; Kynoch Press: Birmingham, England, 1974; Vol. IV, pp 99, 149.

(43) Steward, R. F.; Davison, E. R.; Simpson, W. T. *J. Chem. Phys.* **1965**, *42*, 3175.

(44) Mothelwell, W. D. S.; Clegg, W. PLUTO 78: Program for Plotting Molecular and Crystal Structures, University of Cambridge, England, 1978.

Fluorescence Quenching and Photoreactions of 2,3-Diazabicyclo[2.2.2]oct-2-enes. A Case of Charge Transfer and Hydrogen Atom Transfer

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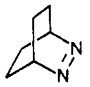
A variety of organic compounds have been found to quench the long-lived fluorescence of 2,3-diazabicyclo[2.2.2]oct-2-ene (DBO), but photochemical reactions take place only with good hydrogen atom donors and tetrahalomethanes. A hydrogen isotope effect on k_q of 1.7–3.0 was observed with 1,3- and 1,4-cyclohexadiene. While both quenchers photoreduced DBO, the 1,3-isomer also dimerized to a mixture characteristic of triplet diene. The results are rationalized in terms of the usual encounter complex and ion pair except that the former can undergo hydrogen transfer or react with 1,3-cyclohexadiene. A second case of photochemically induced electron transfer fragmentation was found in the reaction of 1-phenyl-DBO with bromotrichloromethane.

2,3-Diazabicyclo[2.2.2]oct-2-ene (DBO) was first prepared by Cohen and Zand in 1962.[1] Unlike typical azoalkanes,[2,3] this compound exhibits a low quantum yield for loss of nitrogen in solution; hence, DBO and many of its derivatives have been termed "reluctant azoalkanes". The photoreactions of some substituted DBO's are nevertheless interesting because unusual biradical and electron-transfer reactions take place.[4] Loss of an electron from azoalkanes produces the radical cations, whose chemistry is now beginning to unfold.[4-8]



DBO

The extraordinary long-lived, fluorescent singlet state of DBO can be quenched with such substances as olefins,[9,10] halocarbons,[4,11] and hydrazines.[12] The quenching effiency of olefins has been explained quantitatively on the

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(1) Cohen, S. G.; Zand, R. *J. Am. Chem. Soc.* **1962**, *84*, 586.

(2) Engel, P. S. *Chem. Rev.* **1980**, *80*, 99.

(3) Adam, W.; DeLucchi, O. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 762.

(4) Engel, P. S.; Keys, D. E.; Kitamura, A. *J. Am. Chem. Soc.* **1985**, *107*, 4964.

(5) Shine, H. J.; Bae, D. H.; Mansurul Hoque, A. K. M.; Kajstura, A.; Lee, W. L.; Shaw, R. W.; Soroka, M.; Engel, P. S.; Keys, D. E. *Phosphorus Sulfur* **1985**, *23*, 111.

(6) Bae, D. H.; Engel, P. S.; Mansurul Hogue, A. K. M.; Keys, D. E.; Lee, W. K.; Shaw, R. W.; Shine, H. J. *J. Am. Chem. Soc.* **1985**, *107*, 2561.

(7) Adam, W.; Dörr, M. *J. Am. Chem. Soc.* **1987**, *109*, 1570.

(8) Blackstock, S. C.; Kochi, J. K. *J. Am. Chem. Soc.* **1987**, *109*, 2484.

(9) Solomon, B. S.; Thomas, T. F.; Steel, C. *J. Am. Chem. Soc.* **1968**, *90*, 2249.

(10) Solomon, B. S.; Steel, C.; Weller, A. *J. Chem. Soc. D* **1969**, 927.

(11) Engel, P. S.; Horsey, D. W.; Keys, D. E.; Nalepa, C. J.; Soltero, L. R. *J. Am. Chem. Soc.* **1983**, *105*, 7108.

(12) Clark, W. D. K.; Steel, C. *J. Am. Chem. Soc.* **1971**, *93*, 6347.

0022-3263/87/1952-5015$01.50/0