Study of the Syntheses and Properties of 5,12-Diaza[2$_4$](1,2,4,5)cyclophane and 5,15-Diaza[2$_4$](1,2,4,5)cyclophane[1]

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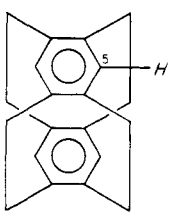
Abstract: The conversion of diethyl 2,6-dimethylpyridine-3,5-dicarboxylate (**5**) to 5,12-diaza[2$_4$](1,2,4,5)cyclophane (**2**) and to 5,15-diaza[2$_4$](1,2,4,5)cyclophane (**3**) has been accomplished in seven steps using the *o*-xylylene dimerization procedure involving 3-carbomethoxy-2-methyl[5,6]cyclobutapyridine (**8**), 7,13-bis(chloromethyl)-6,14-dimethyl-5,15-diaza[2$_2$](1,2)cyclophane (**13**), and 7,14-bis(chloromethyl)-6,13-dimethyl-5,12-diaza[2$_2$](1,2)cyclophane (**14**) as key intermediates. The overall properties of the two cyclophanes **2** and **3**, but especially the between-deck interactions of the two pyridine rings, have been examined by all of the usual spectroscopic methods plus photoelectron spectroscopy, X-ray single-crystal analyses, and basicity measurements. Both cyclophanes, **2** and **3**, have been converted to their corresponding mono-*N*-oxides, **16** and **18**, their di-*N*-oxides, **17** and **19**, their mono-*N*-methyl quaternary ions, **24** and **26**, and their *N*,*N*′-dimethyl diquaternary ions, **27** and **28**. Each cyclophane, **2** and **3**, has in turn also been converted to its corresponding 1,2-diazepine analogue, **47** and **50**. Treatment of 5,12-diaza[2$_4$](1,2,4,5)cyclophane (**2**) with 1,2-dibromoethane and with 1,3-dibromopropane has led respectively to 5,12-diaza[2$_5$](1,2,3,4,5)cyclophanebis(onium) dibromide (**30**) and bis(triflate) (**31**) and to 5,12-diaza[2.2.3.2.2](1,2,3,4,5)cyclophanebis(onium) dibromide (**32**) and bis(triflate) (**33**). The conversion of *anti*-4,12-diaza[2$_2$](1,3)cyclophane (**34**) to 4,12-diaza[2$_3$](1,2,3)-cyclophanebis(onium) dibromide (**38**) and bis(triflate) (**39**) has been successfully accomplished to show that the diquaternization of pyridinophanes is a general method of elaborating bridges with diaza[2$_n$]cyclophanes. Areas of potential interest presented by the diaza[2$_n$]cyclophanes are discussed.

Syntheses of all of the possible symmetrical [2$_n$]cyclophanes have been completed,[2,3] and extensive correlations have been made of the changes in properties of the [2$_n$]cyclophanes with changes in the distance between decks,[4,5] changes in the geometry of the benzene rings,[6,7] and changes in substitution patterns.[8,9] A comparable study of cyclophanes having decks of pyridine rings would provide much additional insight into questions of bonding, ring strain, and π–π electron interactions. We now present such a study.

Although there have been previous reports on the syntheses of mono- and diaza[2$_2$](1,3)cyclophanes,[10–13] mono- and diaza-[2$_2$](1,4)cyclophanes,[14–16] and 8-aza[2$_2$](1,3)(1,4)cyclophane,[17] their chemistry has been little studied and there are no syntheses described for multibridged diaza[2$_n$]cyclophanes. Of the multibridged [2$_n$]cyclophanes, [2$_4$](1,2,4,5)cyclophane (**1**) has been much studied,[18] its chemistry is unusual and interesting,[6,7] and three different routes have been employed for its preparation.[18–20] We chose, therefore, to explore the analogous skeleton and our target molecules became 5,12-diaza[2$_4$](1,2,4,5)cyclophane (**2**) and 5,15-diaza[2$_4$](1,2,4,5)cyclophane (**3**).



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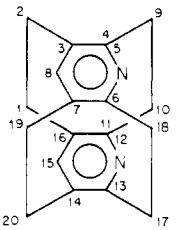

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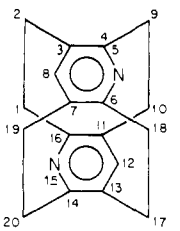

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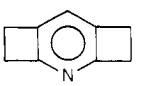
We first attempted to prepare **2** and **3** by the gas-phase dimerization of pyridino[2,3:5,6]dicyclobutene[21,22] (**4**), analogous to a reported preparation of **1**,[20] but no useful product resulted.



2 and 3

4

We then turned to a stepwise procedure.[19] As shown in Scheme I, commercially available diethyl 2,6-dimethylpyridine-3,5-dicarboxylate (**5**) was reduced with lithium aluminum hydride in tetrahydrofuran, followed by heating with methanol,[23] to give the hydroxymethyl ester **6**. Conversion of **6** to **7** followed by gas-phase pyrolysis at 775 °C, and 10^{-2} mm of pressure led to the cyclobutapyridine derivative **8** in 48% yield. Subjection of **8** to a gas-phase dimerization at 450 °C in a nitrogen-flow apparatus[20]

(1) A preliminary description of the syntheses of these cyclophanes was presented in *Angew. Chem.* **1981**, *93*, 587; *Angew. Chem., Int. Ed. Engl.* **1981**, *20*, 571. In that report they were named 4,13-diaza- and 4,16-diaza[2$_4$](1,2,4,5)cyclophane. In view of recently suggested changes in the nomenclature for [2$_n$]cyclophanes,[2] the names have been changed to 5,12-diaza- and 5,15-diaza[2$_4$](1,2,4,5)cyclophanes for this publication.

(2) Boekelheide, V. *Top. Curr. Chem.* **1983**, *113*, 87–143.
(3) Boekelheide, V. *Acc. Chem. Res.* **1980**, *13*, 65–70.
(4) Kovac, B.; Mohraz, M.; Heilbronner, E.; Boekelheide, V.; Hopf, H. *J. Am. Chem. Soc.* **1980**, *102*, 4314–4324.
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(11) Fletcher, J. R.; Sutherland, I. O. *Chem. Commun.* **1969**, 1504.
(12) Boekelheide, V.; Lawson, J. A. *Chem. Commun.* **1970**, 1558–1560.
(13) Bruhin, J.; Kneubühler, W.; Jenny, W. *Chimia* **1973**, *27*, 277–278.
(14) Bruhin, J.; Jenny, W. *Chimia* **1972**, *26*, 420–422.
(15) Bruhin, J.; Jenny, W. *Tetrahedron Lett.* **1973**, 1215–1218.
(16) (a) Bruhin, J.; Jenny, W. *Chimia* **1971**, *25*, 238–239. (b) Bruhin, J. Doctoral Dissertation, Universität Bern, Bern, Switzerland, 1976.
(17) Boekelheide, V.; Gałuszko, K.; Szeto, K. *J. Am. Chem. Soc.* **1973**, *96*, 1578–1581.
(18) Gray, R.; Boekelheide, V. *J. Am. Chem. Soc.* **1979**, *101*, 2128–2136.
(19) Boekelheide, V.; Ewing, G. *Tetrahedron Lett.* **1978**, 4245–4248.
(20) Eaton, B.; Laganis, E. D.; Boekelheide, V. *Proc. Natl. Acad. Sci. U.S.A.* **1981**, *78*, 6564–6566.
(21) Thummel, R. P.; Kohli, D. K. *Tetrahedron Lett.* **1979**, 143–144.
(22) Naiman, V. A.; Vollhardt, K. P. C. *Angew. Chem.* **1979**, *91*, 440–441; *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 411–412.
(23) Ester interchange provided the methyl ester necessary for the subsequent pyrolysis step.

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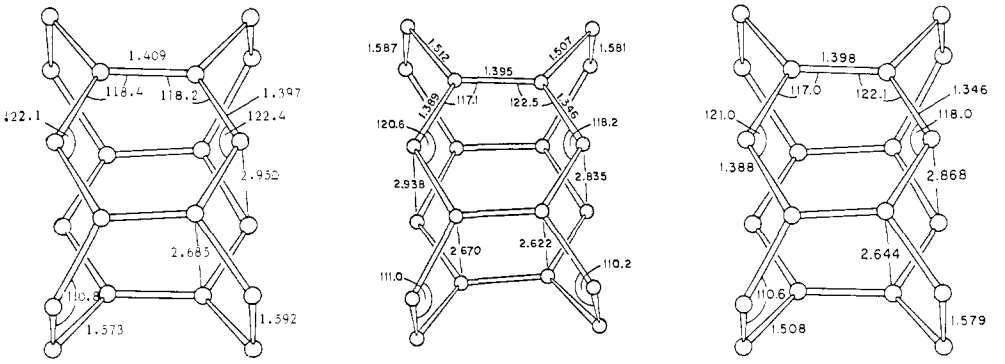
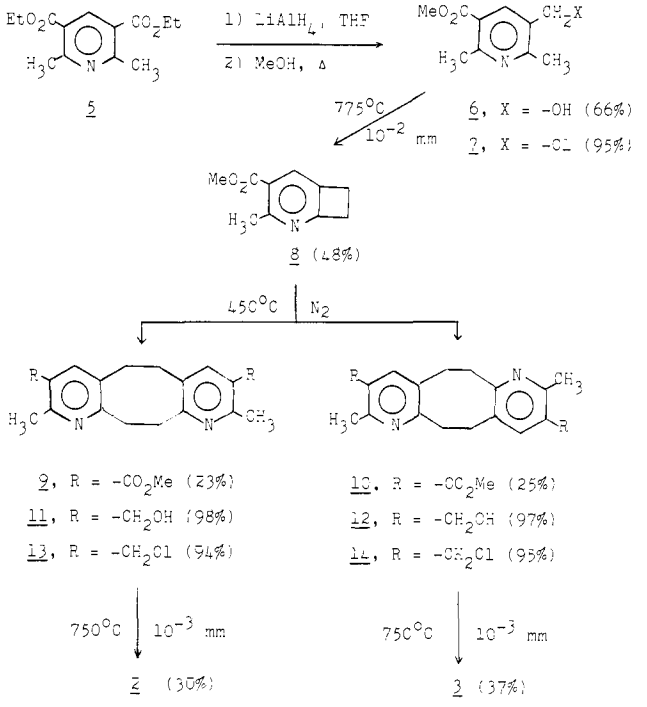


1 2 3

Figure 1. Molecular geometry of compounds **1**, **2**, and 3, showing bond lengths (Å), bond angles (deg), and distances between decks (Å) as determined by single-crystal, X-ray analysis.[24-26]

Scheme I



gave both possible dimers, **9** and **10**, in roughly equal amounts. Separation and purification of the individual dimers was readily possible by chromatography, so that **9** and **10** could then be carried forward separately to their respective cyclophanes, **2** and **3**.

Reduction of the ester dimers with lithium aluminum hydride in tetrahydrofuran led smoothly to the hydroxymethyl dimers **11** and **12**. Treatment of these individually with thionyl chloride gave the corresponding chloromethyl dimers **13** and **14**. Finally, separate gas-phase pyrolyses of **13** and **14** at 775 °C and 10^{-3} mm of pressure gave the desired 5,12-diaza[2₄](1,2,4,5)cyclophane (**2**) and the 5,15-diaza[2₄](1,2,4,5)cyclophane (**3**). Presumably, a bis(*o*-xylylene) type intermediate is involved in each of these gas-phase, pyrolytic cyclizations.[19]

The molecular geometries of **2** and **3** have been determined by single-crystal X-ray analyses,[24,25] and these are presented in Figure 1 and are compared with the crystal structure of [2₄](1,2,4,5)-cyclophane (**1**).[26] The overall geometries are quite similar, with the pyridine rings of **2** and **3** being boat-shaped analogous to the boat-shaped benzene rings of **1**. The mean distance between decks for **2** and **3** is only 2.644 Å, surprisingly shorter than the value of 2.688 Å for **1**. Probably this is due largely to the nonbonded, steric, between-decks interaction of the aromatic C–H bonds in **1**. Thus, the distance between decks of the C–H aromatic carbons in **1** is 2.950 Å, whereas the distance between decks of the C–H aromatic carbon and the pyridine nitrogen of **3** is 2.868 Å and that between the two pyridine nitrogens of **2** is only 2.835 Å.

Table I. pK_a Values for the Conjugate Acids of 5,12-Diaza[2₄](1,2,4,5)cyclophane (**2**), 5,15-Diaza[2₄](1,2,4,5)cyclophane (**3**), Their *N*-Oxides, and Selected Reference Compounds[a]

compound	pK_{a_1}	pK_{a_2}
2	7.71	2.81
3	7.23	5.70
2,3,5,6-tetramethylpyridine	7.91[29]	
16	6.70	−0.3
17	1.93	<<0
18	5.85	−0.1
19	1.10	<<0
pyridine *N*-oxide	0.79[30]	
1,10-phenanthroline *N*-oxide	6.63[31]	

[a] pK_a's were measured in water at 22 °C by spectrophotometric titration.[28]

The spectral properties of **2** and **3** provide evidence for a strong between-decks, π–π electron interaction. The ultraviolet absorption spectra of **2** and **3** both show a long-wavelength band at 307 nm of high intensity (ϵ 6170 and 5240, respectively). This is exactly in the region assigned to the "cyclophane band" of the [2ₙ]cyclophanes.[2] The various diaza[2₂](1,4)cyclophanes also show absorption bands in this region, but at lower intensities.[16]

Photoelectron spectral studies of **2** and **3** confirm the strong π–π electron interaction between decks.[27] The first ionization potentials of **2** and **3** occur at 8.2 and 8.1 eV, respectively, whereas pyridine itself shows its first ionization potential only at 9.7 eV. An interpretation of the between-decks, π–π electron interactions for **2** and **3** has been made as well as orbital assignments for the various low-ionization energies.[27] Of particular interest is the interaction of the nitrogen lone pairs at the 5- and 12-positions of **2**. As shown in Figure 1, these nitrogen atoms are separated by only 2.835 Å, and the interaction of their lone-pair orbitals leads to a surprisingly large split of 0.8 eV. By contrast, and in accord with this assignment, the nitrogen lone-pair orbitals at the 5- and 15-positions of **3** show no interaction and no splitting.[27]

The basicities of **2** and **3** were determined by spectrophotometric microtitration in water at 22 °C,[28] and the data for the pK_a's of their conjugate acids are presented in Table I. Both cyclophanes are strongly basic, being comparable to 2,3,5,6-tetramethylpyridine[29] (pK_a = 7.91). However, differences in the conditions for the experimental measurements of **2** and **3**, as compared to

(24) Hanson, A. W. *Cryst. Struct. Commun.* **1981**, *10*, 751–756.
(25) Hanson, A. W. *Cryst. Struct. Commun.* **1981**, *10*, 313–318.
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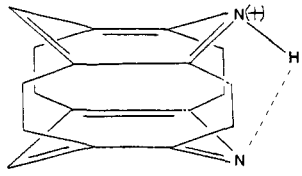
(27) Yang, Z.-z.; Heilbronner, E.; Kang, H. C.; Boekelheide, V. *Helv. Chim. Acta* **1981**, *64*, 2029–2035.
(28) We thank K. Jäkel of *Ciba-Geigy*, Basel, Switzerland, for making these measurements.
(29) Thummel, R. P.; Kohli, D. K. *J. Org. Chem.* **1977**, *42*, 2742–2747.

Table II. ^{1}H NMR Chemical Shift Values for the Aromatic Protons in 5,12-Diaza[2$_4$](1,2,4,5)cyclophane (2), 5,15-Diaza[2$_4$](1,2,4,5)cyclophane (3), and Their *N*-Oxide Derivatives Compared with [2$_4$](1,2,4,5)Cyclophane (1)

compounds	^{1}H NMR aromatic protons chemical shift values, δ
1	5-C-H, 5.96
2	8-C-H, 6.24
3	8-C-H, 6.63
16	H_a, 6.02; H_b, 6.46
18	H_a, 6.46; H_b, 7.42
17	H_a, 6.01
19	H_a, 6.89

reference model compounds, as well as uncertainties regarding solvation effects and steric hindrance, make it impossible to draw any conclusions regarding the presence or absence of a "cyclophane effect" influencing basicity.

Protonation of **2** is thought to involve hydrogen bonding with the second pyridine nitrogen, as shown by **15**, thus explaining the



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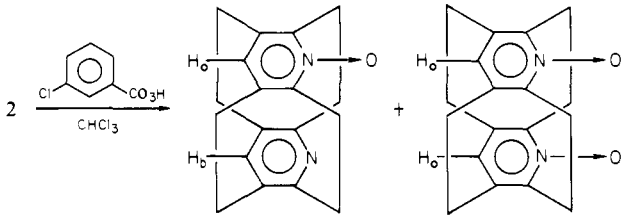
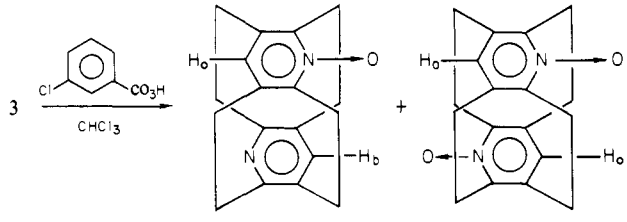
greater basicity of the pK_{a_1} value for **2** relative to that of **3**. This would also explain why **3** has a pK_{a_2} value more basic than that of **2** by 2.89 pK units.

The strong basicities of **2** and **3** are also revealed by the ease with which **2** and **3** undergo the formation of *N*-oxides and quaternary pyridinium salts. Treatment of **2** with 1 equiv of *m*-chloroperbenzoic acid readily gave the corresponding mono-*N*-oxide **16**, whereas treatment of **2** with 2 equiv of *m*-chloroperbenzoic acid led to the di-*N*-oxide **17**. Similarly, **3** was converted to its corresponding mono- and di-*N*-oxides, **18** and **19**, respectively.

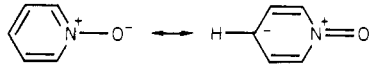


16 17



18 19

Pyridine *N*-oxides are known to be relatively weak bases,[30] and this is attributed largely to the contribution of canonical structures such as **20** to the resonance hybrid. Thus, as shown in Table I,



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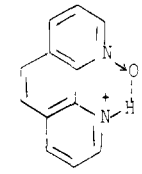
the di-*N*-oxides **17** and **19** are much weaker bases than their corresponding free amines **2** and **3**. It is of interest that the pK_{a_1} value for mono-*N*-oxide **18** is 1.38 pK units less basic than its parent amine **3**. This suggests that the electron-withdrawing effect of the *N*-oxide group is efficiently transmitted through the cyclophane moiety and overall effects a lowering of the basicity of the free pyridine nitrogen.

The metal complexing ability and strong basicity of 1,10-phenanthroline *N*-oxide (pK_{a_1} = 6.63) have attracted attention.[31] Metal complexation is attributed to its chelating potential, and its basicity is attributed to strong hydrogen bonding, as shown in structure **21**. The geometry of mono-*N*-oxide **16** suggests



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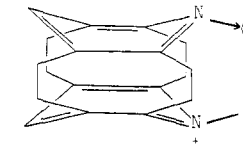


22

similar possibilities for hydrogen bonding and chelation and, in fact, the pK_{a_1} of **16** is 6.70, slightly weaker than that of 1,10-phenanthroline *N*-oxide. Hydrogen bonding in **22** must be comparably as strong as for **21**.

It is typical of [2$_n$]cyclophanes that the signal of the aromatic protons are shifted upfield due to a ring current effect from the opposite deck.[2] For example, the aromatic protons of [2$_4$]-(1,2,4,5)cyclophane (**1**) appear at δ 5.96, whereas those of benzene are at δ 7.37, an upfield shift of 1.41 ppm. As shown in Table II, the aromatic protons (8-C–H's) of **2** and **3** appear at δ 6.24 and 6.63, respectively, corresponding to upfield shifts of 1.36 and 0.97 ppm relative to the 4-C–H proton of pyridine (δ 7.60). The "cyclophane" upfield shifts are almost the same for **1** and **2**, suggesting the presence of comparable ring currents for each. In the case of *3*, a ring current comparison is not valid due to the anisotropy effect of the geminal nitrogen lone pair in the opposite deck on the chemical shift of the 8-C–H proton.

The chemical shift values for the H_a protons of **16** and **18** in each case are shifted downfield by about 0.2 ppm relative to the chemical shift values of the corresponding 8-C–H protons of **2** and **3**. Quite probably, the *N*-oxide group has a composite effect both changing the ring current and also changing the electron density at H_a. The sharp downfield shift for the H_b proton of **18** suggests that the anisotropy effect of the *N*-oxide group is appreciably larger than that of nitrogen and its lone pair.

All four *N*-oxides, **16**, **17**, **18**, and **19**, show the typical strong *N*-oxide stretching band in the infrared region around 1278–1290 cm^{-1}. Also, as is typical for aromatic *N*-oxides,[32] the mass spectra of **16** and **18** show the parent molecular ions followed by strong $M^+ - 16$ peaks, indicating easy loss of the oxygen atom. In addition to the parent molecular ion, **19** shows strong signals at $M^+ - 16$ and $M^+ - 32$, corresponding to the loss of one and two oxygen atoms. In the case of **17**, loss of oxygen occurs so readily that the highest signal observed was that corresponding to loss of two oxygen atoms ($M^+ - 32$).

Treatment of **2** or **3** with methyl iodide leads readily in high yield to the corresponding *N*-methyl quaternary iodides **23** and **25**, which, in turn, were readily converted to the corresponding triflates **24** and **26**. To effect diquaternization, more drastic conditions were required, but heating **2** or **3** at 130 °C with methyl *p*-toluenesulfonate gave the corresponding diquaternary salts **27** and **28** in good yield.

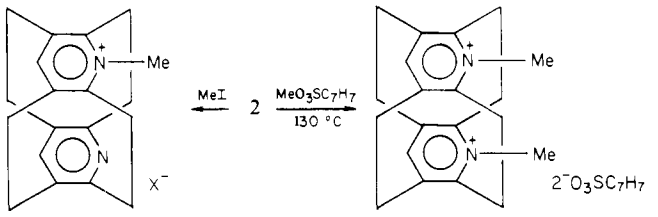
In view of this success, and in the light of the known conversion of 2,2′-bipyridine with 1,2-dibromoethane to the commercial herbicide "Diquat",[33] we investigated the reaction of **2** with 1,2-dibromoethane. This readily gave the monoquaternary salt **29**, which, when heated in acetonitrile at 165 °C in a sealed tube,

(30) Jaffe, H. H.; Doak, G. O. *J. Am. Chem. Soc.* **1955**, *77*, 4441–4444.

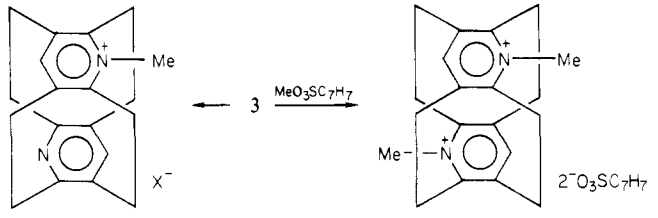
(31) Corey, E. J.; Borror, A. L.; Foglia, T. *J. Org. Chem.* **1965**, *30*, 288–290.

(32) Bild, N.; Hesse, M. *Helv. Chim. Acta* **1967**, *50*, 1885–1892.

(33) (a) Homer, R. F.; Tomlinson, T. E. *Nature (London)* **1958**, *181*, 446–447; (b) *J. Chem. Soc.* **1960**, 2498–2503.

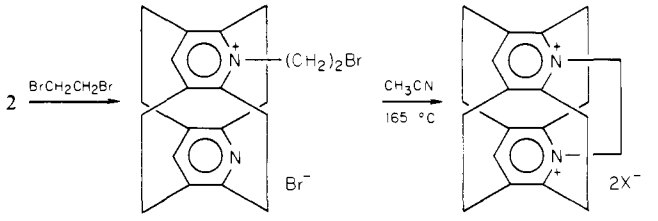


23, $X^- = I^-$
24, $X^- = {}^-O_3SCF_3$



25, $X^- = I^-$
26, $X^- = {}^-O_3SCF_3$

was converted in high yield to the desired 5,12-diaza[2₅]-(1,2,3,4,5)cyclophanebis(onium) dibromide (**30**). Treatment of

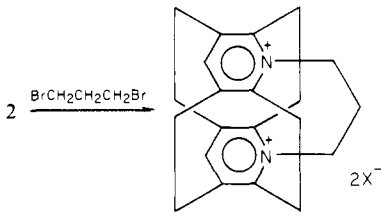


29

30, $X^- = Br^-$
31, $X^- = {}^-O_3SCF_3$

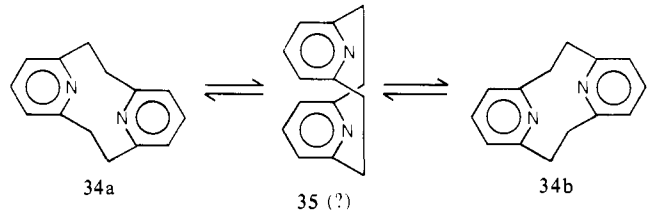
30 with a solution of silver triflate in methanol provided the corresponding triflate **31** as well.

In a similar fashion treatment of **2** with 1,3-dibromopropane gave 5,12-diaza[2.2.3.2.2](1,2,3,4,5)cyclophanebis(onium) dibromide (**32**) and its corresponding triflate **33**.



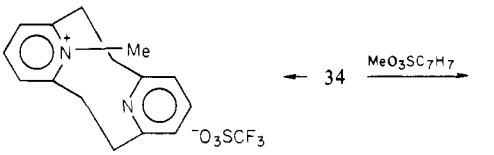
32, $X^- = Br^-$
33, $X^- = {}^-O_3SCF_3$

Gault, Price, and Sutherland have examined the conformational flipping of *anti*-4,12-diaza[2₂](1,3)cyclophane (**34**) by variable-temperature ^1H NMR studies and have assigned a $\Delta G^{\ddagger}$ value for the conformational flipping process (**34a** ⇌ **34b**) of 14.8 kcal/mol.[34] It was not established whether the syn conformer **35** was



34a 35 (?) 34b

present in the equilibrium. Since quaternization would introduce a high enough energy barrier to freeze the conformational flipping process, it was of interest to see what quaternary salts would be formed. Treatment of **34** with methyl iodide or methyl *p*-toluenesulfonate readily gave the quaternary salts **36** and **37**, whose



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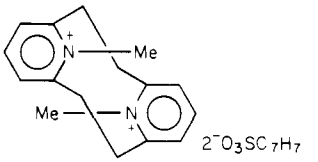
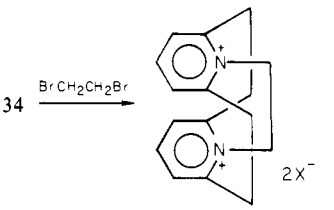


37

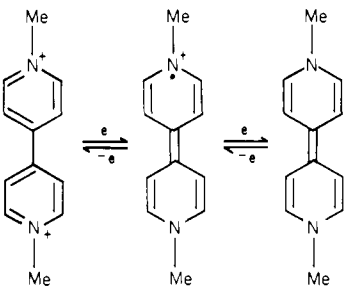
structural assignment as anti isomers is clearly indicated from their spectra.[35]

However, as a test for the generality of the diquaternary procedure for synthesizing diaza[2ₙ]cyclophanebis(onium) salts, **34** was also heated with 1,2-dibromoethane. This readily gave in good yield the corresponding 4,12-diaza[2₃](1,2,3)cyclophanebis(onium) dibromide (**38**), from which the corresponding triflate **39** was also prepared.



38, $X^- = Br^-$ (74%)
39, $X^- = {}^-O_3SCF_3$

The redox behavior of diquaternary pyridinium ions of the Weitz type has been extensively studied, particularly by Hünig,[36] and the presence of intermediate radical cations has been demonstrated. This is shown for the simple viologen example below (**40** ⇌ **41** ⇌ **42**).



40 41 42

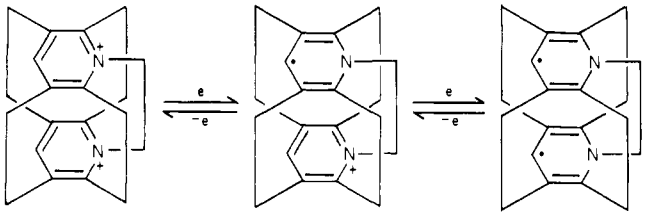
An important reason for the preparation of the various cyclophane quaternary ions was the opportunity for exploring the redox behavior of these ions. As shown below, it was anticipated that reduction of **31** would, in an analogous fashion, lead to the corresponding radical cation **43** and this, in turn, would give the diradical **44**. It was expected that its cage structure would prevent **44** from undergoing normal covalent bond formation and so it might be possible to examine the properties of a stable diradical. The recent work of Kosower on single diradicals suggests that such experiments would be particularly interesting.[38] An electro-

(34) Gault, I.; Price, B. J.; Sutherland, I. O. *Chem. Commun.* **1967**, 540–541.

(35) We thank Professor Paul Scudder for a generous gift of 4,12-diaza-[2₂](1,3)cyclophane (**34**), formerly named [2.2](2.6)pyridinophane.

(36) Hünig, S.; Berneth, H. *Top. Curr. Chem.* **1980**, *92*, 3–41.

(37) Boekelheide, V.; Pepperdine, W. *J. Am. Chem. Soc.* **1970**, *92*, 3684–3688.



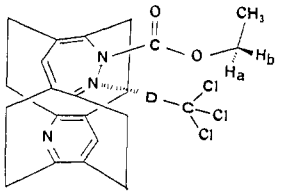
31 43 44

chemical study of the redox behavior of the mono- and diquaternary salts of the diazacyclophanes prepared in this work is still in progress and will be reported elsewhere.

A problem of continuing interest is the synthesis of cyclophanes with $4n$ π-electron decks. A variety of methods for converting pyridine rings to seven-membered, heterocyclic rings having $4n$ π-electrons have been developed.[39-41] The possible conversion of **2** and **3** to their corresponding 1,2-diazepine analogues appeared particularly attractive. As shown in Scheme II, treatment of **3** with *O*-(mesitylsulfonyl)hydroxylamine[42] in dichloromethane readily gave the *N*-amino derivative **45** in 77% yield. On reaction with ethyl chloroformate in the presence of potassium carbonate, **45** was converted to the ylide **46** in 82% yield. Irradiation of a solution of **46** in benzene using a 450-W Hanovia medium-pressure lamp with a Pyrex filter then led to the desired 1,2-diazepine derivative **47** in 95% yield. Similarly, **2** was converted in good yield to the corresponding 1,2-diazepine derivative **50**.

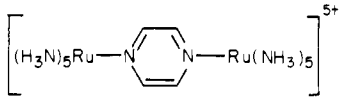
Although 1,2-diazepines are the normal products from the irradiation of nitrogen ylides, there are known examples in which 1,3-diazepines are formed.[43,44] A clear decision between 1,2- or 1,3-diazepine structures could not be made from the spectral properties of **47** and **50**, and so an X-ray crystallographic analysis of **47** was made.[45] The geometry of **47** is presented in Figure 2 and shows that, indeed, the assigned 1,2-diazepine structure **47** is correct. As is evident, the pyridine ring has the usual boat shape with the nitrogen and γ-carbon lying out of the plane by 0.096 and 0.082 Å, respectively. The seven-membered diazepine ring is a perturbed boat with localized double bonds.

The ^{1}H NMR spectra of **47** and **50** show the vinyl proton of the seven-membered ring at δ 4.50, an upfield shift of 1.50 ppm from the normal value for ordinary (1*H*)-1,2-diazepines.[46] Presumably, this upfield shift is largely due to a ring current effect from the opposite pyridine ring. On the other hand, the chemical shift values for the aromatic pyridine protons in **47** and **50** are normal, giving no indication of a ring current effect from the seven-membered ring. In deuteriochloroform the proton spectra of both **47** and **50** show the methylene protons of the ethyl ester as a complex double quartet. The spectra were temperature independent, but when spectra were taken in toluene-d_8 or acetonitrile-d_3, the methylene protons appear as a simple, clean quartet. In view of the known tendency for chloroform to undergo hydrogen bonding with amines,[47] these results suggest that **47** and **50** are forming rather tight complexes of the type shown by **51**.

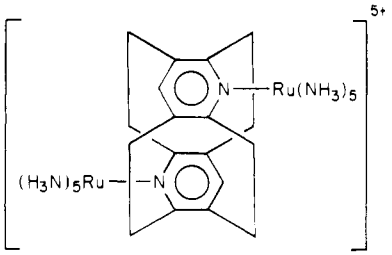


51

The delocalization of π-electrons in [2_n]cyclophanes suggests that cyclophane **3** can be regarded as an analogue of pyrazine and so might show similar properties. The Creutz–Taube ruthenium, mixed-valence, complexes of pyrazine, such as **52**, are a classic



52



53

example of pyrazine chemistry.[48,49] A study of the properties of a cyclophane analogue, such as **53**, might provide much insight regarding the electron transmission ability of [2_n]cyclophanes. However, despite much effort it has not been possible to prepare **53**. Apparently, the cyclophane bridges offer too much steric hindrance to allow ruthenium complexation with the pyridine nitrogens of **3**. No reaction occurs whatsoever. It appears that a less hindered pyridinophane is needed to utilize the Creutz–Taube complexes for studying electron delocalization of [2_n]-cyclophanes.

The continuing interest in cyclophanes lies in the special knowledge they can provide regarding questions of bonding, π-electron interactions, strain energies, and bond deformation. The present study shows that multibridged [2_n]cyclophanes can be made with pyridine decks, and their geometry and spectral properties have been measured and interpreted. Some of the possibilities and limitations of conducting pyridine chemistry with molecules having cyclophane skeletons have been explored.

Experimental Section[50]

3-Carbomethoxy-5-(hydroxymethyl)-2,6-dimethylpyridine (6). To a solution of 25.0 g of diethyl 2,6-dimethylpyridine-3,5-dicarboxylate (**5**)[51] in 200 mL of dry tetrahydrofuran there was added slowly a slurry of 2.83 g of lithium aluminum hydride in 100 mL of tetrahydrofuran over a 1-h period while the mixture was being stirred and cooled in an ice bath. After the addition was complete, vigorous stirring was continued for 15 min, and a saturated aqueous solution of sodium sulfate was added. Most of the solvent was removed under reduced pressure, 250 mL of methanol was added, and the resulting mixture was boiled under reflux for 12 h. After concentration to remove methanol, 150 mL of tetrahydrofuran was added, and the slurry was boiled a few minutes and then filtered. The

(38) Hermolin, J.; Levin, M.; Kosower, E. M. *J. Am. Chem. Soc.* **1981**, *103*, 4808–4813.
(39) Ishikawa, M.; Kaneko, C.; Yokoe, I.; Yamada, S. *Tetrahedron* **1969**, *25*, 295–300.
(40) Spence, G. G.; Taylor, E. C.; Burchardt, O. *Chem. Rev.* **1970**, *70*, 231–265.
(41) Streith, J. *Pure Appl. Chem.* **1977**, *49*, 305–315.
(42) Tamura, Y.; Minamikawa, J.; Ikeda, M. *Synthesis* **1977**, 1–17.
(43) Tsuchiya, T.; Enkaku, M.; Kurita, J.; Sawanishi, H. *J. Chem. Soc., Chem. Commun.* **1979**, 534–535.
(44) Tsuchiya, T.; Enkaku, M.; Okajima, S. *J. Chem. Soc., Chem. Commun.* **1980**, 454–455.
(45) Hanson, A. W., private communication. We thank Dr. Hanson for his kindness in making this analysis.
(46) Sasaki, T.; Kanematsu, K.; Kakehi, A.; Ichikawa, I.; Hayakawa, K. *J. Org. Chem.* **1970**, *35*, 426–433.
(47) Reingold, I. D.; Schmidt, W.; Boekelheide, V. *J. Am. Chem. Soc.* **1979**, *101*, 2121–2128.
(48) Creutz, C.; Taube, H. *J. Am. Chem. Soc.* **1969**, *91*, 3988–3989; **1973**, *95*, 1086–1094.
(49) Citrin, P. H.; Ginsberg, A. P. *J. Am. Chem. Soc.* **1981**, *103*, 3673–3679.
(50) Elemental and mass spectral analyses were determined by Dr. Richard Wielesek of the University of Oregon Microanalytical Laboratories. All of the standard mass spectra were taken on a CEC-21B-110 instrument set at 70 eV. We thank Dr. Veit of the Institut für Organische Chemie, Technische Hochschule, Darmstadt, for measuring the field-desorption mass spectra. Infrared spectra were measured on a Beckman IR-10 or a Sargent Welch 3-200 infrared spectrometer. ^{1}H NMR spectra were measured with a Varian XL-100 spectrometer using deuteriochloroform as solvent with residual chloroform (δ 7.27) as an internal standard unless otherwise specified. ^{13}C NMR were obtained with a Nicolet NT-360 spectrometer. Melting points were taken by using sealed, evacuated capillaries on a Mel-Temp apparatus and are uncorrected.
(51) Supplied by Aldrich Chemical Co.

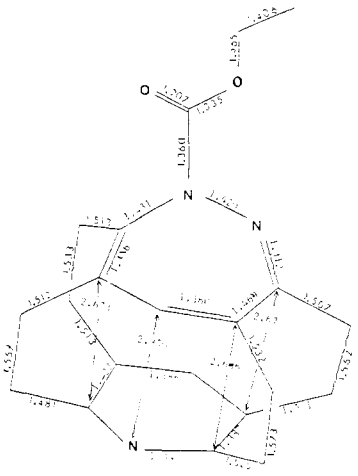
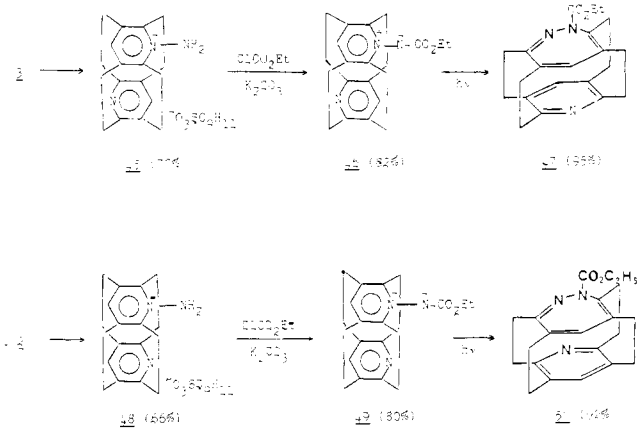


Figure 2. Molecular geometry of compound **50**, showing bond lengths (Å) and distances between decks (Å) as determined by single-crystal X-ray analysis.[45]

Scheme II



precipitate was again taken up in tetrahydrofuran, boiled, and filtered. This process was repeated 3 times. The combined tetrahydrofuran filtrate and the residual solid was chromatographed over *Florisil* with a 1% methanol in chloroform solution for elution. The yellow solid from the main fraction of eluate was recrystallized from a mixture of benzene and cyclohexane to give 12.9 g (66%) of white needles: mp 145–146 °C; IR (KBr) ν_{max} 3140 (OH), 1725 cm^{-1} (C=O); UV (C_2H_5OH) λ_{max} 228 nm (ϵ 9620), 274 (5300); ^1H NMR δ 8.20 (1 H, s, Ar H), 4.76 (2 H, br s, CH_2OH), 3.93 (3 H, s, OCH_3), 2.83 (3 H, s, CH_3), 2.58 (3 H, s, CH_3), 1.90 (1 H, br s, OH); mass spectrum, *m/e* 196, 195, 179, 177, 176, 165, 163.

Anal. ($C_{10}H_{13}NO_3$) C, H, N.

By the same procedure and in comparable yield, **6** can also be made directly starting with dimethyl 2,6-dimethylpyridine-3,5-dicarboxylate. The reduction of only one ester group, on treatment of pyridine-3,5-dicarboxylates with lithium aluminum hydride, has been observed previously.[37]

3-Carbomethoxy-5-(chloromethyl)-2,6-dimethylpyridine (7). Addition of 16.1 g of thionyl chloride to 8.8 g of 3-carbomethoxy-5-(hydroxymethyl)-2,6-dimethylpyridine (**6**) was carried out slowly with stirring and cooling. The mixture was then allowed to warm to room temperature and was stirred another 2 h. It was then taken up in 50 mL of chloroform and slowly poured onto 50 g of ice. The resulting mixture was stirred vigorously and made basic with a 15% aqueous solution of sodium carbonate, and the organic layer was separated. The aqueous layer was extracted with chloroform, and the combined chloroform extracts were washed with water, dried, and concentrated. Sublimation (40 °C, 10^{-2} mm) of the residual solid afforded 9.2 g (95%) of white needles: mp 44.5–45.0 °C; IR (KBr) ν_{max} 1722 cm^{-1} (C=O); UV (EtOH) λ_{max} 228 nm (ϵ 12200), 274 (6260); ^1H NMR δ 8.10 (1 H, s, Ar H), 4.58 (2 H, s, CH_2Cl), 3.89 (3 H, s, OCH_3), 2.79 (3 H, s, CH_3), 2.62 (3 H, s, CH_3); mass spectrum *m/e* 215, 213, 184, 182, 181, 179, 178, 146.

Anal. ($C_{10}H_{12}NO_2Cl$) C, H, N.

3-Carbomethoxy-2-methyl[5,6]cyclobutapyridine (8). A sample of 10.0 g of 3-carbomethoxy-5-(chloromethyl)-2,6-dimethylpyridine (**7**) was sublimed at 10^{-2} mm into the hot zone (775 °C) of an empty quartz pyrolysis tube (30 × 5 mm) while the exit gases were being collected on a cold finger held at −30 °C. When the pyrolysis was complete, the material on the cold finger was removed by washing with 200 mL of water. Chloroform (150 mL) was added to the above aqueous solution. This two-phase mixture was made basic by the addition of 20% aqueous sodium hydroxide solution while stirring and cooling with an ice bath. The organic layer was separated, and the aqueous layer was extracted with three 100-mL portions of chloroform. The combined extracts were washed with 160 mL of water, dried, and concentrated. Fractional distillation (25 °C, 10^{-2} mm) of the yellow oil afforded 4.0 g (48%) of a colorless oil: IR (neat) ν_{max} 1725 (C(=O)OEt), 1240 cm^{-1}; UV (C_2H_5OH) λ_{max} 217 nm (sh, ϵ 4700), 222 (sh, 5070), 228 (5270), 283 (6410); ^1H NMR δ 7.70 (1 H, s, Ar H), 3.83 (3 H, s, CO_2CH_3), 3.41–3.27 (2 H, m, CH_2), 3.11–2.97 (2 H, m, CH_2), 2.73 (3 H, s, CH_3); mass spectrum, *m/e* 177 (M^+), 146, 145.

Anal. ($C_{10}H_{11}NO_2$) C, H, N.

7,14-Bis(carbomethoxy)-6,13-dimethyl-5,12-diaza[2₂](1,2)cyclophane (9) and 7,13-Bis(carbomethoxy)-6,14-dimethyl-5,15-diaza[2₂](1,2)-cyclophane (10). A vertical 30 × 3 cm quartz tube held at 450 °C with a 1-cm zone of Pyrex helices at the top was employed. A 5.5-g sample of 3-carbomethoxy-2-methyl[5,6]cyclobutapyridine (**8**) was added dropwise via syringe pump at the rate of 1 mL/h into a nitrogen stream (2 mL/s) at atmospheric pressure, carrying it into the hot zone, and the exit gases were passed through an ice-cooled trap. The material on the cold trap and the lower portions of the tube were removed by washing with chloroform, and the combined chloroform washings were concentrated to give a brown solid. This was purified by column chromatography over silica gel using a 1:1 mixture of cyclohexane and ethyl acetate as eluant.

The first fraction of eluate gave 7,13-bis(carbomethoxy)-6,14-dimethyl-5,15-diaza[2₂](1,2)cyclophane (**10**) as a white solid. This was recrystallized from ethyl acetate to give 1.38 g (25%) of white cubes: mp 220–221 °C; IR (KBr) ν_{max} 1724 (C=O) cm^{-1}; UV (C_2H_5OH) λ_{max} 227 nm (ϵ 17800), 278 (12400); ^1H NMR δ 7.79 (2 H, s, Ar H), 3.84 (6 H, s, OCH_3), 3.46–3.06 (8 H, m, CH_2), 2.68 (6 H, s, CH_3); mass spectrum, *m/e* 356, 355, 354 (M^+), 353, 340, 339, 328, 327, 326, 323.

Anal. ($C_{20}H_{22}N_2O_4$) C, H, N.

The second fraction of eluate gave 7,14-bis(carbomethoxy)-6,13-dimethyl-5,12-diaza[2₂](1,2)cyclophane (**9**) as a white solid. This was recrystallized from ethyl acetate to yield 1.27 g (23%) of white plates: mp 191–192 °C; IR (KBr) ν_{max} 1710 (C(=O)OEt) cm^{-1}; UV (C_2H_5OH) λ_{max} 227 nm (ϵ 19300), 277 (11100); ^1H NMR δ 7.79 (2 H, s, Ar H), 3.85 (6 H, s, OCH_3), 3.39 (4 H, s, CH_2), 3.13 (4 H, s, CH_2), 2.69 (6 H, s, CH_3); mass spectrum, *m/e* 355, 354 (M^+), 353, 340, 339, 323, 322, 190.

Anal. ($C_{20}H_{22}N_2O_4$) C, H, N.

7,13-Bis(hydroxymethyl)-6,14-dimethyl-5,15-diaza[2₂](1,2)cyclophane (12). To a solution of 500 mg of 7,13-bis(carbomethoxy)-6,14-dimethyl-5,15-diaza[2₂](1,2)cyclophane (**10**) in 100 mL of dry tetrahydrofuran was slowly added 125 mg of lithium aluminum hydride with stirring, and the mixture was stirred under nitrogen at room temperature for 5 h. Then, while the mixture was cooled in an ice bath, a saturated aqueous solution of sodium sulfate was added with stirring. The resulting slurry was filtered, and the precipitate was extracted with three 25 mL portions of ethanol. The combined tetrahydrofuran and ethanol filtrates were concentrated. Recrystallization of the residual solid from a mixture of methanol and dichloromethane gave 408 mg (97%) of a white powdery solid: mp 290–291 °C; IR (KBr) ν_{max} 3280 (OH), 1438 cm^{-1}; UV (C_2H_5OH) λ_{max} 214 nm (ϵ 13200), 271 (9110), 276 (9160), 280 (sh, 8090); ^1H NMR (Me_2SO-d_6) δ 7.28 (2 H, s, Ar H), 4.35 (4 H, s, CH_2OH), 3.28–3.00 (8 H, m, CH_2), 2.22 (6 H, s, CH_3); mass spectrum, *m/e* 298 (M^+), 297, 284, 283, 281, 280.

Anal. ($C_{18}H_{22}N_2O_2$) C, H, N.

7,14-Bis(hydroxymethyl)-6,13-dimethyl-5,12-diaza[2₂](1,2)cyclophane (11). A mixture of 100 mg of lithium aluminum hydride in 25 mL of dry tetrahydrofuran and 400 mg of 4,14-bis(carbomethoxy)-6,13-dimethyl-5,12-diaza[2₂](1,2)cyclophane (**9**) in 25 mL of dry tetrahydrofurn was allowed to react, and then the reaction mixture was worked up in the same manner as described for the preparation of 7,13-bis(hydroxymethyl)-6,14-dimethyl-5,15-diaza[2₂](1,2)cyclophane (**12**). Recrystallization of the residual solid gave 300 mg (98%) of a white powdery solid: mp 284–285 °C; IR (KBr) ν_{max} 3130 (OH), 1440 cm^{-1}; UV (C_2H_5OH) λ_{max} 216 nm (ϵ 14600), 271 (sh, 9430), 276 (9510), 280 (8480); ^1H NMR (Me_2SO-d_6) δ 7.28 (2 H, s, Ar H), 4.36 (4 H, s, CH_2OH), 3.21 (4 H, s, CH_2), 3.09 (4 H, s, CH_2), 2.24 (6 H, s, CH_3); mass spectrum, *m/e* 298 (M^+), 297, 284, 283, 281.

Anal. ($C_{18}H_{22}N_2O_2$) C, H, N.

7,13-Bis(chloromethyl)-6,14-dimethyl-5,15-diaza[2₂](1,2)cyclophane (14). Thionyl chloride (3.3 g, 2.0 mL) was added slowly to 590 mg of solid 7,13-bis(hydroxymethyl)-6,14-dimethyl-5,15-diaza[2₂](1,2)-cyclophane (**12**) while the mixture was cooled in an ice bath. The re-

sulting mixture was stirred at room temperature for 5 h. After addition of 10 mL of chloroform, the mixture was slowly poured into 5 g of ice. The resulting two-phase mixture was stirred vigorously for about 5 min. Then it was made basic by the addition of a 20% aqueous sodium carbonate solution. The organic layer was separated, and the aqueous layer was extracted with three 15-mL portions of chloroform. The combined extracts were washed with 30 mL of water, dried, and concentrated. Sublimation (120 °C, 10^{-2} mm) of the residual solid gave 630 mg (95%) of a white powdery solid: mp 252 °C dec; IR (KBr) ν_{max} 1444 cm^{-1}; UV (C_2H_5OH) λ_{max} 217 nm (ϵ 15000), 220 (15100), 274 (11200); ^1H NMR δ 7.29 (2 H, s, Ar H), 4.49 (4 H, s, CH_2Cl), 3.44–3.05 (8 H, m, CH_2), 2.52 (6 H, s, CH_3); mass spectrum, *m/e* 336, 335, 334 (M^+), 321, 320, 319, 301, 300, 299, 298, 285, 283, 263, 262.

Anal. ($C_{18}H_{22}N_2Cl_2$) C, H, N.

7,14-Bis(chloromethyl)-6,13-dimethyl-5,12-diaza[2$_2$](1,2)cyclophane (13). A mixture of 6.9 g of thionyl chloride and 980 mg of 7,14-bis(hydroxymethyl)-6,13-dimethyl-5,12-diaza[2$_2$](1,2)cyclophane (**11**) was allowed to react, and then the mixture was worked up in the same manner as described for the preparation of 7,13-bis(chloromethyl)-6,14-dimethyl-5,15-diaza[2$_2$](1,2)cyclophane (**14**). Sublimation (120 °C, 10^{-2} mm) of the residual solid gave 1.04 g (94%) of a white powdery solid: mp 238 °C dec; IR (KBr) ν_{max} 1442 cm^{-1}; UV (C_2H_5OH) λ_{max} 217 nm (ϵ 15600), 221 (15400), 276 (8880); ^1H NMR δ 7.29 (2 H, s, Ar H), 4.52 (4 H, s, CH_2Cl), 3.36 (4 H, s, CH_2), 3.09 (4 H, s, CH_2), 2.54 (6 H, s, CH_3); mass spectrum, *m/e* 336, 335, 334 (M^+), 321, 320, 319, 300, 299, 298, 297, 179.

Anal. ($C_{18}H_{22}N_2Cl_2$) C, H, N.

5,15-Diaza[2$_4$](1,2,4,5)cyclophane (3). Slow sublimation at 10^{-3} mm of 500 mg of 7,13-bis(chloromethyl)-6,14-dimethyl-5,15-diaza[2$_2$](1,2)-cyclophane (**14**) into the hot zone (775 °C) of an empty quartz tube (30 × 5 cm) followed by condensation of the exit gases on a cold finger at −40 °C gave a light brown solid. This pyrolysate was removed by washing with 50 mL of water. Chloroform (30 mL) was added to the above aqueous solution. This two-phase mixture, while it was cooled in an ice bath, was made basic by the addition of a 20% aqueous sodium hydroxide solution with stirring. The organic layer was separated and the aqueous layer was extracted with three 30-mL portions of chloroform. The combined chloroform layers were washed with 100 mL of water, dried, and concentrated. The residual solid was purified by column chromatography over silica gel using a 3% methanol in chloroform solution as eluant. The white solid from the main fraction of eluate was recrystallized from dichloromethane to yield 145 mg (37%) of white prisms: mp >350 °C dec; IR (KBr) ν_{max} 2940 cm^{-1}, 1548, 1467, 1415, 1218, 930; UV (C_2H_5OH) λ_{max} 298 nm (sh, ϵ 4370), 307 (5240); ^1H NMR δ 6.63 (2 H, s, Ar H), 3.66–2.80 (16 H, m, CH_2); ^{13}C NMR ($CDCl_3$, proton decoupled) δ 163.3, 147.7 ($J_{^{13}CH}$ = 158 Hz), 136.6, 35.2, 31.5; mass spectrum, *m/e* 263, 262 (M^+), 261, 247, 234, 135. Anal. Calcd for $C_{18}H_{18}N_2$: C, 82.41; H, 6.92; N, 10.68. Found: C, 82.30; H, 7.11; N, 10.53.

5,12-Diaza[2$_4$](1,2,4,5)cyclophane (2). Pyrolysis was carried out with 600 mg of 7,14-bis(chloromethyl)-6,13-dimethyl-5,12-diaza[2$_2$](1,2)-cyclophane (**13**), in the same manner as described for the preparation of 5,15-diaza[2$_4$](1,2,4,5)cyclophane (**3**). The crude product was purified by column chromatography over silica gel using a 5% methanol in chloroform solution. The resulting solid isolated from the main fraction of eluate was recrystallized from dichloromethane to afford 141 mg (30%) of white prisms: mp >310 °C dec; IR (KBr) ν_{max} 2945 cm^{-1}, 1548, 1468, 1445, 1216; UV (C_2H_5OH) λ_{max} 300 nm (ϵ 6170), 307 (6140); ^1H NMR δ 6.24 (2 H, s, Ar H), 3.58–3.12 (12 H, m, CH_2), 2.87–2.68 (4 H, m, CH_2); ^{13}C NMR ($CDCl_3$, proton decoupled) δ 163.8, 147.0 ($J_{^{13}CH}$ = 172 Hz), 136.5, 34.9, 32.6; mass spectrum, *m/e* 263, 262 (M^+), 261, 247, 234, 208. Anal. Calcd for $C_{18}H_{18}N_2$: C, 82.41; H, 6.92; N, 10.68. Found: C, 82.53; H, 7.00; N, 10.64.

[6,7:13,14]Dicyclobuta-5,12-diaza[2$_2$](1,2)cyclophane. During the purification of the crude pyrolysis product by column chromatography in the previous experiment, 38 mg (8%) of a white solid was obtained from the first fraction of eluate. Recrystallization from ethyl acetate gave white needles: mp 215–216 °C; IR (KBr) ν_{max} 2920 cm^{-1}, 1589, 1395, 922; UV (C_2H_5OH) λ_{max} 280 nm (ϵ 14900), 286 (sh, 14500); ^1H NMR δ 6.81 (2 H, s, Ar H), 3.34 (4 H, s, CH_2), 3.03 (4 H, s, CH_2), 3.40–3.20 (4 H, m, CH_2), 3.10–2.90 (4 H, m, CH_2); ^{13}C NMR ($CDCl_3$, proton decoupled) δ 161.0, 159.5, 137.5, 133.9, 131.3, 36.9, 34.4, 34.2, 26.3; mass spectrum, *m/e* 263, 262 (M^+), 261, 249, 248, 247, 141.

Anal. Molecular weight calcd for $C_{18}H_{18}N_2$: 262.147. Found: 262.146 (high-resolution mass spectrum).

5,15-Diaza[2$_4$](1,2,4,5)cyclophane *N,N'*-Dioxide (19). To a solution of 20 mg of 5,15-diaza[2$_4$](1,2,4,5)cyclophane (**3**) in 5 mL of chloroform was added a solution of 35 mg of *m*-chloroperbenzoic acid (Aldrich, 85%) in 3 mL of chloroform under nitrogen with stirring, and the reaction flask was protected from light with aluminum foil. After the solution had been stirred for 48 h at room temperature, it was poured into 10 mL of a 10% aqueous sodium hydroxide solution. The chloroform layer was separated, and the aqueous layer was extracted with three 15-mL portions of chloroform. The combined chloroform extracts were washed with water, dried, and concentrated. Recrystallization of the residual solid from chloroform afforded 22 mg (98%) of white prisms: mp >350 °C dec; IR (KBr) ν_{max} 2965 cm^{-1}, 1371, 1278 (N→O), 1245, 1198, 1169, 1020; UV (C_2H_5OH) λ_{max} 230 nm, 262, 280 (sh); ^1H NMR δ 6.89 (2 H, s, Ar H), 3.96–2.60 (16 H, m, CH_2); ($CDCl_3$ + CF_3COOH) δ 7.88 (2 H, s, Ar H), 4.12–3.10 (18 H, m, CH_2 and OH); mass spectrum, *m/e* 294 (M^+), 275, 278 (M^+ − 16), 277, 263, 262 (M^+ − 32), 261, 247.

Anal. Molecular weight calcd for $C_{18}H_{18}N_2O_2$: 294.137. Found: 294.137 (high-resolution mass spectrum).

5,15-Diaza[2$_4$](1,2,4,5)cyclophane *N*-Oxide (18). A mixture of 25 mg of 5,15-diaza[2$_4$](1,2,4,5)cyclophane (**3**) and 20 mg of *m*-chloroperbenzoic acid was allowed to react for 12 h, and then the reaction mixture was worked up in the same manner as described for the preparation of 5,15-diaza[2$_4$](1,2,4,5)cyclophane *N,N'*-dioxide (**19**). Purification of the residue by preparative, thin-layer chromatography over silica gel using 10% methanol in chloroform for elution gave two compounds. The first fraction of eluate afforded 7 mg (24%) of the *N,N'*-dioxide **19**, identical in all respects with the sample prepared previously. The second fraction of eluate gave a white solid, which, after recrystallization from dichloromethane, afforded 17 mg (63%) of white prisms: mp >340 °C dec; IR (KBr) ν_{max} 2950 cm^{-1}, 1280 (N→O), 1242, 1047; ^1H NMR δ 7.42 (1 H, s, Ar H), 6.46 (1 H, s, Ar H), 3.90–3.62 (2 H, m, CH_2), 3.40–2.57 (14 H, m, CH_2); ($CDCl_3$ + CF_3COOH) δ 8.14 (1 H, s, Ar H), 7.68 (1 H, s, Ar H), 4.00–3.12 (20 H, m, CH_2 and OH); UV (C_2H_5OH) λ_{max} 232 nm (ϵ 10500), 252 (9650), 304 (6790); ^{13}C NMR ($CDCl_3$, proton decoupled) δ 162.4, 151.4, 138.8, 137.9, 136.6, 134.6, 34.6, 32.2, 29.4, 26.9; mass spectrum, *m/e* 279, 278 (M^+), 262 (M^+ − 16), 261.

Anal. Molecular weight calcd for $C_{18}H_{18}N_2O$: 278.142. Found: 278.141 (high-resolution mass spectrum).

5,12-Diaza[2$_4$](1,2,4,5)cyclophane *N*-Oxide (16). A mixture of 5,12-diaza[2$_4$](1,2,4,5)cyclophane (**2**) and 12 mg of *m*-chloroperbenzoic acid was allowed to react for 12 h, and then the reaction mixure was worked up in the same manner as described for the preparation of 5,15-diaza[2$_4$](1,2,4,5)cyclophane *N,N'*-dioxide (**19**). Purification of the crude product by preparative, thin-layer chromatography over alumina (neutral) using 1% methanol in chloroform for elution gave 12 mg of a white crystalline product. Recrystallization of this from dichloromethane gave 9 mg (55%) of white needles: mp >340 °C dec; IR (KBr) ν_{max} 2960 cm^{-1}, 1315, 1280 (N→O), 1045; UV (C_2H_5OH) λ_{max} 228 nm (ϵ 7580), 250 (8190), 308 (6100); ^1H NMR δ 6.46 (1 H, s, Ar H), 6.02 (1 H, s, Ar H), 4.16–3.80 (2 H, m, CH_2), 3.40–2.56 (14 H, m, CH_2); ($CDCl_3$ + CF_3COOH) δ 7.43 (1 H, s, Ar H), 7.00 (1 H, s, Ar H), 4.00–3.12 (17 H, m, CH_2 and OH); ^{13}C NMR ($CDCl_3$, proton decoupled) δ 161.8, 152.1, 145.3, 138.7, 136.4, 132.8, 32.8, 32.6, 32.4, 26.7; mass spectrum, *m/e* 278 (M^+), 262 (M^+ − 16), 261.

Anal. Molecular weight calcd for $C_{18}H_{18}N_2O$: 278.142. Found: 278.141 (high-resolution mass spectrum).

5,12-Diaza[2$_4$](1,2,4,5)cyclophane *N,N'*-Dioxide (17). A mixture of 17 mg of 5,12-diaza[2$_4$](1,2,4,5)cyclophane (**2**) and 30 mg of *m*-chloroperbenzoic acid was allowed to react for 48 h, and then the reaction mixture was worked up in the same manner as described for the preparation of 5,15-diaza[2$_4$](1,2,4,5)cyclophane *N,N'*-dioxide (**19**). Purification of the crude product by preparative, thin-layer chromatography over alumina (neutral) using 1% methanol in chloroform for elution led to 6 mg (29%) of 5,12-diaza[2$_4$](1,2,4,5)cyclophane *N*-oxide (**16**) and 7 mg of a white powdery solid. Recrystallization of this white solid from chloroform gave 5 mg (22%) of white powdery crystals; mp >250 °C dec; IR (KBr) ν_{max} 2960 cm^{-1}, 1365, 1290 (N→O), 1270 (sh), 1260 (sh), 1238 (sh), 1175; UV (C_2H_5OH) λ_{max} 228 nm (ϵ 20600), 245 (sh, 12200), 292 (16400), 325 (sh, 1730); ^1H NMR δ 6.01 (2 H, s, Ar H), 4.60–2.65 (16 H, m, CH_2); ($CDCl_3$ + CF_3COOH) δ 7.27 (2 H, s, Ar H), 4.60–3.20 (18 H, m, CH_2 and OH).

Anal. ($C_{18}H_{18}N_2O_2$) C, H, N.

***N*-Methyl 5,12-Diaza[2$_4$](1,2,4,5)cyclophanonium Iodide (23) and *N*-Methyl 5,12-Diaza[2$_4$](1,2,4,5)cyclophanonium Triflate (24).** A mixture of 20 mg of 5,12-diaza[2$_4$](1,2,4,5)cyclophane (**2**) and 0.3 mL of iodomethane in 5 mL of acetonitrile was boiled under reflux for 2 h. After concentration, the residual solid was washed with ether and then dried to give 28 mg (93%) of **23** as pale yellow crystals: mp 250 °C dec; ^1H NMR (D_2O) δ 7.38 (1 H, s, Ar H), 6.92 (1 H, s, Ar H), 3.96 (3 H, s, N^+CH_3), 3.90–3.04 (16 H, m, CH_2).

To a stirred solution of 25 mg of **23** in 5 mL of methanol was added 18 mg of silver trifluoromethanesulfonate, and then the mixture was stirred under nitrogen at room temperature for 1 h. The insoluble silver iodide was removed by filtration and the filtrate was concentrated. The residual solid was washed several times with benzene. Recrystallization

of this from acetonitrile gave 26 mg (98%) of **24** as white needles: mp 248 °C; UV (C_2H_5OH) λ_{max} 286 nm (λ 2770), 318 (5030); ^1H NMR (D_2O) δ 7.41 (1 H, s, Ar H), 6.96 (1 H, s, Ar H), 3.99 (3H, s, N^+CH_3), 3.90–3.00 (16 H, m, CH_2); field-desorption mass spectrum, *m/e* 278, 277, 263.

***N*-Methyl 5,15-Diaza[2₄](1,2,4,5)cyclophanonium Iodide (25) and *N*-Methyl 5,15-Diaza[2₄](1,2,4,5)cyclophanonium Triflate (26).** A mixture of 10 mg of 5,15-diaza[2₄](1,2,4,5)cyclophane (3) and 3 mL of iodomethane was stirred under nitrogen atmosphere at room temperature for 12 h. After removal of the excess iodomethane, the residual solid was washed with ethyl ether and dried to give 15 mg (95%) of **25** as yellow crystals: mp 283 °C dec; ^1H NMR (D_2O) δ 7.51 (1 H, s, Ar H), 7.30 (1 H, s, Ar H), 3.87 (3 H, s, N^+CH_3), 3.85–3.00 (16 H, m, CH_2). A mixture of 10 mg of **25** in 3 mL of methanol containing 7 mg of silver trifluoromethanesulfonate was allowed to react and then the reaction mixture was worked up in the same manner as described for the preparation of *N*-methyl 5,12-diaza[2₄](1,2,4,5)cyclophanonium triflate (**24**). Recrystallization of the crude product from methanol yielded 10 mg (98%) of **26** as white prisms: mp 260 °C dec; UV (C_2H_5OH) λ_{max} 292 nm (ϵ 2360), 320 (3550); ^1H NMR (D_2O) δ 7.52 (1 H, s, Ar H), 7.32 (1 H, s, Ar H), 3.86 (3 H, s, N^+CH_3), 3.80–3.00 (16 H, m, CH_2); field-desorption mass spectrum, *m/e* 278, 277, 262.

***N*,*N*'-Dimethyl 5,12-Diaza[2₄](1,2,4,5)cyclophanebis(onium) Bis(*p*-toluenesulfonate) (27).** A mixture of 15 mg of 5,12-diaza[2₄](1,2,4,5)-cyclophane (**2**) and 0.5 mL of methyl p-toluenesulfonate was stirred under nitrogen at room temperature for 3 h. Then the reaction mixture was stirred at 130 °C for an additional 24 h. After the reaction mixture was cooled to room temperature, 5 mL of benzene was added to precipitate the product. This was collected by filtration and recrystallized from a mixture of methanol and tetrahydrofuran to give 22 mg (60%) of off-white needles: mp 250 °C dec; UV (C_2H_5OH) λ_{max} 260 nm (sh, ϵ 2910), 268 (sh, 2390), 298 (sh, 2080), 331 (6170); ^1H NMR (D_2O) δ 7.68 (4 H, d, J = 8 Hz, Ar H), 7.66 (2 H, s, Ar H), 7.36 (4 H, d, J = 8 Hz, Ar H), 4.22 (6 H, s, N^+CH_3), 3.99–3.10 (16 H, m, CH_2), 2.40 (6 H, s, CH_3).

Anal. ($C_{37}H_{38}N_2O_6S_2$) C, H, N.

***N*,*N*'-Dimethyl 5,15-Diaza[2₄](1,2,4,5)cyclophanebis(onium) Bis(*p*-toluenesulfonate) (28).** A mixture of 20 mg of 5,15-diaza[2₄](1,2,4,5)-cyclophane (3) and 0.5 mL of methyl *p*-toluenesulfonate was stirred under nitrogen at 130 °C for 24 h. After the reaction mixture was cooled to room temperature, 3 mL of benzene was added. The resulting precipitate was collected by filtration and recrystallized from methanol to yield 34 mg (70%) of white prisms: mp 297 °C dec; UV (C_2H_5OH) λ_{max} 256 nm (10 100), 319 (7240); ^1H NMR (D_2O) δ 8.03 (2 H, s, Ar H), 7.51 (4 H, d, J = 8 Hz, Ar H), 7.39 (4 H, d, J = 8 Hz, Ar H), 4.06 (6 H, s, N^+CH_3), 3.86–3.23 (16 H, m, CH_2), 2.40 (6 H, s, CH_3.

Anal. ($C_{37}H_{38}N_2O_6S_2$) C, H, N.

***N*-(2-Bromoethyl)-5,12-diaza[2₄](1,2,4,5)cyclophanonium Bromide (29).** A mixture of 20 mg of 5,12-diaza[2₄](1,2,4,5)cyclophane (**2**) and 0.5 mL of 1,2-dibromoethane was stirred under nitrogen at 100 °C for 24 h. After the reaction mixture was cooled to room temperature, 3 mL of ethyl ether was added. The resulting precipitate was collected by filtration and recrystallized from a mixture of acetonitrile and methanol to give 15 mg (45%) of pink needles: mp 203 °C dec; ^1H NMR (D_2O) δ 7.40 (1 H, s, Ar H), 6.82 (1 H, s, Ar H), 4.90 (2 H, t, J = 6 Hz, $N^+CH_2CH_2Br$), 3.82–2.86 (18 H, m, CH_2 and CH_2Br).

Anal. ($C_{20}H_{22}N_2Br_2$) C, H, N.

5,12-Diaza[2₅](1,2,3,4,5)cyclophanebis(onium) Dibromide (30). A solution of 25 mg of *N*-2-bromoethyl 5,12-diaza[2₄](1,2,4,5)cyclphanonium bromide (**29**) in 5 mL of acetonitrile was placed in a thick-walled glass tube, carefully degassed, and sealed under vacuum. The tube was heated at 165 °C for 1 day and then opened. After concentration of the solution, the residual solid was recrystallized from acetonitrile to give 24 mg (95%) of pink, powdery crystals: mp 310 °C dec; ^1H NMR (D_2O) δ 7.10 (2 H, s, Ar H), 3.77–2.82 (2 H, m, CH_2).

Anal. ($C_{20}H_{22}N_2Br_2$) C, H, N.

5,12-Diaza[2₅](1,2,3,4,5)cyclophanebis(onium) Bis(triflate) (31). A mixture of 15 mg of 5,12-diaza[2₅](1,2,3,4,5)cyclophanebis(onium) dibromide (**30**) in 3 mL of methanol containing 17 mg of silver trifluoromethanesulfonate was stirred for a few minutes, and then the precipitate of silver was removed by filtration. Concentration of the filtrate followed by recrystallization of the residual solid from acetonitrile gave 18 mg (94%) of pink, powdery crystals: mp 300 °C dec; IR (KBr) ν_{max} 2960 cm^{-1}, 1430, 1270, 1230, 1160, 1045, 1030, 648, 635, UV (C_2H_5OH) λ_{max} 304 nm (sh, ϵ 4530), 308 (4800); ^1H NMR (D_2O) δ 7.27 (2 H, s, Ar H), 3.85–3.04 (20 H, m, CH_2).

Anal. ($C_{22}H_{22}N_2O_6F_6S_2$) C, H, N.

5,12-Diaza[2.2.3.2.2](1,2,3,4,5)cyclophanebis(onium) Dibromide (32) and 5,12-Diaza[2.2.3.2.2](1,2,3,4,5)cyclophanebis(onium) Bis(triflate) (33). A mixture of 20 mg of 5,12-diaza[2₄](1,2,4,5)cyclophane (**2**) in 0.5 mL of 1,3-dibromopropane was heated at 100 °C with stirring for 24 h. After the mixture was cooled to room temperature, 3 mL of ether was added. The resulting precipitate was collected by filtration and washed with ether. It was then transferred to a thick-walled tube containing 5 mL of acetonitrile. After the tube had been sealed, it was heated at 165 °C for 24 h. It was then opened and the solution was concentrated. Recrystallization of the residual solid from acetonitrile gave 17 mg (48%) of **32** as light tan needles: mp 320 °C dec; ^1H NMR (D_2O) δ 7.15 (2 H, s, Ar H), 3.80–2.94 (22 H, m, CH_2). A mixture of 10 mg of **32** in 3 mL of methanol containing 15 mg of silver trifluoromethanesulfonate was stirred for a few minutes before removing the precipitate of silver bromide by filtration. Concentration of the filtrate followed by recrystallization of the residual solid from acetonitrile gave 12 mg (98%) of 33 as white needles: mp 315 °C dec; ^1H NMR (D_2O) δ 7.48 (2 H, s, Ar H), 3.90–3.06 (22 H, m, CH_2).

Anal. ($C_{23}H_{24}N_2O_6F_6S_2$) C, H, N.

***N*-Methyl *anti*-4,12-Diaza[2₂](1,3)cyclophanonium Triflate (36).** A solution of 20 mg of *anti*-4,12-diaza[2₂](1,3)cyclophane (**34**) and 0.3 mL of iodomethane in 3 mL of acetonitrile was boiled under reflux in a nitrogen atmosphere for 12 h. After concentration the residual solid was recrystallized from acetonitrile to give 23 mg (70%) of *anti*-4,12-diaza-[2₂](1,3)cyclophanonium iodide as pale yellow cubes: mp 256–258 °C; ^1H NMR (D_2O) δ 8.34 (1 H, t, J = 7.5 Hz, Ar H), 7.93 (2 H, d, J = 7.5 Hz, Ar H), 7.78 (1 H, t, J = 7.5 Hz, Ar H), 7.48 (2 H, d, J = 7.5 Hz, Ar H), 3.72–3.12 and 2.82–2.52 (8 H, m, CH_2), 2.56 (3 H, s, N^+CH_3). A mixture of 15 mg of *anti*-4,12-diaza[2₂](1,3)-cyclophanonium iodide in 5 mL of methanol containing 12 mg of silver trifluoromethanesulfonate was stirred for a few minutes before removing the precipitate of silver iodide by filtration. Concentration of the filtrate followed by recrystallization of the residual solid from a mixture of acetonitrile and tetrahydrofuran gave 15 mg (95%) of white cubes: mp 213–215 °C; UV (C_2H_5OH) λ_{max} 268 nm (4040), 304 (3310); ^1H NMR (D_2O) δ 8.34 (1 H, t, J = 7.5 Hz, Ar H), 7.93 (2 H, d, J = 7.5 Hz, Ar H), 3.75–2.54 (8 H, m, CH_2), 2.57 (3 H, s, N^+CH_3); field-desorption mass spectrum, *m/e* 226, 225, 210.

***N*,*N*'-Dimethyl *anti*-4,12-Diaza[2₂](1,3)cyclophanebis(onium) Bis(triflate) (37).** A mixture of 20 mg of **34** and 0.5 mL of methyl *p*-toluenesulfonate was stirred under nitrogen at 125 °C for 48 h. After the reaction mixture was cooled to room temperature, 5 mL of benzene was added to precipitate the product. The resulting precipitates were collected and recrystallized from acetonitrile to give 22 mg (40%) of white needles: mp 281 °C dec; UV (C_2H_5OH) λ_{max} 255 (ϵ 1690), 261 (1770), 268 (1580); ^1H NMR (D_2O) δ 8.54–8.14 (6 H, m, Ar H), 7.66 (4 H, d, J = 8 Hz, Ar H), 7.36 (4 H, d, J = 8 Hz, Ar H), 3.90–3.59 (8 H, m, CH_2), 2.85 (6 H, s, N^+CH_3), 2.38 (6 H, s, CH_3); field-desorption mass spectrum, *m/e* 240, 239, 238, 226, 225.

4,12-Diaza[2₃](1,2,3)cyclophanebis(onium) Dibromide (38). A mixture of 20 mg of **34** and 0.5 mL of 1,2-dibromoethane was stirred under nitrogen at 130 °C for 32 h. After the reaction mixture was cooled to room temperature, 5 mL of ethyl ether was added. The resulting precipitate was collected and recrystallized from methanol to afford 28 mg (74%) of pale pink plates: mp 340 °C dec; ^1H NMR (D_2O) δ 8.20 (2 H, t, J = 7.5 Hz, Ar H), 7.70 (4 H, d, J = 7.5 Hz, Ar H), 5.42 (4 H, s, $N^+CH_2CH_2N^+$), 4.38–3.60 (8 H, M, CH_2); field-desorption mass spectrum, *m/e* 239, 238, 237, 236, 210.

Anal. ($C_{16}H_{18}N_2Br_2$) C, H, N.

4,12-Diaza[2₃](1,2,3)cyclophanebis(onium) Bis(triflate) (39). To a stirred solution of 10 mg of 4,12-diaza[2₃](1,2,3)cyclophanebis(onium) dibromide (**38**) in 5 mL of methanol was added 8 mg of silver trifluoromethanesulfonate, and the mixture was stirred under nitrogen at room temperature for 1 h. The insoluble silver bromide was removed by filtration and the filtrate was concentrated. The residual solid was washed several times with benzene and recrystallized from methanol to afford 12 mg (85%) of white thin plates: mp 320 °C dec; IR (KBr) ν_{max} 3100 cm^{-1}, 3075, 1622, 1581, 1491, 1275, 1255, 1230, 1182, 1156, 1032, 650; UV (C_2H_5OH) λ_{max} 225 nm (ϵ 7450), 276 (14300); ^1H NMR (D_2O) δ 8.16 (2 H, t, J = 7.5 Hz, Ar H), 7.69 (4 H, d, J = 7.5 Hz, Ar H), 5.40 (4 H, s, $N^+CH_2CH_2N^+$), 4.32–3.52 (8 H, m, CH_2).

Anal. ($C_{18}H_{18}N_2F_6S_2O_6$) C, H, N.

***N*-((Ethoxycarbonyl)imino)-5,15-diaza[2₄](1,2,4,5)cyclophanonium Ylide (46).** A solution of 32 mg of *O*-(mesitylsulfonyl)hydroxylamine in 5 mL of dichloromethane was added dropwise to a solution of 30 mg of 5,15-diaza[2₄](1,2,4,5)cyclophane (3) in 5 mL of dichloromethane with constant stirring under nitrogen in an ice bath. The reaction mixture was stirred at room temperature for 1 h. Then ethyl ether (15 mL) was added and the resulting crystalline precipitate was collected by filtration. Recrystallization of this precipitate from a mixture of water and methanol gave 42 mg (77%) of **45** as white prisms: mp 256 °C dec; IR (KBr) ν_{max} 3440 cm^{-1} (NH), 1211, 1192, 1098, 1027, 683; ^1H NMR (CD_3OD) δ 7.47 (1 H, s, Ar H), 7.34 (1 H, s, Ar H), 6.86 (2 H, s, Ar H), 3.74–3.00

(16 H, m, CH_2), 2.62 (6 H, s, CH_3), 3.33 (3 H, s, CH_3).

To a stirred solution of 20 mg of **45** in 3 mL of ethanol was added successively a solution of 8 mg (7 μL) of ethyl chloroformate in 1 mL of ethanol and 12 mg of anhydrous potassium carbonate. The reaction mixture was stirred at room temperature under nitrogen for 12 h, and the resulting inorganic precipitate was removed by filtration. The filtrate was concentrated, and the residue was extracted with chloroform. The extract was dried and concentrated. Recrystallization of the residual solid from benzene gave 12 mg (82%) of white needles: mp 259 °C dec; IR (KBr) ν_{max} 1627 cm^{-1} (C=O), 1280, 1085; UV (C_2H_5OH) λ_{max} 253 nm (ϵ 4660), 311 (5990), 332 (sh, 3030); ^1H NMR δ 7.46 (1 H, s, Ar H), 6.95 (1 H, s, Ar H), 4.11 (2 H, q, J = 7 Hz, CH_2CH_3), 3.96–2.86 (16 H, m, CH_2), 1.29 (3 H, t, J = 7 Hz, CH_2CH_3); mass spectrum, m/e 349 (M^+), 263, 262, 261, 247.

Anal. Molecular weight calcd for $C_{21}H_{23}N_3O_2$: 349.179. Found: 349.180 (high-resolution mass spectrum).

***N*-((Ethoxycarbonyl)imino)-5,12-diaza[2$_4$](1,2,4,5)cyclophanonium Ylide (49).** A solution of 17 mg of *O*-(mesitylsulfonyl)hydroxylamine in 3 mL of dichloromethane was added dropwise with stirring to 15 mg of 5,12-diaza[2$_4$](1,2,4,5)cyclophane (**2**) in 3 mL of dichloromethane with cooling. The reaction was then allowed to warm and was stirred at room temperature for 1 h. Addition of ether caused the separation of a precipitate, which was collected by filtration. Recrystallization of this precipitate from a mixture of acetonitrile and methanol gave 18 mg (66%) of **48** as white powdery crystals: mp 264 °C dec; IR (KBr) ν_{max} 3240 cm^{-1} (NH), 1210, 1191, 1098, 1027, 683; ^1H NMR (CD_3OD) δ 7.28 (1 H, s, Ar H), 6.86 (2 H, s, Ar H), 6.84 (1 H, s, Ar H), 3.90–2.90 (16 H, m, CH_2), 2.62 (6 H, s, CH_3), 2.22 (3 H, s, CH_3).

To a stirred solution of 14 mg of **48** in 2 mL of ethanol was added successively a solution of 6 mg of ethyl chloroformate in 1 mL of ethanol and 10 mg of anhydrous potassium carbonate. The reaction mixture was stirred at room temperature under nitrogen for 12 h before removing the inorganic precipitate by filtration. The precipitate was extracted with chloroform, and the combined chloroform extracts and filtrate was concentrated. Recrystallization of the residual solid from benzene gave 8 mg (80%) of white needles: mp 225 °C dec; IR (KBr) ν_{max} 1600 cm^{-1} (C=O), 1370, 1300, 1080; UV (C_2H_5OH) λ_{max} 255 nm (ϵ 3810), 315 (4950), 338 (sh, 2530); ^1H NMR δ 6.51 (1 H, s, Ar H), 6.46 (1 H, s, Ar H), 4.11 (2 H, q, J = 7 Hz, CH_2CH_3), 4.00–2.72 (16 H, m, CH_2), 1.28 (3 H, t, J = 7 Hz, CH_2CH_3); mass spectrum, m/e 349 (M^+), 263, 262, 261, 247.

Anal. Molecular weight calcd for $C_{21}H_{23}N_3O_2$: 349.179. Found: 349.179 (high-resolution mass spectrum).

Photorearrangement of 46 To Give 47. A stirred solution of 15 mg of **46** in 10 mL of benzene was irradiated with a 450-W Hanovia medium-pressure mercury lamp through a Pyrex filter under argon for 2.5 h until all the starting material was consumed. The consumption of starting material was monitored by thin-layer chromatography over silica gel. After concentration of the solution, the residual solid was purified by preparative, thin-layer chromatography over silica gel using 5% methanol in chloroform as eluant to give 14 mg (95%) of yellow crystals. Recrystallization from acetonitrile gave yellow prisms: mp 240 °C dec; IR (KBr) ν_{max} 2946 cm^{-1}, 2918, 1695 (C(=O)OEt), 1409, 1379, 1342, 1321, 1180, 1140; UV (C_2H_5OH) λ_{max} 267 nm (3770), 293 (sh, 2710); ^1H NMR δ 6.94 (1 H, s, Ar H), 4.54 (1 H, brs, CH=C) 4.23 (2 H, several overlapping quartets, J = 7 Hz, CH_2CH_3), 3.60–2.10 (16 H, m, CH_2), 1.30 (3 H, t, J = 7 Hz, CH_2CH_3); (toluene-d_8) δ 6.52 (1 H, s, Ar H), 4.29 (1 H, brs, CH=C), 4.04 (2 H, q, J = 7 Hz, CH_2CH_3), 3.10–2.00 (16 H, m, CH_2), 1.07 (3 H, t, J = 7 Hz, CH_2CH_3); (CD_3CN) δ 6.99 (1 H, s, Ar H), 4.40 (1 H, brs, CH=C), 4.08 (2 H, q, J = 7 Hz, CH_2CH_3), 3.40–2.10 (16 H, m, CH_2), 1.22 (3 H, t, J = 7 Hz, CH_2CH_3); mass spectrum, m/e 350, 349 (M^+), 277, 276, 263, 262, 261.

Anal. Molecular weight calcd for $C_{21}H_{23}N_3O_2$: 349.179. Found: 349.178 (high-resolution mass spectrum).

Photorearrangement of 49 To Give 50. A stirred solution of 11 mg of **49** in 10 mL of benzene was irradiated in the same manner as described for the preparation of **47**. Purification of the crude product by preparative thin-layer chromatography over silica gel using 10% methanol in chloroform as eluant gave 10 mg (92%) of yellow crystals: mp 155 °C dec; IR (KBr) ν_{max} 2979 cm^{-1}, 2895, 1694 (C=O), 1450, 1413, 1378, 1188, 1175, 1107, 1056; UV (C_2H_5OH) λ_{max} 263 nm (ϵ 3770), 298 (2930); ^1H NMR δ 7.18 (1 H, s, Ar H), 4.50 (1 H, brs, CH=C), 4.18 (2 H, several overlapping quartets, J = 7 Hz, CH_2CH_3), 3.60–2.10 (16 H, m, CH_2), 1.28 (3 H, t, J = 7 Hz, CH_3); (toluene-d_8) δ 6.52 (1 H, s, Ar H), 4.29 (1 H, brs, CH=C), 4.04 (2 H, q, J = 7 Hz, CH_2CH_3), 3.10–2.00 (16 H, m, CH_2), 1.07 (3 H, t, J = 7 Hz, CH_2CH_3); (CD_3CN) δ 7.32 (1 H, s, Ar H), 4.37 (1 H, brs, CH=C), 4.09 (2 H, q, 7 Hz, CH_2CH_3), 3.40–2.10 (16 H, m, CH_2), 1.22 (3 H, t, J = 7 Hz, CH_2CH_3); mass spectrum, m/e 350, 349, (M^+), 276, 262.

Anal. Molecular weight calcd for $C_{21}H_{23}N_3O_2$: 349.179. Found: 349.179 (high-resolution mass spectrum).

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Registry No. 2, 77825-18-4; 3, 77225-38-8; **5**, 1149-24-2; **6**, 77825-09-3; **7**, 77825-10-6; **8**, 77825-11-7; **9**, 77825-13-9; **10**, 77825-12-8; **11**, 89398-77-6; **12**, 77825-14-0; 13, 77825-17-3; **14**, 77825-15-1; **16**, 89398-78-7; **17**, 89398-79-8; **18**, 89398-80-1; **19**, 89398-81-2; **23**, 89398-82-3; **24**, 89398-84-5; **25**, 89398-85-6; **26**, 89398-87-8; **27**, 89398-89-0; **28**, 89398-91-4; **29**, 89414-13-1; **30**, 89398-92-5; **31**, 89398-94-7; **32**, 89398-95-8; 33, 89398-97-0; **34**, 6574-83-0; **36**, 89398-99-2; **37**, 89399-01-9; **38**, 89399-02-0; **39**, 89399-04-2; **45**, 89399-06-4; **46**, 89399-07-5; **47**, 89399-08-6; **48**, 89399-10-0; **49**, 89399-11-1; **50**, 89399-12-2; [6,7:13,14]dicyclobuta-5,12-diaza[2$_2$](1,3)cyclophanium iodide, 89399-13-3; *N*-methyl 4,12-diaz[2$_2$](1,3)cyclophanium iodide, 89399-14-4; silver trifluoromethanesulfonate, 2923-28-6; methyl *p*-toluenesulfonate, 80-48-8; 1,2-dibromoethane, 106-93-4; 1,3-dibromopropane, 109-64-8; *O*-(mesitylsulfonyl)hydroxylamine, 36016-40-7; ethyl chloroformate, 541-41-3.

Reaction of Chromium Carbene Complexes with Imines. Synthesis of β-Lactams

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Abstract: Under thermal conditions imines react with pentacarbonyl[(methoxy)(alkyl)carbene]chromium(0) complexes at the α-carbon of the carbene complex, producing new carbene complexes. When photolyzed with visible light (sunlight) a clean cycloaddition occurs to give β-lactams in good yield. Acyclic N-alkylated imines were converted to monocyclic β-lactams. Cyclic imines such as dihydroisoquinolines, quinolines, and benzothiazines were converted to polycyclic β-lactams. Thiazolines were converted to penam derivatives. Methyl D-5,5-dimethyl-Δ^2-thiazoline-4-carboxylate was converted to the penicillin analogue stereospecifically, giving an optically active bicyclic β-lactam. Acyclic chiral imines underwent reaction with lower stereoselectivity, giving a maximum of 60% diastereomeric excess.

Heteroatom-stabilized carbene complexes of chromium are readily synthesized in a number of different ways.[1] Most commonly used is the reaction of chromium hexacarbonyl with organolithium reagents to produce the "ate" complex, alkylation of

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