Reactions of Dichloroperfluorocycloalkenes with Tetraazamacrocyclic Amines

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Received December 10, 1993®

1,2-Dichlorotetrafluorocyclobutene-1 (**1**), 1,2-dichlorohexafluorocyclopentene-1 (**2**), and 1,2-dichlorooctafluorocyclohexene-1 (**3**) react with tetraaza macrocyclic amines (1,4,7,10-tetraazacyclododecane (**A**), 1,4,7,10-tetraazacyclotridecane (**B**), 1,4,8,11-tetraazacyclotetradecane (**C**), 1,4,7,11-tetraazacyclotetradecane (**D**), 1,4,8,12-tetraazacyclopentadecane (**E**), and 1,5,9,13-tetraazacyclohexadecane (**F**)) by heating at 70–80 °C for 8–12 h in the presence of stoichiometric amounts of triethylamine in benzene under nitrogen. Cycloalkene **1** forms products in the ratio of 1:3, cycloalkene **2** gives 1:2 products, and cycloalkene **3** results in 1:1 substituted derivatives of the tetraazamacrocyclic amines **A–F**, respectively, in good yields. With all three dichloroperfluorocyclic alkenes (**1–3**), macrocyclic amine **A** forms solid compounds that exhibit sharp melting points whereas other substituted derivatives of the tetraazamacrocyclic amines **B–F** are viscous oils. All of these substituted derivatives are very stable and do not decompose on exposure to moist air at ambient temperature over long periods. The crystal structures of 1,4,7-tris(chlorotetrafluorocyclobutenyl)-1,4,7,10-tetraazacyclododecane (**1A**) and 1,7-bis(chlorohexafluoropentenyl)-1,4,7,10-tetraazacyclododecane (**2A**) have been determined by X-ray diffraction methods.

Introduction

The field of macrocycles with pendant donor groups has grown rapidly since the appearance of a review[1] on these ligands. Hancock and Martell[2] have discussed the effects of the presence of pendant donor groups on complexation properties. Many macrocycles[3-9] are known with neutral oxygen donors on pendant groups because they are readily synthesized. Macrocyclic tetraaminotetracarboxylate complexes[10-12] of lanthanide metal ions are currently attracting much attention for separation of lanthanides, as magnetic resonance imaging (MRI) contrast enhancing agents,[13] and as radiopharmaceuticals.[14,15]

The synthesis of fluorinated heterocyclic compounds is one of the areas of study in this laboratory[16-19] and in others.[20-23] (Trifluoromethyl)sulfenyl, (trifluoromethyl)sulfinyl and (trifluoromethyl)sulfonyl derivatives of some tetraazamacrocyclic amines and other heterocyclic amines are known.[24] Many of these compounds are used in applications such as blood substitutes,[23] antistatic coatings,[25] and inert fluids.[18] Heterocyclic compounds that contain one or two fluorine atoms or a trifluoromethyl group are commonly biologically active materials,[22,26,27] whereas metalloheterocycles are synthesized and studied extensively in the preparation of conducting polymers.[28-30]

Our current interest is in the examination of the reactivity of dichloroperfluorocycloalkenes with secondary amines,[19] and a variety of tetraaza macrocycles that contain monochloroperfluorocycloalkenes as substituents are reported here. We believe that there are no previous reports on these monochloroperfluorocycloalkenyl derivatives of tetraaza macrocyclic amines. In this paper, we report the synthesis of a variety of monochlorotetrafluorocyclobutenyl, monochlorohexafluorocyclopentenyl, and monochlorooctafluorocyclohexenyl N-substituted tetraaza macrocyclic amines. It is demonstrated that these tetraaza macrocyclic amines, including 1,4,7,10-tetraazacyclododecane (**A**), 1,4,7,10-tetraazacyclotridecane (**B**), 1,4,8,11-tetraazacyclotetradecane (**C**), 1,4,7,11-tetraazacyclotetradecane (**D**), 1,4,8,12-tetraazacyclopentadecane (**E**), and 1,5,9,13-tetraazacyclohexadecane (**F**) react smoothly in the presence of an organic base to give the N-substituted products. The metathetical reactions proceed in a straightforward manner. In spite of the polyfunctionality of the heterocyclic amines and of the alkenes, monomeric products form under the reaction conditions used. These new materials are isolated and characterized.

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® Abstract published in *Advance ACS Abstracts,* April 15, 1994.

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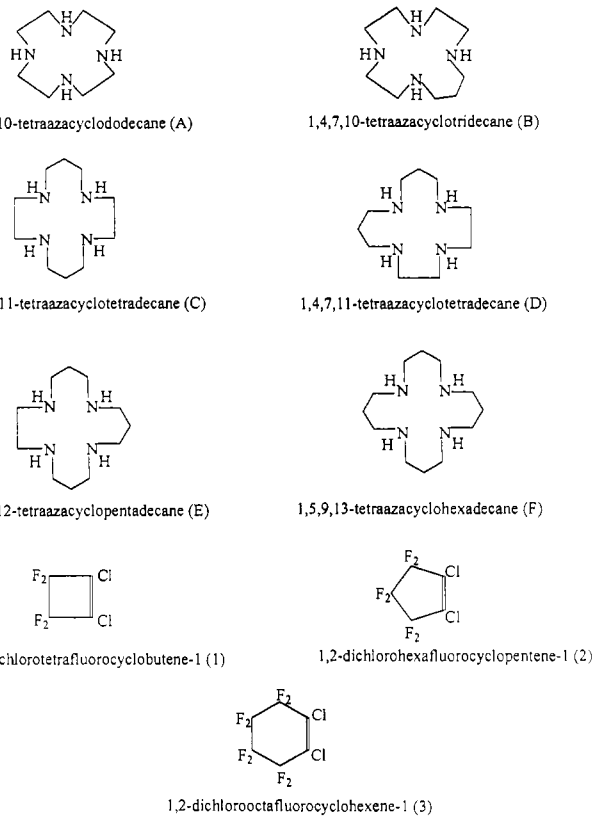
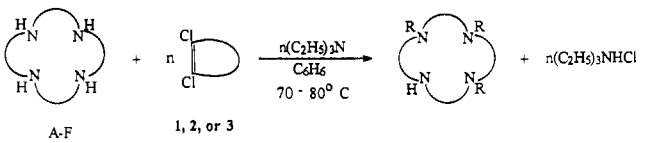
Chart 1



Results and Discussion

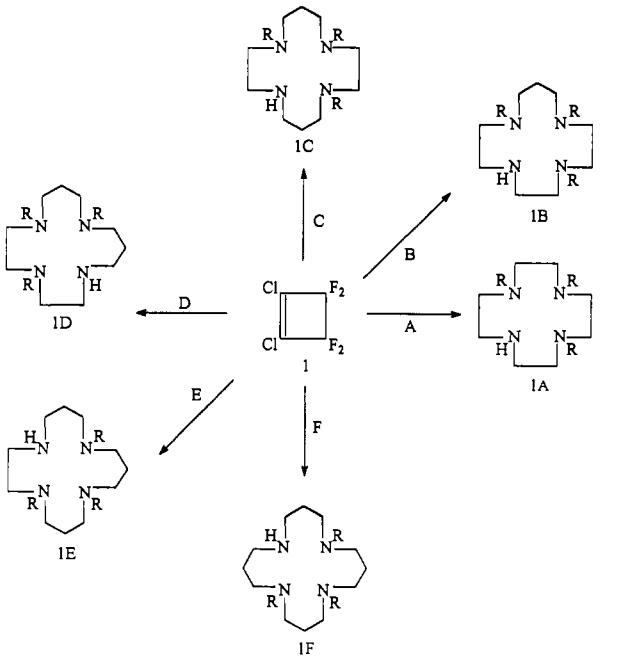
Nucleophilic reactions with a wide variety of fluorocarbons are subjects of wide interest.[17,19,31] Older literature dealing with nucleophilic attack on poly and perfluorinated acyclic and cyclic olefins has been reviewed,[32] and an excellent series of papers on the chemistry of polyfluorinated cycloalkenes appeared recently.[33] Generally it is considered that the reactions of polyfluorinated olefins proceed by addition followed by concomitant β-elimination, but this phenomenon is not observed in this case.

The tetraaza macrocyclic amines (Chart 1) react with 1,2-dichlorotetrafluorocyclobutene-1 (**1**), 1,2-dichlorohexafluorocyclopentene-1 (**2**), and 1,2-dichlorooctafluorocyclohexene-1 (**3**), in the presence of triethylamine, to form the products which are indicated in Schemes 1–3, respectively. The techniques used in carrying out these reactions are similar and are described in the Experimental Section. The general reaction of tetraaza macrocyclic amines with dichloroperfluorocycloolefins is



where n is the number of alkenyl groups (R) substituted in the macrocyclic tetraamine. It is well established that fluorinated cyclic or vinyl olefins undergo nucleophilic substitution reactions, e.g., the reactions of 1,2-dichloro(hexafluoro)cyclopentene-1 with secondary aliphatic amines or pyrrolidine and 3,3,4,4-tetrafluoropyrrolidine[34] to give singly substituted (C-1) products[35] and bicyclic amines with secondary acyclic diamines.[19] It is demonstrated that displacement of both chlorine atoms from the cycloolefin ring is possible only when a strong nucleophilic reagent, such as trialkyl phosphite,[36] polyfluorinated sulfonamide[17] or

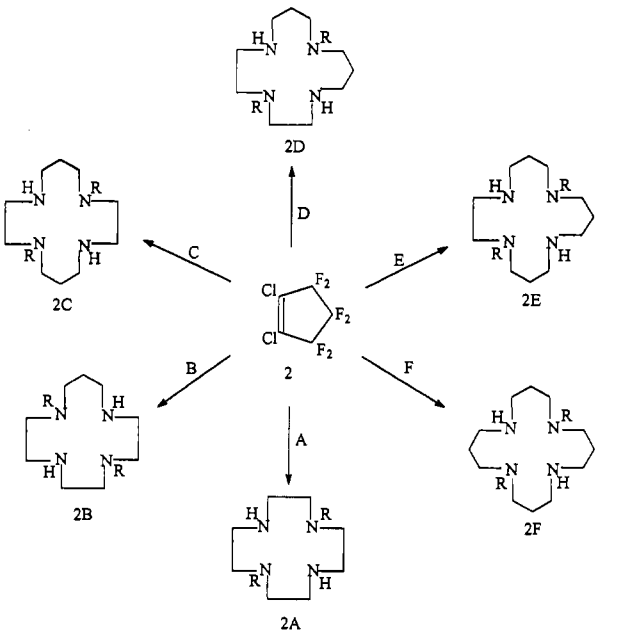
Scheme 1



A-F refer to the reactants in Chart I

R = chlorotetrafluorocyclobutenyl group

Scheme 2



A-F refer to the reactants in Chart I

R = chlorohexafluorocyclopentenyl group

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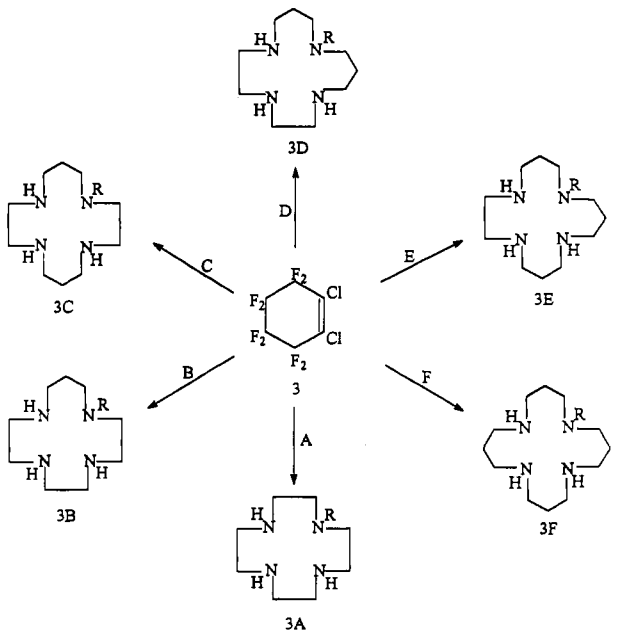
Scheme 3



A-F refer to the reactants in Chart I

R = chlorooctafluorocyclohexenyl group

mercaptide anion[37,38] is employed in the metathesis reaction. The results of our study of the reactions of tetraaza macrocyclic secondary amines **A–F** with cyclic olefins **1–3** are consistent with single substitution reactions with no evidence for disubstitution occurring on the cyclic olefin.

Although 1,2-dichlorohexafluorocyclopentene-1 (**2**) reacts smoothly with all of the tetraaza macrocyclic amines **A–F** to form the 1:2-substituted tetraaza macrocyclic amines **2A–F**, higher temperatures (~80 °C) and longer times (~24 h) are required than with acyclic amines.[19] When the reactions are run in the presence of excess alkene **2** with all macrocyclic amines **A–F** for 2 days in attempts to obtain 1:4 products, the unreacted alkene **2** is recovered and only the 1:2-substituted monochlorohexafluorocyclopentenyl tetraaza macrocyclic amines are found. Attempts to obtain 1:1 derivatives of these macrocyclic amines **A–F** with alkene **2** by reversing the reaction stoichiometry result only in the isolation of the 1:2 products.

To further study this nucleophilic substitution reaction, 1,2-dichlorotetrafluorocyclobutene-1 (**1**) and 1,2-dichlorooctafluorocyclohexene-1 (**3**) are each reacted with tetraaza macrocyclic secondary amines **A–F**. In each case, alkene **1** forms 1:3 products whereas **3** forms only 1:1 products with the heterocyclic amines. Only one chlorine atom is displaced and no cyclization is observed which would result from intramolecular nucleophilic attack at the carbon bonded to the second chlorine atom with concomitant double bond shift. The behavior of **1** and **3** is similar to the reactivity of **2** with heterocyclic amines **A–F**. The only difference is the rate of reactivity toward the secondary amines, *viz.*, **1** ≫ **2** > **3**, as is expected.

All attempts to obtain 1:4 and 1:1 products of **1** and **3** with macrocyclic amines **A–F** failed, and only 1:3 and 1:1 products are obtained, respectively. All of the compounds (1:3; 1:2; 1:1) that result from **1–3** with macrocyclic amines **A–F** show M^+ ions in their mass spectra. Alkene **1** forms a solid 1:3 product with amine **A** and colorless oils with amines **B–F** whereas alkene **3** forms crystalline solids with macrocyclic amines **A–F**. 1,2-Dichlorohexafluorocyclopentene-1 (**2**) gives colorless oils with macrocyclic amines **B–F** while forming a crystalline solid **2A** with 1,4,7,10-tetraazacyclododecane (**A**). Not one of the products decomposes on standing or hydrolyzes when exposed to the atmosphere for long periods. Stability is checked by following the ^{19}F NMR spectra of the products, **1A–F**, **2A–F**, and **3A–F**, which are soluble/miscible in chloroform, methylene chloride, ether, and benzene.

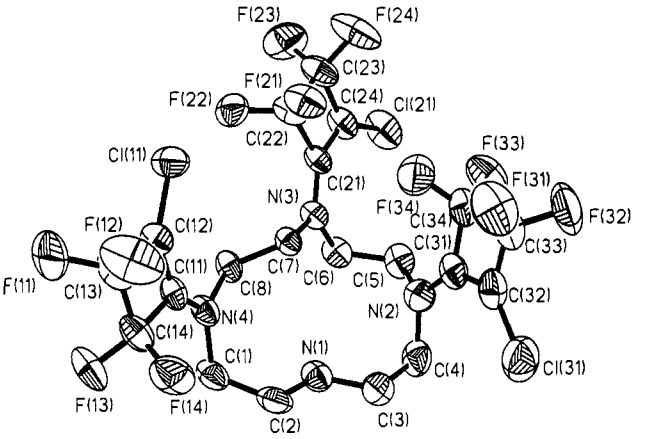


Figure 1. Compound 1A.

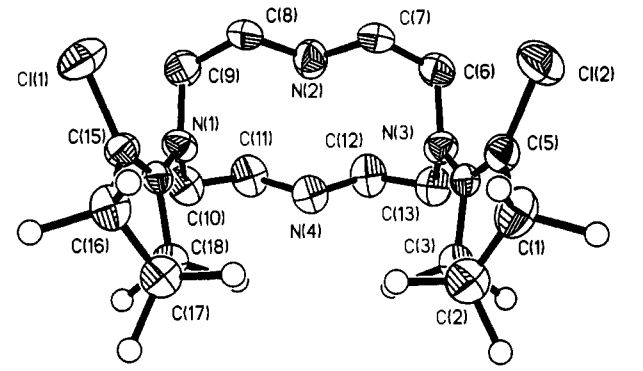


Figure 2. Compound 2A.

Compounds **1A** and **2A** are crystallized from an ether/hexane mixture, and these crystals are used for X-ray crystal structure determination. Although the monochlorooctafluorocyclohexenyl derivatives of tetraaza macrocyclic amines **3A–F** are solids, all attempts to obtain crystals of crystallographic quality failed. It is also observed that when all of the products which are oils are stored under vacuum at 25 °C for long periods, no change in physical state occurs. The symmetric tetraaza macrocyclic amines **A**, **C**, and **F** form only 1:3, 1:2, and 1:1 products with cyclic alkenes **1–3**, respectively. However, when the unsymmetric heterocyclic amines **B**, **D**, and **E** form products 1:3, 1:2, and 1:1 with alkenes **1–3**, respectively, isomeric mixtures result and all efforts to separate these isomers are unsuccessful.

In our investigations of reactivity of cyclic olefins toward tetraaza macrocyclic amines under the conditions used, only one chlorine atom is substituted and all attempts failed to displace both the chlorine atoms of the cyclic olefins or to cause cyclization to occur. The crystal structures of compounds **1A** and **2A** are given in Figures 1 and 2, respectively. Their crystallographic data are summarized in Table 1. The selected bond distances and angles are in Tables 2 and 3 for **1A** and **2A**, respectively. In the structure of **1A** (trisubstituted ring system), the macrocyclic ring itself has an unexpected, non-minimum-energy conformation, with the N(2)–C(5)–C(6)–N(3) ethylenediamine linkage twisted out of the plane of the rest of the ring. This allows the chlorotetrafluorocyclobutenyl ring 2′ to lie nearly in the plane of the macrocyclic ring, rather than protruding above the plane. The logical minimum energy ring conformation (for an unsubstituted ring) would have the protons on N(1) and N(3) lying on one side of the ring and those for N(2) and N(4) lying on the

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Table 1. Crystallographic Data for Compounds **1A** and **2A**

	1A	**2A**
empirical formula	$C_{20}H_{17}F_{12}N_4Cl_3$	$C_{18}H_{18}F_{12}N_4Cl_2$
fw	647.8	589.3
crystal system	triclinic	monoclinic
space group	$P\bar{1}$	$P2_1/c$
a, Å	8.664(3)	7.975(2)
b, Å	9.591(4)	28.718(6)
c, Å	16.340(6)	10.641(2)
α, deg	73.87(3)	
β, deg	89.61(3)	108.92(3)
γ, deg	74.30(4)	
V, Å^3	1252.2(9)	2305.4(9)
Z	2	4
T, °C	22	21
λ, Å	0.710 73	0.710 73
D_{calc}, g cm^{-3}	1.72	1.698
R^a	0.0699	0.0579
$R_w{}^a$	0.1050	0.0647

^{a} $R = \sum||F_o| - |F_c||/\sum|F_o|$ and $R_w = \{\sum w(|F_o| - |F_c|)^2/\sum w|F_o|^2\}^{1/2}$.

Table 2. Selected Bond Lengths (Å) and Bond Angles (deg) for $C_{20}H_{17}F_{12}N_4Cl_3$ (**1A**)

	Bond Distances		
C(11)–C(12)	1.350(6)	C(12)–C(11)	1.703(4)
C(12)–C(13)	1.440(5)	C(1)–N(4)	1.474(6)
C(11)–N(4)	1.332(5)	C(1)–C(2)	1.512(8)
	Bond Angles		
C(8)–N(4)–C(1)	119.7(3)	C(11)–C(12)–C(13)	95.9(4)
N(4)–C(11)–C(12)	139.8(3)	C(2)–N(1)–C(3)	114.1(4)
C(11)–C(12)–Cl(11)	134.8(3)	C(12)–C(13)–C(14)	87.0(4)

Table 3. Selected Bond Lengths (Å) and Bond Angles (deg) for $C_{18}H_{18}F_{12}N_4Cl_2$ (**2A**)

	Bond Distances		
C(12)–C(13)	1.519(5)	C(5)–C(1)	1.466(5)
C(13)–N(3)	1.488(5)	C(1)–C(2)	1.504(8)
N(3)–C(4)	1.347(4)	C(5)–Cl(2)	1.720(4)
C(4)–C(5)	1.358(5)		
	Bond Angles		
C(11)–N(4)–C(12)	112.8(3)	C(4)–N(3)–C(6)	120.5(3)
N(4)–C(12)–C(13)	113.1(3)	N(3)–C(4)–C(5)	132.3(3)
C(13)–N(3)–C(6)	116.8(3)	C(4)–C(5)–C(1)	114.4(3)
C(13)–N(3)–C(4)	121.3(3)	C(4)–C(5)–Cl(2)	129.6(3)

opposite side. The angles between the N–C and N–H bonds and the normal to the plane defined by the four N atoms have been calculated: N(1)–HN(1), 23.4°; N(2)–C(31), 159.2°; N(3)–C(21), 100.5°; N(4)–C(11), 136.2°. Here 0 and 180° correspond to the bond lying parallel to the plane normal to the plane of the N atoms (but on opposite sides), while 90° corresponds to the bond lying in the plane of the ring. Thus all three rings lie on the same side of the ring, opposite to the proton, with the chlorotetrafluorocyclobutenyl ring 1′ closest to parallel to the normal and ring 2′ lying closest to the plane of the four nitrogens. The orientations of the butenyl rings relative to the plane of the four N atoms of the macrocyclic amine are determined by calculating angles between the normals to the butenyl ring planes and the normal to the N atoms of this plane. For ring 1′ the angles are 44.1°; ring 2′, 36.4°; and ring 3′, 107.4°.

The crystal structure of compound **2A** is as expected with the rings situated on the nonadjacent N atoms of the tetraaza macrocyclic amine ring. Structure solution proceeded in a straightforward fashion, with identification of the principal sites for all non-hydrogen atoms obtained from the initial direct methods analysis. Upon refinement of their positional and anisotropic thermal parameters, substantial additional electron density is observed in the region of the fluorine atoms on the five-membered rings. This is readily interpretable in terms of a conformational disorder of the rings. This disorder is modeled in the following fashion: (1) all disordered C–F distances are loosely constrained to a common distance; (2) all disordered F–C–F angles are loosely constrained to 109.5°; (3) the disorder in ring 1 (atoms C(1)–C(5)) involves only C(2), while the disorder in ring 2 (atoms C(14)–C(18)) involves only C(17); (4) the disorder of F atoms in ring 1 involves the F atoms bonded to C(1) and C(2) while in ring 2 it involves C(16) and C(17); (5) common site occupancy factors are assigned to the disordered atoms for each conformation on each ring, with the additional constraint that the total occupancy is one for each ring; (6) anisotropic thermal parameters are utilized for the principal sites (unprimed labels, site occupancy factors of 0.919(6) and 0.882(8) for two rings respectively). Isotropic thermal parameters are used for the minor sites (primed labels).

With these constraints, the refinement proceeds in a straightforward fashion. Since both of the group occupancy factors lie within 3σ of the mean (0.900), it seems reasonable that the disorder is correlated.

In addition, the C–H protons are included at calculated positions with fixed isotropic thermal parameters ($U = 0.08$ Å^2). The sites for the N–H protons for each of the two secondary N atoms are determined by placing H atoms at both calculated sites on each N atom, followed by refinement of the isotropic thermal parameter. The site associated with each N atom which has the lowest U is retained.

It is interesting to compare the products in this study of secondary macrocyclic amines and dichloroperfluorocycloolefins with those from secondary acyclic amines, i.e., 1,2-dimethylethylenediamine and 1,3-dimethylpropylenediamine.[19] In the former case, we find that both monodentate and spiro compounds result with alkenes **2** and **3**, whereas only monodentate substitution occurs with **1**; i.e., ring closure does not occur. When 1,3-dimethylpropylene is reacted with **1**, **2**, or **3**, only acyclic products are observed, i.e., ring closure does not occur. Invariably only a single chlorine atom is replaced. In the case of the macrocyclic amines, it is somewhat surprising that only acyclic products are found; i.e., given the distortion observed in the macrocyclic ring of **1A**, it is expected that cyclization should occur.

Experimental Section

Reagents and solvents are obtained from Aldrich and used as received unless specifically noted. 1,4,7,10-Tetraazacyclododecane (**A**), 1,4,7,-10-tetraazacyclotridecane (**B**), 1,4,8,11-tetraazacyclotetradecane (**C**), 1,4,7,11-tetraazacyclotetradecane (**D**), 1,4,8,12-tetraazacyclopentadecane (**E**), and 1,5,9,13-tetraazacyclohexadecane (**F**) are prepared by literature methods[39] or received as gifts (3M Co.). 1,2-Dichlorotetrafluorocyclobutene-1 (**1**), 1,2-dichlorohexafluorocyclopentene-1 (**2**), and 1,2-dichlorooctafluorocyclohexene-1 (**3**) are obtained from PCR, Inc., and used without further purification. The structures of the reactants are given in Chart 1. Infrared spectra are recorded with a Perkin-Elmer 1710F infrared spectrometer as liquid films between KBr disks. KBr pellets are prepared for solid samples. The ^{19}F NMR spectra are obtained on a JEOL FX-90Q Fourier transform spectrometer operating at 84.26 MHz. $CDCl_3$ is used as the solvent with $CFCl_3$ as an external reference. Chemical shifts upfield from $CFCl_3$ are assigned negative values. The ^{1}H NMR spectra are obtained at 89.94 MHz. Melting points are determined with a Thomas-Hoover apparatus. Mass spectra are recorded with a VG 7070HS mass spectrometer at an ionization potential of 17 or 70 eV. Elemental analyses are performed by Beller Mikroanalytisches Laboratorium, Göttingen, Germany.

X-ray structural determination. Crystals are obtained for compounds **1A** and **2A** from an ether/hexane solvent mixture. The crystal data and details of measurements for compounds **1A** and **2A** are reported in Table 1. Diffraction intensities are collected at ambient temperature on a Siemens R3m/V X-ray diffractometer for compounds **1A** and **2A** with graphite monochromatized Mo-Kα radiation ($\lambda = 0.710\ 73$ Å). Indices hkl for compounds **1A** and **2A** are measured and all computations are carried out using the SHELXTL (version 5.1) structure solution package. The unit cell parameters are obtained from the least-squares fit of 25 reflections ($17° < 2\theta < 28°$ for **1A**; $3° < 2\theta < 60°$ for **2A**). Three standard reflections monitored every 97 reflections showed insignificant

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variations. The C–H protons are included at calculated positions with fixed isotropic thermal parameters ($U = 0.08$ Å^2). The sites for the N–H protons for each of the secondary N atoms are determined by placing H atoms at both calculated sites on each N atom followed by refinement of the isotropic thermal parameter. The site associated with each N atom which has the lowest U was retained.

General Procedure. All reactions are carried out in dilute solutions under an inert atmosphere. They are run on a 0.5–1.0 mmol scale in the presence of dry solvents in a 250-mL round-bottomed Pyrex flask equipped with a 14/20 ₮ ground glass joint and magnetic stirring bar. A stoichiometric amount of macrocyclic amine **A–F** is weighed and dissolved in 150–200 mL of dry benzene. Triethylamine is added to the flask in stoichiometric amount. The required amount of dichloroperfluorocycloalkene **1–3** is weighed and mixed in 10 mL of dry benzene and then added slowly to the flask with stirring. A water condenser is attached to the flask. After the reaction mixture is stirred under nitrogen for 30 min at 25 °C, it is heated at 60–90 °C in an oil bath with stirring. The reaction mixture is cooled and then filtered to remove the triethylamine hydrochloride that forms during the reaction. The filtrate is concentrated by distilling off the benzene and is then dried under vacuum. A solid or viscous oil is obtained and any remaining triethylamine hydrochloride is removed from all products by using a silica gel-G column with C_6H_6 as eluent.

Synthesis. 1,4,7-Tris(chlorotetrafluorocyclobutenyl)-1,4,7,10-tetraazacyclododecane (1A) is prepared as described above. Benzene is used as solvent at ~60 °C. A white crystalline solid is obtained in 46% yield (mp 137 °C). Spectral data obtained are as follows. IR (KBr pellet): 3117 w, 2967 s, 2942 s, 2876 m, 1630 s, 1410 s, 1303 vs, 1242 m, 1196 m, 1086 s, 979 m, 855 s, 765 m, 748 w cm^{-1}. NMR: ^{19}F δ −111.02 (6 F), −113.18 (6 F); ^{1}H δ 2.92 (m, 4 H), 3.47 (M, 8 H), 3.81 (m, 4 H), 1.55 (bs, 1 H); MS (FAB) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 646 (M^+) 1, 627 (M^+ − F) 40. Anal. Calcd for $C_{20}H_{17}N_4F_{12}Cl_3$: C, 37.15; H, 2.63. Found: C, 37.40; H, 2.20.

1,7-Bis(chlorohexafluorocyclopentenyl)-1,4,7,10-tetraazacyclododecane (2A) is prepared as above. Benzene is used as solvent, and heating is continued at ~80 °C for 24 h. A white crystalline solid is obtained in 60% yield (mp 135 °C). Spectral data obtained are as follows. IR (KBr pellet): 3140 m, 2928 vs, 2835 vs, 1630 vs, 1440 m, 1345 vs, 1200 vs, 1120 vs, 970 s, 800 m, 735 m, 600 m cm^{-1}. NMR: ^{19}F δ −108.30 (8 F), −130.15 (4 F); ^{1}H δ 3.71 (m, 8 H), 2.74 (m, 8 H), 1.35 (b, 2 H). MS (FAB) [*m*/*e* (species) intensity]: 588 (M^+) 100. Anal. Calcd for $C_{18}H_{18}N_4F_{12}Cl_2$: C, 36.70; H, 3.06. Found: C, 37.47; H, 3.26.

1-Mono(chlorooctafluorocyclohexenyl)-1,4,7,10-tetraazacyclododecane (3A) is prepared as described except that the reaction mixture is heated at reflux for 6 days. Recrystallization is done by using an ether/hexane (80/20) solvent mixture. A white, crystalline solid is obtained in 30% yield (mp 67 °C). Spectral data obtained are as follows. IR (KBr pellet): 3120 w, 2938 vs, 2890 vs, 2836 vs, 1630 s, 1462 s, 1341 vs, 1300 s, 1267 s, 1210 vs, 1173 s, 1114 s, 1066 m, 1023 s, 989 s, 958 ms, 903 m, 860 vs, 827 w, 811 m, 747 m cm^{-1}. NMR: ^{19}F δ −11.5 (4 F), −134.5 (2 F), −135.0 (2 F); ^{1}H δ 3.15 (m, 4 H), 2.69 (m, 4 H), 2.66 (m, 4 H), 2.53 (m, 4 H), 1.30 (bs, 3 H). MS (FAB) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 430 (M^+) 42.4. Anal. Calcd for $C_{14}H_{19}N_4F_8Cl$: C, 39.06; H, 4.42. Found: C, 38.5; H, 4.64.

1,4,7-Tris(chlorotetrafluorocyclobutenyl)-1,4,7,11-tetraazacyclotridecane (1B) is purified by using ether as solvent, and an oily liquid was obtained in 30% yield. Spectral data obtained are as follows. IR (KBr disks): 3419 w, 2936 m, 1656 vs, 1276 vs, 1126 s, 985 s, 868 m, 705 m, 640 w cm^{-1}. NMR: ^{19}F NMR δ −106.48 (6 F), −107.10 (6 F); ^{1}H δ 2.45–3.50 (m, 16 H), 2.25 (bs, 1 H), 1.40–1.80 (m, 2 H). MS (CI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 660 (M^+) 0.31, 641 (M^+ − F) 20.06.

1,7-Bis(chlorohexafluorocyclopentenyl)-1,4,7,10-tetraazacyclotridecane (2B) is prepared as described. The mixture is held at ~80 °C for 24 h. The compound is purified by using ether solvent, and a colorless oily liquid is obtained in 30% yield. Spectral data obtained are as follows. IR (KBr disks): 3420 w, 2955 m, 1626 vs, 1456 m, 1421 m, 1366 m, 1335 s, 1273 s, 1191 m, 1127 s, 1023 m, 985 s, 869 s, 750 s, 640 w, 623 w cm^{-1}. NMR: ^{19}F δ −107.78 (4 F), −109.40 (4 F), −129.44 (4 F); ^{1}H δ 2.55–3.20 (m, 16 H), 2.20 (bs, 2 H), 1.35–1.80 (m, 2 H). MS (CI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 602 (M^+) 28.41, 583 (M^+ − F) 100.

1-Mono(chlorooctafluorocyclohexenyl)-1,4,7,10-tetraazacyclotridecane (3B) is prepared as described earlier except that the mixture is heated at reflux for 6 days. Recrystallization is done by using an ether/hexane (80/20) solvent mixture, and a white solid is obtained in 25% yield (mp 130 °C). Spectral data obtained are as follows. IR (KBr pellet): 3274 m, 2930 s, 2823 s, 1656 ms, 1461 s, 1343 s, 1120 m, 1025 s, 975 m, 808 m, 730 m, 591 w cm^{-1}. NMR: ^{19}F δ −116.92 (2 F), −117.24 (2 F), 133.08 (2 F); ^{1}H δ 2.50–3.20 (m, 16 H), 2.30 (bs, 3 H), 1.35–1.85 (m, 2 H). MS (CI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 444 (M^+) 52.53, 425 (M^+ − F) 33.74.

1,4,8-Tris(chlorotetrafluorobutenyl)-1,4,8,11-tetraazacyclotetradecane (1C) is prepared by using benzene as solvent, and the reaction is heated at 60 °C for 24 h. Purification of **1C** is accomplished by using an ether/hexane (80/20) solvent mixture, and a colorless oil is obtained in 60% yield. Spectral data obtained are as follows. IR (KBr disks): 3290 vw, 2925 s, 2850 m, 1660 s, 1412 m, 1300 vs, 1084 vs, 1050 s, 972 m, 848 s, 712 s, 636 m cm^{-1}. NMR: ^{19}F δ −110.56 (6 F), −112.99 (6 F); ^{1}H δ 2.50–2.85 (m, 16 H), 1.65–1.80 (m, 4 H), 2.20 (bs, 1 H). MS (EI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 674 (M^+) 0.35, 655 (M^+ − F) 6.2.

1,8-Bis(chlorohexafluoropentenyl)-1,4,8,11-tetracyclotetradecane (2C) is prepared as described, and the reaction is held at ~80 °C for 24 h. Purification is achieved by using an ether/hexane (80/20) solvent mixture, which gives a colorless oil in 50% yield. Spectral data obtained are as follows. IR (KBR disks): 3390 m, 2942 s, 2860 m, 1635 s, 1460 ms, 1320 w, 1250 ms, 1115 s, 980 m, 810 ms, 650 w cm^{-1}. NMR: ^{19}F δ −106.33 (4 F), −108.53 (4 F), −128.63 (4 F); ^{1}H δ 2.54–2.73 (M, 16 H), 2.23 (bs, 2 H), 1.62–1.73 (m, 4 H). MS (EI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 616 (M^+) 4.94, 597 (M^+ − F) 22.53.

1-Mono(chlorooctafluorohexenyl)-1,4,8,11-tetraazacyclotetradecane (3C) is prepared under reflux for 6 days, and an ether/hexane (80/20) solvent mixture is used for purification. A white solid is obtained in 20% yield (mp 140 °C). Spectral data obtained are as follows. IR (KBr pellet): 3290 w, 2930 m, 2855 m, 1659 s, 1599 m, 1579 m, 1448 m, 1319 s, 1278 s, 1178 w, 1147 w, 942 w, 920 m, 811 m, 765 m, 702 m cm^{-1}. NMR: ^{19}F δ −107.49 (2 F), −109.17 (2 F), −132.56 (2 F), −134.18 (2 F); ^{1}H δ 2.65–3.0 (m, 16 H), 2.45 (bs, 3 H), 1.80–1.60 (m, 4 H). MS (CI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 458 (M^+) 25.43, 439 (M^+ − F) 18.62.

1,4,7-Tris(chlorotetrafluorocyclcobutenyl)-1,4,7,11-tetraazacyclotetradecane (1D) is prepared in benzene as solvent, and the reaction is run for 24 h at 60 °C. An ether/hexane (80/20) solvent mixture is used for purification. The product is a colorless oil in 60% yield. Spectral data obtained are as follows. IR (KBr disks): 3408 bm, 2960 s, 1631 m, 1295 s, 1262 s, 1090 vs, 973 m, 855 m, 800 m, 737 w, 602 w cm^{-1}. NMR: ^{19}F δ −112.08 (6 F), −113.14 (6 F); ^{1}H, δ 2.7–3.2 (m, 16 H), 2.5 (bs, 1 H), 1.70–1.95 (m, 4 H). MS (CI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 674 (M^+) 2.6, 655 (M^+ − F) 100.

1,7-Bis(chlorohexafluorocyclopentenyl)-1,4,7,11-tetraazacyclotetradecane (2D) is prepared at 80 °C for 24 h. The compound is purified by using a solvent mixture of ether/hexane (80/20) and is obtained as colorless oil in 30% yield. Spectral data obtained are as follows. IR (KBr disks): 3316 m, 2954 vs, 2810 vs, 1640 vs, 1472 s, 1424 s, 1260 vs, 1190 s, 1124 vs, 990 s, 860 m, 700 m, 625 m cm^{-1}. NMR: ^{19}F δ −106.21 (4 F), −108.53 (4 F), −128.40 (4 F); ^{1}H δ 2.80–3.25 (m, 16 H), 2.60 (bs, 2 H), 1.80–1.95 (m, 4 H). MS (CI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 616 (M^+) 27.91, 597 (M^+ − F) 100.

1-Mono(chlorooctafluorocyclohexenyl)-1,4,7,11-tetraazacyclotetradecane (3D) is prepared under reflux for 6 days with benzene as solvent. Recrystallization is accomplished by using an ether/hexane (80/20) solvent mixture. A white crystalline solid is obtained in 20% yield (mp 135 °C). Spectral data obtained are as follows. IR (KBr pellet): 3278 m, 2960 s, 2927 s, 2817 s, 1647 m, 1460 ms, 1345 s, 1288 s, 1090 bs, 1030 s, 845 s, 675 w cm^{-1}. NMR: ^{19}F δ −108.5 (2 F), −110.25 (2 F), −133.50 (2 F), −135.50 (2 F); ^{1}H δ 2.75–3.20 (m, 16 H), 2.5 (bs, 3 H), 1.70–1.95 (m, 4 H). MS (CI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 458 (M^+) 21.87, 439 (M^+ − F) 14.45.

1,4,8-Tris(chlorotetrafluorocyclohutenyl)-1,4,8,12-tetraazacyclopentadecane (1E) is prepared at 60 °C for 24 h. An ether/hexane (80/20) solvent mixture is used for purification. A colorless oil is obtained in 45% yield. Spectral data obtained are as follows. IR (KBr disks): 3398 m, 2935 s, 2850 m, 1662 vs, 1448 s, 1361 m, 1319 s, 1278 m, 1167 m, 1076 w, 1029 w, 968 m, 827 w, 756 s, 706 s cm^{-1}. NMR: ^{19}F δ −110.62 (6 F), −113.22 (6 F); ^{1}H δ 2.9–3.2 (m, 16 H), 2.3 (bs, 1 H), 1.75–2.20 (pent, 6 H). MS (CI^+) [*m*/*e* (species) intensity] (observed isotope ratios are correct): 688 (M^+) 0.38, 669 (M^+ − F) 20.53.

1,8-Bis(chlorohexafluorocyclopentenyl)-1,4,8,12-tetraazacyclopentadecane (2E) is prepared in a reaction at 80 °C for 24 h at 80 °C. An ether/hexane (80/20) solvent mixture is used to obtain the pure compound

as a colorless oil in 50% yield. Spectral data obtained are as follows. IR (KBr disks): 3190 w, 2925 vs, 2830 vs, 1630 vs, 1460 s, 1372 m, 1248 m, 1060 m, 936 m, 790 bs, 648 m cm^{-1}. NMR: ^{19}F δ −105.81 (4 F), −106.39 (4 F), −128.34 (4 F); ^{1}H δ 2.85–3.25 (M, 16 H), 2.3 (bs, 2 H), 1.80–2.25 (q, 6 H). MS (CI^+) [*m/e* (species) intensity] (observed isotope ratios are correct): 630 (M^+) 1.09, 611 ($M^+ - F$) 3.5.

1-Mono(chlorooctafluorocyclohexenyl)-1,4,8,12-tetraazacyclopentadecane (3E) is prepared by heating at reflux for 6 days. Recrystallization is accomplished by using an ether/hexane (80/20) solvent mixture. A white crystalline solid is found in 25% yield (mp 110 °C). Spectral data obtained are as follows. IR (KBr pellet): 3205 bs, 2931 s, 2857 s, 1637 s, 1438 w, 1341 m, 1280 m, 1189 m, 1146 m, 1024 s, 960 s, 824 m, 736 m, 700 m cm^{-1}. NMR: ^{19}F δ −107.90 (2 F), −109.52 (2 F), −132.70 (2 F), −134.52 (2 F); ^{1}H δ 2.65–2.95 (m, 16 H), 2.25 (bs, 3 H), 1.65–2.0 (q, 6 H). MS (EI^+) [*m/e* (species) intensity] (observed isotope ratios are correct): 472 (M^+) 13.0.

1,5,9-Tris(chlorotetrafluorocyclobutenyl)-1,5,9,13-tetraazacyclohexadecane (1F) is prepared by using benzene at 60 °C for 24 h. An ether and hexane solvent mixture (80/20) is used for purification, and a colorless oil is obtained in 60% yield. Spectral data obtained are as follows. IR (KBr disks): 3213 m, 2932 vs, 2867 vs, 2814 vs, 1662 vs, 1622 w, 1600 m, 1579 m, 1342 s, 1311 s, 1278 vs, 1260 s, 1198 m, 1143 vs, 920 m, 837 m, 734 s cm^{-1}. NMR: ^{19}F δ −108.80 (6 F), −133.75 (6 F); ^{1}H δ 2.7–2.95 (m, 16 H), 1.40–2.10 (m, 8 H), >NH (under ring CH_2 protons). MS (CI^+) [*m/e* (species) intensity] (observed isotope ratios are correct): 702 (M^+) 8.20.

1,9-Bis(chlorohexafluorocyclopentenyl)-1,5,9,13-tetraazacyclohexadecane (2F) is prepared as described in the general procedure. An ether/hexane (80/20) solvent mixture is employed for purification. A colorless oil is obtained in 50% yield. Spectral data obtained are as follows. IR (KBr disks): 3299 w, 2936 m, 2861 m, 1632 vs, 1476 m, 1468 m, 1276 vs, 1188 m, 1125 s, 980 m, 910 m, 866 m, 735 w cm^{-1}. NMR: ^{19}F δ −105.87 (4 F), −108.76 (4 F), −128.11 (4 F); ^{1}H δ 2.75–2.90 (m, 16 H), 1.45–2.20 (m, 8 H), >NH protons (under ring CH_2 protons). MS (CI^+) [*m/e* (species) intensity] (observed isotope ratios are correct): 644 (M^+) 2.70, 624 ($M^+ - HF$) 31.83.

1-Mono(chlorooctafluorocyclohexenyl)-1,5,9,13-tetraazacyclohexadecane (3F) is prepared by using benzene as solvent and is heated at reflux for 6 days. An ether/hexane (80/20) solvent mixture is used for purification and recrystallization. A crystalline solid is obtained in 20% yield (mp 142 °C). Spectral data obtained are as follows. IR (KBr pellet): 3286 m, 2927 vs, 2818 s, 1637 m, 1561 w, 1487 m, 1365 m, 1300 s, 1165 s, 1129 vs, 1072 m, 920 w, 732 s cm^{-1}. NMR: ^{19}F δ −106.16 (2 F), −107.14 (2 F), −132.33 (2 F), 133.89 (2 F); ^{1}H δ 2.60–2.45 (m, 16 H), 1.50–2.0 (m, 8 H), >NH protons (under ring CH_2 protons). MS (CI^+) [*m/e* (species) intensity] (observed isotope ratios correct): 486 (M^+) 0.93, 467 ($M^+ - F$) 1.09.

Acknowledgment. We are grateful to the National Science Foundation (Grant CHE-9003509) and the Air Force Office of Scientific Research (Grant 91-0189) for support of this research. We thank Gary Knerr for mass and ^{19}F NMR spectral data, and Dr. J. E. Richman, 3M Co., St. Paul, MN, for providing the macrocyclic amines.

Supplementary Material Available: Listings of isotropic thermal and positional parameters, bond distances, bond angles, anisotropic thermal parameters, and hydrogen atom parameters (15 pages). Ordering information is given on any current masthead page.