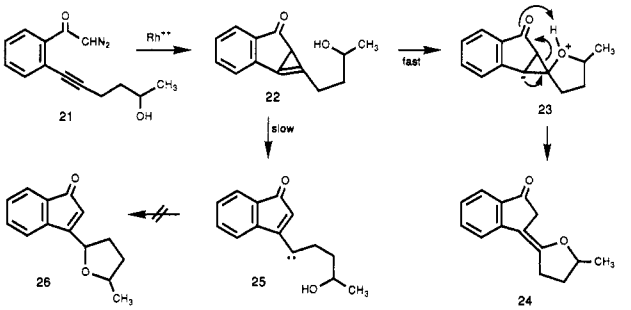
and 52% yield, respectively.

We have carried out a number of experiments designed to provide evidence for the intermediacy of a strained cyclopropene in these transformations. Our strongest evidence for a cyclopropene comes from studies which take advantage of the addition reaction of alcohols with cyclopropenes.[17] Compound **21** was prepared by treating methyl (*o*-bromophenyl)benzoate with the ethylene ketal of hex-1-yn-5-one under typical Heck arylation conditions.[18] The palladium-coupled product was easily converted into **21** using traditional methods. A sample of **21** was allowed to react with rhodium(II) mandelate in benzene at 25 °C. The only product isolated in 85% yield corresponded to structure **24**.[19] No signs of product **26** derived by vinylcarbene insertion into the neighboring OH group could be detected in the crude reaction mixture. We can account for **24** in the following manner. Intramolecular addition of the rhodium stabilized carbenoid onto the acetylenic π-bond generates the highly strained cyclopropene **22**. This species is too strained to survive at ambient temperature, but attack of the hydroxyl group onto the double bond would result in **23**, which rapidly undergoes ring cleavage to give **24**. In this case, intramolecular nucleophilic addition of the hydroxyl group on the cyclopropene ring is faster than ring opening to vinylcarbene **25**, which if formed, would have produced indenone **26**.



In conclusion, the facility with which the intramolecular rhodium(II)-catalyzed cyclization reaction of alkynyl-substituted diazo ketones occurs makes this process particularly attractive for the synthesis of a variety of polycyclic ring systems. We are continuing to explore the scope and mechanistic details of these cyclization reactions and will report additional findings at a later date.

Acknowledgment. We gratefully acknowledge support of this work by the National Institutes of Health and the National Science Foundation. Use of the high-field NMR spectrometer used in these studies was made possible through a NSF equipment grant. U.C. thanks the NATO Foundation for a travel grant and the MPI for partial financial support.

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(19) All new compounds were characterized by ^{1}H and ^{13}C NMR, by high-resolution mass spectra, and by proper analytical data: NMR **24** ($CDCl_3$, 300 MHz) δ 1.39 (d, 3 H, J = 6.2 Hz), 1.70-1.85 (m, 1 H), 2.25-2.40 (m, 1 H), 2.85-3.10 (m, 2 H), 3.25 (s, 2 H), 4.50 (m, 1 H), 7.18 (t, 1 H, J = 7.5 Hz), 7.41 (d, 1 H, J = 7.5 Hz), 7.55 (t, 1 H, J = 7.5 Hz), and 7.35 (d, 1 H, J = 7.5 Hz).

Articles

Chemistry and Structure of Phenylcubanes

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Phenylcubanes show unusual reactivity toward metalation and oxidation. Metalation of 1,4-bis((diisopropylamino)carbonyl)-2,7-diphenylcubane, **1**, occurs at the cubane skeleton while oxidation of 1,4-bis((diisopropylamino)methyl)-2,7-diphenylcubane, **7**, resulted in the formation of benzoic acid. The X-ray structure of **7** shows a short phenyl-cubane bond length of 1.484 Å, and the C_1-C_2 bond, the cubane bond between the two substituents, is substantially longer than in an unsubstituted cubane (1.607 vs 1.558 Å). The selective functionalization of either the phenyl or the cubane moiety and the synthesis of 1,4-diphenylcubane-2,7-dicarboxylic acid, **8**, via oxidation of the (diisopropylamino)methyl group under mild conditions, were achieved.

There has been renewed interest in the chemistry of cubane since some of its derivatives, particularly nitrocubanes, have shown promise as high-density energetic materials.[1] In this connection we became interested in

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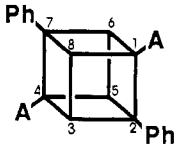
the synthesis and chemistry of phenylcubanes.[2] The exceptional strain energy (166 kcal/mol)[3] and rigid framework of the cubane skeleton, combined with the well-developed chemistry of phenyl groups, also suggests promise for phenylcubanes in pharmaceuticals and polymers.

Our main objective was to synthesize diphenylcubane diamide 1, a potential precursor to polysubstituted phenylcubanes. In this compound the amide groups should not only serve to direct further functionalization, but also can be converted to carboxyl groups and ultimately to nitro groups.[4]

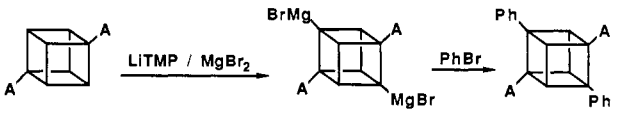


1

In our recent communication,[5] a novel method for introducing phenyl groups on the cubane skeleton was employed. Ortho-directed metalation of cubane diamide 2 followed by direct introduction of phenyl groups via in situ formation of a benzyne intermediate gave diphenylcubane diamide 1. We now report in more detail the synthesis and unusual chemistry of 1.

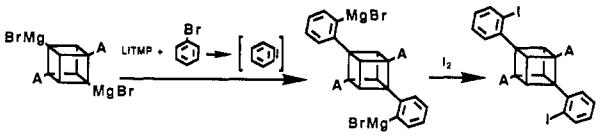
Results and Discussion

Reaction of 1,4-bis(aminocarbonyl)cubane 2 with excess LiTMP/$MgBr_2$ gave the diGrignard intermediate 3 directly. The direct formation of diGrignard 3 is of interest since many tetrasubstitued cubanes now can be obtained from it on a large scale within short period of time without using toxic chemicals.[5,6] Subsequent reaction of 3 with bromobenzene gave diphenylcubane diamide 1 in 53% yield.



2 3 1

We postulate a mechanism in which a benzyne intermediate is formed in situ from the reaction of excess LiTMP with bromobenzene. Benzyne subsequently reacts with diGrignard 3 to give intermediate 4,[7] a potential precursor for phenyl-substituted cubanes. For example, quenching intermediate 4 with iodine gave (iodophenyl)-cubane 5.



3 4 5

The structure of 5 was clear from its ^1H and ^{13}C NMR spectra. the 300-MHz ^1H NMR spectrum shows a four-proton singlet at δ 4.62 for the cubane protons and three resonances for the phenyl protons with a two-proton multiplet at δ 6.93, a four-proton multiplet at δ 7.33, and a two-proton doublet at δ 7.84 ppm. Carbon-13 NMR shows six resonances for the phenyl carbons with Ph–I carbon at δ 96.2 ppm, completely consistent with ortho-substituted (iodophenyl)cubane 5.

In this reaction four major events occur in one pot. They are the formation of diGrignard 3, benzyne,[8a] the phenyl–cubane bond and substitution on the phenyl ring. Other functionalization of the benzene ring should also be possible. For example, treatment of 4 with CO_2 should give the corresponding *o*-cubylbenzoic acid. The use of dibromobenzene instead of bromobenzene should result in the formation of dibenzyne and ultimately a polymeric phenylcubane product.[8b]

In pursuit of more highly substituted phenylcubanes, and to study the effect of phenyl groups on the cubane skeleton, we attempted the metalation of 1. A study by Stock and co-workers on base-catalyzed hydrogen–isotope exchange showed that cubane is as acidic as benzene.[9] Amido group substitution on cubane should increase the acidity of the cubane skeleton.[10,11] Although benzene and many other aromatic hydrocarbons can be readily metalated by *n*-BuLi/TMEDA,[12] cubane diamide gives only a small amount of the dilithiated product under these reaction conditions.[10] It was therefore, of interest to see whether the metalation of 1 occurs on the phenyl ring or on the cubane skeleton. In our initial attempts the reaction of compound 1 with LiTMP or *n*-BuLi/TMEDA under various reaction conditions gave no lithiated product.[13c]

(1) Recent calculations for octanitrocubane have predicted the crystal structure and a crystal density of 1.991 g cm^{-3} (Ammon, H. L.; Du, Z., unpublished results); other density predictions have gone as high as 2.1 g cm^{-3}.

(2) For a history and the summary of work on attempted syntheses of phenylcubanes, see: Barborak, J. C. Ph.D. Thesis, The University of Texas at Austin, 1968. Freedman, H. H. *J. Am. Chem. Soc.* **1961**, *83*, 2195. Freedman, H. H.; Petersen, D. R. *J. Am. Chem. Soc.* **1962**, *84*, 2837. Büchi, G.; Perry, C. W.; Rob, E. W. *J. Org. Chem.* **1962**, *27*, 4106. Tsutsui, M. *Chem. Ind. (London)* **1962**, 780. Cookson, R. C.; Jones, D. W. *Proc. Chem. Soc.* **1963**, 115. Freedman, H. H.; Gohlke, R. S. *Proc. Chem. Soc.* **1963**, 249. Pawley, G. S.; Lipscomb, W. N.; Freedman, H. H. *J. Am. Chem. Soc.* **1964**, *86*, 4725. Throndsen, H. P.; Wheatley, P. J.; Zeiss, H. *Proc. Chem. Soc.* **1964**, 357. Slobodin, Ya. M.; Khitrov, A. P. *Zh. Org. Khim.* **1970**, *6*, 1751. Slobodin, Ya. M.; Aleksandrov, I. V.; Khitrov, A. P. *Ibid.* **1977**, *13*, 1377. For other attempted syntheses, see ref 5.

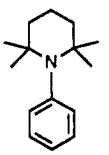
(3) Allinger, N. L.; Tribble, M. T.; Miller, M. A.; Wertz, D. *J. Am. Chem. Soc.* **1971**, *93*, 1637. Engler, E. M.; Andose, J. D.; Schleyer, P. V. R. *J. Am. Chem. Soc.* **1973**, *95*, 8005.

(4) For the synthesis of 1,4-dinitrocubane from cubane-1,4-dicarboxylic acid, see: Eaton, P. E.; Ravi Shankar, B. K.; Price, G. D.; Pluth, J. J.; Gilbert, E. E.; Alster, J.; Sandus, O. *J. Org. Chem.* **1984**, *49*, 185.

(5) Bashir-Hashemi, A. *J. Am. Chem. Soc.* **1988**, *110*, 7234.

(6) For indirect formation of diGrignard 3 via reverse transmetalation reaction, see: Eaton, P. E.; Cunkle, G. T.; Marchioro, G.; Martin, R. M. *J. Am. Chem. Soc.* **1987**, *109*, 948.

(7) In a competitive reaction LiTMP reacts with benzyne to give *N*-phenyl-2,2,6,6-tetramethylpiperidine, III, as a major product: ^1H NMR ($CDCl_3$) δ 0.93 (s, 12 H), 1.55 (m, 4 H), 1.70 (m, 2 H), 7.22 (m, 5 H).



III

(8) (a) For the chemistry of benzyne, see: Hoffman, R. W. *Dehydrobenzene and Cycloalkynes*; Academic Press: New York, 1967. (b) For a skillful use of dibenzyne for the construction of polyphenyl compounds, see: Du, C.-J. F.; Hart, H.; Ng, K.-K. D. *J. Org. Chem.* **1986**, *51*, 3162. Harada, K.; Hart, H.; Du, C.-J. F. *J. Org. Chem.* **1985**, *50*, 5524.

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(10) Eaton, P. E.; Castaldi, G. *J. Am. Chem. Soc.* **1985**, *107*, 724 and references therein.

(11) For a theoretical calculation, see: Jayasuriya, K.; Alster, J.; Polizer, P. *J. Org. Chem.* **1987**, *52*, 2306.

(12) Rausch, M. D.; Ciappenelli, D. J., *J. Organomet. Chem.* **1967**, *10*, 127. Neugebauer, W.; Kos, A. J.; Schleyer, P. V. R. *J. Organomet. Chem.* **1982**, *228*, 107.

(13) (a) For excellent reviews, see: Gschwend, H. W.; Rodrigues, H. R. *Org. React. (N.Y.)*. **1979**, *26*, 1. Beak, P., Meyers, A. I. *Acc. Chem. Res.* **1986**, *19*, 356. (b) Beak, P.; Snieckus, V. *Acc. Chem. Res.* **1982**, *15*, 306. (c) At elevated temperatures, however, aryl- or alkyllithiums slowly add to diisopropylamide group (see also ref 6).

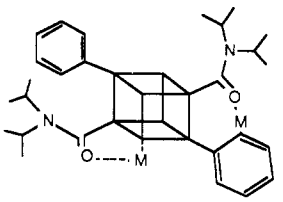
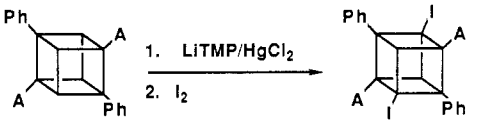


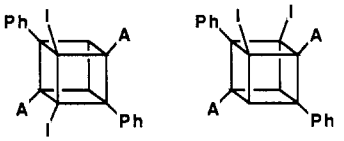
Figure 1.

However, use of a 10-fold excess of LiTMP with 4 equiv of $HgCl_2$ at 0 °C in THF, followed by quenching with I_2, gave compound **6**, a hexasubstituted cubane with three chemically different substituents, in 68% yield.



1 6

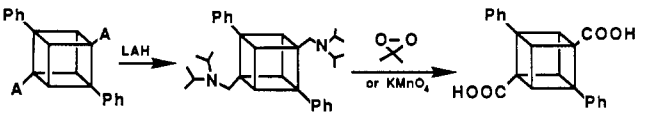
Assignment of the structure is based on the ^1H and ^{13}C NMR spectra. The 300-MHz ^1H NMR spectrum shows that the two-proton singlet on the cubane skeleton moved downfield to δ 5.31 ppm; the phenyl protons appeared as a 10-proton multiplet. The decoupled ^{13}C NMR shows four resonances for the cubyl carbons, as required by the symmetry of **6**. The cubyl–I carbon comes at δ 44.6 as a singlet, cubyl-H carbon at δ 55.0 as a doublet (J = 168 Hz), and the other quaternary cubane carbons at δ 66.15 and δ 66.39 ppm. The phenyl group shows four resonances as required. The 1,2-diiodo and 1,3-diiodo isomers I and II are eliminated on the following grounds. The 1,2-isomer requires the unfavorable formation of an intermediate with two adjacent anionic centers. The ^{13}C NMR spectrum of II should give an unsymmetric resonance pattern with six different cubane carbons.



I II

The regioselectivity of the metalation might be due to increased acidity of the cubane protons caused by the phenyl groups. Our failure to metalate the phenyl groups with *n*-BuLi/TMEDA supports this conclusion. The proximity of the cubane protons to the amide carbonyl might be another factor in determining the metalation site. The ortho protons of the phenyl group seem to be closer than the cubane protons to the amide carbonyl. However, X-ray data show (vide infra) that the phenyl groups are staggered with respect to the cubane C_1–C_2 bond causing the phenyl protons to be further than the cubane protons from the carbonyl of the amide group. Furthermore, metalation of cubane via amide ortho-directing activation should go through the more favored five-membered ring intermediate, rather than the unfavored seven-membered ring intermediate required for phenyl metalation[13a] (Figure 1).

In order to synthesize dicarboxylic acid **8** a potential precursor to polynitrocubanes,[4] we have sought conditions in which the amide group could be converted to a carboxyl group without affecting the cubane skeleton. Conversion of a diisopropyl amide group to a carboxyl group is difficult process.[13b] Hydrolysis under strongly acidic or basic conditions was unsuccessful. However, when compound **1** was reduced with $LiAlH_4$ in THF and the product reacted with dimethyldioxirane or $KMnO_4$ in aqueous base at room temperature, the diphenylcubanedicarboxylic acid **8** was obtained in 25% and 45% yields., respectively.[14]



1 7 8

The ^1H NMR spectrum of **8** in DMSO shows a four-proton singlet at δ 4.35 for the cubane protons with two sets of multiplets at δ 7.27 and 7.36 for the phenyl protons. Mass spectral and elemental analysis data were in agreement with structure **8**.

To our surprise, reaction of **7** with hot or concentrated $KMnO_4$ solution or $KMnO_4/CH_2Cl_2$ gave mostly benzoic acid. We found that slow addition of the oxidizing reagent to the reaction mixture is important since oxidation of the (diisopropylamino)methyl group competes with oxidation of the cubane skeleton. This unusual susceptibility of the cubane skeleton to oxidation might be attributed to the increased p character of the endocyclic C_1–C_2 bond due to the increased bond distance (1.607 vs 1.558 Å) between the two substituted carbons.[15]

X-ray Structure of Phenylcubane 7. In order to obtain the phenyl–cubane bond distance, an X-ray structure of compound **7** was determined. The molecular geometry of **7** exhibits some interesting features.

Excluding C_1–C_2, the cubane bond between the carbon atoms containing the phenyl and (diisopropylamino)-methyl substituents, the three unique cubane C–C bond lengths average 1.558 (5) Å. This value is similar to other normal cubane distances.[16] The C_1–C_2 length of 1.607 (4) Å clearly is stretched by its substituents. There is only one other example of a 1,2-disubstituted cubane (2-(*tert*-butylcubyl)cubane)[16] in which the appropriate C–C distance is 1.606 (6) Å. In these examples, both of the substituent-to-cubane bonds are shorter than would be expected from noncubane examples. In compound **7** the C_2–C_{11} (cubane–CH_2) and C_1–C_5 (cubane–phenyl) distances of 1.502 (5) and 1.484 (4) Å, respectively, suggest that the cubane orbitals used in the formation of the exocyclic bonds have substantially more s character than a typical sp^3 orbital. This s character explanation for observed bond shortening has been advanced in other instances.[16]

The exocyclic bond angles at C_1 and C_2 that face each other (124.6 (3), 124.7 (3)° are smaller than the external angles (126.3 (4)°) average) at these atoms. This is unexpected since the C_5–C_1–C_2–C_{11} fragment is almost perfectly eclipsed with a 1.0 (4)° dihedral angle. The phenyl groups are in a staggered conformation relative to the C_2–C_1 bond of cubane (C_2–C_1–C_5–C_6 = 99.2 (4)°).

Some selected interatomic distances and angles are given in Figure 2.

In conclusion we have developed a methodology for the practical synthesis of highly substituted cubanes. A novel method employing a benzyne intermediate was applied to the synthesis of phenylcubanes. This methodology provides a route to higher substituted phenylcubanes by the

(14) The application of this novel reaction in other instances will be published jointly with Professor P. E. Eaton. We appreciate the advice of Prof. P. E. Eaton and the collaboration of Dr. C.-Xi Yang throughout this research.

(15) Allinger, N. L.; Eaton, P. E. *Tetrahedron Lett.* **1983**, *24*, 3897. Hoffman, R.; Davidson, R. B. *J. Am. Chem. Soc.* **1971**, *93*, 5699.

(16) Gilardi, R.; Magini, M.; Eaton, P. E. *J. Am. Chem. Soc.* **1988**, *110*, 7232.

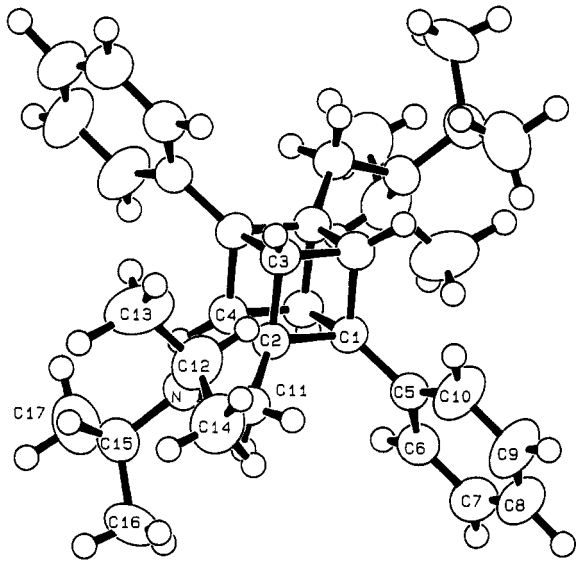


Figure 2. ORTEP view of 1,4-bis((diisopropylamino)methyl)-2,7-diphenylcubane (**7**). The center of the cage is coincident with a crystallographic center of symmetry. In the following lists, unprimed and primed atoms are related by this symmetry operation. Selected bond distances, Å: C_1–C_5 = 1.484 (4); C_1–$C_{4'}$ = 1.556 (4); C_1–$C_{3'}$ = 1.569 (5); C_1–C_2 = 1.607 (4); C_2–C_{11} = 1.502 (5); C_2–C_4 = 1.559 (4); C_2–C_3 = 1.566 (5); C_3–$C_{4'}$ = 1.552 (5). Selected bond angles, deg: C2–C1–C3′ = 88.7 (2); C2–C1–C4′ = 88.9 (2); C3′–C1–C4′ = 89.9 (2); C2–C1–C5 = 124.6 (3); C4′–C1–C5 = 126.4 (3); C3–C1–C5 = 126.5 (3); C1–C2–C4 = 89.3 (2); C1–C2–C3 = 89.1 (2); C3–C2–C4 = 89.9 (2); C1–C2–C11 = 124.7 (3); C3–C2–C11 = 126.6 (3); C4–C2–C11 = 125.6 (3); C1′–C3–C2 = 89.7 (2); C1′–C3–C4′ = 90.9 (2); C2–C3–C4′ = 90.5 (2); C1′–C4–C2 = 90.4 (2); C1′–C4–C3′ = 91.5 (3); C2–C4–C3′ = 91.1 (2).

selective functionalization of either the phenyl or cubane skeleton. Diisopropylcarboxamide, a potential ortho-directing group was converted to the carboxylic acid under mild reaction conditions.

Experimental Section

NMR spectra were recorded on a Bruker or G.E. 300-MHz spectrometer using $CDCl_3$ as solvent. All chemical shifts are reported in ppm, downfield from internal tetramethylsilane. Mass spectra were measured on a Finnegan OWA 1020B. IR spectra were recorded on a Perkin-Elmer 467 spectrometer. All melting points are uncorrected. Cubane-1,4-dicarboxylic acid was purchased from EniChem, Italy.

1,4-Bis((diisopropylamino)carbonyl)-2,7-diphenylcubane (1). *n*-Butyllithium (20 mmol in 12.5 mL of hexane) was added slowly to a stirred solution of 2,2,6,6-tetramethylpiperidine (TMPH) (3.4 mL, 20 mmol) in 50 mL of dry THF at −78 °C under argon. The solution was allowed to reach 0 °C in 30 min, and then anhydrous magnesium bromide etherate (Aldrich, 2.5 g, 10 mmol) and cubane diamide **2**[10] (0.5 g, 1.4 mmol) were added all at once. The reaction mixture was stirred at 0 °C for 12 h. Bromobenzene (2.0 mL, 20 mmol) was added to the light brown solution at 0 °C. After being stirred at room temperature for 1.0 h, the reaction mixture was quenched with water. Solvents were removed under reduced pressure. The residue was dissolved in 100 mL of CH_2Cl_2 and 100 mL of 10% aqueous HCl and separated. The organic phase was washed with 10% aqueous HCl (3 × 20 mL) and then with brine and dried over anhydrous Na_2SO_4. The solvent was removed in vacuo, and the resulting dark solid was triturated with MeOH (2.0 mL) to give 330 mg of **1** as a white solid. An analytical sample was obtained by recrystallization from acetone: mp 180–181 °C; ^1H NMR δ 0.6 (d, J = 6.8 Hz, 12 H), 1.28 (d, J = 6.8 Hz, 12 H), 3.06 and 3.20 (septets, J = 6.8 Hz, 2 H each), 4.45 (s, 4 H), 7.20–7.40 (m, 10 H); ^{13}C NMR δ 20.4, 20.6, 45.8, 47.0, 48.8, 59.4, 60.1, 125.9, 126.9, 128.5, 138.9, 168.1 ppm; MS (EI) 510 (M^+), 467, 411, 382, 283, 252 (100), 128, and 100; IR (KBr) 1630, 700 cm^{-1}. Anal. Calcd for $(C_{34}H_{42}O_2N_2)$: C, 80.00; H, 8.23; N, 5.49. Found: C, 79.78; H, 8.46; N, 5.32.

From the methanol solution was obtained 56 mg of cubane diamide **2** and 1.4 g of *N*-phenyl-2,2,6,6-tetramethylpiperidine hydrochloride:[7] mp 200 °C; ^1H NMR δ 1.40 (s, 6 H), 1.67 (s, 6 H), 3.10 (m, 6 H), 7.48 (m, 5 H).

2,7-Bis(*o*-iodophenyl)cubane-1,4-dicarboxamide (5). To a solution of LiTMP (10 mmol) in 50 mL of THF at 0 °C under argon were added **2** (180 mg, 0.5 mmol) and anhydrous magnesium bromide etherate (0.5 g, 2.0 mmol) all at once. The reaction mixture was stirred at 0 °C for 10 h. To the light brown solution at 0 °C was added bromobenzene (1.0 mL, 10 mmol), and after 0.5 h, iodine (2.54 g, 10 mmol). The reaction mixture was stirred for 2 h at 0 °C. The solvents were removed under reduced pressure. The residue was dissolved in 50 mL of CH_2Cl_2 and 50 mL of 10% aqueous HCl and separated. The organic phase was washed with 20 mL of 10% aqueous HCl and then with 10% aqueous $Na_2S_2O_3$ and, finally, with brine. The extract was dried (Na_2SO_4), and the solvent was removed in vacuo. The solid residue was chromatographed over silica gel using CH_2Cl_2/EtOAc, 10:1, as eluent to give 110 mg of **5** as a colorless solid: mp 180–182 °C dec; ^1H NMR δ 0.61 (d, J = 6.8 Hz, 12 H), 1.33 (d, J = 6.8 Hz, 12 H), 3.11 (septets J = 6.8 Hz, 2 H), 3.21 (septets, J = 6.8 Hz, 2 H), 4.62 (s, 4 H), 6.93 (m, 2 H), 7.33 (m, 4 H), 7.84 (d, 2 H); ^{13}C NMR δ 20.6, 20.8, 45.5, 45.7, 48.9, 58.7, 65.0, 96.2, 128.1, 128.6, 129.3, 139.7, 141.4, 168.7; MS (CI) 763 $(M + 1)^+$, 747, 717, 677, 665, 637 (100), 511, 281, 252, 157, 143, 129; IR (KBr) 1635, 1020, 720 cm^{-1}. Anal. Calcd for $(C_{34}H_{40}N_2O_2I_2)$: C, 53.54; H, 5.25; N, 3.67. Found: C, 53.26; H, 5.58; N, 3.60.

3,6-Diiodo-2,7-diphenylcubane-1,4-dicarboxamide (6). To a solution of LiTMP (10.0 mmol) in 50 mL of THF at 0 °C under argon were added **1** (510 mg, 1.0 mmol) and mercuric chloride (1.0 g, 4.0 mmol) in one portion. The reaction mixture was stirred at 0 °C for 8 h. To the light brown solution at 0 °C was added water (2.0 mL) and, after 30 min, iodine (2.0 g, 8.0 mmol). The mixture was stirred overnight. The solvents were removed under reduced pressure, and the residue was dissolved in CH_2Cl_2 (50 mL) and 10% aqueous HCl (50 mL). The organic phase was separated and washed successively with 10% aqueous HCl (20 mL), 10% aqueous $Na_2S_2O_3$ (30 mL), and brine. The extract was dried (Na_2SO_4), and the solvent was removed in vacuo. The solid residue was triturated with methanol (2.0 mL) to give **6** as a colorless solid (520 mg, 68%). A pure sample was recrystallized from acetone/CH_2Cl_2: mp 190–192 °C dec; ^1H NMR ($CDCl_3$) δ 0.20 (d, J = 6.8 Hz, 6 H), 1.12 (d, J = 6.8 Hz, 6 H), 1.35 (d, J = 6.8 Hz, 12 H), 3.20 (septets, J = 6.8 Hz, 2 H), 3.45 (septets, J = 6.8 Hz, 2 H), 5.31 (s, 2 H), 7.26–7.46 (m, 10 H) ppm; ^{13}C NMR δ 19.8, 20.1, 20.5, 23.9, 44.6 (cubyl-I), 46.5, 49.3, 55.0 (cubyl-H), 66.15, 66.39, 127.1, 128.2, 128.3, 136.3, 164.3 ppm; MS (EI) 762 (M^+), 662, 635, 507, 487, 281, 252 (100). Anal. Calcd for $C_{34}H_{40}N_2O_2I_2$: C, 53.54; H, 5.25; N, 3.67. Found: C, 53.38; H, 5.45; N, 3.56.

1,4-Bis((diisopropylamino)methyl)-2,7-diphenylcubane (7). Lithium aluminum hydride (380 mg, 10 mmol) was added to a suspension of **1** (510 mg, 1 mmol) in 50 mL of THF at 0 °C. The mixture was refluxed overnight under argon. The stirred suspension was cooled to 0 °C. Ethyl acetate (6.0 mL) was added dropwise, followed by a saturated aqueous solution of potassium sodium tartrate (2.0 mL). The mixture was stirred for 20 min at room temperature and filtered through Celite. The solution was dried (Na_2SO_4) and concentrated. The resulting solid was triturated with acetone (2.0 mL) to give **7** (450 mg, 93%) as a colorless solid: mp 142–143 °C; ^1H NMR ($CDCl_3$) δ 0.76 (d, J = 6.8 Hz, 24 H), 2.53 (s, 4 H), 2.75 (septets, J = 6.8 Hz, 4 H), 3.95 (s, 4 H), 7.14–7.35 (m, 10 H); ^{13}C NMR δ 20.6, 43.9, 46.5, 47.5, 58.3, 59.0, 125.3, 126.0, 127.9, 141.0; MS (EI) 482 (M^+), 467, 439, 396, 381, 368, 281 (100), 252; IR (KBr) 1600, 700 cm^{-1}.

1,4-Diphenylcubane-2,7-dicarboxylic Acid (8). To a well-stirred suspension of **7** (240 mg, 0.5 mmol) in 50 mL of 1% aqueous NaOH at room temperature was added dropwise a solution of $KMnO_4$ (3.0 g, 20 mmol) in 100 mL of distilled water. The mixture was stirred at room temperature for 6 h. The excess of $KMnO_4$ was reduced with a saturated aqueous $Na_2S_2O_3$, and the resulting MnO_2 was filtered through Celite. The filterate was acidified with concentrated aqueous HCl, and organic materials were extracted with ethyl acetate (3 × 20 mL). The organic layer was washed with brine and dried (Na_2SO_4). The solvent was removed in vacuo, and the resulting solid was triturated with

acetone (1.0 mL) to give 8 (76 mg, 45%): mp 168–170 °C dec; ^{1}H NMR (DMSO) δ 4.35 (s, 4 H), 7.27–7.36 (m, 10 H), 12.60 (s, 2 H); MS (CI) 345 (M + 1)$^+$, 327 (100), 301, 299, 283, 271, 257, 198, 99; IR (KBr) 1680, 680 cm^{-1}. Anal. Calcd for $C_{22}H_{16}O_4$: C, 76.74; H, 4.65. Found: C, 76.46; H, 4.85. ^{1}H NMR of methyl ester of 8 (MeOH/cat. CH_3SO_3H/reflux/6 h) ($CDCl_3$) δ 3.48 (s, 6 H, 4.48 (s, 4 H), 7.21 (m, 6 H), 7.36 (m, 4 H). From the acetone solution was obtained 62 mg of benzoic acid.

When a solution of 7 (240 mg, 0.5 mmol) in a 0.06 M solution of dimethyldioxirane[17] in wet acetone (100 mL, 6.0 mmol) was stirred at room temperature for 12 h, the yield of 8 was only 25%.

X-ray Crystallographic Determination of 7. Rectangular-shaped crystals were obtained from methylene chloride/hexane solution. A 0.25 × 0.3 × 0.4 mm crystal was used for X-ray data measurements with Mo Kα radiation (λ = 0.710 69 Å; incident beam graphite monochromator) on an Enraf-Nonius CAD-4 diffractometer. Monoclinic space group, $P2_1/n$; a = 9.641 (2) Å, b = 15.900 (5) Å, c = 10.864 (2) Å, β = 117.92 (1)°; Z = 2.; ρ_{calcd} = 1.03 g cm^{-3}. A total of 3322 reflections measured to $2\theta_{max}$ = 50°; 2648 unique data; 1348 with $I > 3\sigma(I)$. Crystallographic calculations were done on a Digital Equipment Corp. MicroVax II computer with the TEXSAN system of programs.[18a] Structure solution by the MITHRIL direct methods[18b] subroutine of TEXSAN. Structure refinement by full-matrix least-squares method with anisotropic temperature factors for C and N, and isotropic terms of H; minimization of $\sum w(F_o - F_c)^2$, $w = 1/\sigma^2(F_o)$. Final R, R_w, and goodness-of-fit values of 0.054, 0.060, and 2.0, respectively. Tables of atomic coordinates and temperature factors and bond lengths and angles are available as supplementary material.

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Supplementary Material Available: Full table of crystallographic data, bond distances and angles, anisotropic thermal parameters, and hydrogen coordinates for 7 (6 pages). Ordering information is given on any current masthead page.

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New Tetraheterocyclic Macrocycles Containing Triazole, Pyrazole, Pyridine, and/or Furan Subunits. Synthesis and Cation Binding Properties

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Ten new tetraheterocyclic macrocyclic ligands **2–4** in the porphyrinogen series were prepared. Their structures differ from **1** in (1) the type of junction between hetrocycles (NCH_2C or CCH_2C), (2) the donor nature of the complexation sites, (3) the five- or six-membered geometry of the included heterocycles, and (4) their symmetry. The capabilities of **2–4** for extraction and transport of alkali metal and NH_4^+ cations were less than those of **1**. The rigid dipyrazole ditriazole macrocycles **3** extract Na^+ selectively, whereas the more flexible dipyrazole monotriazole monopyridine macrocycles **2** have the best transport selectivity for Na^+.

Introduction

Synthetic polydentate macrocyclic receptors containing oxygen donor atoms, such as crown ethers,[1,2] cryptands,[2,3] and spherands,[2,4] are well known for their ability to complex alkali and alkaline earth cations. Recently a new class of polydentate sp^2 hybrid nitrogen donor macrocycles that includes polypyridine[5,6] and mixed pyridine–imine[7,8] ligands has been shown to form complexes with these ions. These complexes are so stable that it is often difficult to obtain the free macrocycles from them. For some years we have investigated polypyrazole macrocycles, which have the unusual property of being able not only to extract, transport, and release alkali cations[9–11] like crown ethers but also to form stable complexes with transition metal cations.[12] For instance, the tetrazaporphyrinogen mac-

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