Table VIII. ^{1}H NMR Chemical Shifts of 2a, 2b, 3 and Their Zinc Derivatives in $CDCl_3$

	chemical shift δ^a							
	2a	2a-Zn	2a-Zn with pyridine-d_5[b]	2b	2b-Zn	2b-Zn with pyridine-d_5[b]	3	3-Zn
H10,20	10.16	10.06	9.98	10.12	10.10	9.96	10.20	10.18
H6′	8.32	8.26	8.30	8.02	8.11	8.10	8.01	8.03
H5′	7.72	7.72	7.64	7.68	7.73	7.64	7.67	7.76
H4′	7.87	7.89	7.81	7.88	7.88	7.82	7.67	7.76
H3′	7.92	7.89	7.93	7.94	7.88	7.96	7.67	7.76
H2′	-	-	-	-	-	-	8.01	8.03
H2,H6	5.32	5.49	5.42	5.52	5.22	5.85	-	-
H3,H5	3.66	3.71	3.84	3.51	2.87	4.21	-	-
$N(CH_3)_2$	1.23	1.23	1.43	0.81	0.27	1.49	-	-
CH_3 (pyrrole)	2.55	2.50	2.48	2.51	2.53	2.43	2.46	2.42
CH_2 (α-butyl)	3.94	3.89	3.91	3.94	3.97	3.87	3.93	3.92
CH_2 (β-butyl)	2.17	2.16	2.09	2.21	2.21	2.11	2.17	2.13
CH_2 (γ-butyl)	1.77	1.78	1.70	1.83	1.85	1.72	1.71	1.73
CH_3 (δ-butyl)	1.12	1.13	1.06	1.16	1.19	1.09	1.10	1.08
NH	-2.49	-	-	-2.89	-	-	-2.33	-

[a] See structure for numbering of the protons. [b] The δ values given in this column are slightly different from those given in Table V, because of the large excess of added pyridine-d_5, resulting in increased complex formation, especially for **2b**-Zn.

intramolecular ligation. The assumption of intramolecular ligation in **2b**-Zn is supported by ^{1}H NMR and UV data.

Experimental Section

The ^{1}H NMR spectra were recorded on a 200-MHz Bruker AC-200E spectrometer. All spectra were measured in $CDCl_3$ solution. The UV spectra were measured on a Beckman DU-7 and a Varian DMS 100 spectrophotometer in $CHCl_3$ solution. The porphyrins **2a**, **2b**, and **3** and their zinc derivatives gave satisfactory CHN analyses, when we assumed the presence of 0-0.25 mol of CH_2Cl_2 per mole of porphyrin. The tendency of ortho-substituted 5,15-diphenylporphyrins to occlude solvent molecules has been described before.[5] The FD mass spectra, measured on a MS 902 equipped with a VG ZAB console, showed parent peaks at m/z 1140 (**2a** and **2b**), m/z 1202-1208 (**2a**-Zn and **2b**-Zn), m/z 742 (**3**), and m/z 802-808 (**3**-Zn). These values are in accordance with the structures proposed. Chromatography was performed on silica gel (Merck, 0.040-0.063 mm).

Preparations. 5,15-Bis[2-[[[4-(dimethylamino)phenyl]sulfonyl]oxy]phenyl]-2,8,12,18-tetra-*n*-butyl-3,7,13,17-tetramethylporphyrin (2). A mixture of 2.0 g (6.6 mmol) of 2-[[[4-(dimethylamino)phenyl]sulfonyl]oxy]benzaldehyde,[5] 1.88 g (6.6 mmol) of 3,3′-di-*n*-butyl-4,4′-dimethyl-2,2′-dipyrrolylmethane,[5] and 0.33 g of *p*-toluenesulfonic acid in 80 mL of methanol was stirred for 6 h at room temperature and left overnight in the refrigerator. The precipitate of hexahydroporphyrin (2.64 g, 70%) was sucked off, washed with cold methanol, dried, and dissolved in 250 mL of THF. A solution of 1.91 g (8.4 mmol) of 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) in 50 mL of THF was added gradually over a period of 5 min, and the mixture was stirred for 1 h at room temperature. The precipitate of crude **2b** was filtered off, washed with THF, and purified by column chromatography over silica gel (gradient elution with CH_2Cl_2 containing 1-5% of methanol). The yield of pure $\alpha\beta$ atropisomer **2b** was 0.41 g (11% overall from aldehyde). ^{1}H NMR: see Table VIII. From the filtrate, resulting from the DDQ oxidation step, the solvent was removed in vacuo. The residue (crude **2a**) was purified by column chromatography over silica gel (elution with CH_2Cl_2). Yield: 0.72 g of pure $\alpha\alpha$ atropisomer, **2a** (19% overall from aldehyde). ^{1}H NMR: see Table VIII.

5,15-Diphenyl-2,8,12,18-tetra-*n*-butyl-3,7,13,17-tetramethylporphyrin (3). To a solution of 2.12 g (20 mmol) of benzaldehyde and 5.72 g (20 mmol) of 3,3′-di-*n*-butyl-4,4′-dimethyl-2,2′-dipyrrolylmethane in 250 mL of methanol, 1.00 g of *p*-toluenesulfonic acid was added. The mixture was stirred for 2 h at room temperature and left overnight in the refrigerator. The precipitated hexahydroporphyrin was filtered off and washed with cold methanol, yield 6.4 g (86%). To a solution of 6.4 g of the hexahydroporphyrin (8.6 mmol) in 350 mL of THF, a solution of 7.49 g (33 mmol) of DDQ in 100 mL of THF was added. The mixture was stirred for 2 h at room temperature. The THF was evaporated in vacuo, and the residue was dissolved as far as possible in 150 mL of CH_2Cl_2. After filtration 400 mL of a mixture of methanol and triethylamine, 3:1, was added to the filtrate with stirring. After stirring for another half hour the precipitate was sucked off and washed with cold methanol, yield 5.1 g (80%). To obtain an analytically pure sample the product was chromatographed over silica gel, eluent CH_2Cl_2. ^{1}H NMR: see Table VIII.

Zinc Derivatives of 2a, 2b, and 3. The zinc derivatives of **2a**, **2b**, and **3** were obtained by adding a solution of 0.5 g (2.3 mmol) of zinc acetate dihydrate in 10 mL of methanol to a solution of 100 mg of **2a**, **2b** (0.09 mmol), or **3** (0.13 mmol) in 100 mL of CH_2Cl_2. The mixture was kept in an ultrasonic bath for $^1/_2$ h. After washing the solution with water and filtraftion of the organic layer the solvent was removed in vacuo; the zinc derivatives were obtained in practically quantitative yield. ^{1}H NMR: see Table VIII.

Formation of Pyridinates. All experiments were carried out in the NMR tube. The ^{1}H NMR spectra obtained by adding a 25-fold excess of pyridine-d_5 to $CDCl_3$ solutions of **2a**-Zn and **2b**-Zn are given in Table VIII. The results of the low-temperature ^{1}H NMR measurements on **3**-Zn, **2a**-Zn, and **2b**-Zn in the presence of pyridine are given in Tables III and V.

Improved Synthesis of Cubane-1,2,4,7-tetracarboxylic Acid

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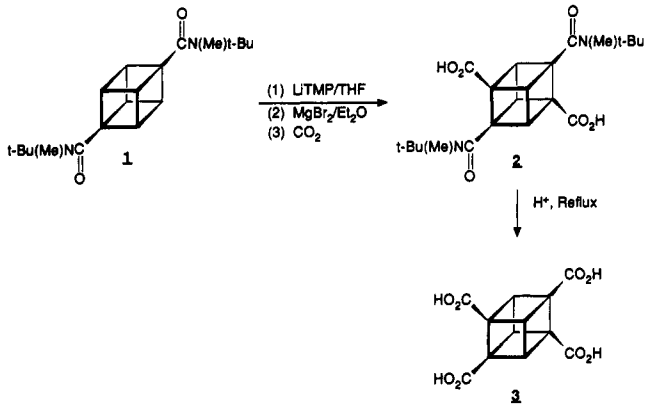
We report here a simplification in the synthesis of cubane-1,2,4,7-tetracarboxylic acid (**3**), a key intermediate from which other cubane derivatives are synthesized. Limitations in the synthetic routes to this compound have prevented the preparation of other, interesting cubane compounds.

The original breakthrough in the synthesis of functionalized cubanes was made by Eaton and co-workers[1] with the discovery that *N,N*-diisopropylamide groups could be

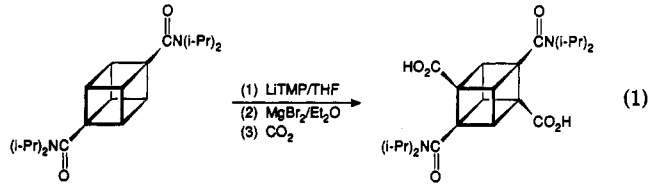
(1) Eaton, P. E.; Castaldi, G. *J. Am. Chem. Soc.*, **1985**, *107*, 724. (b) Eaton, P. E.; Cunkle, G. T.; Marchioro, G.; Martin, R. M. *Ibid.* **1987**, *109*, 948. (c) Eaton, P. E.; Daniels, R. G.; Casucci, D.; Cunkle, G. T. *J. Org. Chem.* **1988**, *53*, 2728. (d) Eaton, P. E.; Higuchi, H.; Millikan, R. *Tetrahedron Lett.* **1987**, *28*, 1055. (e) 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. (f) Eaton, P. E.; Lee, C. H.; Xiong, Y. *J. Am. Chem. Soc.* **1989**, *111*, 8016.

0022-3263/91/1956-1305$02.50/0

Scheme I



used as activating/directing groups to make ortho lithiation[2] of cubane possible (eq 1).

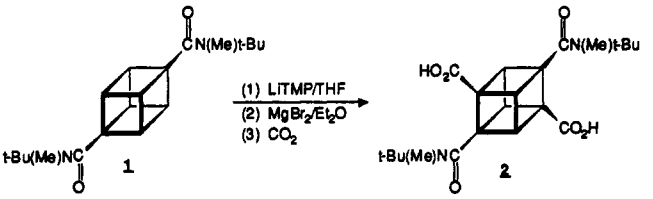


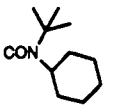
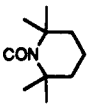
(1)

The cubyl anion was originally trapped in this route by the exchange of lithium for mercury. Bashir-Hashemi and Eaton developed the necessary methodology for hydrolysis of the *N,N*-diisopropylamide groups to give the tetraacid. This route was significantly improved by Bashir-Hashemi with the discovery that $MgBr_2$ etherate could be substituted for $HgCl_2$.[3,4] The synthesis of the cubane tetraacid is a multistep process involving the lithiation of *N,N,N′,N′*-tetraisopropylcubane-1,4-dicarboxamide using lithium tetramethylpiperidine (LiTMP) as the base, trapping of the carbanion as the magnesium salt, carboxylation with CO_2, and then a reduction, an oxidation, methylation, and finally acid hydrolysis of the *N,N*-diisopropylamides to give **3**. The reduction and oxidation step are necessary because the *N,N*-diisopropylamide groups proved resistant to hydrolysis with very strong acids, bases, and oxidants. This group was even resistant to refluxing red fuming nitric acid, returning only unchanged starting material. The number of steps required limits the availability of **3**.

We have improved the synthesis of **3** by a subtle variation in the amide group, which results in a significantly shorter route that substitutes a simple hydrolysis step for the oxidation and reduction steps (Scheme I). The crucial improvement results from our discovery that a different amide, bis(*N*-*tert*-butyl-*N*-ethyl)amide **1**, cannot only be used in place of the *N,N*-diisopropylamide for the ortho lithiation of the cubane nucleus but also can be removed through direct acid hydrolysis, thereby significantly reducing the number of steps required. We explored several other amides before discovering one capable of replacing the diisopropylamide (Table I). The metalations listed in Table I were done by the method of Bashir-Hashemi.[3,4] The hydrolysis of **2** to **3** was done with 70% nitric acid, because this method allows ready isolation of **3** as a filterable solid precipitate while the other byproducts are oxidized or dissolved by the acid. Dilute hydrochloric or other dilute acids are also effective for the hydrolysis reaction.

Table I. Attempted Metalation–Carboxylations of Cubane-1,4-dicarboxamides



R	carboxylation observed (% yield)
	none
	none
	none
	25
	75

The advantages of the *N*-*tert*-butyl-*N*-ethylamide over the *N,N*-diisopropylamide are the former's greater ease of removal by acid hydrolysis and higher yield in the carboxylation. The *N*-*tert*-butyl-*N*-ethylamide can be removed nearly quantitatively by acid hydrolysis in one step, eliminating several steps from the long sequence previously required.

This hydrolysis step illustrates the oxidative and protic stability of the cubane nucleus when substituted with electron-withdrawing groups. Despite the fact that cubane is not normally considered to be stable under extreme conditions, we have refluxed **2** in dilute HCl or red fuming HNO_3 and obtained a high yield of **3**. Under the same conditions, the corresponding *N,N*-diisopropylamide is recovered (unchanged) nearly quantitatively, with no decomposition or hydolysis.

Experimental Section

Materials. ^1H NMR spectra were recorded at 90 MHz. Cubane-1,4-dicarboxylic acid dimethyl ester was purchased from Fluorochem (Azusa, CA) or EniChem Sintesi (Milan, Italy) and converted to the free acid by refluxing in dilute HCl. Aldrich Chemical Co. was the major supplier of the remaining chemicals.

***N*-Ethyl-1,1-dimethylethanamine.** Ethyl bromide (109 g, 1.0 mol) was mixed with *tert*-butylamine (220 g, 3 mol) and stirred with cooling in a large ice bath, allowing the reaction temperature to rise slowly over a period of approximately 5 h to room temperature. The reaction mixture, which contained a large amount of crystalline precipitate, was stirred for an additional 24 h and worked up. The workup consists of extraction with 1 × 500 mL of 10 M NaOH, followed by distillation at atmospheric pressure and collection of the 85–93 °C fraction (yield ~100 g). This fraction was redistilled from calcium hydride to give pure, dry *N*-ethyl-1,1-dimethylethanamine: bp 89 °C; 85 g (85%); ^1H NMR ($CHCl_3$) δ 1.1 (s, 9 H, *tert*-butyl), 1.1 (t, J = obscured by *tert*-butyl, 3 H, CH_3), 2.6 (q, J = 8 Hz, 2 H, CH_2).

***N,N′*-Di-*tert*-butyl-*N,N′*-diethylcubane-1,4-dicarboxamide (1).** Cubane-1,4-dicarboxylic acid (30.0 g, 0.156 mol) was added to 500 mL of dry chlorobenzene under an argon purge. PCl_5 (97.5 g, 0.468 mol, 50% excess) was added to the diacid in two portions.

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The reaction was stirred for 2 h at room temperature, and then excess PCl_5 was destroyed by stirring with acetic anhydride (14.7 mL, 0.156 mol) for 15 min. The solution was concentrated to dryness at 50 °C by using aspirator pressure at first and then higher vacuum. To remove residual acetic anhydride, the cubane-1,4-bis(carbonyl chloride) was dissolved in dry, ethanol-free $CHCl_3$, followed by concentrating to dryness at 50 °C at reduced pressure. This step was repeated two or three times, until no anhydride was present. Finally, the pale yellow crystals were dried under high vacuum for ~2 h at 50 °C. The cubane-1,4-bis(acid chloride) was dissolved in 500 mL of dry $CHCl_3$ and transferred to a 1-L flask with mechanical stirrer, argon purge, 50-mL addition funnel, and cold water bath (5–10 °C). Triethylamine (31.6 g, 0.312 mol) was added slowly over 5 min and then *N*-*tert*-butyl-*N*-ethylamine (31.6 g, 0.312 mol) was added dropwise over 20 min while the cold water bath was maintained. After the addition, the reaction mixture was stirred for 2 h at room temperature and washed with 5% HCl (3 × 100 mL), 5% KOH (2 × 100 mL), and saturated NaCl (1 × 100 mL). The yellow $CHCl_3$ layer was treated with activated carbon, dried ($MgSO_4$), and filtered over Celite to give a less colored solution, which when concentrated to dryness left a pale yellow solid. This solid was slurried in 400 mL of dry ethyl acetate at 40–50 °C, cooled in ice, filtered, washed with cold ethyl acetate, and dried under high vacuum to yield 41.0 g (73%) of the title compound as pure white crystals: mp 185–188 °C; ^1H NMR (^1H, $CDCl_3$, TMS standard) δ 1.3 (t, 3 H, J = 7 Hz, CH_3), 1.4 (s, 9 H, *tert*-butyl), 3.8 (q, 2 H, J = 7 Hz, CH_2), 4.55 (s, 6 H); IR (KBr) 2970, 1610, 1390, 1205 cm^{-1}.

***N,N'*-Di-*tert*-butyl-*N,N'*-diethyl-2,7-dicarbamoylcubane-1,4-dicarboxylic Acid (2).** 2,2,6,6-Tetramethylpiperidine (107 g, 0.760 mol, 10 equiv) and tetramethylethylenediamine (12.6 mL, 1.1 equiv) were added to 600 mL of dry THF (distilled over CaH) in a 2-L flask equipped with an argon purge. The reaction mixture was cooled in dry ice/acetone, and 2.5 M *n*-butyllithium in hexane (304 mL, 0.760 mol, 10 equiv) was added dropwise with stirring over 2 h at −78 °C, and then the reaction was stirred at 0 °C for 1 h. The reaction mixture was cooled in a dry ice/acetone bath. $MgBr_2$ etherate (98.1 g, 0.380 mol, 5 equiv) and 1 (27.2 g, 0.076 mol, 1 equiv) were added all at once, and the mixture was then placed in the bath and stirred for 8 h. The reaction mixture was cooled in dry ice/acetone, and CO_2 was bubbled through the stirring reaction for 12 h at dry ice/acetone temperature to yield a light tan suspension, which was concentrated to dryness on the rotovap, first using aspirator pressure and then higher vacuum for about 2 h. The light tan solid was vigorously stirred with 1500 mL of H_2O for 1 h, and the resulting suspension was transferred to a 2-L flask and then cooled to 0 °C. Ice-cold 19% HCl was added slowly with stirring to bring the pH to 1 (about 250 mL; there was some foaming). The suspension was filtered to give a light brown paste, which was dissolved in 600 mL of boiling CH_2Cl_2, cooled in the freezer overnight, filtered, and washed with cold CH_2Cl_2 to give 20.0 g of diacid **2** as colorless plates which decompose exothermically without melting at 239.3 °C. The mother liquor was concentrated to one-third volume and cooled to give a second crop of 5.5 g for a total yield of 25.5 g (75%): ^1H NMR (CD_3OD) δ 1.25 (t, J = 6 Hz, 6 H), 1.5 (s, 9 H), 3.75 (q, J = 6 Hz, 4 H), 4.6 (s, 4 H), failed to observe carboxylic acid proton. Anal. Calcd C, 64.56; H, 7.67; N, 6.27. Found: C, 64.54; H, 7.55; N, 6.27.

Cubane-1,2,4,7-tetracarboxylic Acid (3). Compound **2** (5.82 g, 0.013 mol) was added to 125 mL of 70% HNO_3. The mixture was heated and at 58 °C the reaction instantly turned dark red, evolving NO_2, and the temperature went rapidly to 75 °C. Mild reflux was continued for 4 h, at which time the reaction was pale yellow. The reaction was cooled in the freezer overnight, filtered, washed with cold 70% HNO_3 and then, after changing the filter flask, with 100% ethanol, and dried to give 3.44 g of the product (95%) as a pure white powder which decomposes quite exothermically at 267 °C. Dilute HCl at reflux can be substituted for nitric acid; however, the isolation of the product is more difficult. Identification was based on comparison with the known material.[5] ^1H NMR (CD_3OD) δ 4.3 (s). Anal. Calcd: C, 51.44; H, 2.88. Found: C, 51.21; H, 2.88.

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A New Method for the Synthesis of Acylsilanes via One-Carbon Homologation of Aldehydes

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Recently acylsilanes have received increasing research interest from the physical organic[1] and synthetic organic[2] view points. For example, highly diastereoselective addition of nucleophiles[3] and stereoselective Wittig reactions[4] utilizing the bulky silyl groups demonstrate the synthetic utility of acylsilanes. Recently we have developed an electrochemical oxidation of acylsilanes in which the carbon–silicon bond is cleaved and oxygen and nitrogen nucleophiles are introduced at the carbonyl carbon.[5] Easy migration of the silyl group from carbon to oxygen immediately after a nucleophile attacks the carbonyl carbon is also an important property of acylsilanes.[6]

Although several methods for the synthesis of acylsilanes have been reported,[7] recent developments in the synthetic applications of acylsilanes increase the demand for new versatile methods. In this paper we present a new method for the synthesis of acylsilanes from aldehydes by one-carbon homologation. This reaction provides general and convenient access to saturated, α,β-unsaturated, and (α-haloacyl)silanes.

Methoxybis(trimethylsilyl)methane was deprotonated with *n*-butyllithium in tetrahydrofuran (THF), and the resulting anion was allowed to react with aldehydes. The crude 1-methoxy-1-(trimethylsilyl)-1-alkenes (1) thus obtained were readily hydrolyzed[8] with dilute hydrochloric

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(4) (a) Soderquist, J. A.; Anderson, C. L. *Tetrahedron Lett.* **1988**, *29*, 2777–2778. (b) Soderquist, J. A.; Anderson, C. L. *Ibid.* **1988**, *29*, 2425–2428.

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