J. Am. Chem. Soc. **1993**, *115*, 10195–10202

Systematic Substitution on the Cubane Nucleus. Synthesis and Properties of 1,3,5-Trinitrocubane and 1,3,5,7-Tetranitrocubane

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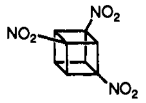
Received June 1, 1993●

Abstract: A systematic methodology is developed for the synthesis of highly symmetric, polysubstituted cubanes. The synthesis of cubanes with C_{3v} and T_d symmetry is achieved. Details are given for the preparation of 1,3,5-trinitrocubane and 1,3,5,7-tetranitrocubane, compounds of interest as superior high-energy, shock-insensitive explosives. The structures of these new materials, determined by single-crystal X-ray analysis, are discussed in detail. DSC analysis of their thermal decomposition is presented. The effect of nitro groups on the ^{13}C-NMR spectra of cubanes is noted.

Nitrocubanes are sought after as powerful, shock-insensitive, high-density explosives.[1] 1,3- and 1,4-dinitrocubanes are already known.[2,3] These are stable compounds with decomposition points above 250 °C. Neither shows evidence of shock sensitivity under ordinary conditions. These nitrocubanes are (now) simply made by oxidation of the corresponding amines, themselves prepared from the parent cubane diacids, compounds which have been known for some time.[4,5]

Almost all more highly nitrated cubanes would have adjacent nitro groups. But no cubane having vicinal nitro groups is yet known. Although we have available 1,2-diaminocubane, all efforts to make 1,2-dinitrocubane by its oxidation have failed, thwarted by unstoppable cage cleavage reactions.[6] A recent *ab initio* calculation has 'confirmed' the destabilizing effect of adjacent nitro and amino groups on the cubane nucleus.[7]

Thus, as an interim measure, we sought to prepare the few more highly nitrated cubanes that do not have adjacent nitro groups.[8] Of the three possible trinitrocubanes—1,2,3-, 1,2,4-, and 1,3,5- —only the last (**1**), with C_{3v} symmetry,[9a] qualifies. Similarly, of the six possible tetranitrocubanes, the tetrahedrally symmetric (T_d)[9b] 1,3,5,7-isomer (**2**) is the only one without vicinal nitro groups. Here we report the first successful preparations of cubanes with these substitution patterns and their characterization.[10]



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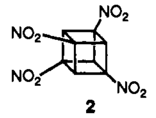

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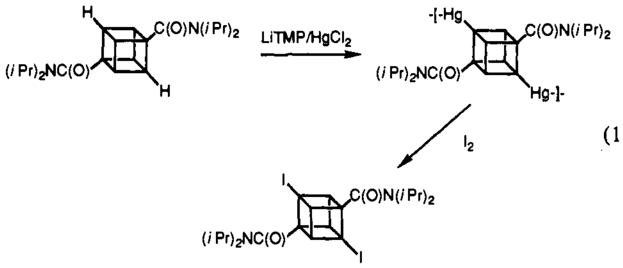
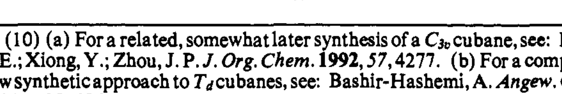
Aminocubanes, the precursors for nitrocubanes, are prepared from the corresponding acids using one relative or another of the Curtius reaction. Retrosynthetic analysis of the T_d problem suggests therefore the preparation of cubane-1,3,5,7-tetracarboxylic acid. The ortho-metalation methodology for systematic substitution on the cubane nucleus developed in this laboratory over the last few years[11] provides only for the introduction of substituents *adjacent* to ortho-activating functional groups, e.g. eq 1.



(1)

Unfortunately, there is no extension of this methodology permitting 'meta-metalation' as would be required for any *direct* synthesis of a tetrasubstituted cubane without substituents on adjacent cubane carbons. To get around this, we needed to take an indirect route. Thus, as illustrated in eq 2, we proposed to use



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† The University of Chicago.

‡ Naval Research Laboratory.

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(6) Such cage openings apparently always occur when the cubane nucleus bears an electron-donating group adjacent to an electron acceptor; no example of a cubane so substituted has ever been isolated.

(7) Murray, J. S.; Seminario, J. M.; Politzer, P. *Struct. Chem.* **1991**, *2*, 153.

(8) The search for methods other than amine oxidation to introduce multiple nitro groups onto the cubane cage has not yet been fruitful.

(9) (a) More properly, pseudo-C_{3v}; rotation about the carbon–nitrogen bonds will lead to some conformers in which the nitro groups are not fully equivalent. (b) More properly, pseudo-T_d.

(10) (a) For a related, somewhat later synthesis of a C_{3v} cubane, see: Eaton, P. E.; Xiong, Y.; Zhou, J. P. *J. Org. Chem.* **1992**, *57*, 4277. (b) For a completely new synthetic approach to T_d cubanes, see: Bashir-Hashemi, A. *Angew. Chem.* **1993**, *105*, 585.

(11) (a) Eaton, P. E.; Castaldi, G. *J. Am. Chem. Soc.* **1985**, *107*, 724. (b) Eaton, P. E.; Cunkel, G. T.; Marchioro, G.; Martin, R. M. *J. Am. Chem. Soc.* **1987**, *109*, 948. (c) Eaton, P. E.; Daniels, R. G.; Casucci, D.; Cunkel, G. T. *J. Org. Chem.* **1987**, *52*, 2100. (d) Eaton, P. E.; Higuchi, H.; Millikan, R. *Tetrahedron Lett.* **1987**, *28*, 1055.

(12) The yield of the 2,6,8-trimercuriated compound and the derived triiodo product was eventually improved to 88%. See ref 10a.

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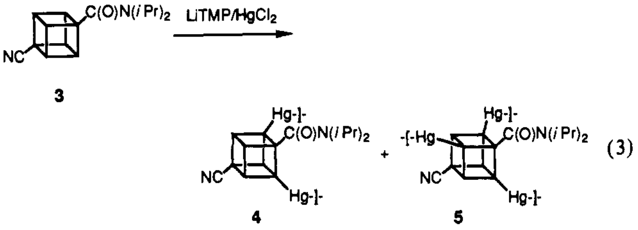
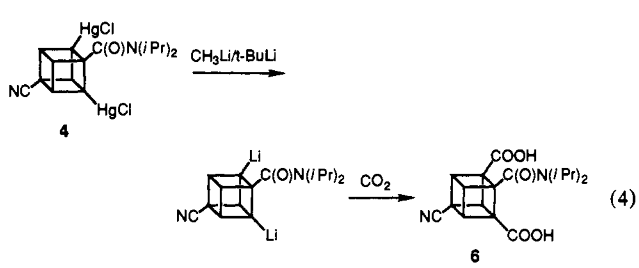
ortho-metalation to introduce a substituent on each of the three ortho (adjacent) carbons (C's 2, 6, and 8) surrounding the activating group (on C1)—these substituents would necessarily be meta to one another—and then to remove the ortho-activating group. If one started with an appropriate 1,4-disubstituted cubane, this sequence would lead by way of the 1,2,4,6,8-pentasubstituted cubane to one tetrasubstituted (2, 4, 6, 8 = 1, 3, 5, 7) with the desired symmetry pattern.

The choice of original substituents on the starting 1,4-disubstituted cubane is critical: both must be amenable to introduction and alteration; one (A) must provide suitable ortho-activation for the metalation steps; and the other (A′) should be electron-withdrawing to facilitate formation of the perquisite intermediate anions, but it must not compete with the first as a director for ortho-metalation. Based on these considerations, we selected 4-cyano(diisopropylcarbamoyl)cubane (**3**) and examined its behavior under ortho-metalation conditions. The synthesis, presented elsewhere,[10a] proceeds from commercially available 1,4-dicarbomethoxycubane in fine overall yield. Treatment of **3** with a large excess of lithium tetramethylpiperidide (LiTMP) in the presence of HgCl$_2$ gave mostly the 2,6-dimercuriated cubane **4** along with some of the 2,6,8-trimercuriated compound **5** (eq 3).[10a]



(3)

Although mercuriated cubanes are useful precursors of halocubanes,[11a] they are not sufficiently reactive for direct carboxylation. For this reason, we developed earlier the process of reverse transmetalation wherein the lithium progenitor of the cubylmercury, originally formed only transiently, is regenerated stoichiometrically under conditions where it is (relatively) stable.[11b] Taking this further and applying 'double reverse transmetalation'[11b] to the case at hand, we were able to form and then capture the dilithio derivative of **4**. Thus, **4** was first isolated (as its chloride) and then treated with CH$_3$Li/*t*-BuLi in ether at −78 °C. Carboxylation gave the cyano amido diacid **6** in 50% yield based on starting cyanoamide **3** (eq 4). This material was ultimately taken on to cubane-1,3,5-tricarboxylic acid and 1,3,5-trinitrocubane (*vide infra*).

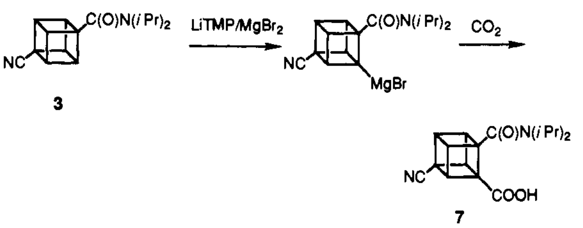


(4)

Although such reverse transmetalation and halogen–metal exchange techniques allowed us to add two carboxylic acid groups in controlled fashion to **3**, we were unable to extend this to introduction of three such groups. Neither the 2,6,8-triiodo derivative of **3** nor its trimercury precursor **5** could be taken successfully to suitably reactive species. We had to move instead to a more lengthy, fully sequential, linear synthesis.

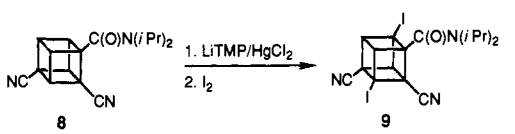
The reagent LiTMP/MgBr$_2$, first employed by Bashir-Hashemi as a complement to LiTMP/HgCl$_2$ in ortho-activated metalations of cubane, is exceedingly useful.[13,14] The reactions proceed in a similar way; initial lithiation is followed by transmetalation, but with magnesium rather than mercury. LiTMP/MgBr$_2$ has certain advantages. No toxic mercury salts are used, and the Grignard formed is broadly reactive. On the other hand, LiTMP/MgBr$_2$ reactions, unlike those with LiTMP/HgCl$_2$, are limited to the introduction of just one metalated center ortho to an amide activating group; the amide is then "tied up" stabilizing this center and is unavailable for activation of another ortho position. This is useful in some cases (as below) but not in others (see ref 10a).

Treatment of cyano amide **3** with LiTMP/MgBr$_2$ followed by CO$_2$ gave the monoacid **7** in 85% yield (eq 5). It was assumed that the carboxylic group was introduced adjacent to the amide group, the stronger activator. This was ultimately confirmed by X-ray analysis (*vide infra*) of **2**, obtained as the end product of the whole scheme; its observed T_d substitution pattern could only have arisen if the carboxyl group in **7** was positioned as assigned.



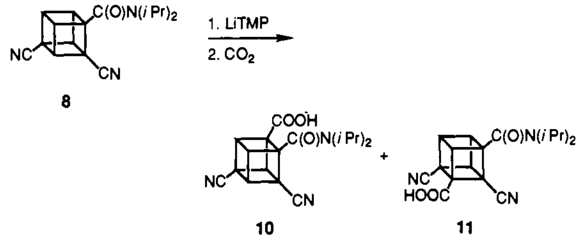
(5)

Before further metalation could be realized, the carboxylic acid group in **7** had to be masked or, better, changed to a facilitating electron-withdrawing group. For this, **7** was converted to the dicyano amide **8** in good yield using standard methodology (see Experimental Section). The two electron-withdrawing cyano groups together with the amide provide a much activated substrate for ortho-metalation. Double lithiation/mercuriation happened quickly even at −78 °C. Unfortunately, it led to an undesired substitution pattern (**9**, eq 6).



(6)

When dicyano amide **8** was treated at −78 °C with LiTMP *without* HgCl$_2$ and the mixture carboxylated (eq 7), acid **10** and the undesired positional isomer **11** were produced in approximately equal amounts;[15a] no starting material remained. Activation by two cyano groups along with the amide is sufficient to provide for complete monolithiation. Equations 6 and 7 make it clear that activation of a cubyl C–H for lithiation by two flanking cyano groups working in concert rivals ortho-activation by a single amido group; competitive lithiations occur at C3 and C6. We were to find that we could sidestep this loss of regioselectivity by using magnesium amide bases like TMPMgBr or (TMP)$_2$Mg



(7)

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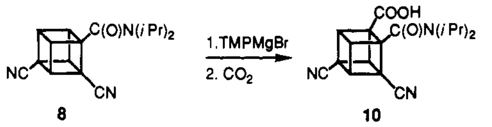
[13] (a) Bashir-Hashemi, A. *J. Am. Chem. Soc.* **1988**, *110*, 7234. (b) Bashir-Hashemi, A.; Ammon, H. L.; Choi, C. S. *J. Org. Chem.* **1990**, *55*, 416. (c) Bottaro, J. C.; Penwell, P. E.; Schmitt, R. J. *J. Org. Chem.* **1991**, *56*, 1305.

[14] Bashir-Hashemi, A.; Eaton, P. E.; Chou, T.-C.; Xiong, Y.; Pramod, K. In preparation.

[15] (a) Eaton, P. E.; Xiong, Y.; Lee, C. H. *J. Chin. Chem. Soc.* **1991**, *38*, 303. (b) Eaton, P. E.; Lee, C. H.; Xiong, Y. *J. Am. Chem. Soc.* **1989**, *111*, 8016.

instead of lithium amides. Indeed, this observation led to the discovery of ortho-magnesiation of strained aliphatic systems and aromatics as well.[15]

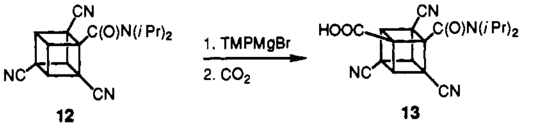
When the dicyano amide **8** was treated with TMPMgBr in THF at room temperature for 1 h and the mixture quenched with CO_2 at −78 °C, the *only* product (90% isolated yield!) was acid **10** (eq 8). Similar results were obtained using $(TMP)_2Mg$ in



(8)

THF at −78 °C. We stress that *these regiospecific metalations occur only when the magnesium bases are used in the absence of lithium salts.* It is clear from a comparison of eqs 7 and 8 that cyano groups are ineffective activators for ortho-magnesiation but can be important for ortho-lithiation. We expect that this difference will help lead to a deeper understanding of orthometalation processes.

To continue the sequential functionalization of **3**, **10** was converted to the much-activated tricyano amide **12**. Even though the C–H group at C5 in **12** is surrounded by three cyano groups, treatment with TMPMgBr followed by CO_2 gave primarily carboxylation at C8 and thus the sought-after substitution pattern in **13** (77% isolated yield, eq 9). A trace (<5%) of what was probably the 5-carboxylated isomer was barely visible in the proton NMR spectrum of the crude reaction mixture.



(9)

The three varieties of functional groups in **6** and **13** are open to innumerable transformations. Of interest here is selective removal of the carboxamido group. We know Barton decarboxylation[16] to be particularly effective for reductive decarboxylation of cubane acids.[17] Conversion of the carboxamido group in **6** and that in **13** to the only carboxylic acid group in each of these polyfunctional molecules required substantial manipulation. To this end, using **13** for example (Scheme I), the cyano groups were hydrolyzed, the resulting amido tetraacid **14** was reduced with lithium aluminum hydride to the amino tetrol **15**, the alcohols were protected as acetates (→ **16**), and the carbinylamine was oxidized to the carboxylic acid **17** with dimethyldioxirane.

The oxidation of **16** to **17** in which $CH_2N(i\text{-}Pr)_2$ is converted to a carboxylic acid is an extraordinary and exceptionally useful reaction. Combined with amide reduction it provides a way of 'hydrolyzing' highly hindered amides of tertiary amines, a process often impossible by normal methods. The reaction of the carbinyl amine with dimethyldioxirane in aqueous acetone is not fully understood. We do know that the aldehyde is an intermediate, for it can be isolated if the quantity of dimethyldioxirane is limited. The amine oxide may be an intermediate,[18] but only if the next step involves further oxidation; the oxide, prepared independently, is stable in aqueous acetone. The isopropyl groups on the amide are not critically important; $CH_2N(t\text{-}Bu)CH_3$ on the cubane nucleus is oxidized similarly.

Each of the intermediates **14–17** was characterized by NMR, but none was isolated pure. The crude materials were of sufficient quality to be used directly in subsequent steps. Barton decarboxylation of **17** by radical decomposition of its PTOC ester **18** in the presence of *t*-butyl thiol was satisfyingly successful, giving the tetraacetate **19** in good yield. The sequence (Scheme II) was completed using hydrolysis/oxidation with basic permanganate to give the T_d tetraacid **20**.

Conversion of **20** to T_d tetranitrocubane **2** was effected as shown in Scheme III.[19] A few things are worthy of particular note. The highly symmetrical tetraacid is exceedingly insoluble and did not react with thionyl chloride or oxalyl chloride, even on refluxing or sonication with these reagents. Nonetheless, when suspended in acetonitrile, it reacted with amazing rapidity with thionyl chloride at room temperature and in 1–2 h gave cleanly the corresponding acid chloride. The reaction of the acid chloride with trimethylsilylazide was facile and gave the tetrakis(azidoacyl)cubane **21**, a treacherous explosive. *It is imperative that such (azidoacyl)cubanes be made only with careful attention to proper safety practices.*[20] Thermal rearrangement of **21** in refluxing chloroform smoothly gave the tetraisocyanate **22**. This is a stable compound which can be isolated and characterized. It may prove of interest as a monomer for high-energy, starburst dendritic polymers. However, for the purpose of the present work it was taken on without purification to the T_d tetranitro compound **2** by treatment with dimethyldioxirane in wet acetone.[2]

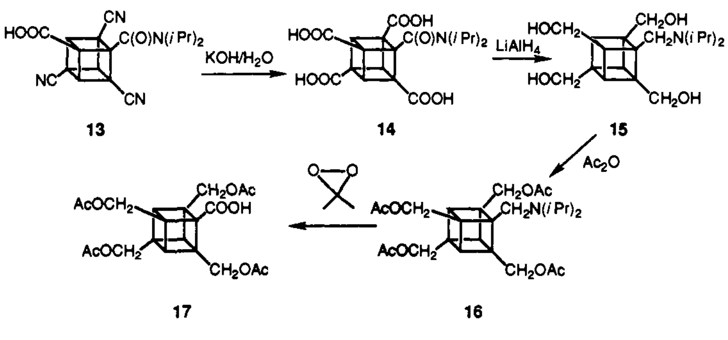
Compound **6** put through the same series of conversions outlined in Schemes I–III gave the C_{3v} triacid 1,3,5-tricarboxycubane (**23**) and C_{3v} trinitrocubane **1**.

The proton and carbon NMR spectra of **1** and **2** agree with the C_{3v} and T_d substitution patterns, respectively, expected from the synthetic schemes. It is worth noting that the nitro groups affect the chemical shifts of the cubane carbons additively. For all nitrocubanes made to date, each nitro group shifts the resonance of the carbons ipso, ortho, and para to it downfield by 38.0, 5.9, and 0.7 ppm, respectively, and each shifts the resonance of a carbon meta to it upfield by 4.9 ppm.

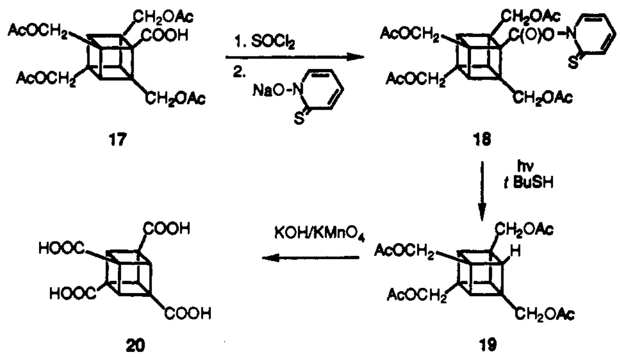
C_{3v} trinitrocubane and T_d tetranitrocubane are thermodynamic powerhouses. Yet, like cubane itself,[21] both are remarkably stable kinetically. As shown in Figure 1, the differential scanning calorimetric record for T_d tetranitrocubane, rapid thermal decomposition of the nitro compounds does not start until over 250 °C. The C_{3v} compound behaves similarly.

The X-ray structures of **1** and **2** are shown in Figures 2 and 3. Although **1** and **2** have symmetrical substitution patterns, nominally C_{3v} and T_d, respectively, the orientations of the attached nitro groups do not follow any pattern. In the crystals studied, **1** and **2** sit on sites that have no symmetry in the surrounding

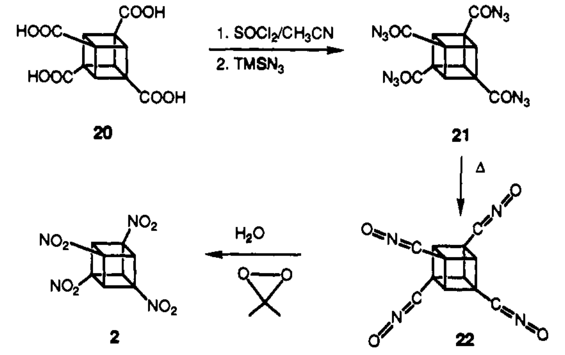
Scheme I



Scheme II



Scheme III



packing environment. Each nitro group experiences slightly different packing forces and adjusts its torsion accordingly. Figure 2 views **1** down the potential C_{3v} axis, and the nonequivalent nitro torsions are apparent. Figure 3 views **2** down the edge of a plane passing through face diagonals of the cubane nucleus; this plane happens to be an approximate mirror plane of symmetry found in this structure. Torsion angles C2–C3–N3–O3b and C6–C7–N7–O7a, that straddle the plane, would be required to have special values of 0° to 90° if the mirror symmetry was exact; their actual values are −11.7° and 95.9°, respectively. No other elements of symmetry of the cube are adhered to, even approximately, by the nitro groups.

Two types of distortion of the cubane cages **are** visible in the detailed structural results of the X-ray analyses of both **1** and **2**. First (see Table I), the internal bond angles at the nitro-substituted corners are all greater than 90° (averages: 91.3° in **1** and 91.7° in **2**). The angles at the even-numbered methine carbons are all less than 90° (averages: 88.7° in **1** and 88.3° in **2**). The net overall distortion is thus a 'tetrahedral compression' of the cage at the four odd-numbered vertices and a concomitant expansion outward of the other tetrahedral set, the even-numbered carbon atoms. The distances traversed are very small; calculations on a model cube (1.55-Å edge) show that appropriate movements of only 0.01 Å in x, y, and z at each corner will reproduce the average 1.5° distortion. However, because of the concerted nature of the deviations, the cube-face diagonals change somewhat more; e.g., in **2**, the odd–odd diagonals average 2.170 Å (range 2.158–2.178) while the even–even diagonals average 2.235 Å (range 2.229–2.239). From this one experiment, it is difficult to state with assurance whether the origin of this angular distortion is steric (i.e., caused by interatomic repulsions) or an example of an electronic rehybridization. However, it does not seem to correlate with the alleviation of any *intra*molecular repulsions. As noted above, the smaller, less-polar methine carbons move *apart*, while the bulkier, highly polar, electrostatically repulsive nitro carbons move *together*, albeit slightly, along cube-face diagonals. In addition, the slight expansion of the bond angles at the nitro carbon atoms *reduces* the distances between the nitro oxygen atoms and the 'ortho'-carbons of the cage. Many of these O···C distances lie slightly below the C···O van der Waals radius limit of 3.1–3.2 Å, which is usually considered to be the distance at which nonbonded repulsion begins to rise sharply. For example, in **2**, every nitro group has at least one such contact, ranging from 2.88 to 3.00 Å. Each of these approaches would be slightly *longer* if the cube were orthogonal. It is conceivable that *inter*molecular steric interactions, crystal packing forces, might combine to produce the angular distortion effect.

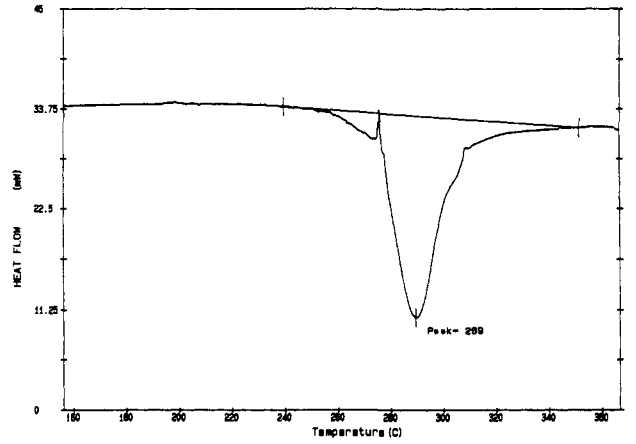


Figure 1. Thermal decomposition of 1,3,5,7-tetranitrocubane by differential scanning calorimetry: sample size, 0.75 mg; scanning rate, 15 °C/min.

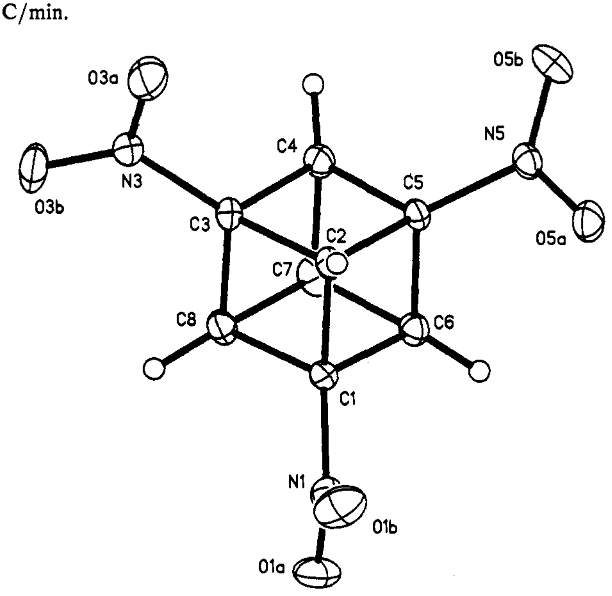


Figure 2. Molecular structure and numbering scheme for 1,3,5-trinitrocubane, viewed down an axis just a few degrees away from the potential 3-fold axis. Nonequivalent orientations of the nitro groups destroy the 3-fold symmetry about this axis. Torsion angles illustrating the dissymmetry are C2–C1–N1–O1b = −3.8°, C2–C3–N3–O3a = 41.9°, and C2–C5–N5–O5a = 53.4°.

The second type of distortion noted is likely to be electronic in nature and is easily overlooked because the nitro torsions follow no symmetry pattern. At first glance, there appears to be no pattern to the small variations in cube-edge distances in **1** and **2**, that range in each molecule from ca. 1.53 to 1.57 Å. A

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(19) The procedure is closely related to that worked out earlier for 1,4-dinitrocubane.[2]

(20) For an improved, safer procedure, see: Hertzler, R. L.; Eaton, P. E. *Abstracts of Papers*, 205th National Meeting of the American Chemical Society, Denver, CO, Spring 1993; American Chemical Society: Washington, DC, 1993; Paper 128.

(21) For an overview of the properties and chemistry of cubane, see: Eaton, P. E. *Angew. Chem., Int. Ed. Engl.* **1992**, *31*, 1421.

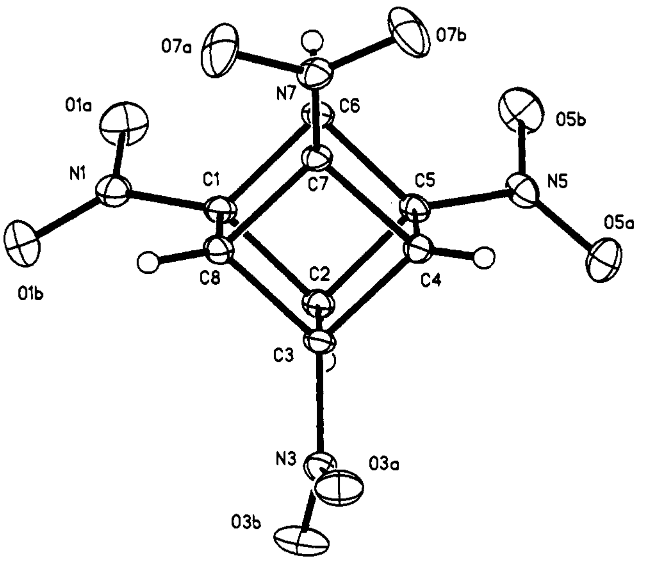

Figure 3. Molecular structure and numbering scheme for 1,3,5,7-tetranitrocubane. There is no crystallographic site symmetry, and thus each nitro group experiences and is influenced by differing local forces. However, the vertical plane containing C2, C3, C6, and C7 approximates a mirror plane of symmetry.

Table I. Angles (deg) between Adjacent Cube Edges[a]

	1,3,5-Trinitrocubane		
C2–C1–C6	91.9(2)	C1–C2–C3	88.4(2)
C2–C1–C8	92.0(2)	C1–C2–C5	88.9(2)
C6–C1–C8	90.6(2)	C3–C2–C5	88.3(2)
C2–C3–C4	91.1(2)	C3–C4–C5	88.3(2)
C4–C3–C8	91.3(2)	C3–C4–C7	88.5(2)
C2–C3–C8	91.6(2)	C5–C4–C7	89.1(2)
C2–C5–C4	92.2(2)	C5–C6–C7	88.8(2)
C2–C5–C6	91.2(2)	C1–C6–C7	89.5(2)
C4–C5–C6	91.5(2)	C1–C6–C5	87.9(2)
C4–C7–C6	90.6(2)	C3–C8–C7	89.4(2)
C4–C7–C8	90.8(2)	C1–C8–C7	89.5(2)
C6–C7–C8	90.3(2)	C1–C8–C3	88.0(2)
	1,3,5,7-Tetranitrocubane		
C2–C1–C6	91.1(2)	C1–C2–C3	88.7(2)
C2–C1–C8	91.4(2)	C1–C2–C5	87.9(2)
C6–C1–C8	92.0(2)	C3–C2–C5	88.2(2)
C2–C3–C4	91.9(2)	C5–C4–C7	87.8(2)
C2–C3–C8	91.3(2)	C3–C4–C7	88.3(2)
C4–C3–C8	91.0(2)	C3–C4–C5	88.2(2)
C2–C5–C4	91.7(2)	C5–C6–C7	88.2(2)
C2–C5–C6	91.8(2)	C1–C6–C7	87.6(2)
C4–C5–C6	92.6(2)	C1–C6–C5	89.2(2)
C4–C7–C6	91.3(2)	C3–C8–C7	88.6(2)
C4–C7–C8	92.1(2)	C1–C8–C7	88.6(2)
C6–C7–C8	91.9(2)	C1–C8–C3	88.6(2)

[a] The bond angles occurring at the odd-numbered corners of the cube, all nitro-substituted but one, are on the left and are all greater than 90°. The angles at the even-numbered corners, all hydrogen substituted, are on the right and are all less than 90°.

correlation is found when the orientation of the nearest nitro group, as measured by certain torsion angles, is considered (see Table II).

As any nitro group, assumed to have two-fold planar symmetry, situated on a trigonal site (e.g., a cube corner) rotates, it passes through two symmetrical extrema, **A** and **B**, located only 30° from one another on the torsional pathway. Through symmetry, any other conformer can be energetically equated to **A** or **B** or to a conformer lying in the narrow range separating **A** and **B**. Thus, one end of each nitro group necessarily comes within 30° of eclipsing one of the three adjacent cube edges. Another way to state this is, in general, a nitro group on a cube always displays one and only one C–C–N–O torsion angle in the –30 to 30° range (herein called semieclipsed, also termed synclinal in the literature). [One exception: the special case, **A**, contains *two* torsions in this range; *viz.*, +30 and –30°.] It so happens that, of the 24 cube edges in **1** and **2**, the three shortest in **1** and the four shortest in **2** are those that are semieclipsed with the seven nitro groups. The remaining cube-edge distances are roughly correlated with the absolute magnitude of the torsion to the nearest NO bond, which fall in the 30–90° range (see Table II for a listing of all values). This pattern of bond shortenings illustrates again that the cubane cage is a flexible entity affected by its electronic environment. Similar bond contractions are observed in two cubanourea compounds at a cube edge that is eclipsed by a urea grouping.[22] Cube-edge distances spanning a wide range from 1.522 Å (in *N*-(azidocarbonyl)-*N'*-nitrocubanourea)[23] to 1.607 Å (in a bulkily substituted phenylcubane),[13b] have now been observed in X-ray determinations.

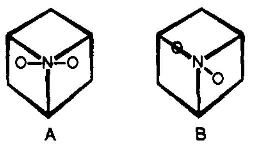

Table II. Cube-Edge Lengths (Å) and Adjacent Nitro Torsion Angles (deg)[a]

	1,3,5-Trinitrocubane		
C1–C2	1.533(4)	C2–C1–N1–O1B	–3.8(0.4)
C4–C5	1.538(4)	C4–C5–N5–O5B	–2.5(0.4)
C3–C8	1.544(4)	C8–C3–N3–O3B	–18.8(0.4)
C1–C8	1.550(4)	C8–C1–N1–O1A	55.5(0.4)
C2–C5	1.552(4)	C2–C5–N5–O5A	53.4(0.3)
C2–C3	1.553(4)	C2–C3–N3–O3A	41.9(0.4)
C6–C7	1.555(4)	no adjacent nitro group	
C5–C6	1.556(4)	C6–C5–N5–O5A	–61.0(0.3)
C1–C6	1.558(4)	C6–C1–N1–O1A	–61.5(0.3)
C7–C8	1.562(4)	no adjacent nitro group	
C4–C7	1.563(4)	no adjacent nitro group	
C3–C4	1.566(4)	C4–C3–N3–O3A	–76.6(0.4)
	1,3,5,7-Tetranitrocubane		
C5–C6	1.538(3)	C6–C5–N5–O5B	–20.9(0.4)
C1–C8	1.548(4)	C8–C1–N1–O1B	–24.9(0.3)
C2–C3	1.548(4)	C2–C3–N3–O3B	–11.7(0.4)
C7–C8	1.550(4)	C8–C7–N7–O7A	–23.0(0.4)
C4–C5	1.551(4)	C4–C5–N5–O5A	36.6(0.3)
C4–C7	1.560(3)	C4–C7–N7–O7B	35.1(0.4)
C6–C7	1.562(4)	C6–C7–N7–O7B	–83.4(0.3)
C1–C6	1.562(4)	C6–C1–N1–O1A	33.3(0.3)
C1–C2	1.567(3)	C2–C1–N1–O1A	–84.9(0.3)
C3–C4	1.567(4)	C4–C3–N3–O3A	49.0(0.4)
C3–C8	1.569(3)	C8–C3–N3–O3A	–71.9(0.4)
C2–C5	1.571(4)	C2–C5–N5–O5A	–80.3(0.3)

[a] The distances are sorted, for each compound, in order of increasing bond length, to illustrate the correlation between the shorter cubane bond lengths and nearby nitro-group torsions in the eclipsed range ($-30° \leq \tau \leq 30°$). The seven nitro groups each display one such torsion, and these seven 'eclipses' fall at the top of the two lists given above.

Experimental Section

Most cubane compounds are quite stable kinetically. Nonetheless, as they are all high-energy materials, it is prudent to run all reactions thereof behind safety shields. Great care should be taken to assure that crude reaction products are not concentrated at elevated temperature, particularly in the presence of acidic or metallic contaminants.

The procedure "removal of solvent" refers to evaporation of a rotary evaporator at house vacuum (*ca.* 50 Torr) unless use of an oil pump is specified. The evaporator bath was not heated above room temperature. Other general procedures and details have been published previously.[24]

Magnesium Bis(2,2,6,6-tetramethylpiperidide) (MgTMP$_2$). A solution of *n*-BuLi in hexanes (Aldrich, 80 mL, 200 mmol) was added slowly to anhydrous TMPH (34 mL, 200 mmol) in stirred THF (150 mL) kept at <–70 °C in a dry ice/acetone bath. The solution was allowed to warm

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(22) Eaton, P. E.; Pramod, K.; Gilardi, R. *J. Org. Chem.* **1990**, *55*, 5746.

(23) Gilardi, R.; George, C.; Karle, J.; Eaton, P. E.; Rao, M. *J. Heterocycl. Chem.*, in press.

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to −20 °C and held there for 30 min. This solution of LiTMP was then transferred by cannula to a stirred suspension of finely powdered $MgBr_2{\cdot}OEt_2$ (Aldrich, 27.0 g, 105 mmol) in THF (80 mL) at <−70 °C. The mixture was stirred at 0 °C until homogeneous (about 2 h). It was then warmed to room temperature. This solution (338 mL, 0.3 M in $MgTMP_2$) could be stored in Aldrich SureSeal bottles in the freezer for at least several months without significant degradation.

Magnesium (2,2,6,6-Tetramethylpiperidide) Bromide (BrMgTMP). This was prepared just as above using LiTMP (100 mmol) and $MgBr_2{\cdot}OEt_2$ (25.8 g, 100 mmol) in THF (63 mL) to give a solution 0.5 M in BrMgTMP. This solution could be stored in Aldrich SureSeal bottles in the freezer for at least several months without significant degradation.

Bismercuriation of 3. A freshly prepared LiTMP solution (210 mmol; prepared from 84.5 mL of *n*-BuLi and 35.8 mL of TMPH in 200 mL of THF) containing TMEDA (25 mL) was added to a solution of **3** (1.80 g, 7.01 mmol) and $HgCl_2$ (11.5 g, 42 mmol) in THF (200 mL) at −78 °C. The mixture was stirred at −15 °C for 2 h and then quenched with water (5 mL). The $CHCl_3$ layer was separated; the aqueous layer was extracted with more $CHCl_3$. The combined $CHCl_3$ extract was washed with 1 N hydrochloride acid (3 × 100 mL) and brine and then dried over Na_2SO_4. Removal of solvent left a pale-yellow residue. This was dissolved in acetonitrile (25 mL) containing $HgCl_2$ (4 g), and the whole was stirred at room temperature for 24 h. The precipitate was collected, washed generously with ether, and dried overnight (0.01 Torr, 78 °C) to give 4.60 g of white solid dimercury compound **4**. The crude (the contaminant is trimercuriated compound **5**) was used without further purification: mp 248 °C dec; ^{1}H NMR (acetone-d_6) δ 1.38 (d, 6 H), 1.40 (d, 6 H), 3.48 (sept, 1 H), 3.76 (sept, 1 H), 4.60 (t, 1 H), 4.64 (m, 2 H), 4.70 ppm (t, 1 H); IR (KBr) ν 2978 (m), 2931 (w), 2217 (m), 1589 (s), 1576 (s), 1367 (m), 1340 (m), 1203 (w), 1035 cm^{-1} (m).

4-Cyano-2,4-bis(hydroxycarbonyl)-1-(diisopropylcarbamoyl)cubane (6). Crude **4** was suspended in ether (170 mL) cooled in a dry ice/acetone bath. CH_3Li in ether (11.2 mL, 19 mmol) was added. After 20 min, *t*-BuLi in hexanes (15 mL, 25.5 mmol) was added. The mixture was stirred near −78 °C for another 15 min and then quenched by bubbling in CO_2 gas for 15 min. The solvent was removed (caution: volatile dialkylmercuries are present) and the residue taken up in ethyl acetate (200 mL) and cold 2 N hydrochloric acid (200 mL). The organic layer was separated, washed with additional acid, and then extracted thoroughly with 5% aqueous Na_2CO_3. (The organic layer contains large amounts of volatile dialkylmercury compounds; it was treated with NaI and then disposed of properly.) The combined base extract was acidified with hydrochloric acid and then extracted with ethyl acetate (3 × 100 mL). The extract was washed with brine and dried over Na_2SO_4. Removal of solvent left 1.18 g (50% overall from **3**) of diacid **6** as a pale-yellow solid: mp 230 °C dec; ^{1}H NMR (acetone-d_6) δ 4.72 (t, 1 H), 4.54 (m, 2 H), 4.47 (t, 1 H), 3.58 (sept, 1 H), 3.39 (sept, 1 H), 1.40 (d, 6 H), 1.28 ppm (d, 6 H); IR ν 3450 (br), 3009 (w), 2214 (w), 1729 (s), 1705 (s), 1513 (s), 1373 (m), 1208 (m), 749 (w), 694 cm^{-1} (w). The dimethyl ester was prepared by reaction with diazomethane: ^{1}H NMR δ 4.74 (t, 1 H), 4.46 (dd, 2 H), 4.30 (t, 1 H), 3.76 (s, 6 H), 3.30 (sept, 1 H), 3.15 (sept, 1 H), 1.36 (d, 6 H), 1.12 ppm (d, 6 H); ^{13}C NMR δ 168.10, 163.57, 116.64, 64.48, 54.61, 52.12, 50.99, 49.08, 48.96, 46.19, 45.98, 35.65, 21.12, 20.17 ppm; IR ν 2969 (m), 2226 (w), 1731 (s), 1632 (s), 1438 (m), 1348 (m), 1312 (m), 1210 (s), 1162 (m), 1036 cm^{-1} (m).

4-Cyano-2-(hydroxycarbonyl)-1-(diisopropylcarbamoyl)cubane (7). A solution of $MgTMP_2$ in THF (110 mL, 33 mmol) was added slowly to solid cyano amide **3** (2.84 g, 11.1 mmol) in a stirred, round-bottomed flask cooled in a dry ice/acetone bath. The cooling bath was removed afterward, and the mixture was allowed to warm. It was stirred for 1 h at room temperature and then cooled to −78 °C; gaseous CO_2 was bubbled in for 15 min. The mixture was allowed to warm to room temperature and then was concentrated to ca. 50 mL under vacuum (no heating). Methylene chloride (100 mL) was added followed by ice and cold concentrated hydrochloric acid. The mixture was diluted with water and extracted with CH_2Cl_2. The extract was washed with dilute hydrochloric acid and then brine and dried over Na_2SO_4. Removal of solvent left 3 g of a yellowish solid. This was triturated with ethyl acetate, leaving white crystals of **7**, two crops, 2.80 g (85%): mp 230–240 °C dec; ^{1}H NMR δ 4.59 (m, 2 H), 4.34 (m, 1 H), 4.28 (t, J = 4.9 Hz, 2 H), 3.40 (m, 2 H), 1.40 (d, J = 7 Hz, 6 H), 1.25 ppm (d, J = 7 Hz, 6 H); ^{13}C NMR δ 170.83, 170.53, 116.84, 62.34, 56.51, 50.14, 49.18, 47.77, 47.45, 47.60, 37.85, 20.78, 20.01 ppm. Anal. Calcd for $C_{17}H_{20}N_2O_3$: C, 67.98; H, 6.71; N, 9.33. Found: C, 68.01; H, 6.65; N, 9.42.

2,4-Dicyano-1-(diisopropycarbamoyl)cubane (8). Acid **7** (1.23 g) was suspended in CH_2Cl_2 (10 mL). Oxalyl chloride (5 mL) was added. The starting material dissolved immediately with vigorous bubbling. Subsequently, a large amount of white precipitate formed. The mixture was stirred at room temperature for 45 min, and then the solvent and excess reagent were removed under vacuum (no heating), leaving the acid chloride as a white solid. This was dissolved in THF (30 mL). The solution was cooled to near −78 °C, and liquid ammonia (~5 mL) was added. The mixture was allowed to warm to room temperature over 30 min, and then the solvent and excess ammonia were removed under vacuum. The residue was taken up with CH_2Cl_2, washed with dilute hydrochloric acid and then brine, and dried over Na_2SO_4. Removal of solvent left 1.25 g (99%) of **2-carbamoyl-4-cyano-1-(diisopropylcarbamoyl)cubane**. Crystallization from acetonitrile gave an analytical sample: mp 214 °C dec; ^{1}H NMR (acetone-d_6) δ 8.60 (br s, 1 H), 5.44 (br, s, 1H), 4.51 (m, 2 H), 4.28 (m, 1 H), 4.25 (t, J = 5 Hz, 2 H), 3.36 (m, 2 H), 1.41 (d, J = 7 Hz, 6 H), 1.22 ppm (d, J = 7 Hz, 6 H); ^{13}C NMR (acetone-d_6) δ 170.7, 168.7, 117.5, 62.8, 58.3, 49.3, 48.7, 47.4, 46.9, 46.6, 37.4, 20.3, 21.0 ppm; IR (KBr) ν 3320 (m), 3040 (m), 3000 (m), 2970 (m), 2220 (m), 1667 (s), 1446 (m), 1369 (s), 1345 (s), 730 cm^{-1} (m). Anal. Calcd for $C_{17}H_{21}N_3O_2$: C, 68.20; H, 7.07; N, 14.04. Found: C, 68.20; H, 7.22; N, 13.52. Part of this material (1.20 g, 4.00 mmol) was dissolved in a mixture of $CHCl_3$ (35 mL), DMF (5 mL), and TMEDA (4 mL, 28 mmol). The solution was cooled to −10 °C. Thionyl chloride (2 mL) was added slowly. The cooling bath was removed; the reaction mixture was stirred for 20 min and then poured into cold 0.5 N hydrochloric acid (300 mL). This was extracted with $CHCl_3$. The extract was washed with dilute hydrochloric acid and then brine and dried over Na_2SO_4. Removal of solvent left an off-white solid. This was washed with ethyl acetate, leaving 760 mg of product. The wash liquor was concentrated and flash chromatographed (silica gel; CH_2Cl_2/ethyl acetate, 5:1) to give another 180 mg; total 940 mg (77%). Crystallization from ethyl acetate gave an analytical sample to **8**: mp 220 °C dec; ^{1}H NMR δ 4.62 (m, 2 H), 4.35 (t, J = 5 Hz, 2 H), 4.26 (m, 1 H), 3.37 (sept, J = 7 Hz, 1 H), 3.28 (sept, J = 7 Hz, 1 H), 1.42 (d, J = 7 Hz, 6 H), 1.30 ppm (d, J = 7 Hz, 6 H); ^{13}C NMR δ 168.4, 116.5, 115.3, 61.3, 49.5, 49.3, 47.1, 46.5, 42.1, 38.6, 21.3, 20.4 ppm; IR (KBr) ν 2974 (m), 2231 (m), 2218 (m), 1637 (s), 1457 (m), 1369 (s), 1347 (s), 1213 (m), 1088 (m), 730 cm^{-1} (m). Anal. Calcd for $C_{17}H_{19}N_3O$: C, 72.57; H, 6.81; N, 14.94. Found: C, 72.27; H, 6.61; N, 14.89.

2,4-Dicyano-3,6-diiodo-1-(diisopropylcarbamoyl)cubane (9). A solution of LiTMP in THF (0.99 mmol, freshly prepared as above) was added to 51 mg (0.18 mmol) of dicyano amide **8** and $HgCl_2$ (267 mg, 0.99 mmol) in THF (6 mL) near −78 °C. The mixture was stirred for 1 h and then allowed to warm (2 h) to −15 °C. It was maintained at −15 °C for another 2 h, and then reacted with H_2O/I_2 (5 mL/2 g) for 24 h. The mixture was extracted with chloroform; the extract was washed with 1 N hydrochloric acid and then aqueous Na_2SO_3, water, and brine and then dried over Na_2SO_4 and concentrated. The residue was flash chromatographed (15–20% ethyl acetate in hexanes) to give 13.5 mg (14%) of **9**: ^{1}H NMR δ 4.86 (X of ABX), 4.60 (B of ABX, J_{AB} = −2.56 Hz), 4.58 (A of ABX, J_{AB} = 5.75 Hz, J_{AX} = 1.78 Hz), 3.42 (sept, J = 7 Hz, 1 H), 3.30 (sept, J = 7 Hz, 1 H), 1.6 (d, J = 7 Hz, 3 H), 1.45 (d, J = 7 Hz, 3 H), 1.37 (d, J = 7 Hz, 3 H), 1.32 ppm (d, J = 7 Hz, 3 H). Anal. Calcd for $C_{16}H_{18}I_2N_2O$: C, 37.82; H, 3.57; N, 5.51. Found: C, 37.65; H, 3.70; N, 5.55.

2,4-Dicyano-1-(diisopropylcarbamoyl)-6-(hydroxycarbonyl)cubane (10). Dicyano amide **8** (1.48 g, 5.26 mmol) was suspended in THF (30 mL) cooled to near −78 °C. A solution of BrMgTMP in THF (110 mL, 53 mmol) was added slowly. The cooling bath was removed. The mixture was stirred for 40 min and then recooled in a dry ice/acetone bath and quenched with gaseous CO_2 for 15 min. The solvent was removed (no heating); cold 2 N hydrochloric acid (200 mL) was added. The mixture was extracted with ethyl acetate (3 × 80 mL). The combined organic phase was extracted with 5% aqueous Na_2CO_3 (3×). The basic extract was acidified to pH 2 with hydrochloric acid and then extracted thoroughly with ethyl acetate. This extract was washed with brine and dried over Na_2SO_4. Removal of solvent left 1.78 g (78%) of pale-yellow solid **10**. Crystallization from acetonitrile gave an analytical sample: mp 208 °C dec; ^{1}H NMR (acetone-d_6 δ 4.91 (t, 1 H), 4.85 (m, 1 H), 4.55 (t, 1 H), 4.41 (m, 1 H), 3.61 (sept, 1 H), 3.51 (sept, 1 H), 1.42 (m, 9 H), 1.35 ppm (d, 3 H); ^{13}C NMR (acetone-d_6) δ 169.8, 168.4, 117.3, 116.2, 65.7, 56.8, 53.6, 51.2, 50.5, 48.5, 20.2, 47.7, 42.9, 38.0, 21.2, 20.8, 20.5 ppm; IR (KBr) ν 2945 (m), 2895 (m), 2800–2400 (br), 1730 (s), 1564 (s), 1502 (m), 1371 (m), 1034 (m), 624 cm^{-1} (m). Anal. Calcd for $C_{18}H_{19}N_3O_3$: C, 66.45; H, 5.89; N, 12.91. Found: C, 66.40; H, 5.87; N, 12.90.

1-(Diisopropylcarbamoyl)-2,4,6-tricyanocubane (12). Acid **10** (1.21 g) was suspended with stirring in CH_2Cl_2 (5 mL); thionyl chloride (6 mL) was added. The solution went clear after 2 h at room temperature. It was taken to dryness under vacuum without heating. The solid residue was dissolved in THF (40 mL); the solution was cooled to near –78 °C, and liquid ammonia (5 mL) was added. A voluminous white precipitate formed. The mixture was stirred at room temperature for 45 min, and then the solvent and excess reagent were removed. The residue was suspended in 0.05 M hydrochloric acid (70 mL). The solid was collected by filtration, washed with water and ether, and dried *in vacuo* to give an off-white solid (1.00 g). Extraction of the aqueous acid solution with ethyl acetate gave a further 100 mg (total 1.10 g, 92%). Crystallization from ethyl acetate gave an analytical sample of **2-carbamoyl-4,6-dicyano-1-(diisopropylcarbamoyl)cubane**: mp 160–163 °C; ^{1}H NMR (acetone-d_6) δ 7.92 (br, 1 H), 6.60 (br, 1 H), 4.85 (td, 1 H), 4.69 (m, 1 H), 4.47 (m, 1 H), 4.42 (td, 1 H), 3.47 (sept, 1 H), 3.40 (sept, 1 H), 1.37 (dd, 6 H), 1.27 (d, 3 H), 1.24 ppm (d, 3 H); ^{13}C NMR (acetone-d_6) δ 169.15, 165.41, 117.41, 116.54, 64.96, 58.50, 53.13, 51.21, 50.28, 49.52, 47.29, 46.75, 41.14, 37.45, 21.28, 21.25, 20.61, 20.51 ppm. Anal. Calcd for $C_{18}H_{20}N_4O_2$: C, 66.65; H, 6.21; N, 17.27. Found: C, 63.47; H, 6.45; N, 16.32. Part of this material (809 mg) was refluxed with thionyl chloride (15 mL) for 1.5 h. The suspension initially cleared to give a pale-yellow solution, but later a yellow solid precipitated. The excess reagent was evaporated. The residue was dissolved in acetonitrile (60 mL) and the solution filtered through a short silica gel column. The column was washed with hot acetonitrile (80 mL) and the combined eluate evaporated, leaving 794 mg of an off-white solid (99%). Crystallization from acetonitrile gave an analytical sample of **12**: mp 220 °C dec; ^{1}H NMR (acetone-d_6) δ 5.12 (t, 1 H), 4.71 (dd, 2 H), 4.57 (t, 1 H), 3.52 (sept, 1 H), 3.46 (sept, 1 H), 1.40 (d, 6 H), 1.35 ppm (d, 6 H); ^{13}C NMR (acetone-d_6) δ 163.51, 117.02, 115.87, 63.49, 53.60, 51.56, 49.83, 49.10, 46.89, 42.38, 39.47, 21.33, 20.61 ppm; IR (KBr) ν 2978 (m), 2967 (m), 2228 (m), 1622 (s), 1471 (m), 1457 (m), 1443 (m), 1375 (m), 1344 (s), 1204 (m), 1034 cm^{-1} (m). Anal. Calcd for $C_{18}H_{18}N_4O$: C, 70.57; H, 5.92; N, 18.29. Found: C, 70.09; H, 5.91; N, 18.33.

1-(Diisopropylcarbamoyl)-8-(hydroxycarbonyl)-2,4,6-tricyanocubane (13). A solution of BrMgTMP in THF (50 mL, 25 mmol) was added to a suspension of **12** (680 mg, 2.22 mmol) in THF (25 mL) cooled near –78 °C. The temperature was raised to –20 °C and the mixture stirred for 1 h; the solid all dissolved. The solution was then cooled in a dry ice/acetone bath. Carbon dioxide was bubbled in for 5 min. The solvent was removed. Cold 5 N hydrochloric acid (20 mL) was added with stirring. The white residual solid was collected, washed with water, and then dried under vacuum to give 600 mg (77%) of **13**. This was purified by crystallization from acetonitrile: mp 230–240 °C dec; ^{1}H NMR (acetone-d_6) δ 5.34 (t, J = 2.7 Hz, 1 H), 4.86 (d, J = 2.7 Hz, 2 H), 3.65 (sept, J = 7 H), 3.50 (sept, J = 7 Hz, 1 H), 1.22 ppm (d, J = 7 Hz, 12 H); ^{13}C NMR (acetone-d_6) δ 168.27, 164.32, 116.44, 115.70, 68.03, 56.43, 54.89, 53.96, 50.65, 47.94, 43.03, 37.83, 22.28, 20.37 ppm.

1-(Diisopropylcarbamoyl)-2,4,6,8-tetrakis(hydroxycarbonyl)cubane (14). An aqueous solution of KOH (6 g in 5 mL) was added to **13** (450 mg) dissolved in 5 mL of ethanol. The solution was refluxed for 3.5 h and then acidified to pH 4 with cold concentrated hydrochloric acid. The solvents were removed at the oil pump, and the residue was dried *in vacuo*. The white solid residue was extracted with hot acetone (2 × 100 mL). The extract was taken to dryness to leave 550 mg (~100%) of tetraacid **14**, used without purification. ^{1}H NMR (acetone-d_6) δ 4.59 (s, 3 H), 3.59 (sept, J = 7 Hz, 1 H), 3.08 (sept, J = 7 Hz, 1 H), 1.40 (d, J = 7 Hz, 6 H), 1.20 ppm (d, J = 7 Hz, 6 H).

1-((*N,N*-Diisopropylamino)methyl)-2,4,6,8-tetrakis(acetoxymethyl)-cubane (16). Tetraacid **14** (550 mg, 1.28 mmol) was refluxed with $LiAlH_4$ (1.1 g, excess) in THF (30 mL) for 20 h. More THF (100 mL) was added, and then the excess reagent was quenched with ethyl acetate (5 mL), followed by saturated aqueous Na_2SO_4. The mixture was filtered, and the collected salts were washed with THF (50 mL). The combined filtrate was dried over Na_2SO_4. Evaporation of solvent left ~400 mg of pale yellow, crystalline **15**. This was treated directly with acetic anhydride (15 mL) at room temperature overnight. The excess reagent was removed (oil pump) to give 632 mg (89%) of a light-brown oil identified as **16**: ^{1}H NMR δ 4.30 (s, 6 H), 4.15 (s, 2 H), 3.55 (s, 3 H), 2.90 (sept, J = 7 Hz, 2 H), 2.86 (s, 2 H), 2.07 (s, 12 H), 0.99 ppm (d, J = 7 Hz, 12 H); ^{13}C NMR δ 171.12, 171.06, 64.09, 63.29, 61.35, 49.47, 47.25, 46.94, 46.20, 40.34, 20.89, 20.83, 20.20 ppm. This was used without purification.

1,3,5,7-Tetrakis(acetoxymethyl)cubane (19). The ester amine **16** (632 mg, 1.14 mmol) was allowed to react overnight with dimethyldioxirane in acetone (100 mL, ca. 0.05 M).[2b] The solvent was removed and the residue dried under vacuum to leave 520 mg of a pale-yellow oil, the acid **17**. This was stirred at room temperature for 1 h in excess thionyl chloride (8 mL). The excess was removed thoroughly on the rotary evaporator without heating, and then the residue was dissolved in 20 mL of dry benzene. The sodium salt of *N*-hydroxypyridinethione (anhydrous, 270 mg, ca. 1.5 equiv) and 4-(*N,N*-dimethylamino)pyridine (5 mg) were added, and the mixture was stirred at room temperature for 15 min to make PTOC ester **18**. *t*-BuSH (0.8 mL, freshly distilled) was added and the whole then refluxed over a sunlamp for 1.5 h. The cooled mixture was diluted with chloroform (50 mL) and the solution washed with Chlorox (2×), cold concentrated hydrochloric acid (2×), water, and brine and then dried over Na_2SO_4. Evaporation left 322 mg of tetraacetate **19**. Crystallization from hexane gave an analytical sample: mp 62.5–63.5 °C; ^{1}H NMR δ 4.14 (s, 8 H), 3.60 (s, 4 H), 2.04 ppm (s, 12 H); ^{13}C NMR δ 171.11, 63.96, 47.70, 46.96, 20.78 ppm; IR (neat) ν 2985 (w), 2907 (w), 1738 (s), 1443 (w), 1426 (w), 1386 (m), 1365 (m), 1231 (s), 1036 (m), 954 (m), 891 cm^{-1} (m). Anal. Calcd for $C_{20}H_{24}O_8$: C, 61.22; H, 6.17. Found: C, 60.82; H, 6.07.

1,3,5,7-Tetrakis(hydroxycarbonyl)cubane. Cubane-1,3,5,7-tetracarboxylic Acid (20). Tetraacetate **19** (310 mg) in 10 mL of 10% aqueous NaOH solution was treated at 60 °C with $KMnO_4$ (800 mg, excess) for 20 h. The excess permanganate was reduced by slow addition of powdered $NaHSO_3$. The brown solid was filtered and washed with 5% aqueous NaOH (10 mL). The filtrate was acidified with cold concentrated hydrochloric acid to pH 4, and then the solution was evaporated to dryness at the oil pump without heating. The residue was extracted thoroughly with hot acetone. The extract was taken to dryness and the process repeated to give a white solid (ca. 300 mg). This was washed with hot chloroform to leave 190 mg (85%) of tetraacid **29**: mp 240 °C dec; ^{1}H NMR (acetone-d_6) δ 4.62 ppm (s, 4H); ^{13}C NMR (acetone-d_6) δ 49.47, 54.22, 170.56 ppm. The tetramethyl ester was prepared by reaction with diazomethane: mp 125–127 °C; ^{1}H NMR δ 4.63 (s, 4 H), 3.75 ppm (s, 12 H); ^{13}C NMR δ 169.42, 53.48, 52.13, 48.87 ppm. Anal. Calcd for $C_{16}H_{16}O_8$: C, 57.15; H, 4.80. Found: C, 56.90; H, 4.73.

1,3,5,7-Tetranitrocubane (2). *Caution! This procedure involves an extremely explosive acyl azide. Use face mask, gloves, heavy shields, and great care.* Tetraacid **20** (24 mg, 0.086 mmol) was stirred at room temperature for 2 h with thionyl chloride (2 mL) in acetonitrile (3 mL). The excess reagent and solvent were removed without heating. The resulting crystalline acid chloride was stirred at room temperature for 2 h in dry methylene chloride (5 mL) containing 1.5 mL of trimethylsilyl azide. The solvent and excess reagent were removed under vacuum to leave the oily acyl azide **21**. This was refluxed in dry chloroform (6 mL) for 1.5 h. The solvent was removed. The solid residue, the tetraisocyanate **22**, was treated overnight with 50 mL of dimethyldioxirane (~0.05 M) in wet acetone.[2b] Evaporation of solvent left a yellow solid; this was flash chromatographed (silica gel, CH_2Cl_2/CH_3CN, 10:1) to give 7 mg (30%) of 1,3,5,7-tetranitrocubane (**2**): mp 270 °C dec; ^{1}H NMR (acetone-d_6) δ 6.07 ppm (s, 4 H); ^{13}C NMR (acetone-d_6) δ 73.2, 67.9 ppm; IR (KBr) ν 3044 (w), 2925 (w), 2845 (w), 1557 (s), 1374 (m), 1240 (w), 962 (w), 755 cm^{-1} (w).

1,3,5-Trinitrocubane (1). This was prepared following the procedures set out above: mp 250 °C dec; ^{1}H NMR (acetone-d_6) δ 5.94 (dq, J = 1.5 Hz, J = 3.2 Hz, 1 H), 5.26 (dd, J = 5.8 Hz, J = 3.2 Hz, 3 H), 4.20 (dq, J = 1.5 Hz, J = 5.8 Hz, 1 H) ppm; ^{13}C NMR (acetone-d_6) δ 77.83, 66.68, 62.00, 34.73 ppm; IR 3002 (w), 1529 (s), 1365 (s), 751 (m) cm^{-1}. Various intermediates on route were characterized as follows.

1-(Hydroxycarbonyl)-2,4,6-tris(acetoxymethyl)cubane: ^{1}H NMR δ 4.35 (s, 4 H), 4.18 (s, 2 H), 4.04 (t, 1 H), 3.79 (dd, 2 H), 3.68 (t, 1 H), 2.07 (s, 6 H), 2.03 ppm (s, 3 H).

1,3,5-Tris(acetoxymethyl)cubane: ^{1}H NMR δ 4.17 (s, 6 H), 3.74 (m, 1 H), 3.73 (d, 3 H), 3.62 (q, 1 H), 2.05 ppm (s, 9 H); ^{13}C NMR δ 171.21, 64.35, 49.94, 47.95, 47.40, 38.21, 20.82 ppm.

1,3,5-Tris(hydroxycarbonyl)cubane (1,3,5-cubanetricarboxylic acid): ^{1}H NMR (acetone-d_6) δ 4.59 (q, 1 H), 4.38 (dd, 2 H), 3.98 ppm (q, 1 H); ^{13}C NMR (acetone-d_6) δ 171.40, 53.53, 52.46, 51.80, 40.99 ppm.

1,3,5-Tris(methoxycarbonyl)cubane: ^{1}H NMR δ 4.64 (q, 1 H), 4.41 (dd, 2 H), 3.97 (q, 1 H), 3.72 ppm (s, 9 H); ^{13}C NMR δ 170.47, 52.83, 51.89, 51.72, 51.05, 40.71 ppm; IR ν 3004 (m), 2955 (m), 1726 (s), 1436 (m), 1350 (m), 1315 (m), 1211 (s), 1166 (m), 1136 (m), 1022 (m), 910 (cm^{-1} (m). Anal. Calcd for $C_{14}H_{14}O_6$: C, 60.43; H, 50.07. Found: C, 60.26; H, 5.05.

Single-Crystal X-ray Diffraction Analysis of 1,3,5-Trinitrocubane. $C_8H_5N_3O_6$, FW = 239.14, orthohombic space group *Pbca*, a = 11.656(2), b = 11.946(2), c = 13.130(2) Å, V = 1828.2 Å^3, Z = 8, ρ_{calc} = 1.738 mg mm^{-3}, λ(Cu Kα) = 1.54184 Å, μ = 1.34 mm^{-1}, F(000) = 976, T = 295 °K.

A clear, colorless 0.04 × 0.15 × 0.47 mm crystalline plate was used for data collection on an automated Siemens R3m/V diffractometer equipped with an incident beam monochromator. Lattice parameters were determined from 25 centered reflections within $40.8 \leq 2\theta \leq 63.9°$. The data collection range of *hkl* was $-13 \leq h \leq 0$, $0 \leq k \leq 13$, $0 \leq l \leq 14$, with $[(\sin\theta)/\lambda]_{max} = 0.547$. Three standards, monitored after every 97 reflections, exhibited random variations with deviations up to ± 2.0% during the data collection. A set of 1492 reflections was collected in the $\theta/2\theta$ scan mode, with scan width from $[2\theta(K_{\alpha1}) = 1.0]$ to $[2\theta(K_{\alpha2}) + 1.0]°$ and ω scan rate (a function of count rate) from 4.0°/min to 15.0°/min. There were 1246 unique reflections, and 1084 were observed with $F_o > 3\sigma(F_o)$. The structure was solved and refined with the aid of the SHELXTL system of programs.[25] The full-matrix least-squares refinement varied 175 parameters: atom coordinates for all atoms, anisotropic thermal parameters for the non-H atoms, isotropic thermal parameters for the hydrogen atoms. Final residuals were $R = 0.046$ and $R_w = 0.051$ with final difference Fourier excursions of 0.32 and –0.20 eÅ.^{3}

Single-Crystal X-ray Diffraction Analysis of 1,3,5,7-Tetranitrocubane. $C_8H_4N_4O_8$, FW = 284.2, monoclinic space group $P2_1/a$, $a = 12.255(2)$, $b = 7.007(1)$, $c = 13.346(2)$ Å, $\beta = 114.78(1)°$, $V = 1040.6(3)$ Å^3, $Z = 4$, $\rho_{calc} = 1.814$ mg mm^{-3}, λ(Cu Kα) = 1.54184 Å, $\mu = 1.416$ mm^{-1}, $F(000) = 576$, $T = 293$ °K.

A clear, colorless 0.10 × 0.35 × 0.45 mm crystal, in the shape of a thick plate, was used for data collection on an automated Siemens R3m/V diffractometer equipped with an incident beam monochromator. Lattice parameters were determined from 25 centered reflections within $37.7 \leq 2\theta \leq 69.9°$. The data collection range of *hkl* was $0 \leq h \leq 14$, $-8 \leq k \leq 7$, $-15 \leq l \leq 13$, with $[(\sin\theta/\lambda]_{max} = 0.575$. Three standards, monitored after every 97 reflections, exhibited random variations with deviations up to ±2.5% during the data collection. A set of 1973 reflections was collected in the $\theta/2\theta$ scan mode, with scan width from $[2\theta(K_{\alpha1}) - 1.0]$ to $[2\theta(K_{\alpha2}) + 1.0]°$ and ω scan rate (a function of count rate) from 3.0°/min to 15.0°/min. There were 1657 unique reflections, and 1532 were observed with $F_o > 3\sigma(F_o)$. The structure was solved and refined with the aid of the SHELXTL system of programs.[25] The full-matrix least-squares refinement varied 198 parameters: atom coordinates and anisotropic thermal parameters for all non-H atoms and isotropic thermal parameters for the hydrogen atoms. Final residuals were $R = 0.052$ and $R_w = 0.073$ with final difference Fourier excursions of 0.37 and –0.29 eÅ^{-3}.

Acknowledgment. The authors are grateful to the Army Research, Development and Engineering Center (via Geo-Centers, Inc.) and the Office of Naval Research (Mechanics Division) for their support of this work.

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