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Synthesis of Polynitroadamantanes. Oxidations of Oximinoadamantanes

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Adamantanes bearing *gem*-dinitro groups on bridge carbons were synthesized from oximinoadamantanes by reaction with nitric acid, or alternatively, by reaction with aqueous hypobromite, reduction of the intermediate *gem*-bromonitroadamantanes, and oxidative nitration. Reaction of oximinoadamantanes with hypochlorous acid gave anomolous *gem*-dichloro compounds instead of chloronitro derivatives. The presence of two *gem*-dinitro groups in 2,2,6,6-tetranitroadamantane markedly enhanced the density (1.75 g cm^{-1}) compared to the related open structure 2,2,6,6-tetranitrobicyclo[3.3.1]nonane (1.45 g cm^{-1}).

Although there is considerable current interest in polynitro cage molecules,[1] adamantanes have received little attention with the exception of the bridgehead-substituted derivative 1,3,5,7-tetranitroadamantane.[2] The present paper is concerned with the synthesis of adamantanes bearing *gem*-dinitro groups at the bridge positions.[3] The difficulty of preparing other nitro bridge substituted cage compounds such as the polynitrobis(homocubanes) has been described.[4] Although 2-nitroadamantane was reported previously, without characterization, by the *m*-chloroperbenzoic acid oxidation of 2-aminoadamantane,[5] there is no general synthetic method for the preparation of bridge-substituted nitroadamantanes.[6] We have investigated oxidation reactions of some oximinoadamantanes with nitric acid, hypobromite, and hypochlorite. Ketoximes generally give nitro compounds[7] or ketones[8] with these reagents, and similar products were usually obtained with adamantane derivatives. However, application of Corey's conditions[9] for converting oximinocyclohexanes to nitrocyclohexanes with aqueous hypochlorous acid resulted in *gem*-dichloroadamantanes instead of the expected *gem*-chloronitro compounds.

Results and Discussion

A. *gem*-Dinitroadamantanes and Bicyclo[3.3.1]nonanes from Oximes. 2-Adamantanone (**1a**) was converted to its oxime (**1b**), which when reacted with *N*-bromosuccinimide in aqueous *p*-dioxane in the presence of sodium bicarbonate, gave a mixture of the *gem*-bromonitro derivative (**1c**) (80%) and 2-adamantanone. Although a transient green color, possibly due to a bromonitroso intermediate was observed, no nitroso compound was isolated. No additional oxidizing agents such as hydrogen peroxide or nitric acid, which was usually

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[1] (a) Paquette, L. A.; Fischer, J. W.; Engel, P. *J. Org. Chem.* **1985**, *50*, 2524 and references therein. (b) 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. (c) Marchand, A. P.; Arney, B. E.; Dave, P. R. *J. Org. Chem.* **1987**, *53*, 443. (d) Review: Marchand, A. P. *Tetrahedron* **1988**, *44*, 2377.

[2] (a) Sollott, G. P.; Gilbert, E. E. *J. Org. Chem.* **1980**, *45*, 5405. (b) For other bridge-head nitroadamantanes: Smith, G. W.; Williams, H. D. *J. Org. Chem.* **1961**, *26*, 2207.

[3] (a) For reviews on synthesis and chemistry of nitro compounds, see: *The Chemistry of Nitro and Nitroso Group*; Feuer, H., Ed.; Wiley-Interscience: New York, 1969; Part 1. (b) Kornblum, N. *Org. React.* (*N.Y.*) **1962**, *12*, 101. (c) For preparation of *gem*-dinitro groups, see: Garver, L. C.; Grakauskas, V.; Baum, K. *J. Org. Chem.* **1985**, *50*, 1699.

[4] (a) Marchand, A. P.; Suri, S. C. *J. Org. Chem.* **1984**, *49*, 2041. (b) Marchand, A. P.; Readdy, D. S. *J. Org. Chem.* **1984**, *49*, 4078. (c) Paquette, L. A.; Nakamura, K.; Engel, P. *Chem. Ber.* **1986**, *119*, 3782 and references therein. (d) Weinstein, D. I.; Alster, J.; Marchand, A. P. *Thermochim. Acta* **1986**, *99*, 113.

[5] (a) Barth, G.; Waespe-Sarcevil, N.; Linder, R. E.; Bunnenberg, E.; Djerassi, C.; Searmans, L.; Moscowitz, A. *J. Chem. Soc., Perkin Trans. 2* **1979**, 907. (b) A polyfunctionalized bridge *C*-nitroadamantane was also prepared by the bis(aldol) condensation of nitromethane and a bicyclo-[3.3.1]nonadione. Stetter, H.; Held, H.; Mayer, J. *Justus Liebigs Ann. Chem.* **1962**, *658*, 153.

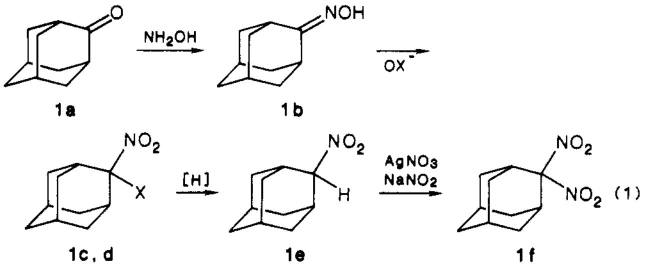
[6] Fort, R. C. *Adamantane, The Chemistry of Diamond Molecules*; Marcal Dekker: New York, 1976.

[7] Oxidation of oximes to nitro compounds proceeds through nitroso intermediates. Oxidation of these intermediates is usually difficult, generally requiring ozone, peracids, or nitric acid. (a) Kyung, J. H.; Clapp, L. B. *J. Org. Chem.* **1976**, *41*, 2024. (b) Emmons, W. D.; Pagano, A. S. *J. Am. Chem. Soc.* **1955**, *77*, 4557. (c) Barnes, M. W.; Patterson, J. M. *J. Org. Chem.* **1976**, *41*, 733. (d) Faulkner, D.; McKervery, M. A. *J. Chem. Soc. C* **1971**, 3906. (e) Korsloot, J. G.; Keizer, V. G. *Tetrahedron Lett.* **1969**, 3517. (f) Bull, J. R.; Jones, E. R. H.; Meakins, G. D. *J. Chem. Soc.* **1965**, 2601. (g) Cherkasova, E. M.; Melnikov, M. N. *J. Gen. Chem. USSR* (*Engl. Transl.*) **1949**, *19*, 280. (h) Iffland, D. C.; Criner, G. X.; Koral, M.; Lotspeich, F. J.; Papanstrassiou, Z. B.; White, S. M. *J. Am. Chem. Soc.* **1953**, *75*, 4044. (i) Amrollah-Madjdabadi, A.; Beugelmans, R.; Lechevallier, A. *Synthesis* **1986**, 825. (j) Amrollah-Madjdabadi, A.; Beugelmans, R.; Lechevallier, A. *Synthesis* **1986**, 828.

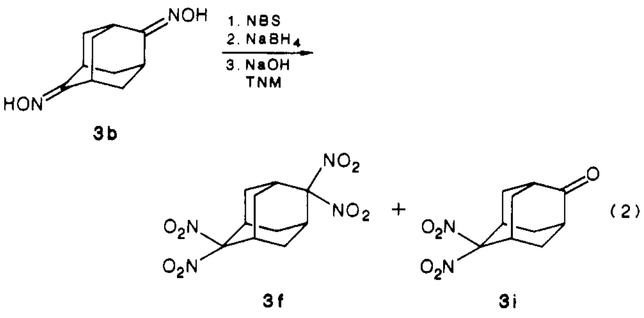
[8] (a) Olah, G. A.; Ho, T. *Synth. Commun.* **1976**, 610. (b) Olah, G. A.; Vankar, Y. D.; Prankash, G. K. S. *Synth. Commun.* **1979**, 113. (c) Vankar, P.; Rathore, G.; Chandrasekaran, S. *J. Org. Chem.* **1986**, *51*, 3063 and references therein.

[9] Corey, E. J.; Estreicher, H. *Tetrahedron Lett.* **1980**, 1117.

required to form halonitro compounds from the halonitroso intermediates,[7] were added. The oxime reacted similarly with sodium hypochlorite at pH >8 to give 76% of 2-chloro-2-nitroadamantane (**1d**). Reduction of the bromonitro compound **1c**, with sodium borohydride in methanol gave 80–90% yields of 2-nitroadamantane (**1e**), and oxidative nitration[10] of the sodium salt of **1e** with sodium nitrite and silver nitrate gave 2,2-dinitroadamantane (**1f**) in 89% yield (eq 1).



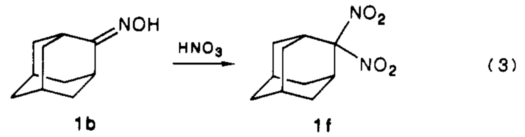
The reactions were extended to the diketones, 2,4-adamantanedione[11] (**2a**), 2,6-adamantanedione[12] (**3a**). Bromination of the dioximes **2b** and **3b** gave 5% and 24% yields, respectively, of the corresponding bromonitro derivatives, **2c** and **3c**, and debromination with sodium borohydride gave 2,4-dinitroadamantane (**2e**) and 2,6-dinitroadamantane (**3e**) in 78% and 66% yields. Attempted oxidative nitrations of both dinitro compounds by the silver method were unsuccessful. However, reaction of the disodium salt of **3e** with sodium nitrite and tetranitromethane gave a 68% yield of 2,2,6,6-tetranitroadamantane (**3f**), as well as a 20% yield of 6,6-dinitro-2-adamantanone (**3i**) (eq 2), which may arise from a Nef reaction of **3e**.



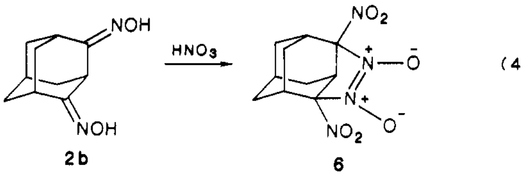
Attempts to prepare 2,2,4,4-tetranitroadamantane (**2f**) were unsuccessful; molecular models indicated severe steric crowding. Compound **3f** is a structural isomer of the previously synthesized 1,3,5,7-tetranitroadamantane[23] and has a similar unusual high thermal stability (mp >300 °C).

In another example with large 1,3 steric interaction, 4e-bromo-2-adamantanone[13] (**4a**), was converted to its oxime, **4b**. Bromination of **4b** gave only the original ketone **4a**. The dioxime of 2,6-bicyclo[3.3.1]nonanedione[14] (**5a**), which has a partial adamantane structure, gave small yields of *gem*-bromonitro derivative **5c**.

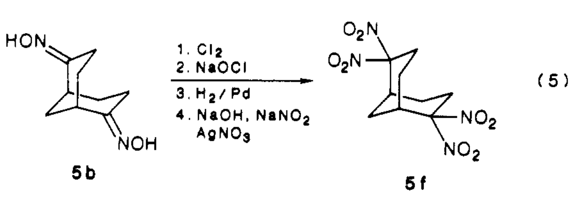
As an alternate synthetic route to *gem*-dinitroadamantanes, the direct nitration of oximinoadamantanes was investigated. The reaction of adamantanone oxime **1b** with 100% nitric acid in refluxing methylene chloride[15] gave a mixture of 70% ketone **1a** and 30% dinitro compound **1f** (eq 3). Use of other solvents (ether or chloroform) or other temperatures (0–25 °C) in methylene chloride gave only ketone **1a**. Addition of hydrogen peroxide to any of these solutions led to the formation of 4-oxo-5-homoadamantanone,[16] the Bayer–Villiger oxidation product of adamantanone. In separate experiments, dilute aqueous mineral acid solutions were found to convert compound **1f** to ketone **1a**.



Direct nitration of the dioximes **3b** and **5b** resulted in deoximation to give ketones **3a** and **5a**. However, 4e-bromo-2-adamantanone (**4a**) reacted with 100% nitric acid in refluxing methylene chloride to give 20% of the *gem*-dinitro compound **4f**. By repeated reoximation and renitration of the crude reaction mixtures, the yield was improved to 60%. Reaction of the 2,4-dioxime **2b** with 100% nitric acid in methylene chloride gave 2,4-dinitro-2,4-dinitrosoadamantane (**6**) and the diketone **2a** (eq 4). Compound **6** was isolated in 10% yield as an internal dimer.[17] Attempts to oxidize this material further with hydrogen peroxide or peracids gave ketone **2a**.



Attempts to prepare the tetranitrobicyclo[3.3.1]nonane **5f** by direct nitration of the corresponding dioxime **5b** or reductive debromination of the bromonitro derivative **5c** were unsuccessful. However, oxidation of 2,6-dichloro-2,6-dinitrosobicyclo[3.3.1]nonane[18] (**5g**) with hypochlorite in benzene in the presence of tetra-*n*-butylammonium hydrogen sulfate gave 2,6-dichloro-2,6-dinitrobicyclo[3.3.1]nonane (**5d**) in 59% yield. Reductive dehalogenation of **5d** with hydrogen over palladium on carbon gave a 60% yield of 2,6-dinitrobicyclo[3.3.1]nonane (**5e**), which was oxidatively nitrated with silver nitrate and sodium nitrite to give 17% of 2,2,6,6-tetranitrobicyclo[3.3.1]nonane (**5f**) (eq 5).



The molecular formula of compound **5f** differs from that of the corresponding 2,2,6,6-tetranitroadamantane **3f** by only one carbon. However, although calculated densi-

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[10] Kaplan, R. B.; Shechter, H. *J. Am. Chem. Soc.* **1961**, *83*, 3535.

[11] Gilbert, E. E. *Synth. Commun.* **1985**, *15*, 53.

[12] (a) Janky, S.; Landa, S. *Collect. Czech. Chem. Commun.* **1970**, *35*, 375. (b) Schaefer, J. P.; Honig, L. M. *J. Org. Chem.* **1968**, *33*, 2655.

[13] Vodicka, L.; Triska, J.; Hajek, M. *Collect. Czech. Chem. Commun.* **1980**, *45*, 2670.

[14] Oxime **5b** was prepared from corresponding diketone, mp 138–140 °C. Stetter, H.; Help, H.; Schulte-Oestrich, A. *Chem. Ber.* **1962**, *95*, 1687.

[15] During the course of this work, 2,2-dinitroadamantane was reported under these conditions. Gilbert, E. E., private communication.

[16] Sasaki, T.; Esuchi, S.; Toru, T. *J. Org. Chem.* **1970**, *35*, 4109.

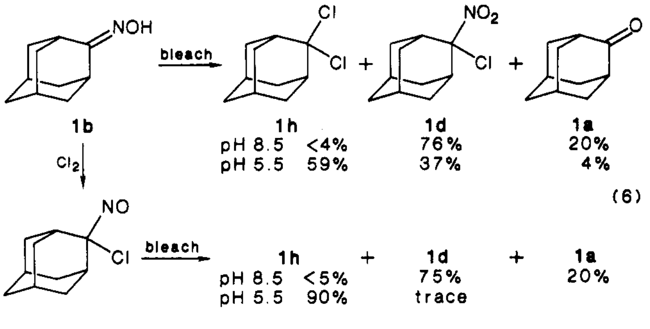
[17] Other examples of internal nitroso dimers: (a) Snyder, J. P.; Heyman, M. L.; Suciu, E. N. *J. Org. Chem.* **1975**, *40*, 1395. (b) Greene, F. D.; Gilbert, K. E. *J. Org. Chem.* **1975**, *40*, 1407. (c) Nielsen, A. T. *J. Org. Chem.* **1962**, *27*, 1993. (d) Singh, P. *J. Org. Chem.* **1975**, *40*, 1405.

[18] Chloronitroso compound **5g** was prepared from the corresponding oxime and chlorine in methylene chloride. Meerwein, H.; Schurmann, W. *Justus Liebigs Ann. Chem.* **1913**, *398*, 196.

ties[1d,19] (**3f** 1.58 g/cm^3; **5f** 1.55 g/cm^3) for these materials differ by only 0.03 g/cm^3, the observed values are quite different with adamantane **3f** more dense (1.75 g/cm^3) and bicyclo[3.3.1]nonane **5f** less dense (1.45 g/cm^2) than expected. Bicyclo[3.3.1]nonanes are known to exist in several conformations,[20] and a conformation that maximizes separation between nitro groups in **5f** may account for the lower density of this material. These observations tend to substantiate the postulate[1d] that density is enhanced for cage compounds over similar noncage compounds. It has been suggested that increasing the number of nitro groups on a cage compound will increase density incrementally, absent effects arising from conformational isomers.[1d,4c,e] *gem*-Dinitroadamantane **1f** exhibits a density (1.45 g/cm^3)[21] close to that calculated (1.38 g/cm^3), whereas 2,2,6,6-tetranitroadamantane **3f** is significantly more dense than its calculated value.

B. *gem*-Dichloro Compounds from Anomolous HOCl Reaction of Oximes. It has been reported that oximes of cyclic ketones are converted to *gem*-chloronitroso derivatives with aqueous hypochlorous acid at pH 5.5, and subsequent oxidation with tetra-*n*-butylammonium hypochlorite in benzene gives high yields of the chloronitro compounds.[9] When this reaction sequence was applied to oximinoadamantanes, the reaction was found to take a different pathway. When benzene solutions of oximes **1b**, **2b**, or **5b** (**3b** and **4b** were not investigated) were added to aqueous solutions of sodium hypochlorite, adjusted to pH 5.5 with phosphoric acid, a transient blue color formed which faded without the presence of phase transfer catalysts. With oxime **1b**, 2,2-dichloroadamantane (**1h**) was obtained in 59% yield, as well as ketone **1a** (4%) and chloronitro compound **1d** (37%). Dioxime **2b** gave 2,2,4,4-tetrachloroadamantane (**2h**) in 17% yield and dioxime **5b** gave 2,2,6,6-tetrachlorobicyclo[3.3.1]nonane (**5h**) in 60% yield.

To shed light on the course of this unusual *gem*-dichlorination, other reaction conditions were investigated. At pH 8, oxime **1b** reacted with sodium hypochlorite in *p*-dioxane–water solution to give *gem*-chloronitro **1d** (76%), ketone **1a** (20%), and only trace amounts of **1h** (eq 6). Compound **1d** was found to be quite stable and was not reduced to give **1e** with sodium borohydride or hydrogen over palladium on carbon.[22] Similarly, **1d** was unchanged after 24 h in solutions containing chloride or hypochlorite ion.



(6)

Chloronitroso compound **1g** was not isolated from reactions of oxime **1b** with acidic or basic solutions of hypochlorite, but transient blue colors indicated its presence. The chloronitroso compound **1g**[23] was prepared from oxime **1b** with chlorine in ether and was subsequently treated with hypochlorite solutions. In benzene, **1g** reacted over a 24-h period with 5% aqueous sodium hypochlorite at pH 8.5 with or without phase transfer agent, to give ketone **1a** (20%) and chloronitro compound **1d** (75%) and only minor amounts of *gem*-dichloro derivative **1h** (<5%). However, under otherwise identical conditions, with the hypochlorite solution at pH 5.5, the reaction of **1g** proceeded to completion in less that 5 min and gave *gem*-dichloro compound **1h** in over 90% yield; only trace amounts of ketone **1b** or chloronitro compound **1d** were formed.

It has been reported that *gem*-dichloride **1h** is formed in 13% yield by the photolysis of **1g**.[24] In the present work, hypochlorite reactions of **1b** were unaffected by the absence of light. Benzene solutions of **1g** in the absence of hypochlorite solutions are stable for over a week, giving no detectable amounts of **1h**. Similarly neither chloronitroso compound **1g** nor chloronitro compound **1d** in benzene solution reacted with aqueous chloride salts at pH 5.5 or 8.5 to give *gem*-dichloro compound **1h**, thus ruling out the possibility that **1h** is produced by a simple solvolytic displacement.

All examples of this anomalous reaction to form *gem*-dichloro conpounds **1h**, **2h**, and **5h** contain an adamantane or partial adamantane structure. Attempts to find other examples of this reaction failed. Reinvestigation of reactions of hypochlorite with oximinocyclohexane and 2- or 4-*tert*-butyl-1-oximinocyclohexane previously reported by Corey[9] to give only chloronitrocyclohexanes were found by GLC to contain no *gem*-dichlorocyclohexane derivatives when compared to authentic samples prepared by reactions of phosphorous pentachloride with the ketones.[25]

The results may be rationalized on the basis of an adduct of the nitroso group and hypochlorous acid, reminiscent of those proposed for the reactions of α-halo amides with hypobromite to give *gem*-dihalides[26] or the conversion of alkyl chlorosulfites to alkyl chlorides.[27] At high pH, elimination of HCl from this nitroso adduct gives the chloronitro compound, whereas at low pH, in most systems, reversal of the hypochlorous acid adduct regenerates the starting nitroso compounds. The 2-adamantyl structure, however, stabilizes carbonium ions[28] and may facilitate ionization of the adduct to a close ion pair.[29] In-

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(19) Cichra, D. A.; Holden, J. R.; Dickinson, C. *Estimation of "Normal" Densities of Explosive Compounds from Emperical Atomic Volumes*; Naval Surface Weapons Center TR 79-273 report, 19 Feb 1980. For discussion of densities of caged molecules, see ref 1d.

(20) (a) Appleton, R. A.; Egan, S. C.; Evans, J. M.; Graham, S. H.; Dixon, J. R. *J. Chem. Soc. C* **1968**, 1110. (b) Webb, N. C.; Becker, M. R. *J. Chem. Soc. B* **1967**, 1317. (c) Brown, W. A. C.; Martin, J.; Sim, G. A. *J. Chem. Soc.* **1965**, 1844. (d) Englinton, G.; Martin, J.; Parker, W. *J. Chem. Soc.* **1965**, 1243.

(21) X-ray structure of **1f**: George, C.; Gilardi, R. *Acta Crystallogr., Sect. C: Cryst. Struct. Commun.* **1983**, *C39*, 1674.

(22) Similar difficulties in reduction of chloronitrobis(homocubane) derivatives has been noted. Marchand, A. P., private communication.

(23) (a) Kayen, A. H. M.; Subrãmanian, L. R.; DeBoer, T. J. *Trav. Chim. Pays-Bas* **1971**, *90*, 866. (b) McKenon, M. A. *Tetrahedron Lett.* **1970**, 1975.

(24) (a) Kayen, A. H. M.; DeBoer, T. J. *Recl. Trav. Chim. Pays-Bas* **1977**, *96*, 237. (b) Kayen, A. H. M.; DeBoer, K.; DeBoer, T. J. *Recl. Trav. Chim. Pays-Bas* **1977**, *96*, 1. (c) Kayen, A. H. M.; Bolsman, T.; DeBoer, T. J. *Recl. Trav. Chim. Pays-Bas* **1976**, *95*, 14. (d) Bolsman, T.; Verhoeven, J. W.; BeBoer, T. J. *Tetrahedron* **1975**, *31*, 1015.

(25) Bourgail, M. *Bull. Soc. Chim. Fr.* **1924**, *35*, 1629.

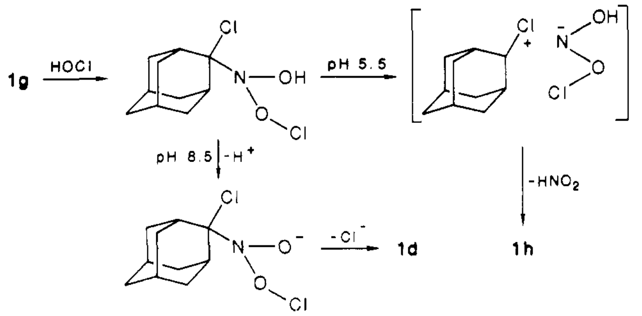
(26) Stevens, C. L.; Dittmer, H.; Kovacs, J. *J. Am. Chem. Soc.* **1963**, *85*, 3394.

(27) Lewis, E. S.; Herndon, W. C.; Duffey, D. C. *J. Am. Chem. Soc.* **1961**, *83*, 1959.

(28) Kirmse, W. *Top. Curr. Chem.* **1979**, *80*, 125ff.

(29) Similar ion pairs are intermediates in SNi reactions: (a) Cram, D. J. *J. Am. Chem. Soc.* **1953**, *75*, 332. (b) Hart, H.; Elia, R. *J. Am. Chem. Soc.* **1961**, *83*, 985. (c) Kice, J. L.; Hanson, G. C. *J. Org. Chem.* **1973**, *38*, 1410.

ternal chlorination would give the observed *gem*-dichloro compounds.



Experimental Section[30]

2-Bromo-2-nitroadamantane (1c). A solution of 2-oximinoadamantane[31] (**1b**) (4.0 g, 0.024 mol) in 50:50 dioxane–water (100 mL) was stirred for 1 h at 20 °C with solid *N*-bromosuccinimide (12.0 g, 0.067 mol) and sodium bicarbonate (6.0 g, 0.07 mol). A transient light blue color formed. The mixture was concentrated and extracted with ether (2 × 30 mL). The combined organic layers were dried ($MgSO_4$) and evaporated, and the residual solid was recrystallized from ethanol–water to give 5.0 g (80%) of **1c**, mp 190–191 °C: IR (KBr) 1540, 1445 cm^{-1}; NMR δ 2.9 (m, 2 H), 2.2–1.9 (m, 12 H). Anal. Calcd for $C_{10}H_{14}BrNO_2$: C, 46.15; H, 5.43; N, 5.38; Br, 30.71. Found: C, 46.00; H, 5.30; N, 5.27; Br, 30.68.

2,4-Dibromo-2,4-dinitroadamantane (2c). Solid 2,4-dioximinoadamantane[11] (**2b**) (5.0 g, 0.025 mol) was added to a mixture of *N*-bromosuccinimide (27 g, 0.15 mol) and sodium bicarbonate (15 g) in 20:80 dioxane–water (150 mL) at 10 °C, and the mixture was stirred for 48 h. A transient green color was observed. The mixture was dilute with water (50 mL) and extracted with CH_2Cl_2 (4 × 100 mL). The combined organic layers were washed with water (100 mL), dried ($MgSO_4$), and evaporated to give 3.1 g of a crude oil. Column chromatography on silica gel (95:5 hexane–actone) gave 0.52 g (5%) of **2c** (mixture of isomers), mp 150–170 °C: IR 1560, 1420 cm^{-1}; NMR δ 3.95 (1 H), 2.0–3.0 (11 H). Anal. Calcd for $C_{10}H_{12}Br_2N_2O_4$: C, 31.27; H, 3.14; N, 7.29. Found: C, 31.23; H, 3.33; N, 7.25.

2,6-Dibromo-2,6-dinitroadamantane (3c). A mixture of 2,6-dioximinoadamantane[32] (**3b**) (0.5 g, 2.5 mmol), *N*-bromosuccinimide (3.0 g, 17 mmol), and sodium bicarbonate (1.5 g, 17 mmol) in 50:50 dioxane–water (50 ml) was stirred at ambient temperature for 48 h. The solvent was evaporated, water (50 mL) was added, and the precipitate was filtered. GLC analysis showed the solid to be a mixture (30:70) of **3c** and ketone **3a**. The mixture was chromatographed on silica gel (90:10 hexane–ethyl acetate), and recrystallized from ethanol–water to give 0.23 g (24%) of **3c**, mp 163–165 °C: IR 1540, 1460 cm^{-1}; NMR δ 1.8–2.8. Anal. Calcd for $C_{10}H_{12}Br_2N_2O_4$: C, 31.27; H, 3.15; N, 7.29; Br, 41.61. Found: C, 31.33; H, 3.14; N, 7.45; Br, 41.44.

2,6-Dibromo-2,6-dinitrobicyclo[3.3.1]nonane (5c). A mixture of 2,6-dioximinobicyclo[3.3.1]nonane[14] (**5b**) (1.5 g, 8.0 mmol), *N*-bromosuccinimide (10.0 g, 56 mmol), and sodium bicarbonate (5.0 g, 59 mmol), in 50:50 dioxane–water (100 mL), was stirred for 30 min at 5 °C and for 2 h at ambient temperature. A transient green color was observed. The mixture was concentrated to one-third its original volume and extracted with CH_2Cl_2 (2 × 100 mL). The combined extracts were dried ($MgSO_4$) and evaporated. The residual oil was chromatographed on silica gel CH_2Cl_2) and recrystallized from ethanol–water to give 0.20 g (6.5%) of **5c** (mixture of isomers), mp 145–148 °C: IR (KBr) 1540, 1450 cm^{-1}; NMR δ 2.0–3.0. Anal. Calcd for $C_9H_{12}N_2O_4Br_2$: C, 29.06; H, 3.25; N, 7.53; Br, 42.96. Found: C, 29.20; H, 3.33; N, 7.36; Br, 43.12.

2-Nitroadamantane (1e).[33] A solution of **1c** (4.0 g, 15 mmol) and sodium borohydride (2.0 g, 50 mmol) in 95% aqueous ethanol (60 mL) was stirred at 20 °C for 1 h. The solution was neutralized with acetic acid, evaporated, and diluted with water (50 mL). The precipitate was filtered and recrystallized from ethanol–water to give 2.4 g (89%) of **1e**, mp 165–166 °C: IR 1540, 1450 cm^{-1}; NMR δ 4.25 (t, J = 3 Hz, 1 H), 2.75 (m, 2 H), 1.9–2.1 (12 H). Anal. Calcd for $C_{10}H_{15}NO_2$: C, 66.27; H, 8.34; N, 7.73. Found: C, 66.33; H, 8.24; N, 7.58.

2,4-Dinitroadamantane (2e). A mixture of **2c** (1.2 g, 3.1 mmol), 5% palladium on carbon (0.2 g), and sodium hydroxide (0.4 g, 0.01 mol) in methanol (50 mL) was treated with hydrogen at 25 psi for 4 h in a Parr apparatus. The catalyst was removed by filtration, the solvent was evaporated, and the residue was dissolved in water (50 mL). The aqueous solution was extracted with ether (50 mL), cooled to 5 °C, and neutralized with acetic acid. After 1 h, the mixture was extracted with ether (2 × 50 mL), these extracts were dried ($MgSO_4$) and evaporated, and the residue was recrystallized from ethanol to give 0.54 g (78%) of **2e** (mixture of isomers), mp 175–180 °C (195 °C dec): IR 1560, 1440 cm^{-1}; NMR δ 2.0 (m, 8 H), 2.6–3.0 (m, 3 H), 3.55 (m, 1 H), 4.6 (m, 2 H). Anal. Calcd for $C_{10}H_{14}N_2O_4$: C, 53.09; H, 6.24; N, 12.38. Found: C, 53.08; H, 6.33; N, 12.18.

2,6-Dinitroadamantane (3e). A solution of **3c** (1.1 g, 2.8 mmol) in THF (50 mL) and water (10 mL) was treated, portionwise, with sodium borohydride (0.5 g), and the mixture was stirred for 20 min at 20 °C. The solution was evaporated to one-third of its original volume and extracted with CH_2Cl_2 (2 × 50 mL). The combined CH_2Cl_2 solutions were dried ($MgSO_4$), and evaporated, and the residue was recrystallized from ethanol to give 0.57 g (66%) of **3e**, mp 165–170 °C: IR 1565, 1440 cm^{-1}; NMR δ 4.4 (2 H), 1.8–2.7 (12 H). Anal. Calcd for $C_{10}H_{14}N_2O_4$: C, 53.09; H, 6.24; N, 12.38. Found: C, 53.15; H, 6.19; N, 12.42.

2,2-Dinitroadamantane (1f) by Oxidative Nitration of 1e. A solution of **1e** (0.20 g, 1.0 mmol), sodium hydroxide (0.2 g, 5 mmol), and sodium nitrite (0.4 g, 5.7 mmol) in 50% aqueous ethanol (20 mL) was stirred at 20 °C for 20 min, and then a solution of silver nitrate (0.5 g, 3 mmol) in water (10 mL) was added. The mixture was stirred 30 min, diluted with water (20 mL), and extracted with ether (2 × 50 mL). The combined ether layers were dried ($MgSO_4$) and evaporated, and the residue was recrystallized from hexane to give 0.20 g (89%) of **1f**, mp 212–213 °C dec: density 1.40 g/cm^3 (silver nitrate flotation); IR 1570, 1460 cm^{-1}; NMR δ 3.4 (2 H), 1.9–2.1 (12 H). Anal. Calcd for $C_{10}H_{14}N_2O_4$: C, 53.09; H, 6.24; N, 12.38. Found: C, 53.20; H, 6.16; N, 12.25.

2,2,6,6-Tetranitroadamantane (3f). A solution of **3e** (0.145 g, 0.64 mmol) and potassium hydroxide (0.07 g, 1.3 mmol) in ethanol (10 mL) was stirred at 25 °C for 3 h, and then tetranitromethane (0.45 g, 2.3 mmol) was added, dropwise. The mixture was stirred for 2 h, diluted with water (50 mL), and extracted with CH_2Cl_2 (2 × 50 mL). The combined extracts were washed with 10% aqueous sodium carbonate (20 mL), dried ($MgSO_4$), and evaporated. The residual solid was recrystallized from ethanol to give 0.11 g (68%) of **3f**, mp >300 °C (sub 290–292 °C): density 1.75 g/cm^3 (silver nitrate flotation); IR 1580, 1460 cm^{-1}; NMR δ 3.4 (4 H), 2.0 (8 H). Anal. Calcd for $C_{10}H_{12}N_4O_8$: C, 37.98; H, 3.82; N, 17.72. Found: C, 37.84; H, 3.92; N, 17.52.

The mother liquors from the recrystallization were evaporated, and the residual semisolid was chromatographed on silica gel (chloroform) to give 0.03 g, (20%) of **3i**: IR 1720 (ketone), 1580, 1460 (NO_2) cm^{-1}; NMR δ 3.7 (2 H), 2.7 (2 H), 2.4 (8 H). Anal. Calcd for $C_{10}H_{12}N_2O_6$: C, 50.01; H, 5.03; N, 11.66. Found: C, 50.26; H, 5.07; N, 11.34.

Nitration of 1b to 1f.[15] To a solution of **1b** (0.10 g, 0.6 mmol) in refluxing CH_2Cl_2 (10 mL) was added, dropwise, 100% nitric acid (2.0 mL). A transient light blue color faded after 5 min, at which time GLC analysis showed the solution contained a mixture (70:30) of **1a** and **1f**. The solution was washed with water (20

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[30] Melting points were observed in sealed tubes and are uncorrected. Elemental analyses were performed by Galbraith Laboratories, Knoxville, TN, and Spang Laboratories, Eagle Harbor, MI. Proton NMR spectra were recorded in $CDCl_3$ on a Varian T-60 spectrometer, and the chemical shifts are reported in parts per million downfield from tetramethyl silane. Infrared spectra were recorded in CH_2Cl_2 with a Perkin-Elmer 700 spectrometer. GLC analyses were performed on a Varian 920 chromatograph on a 4 ft SE-30 column at 130 °C.

[31] Narayam, N. L.; Setescak, L. *J. Heterocycl. Chem.* **1969**, *6*, 445.

[32] Compound **3b**, mp 279–280 °C. Anal. Calcd for: $C_{10}H_{14}N_2O_2$: C, 61.83; H, 7.26; N, 14.41. Found: C, 61.84; H, 7.40; N, 14.19.

[33] Compound **1e** was also prepared in 66% yield by oxidation of 2-aminoadamantane with excess *m*-chloroperbenzoic acid in refluxing 1,2-dichloroethane.

mL) and chromatographed on a medium-pressure silica gel column (CH_2Cl_2) to give 30 mg (21%) of **1f** identical with that prepared above.

4e-Bromo-2,2-dinitroadamantane (4f). To a refluxing solution of **4b**[34] (1.0 g, 4.4 mmol) in CH_2Cl_2 (50 mL) was added dropwise 100% nitric acid (5 mL). The transient green color faded in 1 min, and GLC analysis showed the presence of mixture (70:30) of ketone **4a** and **4f**. The solution was washed with water (30 mL), and the solvent was evaporated to give a waxy solid. The solid was dissolved in ethanol (10 mL) containing hydroxylamine hydrochloride (1.0 g) and 10% aqueous sodium carbonate solution (5 mL). After 24 h, the solvent was evaporated, and the residual oil was dissolved in CH_2Cl_2 (30 mL). This solution was nitrated with nitric acid (5 mL) at reflux. Reoximation and renitration a third time gave a crude product, which contained essentially no ketone by GLC analysis. The solid, thus obtained, was recrystallized from hexane to give 0.80 g (60%) of **4f**, mp 227–230 °C: IR 1585, 1450 cm^{-1}; NMR δ 1.9–2.1 (10 H), 3.2 (1 H), 3.6 (1 H), 4.5 (1 H, H-4^a).[35] Anal. Calcd for $C_{10}H_{13}BrN_2O_4$: C, 39.36; H, 4.29; N, 9.18. Found: C, 39.47; H, 4.35; N, 9.01.

2,4-Dinitro-2,4-dinitrosoadamantane (6). To a mixture of **2b** (1.0 g, 5.1 mmol) in CH_2Cl_2 (50 mL) at reflux was added dropwise 95% nitric acid (3 mL) over 20 min, and the reflux was continued for an additional 20 min, during which time a transient blue color was observed. The solution was cooled, washed with 10% aqueous potassium hydroxide (20 mL) and water (50 mL), and the dried ($MgSO_4$). The solvent was evaporated, and the residue was chromatographed on a silica gel preparative TLC plate (CH_2Cl_2) to give 0.1 g (10%) of **6**, mp 164–165 °C: IR 1575, 1440 cm^{-1}; NMR δ 3.95 (1 H), 3.10 (2 H), 2.0 (9 H); mass spectrum 284 (1.9), 190 (10.1), 178 (10.6), 166 (30.5), 136 (21.9), 119 (39.7), 91 (100), 77 (46), 41 (81). Anal. Calcd for $C_{10}H_{12}N_4O_6$: C, 42.25; H, 4.25; N, 19.71. Found: C, 42.20; H, 4.32; N, 19.23.

2,6-Dichloro-2,6-dinitrobicyclo[3.3.1]nonane (5d). Chlorine gas was passed into a suspension of **5b**[14] (2.0 g, 11 mmol) in CH_2Cl_2 (50 mL). The dioxime slowly dissolved, and the solution became dark blue and then green. After 4 h, the solvent was evaporated and replaced with benzene (50 mL). This solution was stirred with 5% sodium hypochlorite (50 mL) containing 0.2 g of tetra-*n*-butylammonium hydrogen sulfate at 25 °C for 48 h, during which time the color dissipated. After separation, the organic layer was washed with water (50 mL) and 5% sodium thiosulfate solution (50 mL) and then dried ($MgSO_4$). The solvent was evaporated, and the residual oil was chromatographed on silica gel (CH_2Cl_2) and then recrystallized from ethanol to give 1.84 g (59%) of **5d**, mp 111–113 °C: IR 1580, 1460 cm^{-1}; NMR δ 2.0–3.0. Anal. Calcd for $C_9H_{12}Cl_2N_2O_4$: C, 38.18; H, 4.27; N, 9.89. Found: C, 38.28; H, 4.21; N, 9.79.

2,6-Dinitrobicyclo[3.3.1]nonane (5e). A mixture of **5d** (2.8 g, 0.01 mol), 5% palladium on carbon (0.5 g), and sodium hydroxide (0.8 g, 0.02 mol) in methanol (100 mL) was reacted with hydrogen at 40 psi in a Parr apparatus. After 3 h, the catalyst was removed by filtration. The solution was cooled to 5 °C, a solution of ammonium chloride (1.4 g) in water (10 mL) was added, and the mixture was stirred for 1 h. The mixture was evaporated to half its original volume, diluted with water (60 mL), and extracted with CH_2Cl_2 (3 × 25 mL). The combined organic layers were dried ($MgSO_4$), the solvent was removed, and the residual solid was recrystallized from ethanol to give 0.85 g (60.7%) of **5e** (mixture of isomers), mp 126–127 °C: IR 1540, 1440 cm^{-1}; NMR δ 1.5–2.4 (m, 10 H), 2.75 (m, 2 H), 4.6 (m, 2 H). Anal. Calcd for $C_9H_{14}N_2O_4$: C, 50.46; H, 6.59; N, 13.07. Found: C, 50.48; H, 6.46; N, 12.94.

2,2,6,6-Tetranitrobicyclo[3.3.1]nonane (5f). A solution of **5e** (0.21 g, 1 mmol), sodium nitrite (0.3 g, 3 mmol), and sodium hydroxide (0.10 g, 2.5 mmol) in water (10 mL) and methanol (2 mL) was stirred for 30 min at 25 °C, and then a solution of silver nitrate (0.4 g, 2.3 mmol) in water (5 mL) was added. The mixture was stirred for 12 h, diluted with 20 mL of water, and extracted with ether (3 × 20 mL). The combined organic layers were dried ($MgSO_4$) and evaporated, and the residual semisolid was recrystallized from ethanol to give 0.05 g (17%) of **5f**, mp 168–170 °C: density 1.45 g/cm^3 (silver nitrate floatation); IR 1570, 1420 cm^{-1}; NMR δ 2.0 (m, 6 H), 2.9–3.2 (m, 6 H). Anal. Calcd for $C_9H_{12}N_4O_8$: C, 35.53; H, 3.97; N, 18.41. Found: C, 35.72; H, 3.95; N, 18.29.

2-Chloro-2-nitroadamantane (1d). A solution of **1b** (0.2 g, 1.2 mmol) and sodium bicarbonate (0.2 g, 2.3 mmol) in 50:50 dioxane–water (20 mL), was stirred at 20 °C with 5% aqueous sodium hypochlorite solution (30 mL). A transient blue color formed. After 1 h, the solution was diluted with water (100 mL), and the precipitate was filtered and recrystallized from ethanol–water to give 0.20 g (76%) of **1d**, mp 200–201 °C: IR (KBr) 1550, 1455 cm^{-1}; NMR δ 3.0 (2 H), 2.7–2.0 (12 H). Anal. Calcd for $C_{10}H_{14}ClNO_2$: C, 55.68; H, 6.54; N, 6.49. Found: C, 55.49; H, 6.59; N, 6.39.

2,2-Dichloroadamantane (1h). A mixture of 5% sodium hypochlorite (80 mL) and ice (50 g) was acidified with 50% aqueous phosphoric acid to pH 5.5. Then, a solution of **1g**[23a] (0.63 g, 0.003 mol) in benzene (20 mL) was added, and the mixture was decolorized after being stirred at 20 °C for 15 min. The organic layer was separated, washed with water, dried ($MgSO_4$), and evaporated, and the residue was subilimed (80 °C/10 mmHg) to give 0.56 g of **1h**, mp 201–203 °C (lit.[25a,b] mp 201–203 °C) and identical with material prepared by reaction of phosphorus pentachloride and **1a**.[25a]

2,2,4,4-Tetrachloroadamantane (2h). A mixture of 5% sodium hypochlorite (50 mL) and ice (50 g) was acidified with 50% aqueous phosphoric acid to pH 5.5. A suspension of **2b** (2.0 g, 0.01 mol) in benzene (100 mL) was added, and the mixture was stirred at 15–25 °C for 1 h. The organic layer was separated, washed with water, and dried ($MgSO_4$), and the solvent was evaporated to give 1.8 g of an oil. The oil was chromatographed on silica gel (90:10 hexane–acetone) to give 0.35 g (13%) of **2h**,[35] mp 195 °C (sealed tube), sub >110 °C (1 atm): IR 3000, 1450 cm^{-1}; NMR δ 1.7 (2 H), 2.3 (4 H), 2.6 (4 H), 2.85 (2 H). Anal. Calcd for $C_{10}H_{12}Cl_4$: C, 43.8; H, 4.41; Cl, 51.75. Found: C, 43.79; H, 4.52; Cl, 51.60.

2,2,6,6-Tetrachlorobicyclo[3.3.1]nonane (5h). A mixture of 5% sodium hypochlorite (200 mL) and ice (150 g) was acidified with 50% aqueous phosphoric acid to pH 5.5 A suspension of **5b** (5.0 g, 0.027 mol) in benzene (100 mL) was added, and the mixture was stirred at 15–20 °C for 1 h. The solid was dissolved to form a blue solution. The benzene laye was separated and stirred with 100 mL of bleach (pH >8.5) and tetra-*n*-butylammonium hydrogen sulfate (0.5 g) for an additional 2 h, during which time the solution became colorless. The organic layer was separated, washed with 50 mL of water, and dried ($MgSO_4$), and the solvent was evaporated. The residual oil was distilled to give 4.2 g (60%) of **5h**, bp 112–115 °C (0.3 mmHg), mp 20–22 °C: IR 3000, 1460, 1440 cm^{-1}; NMR δ 2.0–2.8. Anal. Calcd for $C_9H_{12}Cl_4$: C, 41.26; H, 4.60; Cl, 54.14. Found: C, 41.19; H, 4.32; Cl, 54.32.

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(34) Compound **4b**, mp 230–235 °C. Anal. Calcd for $C_{10}H_{14}BrNO$: C, 49.19; H, 5.78. Found: C, 49.30; H, 5.68. Oxime was prepared from 4e-bromo-2-adamantanone,[13] mp 159–161 °C.

(35) Compound **2h** was also prepared in 85% yield by reaction of **2a** with phosphorus pentachloride in methylene chloride at 20 °C.