Bridgehead Functionalization of [2]Diadamantane. Aspects of the Chemistry of 2- and 4-Monosubstituted [2]Diadamantanes

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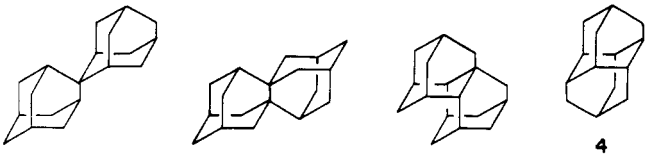
Bromination of [2]diadamantane (2) in carbon tetrachloride proceeds by kinetically controlled competitive attack at the two unique bridgehead positions in 2 to provide a 70:30 mixture of 2-bromo- and 4-bromo[2]diadamantane, 6 and 7, respectively. In contrast, oxidation of 2 with lead tetraacetate occurs under thermodynamically controlled conditions to give exclusively 4-hydroxy[2]diadamantane. Treatment of bromide 6 with aluminum bromide in dibromomethane at 0 °C affords 7. Extended exposure of 7 to these conditions at 25 °C gives a 1:1 mixture of 4,11-dibromo- and 4,13-dibromo[2]diadamantane. Hydrolysis of 6 provides 2-hydroxy[2]diadamantane (18). Unexpectedly, thermolysis of the hypoiodite derived from 18 occurs by cleavage of the C-2–C-3 bond in 18 to give a primary iodo ketone. Base-promoted cyclization of this species affords a proto[2]diadamantanone.

In principle, two adamantanes may be "condensed" so that they have one (1), two (2), three (3), or six (4) carbon atoms in common. With the exception of 3, all of these "diadamantanes" have been synthesized.[1] However, only

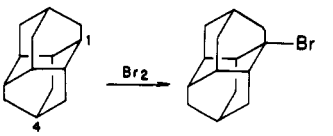


1 2 3 4

the chemistry of 4 has been studied.[2] We now wish to report methods for the functionalization of the two unique bridgehead positions in [2]diadamantane (2) and some aspects of the chemistry of the resulting monosubstituted derivatives of 2.

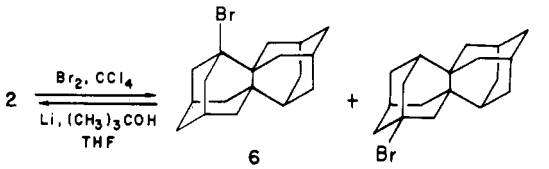
Results and Discussion

Ionic bromination of a polycyclic hydrocarbon has been widely employed as a method for the introduction of a substituent on the skeletal framework.[2b,3] The mechanism of this reaction has not been determined. Although at one time bromination of hydrocarbons was thought to proceed by an ionic pathway with the formation of intermediate bridgehead carbocations,[4] more recently it has been suggested that pentacoordinate intermediates or transition states, or even radical cation pathways, may be involved.[3d] Direct bromination of [6]diadamantane by treatment of 4 at room temperature with neat bromine or with bromine



4 5

diluted with carbon tetrachloride gives exclusively monobromide 5 in high yield.[2a,b] In contrast, reaction of [2]diadamantane with neat bromine gives a complex mixture of products. However, treatment of a carbon tetrachloride solution of 2 with bromine for 48 h at room temperature provides a 70:30 mixture of monobromides 6 and 7, re-



6 7

spectively, in an overall yield of 75%. The integrity of the carbon skeleton in 6 and 7 was established by reduction of a mixture of these compounds with lithium–*tert*-butyl alcohol–tetrahydrofuran[5] to give only 2. Pure 2-bromo[2]diadamantane (6) could be obtained from the mixture of 6 and 7 by fractional crystallization from petroleum ether. Consistent with the presence of a plane of symmetry in 6, the ^{13}C NMR spectrum of 6 contains only twelve signals with six of these being twice as intense as the others. Pure 4-bromo[2]diadamantane (7) was prepared by an independent route (see below).

When bromide 6 is submitted to the same reaction conditions employed for the bromination of 2, it is recovered unchanged. Thus, it can be concluded that the observed preference for bromination at C-2 rather than C-4 in 2 is kinetically determined. The regiospecific bromination of [6]diadamantane at C-1 is also a kinetic result.[2a,b] Molecular mechanics calculations suggest that there should be only a small difference in the strain energies of the carbocations resulting from the development of a positive charge at C-1 *or* C-4 in [6]diadamantane.[2b]

(1) (a) 1: Boelema, E.; Strating, J; Wynberg, H. *Tetrahedron Lett.* **1972**, 1175–1177. Graham, W. D.; Schleyer, P. v. R. *Ibid.* **1972**, 1179–1180. (b) 2: Graham, W. D.; Schleyer, P. v. R.; Hagaman, E. W.; Wenkert, E. *J. Am. Chem. Soc.* **1973**, *95*, 5785–5786. (c) 4: Gund, T. M.; Ōsawa, E.; Williams, Y. Z., Jr.; Schleyer, P. v. R. *J. Org. Chem.* **1974**, *39*, 2979–2987 and references cited therein.

(2) (a) Gund, T. M.; Nomura, M.; Schleyer, P. v. R. *J. Org. Chem.* **1974**, *39*, 2987–2994 and references cited therein. (b) Gund, T. M.; Schleyer, P. v. R.; Unruh, G. D.; Gleicher, G. J. *Ibid.* **1974**, *39*, 2995–3003 and references cited therein. (c) Blaney, F.; Johnston, D. E.; McKervey, M. A.; Rooney, J. J. *Tetrahedron Lett.* **1975**, 99–100. (d) Bewick, A.; Edwards, C. J.; Jones, S. R.; Mellor, J. M. *Ibid.* **1976**, 631–634. (e) Jones, S. R.; Mellor, J. M. *J. Chem. Soc., Perkin Trans 1* **1976**, 2576–2581. (f) Edwards, G. J.; Jones, S. R.; Mellor, J. M. *J. Chem. Soc., Perkin Trans. 2* **1977**, 505–510. (g) Jones, S. R.; Mellor, J. M. *Ibid.* **1977**, 511–517. (h) Leddy, B. P.; McKervey, M. A.; McSweeney, P. *Tetrahedron Lett.* **1980**, *21*, 2261–2264. (i) Janku, J.; Burkhard, J.; Vodicka, L. *Z. Chem.* **1981**, *21*, 67–68.

(3) (a) Karim, A.; McKervey, M. A.; Engler, E. M.; Schleyer, P. v. R. *Tetrahedron Lett.* **1971**, 3987–3990. (b) Ōsawa, E. *Ibid.* **1974**, 115–117. (c) Takaishi, N.; Fujikura, Y.; Inamoto, Y.; Ikeda, H.; Aigami, K.; Ōsawa, E. *J. Chem. Soc., Chem. Commun.* **1975**, 371–372. (d) Ōsawa, E.; Engler, E. M.; Godleski, S. A.; Inamoto, Y; Kent, G. J.; Kausch, M.; Schleyer, P. v. R. *J. Org. Chem.* **1980**, *45*, 984–991. (e) Israel, R. J.; Murray, R. K., Jr. *Ibid.* **1983**, *48*, 4701–4705.

(4) (a) Landa, S.; Kriebel, S.; Knobloch, E. *Chem. Listy* **1954**, *48*, 61–64. (b) Landa, S.; Hala, S. *Collect. Czech. Chem. Commun.* **1959**, *24*, 93–98. (c) Stetter, H.; Schwarz, M.; Hirschhorn, A. *Chem. Ber.* **1959**, *92*, 1629–1635. (d) Stetter, H.; Wulff, C. *Ibid.* **1960**, *93*, 1366–1371. (e) Stetter, H.; Schwarz, M.; Hirschhorn, A. *Angew. Chem.* **1959**, *71*, 429–430. (f) Stetter, H.; Wulff, C. *Ibid.* **1960**, *72*, 351.

(5) Bruck, P.; Thompson, D.; Winstein, S. *Chem. Ind. (London)* **1960**, 405.

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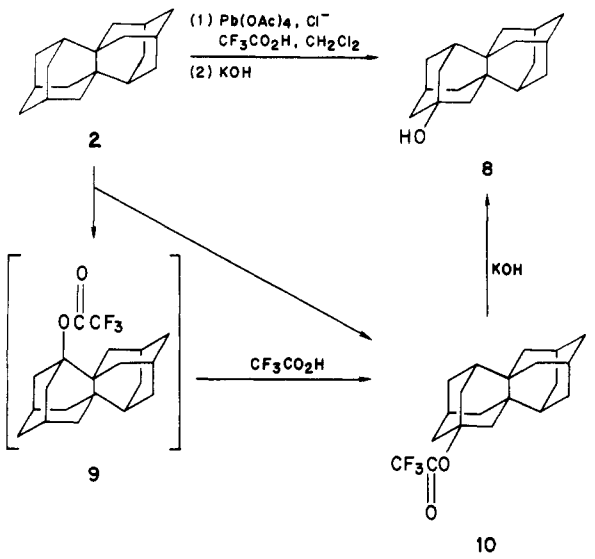
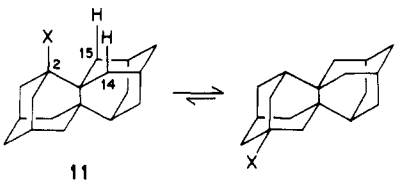
Scheme I



Consequently, the high regioselectivity that has been observed in the ionic bromination of **4** has been attributed to the hyperconjugative stabilization of charge development at C-1 in **4** by β-alkyl branching.[2b] An analogous rationale accounts for the relative reactivities of C-2 and C-4 in the bromination of **2**. With respect to a comparison of the regiospecific bromination of **4** and the moderately regioselective bromination of **2**, it should be noted that while there are two sites of β-alkyl branching for C-1 in **4**, there is only one such site for C-2 in **2**.

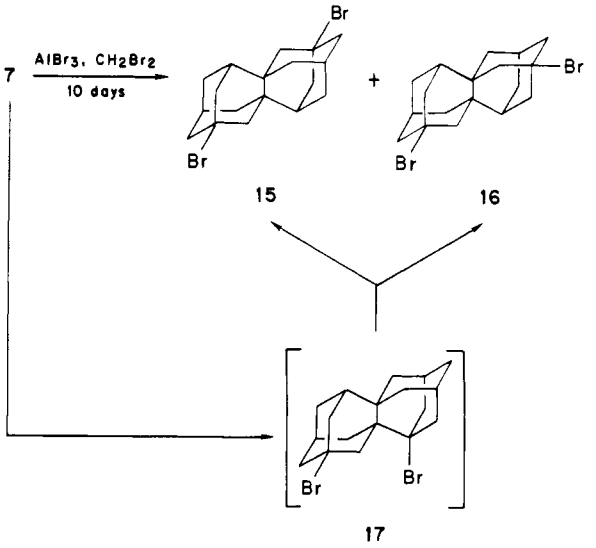
Jones and Mellor have reported that bridgehead functionalization of bicyclic and polycyclic hydrocarbons can also be achieved by oxidation of these substrates with lead tetraacetate and chloride ion in a solution of trifluoroacetic acid and methylene chloride.[2e] Subsequent hydrolysis of the resulting trifluoroacetates gives the corresponding alcohols. The identity of the oxidizing agent in this reaction has not been established. However, it is clear that oxidation does not take place via a radical cation intermediate.[2g] At present, a mechanism proceeding by electrophilic attack at a carbon–hydrogen bond is favored.[2g] Oxidation of **2** with lead tetraacetate under these conditions gives 4-hydroxy[2]diadamantane (**8**) as the only isolated product in 28% yield (Scheme I). Even when the reaction is not allowed to proceed to completion, **8** is the only product that can be detected. The carbon framework of **8** and the skeletal position of the substituent on the cage follow from the observations that treatment of **8** with concentrated hydrobromic acid affords only **7** and hydrolysis of **7** provides only **8**.

The exclusive formation of alcohol **8** in the lead tetraacetate oxidation of **2** seems to be the result of thermodynamic control. A substituent at C-2 in **11** has destabilizing 1,3-interactions with the "axial" hydrogens at C-14 and C-15. Such interactions are not present in **12**. Thus,

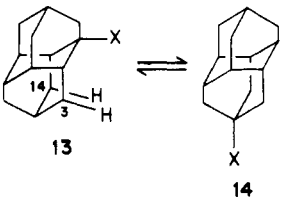


a 4-substituted [2]diadamantane should have a lower enthalpy than its 2-substituted counterpart. In related studies, McKervey and his co-workers have reported the

Scheme II



equilibration of several 1-substituted [6]diadamantanes (**13**) with their 4-substituted positional isomers **14**.[2a,6] For

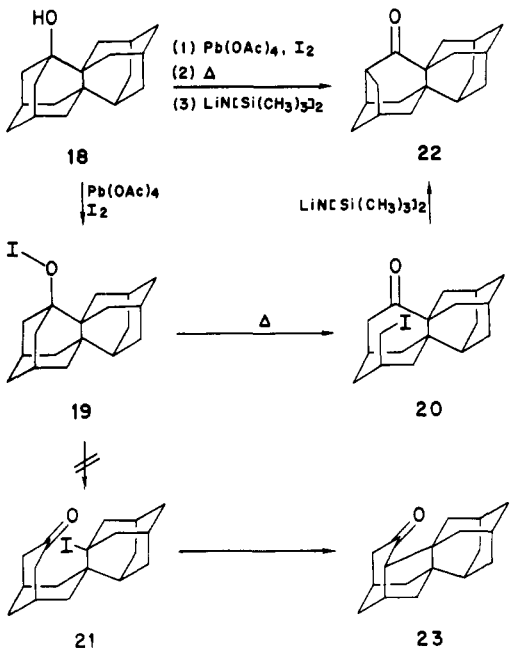


example, the isomeric [6]diadamantanols (**13** and **14**, X = OH) were found to be of equal thermodynamic stability at 48 °C in 98% sulfuric acid.[6b] This situation is the result of counterbalancing factors. The substituent in **13** possesses unfavorable 1,3-interactions with respect to the axially disposed hydrogens at C-3 and C-14. No such interactions are present in **14**. Consequently, the apical isomers **14** are of lower enthalpy than the zonal isomers **13**. However, another factor must be considered. Isomer **13** has C_s symmetry, whereas **14** has C_{3v} symmetry. Since a molecule with C_{3v} symmetry has a symmetry number of 3 compared with 1 for C_s symmetry, the entropy of **14** will be lower than that of **13** due to this symmetry effect. In the case of the [2]diadamantanes **11** and **12**, both isomers have the same symmetry number and so there is no net symmetry effect on their entropies. Consequently, thermodynamically controlled reactions of **2** should favor substitution at C-4. Consistent with this conclusion, we have found that treatment of a solution of bromide **6** in dibromomethane with aluminum bromide for 1 h at 0 °C gives **7**. Thus, the isolation of only alcohol **8** in the lead tetraacetate oxidation of **2** can be rationalized as proceeding initially by competitive attack at C-2 and C-4 of **2** to give trifluoroacetates **9** and **10** (Scheme I). Under the reaction conditions, **9** is isomerized to the thermodynamically favored isomer **10** which is eventually hydrolyzed to **8**. All of these equilibrations of bridgehead-substituted [2]- and [6]diadamantanes are believed to occur via intermolecular hydride-transfer mechanisms.[2a,6]

Extended exposure of bromide **7** to aluminum bromide in dibromomethane leads to the introduction of a second bromine on the [2]diadamantane skeleton. Thus, treat-

(6) (a) Courtney, T.; Johnston, D. E. McKervey, M. A.; Rooney, J. J. *J. Chem. Soc., Perkin Trans. 1* **1972**, 2691–2696. (b) Johnston, D. E.; McKervey, M. A.; Rooney, J. J. *J. Chem. Soc., Chem. Commun.* **1972**, 29–30. (c) Hamilton, R.; Johnston, D. E.; McKervey, M. A.; Rooney, J. J. *Ibid.* **1972**, 1209–1210. (d) McKervey, M. A.; Johnston, D. E.; Rooney, J. J. *Tetrahedron Lett.* **1972**, 1547–1550.

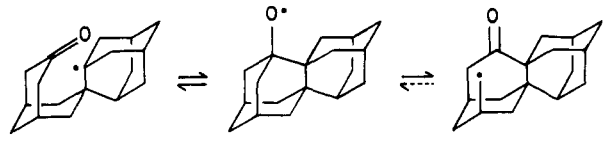
Scheme III



ment of **7** under these conditions for seven days at room temperature provides a 2:3:3 mixture of **7** and dibromides **15** and **16**, respectively (Scheme II). That all of these compounds have a common carbon skeleton is evident from the observation that reduction of this mixture with lithium–*tert*-butyl alcohol–tetrahydrofuran gives only [2]diadamantane. The mixture of **7**, **15**, and **16** could be separated by column chromatography on silica gel. Consistent with the assigned structures, the ^{13}C NMR spectrum of **15** and **16** each contains only nine signals. Indeed, the ^{13}C NMR spectra of **15** and **16** are strikingly similar to each other. Dibromides **15** and **16** could be differentiated by their behavior on column chromatography. The less polar dibromide **15** was eluted from silica gel with hexane, whereas the more polar dibromide **16** required elution with hexane–methylene chloride. Since ionic bromination of [2]diadamantane takes place competitively at C-2 and C-4, and since bromide **6** isomerizes to **7** in the presence of aluminum bromide, then **7** → **15** + **16** may occur at least partially via 2,11-dibromo[2]diadamantane (**17**).

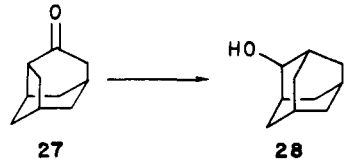
Recently, Majerski and his co-workers have provided a number of examples to show that the thermolysis of tertiary polycyclic hypoiodites, followed by the base-promoted intramolecular C-alkylation of the resulting iodo ketones, provides a useful synthetic route to various cage ketones.[7] As a result of these reports, we became interested in exploring the behavior of the hypoiodite **19** derived from 2-hydroxy[2]diadamantane (**18**) (Scheme III). In principle, thermolysis of **19** could afford the primary iodo ketone **20** or the tertiary iodo ketone **21**. However, it is well-established that the direction of β-fission of the tertiary alkoxy radicals that result from the thermolysis of tertiary hypoiodites generally depends on the relative stabilities of the resulting alkyl free radicals.[8] Thus, thermolysis of **19** would be expected to give the tertiary radical precursor to **21** in strong preference to the primary radical precursor to **20**. Cyclization of **20** and **21** with base would provide proto[2]diadamantanones **22** and **23**, respectively. It was anticipated that ketones **22** and **23** could be differentiated by ^{13}C NMR spectroscopy since the two carbons α to the carbonyl in **22** are tertiary and quaternary, whereas in **23** they are tertiary and secondary.

Alcohol **18** was readily prepared by hydrolysis of bromide **6**. Treatment of **18** with lead tetraacetate and iodine provides hypoiodite **19**. In contrast to our expectations, thermolysis of **19**, followed by cyclization of the resulting iodo ketone with lithium bis(trimethylsilyl)amide, gave only ketone **22**. Thus, product formation from **19** proceeds entirely via primary iodo ketone **20**. It is possible that under these reaction conditions the cleavage of radical **25**



to give **24** may be rapid but reversible, whereas the fission of **25** to afford **26** may be relatively slow and essentially irreversible. Beckwith and his co-workers have clearly established that the behavior of the 9-decalinyloxy radical follows an analogous rationale.[9]

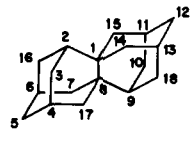
In summary, we have now developed methods for the preparation of both 2- and 4-monosubstituted [2]diadamantane alcohols and bromides. As has been amply demonstrated for both adamantane[10] and [6]diadamantane,[2] the availability of these compounds permits the synthesis of a wide variety of bridgehead derivatives of [2]diadamantane by the interchange of functional groups. It should be noted also that ketone **22** offers a potential entry to 3-substituted [2]diadamantanes since 4-protoadamantanone (**27**) can be readily converted to 2-adamantanol (**28**).[11]



Experimental Section

Melting points were obtained in sealed capillary tubes using a Mel-Temp melting point apparatus and are uncorrected. Infrared spectra were recorded on a Unicam SP1100 spectrophotometer. Proton magnetic resonance spectra were obtained with a Bruker AM 250-MHz spectrometer. Apparent splittings are reported in all cases. Carbon magnetic resonance spectra were recorded with the Bruker instrument at 62.9 MHz. Both the ^{1}H and ^{13}C NMR spectra were referenced to an internal standard of tetramethylsilane. Electron-impact mass spectra were obtained with a Du Pont 21-492B mass spectrometer at an ionization potential of 70 eV.

The numbering scheme employed for the assignment of the ^{13}C NMR signals in [2]diadamantane and its derivatives is as follows:



(7) Janjatovic, J.; Majerski, Z. *J. Org. Chem.* **1980**, *45*, 4892–4898 and references cited therein.

(8) For a review of alkoxy radical fragmentation see: Kochi, J. K. In "Free Radicals"; Kochi, J. K., Ed.; Wiley-Interscience: New York, 1973; Vol 2, Chapter 23, p 665.

(9) Beckwith, A. L. J.; Kazlauskas, R.; Syner-Lyons, M. R. *J. Org. Chem.* **1983**, *48*, 4718–4722.

(10) Fort, R. C., Jr. "Adamantane: The Chemistry of Diamond Molecules"; Marcel Dekker: New York, 1976; Chapter 3.

(11) (a) Lenoir, D.; Hall, R. E.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1974**, *96*, 2138–2148. (b) Farcasiu, D.; Bohm, H.; Schleyer, P. v. R. *J. Org. Chem.* **1977**, *42*, 96–102.

The assignments are based on the observations and conclusions of Duddeck et al. for substituent effects on ^{13}C chemical shifts in derivatives of adamantane, [6]diadamantane, and triadamantane.[12]

[2]Diadamantane[2] (2). Aluminum bromide (60 mg) was added to a solution of 2,2'-binoradamantane[2] (180 mg, 0.74 mmol) in cyclohexane (20 mL) and the resulting mixture was stirred at reflux for 12 h under nitrogen. The organic layer was decanted and the residue was washed with hot cyclohexane (2 × 10 mL). The organic layer and the hexane extracts were combined, washed with water (2 × 20 mL), and then dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure provided 175 mg of a white solid which was column chromatographed on silica gel. Elution with hexane provided 132 mg (73% yield) of **2**. The identity of **2** was confirmed by its ^{13}C NMR spectrum:[2] δ ($CDCl_3$) 39.6 (C-5 and C-12), 37.8 (C-2, C-7, C-9, C-14, C-15, and C-17), 37.2 (C-1 and C-8), 32.5 (C-3, C-10, C-16, and C-18), 29.7 (C-4, C-6, C-11, and C-13).

Bromination of [2]Diadamantane. A solution of **2** (1.098 g, 4.54 mmol) in bromine (22 mL) and carbon tetrachloride (46 mL) was stirred at room temperature for 48 h. The reaction mixture was then poured into ice water (100 mL) and the excess bromine present was destroyed by the slow addition with stirring of solid sodium bisulfite. The organic layer was separated, washed sequentionally with 5% aqueous sodium bisulfite (2 × 25 mL) and water (2 × 25 mL), and dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure afforded 1.63 g of an oil which was column chromatographed on silica gel. Elution with hexane gave 1.095 g (75% yield) of a yellow oil. Analysis of this material by quantitative ^{13}C NMR showed that the only compounds present were bromides **6** and **7** and that they were obtained in a ratio of 70:30, respectively. The oil crystallized upon standing. Two recrystallizations of this material from petroleum ether provided pure **6**: mp 128–129 °C; ^1H NMR δ ($CDCl_3$) 2.84 (d, J = 11.4 Hz, 2 H), 2.56 (d, J = 12.3 Hz, 2 H), 2.34 (d, J = 12.7 Hz, 2 H), 2.22–1.97 (m, 8 H), 1.79–1.56 (m, 6 H), 1.46 (d, J = 12.7 Hz, 2 H), 1.13 (m, 1 H), 1.02 (d, J = 12.7 Hz, 2 H); ^{13}C NMR δ ($CDCl_3$) 80.3 (C-2), 45.0 (C-3 and C-16), 44.0 (C-1), 42.0 (C-8), 39.0 (C-12), 38.0 (C-9), 37.4 (C-5), 37.0 (C-7 and C-17), 34.4 (C-14 and C-15), 33.5 (C-4 and C-6), 32.2 (C-10 and C-18), 29.5 (C-11 and C-13); exact mass calcd for $C_{18}H_{25}Br$ 320.114, found, 320.112.

[2]Diadamantane from a Mixture of 2- and 4-Bromo[2]diadamantane. Lithium metal (112 mg, 16 mmol) was added to a solution of a 70:30 mixture of bromides **6** and **7** in anhydrous *tert*-butyl alcohol (4 mL) and anhydrous tetrahydrofuran (20 mL). The resulting mixture was stirred at room temperature for 5 h. At this point water (10 mL) was added and stirring was continued for 0.5 h. The resulting solution was extracted with ether (2 × 20 mL), and the combined ether extracts were dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure gave 40 mg (100% yield) of a white solid. The ^{13}C NMR spectrum of this material was identical with that of an authentic sample of **2**.

Oxidation of [2]Diadamantane with Lead Tetraacetate. Lead tetraacetate (310 mg, 0.70 mmol, partially dried by suction filtration under dry nitrogen, then further dried over potassium hydroxide under vacuum, and stored in a dessicator over phosphorus pentoxide) and [2]diadamantane (75 mg, 0.31 mmol) were stirred with trifluoroacetic acid (2 mL) that was 0.1 M in lithium chloride and methylene chloride (2 mL) for 24 h in the dark. The reaction mixture was then partitioned between ether (10 mL) and aqueous sodium hydroxide (0.5 g in 12 mL of water). The aqueous layer was extracted with ether (3 × 10 mL). The organic extracts were combined, then washed with saturated aqueous sodium bicarbonate (2 × 10 mL) and water (2 × 10 mL), and dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure provided an oil which was hydrolyzed by refluxing it with 10% aqueous sodium hydroxide for 5 h. The reaction mixture was then extracted with ether (3 × 10 mL) and the ether extracts were combined and dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure provided 48 mg of a white solid residue which was sublimed (125 °C (0.3 mm)) to give 22 mg (28% yield) of **8**: mp 139–144 °C; ^1H NMR δ ($CDCl_3$) 2.9–0.6 (br m); ^{13}C NMR δ ($CDCl_3$) 69.8 (C-4), 46.9 (C-5), 45.6 (C-17), 40.4 (C-2), 40.2 (C-3), 39.5 (C-12), 37.9 (C-14 or C-15), 37.6 (C-9), 37.3 (C-14 or C-15), 36.5 (C-7), 32.6 (C-10 or C-18), 32.5 (C-10 or C-18), 31.3 (C-6, C-11 or C-13), 31.0 (C-16), 31.0 (C-6, C-11 or C-13), 29.6 (C-6, C-11 or C-13); exact mass calcd for $C_{18}H_{26}O$ 258.198, found 258.200.

4-Bromo[2]diadamantane. A suspension of alcohol **8** (52 mg, 0.20 mmol) in 47% hydrobromic acid (5 mL) was sealed in an aerosol bottle and heated at 100 °C for 2.5 h. After the reaction mixture had cooled, it was poured into water (10 mL) and then extracted with ether (3 × 10 mL). The combined ether extracts were dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure provided 59 mg of a tan solid which was sublimed (120 °C, 0.4 mm) to give 40 mg (62% yield) of **7**: ^1H NMR δ ($CDCl_3$) 3.8–0.6 (br m); ^{13}C NMR δ ($CDCl_3$) 68.6 (C-4), 51.1 (C-5), 49.5 (C-17), 44.3 (C-3), 42.6 (C-8), 42.3 (C-2), 39.3 (C-12), 37.8 (C-14 or C-15), 37.5 (C-9), 37.2 (C-14 or C-15), 35.9 (C-7), 33.2 (C-6), 32.4 (C-10 or C-18), 32.3 (C-10 or C-18), 30.5 (C-16), 29.4 (C-11), 29.4 (C-13); exact mass calcd for $C_{18}H_{25}Br$ 320.114, found 320.116.

Isomerization of 2-Bromo[2]diadamantane. A solution of bromide **6** (30 mg, 0.094 mmol) in dibromomethane (3 mL) was stirred with aluminum bromide (30 mg, 0.11 mmol) at 0 °C for 1 h. The reaction mixture was then poured into ice water (5 mL) and the layers were separated. The aqueous layer was extracted with methylene chloride (2 × 5 mL). The combined organic layers were washed sequentially with 5% aqueous potassium hydroxide (2 × 5 mL) and water (2 × 5 mL) and then dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure provided 26 mg of a viscous light yellow oil. Analysis of this material by ^{13}C NMR showed that it was composed of bromide **7** and dibromides **15** and **16** in a ratio of ca. 8:1:1, respectively.

Bromination of 2-Bromo[2]diadamantane. A solution of a 70:30 mixture of bromides **6** and **7** (210 mg, 0.65 mmol) in dibromomethane (21 mL) was stirred with aluminum bromide (210 mg, 0.79 mmol) at room temperature for 7 days. Workup of the reaction mixture as described above provided 207 mg of an oil. Analysis of this material by ^{13}C NMR showed that it was composed of bromide **7** and dibromides **15** and **16** in a ratio of ca. 2:3:3, respectively. This oil was column chromatographed on silica gel. Elution with hexane provided 10 mg of 4,11-dibromo[2]diadamantane (**15**): ^1H NMR δ ($CDCl_3$) 3.05 (d, J = 12.3 Hz, 2 H), 2.70 (t, J = 12.8 Hz, 2 H), 2.35–2.02 (m, 10 H), 1.73 (d, J = 11.2 Hz, 2 H), 1.55–1.45 (m, 6 H), 1.10 (d, J = 13.1 Hz, 2 H); ^{13}C NMR δ ($CDCl_3$) 65.9 (C-4 and C-11), 50.7 (C-5 and C-12), 49.2 (C-15 and C-17), 43.9 (C-3 and C-10), 41.5 (C-2 and C-9), 41.1 (C-1 and C-8), 35.4 (C-7 and C-14), 32.7 (C-6 and C-13), 30.3 (C-16 and C-18); exact mass calcd for $C_{18}H_{24}Br_2$ 398.024, found 398.022. Further elution with 12% methylene chloride/hexane provided 43 mg of a mixture of **7**, **15**, and **16** in a ratio of ca. 1:2:2, respectively. Finally, elution with 50% methylene chloride/hexane gave 8 mg of 4,13-dibromo[2]diadamantane (**16**): ^1H NMR δ ($CDCl_3$) 2.92 (d, J = 12.9 Hz, 2 H), 2.68 (d, J = 12.9 Hz, 2 H), 2.47 (d, J = 12.9 Hz, 2 H), 2.37–2.03 (m, 10 H), 1.73 (d, J = 12.9 Hz, 2 H), 1.6–1.4 (m, 4 H), 1.11 (d, J = 12.9 Hz, 2 H); ^{13}C NMR δ ($CDCl_3$) 66.6 (C-4 and C-13), 50.7 (C-5 and C-12), 48.8 (C-14 and C-17), 44.0 (C-3 and C-18), 41.6 (C-2 and C-9), 41.1 (C-1 and C-8), 35.9 (C-7 and C-15), 32.8 (C-6 and C-11), 30.4 (C-10 and C-16); exact mass calcd for $C_{18}H_{24}Br_2$ 398.024, found 398.022.

[2]Diadamantane from a Mixture of Bromide 7 and Dibromides 15 and 16. Lithium metal (100 mg, 14.0 mmol) was added to 50 mg of a 2:1:1 mixture of **7**, **15**, and **16**, respectively, in anhydrous *tert*-butyl alcohol (3 mL) and anhydrous tetrahydrofuran (15 mL). The resulting reaction mixture was stirred at room temperature for 12 h. Workup according to the procedure described for **6** + **7** → **2** provided 30 mg (89% yield) of a white solid. The ^{13}C NMR spectrum of this material was identical with that of an authentic sample of **2**.

2-Hydroxy[2]diadamantane (18). A stirred mixture of bromide **6** (105 mg, 0.33 mmol) in 0.67 N aqueous hydrochloric acid (3 mL) and *N,N*-dimethylformamide (2.4 mL) was refluxed for 20 h. After cooling, the reaction mixture was extracted with ether (3 × 10 mL). The combined ether extracts were dried over anhydrous magnesium sulfate. Evaporation of the solvent at

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reduced pressure provided 135 mg of a solid which was sublimed (130 °C, 0.4 mm) to give 46 mg (54% yield) of **18** as a white solid: ^{1}H NMR δ ($CDCl_3$) 2.5–0.8; ^{13}C NMR δ ($CDCl_3$) 71.1 (C-2), 41.7 (C-1), 40.2 (C-3 and C-16), 39.4 (C-12), 38.1 (C-5), 37.2 (C-7 and C-17), 37.2 (C-9), 37.2 (C-8), 32.3 (C-10 and C-18), 31.6 (C-14 and C-15), 31.2 (C-4 and C-6), 29.5 (C-11 and C-13); exact mass calcd for $C_{18}H_{26}O$ 258.198, found 258.197.

Ketone 22. A mixture of alcohol **18** (100 mg, 0.387 mmol), dry lead tetraacetate (343 mg, 0.774 mmol, partially dried by suction filtration under dry nitrogen, then further dried over potassium hydroxide under vacuum, and stored in the dark in a desiccator over phosphorus pentoxide), and iodine (177 mg, 0.700 mmol) in dry benzene (20 mL) was stirred under nitrogen at 80 °C for 20 min and then at 70–75 °C for an additional 2 h. The reaction mixture was then allowed to cool to room temperature, and the inorganic salts that precipitated were filtered and washed with ether. The filtrate and the ether washings were combined and shaken with a saturated aqueous solution of sodium thiosulfate (30 mL) until the solution was decolorized. The layers were then separated, and the organic layer was washed with water (2 × 10 mL) and saturated aqueous sodium bicarbonate (2 × 10 mL) and then dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure with no external heating provided the crude oily iodo ketone **20** which was used immediately in the next step.

A solution of lithium bis(trimethylsilyl)amide was prepared by the dropwise addition of *n*-butyllithium (2.0 mmol) to a stirred solution of 1,1,1,3,3,3-hexamethyldisilazane (0.42 mL, 2.0 mmol) in anhydrous tetrahydrofuran (15 mL), which was maintained at 0 °C under nitrogen. The reaction mixture was stirred at 0 °C for 1 h and then it was cooled to −78 °C. A solution of the crude iodo ketone **20** and hexamethylphosphoramide (0.75 mL) in anhydrous tetrahydrofuran (5 mL) was then added dropwise. The resulting solution was stirred for 1 h at −78 °C, for 3 h at −30 °C, and for 2 h at 0 °C. At this point the reaction mixture was quenched with water (2 mL) and diluted with ether (30 mL). The layers were separated, and the organic layer was washed with brine (4 × 20 mL) and then dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure gave 96 mg of a tan solid which was sublimed (105 °C (0.5 mm)) to provide 84 mg (84% yield) of **22** as a white solid: ^{1}H NMR δ ($CDCl_3$) 2.81–2.68 (m, 1 H, CHC=O), 2.57–1.08 (br m, 23 H); ^{13}C NMR δ ($CDCl_3$) 218.0 (s), 50.2 (d), 47.3 (s), 42.8 (t), 40.5 (t), 40.3 (d), 39.3 (s), 39.1 (t), 38.7 (t), 37.4 (t), 37.2 (t), 37.0 (d), 36.5 (t), 33.3 (d), 32.1 (t), 31.9 (t), 28.8 (d), 27.7 (d); IR ν (CCl_4) 2920, 2870, 1699, 1470, 1330, 1255 cm^{-1}; exact mass calcd for $C_{18}H_{24}O$ 256.183, found 256.181.

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Aromaticity in Unusual Heteropolar Monocyclic Rings with (4*n* + 2) π Electrons

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SINDO1 calculations are performed on selected heteropolar monocyclic ring systems with three to eight atoms containing (4*n* + 2) π electrons in the ring in the ground-state equilibrium. Different from Hückel's (4*n* + 2) rule which declares these systems as aromatic, an alternative ring current criterion predicts a whole scale of aromaticity indexes ranging from aromatic to antiaromatic. The smallest planar aromatic ring $Be(CH)_2$ and the smallest nonplanar aromatic ring $(BeCH)_2$ are presented.

1. Introduction

It is widely believed that a ring system of 4*n* + 2 π electrons is aromatic. This famous Hückel rule is the basis for every discussion of aromatic systems.[1,2] Most of the arguments and proofs or disproofs are related to calculations with Hückel's π-electron method. Since the results of the more refined versions[3-5] are essentially topological, they work best for hydrocarbons. It is not surprising that the early discussion, which was very nicely presented in 1961 by Streitwieser,[6] focuses on hydrocarbons and substituted systems. Exceptions from Hückel's rule were discovered in polycyclic rings. In monocyclic rings the effect of a substituent outside of the ring had to be considered. Whereas fulvene was considered initially as aromatic[6] and later as nonaromatic, the cyclopentadienone was considered as antiaromatic due to its CO bond polarization toward oxygen. The simplest explanation was that four π electrons were left in the ring. For the same reason cyclopropenone should be more aromatic than methylenecyclopropene. The question of aromaticity in these compounds was recently raised again by Greenberg et al.,[7] who gave evidence of a moderate aromaticity in cyclopropenone through reexamination of strain energy. Nothing definitive can be said by the above topological methods about systems which are substituted inside the rings because of inherent difficulties with parametrization of heteroatoms.

It is the purpose of this paper to demonstrate that some regularities can be derived but that no general prediction due to the number of π electrons can be made about the

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