Face Selection in Additions to the Trigonal C_2 Site in Quaternized 5-Azaadamantane Derivatives

Jacqueline Lau, Elena M. Gonikberg, Jui-te Hung, and William J. le Noble*

Contribution from the Department of Chemistry, State University of New York, Stony Brook, New York 11794

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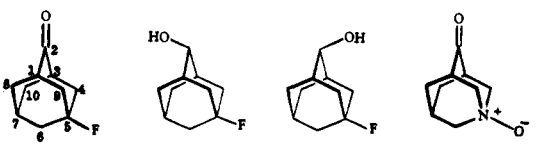
Abstract: The quaternary *N*-allyl bromide salt **5** of allyl α-[2-(5-azaadamantylidene)]benzyl ether upon warming gave the Claisen rearrangement products **6** is the ratio *E*/*Z* = 93:7. The epoxidation of the *N*-oxide **8** of 2-methylene-5-azaadamantane **7** with *m*-CPBA gives rise to the two diastereomeric epoxides **9** in the ratio *E*/*Z* = 19:81. Reaction of the methyl iodide salt of this olefin with bromine in water produces the *E*- and *Z*-dibromides **10** in the ratio 74:26 as well as the corresponding glycols **12** in the ratio 86:14. The same reaction in methanol gives the *E*- and *Z*-isomers of **10** alone, in the ratio of 35:65. The interpretation is that, in all of these reactions, the trigonal carbon preferably undergoes addition at that face which is antiperiplanar to the more electron-rich vicinal bonds, and does so by margins substantially in excess of those observed with the corresponding 5-fluoroadamantanes. This fact lends further strength to our previously drawn conclusion that hyperconjugative transition state stabilization is the principal factor in the electronic component of face selection.

In earlier papers[1] detailing the use of 5-substituted 2-adamantylidene[2] derivatives such as **1** as probes to study the electronic component of face selection in addition (and cleavage) processes, we came to the conclusion that the vicinal bonds antiperiplanar to the reagent (or leaving group) determine the outcome of the question of which isomer will be dominant: approach (and departure) *anti* to the more electron-rich bond(s) is preferred. We attributed this preference to hyperconjugative transition state stabilization. This notion was first used by Baker and Nathan[3] to explain the effect of *p*-alkyl groups on the rates of heterolysis of benzyl chlorides. Some years later, it was elaborated (as σ participation) by Winstein;[4] in more recent times, it was employed by Cieplak[5] to account for the axial approach of small nucleophiles to the carbonyl carbon in cyclohexanones. To give a simple example in the context of our own work, the $NaBH_4$ reduction of 5-fluoroadamantan-2-one gives a 2:1 excess of the *E*-alcohol **2** over the *Z*-isomer.[1] The same idea provides a rationale for the stereochemistry of electrophilic addition,[6] the capture of carbenes,[7] radicals,[8] carbocations[9] and carbanions,[10] sulfur oxidation,[11] olefin−metal complexation,[12] thermal[13] and photo-[14] cycloaddition, and sigmatropic shifts.[10,15] Replacement of the C_5−F group by the isoelectronic N−O functionality has provided an important supporting argument: the preference for *syn* delivery of hydride becomes far more pronounced.[16]



1 *E*-2 *Z*-2 3

Of course, this latter claim demands that such substitutions have the same effect on other types of addition processes. In experiments to test this condition, we encountered the usual restrictions imposed by the introduction of an ionic charge into the substrate: many of the common organic reactions are usually carried out in media that cannot dissolve salt-like substances. Nevertheless, we succeeded in some instances and report the results of these experiments here.

In a first attempt to extend the use of the azaadamantane probe to pericyclic chemistry, we sought to study the Diels−Alder reaction of the thione with a suitable diene.[13] Although we were able to convert 5-azaadamantan-2-one into thione **4**, its sensitivity to hydrolysis precluded its conversion into the *N*-oxide by means of the standard treatment with hydrogen peroxide. A more successful project was our attempt to study the Claisen rearrangement of the *N*-allyl bromide salt of allyl α-[2-(5-azaadamantylidene)]benzyl ether **5**. Heating a solution of 100 mg of **5** in 25 mL of toluene to reflux overnight led to its conversion to a mixture of *E*- and *Z*-**6** (Bz = benzoyl) in 85% yield. The chemical shifts for $C_{4,9}$ and $C_{8,10}$ of *E*- and *Z*-**6** were calculated on the basis of the assumption that the change in chemical shift for these carbons upon rearrangement is the same for **6** as it was earlier found to be for the C_5−F analogs. An obvious match with observed signals was found (see Figure 1);

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(3) Baker, J. W.; Nathan, W. S. *J. Chem. Soc.* **1935**, 1840, 1844.

(4) Winstein, S.; Trifan, D. *J. Am. Chem. Soc.* **1952**, *74*, 1147, 1154.

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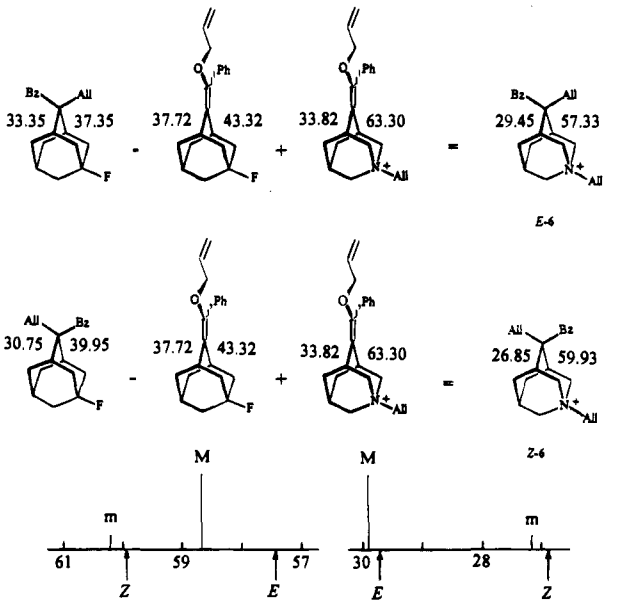
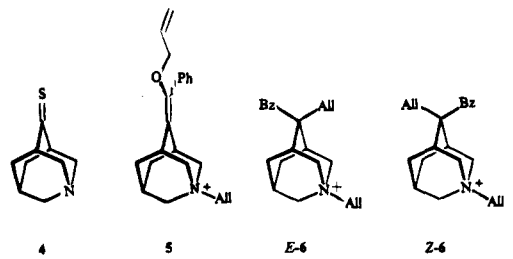
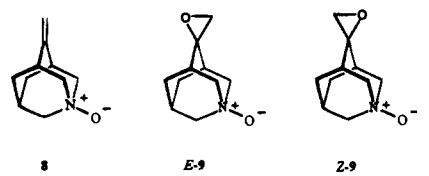


Figure 1. Calculation of the $C_{4,9}$ and $C_{8,10}$ resonances; comparison of the results with the observed values, and assignment of the major isomer (M) as *E*-**6** and the minor isomer as *Z*-**6**.

E-**6** was the major isomer. The ratio measurement was based on the ^{13}C NMR spectrum as well; inverse gated decoupling experiments showed it to be 93:7. The sharp increase in this ratio when compared with the C_5-F measurement (59:41)[15] speaks for itself.

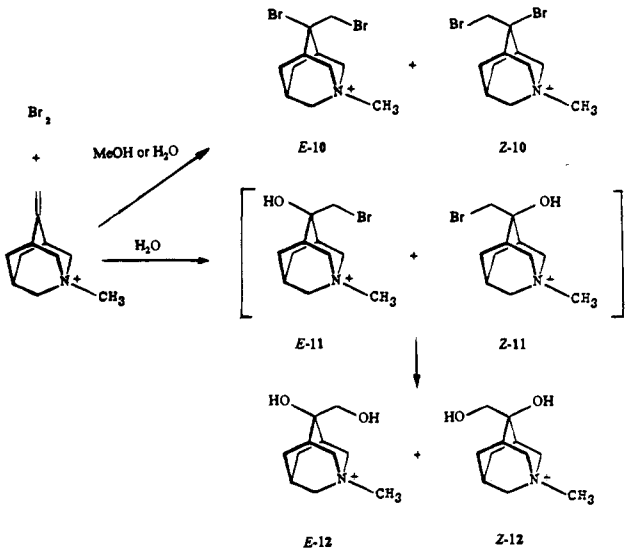


Wittig reaction of 5-azaadamantan-2-one gave the 2-methylene analog **7**,[17] which upon room temperature treatment with 30% hydrogen peroxide produced *N*-oxide **8**. Oxidation of **8** with *m*-CPBA in CD_2Cl_2 at room temperature for 4 days gave a mixture of the *E*- and *Z*-spiro[oxirane-2,2′-(5-azaadamantane)] *N*-oxides (**9**). The configurational assignments were again



based—without separation—on the ^{13}C chemical shifts of $C_{4,9}$ and $C_{8,10}$, which could be calculated in the usual way from those of spiro[oxirane-2,2′-adamantane], methyleneadamantane, and 5-aza-2-methyleneadamantane *N*-oxide. The calculated value for the chemical shift of $C_{8,10}$ ($\delta = 31.80$) of *Z*-**9** agrees well with the observed value of the major isomer ($\delta = 31.77$); these values were δ 30.08 and 30.37, respectively, for the *E*-isomer which was the minor one. It may be noted that the agreement between the observed and calculated values is 10 times better if the major isomer is assigned to have the *Z*-configuration than if it is assumed to be the *E*-isomer. For the $C_{4,9}$ signals, the preference (a factor of 3) is somewhat smaller; we attribute the lesser agreement to the greater proximity of the positively charged nitrogen to $C_{4,9}$. The H_7 signals were used to analyze the mixture, with the result that the *E*/*Z* ratio equals 19:81.

The bromination of the methyl iodide salt of **7** in water led to the immediate precipitation of a mixture of *E*- and *Z*-dibromides **10** (60%), which was dried via the azeotropic distillation of added benzene. The filtrate contained 40% of the *E*- and *Z*-glycols **12** formed by the hydrolysis of bromohydrins **11**, a process known[18] to occur with retention of configuration (heterolysis assisted by the neighboring hydroxyl group). The ^{13}C resonances of both **10** and **12** are readily assigned on the basis of spectral similarities with one another as well as with those of model compound 2-(bromomethyl)-adamantan-2-ol. The latter compound survives in the bromination of 2-methyleneadamantane in aqueous DMSO. The carbon resonances of the model compound were assigned by means of a shift reagent study (an experiment not feasible with compounds **10** and **12** themselves). The *E*/*Z* ratio in the case of **10** was found to be 74:26, so that the zu face had been preferentially attacked in the first bromination step. Similarly, the *E*/*Z* ratio for **12** was determined to be 86:14, and we deduce that the ratio for **11** would have been at least close to that. We also studied the bromination in methanol. The mechanism of that reaction is quite different from that in water because the dibromide **10** is now the exclusive product; the 2-(bromomethyl)-2-methoxy-5-azaadamantanes are essentially undetectible. Observations such as these have been interpreted[19] as meaning that olefin bromination in methanol is a *cis*-addition process. Indeed, we find that the *Z*-isomer is now the predominant one, by a margin of 65:35. Thus, the stereochemistry of this reaction would be a clear indication of a mechanism different in these two reactions even if that were not already known, the second time that such an observation has come to light.[11]



In conclusion, we find that the replacement of C_5-F by positive nitrogen greatly increases the margin of *syn* approach by the reagent not only in nucleophilic addition but also in electrophilic attack and in sigmatropic rearrangement. These facts lend further credence to the proposition that transition state

(17) The synthesis of **3** has been described: Becker, D. P.; Flynn, D. L. *Synthesis* **1992**, 1080. Compound **7** has been mentioned but not described: Dekkers, A. W. J. D.; Verhoeven, J. W.; Speckamp, W. N. *Tetrahedron* **1973**, *29*, 1691. The synthesis of **4** was described in this same paper; its instability was noted.

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hyperconjugation is at the heart of the electronic factor in face selection in all addition and cleavage processes.

Acceptance of this idea, although widespread,[20] has certainly not been universal, and we must take note of the fact that the literature on face selection in reactions of cyclic compounds is rife with alternative suggestions of factors that may play a role; among them are pyramidalization of the trigonal carbon,[21] orbital distortion of the π bond,[22] torsional effects,[23] chelation,[24] and electrostatic effects[25]—all in addition to the other two manifestations of transition state hyperconjugation: the Anh and Felkin models.[26]

The question is not so much which one or ones of these factors are right and which are wrong, as each of them is rooted in the very fundamentals of physical science; rather, the problem is to ferret out those among these influences that are decisive in any given case. It has proven to be a difficult task, since all possible contributions as well as the net overall effect are usually small in terms of energy differences, yet leading to stereoisomer ratios often large in terms of synthetic interest.

We single out electrostatic effects here for special mention since they have been supported by several authors in recent times, mostly on the basis of computational research.[25] The difficulty with calculational support is that it is often not easily translatable into the descriptive and intuitive language still in such common use by organic chemists, and therefore, extrapolations to other systems are risky. The relatively simple type of ion−dipole calculations applied so successfully by Kirkwood and Westheimer[27] to the explanation of substituent effects on acid strength do not seem to have been extended to face selection, although that should certainly be possible. Similarly, one of the simple tenets of electrostatic interactions is their dependence on the solvent, but none of the papers quoted above have addressed this aspect.[28] Our own work, although also not extensive in this regard, has failed to uncover any systematic solvent effects.[1,16]

Perhaps the most persuasive experimental case for electrostatic rather than hyperconjugative effects as the explanation of face selectivity, at least in the case of radical capture, was recently made by W. Adcock.[29] He and his co-workers have reported that the 2-(5-trimethylstannyl)adamantyl radical is captured with essentially random stereochemistry. Even though this observation was based on complex reactions occurring in rather modest yields, the absence of the effect expected from such a strong donor is certainly surprising, and this fact needs to be studied further. But at present, we continue to consider the Cieplak model to provide the greatest predictive power in the stereochemistry of addition and elimination, at least in conformationally restricted systems. The attractive simplicity of this model, the remarkably wide range of reactions to which we have been able to apply it, the correspondence with carbocation chemistry, and the homily of Occam's razor all combine to persuade us so.

Experimental Section

All NMR spectra were measured on a QE-300 and/or an AC-250 spectrometer. The samples were in solution in $CDCl_3$ unless otherwise noted.

5-Azaadamantan-2-one (3). This compound was prepared as described by Becker and Flynn.[17]

5-Azaadamantan-2-thione (4). Ketone **3** (30 mg, 0.2 mM) was dissolved in pyridine (1 mL) which had been distilled from calcium hydride and stored over potassium hydroxide. The solution was heated to reflux, P_4S_{10} (14 mg, 0.03 mM) was added, and reflux continued for 14 h. The solvent was removed under vacuum and the residue sublimed at 55 °C to give **4** as an orange solid. HRMS: obsd 167.0759, calcd 167.0769. ^{1}H NMR: δ 1.84 (bs, 1H, H_7), 2.16−2.35 (m, 4H, $H_{8,10}$), 2.58 (s, 2H, $H_{1,3}$), 3.25−3.56 (m, 6H, $H_{4,6,9}$). ^{13}C NMR: δ 29.33, 58.51, 58.72, 60.74, 63.20 (C_2 was not observed). This compound quickly reverts to **3** if exposed to air or undried solvents.[17]

2-Cyano-5-azaadamantane. This compound was prepared in 75% yield from **3** by means of the van Leusen procedure.[30] The two isomers were not separated. MS: $M^+ = 162$. ^{1}H NMR: δ 1.7−2.3 (m), 3.0−3.5 (m). ^{13}C NMR: δ 25.6 and 25.8 ($C_{1,3}$), 28.8 and 28.9 (C_7), 32.1 and 35.5 ($C_{8,10}$), 36.1 and 36.2 (C_2), 54.1 and 57.3 ($C_{4,9}$), 57.9 and 58.0 (C_6), 122.2 and 122.5 (CN).

2-(5-Azaadamantyl) Phenyl Ketone. In an experiment similar to one reported,[31] the cyanide (550 mg) was dissolved in dry benzene (5 mL) and treated dropwise with a 2.0 M solution (5 mL) of phenyllithium in 15 min at room temperature. After 4 h of stirring, the reaction mixture was cautiously quenched with water (2 mL); the aqueous layer was extracted with methylene chloride, the organic solutions were combined, acetone and concentrated hydrochloric acid (2.5 mL each) were added, and the mixture was heated to reflux for 4 h. After neutralization with sodium bicarbonate and extraction with methylene chloride, column chromatography (basic alumina, 15% hexane in ethyl acetate) produced 460 mg of the ketone as a yellow oil which solidified overnight. MS: $M^+ = 241$. ^{1}H NMR: δ 1.72−2.28 (m), 3.10−3.78 (m), 7.4−8.0 (m). ^{13}C NMR: δ 25.9 ($C_{1,3}$), 28.4 and 28.8 (C_7), 30.6 and 35.9 ($C_{8,10}$), 49.2 and 49.6 (C_2), 52.6 and 58.2 ($C_{4,9}$), 56.9 and 57.4 (C_6), 128.1, 128.8, 132.6, 133.1, 136.0, 136.1 (phenyl).

Allyl α-[2-(5-Azaadamantylidene)]benzyl Ether *N*-Allyl Bromide (5). A solution of the mixture of ketones aforementioned (500 mg) in dry DMF (5 mL) was added dropwise to a suspension of sodium hydride (500 mg) in DMF with stirring. After 4 h, allyl bromide (1.5 mL) was added dropwise; stirring was continued overnight. The mixture was quenched with water and extracted with methylene chloride; column chromatography (basic alumina, 15% methanol in methylene chloride) produced 350 mg of **5** as a yellow oil. MS: M^+ − allyl bromide = 281. The rather complex ^{1}H NMR spectrum is shown on p S-11 of the supporting information. ^{13}C NMR: δ 27.21 (C_7), 28.66 and 30.90 ($C_{1,3}$), 33.45 and 33.82 ($C_{8,10}$), 63.00 (allyl-CH_2), 63.00 and 63.30 ($C_{4,9}$), 67.48 (C_6), 69.84 (allyl), 118.01 (allyl), 118.91 (C_2), 123.37 (allyl), 128.43 (phenyl), 128.70 (allyl), 128.86 (phenyl), 129.98 (allyl), 132.65

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(26) For a discussion of all three hyperconjugation models, see: Li, H.; le Noble, W. J. *Recl. Trav. Chim. Pays-Bas* **1992**, *111*, 199.

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and 133.34 (phenyl), 146.12 (benzyl). The signal at δ 63.00 was resolved into two when the sample was dissolved in C_6D_6.

2-Allyl-2-benzoyl-5-azaadamantane *N*-Allyl Bromide (6). Ether **5** (100 mg) was dissolved in toluene (100 mL), and the solution was heated to reflux overnight. A white solid (85 mg) was obtained. MS: M^+ − allyl bromide = 281. ^{1}H NMR: δ 1.72 and 1.88 (d and d, 2H, J = 13 Hz, $H_{8,10}$), 2.17 (s, 1H, H_7), 2.80 (s, 2H, $H_{1,3}$), 3.12 (d, 2H, J = 5.4 Hz, allyl), 3.70 (s, 2H, H_6), 3.78 and 4.22 (d and d, 2H, J = 12.6 Hz, $H_{4,9}$), 4.66 (d, 2H, J = 6.3 Hz, allyl), 5.0−5.1, 5.4−5.7 and 5.8−6.1 (m, m and m, 2H, allyl), 7.42−7.74 (m, phenyl). The minor isomer was detectible but present in only very small quantities (5−7%). ^{13}C NMR: δ 25.97 (C_7), 27.16 ($C_{8,10}$, minor), 29.91 ($C_{8,10}$, major), 31.97 ($C_{1,3}$), 37.27 (allyl), 53.68 (C_2), 58.66 ($C_{4,9}$, major), 60.21 ($C_{4,9}$, minor), 62.76 (C_6), 66.70, 120.1 and 123.6 (allyl), 127.8 and 128.6 (phenyl), 130.2 (allyl), 130.6 (phenyl), 132.2 (allyl), 137.2 (phenyl), 203.0 (C=O). The ratio of isomers was determined (AM-300) by means of a ^{13}C inverse gated decoupling experiment; major:minor = 93:7.

2-Methylene-5-azaadamantane. Vacuum-dried triphenylmethylphosphonium bromide (2.00 g, 5.6 mM) in dry THF (8 mL) was treated dropwise (15 min) with *n*-butyllithium (3 mL, 2.5 M, 7.5 mM) with stirring, under nitrogen and at room temperature. After 15 min, 500 mg (3.3 mM) of **3** in dry THF (15 mL) was added dropwise and the solution was stirred at room temperature for 2 h. The reaction mixture was quenched with water (0.5 mL), filtered, dried, and reduced to small volume; the residue was extracted with hexane several times, and the hexane solution was exposed to a vacuum to give a colorless liquid (0.36 g). This material can be used for quaternization without further purification. An analytically pure sample was obtained by sublimation at 60−70 °C and 0.5 Torr. The yield was 0.34 g (69%). HRMS: obsd 149.1214, calcd 149.1205. ^{1}H NMR: δ 1.629 (s, 1H, H_7), 1.848−2.036 (dd, 4H, $H_{8,10}$), 2.267 (s, 2H, $H_{1,3}$), 3.116 (s, 2H, H_6), 2.965−3.210 (dd, 4H, $H_{4,9}$), 4.494 (s, 2H, H_{11}). ^{13}C NMR, 27.42 (C_7), 38.31 ($C_{8,10}$), 38.92 ($C_{1,3}$), 58.62 (C_6), 60.68 ($C_{4,9}$), 100.89 (C_{11}), 155.38 (C_2).

2-Methylene-5-azaadamantane *N*-Oxide (8). A solution of the unsaturated amine (157 mg) in a mixture of methanol (9.5 mL) and 30% hydrogen peroxide (0.82 mL) was stirred at room temperature for 22 h. The solvent was evaporated; column chromatography (neutral alumina, 80−200 mesh, 10% methanol in chloroform) gave a white solid which was dried under vacuum (0.1 Torr, 3 h; 83%). Mp: 233−8 °C. HRMS: obsd 165.1148, calcd 165.1154. ^{1}H NMR: δ 1.60−1.77 (dd, 4H, $H_{8,10}$), 2.190 (s, 1H, H_7), 2.587 (s, 2H, $H_{1,3}$), 3.239 (s, 4H, $H_{4,9}$), 3.310 (s, 2H, H_6), 4.599 (s, 2H, H_{11}). ^{13}C NMR: 29.98 (C_7), 34.79 ($C_{8,10}$), 39.27 ($C_{1,3}$), 72.97 (C_6), 73.61 ($C_{4,9}$), 106.83 (C_{11}), 147.27 (C_2).

Spiro[oxirane-2,2′-(5-azaadamantane)] *N*-Oxide (9). Olefin **8** (38.3 mg, 0.232 mM) was dissolved in dichloromethane-d_2 and treated with *m*-CPBA (115 mg, 0.232 mM). After 30 h, an additional quantity of the oxidizing agent (45 mg) was added, and after 48 h, the reaction was complete. Filtration gave a pure solution. ^{1}H NMR: δ 1.879 (s, 2H, $H_{1,3}$), 1.95−2.16 (m, 4H, $H_{8,10}$), 2.489 and 2.491 (s and s, 1H, H_7), 2.878 (s, 2H, H_{11}), 3.97−4.01 (m, 6H, $H_{4,6,9}$). The peaks at δ 2.49 were the basis of the analysis; the ratio was 81:19. The ^{1}H and ^{13}C NMR signals were linked by means of a correlation spectrum. ^{13}C NMR: major peaks given first, δ 29.23 and 29.50 (C_7), 31.77 and 30.37 ($C_{8,10}$), 37.59 and 36.86 ($C_{1,3}$), 54.53 and 54.95 (C_{11}), 66.20 (C_2), 68.61 and 69.89 ($C_{4,9}$), 70.49 and 70.88 (C_6). The assignment of configuration was based on an analysis similar to that shown in Figure 1.

2-Methylene-5-azaadamantane *N*-Methyl Iodide. A solution of 2-methylene-5-azaadamantane (75 mg, 0.5 mM) in methylene chloride (5 mL) was treated with iodomethane (3 drops, *ca.* 0.75 mM). One-half hour later, a white precipitate had formed. Evaporation of the solvent gave the product (140 mg). Mp (sealed capillary): 190−195 °C. MS: 149 (M^+ − CH_3I). ^{1}H NMR: D_2O, δ 2.24 (d, 2H, J = 12 Hz, $H_{8,10}$), 2.34 (s, 1H, H_7), 2.84 (s, 2H, $H_{1,3}$), 2.89 (d, 2H, J = 12 Hz, $H_{8,10}$), 2.97 (s, 3H, CH_3), 3.44−3.58 (m, 6H, $H_{4,6,9}$), 4.88 (s, 2H, CH_2=). ^{13}C NMR: δ 29.8 (C_7), 36.3 ($C_{8,10}$), 39.2 ($C_{1,3}$), 57.1 (CH_3), 68.5 (C_6), 69.7 ($C_{4,9}$), 109.7 (CH_2=), 148.2 (C_2).

Bromination Studies. (a) In Water. The methyl iodide salt (40 mg, 0.14 mM) was added to an aqueous solution of bromine (0.25 mM). A yellow precipitate formed instantly; it was collected and dried by distillation of added benzene. ^{1}H NMR (CD_3CN): 1.90−2.67 (m), 2.966 (s), 3.033 (s), 3.44−4.03 (m), 4.270 (s), 4.254 (s). The former singlets were clearly the signals of the *N*-methyl protons and the latter, those of the bromomethylene groups of the two dibromides, which could also be obtained by reaction in methylene chloride. ^{13}C NMR (CD_3CN): 26.29 and 26.66 (C_7), 29.10 and 31.10 ($C_{8,10}$), 38.05 and 39.12 ($C_{1,3}$), 43.77 and 43.99 (CH_2Br), 54.81 and 55.13 (CH_3), 61.97 and 65.09 ($C_{4,9}$), 67.72 and 68.16 (C_6), 70.79 and 72.70 (C_2). The nature of the precipitate as dibromides **10** was established by a comparison of this product with that obtained by bromination in methylene chloride, in which it is the only product. The configurations and the ratio were determined as described below.

The filtrate was evaporated to give a yellow solid (25 mg); the chemical shift of the exocyclic CH_2 protons revealed the nature of this residue to be a mixture of diols **12**. ^{1}H NMR (CD_3CN): δ 1.88−2.65 (m), 2.959 and 3.011 (s and s, *N*-CH_3), 3.44−4.03 (m, $H_{4,9}$), 4.083 and 4.108 (s and s, CH_2OH). ^{13}C NMR (CD_3CN): δ 26.41 (C_7), 29.59 and 30.59 ($C_{8,10}$), 37.08 ($C_{1,3}$), 55.10 (*N*-CH_3), 62 68 and 65.03 ($C_{4,9}$), 67.60 (C_6), 67.90 (CH_2OH), 78.39 (C_2) (minor isomer: only the CH_2 group signals were detected).

(b) In Methanol. This experiment was identical to the one done in aqueous solution; in this instance, only a mixture of the dibromides **10** was observed.

2-Hydroxy-2-(bromomethyl)adamantane. This compound was prepared from methyleneadamantane to serve as an auxiliary material in the assignment of the configurations of **10** and **12**. The method used was that of Landman and Dalton;[32] it employs NBS in aqueous DMSO and column chromatography (SiO_2, 15% ethyl acetate in hexane) as the means of purification. MS: 227 and 229 (M^+ − OH). ^{1}H NMR: δ 1.50−2.25 (m), 3.81 (s, CH_2Br). ^{13}C NMR: 27.10 ($C_{5,7}$), 32.92 (CH_2, OH side), 34.39 (CH_2, CH_2Br side), 35.88 ($C_{1,3}$), 37.86 (C_6), 45.63 (CH_2Br), 73.05 (C_2). The assignments are based on the shift reagent study with Eu(fod)$_3$ described in the supporting information.

The chemical shifts for $C_{4,9}$ and $C_{8,10}$ were then combined with those of methyleneadamantane and the 5-aza *N*-methyl iodide of this olefin to compute values for the chemical shifts of these atoms in the hypothetical bromohydrin derivatives of the olefinic salt. The results are

$$E, C_{4,9}: \ 34.39 - 39.65 + 69.69 = 64.43$$

$$E, C_{8,10}: \ 32.92 - 39.65 + 36.24 = 29.51$$

$$Z, C_{4,9}: \ 32.92 - 39.65 + 69.69 = 62.96$$

$$Z, C_{8,10}: \ 34.39 - 39.65 + 36.24 = 30.98$$

The computed values for the hypothetical bromohydrins are very close to those observed for compounds **10** and **12** (reported above), and the ^{13}C NMR signals in these mixtures could thence be assigned. Integration of these signals finally gave the ratios of the stereoisomers.

The following experiments are related to but not reported in the main text.

Compound **8** did not react or gave complex mixtures with CCl_3Br and AIBN under a variety of conditions.

5-Azaadamantane *N*-Oxide. This compound was prepared to serve as a possible model to allow better evaluation of the ^{13}C NMR spectra. A mixture of anhydrous hydrazine (1.0 mL, 31.9 mM), potassium *tert*-butoxide (0.33 g, 2.94 mM), and ketone **3** (150 mg, 1 mM) in xylene (10 mL) was heated at 110 °C for 1.5 h. After cooling, the organic layer was separated, washed with water, and dried over potassium carbonate. Removal of the solvent afforded 60 mg (44%) of the known 5-azaadamantane as a pure white solid. ^{1}H NMR: δ 1.67 (s, 3H, $H_{1,3,5}$), 1.96 (dd, 6H, J = 12.3 Hz, CH_2), 3.15 (s, 6H, NCH_2). This amine (60 mg, 0.44 mM) was dissolved in methanol (3 mL), hydrogen peroxide (30%, 0.5 mL) was added, and the mixture was stirred overnight. After evaporation of the solvent, the oxide was obtained as a white solid (57 mg, 85%). ^{1}H NMR (CD_2Cl_2): δ 1.82 (dd, 6H, J = 12.6 Hz, CH_2),

(32) Landman, A. W.; Dalton, D. R. *Org. Synth., Collect. Vol. 6* **1988**, 184.

2.31 (s, 3H, $H_{1,3,6}$), 3.53 (s, 6H, NCH_2). ^{13}C NMR (CD_2Cl_2): δ 30.65 ($C_{1,3,6}$), 33.02 (CH_2), 72.27 (NCH_2).

(2-Methylene-5-azaadamantan-*N*-yl)pentacarbonyltungsten. Compound **8** (0.76 g, 4.5 mM) was added in portions to a vigorously stirred suspension of hexacarbonyltungsten (1.58 g, 4.5 mM) under nitrogen in THF (15 mL). After the addition was complete, the mixture was stirred for an additional 1 h; filtration through a short column of silica gel, removal of solvent, and development on a precoated TLC plate with 50% ethyl acetate−hexane gave 0.45 g (27%) of a yellow solid. Mp: 103−104°. MS (^{184}W): 473 (M^+). ^1H NMR: δ 1.86 (s, 1H, H_7), 1.88 and 2.05 (AB, 4H, J = 11.3 Hz, $H_{8,10}$), 2.39 (s, 2H, $H_{1,3}$), 3.60 (s, 2H, H_6), 3.52 and 3.61 (AB, 4H, J = 12.3 Hz, $H_{4,9}$), 4.70 (s, 2H, CH_2=). ^{13}C NMR: δ 28.96 (C_7), 35.63 ($C_{8,10}$), 39.64 ($C_{1,3}$), 69.70 (C_6), 71.27 ($C_{4,9}$), 104.38 (CH_2=), 150.07 (C_2), 191.12 (*cis*-CO), 199.38 (*trans*-CO). This compound did not intercept CCl_2, could not be reduced with hydrogen over palladium/carbon, did not react with 2,3-dimethylbuta-1,3-diene and with dimethyldioxirane, and gave complex mixtures during hydroboration, oxidation with *m*-CPBA, and reaction with CCl_3Br and AIBN.

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Supporting Information Available: Mass spectral data and ^1H and ^{13}C NMR spectra of the compounds mentioned in the Experimental Section (47 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, can be ordered from the ACS, and can be downloaded from the Internet; see any current masthead page for ordering information and Internet access instructions.

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