Linear Free Energy Relationship Studies of the Dimethyldioxirane C–H Bond Insertion Reaction[1]

Robert W. Murray* and Hong Gu

Department of Chemistry, University of Missouri–St.Louis, St. Louis, Missouri 63121

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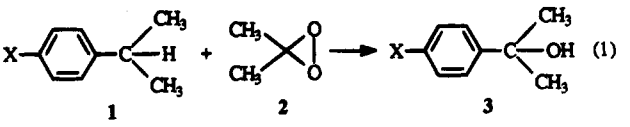
The relative rates of reaction of a series of *p*-substituted cumenes with dimethyldioxrane have been studied. The products are the corresponding cumyl alcohols. Treatment of the rate data with the Hammett substituent constants reveals that the insertion reaction is an electrophilic process with $\varrho = -2.76$. Similar treatment of the data with the Brown–Okamoto substituent constants gives $\varrho^+ = -1.61$. The second-order rate constants for the reaction of a series of substituted adamantanes with dimethyldioxirane were also determined. Again, the products are the corresponding adamantanols. The rate constants were correlated with several types of substituent constants. The best correlations were obtained with the Taft σ^* and σ_I constants which gave $\varrho^* = -1.08$ and $\varrho_I = -2.39$, respectively. Thus, the insertion reaction in this aliphatic system is also electrophilic.

Introduction

Dioxiranes have become an important part of the synthetic chemis's arsenal. These simple oxidants are able to carry out a variety of oxidation reactions in a rapid, high yield manner.[2] Perhaps the most remarkable of these oxidations is the carbon–hydrogen insertion reaction.[3-8] Studies to date have demonstrated that the reaction is stereospecific,[3,4,9] proceeds with a primary kinetic isotope effect,[3] and has a reaction selectivity[3] which is not that of a radical process. While the epoxidation[10,11] and sulfur[12] oxidation reactions of dimethyldioxirane have been shown to be electrophilic by means of linear free energy relationship (LFER) correlations, similar studies have not been reported for the carbon–hydrogen insertion reaction. In this paper we describe the results of LFER studies of the insertion reaction in two series of substrates, one based on an aromatic system and one based on an aliphatic system. Since this work was completed Kovac and Baumstark have described[13] a LFER study in some α-methylbenzyl alcohols. In that study the alcohols were converted to the corresponding acetophenones. The reaction was interpreted in terms of a hydrogen atom abstraction process, although a concerted insertion reaction could not be ruled out. This same group had shown earlier[14] that the oxidation of *p*-substituted benzaldehydes to the corresponding acids by dimethyldioxirane is relatively insensitive to electronic effects. In this case the reaction displayed radical character.

Results

A series of *p*-substituted cumenes (**1**) was reacted with dimethyldioxirane (**2**). The substrate concentration was in excess of that of **2**. The individual *p*-substituted substrates were present in equimolar concentration with the unsubstituted cumene. The reactions were run at 25 °C and the relative reaction rates determined by following the consumption of the substrates using quantitative GLC with internal standards. The GLC analyses indicated that a single product, the corresponding cumyl alcohol (**3**), was produced in each case (eq 1). The results



X = -I, -OCH_3, -O-C_6H_5, -OH, -CH_3, -$COCH_3$

of the rate studies and the substituent constants used in the LFER plots are shown in Table 1. The relative rate data were plotted against Hammett[15] σ constants (Figure 1) and Okamoto–Brown[16] σ^+ constants. The Hammett plot gives $\varrho = -2.76$ ($R = 0.973$) while the Brown–Okamoto plot gives $\varrho^+ = -1.61$ ($R = 0.879$).

In order to study electronic effects in the C–H insertion reaction of **2** in an aliphatic system a similar series of reactions were run in the substituted adamantanes **4**. These substrates were converted to the corresponding 3-hydroxy adamantanes **5** (eq 2) as the sole product.

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Table 1. Summary of Relative Rate Data and Substituent Constants Used in the LFER Plot for the Reaction of 2 with *p*-Substituted Cumene in Acetone at 25 °C

substituent	k_{rel}	log k_{rel}	σ^a	σ^{+b}
-H	1.00 ± 0.00	0.000	0.00	0.00
-I	0.14 ± 0.01	−0.862	0.18	0.13
$-OCH_3$	3.58 ± 0.10	0.554	−0.27	−0.78
$-CH_3$	1.91 ± 0.01	0.280	−0.17	−0.30
-OH	10.17 ± 0.50	1.007	−0.37	−0.92
-PhO	7.05 ± 0.40	0.848	−0.32	−0.50
$-COCH_3$[c]	0.047 ± 0.002	−1.347	0.50	0.51

[a] Taken from ref 37. [b] Taken from ref 16. [c] The k_{rel} was measured at 90 min.

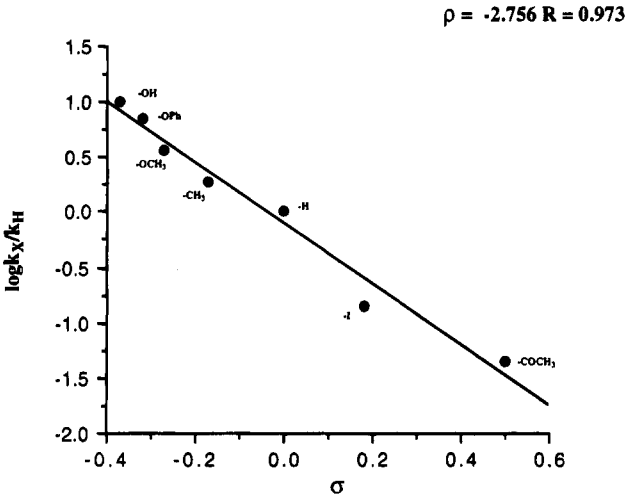

Figure 1. LFER plot of log k_X/k_H *versus* σ for the reaction of **2** with cumenes at 25 °C.

Second-order rate constants for these reactions were obtained using pseudo-first-order conditions with the substrates (**4**) present in excess (10−20-fold). The reaction rates were measured by UV and following the decay of the absorption of **2** at 335 nm. Plots of ln $(A_t - A_\infty)$ *versus* time gave straight lines with excellent correlation coefficients (R = 0.98−0.99). A summary of the rate data as well as the parameters used in the LFER plots is given in Table 2. The plot of the rate constants *versus* Taft[17] substituent constants (σ^*) gives a straight line with ϱ^* = −1.08 and R = 0.894. When the OH substituent is not included in the plot a better correlation is obtained with ϱ^* = −1.04 and R = 0.972. The rate data were also correlated with the Taft[18] σ_I field/inductive constants. Here again, when the data for all substituents used are included in the plot the correlation is not entirely satisfactory (R = 0.867). Eliminating the point for the OH substituent again improves the situation and gives ϱ_I = −2.33 (R = 0.972). Finally, the rate data were correlated with the Grob[19] substituent constants σ_I^q which are based on substituent effects[20] in quinuclidine derivatives. When all of the data points are included in a plot against these constants the correlation gives ϱ^q_I = −0.371 (R = 0.755). In this case eliminating the points for OH and COOH substituents improves the correlation and the plot gives ϱ_I^q = −0.406 with R = 0.942.

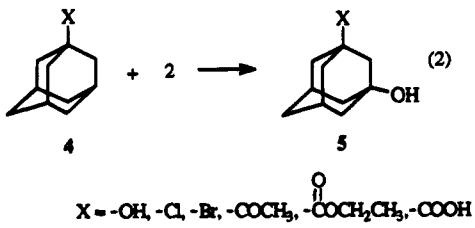

Table 2. Summary of Kinetic Data and Substituent Constants Used in the LFER Plot for the Reaction of 2 with Adamantanes in Acetone at 25 °C

substrate	10^3k_2 (M^{-1} s^{-1})	log k_2	σ_I^a	σ_{Iq}^b	σ^{*c}
AD-H	2.978 ± 0.099	−2.526	0.00	0.00	0.00
AD-Cl	0.213 ± 0.007	−3.671	0.47	2.51	1.05
ADCOOH	0.957 ± 0.049	−2.922		0.72	
AD-OH	1.430 ± 0.063	−2.844	0.27	1.76	0.555
AD-Br	0.290 ± 0.011	−3.391	0.45	2.69	1.00
$ADCOCH_3$	0.406 ± 0.006	−3.391	0.28	1.69	0.60
ADCOOEt	0.557 ± 0.004	−3.254	0.31	1.70	0.699

[a] Taken from ref 18. [b] Taken from ref 19. [c] Taken from ref 17.

Discussion

The results obtained in the substituted cumenes indicate that the dimethyldioxirane insertion reaction is electrophilic in nature. This conclusion is reached when either the Hammett or the Brown−Okamoto substituent constants are used. The lower correlation coefficient obtained when σ^+ values are used could indicate that there is little positive charge generated at the benzylic carbon atom during the course of the reaction. The magnitude (−2.76) of the ϱ value obtained in the Hammett plot suggests that the insertion reaction is quite sensitive to substituent effects. Indeed, this is the highest ϱ value to be reported for a dimethyldioxirane oxidation. In the recent report of Kovac and Baumstark[13] on the conversion of α-methylbenzyl alcohols to the corresponding acetophenones by **2** the ϱ value for the reaction was determined to be −1.57. Thus, in all cases studied to date[10-13] the reaction of **2** with a variety of substrates has shown the dioxirane to be an electrophilic reagent. The oxidation of the α-methylbenzyl alcohols[13] by **2** was interpreted in terms of a hydrogen atom abstraction process. On the basis of the previously observed stereochemical and isotope effects and the observation of a single product in all cases, we believe that the oxidation of compounds **1** by **2** is a concerted insertion reaction and not a radical process.

In the oxidation of substituted adamantanes by **2** the LFER plots were constructed using several sets of substituent constants, namely, σ^*, σ_I, and σ^q_I constants. These plots indicate that the insertion reaction is electrophilic in character since negative values of ϱ are obtained with all sets of substituent constants. Again, in these cases a single oxidation product, the adamantanol **5**, was observed. The reactions appear to be concerted O atom insertion reactions. The effects of hydroxyl and carboxyl substituents in the adamantane series require comment. The use of LFER is based on the interaction of a set of substituents with a reaction site in a manner which parallels the comparable interaction in a model system. Implicit in this use is the assumption that the substituents will influence the reaction site *via* the same interaction mechanisms as in the model or standard used. The improved correlation coefficients observed when one (σ^*,σ_I) or two (σ^q_I) of the

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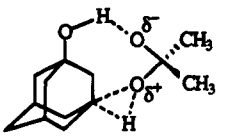
substituents used is excluded from the LFER plots suggests that these substituents are interacting with the reaction site *via* an interaction mechanism which is not incorporated in the various substituent constants used. On the basis of our earlier work[6] on solvent effects in which we have proposed that H-bonding solvents can accelerate the rate of the insertion reaction of **2**, we suggest that intramolecular H-bonding may occur in the activated complexes leading to the insertion reaction in those adamantanes containing OH or COOH substituents. A schematic of this proposed activated complex is shown in **6**. The improvement in correlation coefficients



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observed when these substituents are excluded probably reflects the fact that a similar H-bonding interaction mechanism is not possible in the model systems used to derive the substituent constant values shown in Table 2. The stabilizing influence of intramolecular H-bonding and, in particular, the dependence of this influence on choice of solvent have also been observed.[21,22] Bach and co-workers[23] have pointed out that in a canonical molecular orbital description of a hydrocarbon there are no isolated molecular orbitals associated with any given C−H σ bond. Among the contributing orbitals are some with π symmetry. These authors have suggested that the difference in rate of the insertion reaction of **2** in *cis*- and *trans*-1,2-dimethylcyclohexane may be related to the fact that in the *cis* isomer **2** may take a less hindered π_{CHR} approach to the activated complex. A similar approach in the *trans* isomer would be more hindered. A similar situation may operate here. The kinetics of the C−H insertion reaction has been studied with other oxidants. A LFER study of the hydroxylation of hydrocarbons by *p*-nitroperbenzoic acid has been reported by Schneider and Muller.[24] Using Taft substituent constants they find a ϱ^* value of −2.2 in a series of substituted alkanes, RMeCHR′. They also describe the reaction of methylcyclohexane with substituted perbenzoic acids, a reaction which gave a Hammett $\varrho = +0.57$. Both of these studies indicate that these hydroxylations occur in an electrophilic process.

Experimental Section

Materials. Acetone, reagent grade (Aldrich Chemical Co.), was distilled from anhydrous potassium carbonate prior to use. Methylene chloride and chloroform were purchased from Fischer Scientific and were distilled from P_2O_5 prior to use. Certified grade 2-methyl-2-propanol (Fischer Scientific) was refluxed over sodium for 24 h and then distilled prior to use. Anhydrous diethyl ether (Fischer, certified grade) was used as received. Hexane (Aldrich) was distilled from potassium carbonate before use. Oxone ($2KHSO_5 \cdot KHSO_4 \cdot K_2SO_4$, DuPont) was obtained from Aldrich Chemical Co. and used as received. *p*-Hydroxycumene (98+%) was purchased from Aldrich and recrystallized before use. *p*-Iodocumene (98+%) and *p*-methoxycumene (98+%) were purchased from Lancaster Synthesis and used as received. *p*-Methylcumene (98+%) was purchased from Aldrich and used as such. Decane (99+%) and dodecane (99+%) were purchased from Aldrich. *p*-Bromocumene (98%), *p*-nitrocumene (99%), and *p*-isopropylacetophenone (98%) were obtained from Lancaster Synthesis and used as received. Phenol (analytical reagent grade) was purchased from Mallinckrodt Chemical Co. and used as such. CuCl (91.8%) was purchased from Fisher Scientific and used as received. Adamantane (Aldrich) was recrystallized from acetone prior to use. 1-Adamantanecarboxylic acid (99%) and 1-adamantanol (99%) were purchased from Aldrich and used as received. 1-Chloroadamantane (99%) and 1-bromoadamantane (99%) were purchased from Alfa Products and used as received. 1-Adamantane methyl ketone (99%) and ethyl adamantanecarboxylate (99%) were purchased from Janssen Chimica and used as received. Dimethyldioxirane was synthesized according to the literature[25,26] procedure.

Instrumentation. ^1H and ^{13}C NMR spectra were obtained on a 300 MHz spectrometer with $CDCl_3$ as solvent unless stated otherwise. GC−MS data were obtained using a twin EI and CI quadrupole mass spectrometer connected to a gas chromatograph fitted with an Ultra 1 12 m × 0.2 m × 0.33 μm cross-linked methyl silicone gum column. EI spectra were measured at 70 eV ionizing voltage. UV−vis spectra were obtained on a UV−vis spectrophotometer equipped with a six cell positioner. Temperature could be controlled at 25, 30, and 37 °C. IR experiments were performed on an FT-IR spectrophotometer using a NaCl cell and $CHCl_3$ solvent. Melting points were obtained using a capillary melting point apparatus and are uncorrected.

Chromatography. Gas chromatography was performed on a gas chromatograph equipped with a flame ionization detector and interfaced with an integrator. The column used was a fused silica capillary column (30 m × 0.311 mm, film thickness 0.5 μm) using DB-210 as liquid phase. Helium was used as carrier gas. Some separations were accomplished using a fused silica column (30 m × 0.32 mm) with DB-5 as liquid phase (film thickness 0.25 μm). Temperature program used: temp 1, 50 °C, time 1, 5 min, rate 1, 15°/min; temp 2, 200 °C, time 2, 2 min. Preparative GLC was accomplished using either a 20 ft × 3/8 in. column with 15% SE-30 as liquid phase on Chrom W, 30/60 mesh (PIGV), or a 12 ft × 3.8 in. column with 8% SF-96 as liquid phase on Chrom 6 a/w, 60/80 mesh (PMCS).

Kinetics. (a) Relative Rate Studies of Cumenes. The relative rates for the reaction of dimethyldioxirane with *p*-substituted cumenes at 25 °C were determined using quantitative GLC. Response factors for each of the cumenes were determined using the internal standards decane and dodecane. Three determinations were made for each response factor. Standard solutions in acetone were prepared containing the two internal standards (0.03 mmol each), the unsubstituted cumene (0.12 mmol), and one of the *p*-substituted cumenes (0.12 mmol). This mixture was prepared in a reaction vessel (15 mL vial) and covered with aluminum foil to protect it from light. The reaction vessel and a vial containing freshly prepared dimethyldioxirane in acetone were placed into a temperature controlled (25 °C) water bath for 5 min in order to reach temperature equilibrium. A portion (1 mL, 0.03 mmol) of the dioxirane was added to the reaction vessel, with shaking, followed by immediately injecting 0.5 μL of the reaction mixture into the gas chromatograph in order to determine initial concentrations. The reaction vessel was returned to the water bath and the reaction solutions stirred magnetically. After 30 min 0.5 μL of the reaction solution was injected into the gas chromatograph. The relative rates were determined from eq 3

$$k_{rel} = \frac{k_{p\text{-X-cumene}}}{k_{cumene}} = \frac{\Delta C_{p\text{-X-cumene}}}{\Delta C_{cumene}} \quad (3)$$

where ΔC represents the change in concentration of the

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reactants. Three determinations of k_{rel} were made for each reacting pair. These conditions led to conversions in the range of 0.3−15% depending on the nature of the substituent. The average conversion was 4.8%.

A summary of the relative rate data and the data for the linear free energy plot is given in Table 1.

(b) Absolute Rate Studies for the Reaction of Dimethyldioxirane with 1-Substituted Adamantanes at 25 °C. A freshly prepared solution of dimethyldioxirane was dried with Na_2SO_4 for at least 24 h. The concentration of the dioxirane was determined by UV absorption and a previously constructed working curve. Using 10 mL volumetric flasks, standard solutions of the adamantanes in acetone were prepared. UV cells containing (i) the DMD solution and (ii) the substrate solution were prepared and placed into the cell compartment of the UV spectrometer in order to reach temperature equilibrium. A portion (1 mL) of the DMD solution was transferred into a UV cell containing 1 mL of substrate solution. The reaction mixture was shaken vigorously and returned to the spectrometer, and kinetic data recording was initiated. The change in the absorption at 335 nm was followed for 15 min. The reaction solution was then kept at room temperature for 2 days in order to record the final absorption [Abs(∞)]. This process was repeated twice at several concentrations of the substrate. Pseudo-first-order conditions were used with substrate:DMD ratios varying from 8:1 to 20:1. Plots of ln[Abs(t) − Abs(∞)] versus time gave straight lines with slope = k_{obs}. Plots of k_{obs} *versus* substrate concentration also gave straight lines with slope = k_2. Analysis of the reaction solutions by GLC indicated that a single product was produced in each of the kinetic runs. A summary of the rate and substituent constant data is given in Table 2.

Preparation of *p*-Phenoxycumene. The literature procedure[27] was followed in general. A mixture of 4-bromoisopropylbenzene (9.65 g, 0.05 mol), phenol (18.6 g, 0.2 mol), and CuCl (4.5 g, 0.025 mol) was refluxed at 150 °C under Ar for 48 h. The product was separated by distillation at reduced pressure (90 °C, 4.5 mmHg) and further purified by passing it through a silica gel column. GLC analysis indicated the purity of the product to be 98.9%. ^{1}H NMR ($CDCl_3$): δ 7.2 (m, 9 H), 2.9 (heptet, 1 H), 1.3 (d, 6 H). ^{13}C NMR ($CDCl_3$): δ 157.5, 154.8, 137.7, 129.5, 127.4, 122.7, 118.8, 118.4, 33.5, 24.2.

Identification of Products. (a) Substituted Cumene Reactions. The general procedure for preparing samples of the products for identification purposes was as follows. The substituted cumene (0.72 g; ca. 0.6 mmol) was treated with 100 mL of a freshly prepared acetone solution of DMD in a 250 mL Erlenmeyer flask. The reaction mixture was stirred at room temperature for 24 h. The reaction flask was covered with aluminum foil to protect the contents from light. GLC analysis indicated that only one product was produced in each case.

***p*-Iodocumyl Alcohol.** Using the general procedure the conversion of the *p*-iodocumene to the alcohol was 12% in 12 h. The reaction was continued for another 12 h after another aliquot of DMD was added. The solvent was removed by rotary evaporation. The tertiary alcohol was isolated from the reaction mixture by preparative chromatography using a 20 ft × 3/8 in. SE-30 column (15% liquid phase on Chrom W, 30/60 mesh, (PIGV), or using a 12 ft × 3/8 in. column (liquid phase, 8% SF-96 on Chrom 6 a/w, 60/80 mesh (PMCS)). Other GLC conditions were as follows: oven temp, 95 °C, detector temp, 90 °C, injector temp, 90 °C, collector temp, 90 °C. The product was further purified by passing it through a neutral alumina column, washing the solid with cold hexane, and recrystallizing it from hexane:ether (8:2), mp 56.8−57.2 °C (lit.[28] mp 57−57.5 °C). The product was identified as follows: ^{1}H NMR (CD_3COCD_3): δ 7.67 (d, 2 H), 7.31 (d, 2 H), 1.56 (s, 6 H). ^{13}C NMR (CD_3COCD_3): δ 148.58, 136.88, 126.44, 91.94, 72.13, 31.51. MS (EI) *m/z*: 146 (100), 133 (81), 118 (9.4), 105 (15), 77 (23). The ^{1}H NMR was identical to that of the alcohol synthesized by reacting CH_3MgBr with *p*-iodoacetophenone.

***p*-Phenoxycumyl Alcohol.** The general procedure was used to give the tertiary alcohol characterized as follows. ^{1}H NMR ($CDCl_3$): δ 6.90−7.46 (m, 9 H), 1.60 (s, 6 H). ^{13}C NMR ($CDCl_3$): δ 157.80, 155.76, 143.88, 129.60, 125.78, 123.08, 118.72, 118.38, 72.28, 31.89. MS (EI) *m/z*: 228 (17.4, M^+), 213 (100), 197 (49.0), 115 (14.2), 77 (20.3). The ^{1}H NMR was identical to that of the alcohol synthesized by reacting CH_3MgBr with *p*-phenoxyacetophenone.

***p*-Methoxycumyl Alcohol.** The general procedure was followed with isolation of the product using column chromatography on 35 g of Florisil. The column was eluted with 0−20% diethyl ether in hexane containing 1% triethylamine. The product was identified by NMR: ^{1}H ($CDCl_3$) δ 7.41 (d, 2 H), 6.82 (d, 2 H), 3.74 (s, 3 H), 1.47 (s, 6 H). This spectrum is the same as that for a sample of the product prepared by reacting methylmagnesium bromide with *p*-methoxyacetophenone. ^{13}C NMR ($CDCl_3$): δ 157.95, 141.24, 125.53, 113.25, 71.99, 55.12, 31.67. Lit.[29] ^{1}H NMR ($CDCl_3$): δ 7.15 (m, 4 H), 3.76 (s, 3 H), 2.70 (br, 1 H), 1.51 (s, 6 H). MS (EI): *m/z* 148.10 (100), 133.0 (81.05), 117.95 (9.36), 105.05 (14.94), 77.10 (23.39).

***p*-Hydroxycumyl Alcohol.** The general procedure was followed to give a reaction mixture composed of 10% product and 90% starting material. The NMR spectrum of this mixture showed the presence of the product ^{1}H NMR (acetone-d_6): δ 7.33 (d, 2 H), 6.60 (d, 2 H), 4.63 (s, 1 H), 1.42 (s, 6 H) (lit.[30] ^{1}H NMR (acetone-d_6) δ 7.33 (d, 2 H), 6.64 (d, 2 H), 4.80 (s 1 H), 1.40 (s, 6 H)). MS (EI) *m/z* 133.95 (100, $M^+ - H_2O$), 118.90 (83.25), 90.95 (30.96), 77.05 (13.64). Attempts to isolate the product were unsuccessful because of a facile dehydration reaction. The GLC retention time of the product was identical to that of a sample, prepared by reaction of methylmagnesium bromide with *p*-hydroxyacetophenone, using several temperature programs. ^{13}C NMR ($CDCl_3$) δ: 156.35, 141.78, 126.32, 115.22, 71.81, 32.44.

***p*-Methylcumyl Alcohol.** The general procedure was followed with column chromatography on Florisil used to isolate the product. The product was characterized by NMR. ^{1}H NMR ($CDCl_3$): δ 7.38 (d, 2 H), 7.14 (d, 2 H), 2.32 (s, 3 H), 1.56 (s, 6 H). This spectrum is identical to that of the material produced in the reaction of methyl magnesium bromide with *p*-methylacetophenone. ^{13}C NMR ($CDCl_3$): δ 146.05, 135.87, 128.51, 124.14, 72.09, 31.56, 20.82. MS (EI): *m/z* 134.10 (24.27, $M^+ - 15$), 119.0 (100), 91.0 (22.134), 77.0 (6.68), 51.10 (3.084).

***p*-Acetylcumyl Alcohol.** The general procedure was followed to give the *p*-acetylcumyl alcohol. The product was isolated using column chromatography on silica gel (25 g, 100−200 mesh, Fisher). The column was eluted with ether (10−50 %) in hexane. ^{1}H NMR ($CDCl_3$): δ 7.91 (d, 2 H), 7.56 (d, 2 H), 2.57 (s, 3 H), 1.57 (s, 6 H) (lit.[31] ^{1}H NMR 7.94 (d, 2 H), 7.59 (d, 2 H), 2.60 (s 3 H), 1.60 (s, 6 H)). ^{13}C NMR ($CDCl_3$) δ 197.63, 154.29, 136.65, 128.30, 124.56, 72.54, 31.75, 26.68 (lit.[32] ^{13}C NMR ($CDCl_3$) δ 197.9 (s), 154.7 (s),134.1 (s),128.0 (d), 124.5 (d), 72.0 (s), 31.3 (q), 26.2 (q)). MS (EI): *m/z* 178.20 (2.61, M^+), 163.10 (100), 148.05 (1.9), 121.40 (13.8), 43.05 (77.89). Mp: 102−105 °C (lit.[32] mp 101−103 °C).

(b) Substituted Adamantane Reactions. The general procedure given for the cumene compounds was used here as well.

1,3-Dihydroxyadamantane. The general procedure was followed to give a reaction mixture which GLC analysis showed contained one product. The reaction mixture was dissolved in CH_2Cl_2/hexane (60:40) and then slowly cooled to 0 °C in order to differentially recrystallize the starting material from the product. The solid which formed was filtered off. This process was repeated until the purity of the product sample was >98%. MS(EI) of the product showed the following. MS *m/z* 168 (M^+, 3.2), 111 (100). ^{13}C NMR ($CDCl_3$): δ 70.73, 53.28,

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44.73, 35.92, 32.66. ^{1}H NMR ($CDCl_3$): δ 4.86 (1 H), 2.23 (m, 2 H), 1.66 (s, 2 H), 1.62 (d, 8 H), 1.50 (m, 2 H). These ^{1}H NMR data are essentially the same as the lit.[5] data. IR ($CHCl_3$): 3616, 3518, 2926, 1263, 1259, 1253, 1225 cm^{-1}. Mp: 257–258.5 °C (lit.[32] mp 256–258 °C).

1-Chloro-3-hydroxyadamantane. The general procedure was followed. The product was separated from the starting material by column chromatography (silica gel, 30 g, 100–200 mesh). The column was eluted with hexane/acetone (10:1–3). The product was obtained in 98% purity. Mp: 204.5–205 °C (lit.[33] mp 205–205.5 °C). MS (EI) *m/z* 187 (M^+, 1.5), 95 (100). IR ($CHCl_3$): 3942, 3057, 2980, 2936, 2915, 1447, 1421, 1278, 895, 773 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 2.31 (m), 2.10 (s), 2.02 (m), 1.69 (d), 1.57 (m). ^{13}C NMR ($CDCl_3$): δ 70.28, 55.08, 46.22, 43.46, 40.15, 34.14, 32.33.

1-Bromo-3-hydroxyadamantane. The general procedure was followed to give the title compound with 98% purity, mp 160–160.5 °C (lit.[34] mp 159–160 °C). GC–MS analysis revealed that both 1-bromoadamantane and the title compound give a molecular ion corresponding to loss of Br. MS (EI): *m/z* 152 (M^+ – Br, 15.5), 151 (100). IR ($CHCl_3$): 3595, 2935, 2981, 2922, 1716, 1455, 1237, 1258, 1117, 954, 941 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ 1.55–1.82 (m, 6 H), 2.08–2.41 (m, 8 H) (lit.[34] ^{1}H NMR (CCl_4) δ 1.55–1.82 (m, 6 H), 2.08–2.41 (m, 8 H), 2.32 (s)). ^{13}C NMR ($CDCl_3$) δ 70.40, 44.00, 34.38, 31.63, 31.34, 30.96, 22.72.

1-Acetyl-3-hydroxyadamantane. The general procedure was followed. The product was isolated from the reaction mixture using column chromatography on silica gel (25 g, 100–200 mesh, Fisher). The column was eluted with CH_2Cl_2 (0–15%) in hexane. This procedure afforded the title compound in 99% purity. Mp: 159–160 °C. MS (EI): *m/z* 194.1 (M^+, 8.74), 151.2 (100), 133.2 (7.54), 107.1 (15.95), 93.05 (60.7), 81.05 (11.0). ^{1}H NMR (acetone-d_6): δ 2.28 (m), 2.15–2.09 (m), 1.75–1.58 (m). ^{13}C NMR (acetone-d_6): δ 192.5, 70.01, 53.31, 53.24, 45.85, 44.09, 36.99, 31.68, 24.59. IR (acetone-d_6): 3595, 2981, 2935, 2922, 1726, 1455, 1237, 1258, 1117, 954, 941^{-1}. The X-ray crystal structure has been determined[35] and agrees with the assigned structure.

1-Carbethoxy-3-hydroxyadamantane. The general procedure was followed to give the product as a colorless liquid in 98% purity. MS (EI): *m/z* 224 (M^+, 2.6) 151 (100). IR ($CDCl_3$): 3597, 2983, 2977, 2928, 2915, 2857, 1718, 1455, 1336, 1237, 1244 cm^{-1}. ^{13}C NMR ($CDCl_3$); δ 179.14, 68.33, 60.31, 47.49, 46.35, 44.36, 43.99, 37.70, 35.07, 30.32. ^{1}H NMR ($CDCl_3$): δ 4.07 (q, 2 H), 2.23 (m 2 H), 1.55–1.80 (m, 12 H), 1.20 (t, 3 H). Anal. Calcd for $C_{15}H_{20}O_3$: C, 69.50; H, 8.90. Found C, 69.13; H, 8.81.

1-Carboxy-3-hydroxyadamantane. The general procedure was followed. The product was isolated from the reaction mixture by recrystallizing in 0–15% diethyl ether in hexane. The white solid obtained was washed several times with warm hexane. This gave product with 98% purity. Mp: 202.5–204 °C (lit.[36] mp 202–205 °C). MS (EI): *m/z* 196.3 (M^+, 4.6), 95 (100). IR (CD_3OD): 3628, 3526, 3522, 3516, 2920, 2912, 1744, 1731, 1631, 1269, 1038, 1017 cm^{-1}. ^{1}H NMR (CD_3OD): δ 2.21 (m, 2 H), 1.79–1.61 (m, 12 H). Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 67.09; H, 8.21. The X-ray crystal structure has been determined[35] and agrees with the assigned structure.

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