2 H), 4.21 (d, 1 H, J = 8.4 Hz), 5.97 (dd, 1 H, J = 5.7, 2.9 Hz), 6.15 (dd, 1 H, J = 5.7, 3.0 Hz); ^{13}C NMR (125 MHz) δ 28.19, 42.24, 43.09, 44.23, 49.45, 64.72, 64.85, 108.50, 132.43, 137.61.

***endo*-2-(Bicyclo[2.2.2]oct-5-en-2-yl)-2-methyldioxolane (8a)**: bp 81–83 °C (15 mm); IR (neat) 3044, 1149, 1038, 866, 716 cm^{-1}; ^{1}H NMR (500 MHz) δ 1.11–1.16 (m, 1 H), 1.13 (s, 3 H), 1.17–1.25 (m, 2 H), 1.39–1.46 (m, 1 H), 1.48–1.57 (m, 1 H), 1.72 (ddd, 1 H, J = 13.0, 10.0, 3.0 Hz), 1.94 (m, 1 H), 2.52 (br s, 1 H), 2.63 (br s, 1 H), 3.87–3.92 (m, 4 H), 6.16 (t, 1 H, J = 6.8 Hz), 6.21 (t, 1 H, J = 6.8 Hz); ^{13}C NMR (125 MHz) δ 21.93, 27.90, 28.61, 29.94, 30.55, 31.06, 45.68, 63.67, 64.54, 112.20, 132.92, 133.11. Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.26; H, 9.38.

***endo*-2-(Bicyclo[2.2.2]oct-5-en-2-yl)-2-ethyldioxolane (8b)**: bp 86–88 °C (15 mm); IR (neat) 3044, 1156, 1042, 810, 712 cm^{-1}; ^{1}H NMR (500 MHz) δ 0.85 (t, 3 H, J = 7.4 Hz), 1.16 (ddt, 1 H, J = 12.3, 7.4, 2.4 Hz), 1.19–1.26 (m, 2 H), 1.45–1.46 (m, 1 H), 1.47–1.56 (m, 3 H), 1.68 (ddd, 1 H, J = 12.3, 9.5, 3.3 Hz), 2.00 (t, 1 H, J = 8.8 Hz), 2.52 (br s, 1 H), 2.62 (br s, 1 H), 3.89–3.99 (m, 4 H), 6.16 (t, 1 H, J = 6.5 Hz), 6.21 (t, 1 H, J = 6.5 Hz); ^{13}C NMR (125 MHz) δ 7.68, 23.43, 28.01, 28.41, 29.94, 30.18, 30.93, 43.67, 64.99, 65.44, 113.86, 132.88, 133.03. Anal. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68. Found: C, 74.67; H, 9.82.

***trans-endo*-2-(3-Methylbicyclo[2.2.1]hept-5-en-2-yl)-2-methyldioxolane (3d)**: bp 76–78 °C (15 mm); IR (neat) 3066, 1152, 1040, 948, 801 cm^{-1}; ^{1}H NMR (500 MHz) δ 1.16 (d, 3 H, J = 7.0 Hz), 1.23 (s, 3 H), 1.36 (dq, 1 H, J = 8.3, 2.7 Hz), 1.43 (m, 1 H), 1.50 (d, 1 H, J = 8.3 Hz), 1.86 (dd, 1 H, J = 5.3, 3.0 Hz), 2.34 (br s, 1 H), 2.85 (br s, 1 H), 3.84–3.95 (m, 4 H), 5.92 (dd, 1 H, J = 5.0, 3.0 Hz), 6.16 (dd, 1 H, J = 5.0, 3.0 Hz); ^{13}C NMR (125 MHz) δ 21.85, 23.85, 36.19, 44.93, 47.24, 49.26, 56.15, 64.07, 64.91, 111.46, 133.67, 136.25. Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.12; H, 9.44.

2-(Methylbicyclo[2.2.1]hept-5-en-2-yl)-2-methyldioxolane (3e): bp 73–75 °C (15 mm); IR (neat) 3064, 1371, 1174, 1044, 951, 710 cm^{-1}; ^{1}H NMR (500 MHz) δ 1.26 (s, 1 H), 1.29 (d, 1 H, J = 3.7 Hz), 1.31 (d, 1 H J = 3.7 Hz), 1.33 (s, 3 H), 1.40 (dd, 1 H, J = 11.6, 2.5 Hz), 1.68 (d, 1 H, J = 8.2 Hz), 2.49 (br s, 1 H), 2.74 (br s, 1 H), 3.80–4.02 (m, 4 H), 6.03 (dd, 1 H, J = 5.4, 2.9 Hz), 6.06 (dd, 1 H, J = 5.4, 2.9 Hz); ^{13}C NMR (125 MHz) δ 21.45, 26.48, 36.32, 36.17, 42.68, 48.42, 51.28, 63.26, 65.13, 113.52, 135.39, 135.69. Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.19; H, 9.34.

***endo*-5-(1,1-Diethoxymethyl)bicyclo[2.2.1]hept-2-ene (9)**: bp 66–68 °C (15 mm); IR (neat) 3062, 1118, 1058, 932, 721 cm^{-1}; ^{1}H NMR (500 MHz) δ 0.80 (ddd, 1 H, J = 11.8, 4.5, 3.0 Hz), 1.16 (t, 3 H, J = 7.5 Hz), 1.23 (q, 3 H, J = 7.5 Hz), 1.32 (d, 1 H, J = 8.0 Hz), 1.39 (d, 1 H, J = 8.0 Hz), 1.83 (ddd, 1 H, J = 11.8, 9.4, 3.8 Hz), 2.42 (ddd, 1 H, J = 9.4, 9.3, 4.5 Hz), 2.78 (br s, 1 H), 2.88 (br s, 1 H), 3.44–3.74 (m, 4 H), 3.87 (d, 1 H, J = 9.3 Hz), 5.96 (dd, 1 H, J = 5.6, 3.0 Hz), 6.15 (dd, 1 H, J = 5.6, 3.0 Hz); ^{13}C NMR (125 MHz) δ 15.38, 15.46, 28.60, 42.22, 42.26, 44.02, 49.37, 60.42, 60.85, 106.31, 132.71, 137.59. Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27. Found: C, 73.48; H, 10.11.

***endo*-2-(Bicyclo[2.2.1]hept-5-yl)-5,5-dimethyl-1,3-dioxane (10)**: mp 71–73 °C; IR (KBr) 3064, 1396, 1112, 1023, 721 cm^{-1}; ^{1}H NMR (500 MHz) δ 0.66 (s, 3 H), 0.84 (ddd, 1 H, J = 11.5, 5.6, 2.5 Hz), 1.16 (s, 3 H), 1.20 (d, 1 H, J = 8.0 Hz), 1.36 (d, 1 H J = 8.0 Hz), 1.81 (ddd, 1 H, J = 11.5, 9.0, 4.0 Hz), 2.30 (ddd, 1 H, J = 9.0, 5.5, 3.2 Hz), 2.77 (br s, 1 H), 2.93 (br s, 1 H), 3.26–3.62 (m, 4 H), 3.71 (d, 1 H, J = 9.0 Hz), 5.90 (dd, 1 H, J = 5.6, 3.0 Hz), 6.11 (dd, 1 H, J = 5.6, 3.0 Hz); ^{13}C NMR (125 MHz) δ 21.86, 23.05, 28.39, 30.10, 42.18, 43.60, 43.62, 49.21, 77.10, 77.28, 106.35, 132.69, 137.51. Anal. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68. Found: C, 75.15; H, 9.45.

2-(1,2-Dimethyl-1-cyclohexen-4-yl)-2-methyldioxolane (11): bp 77–79 °C (15 mm); IR (neat) 2984, 2880, 1377, 1151, 1044, 948 cm^{-1}; ^{1}H NMR (500 MHz) δ 1.23–1.33 (m, 2 H), 1.26 (s, 1 H), 1.59 (s, 3 H), 1.61 (s, 3 H), 1.75–2.00 (m, 4 H), 3.87–3.96 (m, 4 H); ^{13}C NMR (125 MHz) δ 18.76, 19.15, 20.90, 24.19, 32.17, 32.98, 43.31, 64.68, 64.72, 111.69, 124.82, 125.34. Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27. Found: C, 73.57; H, 9.98.

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Supplementary Material Available: Spectra and spectral data for compound **3c** (4 pages). Ordering information is given on any current masthead page.

The First Friedel–Crafts Reaction of Nitrobenzene

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It is a widely accepted generalization in chemistry that low selectivity in a reaction implies high reactivity. We were therefore intrigued by the apparent inertness of benzenes with meta-directing substituents, especially the nitro group, toward Friedel–Crafts alkylations, in which the attacking electrophile is R^+.[1-3] Friedel–Crafts alkylations exhibit the lowest selectivity among electrophilic aromatic substitutions,[4] implying an extremely early transition state, and reflecting the power of the alkyl cation as an electrophile. Why then, we wondered, is it possible to, say, nitrate a similarly substituted compound with the weaker electrophile NO_2^+, but not to alkylate it? The mystery is further complicated in light of σ^+ values, which provide a relative measure of the susceptibility of the substrate to electrophilic attack. The higher the σ^+ value, obviously, the lower its reactivity with respect to an attacking electrophile. Yet, some of the polyhalobenzenes, such as pentachlorobenzene, have been alkylated through the Friedel–Crafts reaction, in spite of the fact that their σ^+ values are higher than those of benzenes bearing meta-directing substituents, such as nitrobenzene.[5] The apparent deactivation toward Friedel–Crafts alkylations observed in benzenes with meta-directing substituents therefore stands in direct conflict with expectations based on both the selectivity/reactivity relationship, and σ^+ values. By all indications, these compounds should be inherently reactive toward Friedel–Crafts alkylations.

In fact, a few examples of the Friedel–Crafts alkylation of benzenes with meta-directing groups, including acetophenone, benzonitrile, and benzoic acid and its ester,[6,7] have appeared in the literature, albeit with reportedly very low reactivity. In all of these cases, a large excess of aluminum chloride, rather than the catalytic amount traditionally used, was added. Furthermore, the products obtained were composed almost exclusively of the meta isomer, in stark contrast to the typical selectivity observed in other Friedel–Crafts alkylations. To our knowledge, there are no examples of successful Friedel–Crafts alkylations of benzenes with meta-directing substituents in which only a catalytic amount of $AlCl_3$ was used. We

(1) Olah, G. A. *Friedel-Crafts and Related Reactions*; Interscience Publishers: New York, 1963; Vol. 1, p 34.
(2) March, J. *Advanced Organic Chemistry*, 2 ed.; McGraw-Hill: New York, 1977; p 487.
(3) Morrison, R. T.; Boyd, R. N. *Organic Chemistry*, 4 ed.; Allyn and Bacon: Boston, 1983; p 636.
(4) Stock, L. M.; Brown, H. C. In *Advanced Physical Organic Chemistry*; Academic: London, 1963; Vol. 1, p 50.
(5) Riera, J.; Castaner, J.; Armet, O.; Rovira, C. *An. Quim.* **1986**, *82C*, 268.
(6) Baddeley, G. *J. Chem. Soc.* **1949**, S 229.
(7) Campbell, B. N., Jr.; Spaeth, E. C. *J. Am. Chem. Soc.* **1959**, *81*, 5933–5936.

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Table I. Ethylation Products of Nitrobenzene with Ethanol in Sulfuric Acid at 110 °C for 6 h

position of ethyl	t_R, min	content, %	position of ethyl	t_R, min	content, %
none	7.910	51.87	3,4-	20.433	1.24
2-	11.473	9.51	2,3,6-	20.712	0.15
3-	13.076	28.17	2,3,5-	23.025	0.19
4-	14.398	4.62	2,3,4-	23.869	0.08
2,6-	14.669	0.15	2,4,5-	24.326	0.09
2,3-	16.916	0.67	3,4,5-	26.880	0.07
2,5-	17.408	1.82	2,3,5,6-	26.555	0.03
2,4-	17.664	0.27	2,3,4,5-	30.004	0.02
3,5-	19.215	1.05	2,3,4,5,6-	32.114	0.01

believe that both the (limited) success of the reaction in the presence of an excess of the catalyst, as well as the unexpectedly high regioselectivity observed under these conditions, can be explained in light of a mechanism in which the reaction takes place on a coordinated rather than free substrate.

It is well known that $AlCl_3$ coordinates strongly with the meta-directing groups of the substrate. Thus, when only a small amount of $AlCl_3$ is added, its catalytic activity is lost as it coordinates preferentially with the substrate rather than the reagent, usually an alkyl halide. On the other hand, when at least a 2 molar excess of the catalyst is used, the first mole coordinates with the substrate, leaving the second to react with the reagent, thus generating the carbocation. The positive charge incurred in the coordinated substrate is concentrated at the ortho and para positions, which explains why only the meta isomer is obtained under these conditions. The fact that the reaction proceeds with only very limited reactivity is understood in light of the fact that the coordinated substrate is more positively charged than the free. Similar results were found for the alkylation performed in super acid.[8]

In view of the above findings, we ventured to formulate a plan for reactivating these substrates with respect to alkylation, based on the following considerations: (a) The inert nature of benzenes with meta-directing substituents toward Friedel–Crafts alkylation is a direct result of the preferential coordination of the $AlCl_3$ catalyst to the substrate rather than the alkyl halide reagent. (b) The alkyl cation must be an extraordinarily active electrophile, since it can react with the coordinated and, therefore, further deactivated substrate. (c) If an alternative catalyst is used, which will react preferentially with the reagent rather than the substrate, a change in mechanism may be observed, in which reaction takes place on the free, rather than coordinated, substrate. One would then expect to see greater reactivity, as well as lower selectivity for the reaction, much as is observed in other Friedel–Crafts alkylations.

We now report that the foregoing ideas have been confirmed, as evidenced by our successful ethylation of nitrobenzene in sulfuric acid,[9] using ethanol as the reagent. The latter is well known to be a much stronger base than the nitro group; hence, its success in competing with the substrate for the acid "catalyst". As shown in Table I, 17 of the 19 possible products were detected. The *o*-, *m*-, and *p*-nitroethylbenzenes were formed in a ratio of 19:70:11, respectively (mean of three runs). This distribution represents much lower selectivity than that observed in the nitration of nitrobenzene and is consistent with the poor selectivity found in Friedel–Crafts alkylations involving benzenes with ortho- and para-directing substituents.[4] These results constitute both the first example of Friedel–Crafts alkylation successfully applied to nitrobenzene, as well as the first example of Friedel–Crafts alkylation of an uncoordinated substrate bearing a meta-directing group.

The assignment of the isomers was based on mass spectral data, the GC retention times with linearly programmed temperature (assuming that the increment due to an ethyl group ortho, meta, or para to the nitro group remains constant), and comparison with the results obtained upon ethylation of *o*- and *p*-nitrobenzenes under similar conditions.[10]

Based on these promising early results, work has already been initiated involving the alkylations of various benzenes with meta-directing substituents using alcohols as the source of R^+, in a variety of protonic acids. Preliminary results are encouraging, and we hope to uncover a general synthetic strategy to the class of compounds bearing an alkyl group in the position meta to a meta-directing substituent, which thus far have not easily been prepared.

Experimental Section

Nitrobenzene (2.46 g, 20 mmol), ethanol (1.84 g, 40 mmol), and sulfuric acid (20 mL) were mixed and heated with stirring at 110 °C for 6 h. The mixture was then poured into water, extracted with chloroform, and subjected to analysis by GC-MS (HP-5988-A).

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(8) Yoneda, N.; Fukuhara, T.; Takahashi, Y.; Suzuki, A. *Chem. Lett.* **1979**, 1003-1006.

(9) Although sulfuric acid was used as the solvent in these reactions, no competing sulfonation of the substrates was observed. According to C. Courtot (*Compt. Rend.* **1926**, *182*, 855), the strength of the sulfonating agent is expressed by the π value. The π value needed for sulfonation of nitrobenzene (or nitrotoluenes) is 82, higher than that of 100% sulfuric acid. Thus, it appears that fuming sulfuric acid would be necessary in order to sulfonate these compounds. The acid used in our experiments was ca. 97% and was further diluted both by the ethanol present and the water formed in the reaction. On the other hand, the "yields" indicated were estimated based on the average number of ethyl groups on the ring and were found to be 86% and 92% in two runs. Thus, it appears that there are no extensive side reactions in the process.

(10) In spite of repeated efforts, we were not able to successfully accomplish the separation of the major components on a preparative scale, owing to their highly similar chromatographic behavior. These components have thus far only been separated by means of a capillary column.

A New Route to Functionalized Cyclohexane Derivatives via Epoxy Sulfone Cyclizations[1]

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In the synthesis of six-membered carbocycles, which are widely found in natural products, numerous methods have been developed for efficient and stereospecific carbocyclic annulation.[2] Recently, we reported a novel method for annulation of ketones through α,β-epoxy sulfoxides by the

(1) α,β-Epoxy sulfoxides as useful intermediates in organic synthesis. 24. Part 23: Satoh, T.; Sugimoto, A.; Itoh, M.; Yamakawa, K. *Bull. Chem. Soc. Jpn.* **1989**, *62*, 2942.

(2) See, for example: Ho, T.-L. *Carbocycle Construction in Terpene Synthesis*; VCH Publishers, Inc.: Weinheim, **1988**. Annulation by using epoxides: Rao, A. S.; Paknikar, S. K.; Kirtane, J. G. *Tetrahedron* **1983**, *39*, 2323. Smith, J. G. *Synthesis* **1984**, 629. Cooke, M. P., Jr.; Houpis, I. N. *Tetrahedron Lett.* **1985**, *26*, 3643. Molander, G. A.; Shubert, D. C. *J. Am. Chem. Soc.* **1987**, *109*, 576. Procter, G.; Russell, A. T.; Murphy, P. J.; Tan, T. S.; Mather, A. N. *Tetrahedron* **1988**, *44*, 3953.

0022-3263/90/1955-3962$02.50/0