(m, 2 H), 4.91 (br t, J = 8, 1 H), 5.25 (br d, J = 18, 1 H), 5.74–5.78 (m, 1 H), 6.28 (br dd, J = 12, 18, 1 H).

3-Isopropyl-*o*-benzoquinone (2). A solution of 3-isopropylcatechol (152 mg, 1 mmol) in 15 mL of dichloromethane was treated with a solution of 886 mg (2 mmol) of lead tetraacetate in 5 mL of dichloromethane and the mixture was stirred for 5 min at 23° C and then filtered. The resulting organic solution was washed with dilute aqueous hydrochloric acid, dilute aqueous sodium bicarbonate, and water and then dried and concentrated to give 150 mg (100% crude yield) of **2** as a red, viscous oil: NMR 1.10 (d, J = 6.7, 6 H), 2.95 (septet, J = 7, 1 H), 6.27 (dd, J = 10, 1.2, 1 H), 6.70 (dd, J = 1.2, 6, 1 H), 7.02 (dd, J = 10, 6.4, 1 H).

Rosmariquinone (1). A mixture of 50 mg (0.37 mmol) of **3**, 277 mg (1.85 mmol) of freshly prepared **2**, and 25 mL of absolute ethanol was heated under reflux for 6 h, at which point TLC indicated no increase in product formation. The reaction mixture was concentrated and subjected to column chromatography using 3:97 ethyl ether/petroleum ether as eluant. The product corresponding to TLC R_f 0.30 (5:95 ether/petroleum ether) was collected as a red solid (31 mg, 30%), mp 92–94 °C. One crystallization from hexane raised the melting point to 94–95 °C. An authentic sample of **1** melted at 96–96.5 °C, with mmp 94–95 °C: UV–vis (ethanol) λ_{max} 230 (15 750), 260 (19 000), 370 (2000), 480 (2250).

Acknowledgment. We are grateful to Prof. C.-T. Ho of the Department of Food Science, Rutgers University, for providing the authentic sample of **1** and a preprint of ref 1 and to Rutgers University for research support through the BRSG program.

Registry No. 1, 27210-57-7; 2, 98353-93-6; 3, 18238-29-4; 2,2-dimethylcyclohexanone, 1193-47-1; 2,2-dimethyl-1-vinylcyclohexanol, 18238-28-3; 3-isopropylcatechol, 2138-48-9.

Direct Nucleophilic Attack on Sulfur Atom of a Norbornadienyl Sulfone

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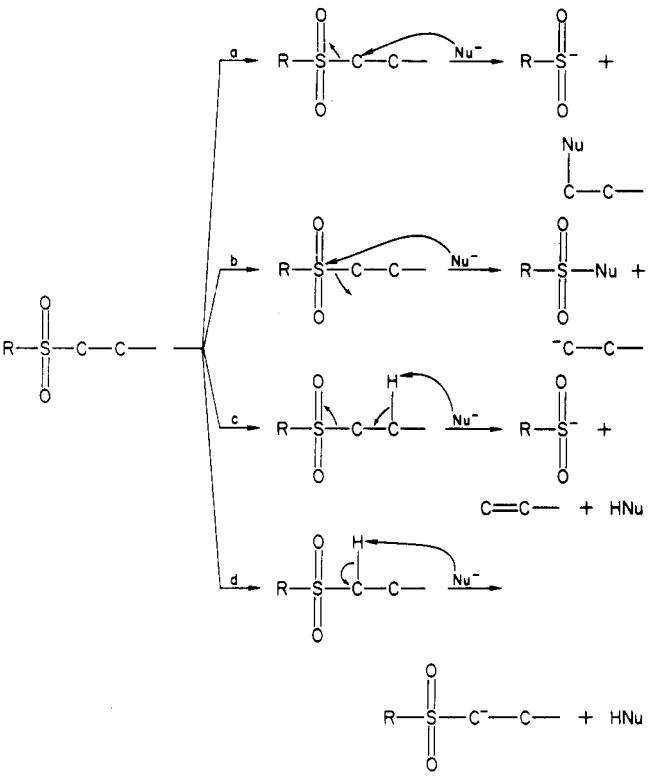
Received June 4, 1985

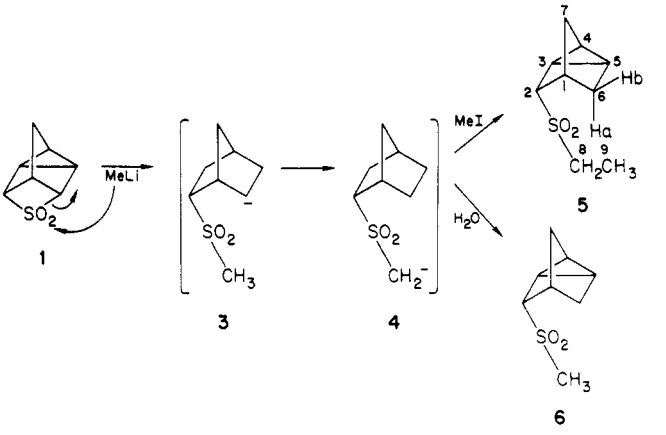
The mode of the reaction of a sulfone with a nucleophilic base is sometimes not easy to predict since sulfone itself is a electron-withdrawing group which can activate α-carbons to become nucleophilic. On the other hand, sulfinate is a moderately good leaving group which caused its α-carbons suitable for nucleophilic substitution. In addition, the strong electronegativity of the oxygens on the sulfone causes the sulfur atom to be a highly electrophilic center. When a sulfone system is treated with a nucleophile or a base, four reaction pathways may take place (Scheme I).

Deprotonation reactions of sulfones via pathway c and pathway d are most frequently observed. Reactions involving the nucleophilic attack at the α-carbon which knocks out a sulfinate (pathway a) have been observed.[2] Very recently, it was shown that this pathway was highly synthetically useful by way of Lewis acid catalyzed Friedel–Crafts alkylation reactions.[3] Reactions by pathway b were reported only in the cases where the leaving groups were moderately stabilized or in systems where no other

Scheme I



Scheme II



electrophilic centers existed.[4] In other words, nucleophilic bases would normally act more like bases than like nucleophiles in reactions with sulfones. The steric crowdedness of the sulfone function should be responsible for these observations. However, nucleophilic substitution reactions by pathways a and b were expected to occur more easily if the steric accessibility could be enhanced. Norbornadienyl sulfone **1**, with its sulfone function in a strained four-membered ring, was found to be a good example for nucleophilic attack.

When a nonnucleophilic base, such as NaH or lithium hexamethyldisilazide (LiHMDS), was treated with **1** followed by alkylation with MeI under various conditions, the starting material was completely recovered, giving a signal of the weak acidity of the α-positions and a good

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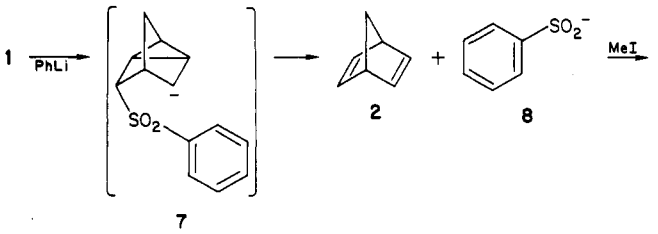
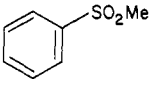
possibility of the nucleophilic substitution reaction.

Several nucleophiles, including sodium methoxide and lithium diisopropylamide, were used to react with 1, but resulted in either no reaction or polymerization. But when compound 1 was treated with 1 equiv of MeLi followed by workup with MeI, product 5 was formed cleanly in high yield (Scheme II). When the same reaction was repeated and worked up with H_2O instead of MeI, product 6 was isolated in good yield. The most reasonable mechanism is proposed as shown in Scheme II where the MeLi acts as a nucleophile and attacks the sulfur atom, giving the unstable secondary carbanion 3. A rapid proton exchange produced the sulfone stabilized primary carbanion 4 which was then reacted with either MeI or H_2O to give 5 or 6. In addition to the interesting mechanism, this reaction provides a new approach toward the synthesis of 3-functionalized nortricyclanes. Replacement of MeLi in the reaction with other reagents as the methyl anion sources, including MeMgCl and Me_3Al, proved less satisfactory because the methyl Grignard reagent gave the same products but was accompanied with a lot of side products and trimethylaluminum gave polymer upon prolonged stirring.

When 1 was added dropwise to PhLi in THF the starting material disappeared within a few minutes. ^1H NMR spectrum of the crude reaction mixture showed that norbornadiene 2 was formed as the major component. After the mixture was treated with MeI and worked up, methyl phenyl sulfone (9)[6] was isolated as the major nonvolatile product (60%). The anticipated ring-opening product 10 was not detected. It was rationalized that under the reaction condition, the carbanion intermediate, formed by the ring-opening reaction of the nucleophilic attack of the phenyl anion on sulfur, rapidly fragmented into norbornadiene 2 and benzenesulfinate (8) which was then methylated to give 9 (eq 1).



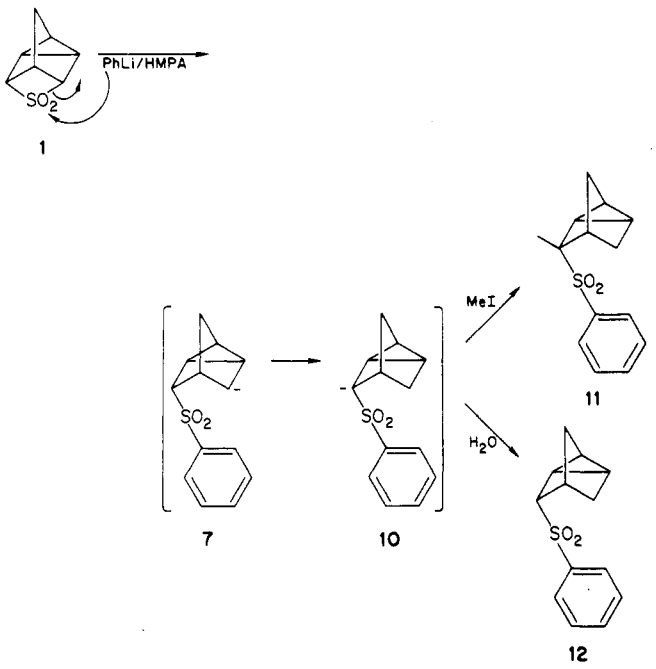


9

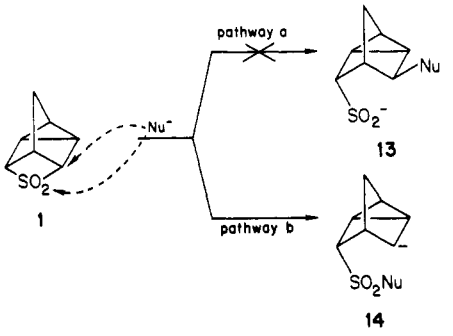
However, if the manipulation was reversed, i.e., by adding PhLi dropwisely to 1 in the presence of HMPA, the major products isolated from workup with MeI were compounds 9 and 10. The major product from workup with H_2O was 12. Although benzenesulfinic acid should be produced as well, no efforts were made to isolate it. Apparently, in addition to the formation of 9 by the pathway described in eq 1, a rapid proton exchange took place to give the more stable anion 10, which led to the formation of 11 and 12 upon proper workup (Scheme III).

In general, a nucleophile has two most possible routes to attack compound 1 (Scheme IV). By pathway a, the nucleophile attacks at C-2 and knocks out the sulfinate which is a relatively good leaving group, giving 13. While by pathway b which gives 14 accordingly, the unstable carbanion is the leaving group. The examples described above have shown that pathway b dominates in this system. The high-yielding ring-opening reactions of norbornadiene sulfone 1 by nucleophilic attack on sulfur atom leading to compounds such as 5 appear to be a good preparative method for the synthesis of 3-functionalized nortricyclanes.[7]

Scheme III



Scheme IV



Experimental Section

^1H NMR and ^{13}C NMR spectra were determined on a JEOL FX-100 NMR spectrometer as solutions in $CDCl_3$. IR spectra were determined on a Perkin-Elmer 297 IR spectrophotometer. Mass spectra were recorded on a Hewlett-Packard 5990B gas chromatograph/mass spectrometer. Elemental analyses were performed at the National Taiwan University. All reactions were carried out under atmosphere of dry nitrogen. All anhydrous solvents were freshly distilled before use.

Reactions of Norbornadienyl Sulfone 1 with MeLi To Give 5 and 6. To compound 1 (101 mg, 0.65 mmol) in THF (2 mL) was added dropwise MeLi (0.65 mmol) at −5 °C, and the reaction mixture was stirred vigorously for 30 min. The reaction was followed by TLC until the complete disappearance of 1, after which time it was quenched with MeI (280 mg, 2.0 mmol). The stirring was continued for another 10 min. The mixture was then eluted through a silica gel column and separated by HPLC (1:1 hexane/EtOAc) to afford 97 mg of 5 (81%): white crystals, mp 40–41 °C; IR ($CHCl_3$) 2889, 1465, 1300, 1265, 1125, 1050 cm^{-1}; ^1H NMR δ 1.1–1.6 (m, 9 H), 2.23 (d, 1 H, J = 12 Hz), 2.44 (br s, 1 H), 2.93 (s, 1 H), 2.97 (q, 2 H, J = 6 Hz); ^{13}C NMR δ 6.4, 11.5, 12.2, 12.7, 30.4, 32.7, 34.9, 47.8, 66.3; mass spectrum, m/e 186 (M^+),

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109, 93, 91 (base), 77. Anal. Calcd for $C_9H_{14}O_2S$: C, 58.04; H, 7.58. Found: C, 57.98; H, 7.71.

When the above reaction was worked up with H_2O and purified similarly, product **6** was obtained (85%): white crystals, mp 76–77 °C; IR ($CHCl_3$) 2960, 1420, 1320, 1270, 1145, 1135 cm^{-1}; ^1H NMR δ 1.26–1.70 (m, 6 H), 2.23 (d, 1 H, J = 12 Hz), 2.45 (br s, 1 H), 2.87 (s, 3 H), 2.98 (s, 1 H); mass spectrum, m/e 172 (M^+), 109, 93 (base), 92, 77, 66. Anal. Calcd for $C_8H_{12}O_2S$: C, 55.79; H, 7.02. Found: C, 55.79; H, 7.02.

Reactions of Norbornadienyl Sulfone 1 with PhLi To Give 9. To PhLi (3.3 mmol) in THF cooled at −75 °C was added dropwise **1** (340 mg, 2.2 mmol) in THF, and the mixture was stirred vigorously for 2 h. At this time, ^1H NMR of the resulting mixture was taken and showed the complete disappearance of **1** and the existence of norbornadiene **2**. To this mixture was then added MeI (1.70 g, 12 mmol), and the stirring was continued at room temperature for another 10 min. Removal of the solvent gave the crude product, whose ^1H NMR showed it to contain essentially pure methyl phenyl sulfone (**9**) (60%). Analytical pure sample was obtained by HPLC (silica gel, 1:1 hexane/EtOAc): colorless oil; IR (liquid) 2890, 1570, 1590, 1480, 1450, 1305, 1150, 1085 cm^{-1}; ^1H NMR δ 2.97 (s, 3 H), 7.56–7.80 (m, 3 H), 7.89–8.10 (m, 2 H); mass spectrum, m/e 156 (M^+), 141, 94, 77 (base). Anal. Calcd for $C_7H_8O_2S$: C, 53.83; H, 5.16. Found: C, 53.90; H, 5.13.

Reactions of Norbornadienyl Sulfone 1 with PhLi/HMPA To Give 11 and 12. To a solution of **1** (334 mg, 2.14 mmol) in THF (10 mL) and HMPA (2 mL) was added PhLi (3.3 mmol) dropwise, and the reaction mixture was stirred vigorously at −75 °C until **1** was completely disappeared (30 min). Then, MeI (1.70 g, 12 mmol) was added, and the stirring was continued at −30 °C for 2 h. Removal of the solvent gave the crude mixture, which was eluted through a silica gel column and separated by HPLC (silica gel, 1:1 hexane/EtOAc) to give **11** (20%) and **9** (40%). Compound **11**: white crystals, mp 83–84 °C; IR (KBr) 3080, 1590, 1450, 1300, 1200, 1150, 1070 cm^{-1}; ^1H NMR δ 1.18 (s, 3 H), 1.25–1.72 (m, 6 H), 1.91 (br s, 1 H), 2.75 (d, 1 H, J = 12 Hz), 7.30–7.64 (m, 3 H), 7.70–7.92 (m, 2 H); ^{13}C NMR δ 12.6, 14.4, 17.5, 18.5, 32.5, 33.6, 38.3, 73.9, 128.5, 128.8, 132.9, 138.9; mass spectrum, m/e 107 ($M^+ - C_6H_5SO_2$, base), 91, 79, 77. Anal. Calcd for $C_{14}H_{16}O_2S$: C, 67.71; H, 6.49. Found: C, 67.76; H, 6.48.

If the above reaction was worked up with H_2O and purified similarly, product **10** was obtained (20%): white crystals, mp 62–63 °C; IR ($CHCl_3$) 2960, 1450, 1300, 1270, 1160, 1095 cm^{-1}; ^1H NMR δ 1.12–1.54 (m, 6 H), 2.24 (s, 1 H), 2.30 (d, 1 H, J = 6 Hz), 2.98 (s, 1 H), 7.36–7.64 (m, 3 H), 7.70–7.92 (m, 2 H); ^{13}C NMR δ 11.4, 12.3, 12.6, 30.2, 32.9, 34.75, 70.0, 127.7, 128.0, 128.6, 133.1, 139.9; mass spectrum, m/e 93 ($M^+ - C_6H_5SO_2$), 91, 77 (base), 65. Anal. Calcd for $C_{13}H_{14}O_2S$: C, 66.64; H, 6.02. Found: C, 66.67; H, 6.03.

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Registry No. 1, 22061-75-2; 5, 98858-00-5; 6, 98858-01-6; 9, 3112-85-4; 11, 98858-02-7; 12, 98858-03-8; PhLi, 591-51-5; MeLi, 917-54-4; sulfur, 7704-34-9.

Nucleophilic Substitution of Alkyliodines via Oxidative Ligand Transfer

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Our interest in alkyl iodosyl species (RI=O) as possible metabolites of cytochrome P-450 catalyzed oxidation of organoiodides[1,2] has led us to examine the reactions of analogous hypervalent alkyliodine compounds. Although hypervalent aryliodine derivatives,[3] known for over a century, are stable, their alkyl counterparts are often highly reactive electrophiles. For example, Wiberg et al.[4] in a recent study of the solvolysis of bridgehead iodides via alkyldibromoiodine intermediates ($RIBr_2$) found that dibromoiodide $(IBr_2)^-$ is one of the most effective leaving groups known and estimated its leaving group ability at approximately 10^{10} greater than iodide (I^-). The synthetic exploitation of this notable leaving group ability has spawned several studies of oxidatively assisted nucleophilic substitution of alkyliodines.[4-10] For example, recent investigations of Zefirov et al.[5] have demonstrated the utility of this methodology in the syntheses of sensitive alkyl sulfonates and perchlorates through trapping of the intermediate hypervalent organoiodides with the weakly nucleophilic sulfonate and perchlorate anions. A variety of agents have been employed in organoiodide oxidation and recently the groups of Koser[6] and Varvoglis[7] have detailed methods for the oxidation of organoiodides at the iodine center by ligand transfer from stable aryliodine(III) reagents. We describe here an efficient means for the oxidatively assisted displacement of alkyliodines under mild, nonnucleophilic conditions by fluoride, chloride, bromide, tosylate, acetate, and trifluoroacetate groups, which utilizes ligand transfer from aryliodine(III) derivatives to produce the requisite hypervalent alkyliodine intermediates for substitution (e.g., 1 + 2 → [3] → 4).

$$\underset{1}{RI} + \underset{2}{ArIX_2} \rightarrow [\underset{3}{RIX_2}] \rightarrow \underset{4}{RX}$$

Data for the reactions of several hypervalent phenyliodine derivatives with 1- and (±)-2-iodooctane and 1-iodo-2,2-dimethylpropane are compiled in Table I. Noteworthy are the mild, *oxidative* reaction conditions employed in these transformations (i.e., devoid of strong nucleophiles), the generally good yields obtained for these formal iodide displacements and the ability to displace iodide with fluoride in modest yields without competing hydrogen iodide elimination. Although the displacements of the primary and secondary alkyl iodides proceeded smoothly without the formation of significant side products (≥97% direct displacement as assigned by capilliary gas chromatography), we have found that the products derived from 1-iodo-2,2-dimethylpropane oxidative substitution are 2-substituted-2-methylbutane derivatives resulting from neopentyl rearrangement in all cases. This methodology may therefore be of limited utility when the incipient or fully positively charged electrophilic site (vide infra) is prone to elimination or rearrangement. In the reactions of hydroxy(tosyloxy)iodobenzene with alkyliodines, it is interesting to note that the tosylate is produced in substantial preference to the alcohol (>95:5).

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