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 $\delta$ 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 $\delta$ 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 $\delta$ 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 $\delta$ 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 $\delta$ 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 $\delta$ 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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**Table I. Reactions of Alkyliodines with Various Hypervalent Phenyliodines**

| | 1-iodooctane | | (±)-2-iodooctane | | 1-iodo-2,2-dimethylpropane[a] | |
|---|---|---|---|---|---|---|
| $PhIX_2$, X = | reactn period, h | yield of 4, % | reactn period, h | yield of 4, % | reactn period, h | yield of 4, % |
| OAc | 20 | 82 | 35 | 78 | 12 | 80 |
| $OCOCF_3$ | 1 | 88 | 4 | 75 | 10 | 75 |
| Br | 1 | 85 | 2 | 82 | 3 | 63 |
| Cl | 1 | 92 | 3 | 80 | 4 | 78 |
| F | 6 | 34 | 8 | 28 | | |
| OH, OTs | 1 | 90 | 4 | 92 | 3 | 85 |

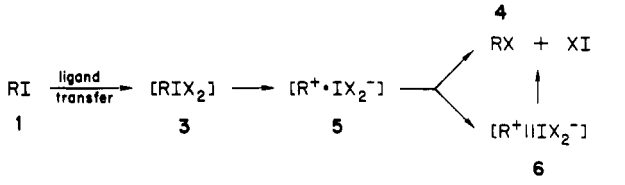
[a] The product isolated in all cases was the corresponding 2-substituted-2-methylbutane derivative, derived from neopentyl to *tert*-pentyl rearrangement. The product from reaction of 1-iodo-2,2-dimethylpropane with difluorophenyliodine could not be isolated, presumably due to its volatility.

Although a variety of factors may be determinants in the generation of this selectivity, the relative facilities for cleavage of the I–OH or I–Tos bonds or of ligand transfer (OH vs. OTos) must play a role. We have found that the leaving group abilities of the phenyliodine ligands does have a significant impact on the reaction period for substitution, which we believe to be a manifestation of ligand transfer being rate determining in the substitution sequence. For the rates of the reactions studied here, the following dependence on the nature of the ligands was observed:

$$OAc < F < OTFA < Cl \lesssim Br < OTos$$

We have noted that pyridine (1.0 equiv) substantially accelerates the reaction for the slower reacting substituents (OAc, F, OTFA), which has implications for both the synthetic utility and mechanism(s) of these reactions. For example, the reaction period at room temperature for complete conversion of (±)-2-iodooctane to the corresponding acetate with iodobenzene diacetate can be reduced from 35 to 8 h upon the introduction of pyridine.

Several investigations have provided an understanding of the reaction mechanism responsible for the displacement, rearrangement, and elimination processes of in situ generated alkyliodine(III) species. Studies by Wiberg[4] and others[8-10] have demonstrated that the reactions of optically active 2-iodooctane with excess chlorine and bromine, which proceed via the hypervalent dihalide species ($RIX_2$), yield predominant, although not exclusive, inversion.[4,8,9] When chlorination was performed in the presence of excess chloride ion, essentially complete inversion was obtained.[4,9] The mechanism illustrated below has been suggested to accommodate these data and is consistent with the results of this study.[4,8-10] Thus, following formation of the hypervalent alkyliodine species, these intermediates undergo unimolecular decomposition to form ion pairs (e.g., **3** → **5**), which can collapse to products with inversion via free ligand displacement or with racemization by further ionization to solvent separated ion pairs. In the processes examined here, formation of the hypervalent intermediate via ligand transfer would be expected to be rate determining. Although the role of pyridine in facilitating these reactions is presently undefined, pyridine may enhance aryliodine to alkyliodine ligand transfer by displacement of one of the iodide ligands in $ArIX_2$, thereby providing positively charged hypervalent organoiodide intermediates [e.g., $ArIX(pyr^+)$]. Such pyridinium-containing species could increase the rate of a stepwise ligand transfer process by promotion (relative to the $ArIX_2$ precursor) of the leaving group ability of the aryliodine group in the hypervalent organoiodide intermediate [e.g., RI + $ArIX(pyr^+)$ → $(RIX)^+$ + ArI + pyr]. Whatever the mechanism(s) of the rate enhancement by pyridine, excess pyridine (≫1.0 equiv) tends to redirect the overall reaction process from displacement to elimination. In summary, within the limitations noted above and despite incomplete knowledge of the mechanism(s) of these ligand transfer-mediated alkyliodine displacements, we anticipate that this method will prove useful in alkyliodine transformations, particularly for their conversion into the corresponding alkyl fluorides.




## Experimental Section

Proton magnetic resonance spectra were recorded at 100 MHz with a JEOL MH-100 spectrometer in deuteriochloroform with tetramethylsilane as an internal standard. Product analysis was determined by TLC or by gas chromatography using a Shimadzu C-RIB FID gas chromatograph with a SE-30 glass capillary column, 53.5 m long, between 60 and 90 °C. Reactions were carried out under an atmosphere of nitrogen. (±)-2-Iodooctane and 1-iodooctane were prepared by the nucleophilic displacement of the corresponding tosylate with iodide ion in acetone. Iodobenzene, iodobenzene diacetate (Aldrich Chemical Co.), and 1-iodo-2,2-dimethylpropane (Fluka A-G Chemical Corp.) were purchased. Iodobenzene dibromide and dichloride,[11] iodobenzene bis(trifluoroacetate),[12] iodobenzene difluoride,[13] and hydroxy(tosyloxy)iodobenzene[6] were prepared by using literature procedures.

All reactions of alkyl iodides with the corresponding hypervalent aryl iodides **2** were done under identical conditions. A typical experimental procedure is given below.

**General Procedure.** The alkyliodine (1.0 mmol) was dissolved in methylene chloride (5 mL), the iodobenzene (III) derivative (1.2 mmol) was added, and the reaction mixture was stirred at ambient temperature. After complete disappearance of the alkyliodine (TLC, GLC), the reaction mixture was diluted with ether (15 mL), and the organic layer was washed sequentially with aqueous sodium bisulfite solution (10%, 2 × 10 mL) and saturated aqueous sodium bicarbonate solution (10 mL). The organic layer was separated and washed once with brine (15 mL) and then dried over anhydrous sodium sulfate, and the solvent was removed in vacuo. Alkyl tosylates were isolated be removal of iodobenzene from the crude product mixture under high vacuum leaving almost pure products. Alkyl halides and acetates were either distilled directly or separated from iodobenzene, by passing chlorine through a chloroform (2 mL) solution of the crude mixture at −10 °C, filtration of the precipitated iodobenzene dichloride, removal of the solvent in vacuo, and distillation. All yields in Table I represent isolated materials and all products were correlated with authentic standards by chromatographic and spectral means.

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