center by hydrogen atom abstraction.

Aside from the caveat cited above, this radical coupling strategy provides a reliable means of carbon–carbon bond formation at a site where conventional electrophile–nucleophile pairing methods are inapplicable. The fact that the phenylseleno lactones serve as the optimal substrates carries the bonus that these are generally stable, readily characterized compounds available in high yield.[4]

The procedures for the conversion of **2a–c** to the product **5a** provide a representative comparison of experimental protocols (see Experimental Section). Refinement and application of this technology will constitute a subsequent report.

Experimental Section

General Procedures. Infrared (IR) spectra were recorded on a Beckman IR 4210 or a Perkin-Elmer 727B spectrometer. Proton magnetic resonance (^{1}H NMR) spectra were recorded at 90 (Varian EM 390) or 400 MHz (Bruker WH-400). Carbon magnetic resonance spectra were recorded on a Varian CFT-20 or an IBM NR-80 spectrometer. Chemical shifts for proton and carbon resonances are reported in ppm (δ) relative to Me$_4$Si (δ 0.0).

Analytical thin-layer chromatography (TLC) was done on Analtech precoated TLC plates with silica gel GHLF (250-μm layer thickness). Column chromatography was done on Merck silica gel 60 (70–230 mesh ASTM) or Baker silica gel (40–140 mesh).

Methylene chloride was dried by distillation from P$_2$O$_5$ and passed through a column of alumina. Toluene was dried by distillation from calcium hydride and storage over sodium. All reactions were run under an atmosphere of dry nitrogen.

Elemental analyses were performed by Robertson Laboratory.

3,3aβ,4,5,6β-Hexahydro-6-(2-(carbomethoxy)ethyl)-2*H*-cyclopenta[*b*]furan-2-one (5a). (A) Production of 5a from the Acetoxymercurio Lactone 2a. To a solution of 0.28 g (2.03 mmol) of sodium trimethoxyborohydride and 1.91 g (22.2 mmol) of methyl acrylate in 7 mL of methylene chloride (CH$_2$Cl$_2$) at 0 °C was added 0.608 g (1.58 mmol) of the acetoxymercurio lactone **2a**[2a] in 7 mL of CH$_2$Cl$_2$ via syringe pump over a 2-h period. The reaction mixture was allowed to warm to room temperature and was stirred for 12 h. After removal of the solvent in vacuo, the crude product was purified by chromatography on silica gel. Elution with 4:1 hexanes–ethyl acetate gave 66 mg (20%) of the lactone ester **5a** as an oil, homogeneous by TLC and spectroscopic criteria; R_f 0.49 (1:1 hexanes–ethyl acetate); IR (CDCl$_3$) 1770, 1735 cm^{-1}; ^{1}H NMR (90 MHz, CDCl$_3$) δ 4.55 (dd, 1 H, J = 2.5, 7.5 Hz), 3.66 (s, 3 H), 3.0–1.1 (m, 12 H); ^{13}C NMR (CDCl$_3$) δ 176.97, 173.17, 89.97, 51.20, 45.59, 37.39, 35.14, 32.07, 31.54, 29.86, 26.90. Distillation [bath temperature 145 °C (0.3 mmHg)] afforded an analytical sample of **5a**.

Anal. Calcd for C$_{11}$H$_{16}$O$_4$: C, 62.23; H, 7.59. Found: C, 62.43; H, 7.71.

(B) Production of 5a from the Iodo Lactone 2b. To a solution of 100 mg (0.40 mmol) of the iodo lactone **2b**,[9] 0.18 mL (5 equiv) of methyl acrylate and a crystal of ABN in 5 mL of dry toluene at 100 °C was added a solution of 0.105 mL (1 equiv) of tri-*n*-butyltin hydride (Bu$_3$SnH) in 0.5 mL of toluene via syringe pump over a 5-h period. A second portion (0.18 mL, 5 equiv) of methyl acrylate was then added together with a crystal of ABN. Again, a solution of 0.105 mL (1 equiv) of Bu$_3$SnH in 0.5 mL of toluene was added dropwise over a 5-h period. The solvent was removed in vacuo and the crude product purified by chromatography on silica gel. Elution with 4:1 hexanes–ethyl acetate gave 46 mg (54%) of the lactone ester **5a**, homogeneous by TLC and spectroscopic criteria.

(C) Production of 5a from the Phenylseleno Lactone 2c. To a solution of 250 mg (0.36 mmol) of the phenylseleno lactone **2c**[4] and 0.80 mL (10 equiv) of methyl acrylate in 2.5 mL of dry toluene at 110 °C was added a solution of 937 mg (3 equiv) of triphenyltin hydride (Ph$_3$SnH)[7a] in 2.5 mL of toluene over a 12-h period via syringe pump.[10] The solvent was removed in vacuo and the residue chromatographed on 50 g of silica gel. Elution with 4:1 hexanes–ethyl acetate gave 132 mg (70%) of the lactone ester **5a**, homogeneous by TLC and spectroscopic criteria.

Acknowledgment. Grateful acknowledgment is extended to the donors of the Petroleum Research Fund, administered by the American Chemical Society, to Research Corp., and to the National Institutes of Health for their generous support for this research. High-field NMR spectra were obtained through the National Science Foundation Regional NMR Center at the University of South Carolina (Grant CHE 78-18723).

Registry No. 1a, 82323-00-0; **1b**, 1729-25-5; **1c**, 75826-35-6; **2a**, 82323-01-1; **2b**, 75658-56-9; **2c**, 65234-92-6; **3a**, 82323-02-2; **3b**, 54486-97-4; **3c**, 65291-16-9; **4a**, 82323-03-3; **4b** (isomer 1), 82323-04-4; **4b** (isomer 2), 82323-05-5; **5a**, 82323-06-6; **5b** (isomer 1), 82323-07-7; **5b** (isomer 2), 82372-88-1; **6a** (isomer 1), 82323-08-8; **6a** (isomer 2), 82323-09-9; **6b**, 82337-91-5; methyl acrylate, 96-33-3; methyl methacrylate, 80-62-6.

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[9] Klein, J. *J. Am. Chem. Soc.* **1959**, *81*, 3611–3614.

[10] More rapid addition of the Ph$_3$SnH resulted in the formation of increased amounts of the reduction product 2 (X = H) at the expense of 5a.

Regioselective Aromatic Hydroxylation. An Oxidative Reaction of Arylcopper(I) and Lithium Diarylcopper(I) Ate Complexes

Gail J. Lambert, Richard P. Duffley, Haldean C. Dalzell, and Raj K. Razdan*

SISA Institute for Research, Inc., Cambridge, Massachusetts 02138

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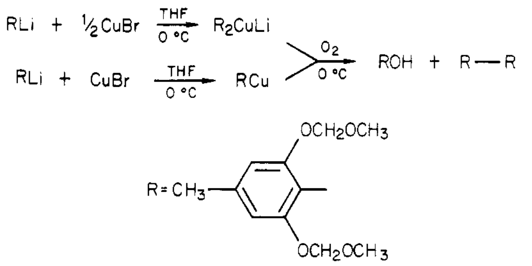
The air oxidation of organocopper compounds (RCu) is a well-documented reaction which leads to dimer as the major product.[1] Preparation of dimers in high yield from aryl-, alkyl-, alkenyl-, alkynyl-, heteroaryl-, and functional alkylcopper compounds have been reported.[2] Whitesides et al.[3] have further shown that high yields of dimer are obtained from air oxidation of copper(I) ate complexes (R$_2$CuLi) such as primary and secondary alkyl, vinyl, ethynyl, and aryl derivatives. Thus, octane was obtained in 84% yield and biphenyl in 75% yield from air oxidation of lithium di-*n*-butylcuprate and lithium diphenylcuprate, respectively.

We have found that when bis[2,6-bis(methoxymethoxy)-4-methylphenyl]cuprate is prepared and oxidized as shown in eq 1 in the manner described by Whitesides et al.[3] for diphenylcuprate, the course of the reaction is changed considerably. The corresponding phenol (ROH

$$\mathrm{RH} \rightarrow 2\ \mathrm{RLi} + [\mathrm{ICuP(C_4H_9)_3}]_4 \xrightarrow[-78\ ^\circ\mathrm{C}]{\mathrm{THF}} \mathrm{R_2CuLi} \xrightarrow[-78\ ^\circ\mathrm{C}]{\mathrm{O_2}} \mathrm{ROH} + \mathrm{R{-}R} \quad (1)$$



(2)

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[1] (a) Posner, G. H. *Org. React.* **1975**, *22*, 253–400 and references therein. (b) Normant, J. F. *Pure Appl. Chem.* **1978**, *50*, 709. (c) Smith, R. A. J.; Hannah, D. J. *Tetrahedron* **1979**, *35*, 1183.

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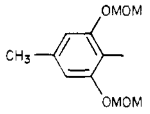
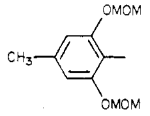
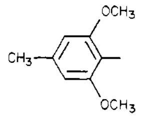
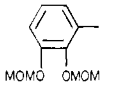
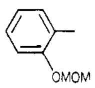
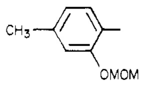
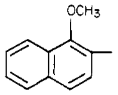
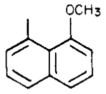
Table I.[a] Autoxidation of Organolithium and Organocopper Compounds

$$\mathrm{RX} \xrightarrow[\text{THF}]{\text{air, 0 °C}} \xrightarrow[\text{room temp}]{\mathrm{Ac_2O}} \mathrm{ROAc} + \mathrm{R{-}R}$$

no.	R[h]	X	% isolated yield of ROAc	% yield of R-R[b]
1		Li	29	c
2		CuLiBr	67[d]	~12
3		CuLiBr	65	~15
4		CuLiBr	58	~28
5		CuLiBr	46	~20
6	Ph	CuLiBr	19	e
7		CuLiBr	35[f]	~27
8		CuLiBr	37[f]	~9
9		CuLiBr	24[g]	~15

[a] It was found advantageous to isolate the phenols as their acetates because of the propensity of some of the phenols to codistill with the solvent and thus hamper quantitative isolation. [b] Estimated in some cases from the NMR spectra of the various chromatographic fractions containing the dimer. [c] Not observed. [d] Purity >98%. [e] Not isolated. [f] The lithiations were conducted according to reported procedures.[8,9] [g] The yield is actually higher than the yield of carboxylic acid reportedly obtained from carbonation of the lithium reagent.[9] [h] MOM = CH_2OCH_3. Products containing MOM groups were further characterized by removal of the protecting group (refluxing with Dowex in methanol) followed by acetylation (pyridine/acetic anhydride) to known compound in 80-100% yields.

in eq 1) is the major product, while the dimer (R-R in eq 1) occurs only in minor amounts. The yield of phenol was somewhat higher when the lithium diarylcuprate (R_2CuLi in eq 2) was prepared instead from RLi and 0.5 equiv of CuBr and then oxidized (air) at 0 °C. Equally high yields of phenol (ROH in eq 1) were obtained with the corresponding arylcopper compound (RCu in eq 2), prepared by treatment of RLi with 1 equiv of CuBr. Furthermore, the yield of phenol (ROH in eq 1) is more than twice that obtained from air oxidation of the corresponding lithium compound, RLi (Table I).

The generality of this hydroxylation reaction was further shown by subjection of a number of other [*o*-(methoxymethoxy)aryl]copper compounds to air oxidation. Although the isolated yields of hydroxylated products as shown in Table I are only moderate to good, they are significant because only a few examples of such autoxidation reactions of organocopper compounds and cuprates have been reported. Hydroxylation procedures utilizing autoxidation of other organometallics are, however, well-known.[4] In the only reported systematic study of the air oxidation of arylcopper compounds and their corresponding copper(I) ate complexes, phenols were formed as byproducts, but dimers were the major products.[5] A noteworthy exception is the air oxidation of (pentabromophenyl) and (pentachlorophenyl)copper, which provided the corresponding phenols in high yields (84%).[6] By contrast, (pentafluorophenyl)copper gave only the dimer, decafluorobiphenyl.[7]

In a typical experiment the arylcopper compounds were prepared from their respective lithium compounds. The latter were obtained from the parent ethers by treatment with *n*-butyllithium in tetrahydrofuran (THF) at 0 °C or by reported procedures. Transmetalation was then effected by addition of 1 equiv of cuprous bromide to the lithium compound in THF at 0 °C. After 1 h, dry air was bubbled through the reaction mixture at 0 °C. Quenching the reaction mixture with acetic anhydride converted the resulting phenoxides to the corresponding acetates, which were easier to isolate than the phenols. The propensity of some of the phenols to codistill with the solvent hampered their quantitative isolation. This problem was not encountered with the acetates.

Inspection of Table I clearly shows that the yield of phenol is highest when copper is flanked by two alkoxy groups and then decreases as the number of alkoxy groups decreases. However, in all the studied compounds in which a methoxy or methoxymethoxy group is ortho to copper, the yield of phenol is higher than that of dimer. Furthermore, the substitution of methoxymethoxy by methoxy does not alter the yield of phenol significantly (compare **2** and **3**).

The regioselectivity of the reaction is illustrated by **7**–**9** in Table I. Regioselective lithiation of *O*-(methoxymethyl)-*m*-cresol at C-6 and of 1-methoxynaphthalene[9] at C-2 and C-8, followed by transmetalation and air oxidation, afforded the single hydroxylated product shown with no other isomer present (HPLC).

A comparison of the NMR spectral data of 3,5-bis(methoxymethoxy)toluene and the various organometallic species derived therefrom is shown in Table II. The downfield shift of the methylene protons and the upfield shift of the aromatic protons in both copper species are similar to those reported for (2,4,6-trimethoxyphenyl)copper.[10] However, a similar downfield shift of the methoxyl protons is not observed. This is clearly indicative of coordination between the metal and the phenoxy oxygen with no involvement of the methoxyl oxygen. These results are consistent with the equivalent reactivities of **2** and **3**.

When the air oxidation of **2** was conducted in the presence of the radical scavengers hydroquinone and galvinoxyl, the phenol to dimer ratio decreased.[11] This

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(4) (a) Sosnowski, G.; Brown, J. H. *Chem. Rev.* **1966**, *66*, 529. (b) Brilkina, T. G.; Shushunov, V. A. "Reactions of Organometallic Compounds with Oxygen and Peroxides"; Iliffe Books Ltd.: London, 1969.

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(6) Smith, C. F.; Moore, G. J.; Tamborski, C. *J. Organomet. Chem.* **1972**, *42*, 257–265.

(7) DePasquale, R. J.; Tamborski, C. *J. Org. Chem.* **1969**, *34*, 1736–1740.

(8) Ronald, R. C. *Tetrahedron Lett.* **1975**, 3973–3974.

(9) Shirley, D. A.; Cheng, C. F. *J. Organomet. Chem.* **1969**, *20*, 251–252.

(10) Van Koten, G.; Leusink, A. J.; Noltes, J. G. *J. Organomet. Chem.* **1975**, *85*, 105–114.

Table II. NMR Spectral Data of Different Metallic Species in THF-d_8

	chemical shift, δ		
species[a]	aromatic protons	OCH_2OCH_3	OCH_2OCH_3
RH	6.50	5.07	3.40
RLi	6.23	5.16	3.32
RCu	6.32	5.43	3.40
R_2CuLi	6.28	5.43	3.39

[a] See eq 1 and 2 for R.

suggests that a free-radical mechanism may be operative for hydroxylation, but without additional work any mecanistic rationalization of our observations is highly speculative.

The strikingly different results reportedly obtained from air oxidation of (pentabromo- and pentachlorophenyl)-copper,[6] on the one hand, and (pentafluorophenyl)copper,[7] on the other, may be due to differences in stability of the radicals produced. The expected enhanced stability[12] of the pentabromo- and pentachlorophenyl radicals compared to the pentafluorophenyl radical may account for the observed formation of phenol from the former and dimer from the latter.

Our findings appear to be consistent with a recent report[13] of the isolation of carboxylic acid esters from the reaction of lithium dialkylcuprates with *S*-(2-pyridyl) thioates in the presence of oxygen. Presumably stabilization of the cuprates by internal complexation with the pyridyl moiety allows reaction with oxygen, giving rise to esters instead of ketones, as is observed in the absence of air.

Although the yields of phenols from the reaction presently described are only moderate to good, the reaction may provide an alternate hydroxylation route where other methods are inappropriate because of interfering functionality.

Experimental Section

Lithiation. Phenyllithium was commercially available (Aldrich Chemical Co.), and the lithium analogues of compounds **7–9** were prepared according to reported procedures.[8,9]

Compound **1** and the lithium precursors of compounds **3–5** were prepared by treatment of the parent ethers (0.01 mol) in dry THF (300 mL) with *n*-butyllithium (4.8 mL of 2.3 M hexane solution, 0.011 mol) at 0 °C under a nitrogen atmosphere. The resulting solutions were stirred at 0 °C for 2–4 h.

Transmetalation. Cuprous bromide (1.51 g of 95%, 0.01 mol) was added all at once at 0 °C to the solution of the lithium compound prepared as described above. [For those lithium compounds which were not prepared in THF (**6–9**), dry THF (250 mL) was added before the addition of cuprous bromide.] The resulting mixture was stirred under nitrogen at 0 °C until the cuprous bromide had almost completely disappeared (1-2 h).

Oxidation Followed by Acetylation. The flask containing the organocopper compound was equipped with a Pasteur pipet with an attached drying tube. Dry air was drawn into the reaction mixture at 0 °C for 45 min by applying an aspirator vacuum to the flask. The reaction mixture became deep green. Acetic anhydride (2-fold excess) was then added, and the resulting mixture was stirred at ambient temperature overnight. The reaction mixture was then treated with 10% (v/v) hydrochloric acid (25 mL) and diluted with ether (100 mL), whereupon two layers separated. The aqueous layer was extracted once with ether (50 mL), and the combined organics were washed with saturated aqueous sodium bicarbonate solution (3 × 50 mL), dried ($MgSO_4$), and concentrated. The resulting oils were analyzed by NMR, and then a 200–300-mg sample was separated by preparative TLC to give the products shown in Table I and described below.

Compound **1** formed **4-acetoxy-3,5-bis(methoxymethoxy)toluene** as an oil: 0.79 g (29%); NMR (CCl_4) δ 2.22 (s, 3 H), 2.28 (s, 3 H), 3.37 (s, 6 H), 5.02 (s, 4 H), 6.58 (s, 2 H). This was converted to the triacetate (see below). No dimer was detected.

Compound **2** formed the same compound as **1** above (209 mg, 67%) and was converted to the triacetate. The yield of dimer (12%) was estimated by NMR after chromatography.

Compound **3** provided **4-acetoxy-3,5-dimethoxytoluene**: 203 mg (64%); white solid; mp 71–74 °C; NMR (CCl_4) δ 2.18 (s, 3 H), 2.25 (s, 3 H), 3.68 (s, 6 H), 6.3 (s, 2 H); mass spectrum, *m/e* (relative intensity) 43 (16.94), 125 (8.07), 153 (19.95), 168 (100), 169 (10), 182 (6.2), 210 ($M^{+\cdot}$, 8.1). The corresponding dimer was isolated as a white solid: 35 mg (15%); NMR (CCl_4) δ 2.33 (s, 6 H), 3.58 (s, 12 H), 6.27 (s, 4 H).

Compound **4** provided **3-acetoxy-1,2-bis(methoxymethoxy)benzene**: white solid; 184 mg (58%); mp 34–36 °C; NMR (CCl_4) δ 2.2 (s, 3 H), 3.42, 3.48 (2 s, 6 H), 5.0, 5.1 (2 s, 4 H), 6.66 (m, 1 H), 6.93 (m, 2 H). It was converted to the triacetate (below). The corresponding dimer was isolated as an oil: 68 mg (28%); NMR (CCl_4) δ 2.97 (s, 6 H), 3.48 (s, 6 H), 4.78 (s, 4 H), 5.15 (s, 4 H), 7.0 (s, 6 H).

Compound **5** gave **2-acetoxy-1-(methoxymethoxy)benzene**: an oil; 124 mg (46%); NMR (CCl_4) δ 2.18 (s, 3 H), 3.37 (s, 3 H), 6.03 (s, 2 H), 6.75–7.18 (m, 4 H). It was converted to the diacetate. The yield of dimer (20%) was estimated by NMR after chromatography.

Compound **6** provided phenyl acetate as an oil: 74 mg (19%); identical with an authentic sample (GLC, NMR). The dimer was the major product (not isolated).

Compound **7** provided **4-acetoxy-3-(methoxymethoxy)toluene**: an oil; 152 g (35%); NMR (CCl_4) δ 2.18 (s, 3 H), 2.3 (s, 3 H), 3.42 (s, 3 H), 5.06 (s, 2 H), 6.77 (br s, 2 H), 6.95 (br s, 1 H). It was converted to the diacetate. The yield of dimer (27%) was estimated by NMR after chromatography.

Compound **8** formed **2-acetoxy-1-methoxynaphthalene**: an oil; 116 mg (37%); mp 84–87 °C; NMR (CCl_4) δ 2.28 (s, 3 H), 3.9 (s, 3 H), 7.57 (m, 6 H). HPLC analysis of the crude product (normal phase column, 85:15 isooctane/chloroform) showed the absence of isomeric 8-acetoxy-1-methoxynaphthalene.

Compound **9** provided **1-acetoxy-8-methoxynaphthalene**: an oil; 48 mg (24%); NMR (CCl_4) δ 2.23 (s, 3 H), 3.8 (s, 3 H), 7.1 (m, 6 H). HPLC analysis of the crude reaction mixture (normal phase column, 85:15 isooctane/chloroform) showed the absence of isomeric 2-acetoxy-1-methoxynaphthalene. The dimer was isolated as a solid: 22 mg (15%); NMR (CCl_4) δ 3.0 (s, 6 H), 6.5 (dd, 2 H), 7.37 (m, 10 H).

General Procedure for Removal of Methoxymethyl Groups and Subsequent Acetylation. The (methoxymethoxy)aryl acetates obtained from the air oxidation of the organocopper reagents **2**, **4**, **5**, and **7** were converted to the corresponding di- or triacetates for identification purposes. Dowex 50W-X4 (ion-exchange resin) was added to a solution of the (methoxymethoxy)aryl acetate in methanol. The resulting mixture was refluxed under nitrogen for 3–4 h until the disappearance of starting material as evidenced by TLC. The solution was then filtered and concentrated.

The product was taken up in a 1:3 mixture of acetic anhydride and pyridine, and the resulting solution was stirred at ambient temperature overnight. The reaction mixture was then poured into ice–water, and the resultant mixture was extracted with ether (3 × 50 mL). The combined extracts were washed first with 10%

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(11) The phenol to dimer ratio decreased with increasing amounts of hydroquinone. A more pronounced decrease was observed when galvinoxyl was employed. However, neither hydroquinone nor galvinoxyl suppressed the formation of phenol completely when 1 equiv was used. The phenol to dimer ratio dropped from 8.5 (no scavenger present) to 4.75 with 1 equiv of hydroquinone and to 2.0 with 1 equiv of galvinoxyl. Since both hydroquinone and galvinoxyl react with oxygen, they may have been deactivated as radical scavengers during the course of the reaction (see: Green, F. D.; Adam, W. *J. Org. Chem.* **1963**, *28*, 3550–3551). Furthermore, hydroquinone quenches the organometallic to some extent (NMR).

(12) Perchloro- and perbromomethyl radicals are more stable than the perfluoromethyl radical presumably because the empty d orbitals of the chlorine and bromine atoms allow delocalization of the unpaired electron (see: Huyser, E. S. "Free Radical Chain Reactions"; Wiley: New York, 1970; pp 69–70). The pentachloro- and pentabromophenyl radicals may be stabilized similarly.

(13) Sunggak, K.; Lee, I. L.; Chung, B. Y. *J. Chem. Soc., Chem. Commun.* **1981**, 1231–1232.

(v/v) hydrochloric acid (2 × 50 mL) and then with saturated sodium bicarbonate solution (2 × 50 mL), dried ($MgSO_4$), and concentrated to give the following: (a) The acetate (0.78 g, 2.9 mmol) obtained from 1 provided 0.64 g (99%) of 3,4,5-triacetoxybenzene.[14] (b) Similarly, the acetate (119 mg, 0.44 mmol) from 2 gave 102 mg (87%) of 3,4,5-triacetoxybenzene.[14] (c) The acetate (178 mg, 0.69 mmol) obtained from 4 formed 108 mg (78%) of 1,2,3-triacetoxybenzene.[15] (d) The acetate (106 mg, 0.54 mmol) obtained from 5 provided 78 mg (100%) of 1,2-diacetoxybenzene.[16] (e) The acetate (116 mg, 0.55 mmol) obtained from 7 gave 108 mg (94%) of 3,4-diacetoxytoluene.[17] The structures of the products were confirmed by melting point, NMR, and mass spectral analysis.

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Registry No. 1, 82280-75-9; 2, 82265-28-9; 3, 82265-29-0; 4, 82265-30-3; 5, 82265-31-4; 6, 65139-70-0; 7, 82265-32-5; 8, 82265-33-6; 9, 82265-34-7; 1,3-bis(methoxymethoxy)-5-methylbenzene, 82265-37-0; 1,3-dimethoxy-5-methylbenzene, 4179-19-5; 1,2-bis(methoxymethoxy)benzene, 3688-89-9; (methoxymethoxy)benzene, 824-91-9; benzene, 71-43-2; 1-(methoxymethoxy)-3-methylbenzene, 57234-27-2; 1-methoxynaphthalene, 2216-69-5; cuprous bromide, 7787-70-4; 4-acetoxy-3,5-bis(methoxymethoxy)toluene, 82265-38-1; 4-acetoxy-3,5-dimethoxytoluene, 82265-39-2; 2,2′,6,6′-tetrakis(methoxymethoxy)-4,4′-dimethyl-1,1′-biphenyl, 82265-40-5; 3-acetoxy-1,2-bis(methoxymethoxy)benzene, 82265-41-6; 2,2′,3,3′-tetrakis(methoxymethoxy)-1,1′-biphenyl, 82265-42-7; 2-acetoxy-1-(methoxymethoxy)benzene, 82265-43-8; phenyl acetate, 122-79-2; 4-acetoxy-3-(methoxymethoxy)toluene, 82265-44-9; 2-acetoxy-1-methoxynaphthalene, 82265-45-0; 1-acetoxy-8-methoxynaphthalene, 82265-46-1; 8,8′-dimethoxy-1,1′-binaphthalene, 82265-47-2; [2,6-bis(methoxymethoxy)-4-methylphenyl]copper (I), 82265-35-8; bis[[2,6-bis(methoxymethoxy)-4-methylphenyl]]copper(I) lithium, 82265-36-9.

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Communications

Transition-State Geometry in the Ene Reactions of Mesoxalic Esters

Summary: The evidence of a temperature-independent k_H/k_D value of 2.557 and a nearly identical inverse $(k_H/k_D)\alpha$ value of 0.950-0.957 at the π centers of allylbenzene strongly suggests a transition-state (TS) structure similar to that proposed for the highly reactive =S=N—. Here a symmetrically structured (2 + 2) charge-transfer complex is formed in a preliminary step, followed by a pseudopericyclic TS similar to that characterized previously[21] for superene reactions.

Sir: The mechanism of the ene reaction[1] and its broad application to organic synthesis[2] have been the subject of considerable study and discussion in the pages of this Journal.[3-5] The evidence gathered by several groups that have studied the ene reaction of dialkyl mesoxalates[3-5] "strongly suggest a concerted mechanism with a late product-like TS".[3] In this commonly held view the H-transfer step takes place in somewhat nonlinear fashion in accompaniment to nonsymmetrical breaking and formation of CH and OH bonds[5] (yet both steps occurring about the same time).[4] In other words, the classical pericyclic mechanism of this reaction discussed in reviews by Hoffmann[1a] and by Oppolzer and Snieckus[1c] is claimed to prevail in the ene reactions of mesoaxalic esters, modified by a slight deviation from linear H transfer in which the concerted transition state (TS) occurs somewhat displaced along the reaction coordinate toward the character of the product.[3-5] The principal purpose of the study on which we now report was to evaluate the various views and mechanistic conclusions through the application of a mechanistic criterion more probative of TS geometry, namely, the temperature dependence of the primary kinetic deuterium isotope effect (TDKIE).

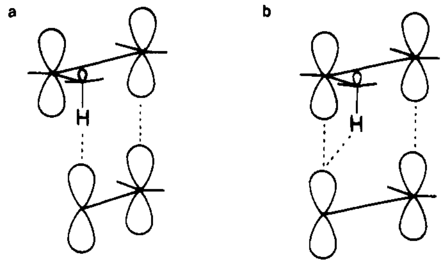

Figure 1.

The precision of k_H/k_D measurement by earlier workers[5] apparently was not sufficient to meet the requirements for the TDKIE exercise.[10] In fact, the results actually obtained over a narrow (30 °C) temperature interval, with k_H/k_D varying from 2.36 ± 0.16 to 2.09 ± 0.13, suggested a temperature-dependent KIE, one that is normally characteristic of linear H transfer.[11] However, the low (average) value of k_H/k_D persuaded the Polish workers that they were dealing with a pericyclic TS in which there was some departure from coaxiality in the transfer of the hy-

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