prepared diazomethane in ether. The reaction mixture was concentrated and chromatographed on silica gel to yield the desired methyl carboxylate.

Preparation and Oxidation of (±)-5. A sample of (±)-**5** was prepared from (±)-**4g** (1.14 g) by treatment with *m*-chloroperbenzoic acid (1.65 g excess) in $CHCl_3$ (50 mL) at 0–5 °C over the weekend. The $CHCl_3$ solution was washed with $NaHCO_3$, dried, and concentrated. The *N*-oxide was purified by chromatography on silica gel; NMR ($CDCl_3$, 220 MHz) δ 1.59 (d, 3 H), 2.14 (s, 3 H), 6.39 (q, 1 H), 7.14–7.43 (m, 3 H), 8.18 (d, 1 H); mass spectrum (70 eV), *m/e* (relative intensity) 181 (12, M^+), 138 (66), 122 (100), 104 (23).

The oxidation of (±)-**5** (362 mg) was carried out as described above to give (±)-**7** (29 mg) in 10% yield.

Preparation and Oxidation of (±)-4j. To a solution of (±)-**4i** (123 mg) in 25 mL of CCl_4 was added an excess of bromine (ca. 150 mg) at room temperature, and the reaction mixture was stirred overnight. The solvent was removed in vacuo, and the residue was chromatographed on silica gel with *n*-hexane–AcOEt (92:8) to give (±)-**4j** (65 mg) as a colorless solid (33% yield): mass spectrum (70 eV), *m/e* (relative intensity) 422, 424, and 426 (M^+, 1, 2, 1), 342 and 344 (17, 18), 264 (90), 222 (81), 205 (100); ^1H NMR ($CDCl_3$) δ 1.58 (d, 3 H), 2.11 (s, 3 H), 5.68 (s, 2 H), 5.96 (q, 1 H), 7.3–7.9 (m, 7 H).

The oxidation of (±)-**4j** (65 mg) was run to give crude (±)-**7** in ca. 40% yield.

Registry No. (±)-**1a**, 79416-46-9; (*S*)-**1b**, 84499-99-0; (*S*)-**2a**, 85828-06-4; (*S*)-**2b**, 84499-97-8; (±)-**3a**, 85880-65-5; (*S*)-**3b**, 84500-01-6; (*S*)-**3c**, 85828-07-5; (*S*)-**3d**, 55095-00-6; (*R*)-**4a**, 84194-74-1; (*S*)-**4b**, 84194-77-4; (±)-**4c**, 73104-87-7; (±)-**4d**, 85828-08-6; (*S*)-**4e**, 85828-09-7; (*S*)-**4f**, 84194-85-4; (±)-**4g**, 85880-66-6; (±)-**4h**, 85880-67-7; (±)-**4i**, 85880-68-8; **4j**, 85828-10-0; (±)-**5**, 85828-11-1; (±)-*trans*-**6**, 85880-69-9; (*R*)-**7**, 60426-97-3; (*S*)-**7**, 14031-88-0; (±)-**7**, 85880-70-2; (±)-(*R**,*R**)-**8**, 36065-08-4; RuO_4, 20427-56-9; $NaIO_4$, 7790-28-5.

Arene–Metal Complex in Organic Synthesis: Directed Regioselective Lithiation of (π-Substituted benzene)chromium Tricarbonyl Complexes[1]

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(3-Methoxybenzyl alcohol)chromium tricarbonyl complex (**8**) and (2-substituted 7-methoxy-1-tetralol)chromium complexes **14–17** are selectively lithiated at the 4-position and 6-position, respectively, by treatment with *n*-BuLi/TMEDA. The regioselectivity of this lithiation is improved with increasing bulk of the butyllithium reagent employed. Since the direct lithiation of the corresponding chromium-free arenes normally proceeds at the 2- and 8-positions, complementarily substituted arenes can be prepared by using chromium tricarbonyl complexes. The different lithiation is explained by the relative configuration of the chromium tricarbonyl group in the (π-arene)$Cr(CO)_3$ complexes and the electrostatic factor. This rationalization is supported, at least in part, by X-ray crystallography of the complex **16**. On the other hand, the chromium complexes of arenes without a free hydroxyl group, such as benzyl methyl ether or ethylene acetals of benzaldehydes, are lithiated at the 2-position preferentially.

Regioselective ortho lithiation of arenes directed by a heteroatom substituent such as the methoxy group is a useful reaction for the functionalization of aromatic compounds.[2] Ortho lithiation of aromatic compounds by alkyllithiums is facilitated by carboxamides, sulfonamides, and 2-oxazolines which are both electron-withdrawing and can coordinate with the lithium atom. When two substituents of this type are located at the 1,3-positions, lithiation occurs predominantly or exclusively at the 2-position;[3] even if the ortho-directing effect of each of these substituents is not so strong. For example, the lithiation of 3-methoxybenzyl alcohol (**1**), 7-methoxy-1-tetralol (**4**), and the octahydrophenanthrol derivative **5** took place at the 2- or 8-position with high regioselectivity to yield γ-lactone derivatives **2**, **6**, and **7** after quenching with carbon dioxide (Scheme I).[4] On the other hand, proton abstraction from (π-arene)chromium tricarbonyl complexes, easily obtained from 3-methoxybenzyl alcohol derivatives and chromium hexacarbonyl, occurs with different regioselectivity from that of metal-free parent arenes. This effect is attributed to the steric bulk and electron-withdrawing properties of the chromium tricarbonyl group. For example, the chromium complexes **8** and **14** were lithiated predominantly at 4- and 6-positions, respectively.[5] (Lithioarene)chromium tricarbonyl complexes thus formed could be reacted with various electrophiles and converted into the substituted arenes. As the chromium tricarbonyl group is easily removed oxidatively in quantitative yield,

(1) Dedicated to Emeritus Prof. Takeo Sakan on the 70th anniversary of his birth.

(2) For a review, see: Gscjwend, H. W.; Rodriguez, H. R. *Org. React.* **1979**, *26*, 1.

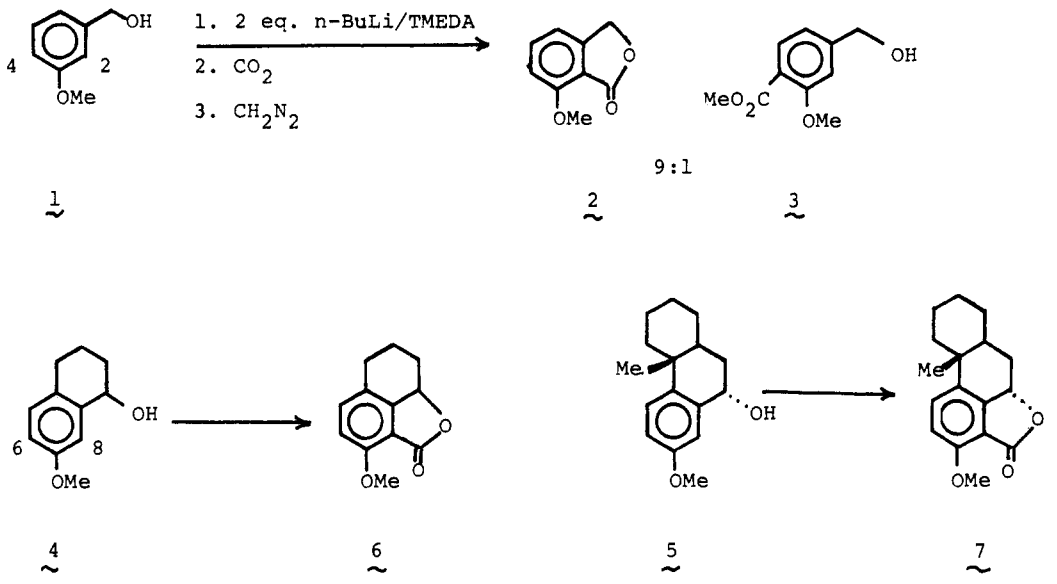
(3) Meta-oxygenated N-substituted benzamides, piperonal cyclohexylimine, the dimethyl acetal of meta-oxygenated benzaldehyde, oxygenated benzylamine, and 2-(3-methoxyphenyl)-4,4-dimethyl-2-oxazoline are selectively lithiated at 2-position via an intramolecular coordination. Amides: Beak, P.; Brown, R. A. *J. Org. Chem.* **1977**, *42*, 1823. Baldwin, J. E.; Bair, K. W. *Tetrahedron Lett.* **1978**, 2559. Forbes, I.; Pratt, R. A.; Raphael, R. A. *Ibid.* **1978**, 3965. de Silva, S. O.; Ahmad, I.; Snieckus, V. *Ibid.* **1978**, 5107 and references cited therein. Imine: Ziegler, F. E.; Fowler, K. W. *J. Org. Chem.* **1976**, *41*, 1564. Dimethyl acetal: Plaumann, H.; Keay, B. A.; Rodorigo, R. *Tetrahedron Lett.* **1979**, 4921. Benzylamine: Slocum, D. W.; Jennings, C. A. *J. Org. Chem.* **1976**, *41*, 3653. Dean, R. T.; Rapoport, H. *Ibid.* **1978**, *43*, 2115. Oxazoline: Meyers, A. I.; Mihelich, E. D. *Ibid.* **1975**, *40*, 3158. Meyers, A. I.; Avila, W. B. *Tetrahedron Lett.* **1980**, *21*, 3335.

(4) Uemura, M.; Tokuyama, S.; Sakan, T. *Chem. Lett.* **1975**, 1195. Similar selective lithiation of meta-oxygenated benzyl alcohol derivatives was reported several groups: House, H. O.; Strickland, R. C.; Zaiko, E. J. *J. Org. Chem.* **1976**, *41*, 2401. Trost, B. M.; Rivers, G. T.; Gold, J. M. *Ibid.* **1980**, *45*, 1835. Winkle, M. R.; Ronald, R. C. *Ibid.* **1982**, *47*, 2101.

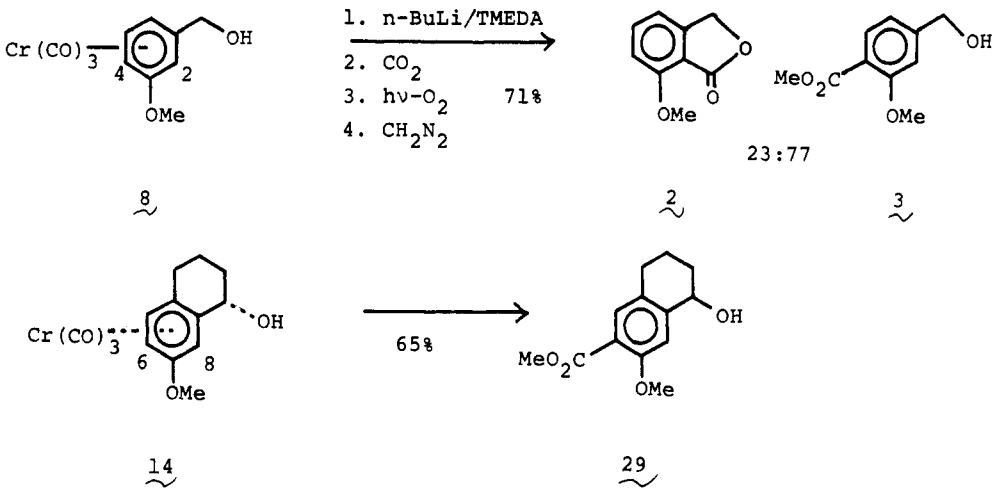
(5) For the preliminary report: Uemura, M.; Nishikawa, N.; Hayashi, Y. *Tetrahedron Lett.* **1980**, *21*, 2069.

0022-3263/83/1948-2349$01.50/0

Scheme I



Scheme II



lithiation of (π-arene)chromium tricarbonyl complexes represents a useful method for the synthesis of substituted benzene derivatives which are not easily obtained by usual electrophilic aromatic substitution. This study reports on the scope of regioselective nuclear lithiation of (π-arene)chromium complexes as a function of alkoxy substituents. Also discussed is the relationship between the regioselectivity and the relative configuration of the chromium tricarbonyl group to the benzene ring, which was established by X-ray crystallography of (2,2-dimethyl-7-methoxy-1-tetralol)chromium tricarbonyl complex (**16**).

Results and Discussion

Lithiation of (3-Oxygenated benzyl alcohol)- and (2-Substituted-7-methoxy-1-tetralol)chromium Tricarbonyl Complexes. Abstraction of the arene ring proton[6] from (π-arene)chromium tricarbonyl complexes by alkyllithiums generally competes with nucleophilic addition of the alkyl group to the arene ring[7] and formation of a carbenoid complex[8] depending on the reaction conditions and nature of the base and nucleophile. However, reaction with *n*-BuLi at low temperature predominantly results in directed lithiation of the arene ring.[6b]

Thus, (3-methoxybenzyl alcohol)chromium tricarbonyl complex (**8**) was treated with 2 equiv of *n*-BuLi and tetramethylethylenediamine (TMEDA) at −78 °C followed by a large excess of solid carbon dioxide to give carboxylated products. The crude product mixture was demetalated by photooxidation, and then methylated with diazomethane. After purification, the two products **2** (23%) and **3** (77%) were obtained (Scheme II).

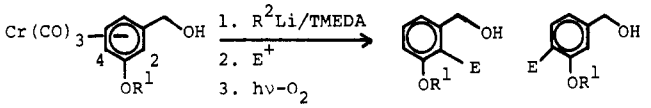
The proportion of C-4 lithiation in **8** increased with increasing bulk of the alkyllithium reagent. However, the chromium complex **8a** gave the 4-carboxylated product exclusively, even with *n*-BuLi, presumably due to additional chelating ability of the methoxymethyl substituent. The results of the reaction of (3-oxygenated benzyl alco-

(6) (a) Semmelhack, M. F.; Bisaha, J.; Czarny, M. *J. Am. Chem. Soc.* **1979**, *101*, 768. (b) Card, R. J.; Trahanovsky, W. S. *J. Org. Chem.* **1980**, *45*, 2555, 2560. (c) Fukui, M.; Endo, Y.; Oishi, T. *Chem. Pharm. Bull.* **1980**, *28*, 3639, Fukui, M.; Ikeda, T.; Oishi, T. *Tetrahedron Lett.* **1982**, *23*, 1605. (d) Nechvatal, G.; Widdowson, D. A.; Williams, D. J. *J. Chem. Soc., Chem. Commun.* **1981**, 1260. Nechvatal, G.; Widdowson, D. A. *Ibid.* **1982**, 467. (e) For a review of π(arene)chromium tricarbonyl complexes, see: Jaouen, G. In "Transition Metal Organometallics in Organic Synthesis"; Alper, H., Ed.; Academic Press: New York, 1978; p 65.

(7) Semmelhack, M. F.; Clark, G. R.; Garcia, J. L.; Harrison, J. J.; Tebtaranonth, Y.; Wulff, W.; Yamashita, A. *Tetrahedron* **1981**, *23*, 3957 and references cited therein. The reaction of π(benzene)chromium tricarbonyl with *t*-BuLi afforded *tert*-butylbenzene in fair yield: Card, R. J.; Trahanovsky, W. S. *Tetrahedron Lett.* **1973**, 3823. Semmelhack, M. F.; Hall, H. T.; Yoshifuji, M.; Clark, G. *J. Am. Chem. Soc.* **1975**, *97*, 1247.

(8) Beck, H. V.; Fischer, E. O.; Kreter, C. G. *J. Organomet. Chem.* **1971**, *26*, C41.

Table I. Lithiation of (3-Oxygenated benzyl alcohol)chromium Tricarbonyl



8 R^1=Me
8a R^1=CH_2OMe
27
28

entry	complex	R^1	R^2	E^+	ratio of 27/28	% yield
1	8	Me	*n*-Bu	CO_2[a]	23:77	71
2	8	Me	*sec*-Bu	CO_2[a]	15:85	55
3	8	Me	*t*-Bu	CO_2[a]	5:95	48
4	8	Me	*t*-Bu	Me_3SiCl	6:94	50
5	8a	CH_2OMe	*n*-Bu	CO_2[a]	2:98	45
6	8a	CH_2OMe	*n*-Bu	Me_3SiCl	2:98	67

[a] Isolated as methyl ester and γ-lactone after treatment with diazomethane.

hol)chromium tricarbonyl complexes with isomeric butyllithiums are summarized in Table I.

Since the effect of chromium coordination on the regioselectivity of lithiation was expected to be manifested more clearly by conformational fixation of the benzylic hydroxyl group, we next attempted the analogous reaction of the chromium complexes of 7-methoxy-1-tetralol and its derivatives. Indeed, *endo*-(7-methoxy-1-tetralol)chromium complex (14) gave exclusively 7-methoxy-6-(methoxycarbonyl)-1-tetralol (29), in contrast to the parent chromium free arene 4. (Schemes I and II). Similarly, (2-substituted 7-methoxy-1-tetralol)chromium complexes 15–17 afforded a single product lithiated only at the 6-position in high yield (Table II). The diastereomeric chromium complex 18 with an *exo*-hydroxyl group still gave predominantly the 6-methoxycarbonylated product under the same reaction conditions (entry 10 in Table II).

The regioselectivity of nuclear lithiation promoted by chromium tricarbonyl complexation is rationalized by the configurational relationship between the arene group and the chromium tricarbonyl group. By analogy to the X-ray structure of 16, the two carbonyl ligands of the $Cr(CO)_3$ group in the complex 14 are also located in proximity to the 6- and 8-positions of the arene ring (Figure 1). The lithiation of 14 with *n*-BuLi is presumably initiated by formation of lithium complex coordinated to both the methoxyl oxygen at C7 and an oxygen of the carbonyl ligand of $Cr(CO)_3$, followed by butyl anion abstraction of hydrogen at either the 6- or 8-position. The 8-position, however, is less susceptible to proton abstraction due to the steric hindrance and electrostatic repulsion by the benzylic alkoxide anion. Thus, the C6 proton is more readily removed. However, in chromium complex 8, the electrostatic repulsion to the butyllithium is smaller than that in the complex 14 due to the flexible conformation of the benzylic alkoxide anion, and lithiation at the 2-position takes place to some extent. Recently, Trahanovsky[6b] and Oishi[6c] et al. have reported independently that the lithiation of (N,N-disubstituted aniline)chromium tricarbonyl complex proceeded at the meta position via prior coordination of butyllithium to the oxygen atom of $Cr(CO)_3$. This argument is based on X-ray analysis of the complexes, in which the relative position of the carbonyl ligands to the benzene ring was shown to be as in Figure 2. Although the (anisole)chromium tricarbonyl complex[9] has been proven to adopt the same configuration (methoxy and a carbonyl ligand are eclipsed) as that of dialkyl-

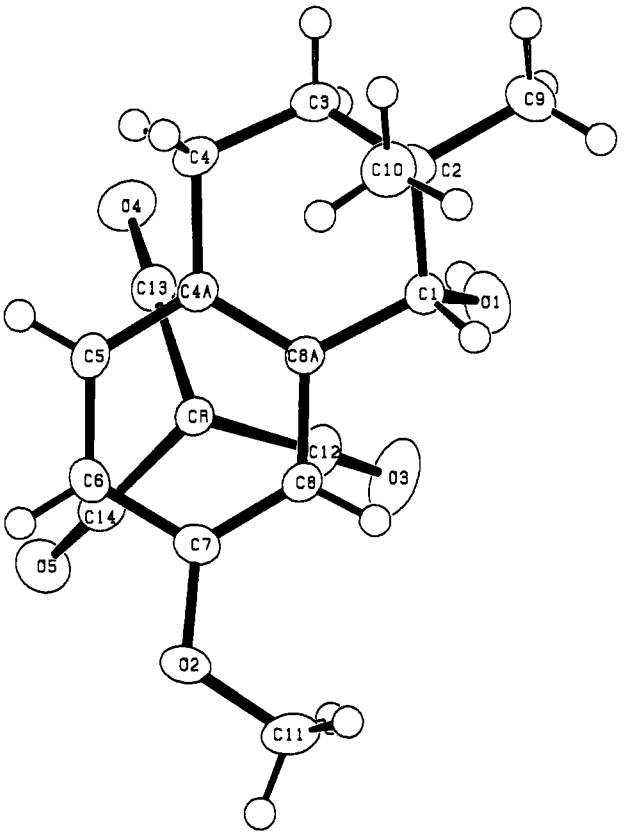


Figure 1. Structure of 16.

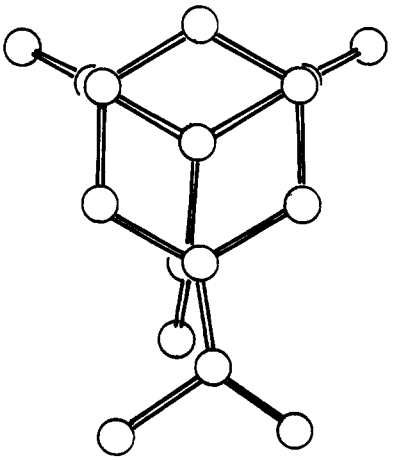
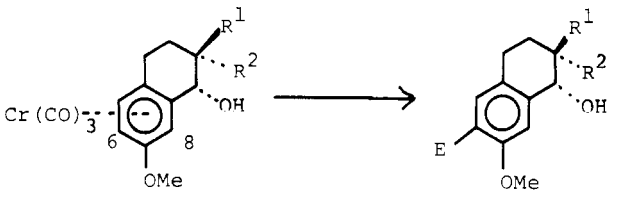


Figure 2. Structure showing the relative positions of the carbonyl ligands to the benzene ring.

(9) Carter, O. L.; McPhail, A. T.; Sim, G. A. *J. Chem. Soc. A* **1966**, 822.

Table II. Lithiation of (7-Methoxy-1-tetralol)chromium Tricarbonyl



entry	complex	R^1	R^2	E^+	% yield
1	14	H	H	CO_2	65
2	14	H	H	Me_3SiCl	96
3	14	H	H	p-$MeOC_6H_4CHO$	90
4	14	H	H	o-$C_6H_4(CO_2Me)_2$	91
5	14	H	H	MeCH=C(Me)COCl	82
6	15	Me	H	CO_2	63
7	15	Me	H	DMF	90
8	16	Me	Me	DMF	92
9	17	CH(OH)Me	H	CO_2	55
10	18[a]	H	H	CO_2	52[b]

[a] *exo*-Hydroxyl complex. [b] Ratio of products at C-6 and C-8 is 86:14.

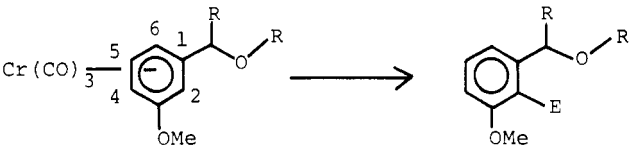
anilines, the configuration of the complex 8 is presumed to be analogous to that of **16** because of dipolar repulsion between the alkoxide anion (at the 1-position) and the carbonyl oxygen.

X-ray Analysis of the Complex 16. Crystals of **16** of composition $C_{16}H_{18}O_5Cr$ were grown from $CHCl_3$. These crystals are triclinic and belong to the space group $P\bar{1}$. Accurate cell constants were a = 11.581 (3) Å, b = 10.491 (2) Å, c = 6.550 (2) Å, α = 91.50 (2)°, β = 93.30 (1)°, and γ = 105.35 (2)°. All unique diffraction maxima with $2\theta \leq 50°$ were recorded in the ω–2θ scan mode by using a computer-controlled four-circle diffractometer and graphite-monochromated Mo Kα (0.7107 Å) X-rays. Of the 2678 reflections surveyed, 2066 (77%) were judged observed ($I \geq 3\sigma(I)$) after correction for Lorentz, polarization, and background effects. No absorption correction was applied (μ = 8.0 cm^{-1}).

The structure was solved by a direct phasing method. All hydrogen atoms were located by a difference electron density synthesis and included in subsequent calculations. Full-matrix least-squares refinement with anisotropic temperature factors for the nonhydrogen atoms and isotropic temperature factors for hydrogens converged to conventional crystallographic discrepancy index of 0.033.[10]

X-ray analysis revealed **16** to exist in the configuration shown in Figure 1. The configuration of the tricarbonyl groups with respect to benzene ring was found to be between staggered and eclipsed, with the carbonyl groups being located near C4A, C6, and C8. The Cr–C(arene) distances are in a narrow range from 2.215 (3) to 2.280 (3) Å. Six benzene carbon atoms, C1, and C4 are coplanar within 0.04 Å, and C2 and C3 deviate by 0.51 and 0.26 Å, respectively, in opposite directions with respect to the plane. The cyclohexene ring is in a half-chair conformation, and the hydroxyl group is axially oriented. There are three important intramolecular O···O distances which may be related to regioselective lithiation at the 6-position. The shortest one is 3.306 (3) Å between O1 and O3. The O2···O5 distance is 4.090 (3) Å and is shorter by 1.364 Å than the O2···O3 distance of 5.454 (3) Å. There is one intermolecular hydrogen bond, O1–H···O1 of 2.983 (3) Å. All other intermolecular distances correspond to van der Waals contacts.

Table III. Lithiation of (Arene)carbonyl Trichlorides without a Free Benzylic Hydroxyl Group



entry	complex	E^+	lithiated positions (ratio)	% yield
1	9	$ClCO_2Me$	2/2,4 (83:15)	67
2	22	$ClCO_2Me$	2/4 (93:7)	84
3	22	Me_3SiCl	2/2,4 (70:25)	90
4	23	$ClCO_2Me$	2/2,5 (80:15)	65
5	24	$ClCO_2Me$	2/2,5 (81:13)	92
6	25	$ClCO_2Me$	2	25
7	26	$ClCO_2Me$	2/4 (59:38)	58
8	20	DMF	8/6 (0:100)	85
9	21	DMF	8/6 (0:100)	90

Lithiation of (Arene)chromium Complexes without a Free Benzylic Hydroxyl Group. Since the hydroxyalkyl group is a poor ortho-directing group[11] lithiation of $Cr(CO)_3$ complexes **9** and **19–26**, possessing a benzylic ether linkage, were next examined. Free arene compounds of this type such as alkylbenzyl ethers and acetals of benzaldehydes are generally not feasible for ortho lithiation, because of the well-known propensity for deprotonation at the benzylic position, followed by Wittig rearrangement[12] or acetal ring cleavage.[13] However, the increased acidity of the ring hydrogen in the corresponding chromium complexes allowed successful ring lithiation. Reaction of (3-methoxybenzyl methyl ether)chromium tricarbonyl complex (**9**) with methyl chloroformate under standard conditions gave the 2-methoxycarbonylated product and the 2,4-bis(methoxycarbonylated) product in an 83:15 ratio (Table III).

This result contrasts with those obtained with complex **8** which bears a free hydroxyl group. Similarly, (3-meth-

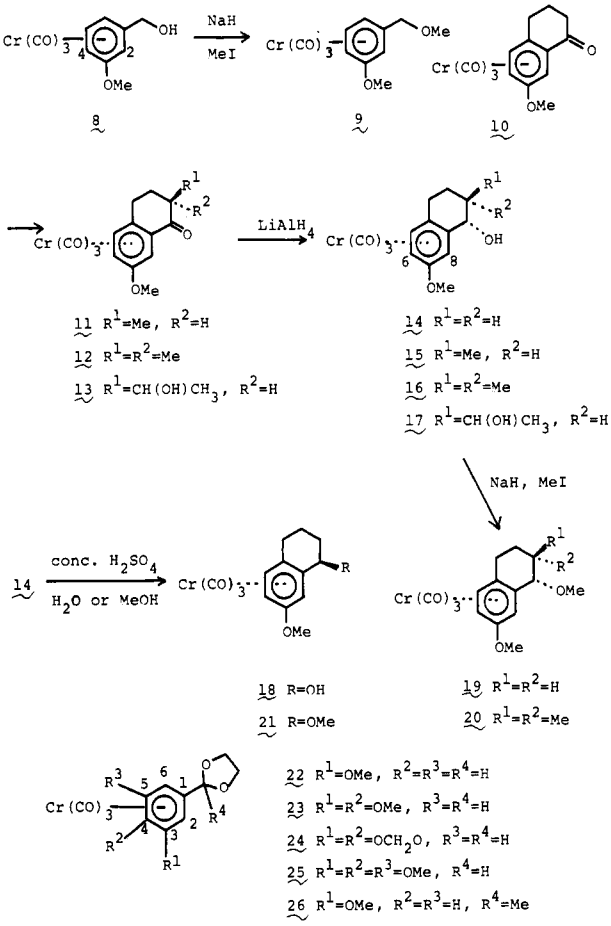
(10) The following crystallographic programs were employed. MULTAN: Germain, G.; Main, P.; Woolfson, M. M. *Acta Crystallogr., Sect. B* **1970**, *B26*, 274. References in: Woolfson, M. M. *Acta Crystallogr., Sect. A* **1977**, *A33*, 219. ORFLS: Busing, W. R.; Martin, K. O.; Levy, H. A. Report ORNL-TM-305; Oak Ridge National Laboratory Oak Ridge, TN. ORTEP: Johnson, C. K. Report ORNL-TM-3794; Oak Ridge National Laboratory Oak Ridge, TN.

(11) Under forcing conditions, nuclear lithiation of benzyl alcohol can be effected well. Panetta, C. A.; Dixit, A. S. *Synthesis* **1981**, 59. Meyer, N.; Seebach, D. *Chem. Ber.* **1980**, *113*, 1304.

(12) Wittig, G.; Davis, P.; Koenig, G. *Ber.* **1951**, *84*, 627.

(13) See: Wakefield, B. J. "The Chemistry of Organolithium Compounds"; Pergamon Press: New York, 1974; p 203.

Scheme III. Synthesis of (π-Arene)Cr(CO)$_3$



oxybenzaldehyde ethylene acetal)chromium complex (**22**) was lithiated at the 2-position with higher selectivity, and chromium complexes of other acetals also reacted predominantly at the position flanked by a methoxyl and the acetal groups. Since the previously mentioned electrostatic repulsion between an alkoxy *anion* and *n*-BuLi is absent in these cases, deprotonation at the 2-position is observed via favorable coordination of lithium with the proximal oxygen atoms of the two ether groups.

This chelating effect is to be distinguished from the steric effect in complex **26** in which lithiation at the 2-position is suppressed by introduction of the methyl group at the 1-position (entry 7 in Table III). The steric susceptibility of this reaction is further exemplified by tetralol methyl ether complexes **20** and **21**, which possess a conformationally fixed hindering methoxyl group at the benzylic position.[14] Thus, we conclude that the steric bulk of the rigid benzylic methoxyl group can override favorable coordination effects.

Synthesis of (π-Arene)chromium Tricarbonyl Complexes. The syntheses of the chromium complexes used in this study are shown in Scheme III. The complexes **8**, **10**, and **22–26** were easily synthesized in good yields by the reaction of the parent arenes with Cr(CO)$_6$ in a Strohmeier-type apparatus.[15] The complex **10** reacted with NaH and MeI to give a mixture of a 2-*exo*-methyl complex, **11**,[16] and 2,2-dimethyl complex **12**. Acid-catalyzed silylation of the complex **10** with *N*-(trimethylsilyl)diethylamine and *p*-TsOH,[17] followed by cross-aldol condensation[18] with paraldehyde, afforded a mixture of diastereomeric complexes **13**.[19] The complexes **10–13** were easily reduced to the *endo*-hydroxyl[20] complexes **14–17**. Complexes **14** and **16** were further converted to *endo*-methyl ether complexes **19** and **20**. The tetralol complexes with an *endo*-hydroxyl group can be inverted to *exo*-hydroxyl or *exo*-methoxyl complexes **18** or **21** on treatment with concentrated H_2SO_4, followed by decomposition with water or methanol.[21]

Experimental Section

All melting points are uncorrected and were determined on a Yanagimoto Model MPJ-2 micro melting point apparatus. IR spectra were recorded by a JASCO Model A-102 spectrometer, and ^{1}H NMR spectra were measured on a JEOL Model PS-100. Mass spectra were determined with a JEOL Model D-300 mass spectrometer. Elemental analysis was performed by a Perkin-Elmer Model 240 automatic elemental analyzer. GC analyses were carried out on a Shimadzu GC-6AM (3% OV-1, 1.5 m). Ether and THF were dried by distillation from sodium benzophenone ketyl before use. TMEDA was purified by distillation from CaH_2. NMR chemical shifts are given in parts per million downfield from Me_4Si, and coupling constants are given in hertz.

Preparation of (Arene)chromium Tricarbonyl Complexes 8, 10, and 22–26 from Cr(CO)$_6$ and the Corresponding Arenes. (3-Methoxybenzyl alcohol)chromium Tricarbonyl (8). A mixture of 3-methoxybenzyl alcohol (2.80 g, 20 mmol) and Cr(CO)$_6$ (3.3 g, 15 mmol) in heptane (75 mL) and butyl ether (150 mL) was refluxed under nitrogen for 30 h in a Strohmeier-type apparatus.[15] After filtration and evaporation in vacuo, a crude product was purified by SiO_2 chromatography with ether–petroleum ether (1:4). Crystallization from ether–pentane gave the complex **8** as yellow crystals: 3.20 g (78%); mp 109–110 °C; IR ($CHCl_3$) 1960, 1900–1860, 1520, 1275 cm^{-1}; NMR ($CDCl_3$) 2.12 (1 H, t, J = 6), 5.23 (1 H, d) 4.57 (2 H, d, J = 6), 4.93 (1 H, dd, J = 1, 6), 5.11 (1 H, d, J = 6), 5.23 (1 H, d, J = 1), 5.59 (1 H, d, J = 6). Anal. Calcd for $C_{11}H_{10}O_5Cr$: C, 48.19; H, 3.68. Found: C, 48.20; H, 3.73.

Complexes **8a**, **10**, and **22–26** were obtained with a similar method. Yields and physical data were as follows.

[3-(Methoxymethoxy)benzyl alcohol]chromium Tricarbonyl (8a): yield 65%; unstable yellow liquid; IR ($CHCl_3$) 3400, 1990, 1910, 1900 cm^{-1}; NMR ($CDCl_3$) 2.20 (1 H, t, J = 7), 3.40 (3 H, s), 4.26 (2 H, d, J = 7), 4.89 (1 H, dd, J = 1, 6), 5.00 (2 H, s), 5.20 (1 H, dd, J = 1, 6), 5.30 (1 H, d, J = 1), 5.50 (1 H, t, J = 6).

(7-Methoxy-1-tetralone)chromium Tricarbonyl (10): yield 65%; mp 95–96 °C; IR ($CHCl_3$) 1975, 1920–1880, 1685, 1540 cm^{-1}; NMR ($CDCl_3$) 2.0–2.95 (4 H, m), 3.66 (3 H, s), 5.36 (1 H, d, J = 6), 5.49 (1 H, dd, J = 2, 6), 5.66 (1 H, d, J = 2). Anal. Calcd for $C_{14}H_{12}O_5Cr$: C, 53.85; H, 3.87. Found: C, 53.61; H, 3.89.

(3-Methoxybenzaldehyde ethylene acetal)chromium Tricarbonyl (22): yield 92%; mp 105 °C; IR ($CHCl_3$) 1980, 1900 (br), 1540 cm^{-1}; NMR ($CDCl_3$) 3.78 (3 H, s), 4.12 (4 H, m), 5.04

(14) The *endo*-methyl ether complex **19** underwent deprotonation at C-1 (benzylic hydrogen abstraction) without nuclear lithiation under similar conditions. The exo-benzylic hydrogen of the π(arene)chromium complex is easily abstracted by base. See: Brocard, J.; Lebibi, J.; Couturier, D. *J. Chem. Soc., Chem. Commum.* **1981**, 1264 and references cited therein.

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(20) Hydride is always introduced from the exo side (the other side to the Cr(CO)$_3$ group about the ring system) and leads to *endo*-hydroxyl compounds (hydroxyl group is placed on the same side as the Cr(CO)$_3$ group; see ref 16).

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(1 H, d, J = 6), 5.14 (1 H, dd, J = 2, 6), 5.38 (1 H, d, J = 2), 5.56 (1 H, t, J = 6), 5.64 (1 H, s). Anal. Calcd for $C_{13}H_{12}O_6Cr$: C, 49.38; H, 3.83. Found: C, 49.31; H, 3.85.

(3,4-Dimethoxybenzaldehyde ethylene acetal)chromium Tricarbonyl (23): yield 75%; mp 125–126 °C; IR ($CHCl_3$) 1980, 1910, 1890 cm^{-1}; NMR ($CDCl_3$) 3.78 (3 H, s), 3.82 (3 H, s), 4.08 (4 H, m), 5.24 (2 H, s), 5.50 (2 H, s). Anal. Calcd for $C_{14}H_{14}O_7Cr$: C, 48.54; H, 4.08. Found: C, 48.56; H, 4.07.

(Piperonal ethylene acetal)chromium Tricarbonyl (24): yield 37%; mp 99–101 °C; IR ($CHCl_3$) 1975, 1890 (br), 1460, 1260 cm^{-1}; NMR ($CDCl_3$) 4.06–4.14 (4 H, m), 5.19 (1 H, d, J = 7), 5.45 (1 H, d, J = 7), 5.51 (1 H, s), 5.70 (2 H, s), 5.96 (1 H, s). Anal. Calcd for $C_{13}H_{13}O_7Cr$: C, 47.28; H, 3.05. Found: C, 47.29; H, 3.05.

(3,4,5-Trimethoxybenzaldehyde ethylene acetal)chromium Tricarbonyl (25): yield 34; mp 153 °C; IR ($CHCl_3$) 1980, 1900, 1890, 1480 cm^{-1}; NMR ($CDCl_3$) 3.86 (6 H, s), 3.91 (3 H, s), 4.14 (4 H, br s), 4.93 (2 H, s), 5.66 (1 H, s). Anal. Calcd for $C_{15}H_{16}O_8Cr$: C, 47.99; H, 4.39. Found: C, 47.88; H, 4.29.

(3-Methoxyacetophenone ethylene acetal)chromium Tricarbonyl (26): yield 92%; mp 92–93 °C; IR ($CHCl_3$) 1980, 1900–1890, 1530, 1050 cm^{-1}; NMR ($CDCl_3$) 1.72 (3 H, s), 3.77 (3 H, s), 4.10–4.25 (4 H, m), 5.17–5.24 (2 H, m), 5.43–5.48 (2 H, m). Anal. Calcd for $C_{14}H_{14}O_6Cr$: C, 50.92; H, 4.27. Found: C, 50.80; H, 4.31.

Methylation of Hydroxyl Group of the Complexes 8, 14, and 16. (3-Methoxybenzyl methyl ether)chromium Tricarbonyl (9). A solution of the complex **8** (474 mg, 1.7 mmol) in dry ether (10 mL) was added by a syringe into a mixture of NaH (50% oil dispersion, 110 mg, 2.29 mmol) in ether (10 mL) and DMF (5 mL) at 0 °C under a nitrogen atmosphere. After 30 min, 0.5 mL of MeI was added, and the mixture was stirred for 3 h. After addition of water, the reaction mixture was extracted with ether. The extract was washed with brine and dried over Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified by SiO_2 chromatography (ether–petroleum ether) to give the complex **9** as yellow crystals: 479 mg; mp 59 °C; IR ($CHCl_3$) 1960, 1900–1860, 1460, 1280 cm^{-1}; NMR ($CDCl_3$) 3.48 (3 H, s), 3.74 (3 H, s), 4.10 (2 H, s), 4.70 (1 H, d, J = 6), 4.90 (1 H, d, J = 6), 5.08 (1 H, s), 5.46 (1 H, t, J = 6). Anal. Calcd for $C_{12}H_{12}O_5Cr$: C, 48.19; H, 3.68. Found: C, 48.20; H, 3.73.

Complexes **14** and **16** were methylated by an analogous procedure as discribed above.

(Methyl ether of 7-methoxy-1-tetralol)chromium Tricarbonyl (19): yield 92%; mp 123 °C; IR ($CHCl_3$) 1975, 1900, 1890 cm^{-1}; NMR ($CDCl_3$) 3.52 (3 H, s), 3.64 (3 H, s), 4.14 (1 H, t, J = 6), 5.15 (1 H, dd, J = 2, 7), 5.34 (1 H, d, J = 2), 5.36 (1 H, d, J = 7). Anal. Calcd for $C_{15}H_{16}O_5Cr$: C, 54.88; H, 4.91. Found: C, 54.80; H, 4.87.

(Methyl ether of 7-methoxy-2,2-dimethyl-1-tetralol)-chromium Tricarbonyl (20): yield 90%; mp 102 °C; IR ($CHCl_3$) 1975, 1900, 1875 cm^{-1}; NMR ($CDCl_3$) 0.96 (3 H, s), 1.12 (3 H, s), 1.2–1.8 (2 H, m), 2.50 (2 H, t, J = 7), 3.52 (1 H, s), 3.64 (3 H, s), 3.68 (3 H, s), 5.10 (3 H, s). Anal. Calcd for $C_{17}H_{20}O_5Cr$: C, 57.30; H, 5.66. Found: C, 57.31; H, 5.67.

Reduction of the Complexes 10–13 with $LiAlH_4$. *endo*-(7-Methoxy-1-tetralol)chromium Tricarbonyl (14). A solution of the complex **10** (1.0 g, 3.2 mmol) in dry ether (30 mL) was added into a mixture of $LiAlH_4$ (487 mg, 12.8 mmol) in ether (20 mL) at 0 °C under a nitrogen atmosphere. After the mixture was stirred for 3 h, water was added. After filtration and evaporation of the organic solvent under reduced pressure, the residue was purified by SiO_2 chromatography to give the complex **14** (800 mg) as yellow crystals: mp 121 °C; IR ($CHCl_3$) 1960, 1880–1860 cm^{-1}; NMR ($CDCl_3$) 3.89 (3 H, s), 4.66–4.98 (1 H, m), 5.47 (1 H, dd, J = 2, 7), 5.63 (1 H, d, J = 7), 5.70 (1 H, d, J = 2). Anal. Calcd for $C_{14}H_{14}O_5Cr$: C, 53.51; H, 4.49. Found: C, 53.38; H, 4.69.

Complexes **11–13** were reduced with $LiAlH_4$ by an analogous procedure as discribed above.

***endo*-(7-Methoxy-2-methyl-1-tetralol)chromium Tricarbonyl (15)**: yield 75%; mp 113–114 °C; IR ($CHCl_3$) 3400, 1980, 1900, 1890 cm^{-1}; NMR 1.20 (3 H, d, J = 7), 3.65 (3 H, s), 4.15 (1 H, t, J = 9), 5.23 (1 H, dd, J = 1, 6), 5.43 (1 H, d, J = 6), 5.45 (1 H, d, J = 1). Anal. Calcd for $C_{15}H_{16}O_5Cr$: C, 54.88; H, 4.91. Found: C, 54.82; H, 4.95.

***endo*-(7-Methoxy-2,2-dimethyl-1-tetralol)chromium Tricarbonyl (16)**: yield 80%; mp 145 °C; IR ($CHCl_3$) 3440, 1975, 1890, 1875 cm^{-1}; NMR ($CDCl_3$) 1.06 (3 H, s), 1.18 (3 H, s), 4.18 (1 H, d, J = 8), 5.28 (1 H, d, J = 7), 5.42 (1 H, dd, J = 2, 7), 5.46 (1 H, d, J = 2). Anal. Calcd for $C_{16}H_{18}O_5Cr$: C, 56.14; H, 5.30. Found: C, 56.24; H, 5.31.

***endo*-(7-Methoxy-2-(1-hydroxyethyl)-1-tetralol)chromium Tricarbonyl (17)**: yield 65%; unstable yellow oil; IR ($CHCl_3$) 3400, 1950, 1870 (br), 1540 cm^{-1}; NMR ($CDCl_3$) 1.28 (3 H, d, J = 8), 3.76 (3 H, s), 4.25 (1 H, m), 5.32 (1 H, m), 5.50 (1 H, dd, J = 2, 6), 5.62 (1 H, d, J = 2).

Preparation of the Complexes 11 and 12 from 10. MeI (1.44 mL, 2.4 mmol) was added slowly into a mixture of the complex **10** (1.80 g, 6 mmol) and NaH (50% oil dispersion, 0.36 g, 7.2 mmol) in dry benzene (180 mL) and DMF (18 mL) at 0 °C under nitrogen. After being stirred for 3 h, the reaction mixture was decomposed with water and worked up as usual. Purification of the crude product over SiO_2 (60 g) with ether–petroleum ether gave two pure compounds. **Monomethyl complex 11**: 1.41 g (73%); mp 71–72 °C; IR ($CHCl_3$) 1980, 1920, 1900, 1680 cm^{-1}; NMR ($CDCl_3$) 1.22 (3 H, d, J = 2), 3.72 (3 H, s), 5.28 (1 H, d, J = 7), 5.40 (1 H, dd, J = 2, 7), 5.58 (1 H, d, J = 2). Anal. Calcd for $C_{15}H_{14}O_5Cr$: C, 55.22; H, 4.33. Found: C, 55.32; H, 4.37. **Dimethyl complex 12**: 280 mg (14%); mp 110–111 °C; IR ($CHCl_3$) 1990, 1920, 1900, 1680, 1600 cm^{-1}; NMR ($CDCl_3$) 1.12 (3 H, s), 1.28 (3 H, s), 3.68 (3 H, s), 5.32 (1 H, d, J = 7), 5.42 (1 H, dd, J = 2, 7), 5.62 (1 H, d, J = 2). Anal. Calcd for $C_{16}H_{16}O_5Cr$: C, 56.47; H, 4.74. Found: C, 56.47; H, 4.76.

***exo*-(7-Methoxy-1-tetralol)chromium Tricarbonyl (18).** A solution of the endo complex **14** (980 mg, 3.1 mmol) in CH_2Cl_2 (4 mL) was added to a mixture of concentrated H_2SO_4 (7 mL) and CH_2Cl_2 (7 mL) at −15 °C under argon. After being stirred for 2 min, the reaction mixture was decomposed with ice–water and worked up as usual. Chromatography with SiO_2 gave pure yellow complex **18**: 490 mg; mp 90–92 °C; IR ($CHCl_3$) 3420, 1960, 1885–1860 cm^{-1}; NMR ($CDCl_3$) 3.72 (3 H, s), 4.77 (1 H, t, J = 6), 5.19 (1 H, dd, J = 2, 7), 5.39 (1 H, d, J = 2), 5.47 (1 H, d, J = 7). Anal. Calcd for $C_{14}H_{14}O_5Cr$: C, 53.51; H, 4.49. Found: C, 53.22; H, 4.67.

***exo*-(Methyl ether of 7-methoxy-1-tetralol)chromium Tricarbonyl (21).** Concentrated H_2SO_4 (10 mL) was added slowly to the mixture of the endo complex **14** (1.0 g, 3.18 mmol) in MeOH (20 mL) at −10 °C under argon. The reaction mixture was allowed to stir for 10 min and poured into ice–water. Purification with SiO_2 chromatography (ether–petroleum ether) gave 520 mg of the complex **21**: mp 72 °C; IR ($CHCl_3$) 1980, 1900, 1890, 1550 cm^{-1}; NMR ($CDCl_3$) 3.54 (3 H, s), 3.74 (3 H, s), 4.32 (1 H, t, J = 6), 5.20 (1 H, dd, J = 2, 6), 5.32 (1 H, d, J = 2), 5.46 (1 H, d, J = 6). Anal. Calcd for $C_{15}H_{16}O_5Cr$: C, 54.88; H, 4.91. Found: C, 55.00; H, 4.90.

General Procedure for the Lithiation of Complexes. Unless otherwise specified, all reactions were performed in flame-dried glassware under an argon atmosphere by addition of a solution of the complex in dry THF or ether dropwise to a cold stirred solution of a 1:1 alkyllithium–TMEDA complex in dry THF or ether at −78 °C. After the reaction period, the mixture was treated with an electrophilic reagent at −78 °C. After the reaction mixture had been allowed to warm to ambient temperature, water was added and the mixture then extracted with either. The extract was exposed to sunlight for several hours until a color of the complex disappeared. After filtration and washing of the filtrate with ether, removal of the solvent in vacuo gave the crude product. The reaction products of the complexes **8**, **8a**, and **14** with trimethylchlorosilane were obtained as free hydroxyl compounds after hydrolysis of the silyl ether by treatment with dilute HCl. The products of the complexes **23–26** with $ClCO_2Me$ were purified after hydrolysis of the ethylene acetal group with dilute HCl. The crude products were purified by chromatography, and the ratio of the crude products was determined by ^1H NMR spectroscopy and GLC.

Methoxycarbonylation of the Complex 8. To a solution of the complex **8** (274 mg, 1 mmol) and TMEDA (278 mg, 2.4 mmol) in dry ether (15 mL) at −78 °C was added dropwise 1.6 mL (1.5 M in hexane, 2.4 mmol) of *n*-BuLi solution under argon. After being stirred for 4 h, the resulting mixture was poured into an ether solution of saturated dry ice. After being allowed to stand

overnight, the reaction mixture was acidified with dilute HCl, and then the product was extracted with ether. The extract was exposed to sunlight for 2 h to give a colorless solution. The precipitate was filtered, and then the solution was treated with an excess of diazomethane. After evaporation of the solvent under reduced pressure, the ratio of the crude product was determined by GLC (3% OV-1, 1.5 m, 150 °C) and ^{1}H NMR. Purification with SiO_2 (ether–petroleum ether) gave two carboxylated products. **7-Methoxyphthalide (2)**: 26 mg; mp 110 °C (lit.[22] mp 107–109 °C); IR ($CHCl_3$) 1745 cm^{-1}; NMR ($CDCl_3$) 3.90 (3 H, s), 5.17 (2 H, s), 6.83 (1 H, dd, J = 2, 8), 6.93 (1 H, dd, J = 2, 8), 7.50 (1 H, t, J = 8). Anal. Calcd for $C_9H_8O_3$: C, 65.83; H, 4.91. Found: C, 65.81; H, 4.90. **3-Methoxy-4-(methoxycarbonyl)benzyl alcohol (3)**: 145 mg; colorless oil; IR ($CHCl_3$) 3450, 1710, 1610 cm^{-1}; NMR ($CDCl_3$) 3.86 (6 H, s), 4.70 (2 H, s), 6.89 (1 H, dd, J = 1, 8), 6.97 (1 H, d, J = 1), 7.73 (1 H, d, J = 8); MS (30 eV), m/e (relative intensity) 196 (M^+, 46), 165 (100), 163 (82).

Trimethylsilylation of the Complex 8 with t-BuLi. The complex 8 (138 mg, 0.5 mmol) was lithiated with t-BuLi (1.35 M in pentane, 1.0 mL, 1.4 mmol) and TMEDA (162 mg, 1.4 mmol), and then the mixture was treated with Me_3SiCl (0.5 mL). After a workup as usual, pure **3-methoxy-4-(trimethylsilyl)benzyl alcohol** was obtained as colorless oil: yield 53 mg (50%); IR ($CHCl_3$) 3410, 1600 cm^{-1}; NMR ($CDCl_3$) 0.19 (9 H, s), 3.68 (3 H, s), 4.40 (2 H, s), 6.60 (1 H, dd, J = 1, 7), 6.70 (1 H, d, J = 1), 7.16 (1 H, d, J = 7); MS, m/e (relative intensity) 210 (M^+, 23), 195 (53), 165 (100).

Complexes **8a** and **14–18** were lithiated with a similar method (n-BuLi/TMEDA, ether, −78 °C) and quenched by the proper electrophiles. Physical data were as follows.

Electrophilic Substitution of Lithiated Complex 8a. (a) With CO_2; 3-(methoxymethoxy)-4-(methoxycarbonyl)benzyl alcohol: IR (neat) 3420, 1715, 1450 cm^{-1}; NMR ($CDCl_3$) 1.60 (1 H, s), 3.40 (3 H, s), 3.92 (3 H, s), 4.56 (2 H, s), 4.68 (2 H, s), 6.82 (1 H, dd, J = 1, 8), 6.96 (1 H, d, J = 1), 7.76 (1 H, d, J = 8); MS m/e (relative intensity) 226 (M^+, 20), 195 (66), 165 (56), 150 (100).

(b) With Me_3SiCl; 3-(methoxymethoxy)-4-(trimethylsilyl)benzyl alcohol: liquid; 67% yield; IR (neat) 3420, 1600, 1390 cm^{-1}; NMR ($CDCl_3$) 0.24 (3 H, s), 2.36 (1 H, s), 3.44 (3 H, s), 4.62 (2 H, s), 5.16 (2 H, s), 6.82 (1 H, dd, J = 1, 7), 7.02 (1 H, d, J = 1), 7.32 (1 H, d, J = 7); MS, m/e (relative intensity) 240 (M^+, 18), 195 (36), 165 (36), 163 (47), 89 (63), 75 (100).

Electrophilic Substitution of Lithiated Complex 14. (a) With CO_2; 7-methoxy-6-(methoxycarbonyl)-1-tetralol: liquid; 65% yield; IR (neat) 3420, 1715, 1610 cm^{-1}; NMR ($CDCl_3$) 3.75 (3 H, s), 3.79 (3 H, s), 4.56 (1 H, m), 6.94 (1 H, s), 7.35 (1 H, s); MS, m/e (relative intensity) 218 ($M^+ - H_2O$, 100), 216 (54), 187 (79), 185 (64), 159 (37).

(b) With Me_3SiCl; 7-methoxy-6-(trimethylsilyl)-1-tetralol: 80% yield; IR ($CHCl_3$) 3420, 1600, 1560 cm^{-1}; NMR ($CDCl_3$) 0.24 (9 H, s), 3.83 (3 H, s), 6.96 (1 H, s), 7.12 (1 H, s); MS, m/e (relative intensity) 232 ($M^+ - H_2O$, 43), 217 (27), 187 (100), 143 (31).

(c) With p-anisaldehyde; 7-methoxy-6-(1-hydroxy-4-methoxybenzyl)-1-tetralol: mp 129 °C; 90% yield; IR ($CHCl_3$) 3420, 1615, 1510 cm^{-1}; NMR ($CDCl_3$) 3.78 (6 H, s), 4.70 (1 H, m), 5.94 (1 H, s), 6.82 (2 H, d, J = 9), 6.96 (2 H, br), 7.37 (2 H, d, J = 9). Anal. Calcd for $C_{19}H_{22}O_4$: C, 72.59; H, 7.05. Found: C, 72.30; H, 7.06.

(d) With dimethyl phthalate; 7-methoxy-6-[o-(methoxycarbonyl)benzoyl]-1-tetralol: liquid; 91% yield; IR (neat) 3410, 1720, 1650, 1605, 1280 cm^{-1}; NMR ($CDCl_3$) 3.58 (3 H, s), 3.68 (3 H, s), 4.76 (1 H, m), 7.06 (1 H, s), 7.51 (1 H, s), 7.34–7.91 (4 H, m); MS, m/e (relative intensity) 322 ($M^+ - H_2O$, 54), 320 (32), 187 (100), 185 (35), 163 (51).

(e) With tigloyl chloride; 7-methoxy-6-tigloyl-1-tetralol: oil; 82% yield; IR ($CHCl_3$) 3410, 1640, 1605, 1220 cm^{-1}; NMR ($CDCl_3$) 1.82 (3 H, d, J = 6), 1.85 (3 H, br s), 3.70 (3 H, s), 4.57 (1 H, m), 6.23 (1 H, m), 6.71 (1 H, s), 6.90 (1 H, s); MS, m/e (relative intensity) 242 ($M^+ - H_2O$, 44), 240 (22), 187 (100), 185 (27).

Electrophilic Quenching of Lithiated Complex 15. (a) With CO_2; 7-methoxy-2-methyl-6-(methoxycarbonyl)-1-tetralol: colorless liquid; 63% yield; IR ($CHCl_3$) 3420, 1720, 1615, 1570 cm^{-1} NMR ($CDCl_3$) 1.33 (3 H, d, J = 7), 3.87 (3 H, s), 3.90 (3 H, s), 4.70 (1 H, d, J = 8), 7.20 (1 H, s), 7.30 (1 H, s); MS, m/e (relative intensity) 232 ($M^+ - H_2O$, 100), 230 (72), 201 (78), 199 (80), 173 (31), 158 (40).

(b) With DMF; 7-methoxy-2-methyl-6-formyl-1-tetralol: mp 108–109 °C; IR ($CHCl_3$) 3450, 1675, 1610 cm^{-1}; NMR ($CDCl_3$) 1.19 (3 H, d, J = 6), 3.90 (3 H, s), 4.25 (1 H, t, J = 8), 7.16 (1 H, s), 7.45 (1 H, s), 10.30 (1 H, s). Anal. Calcd for $C_{13}H_{16}O_3$: C, 70.89; H, 7.32. Found: C, 70.86; H, 7.37.

Formylation of Complex 16. 7-Methoxy-2,2-dimethyl-6-formyl-1-tetralol: mp 118 °C; 92% yield; IR ($CHCl_3$) 3470, 1680, 1610 cm^{-1}; NMR ($CDCl_3$) 0.95 (3 H, s), 1.05 (3 H, s), 3.88 (3 H, s), 4.25 1 H, d, J = 7), 7.10 (1 H, s), 7.45 (1 H, s), 10.30 (1 H, s). Anal. Calcd for $C_{14}H_{18}O_3$: C, 71.77; H, 7.74. Found: C, 71.84; H, 7.74.

Methoxycarbonylation of Complex 17. 2-(1-Hydroxyethyl)-7-methoxy-6-(methoxycarbonyl)-1-tetralol: colorless oil; 55% yield; IR ($CHCl_3$) 3430, 1720, 1615, 1570 cm^{-1}; NMR ($CDCl_3$) 1.33 and 1.35 (3:2 ratio, 3 H, d, J = 7), 3.87 (3 H, s), 3.90 (3 H, s), 4.76 and 4.86 (3:2 ratio, 1 H, d, J = 8), 7.20 (1 H, s), 7.30 (1 H, s); MS, m/e (relative intensity) 262 ($M^+ - H_2O$, 4), 244 (100), 242 (51), 218 (34), 213 (64), 211 (48), 185 (29), 187 (30).

Lithiation and Methoxycarbonylation of Complex 9. The complex **9** (286 mg, 1.0 mmol) was lithiated with n-BuLi (0.8 mL, 1.2 mmol) and TMEDA (0.18 mL, 1.2 mmol) in dry THF (15 mL), and then the reaction mixture was treated with methyl chlorocarbonate (0.5 mL). After a work up as usual, the crude product was purified over SiO_2. **2-(Methoxycarbonyl)-3-methoxybenzyl methyl ether**: oil; 120 mg; IR (neat), 1720, 1610, 1460 cm^{-1}; NMR (CCl_4) 3.25 (3 H, s), 3.78 (6 H, s), 4.35 (2 H, s), 6.72 (1 H, d, J = 8), 6.86 (1 H, d, J = 8), 7.20 (1 H, t, J = 8); MS, m/e (relative intensity) 210 (M^+, 22), 178 (32), 163 (100), 151 (35). **2,4-Bis(methoxycarbonyl)-3-methoxybenzyl methyl ether**: oil; 25 mg; IR (neat) 1720, 1605 cm^{-1}; NMR (CCl_4) 3.30 (3 H, s), 3.82 (3 H, s), 3.84 (6 H, s), 4.36 (2 H, s), 7.10 (1 H, d, J = 8), 7.72 (1 H, d, J = 8); MS, m/e (relative intensity) 268 (M^+, 5), 236 (100), 221 (82), 193 (29).

The complexes **22–26** were lithiated with a similar method (n-BuLi/TMEDA, THF, −78 °C), and the reaction products of the complexes **23–26** with methyl chlorocarbonate were isolated as carbonyl compounds after treatment with 2 N HCl. Physical data were as follows.

Lithiation and Electrophilic Substitution of Complex 22. (a) With $ClCO_2Me$; 3-methoxy-2-(methoxycarbonyl)benzaldehyde ethylene acetal: yield 84%; IR (CCl_4) 1720, 1600, 1470, 1270 cm^{-1}; NMR (CCl_4) 3.73 (3 H, s), 3.77 (3 H, s), 3.84 (4 H, s), 5.86 (1 H, s), 6.79 (1 H, dd, J = 1, 7), 7.02 (1 H, dd, J = 1, 7), 7.21 (1 H, t, J = 7); MS, m/e (relative intensity) 238 (M^+, 34), 207 (42), 179 (51), 135 (70), 73 (100).

(b) With Me_3SiCl; 2-(trimethylsilyl)-3-methoxybenzaldehyde ethylene acetal: IR ($CHCl_3$) 1240, 1030 cm^{-1}; NMR (CCl_4) 0.25 (9 H, s), 3.76 (3 H, s), 3.90 (4 H, m), 5.84 (1 H, s), 6.68 (1 H, m), 7.14–7.16 (2 H, m); MS, m/e (relative intensity) 252 (M^+, 2), 237 (35), 193 (100), 163 (13). **2,4-Bis(trimethylsilyl)-3-methoxybenzaldehyde ethylene acetal**: IR ($CHCl_3$) 1580, 1240, 1060 cm^{-1}; NMR (CCl_4) 0.20 (9 H, s), 0.28 (9 H, s), 3.60 (3 H, s), 3.90 (4 H, m), 5.90 (1 H, s), 7.08 (1 H, d, J = 8), 7.30 (1 H, d, J = 8); MS, m/e (relative intensity) 324 (M^+, 7), 309 (73), 265 (74), 235 (100).

Methoxycarbonylation of the Complexes 23–26. (a) With complex 23; 2-(methoxycarbonyl)-3,4-dimethoxybenzaldehyde: IR (CCl_4) 1720, 1680, 1260 cm^{-1}; NMR (CCl_4) 3.79 (3 H, s), 3.87 (3 H, s), 3.91 (3 H, s), 6.91 (1 H, d, J = 8), 7.44 (1 H, d, J = 8), 9.63 (1 H, s); MS, m/e (relative intensity) 224 (M^+, 37), 209 (40), 196 (54), 193 (45), 165 (100). **2,5-Bis(methoxycarbonyl)-3,4-dimethoxybenzaldehyde**: IR (CCl_4) 1720, 1680 cm^{-1}; NMR ($CDCl_3$) 3.84 (6 H, s), 3.90 (3 H, s), 3.95 (3 H, s), 7.86 (1 H, s), 9.80 (1 H, s); MS, m/e (relative intensity) 282 (M^+, 47), 251 (100), 235 (92), 224 (89).

(b) With complex 24; 2-(methoxycarbonyl)piperonal: IR ($CHCl_3$) 1720, 1680, 1600 cm^{-1}; NMR ($CDCl_3$) 3.90 (3 H, s), 6.07 (2 H, s), 6.84 (1 H, d, J = 8), 7.40 (1 H, d, J = 8), 9.96 (1 H, s); MS, m/e (relative intensity) 208 (M^+, 82), 193 (92), 180 (40), 177 (100), 149 (91). **2,5-Bis(methoxycarbonyl)piperonal**: IR ($CHCl_3$) 1720, 1680 cm^{-1}; NMR ($CDCl_3$) 3.80 (6 H, s), 6.10 (2 H, s), 7.78 (1 H, s), 9.89 (1 H, s); MS, m/e (relative intensity) 266

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(M^+, 72), 251 (57), 235 (83), 234 (46), 208 (39), 180 (100).

(c) With complex 25; 2-(methoxycarbonyl)-3,4,5-trimethoxybenzaldehyde: IR ($CHCl_3$) 1720, 1690, 1620 cm^{-1}; NMR ($CDCl_3$) 3.74 (3 H, s), 3.80 (3 H, s), 3.81 (3 H, s), 3.82 (3 H, s), 7.06 (1 H, s), 9.68 (1 H, s); MS, *m/e* (relative intensity) 254 (M^+, 29), 239 (26), 226 (59), 223 (38), 195 (100).

(d) With complex 26; 2-(methoxycarbonyl)-3-methoxyacetophenone: IR ($CHCl_3$) 1720, 1685, 1580 cm^{-1}; NMR ($CDCl_3$) 2.62 (3 H, s), 3.88 (3 H, s), 3.95 (3 H, s), 7.14 (1 H, m), 7.42 (2 H, m); MS, *m/e* (relative intensity) 208 (M^+, 11), 193 (100), 177 (38), 105 (20). **4-(Methoxycarbonyl)-3-methoxyacetophenone**: IR ($CHCl_3$) 1720, 1680, 1600, 885 cm^{-1}; NMR ($CDCl_3$) 2.64 (3 H, s), 3.92 (3 H, s), 3.96 (3 H, s), 7.52 (1 H, s), 7.50 (1 H, d, J = 7), 7.82 (1 H, d, J = 7); MS, *m/e* (relative intensity) 208 (M^+, 56), 193 (100), 177 (78), 165 (28), 133 (25).

Formylation of the Complexes 20 and 21. (a) With complex 21; 1,2,3,4-tetrahydro-1,7-dimethoxy-6-formylnaphthalene: IR (CCl_4) 1680, 1610 cm^{-1}; NMR (CCl_4) 3.40 (3 H, s), 3.84 (3 H, s), 4.16 (1 H, br s), 6.86 (1 H, s), 7.34 (1 H, s), 10.20 (1 H, s); MS, *m/e* (relative intensity) 220 (M^+, 13), 188 (100), 187 (23), 159 (23), 128 (21).

(b) With complex 20; 1,2,3,4-tetrahydro-2,2-dimethyl-1,7-dimethoxy-6-formylnaphthalene: IR ($CHCl_3$) 1680, 1610 cm^{-1}; NMR (CCl_4) 1.84 (3 H, s), 1.90 (3 H, s), 3.40 (3 H, s), 3.85 (3 H, s), 6.70 (1 H, s), 7.40 (1 H, s), 10.22 (1 H, s); MS, *m/e* (relative intensity) 248 (M^+, 13), 216 (59), 214 (32), 192 (100), 177 (41).

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Registry No. 1, 612-16-8; 2, 28281-58-5; 3, 57757-74-1; 4, 32820-10-3; 5, 85865-41-4; 6, 57757-81-0; 7, 85954-54-7; 8, 52520-37-3; 9, 85882-76-4; 10, 74411-87-3; 11, 85882-77-5; 12, 85882-78-6; 13, 74431-72-4; 14, 85882-79-7; 15, 85882-80-0; 16, 85882-81-1; 17, 74411-86-2; 18, 85922-59-4; 19, 85882-82-2; 20, 85882-83-3; 21, 85922-60-7; 22, 85893-28-3; 23, 71250-06-1; 24, 85893-29-4; 25, 85882-84-4; 26, 85882-85-5; 29, 76290-90-9; $Cr(CO)_6$, 13007-92-6; Me_3SiCl, 75-77-4; $ClCO_2Me$, 79-22-1; CO_2, 124-38-9; DMF, 68-12-2; 3-methoxy-4-(trimethylsilyl)benzyl alcohol, 85865-42-5; 3-(methoxymethoxy)-4-(methoxycarbonyl)benzyl alcohol, 85865-43-6; 3-(methoxymethoxy)-4-(trimethylsilyl)benzyl alcohol, 85865-44-7; 7-methoxy-6-(methoxycarbonyl)-1-tetralol, 76290-90-9; 7-methoxy-6-(trimethylsilyl)-1-tetralol, 76290-91-0; 7-methoxy-6-(1-hydroxy-4-methoxybenzyl)-1-tetralol, 76290-92-1; *p*-anisaldehyde, 123-11-5; dimethyl phthalate, 131-11-3; tigloyl chloride, 35660-94-7; 7-methoxy-6-[*o*-(methoxycarbonyl)-benzoyl]-1-tetralol, 76290-93-2; 7-methoxy-6-tigloyl-1-tetralol, 85865-45-8; 7-methoxy-2-methyl-6-(methoxycarbonyl)-1-tetralol, 76290-95-4; 7-methoxy-2-methyl-6-formyl-1-tetralol, 85865-46-9; 7-methoxy-2,2-dimethyl-6-formyl-1-tetralol, 85865-47-0; 2-(1-hydroxyethyl)-7-methoxy-6-(methoxycarbonyl)-1-tetralol, 76290-96-5; 2-(methoxycarbonyl)-3-methoxybenzyl methyl ether, 85865-48-1; 2,4-bis(methoxycarbonyl)-3-methoxybenzyl methyl ether, 85865-49-2; 3-methoxy-2-(methoxycarbonyl)benzaldehyde ethylene acetal, 85865-50-5; 2-(trimethylsilyl)-3-methoxybenzaldehyde ethylene acetal, 85865-51-6; 2,4-bis(trimethylsilyl)-3-methoxybenzaldehyde ethylene acetal, 85865-52-7; 2-(methoxycarbonyl)-3,4-dimethoxybenzaldehyde, 62059-59-0; 2,5-bis(methoxycarbonyl)-3,4-dimethoxybenzaldehyde, 85865-53-8; 2-(methoxycarbonyl)piperonal, 85865-54-9; 2,5-bis(methoxycarbonyl)piperonal, 85865-55-0; 2-(methoxycarbonyl)-3,4,5-trimethoxybenzaldehyde, 85865-56-1; 2-(methoxycarbonyl)-3-methoxyacetophenone, 85865-57-2; 4-(methoxycarbonyl)-3-methoxyacetophenone, 85865-58-3; 1,2,3,4-tetrahydro-1,7-dimethoxy-6-formylnaphthalene, 85865-59-4; 1,2,3,4-tetrahydro-2,2-dimethyl-1,7-dimethoxy-6-formylnaphthalene, 85865-60-7.

Supplementary Material Available: Three tables listing fractional coordinates, temperature factors, bond distances, and bond angles of complex 16 (5 pages). Ordering information is given on any current masthead page.

General Method for the Synthesis of Phthalaldehydic Acids and Phthalides from *o*-Bromobenzaldehydes via Ortho-Lithiated Aminoalkoxides

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A general method for the synthesis of phthalaldehydic acids and phthalides, many of which are key intermediates in natural product synthesis, has been developed. *o*-Bromobenzaldehydes **1a–f** were first protected in situ as α-morpholinoalkoxides by reaction with lithium morpholide. Treatment of the α-morpholinoalkoxides **3a–f** with *n*-butyllithium (to exchange bromine with lithium) followed by sequential treatment with solid CO_2 and dilute acid afforded the phthalaldehydic acids **6a–f**, respectively. Reduction of **6a–f** with $NaBH_4$ in EtOH furnished the phthalides **7a–f**, respectively, in nearly quantitative yields. Efficient methods for the synthesis of the *o*-bromobenzaldehydes **1a–d**, which were not readily available, are also described.

Phthalaldehydic acids and phthalides are useful synthons for a number of classes of natural products. Phthalides have been used as key intermediates in the synthesis of functionalized naphthalenes and anthracenes, which in turn are used as synthons for tricyclic and tetracyclic linear aromatic natural products.[1,2] Phthalides have also been utilized in the synthesis of phthalide isoquinoline alkaloids,[1,3] some of which exhibit central nervous system activity.[3] Major methods for the synthesis of the more useful phthalides, namely, phthalides with alkoxy substituents on the benzene ring,[2] involve appropriate transformation of suitable ortho-lithiated benzyl alcohols,[3-6] *N,N*-dialkylbenzylamine,[3] or benzamides.[7]

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