Synthesis, Properties, and Reactions with C-Nucleophiles of (Phenyloxazoline)-, (Phenylmethanimine)-, and (Benzaldehyde hydrazone)tricarbonylchromium(0) Complexes

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The title complexes react efficiently with carbon nucleophiles to give *ortho* addition products with good to excellent regioselectivity. 2-Lithio-2-methylpropionitrile substantially adds *meta* and *para* at low temperature but rearranges at 0 °C to give predominantly *ortho* selectivity. Smaller nucleophiles ($LiCH_2S(O)C_6H_4$-*p*-Me, $LiCH_2CO_2$-*t*-Bu) and simple alkyllithium reagents (MeLi, *n*-BuLi, *t*-BuLi (in the absence of HMPA), (vinyl)Li, PhLi) exclusively add *ortho* to the functional group. Arene lithiation is not a competitive reaction with these complexes. Oxidative (I_2) decomplexation yields the free 1,2-disubstituted arenes. Under the workup conditions the phenyloxazolines *ortho* substituted by a 2-methylpropionitrile, 2-propionitrile, or acetonitrile group are not stable. Intramolecular addition of oxazoline to the nitrile leads to the carboxylic acid in the first case and to isoquinolone products in the two other cases. *ortho* regioselectivity is ascribed to chelation of the incoming organolithium reagent. The rearrangement of the nitrile-stabilized nucleophiles shows that *ortho* addition is also favored thermodynamically. *ortho*/*para* regioselectivity is assisted by the electron-withdrawing nature of the oxazoline and methanimine functions. The aldehyde hydrazone function, however, is shown to have resonance donor character, and the exclusive *ortho* addition here must be ascribed entirely to the chelation effect.

Introduction

The regioselective preparation of polysubstituted arenes is an important synthetic goal in a large number of industrial and academic laboratories.[1] Many natural and synthetic products are benzene derivatives or incorporate aromatic and heterocyclic rings. These compounds often display important biological activity and are therefore of interest for pharmaceutical and agrochemical use.[2] The large repertoire available to the chemist to form or transform arenes underscores the importance of this class of compounds. Despite this fact, the regioselective preparation of 1,2-disubstituted or more contiguously substituted aromatic hydrocarbons remains a challenge. This has stimulated the search for and the development of new methodologies for the 1,2 (*ortho*)-functionalization of benzene, the simplest arene: electrophilic aromatic substitution, either *via* protection–deprotection of the *para* position[3] or under metal coordination control;[4] sigmatropic rearrangements;[5] directed *ortho* metalation followed by reaction with an electrophile;[6] radical nucleophilic substitution ($S_{RN}1$);[7] nucleophilic aromatic substitution (S_NAr);[8] reactions *via* σ-aryl–transition-metal complexes.[9] For many of these methodologies, *ortho*-disubstituted benzene precursors are required.

Significant advances have been made in the development

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Scheme I

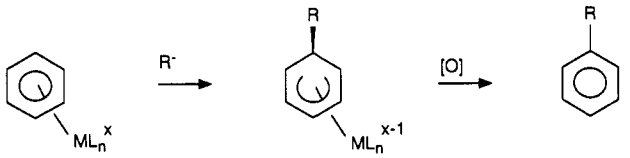
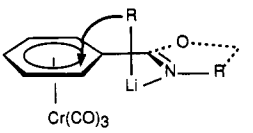
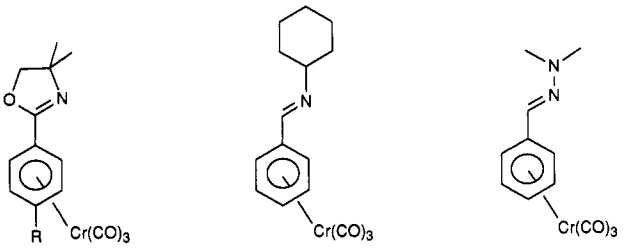


Chart I





1a : R = H

1b : R = OMe

2

3

of synthetically useful procedures to achieve formal nucleophilic aromatic substitution for hydrogen. This transformation can be accomplished with electrophilic arenes *via* the vicarious nucleophilic substitution reaction[10] and *via* a nucleophile addition–oxidation reaction sequence.[11] Activation of the aromatic ring toward nucleophilic attack is required for both these reactions and is usually provided by strongly electron-withdrawing σ-bound substituents. The limited range of reactive substrates and the moderate regioselectivity are serious drawbacks in these methodologies.

Formal replacement of an aromatic hydrogen by a nucleophile can also be achieved *via* the organometallic route shown in Scheme I. Here, the arene (e.g. benzene) is activated toward the addition of a nucleophile *via* complexation to an electrophilic transition-metal fragment. This reaction generates η^5-cyclohexadienyl–metal complexes, which, on oxidative decomplexation, yield the substituted arene. Nucleophilic addition is feasible for a wide range of arene–transition-metal complexes.[12] The degree of arene activation can be fine-tuned *via* the activating group. The choice of the metal fragment is therefore dictated by the accessibility of the complexes, the type of nucleophile to be added, and the conditions required for the oxidation–decomplexation step. The cationic fragments $Mn(CO)_3^+$, $Fe(\eta^5\text{-}C_5H_5)^+$, and $Fe(\eta^6\text{-}C_6H_6)^{2+}$ have been receiving increasing attention recently, but by far the most frequently used is the neutral $Cr(CO)_3$ group.

Substituted (η^6-arene)$Cr(CO)_3$ complexes react with a wide range of nucleophiles with often high regioselectivity,[12a] and this feature together with the facile *in situ* oxidative decomplexation makes this methodology particular attractive. Complementary to electrophilic aromatic substitution, *meta* selectivity dominates with strong π-donor substituents and *para* selectivity with π-acceptor substituents or bulky groups. A clear limitation is the lack of a general method for the synthesis of *ortho*-disubstituted benzenes *via* this methodology. In recent independent work in two laboratories,[13,14] several organolithium reagents were shown to add to (η^6-arene)$Cr(CO)_3$ complexes possessing a benzylic heteroatom function (nitrogen or oxygen). In the course of some of these reactions, elimination of the benzylic OR or NR_2 groups took place to afford, after decomplexation, *ortho*-substituted toluenes. The exclusive *ortho* regioselectivity, which must be attributed to lithium coordination, was a remarkable reversal of the *meta* or *ortho*/*meta* selectivity of (η^6-toluene)$Cr(CO)_3$ itself.[15] This methodology, however, suffers from the very limited range of nucleophiles that can be used, with arene lithiation being a competitive process. We thought that acceptor substituents, capable of lithium coordination, would be more suitable functional groups for the synthesis of *ortho*-substituted arenes *via* the nucleophile addition–oxidation sequence. We selected the oxazoline and methanimine functions for their known efficiency to bring about *ortho* lithiation of the benzene ring[16] and, in the case of naphthalene, *ortho*-nucleophilic addition reactions.[17] Although it has not been previously used for arene functionalization, we included the hydrazone function as a further promising candidate (Chart I).[18]

In this article we report on the synthesis of the new complexes **1–3**,[19] their spectroscopic and (for **1a**) structural properties, and their reactions with carbon nucleophiles. Some of the results presented here have been reported in preliminary form.[20]

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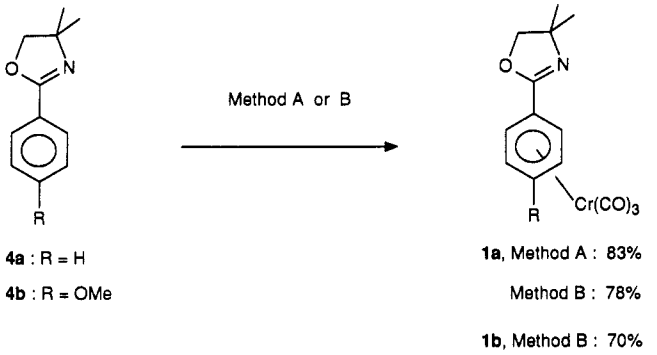
Scheme II



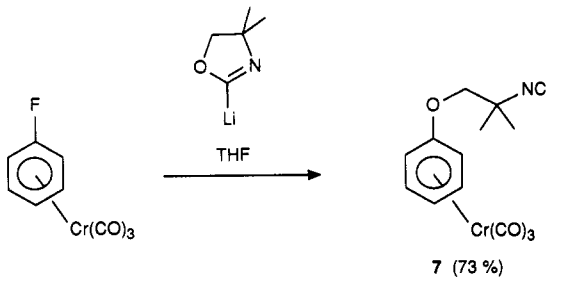
Results and Discussion

Preparation of Complexes 1–3. Complex **1a** was synthesized using the standard procedure of thermolysis of $Cr(CO)_6$[21] in the presence of arene **4a** (method A).[22a,b,23] Purification by flash chromatography and recrystallization afforded air-stable yellow needles of **1a** (83% yield). A synthesis under milder conditions involved heating a 1:2 mixture of the labile complex (η^6-naphthalene)$Cr(CO)_3$ (**5**)[24] and the phenyloxazoline **4a** or **4b**[22b,c] in THF for 20 h (method B). This afforded after workup respectively **1a** in 78% and **1b** in 70% yield (Scheme II). Excess ligand **4a** or **4b** could be recovered.

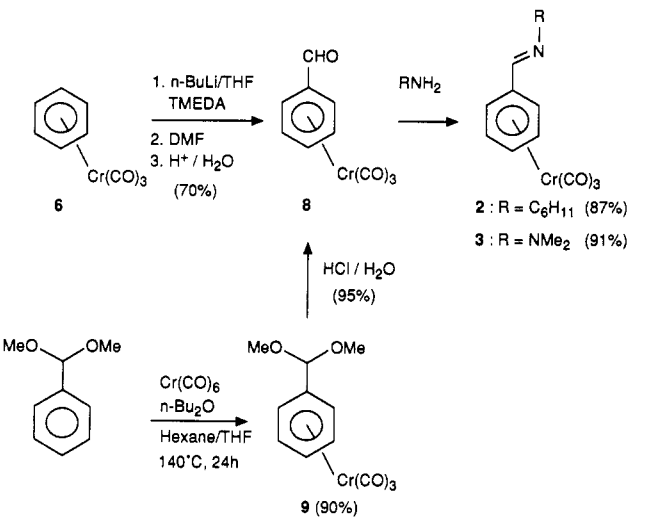
Some alternative synthetic routes to complex **1a** were briefly investigated but did not meet with success. Lithiation of (η^6-benzene)$Cr(CO)_3$ (**6**) with nBuLi/TMEDA[25] followed by treatment with 4,4-dimethyl-2-(phenylthio)oxazoline either by direct means or after addition of nickel phosphine complexes did not give **1a**.[26,27] The complementary strategy of nucleophilic substitution of fluoride in (η^6-fluorobenzene)$Cr(CO)_3$[21] by 2-lithio-4,4-dimethyloxazoline[28] yielded complex **7** exclusively in 73% yield. The alkoxide nucleophile, in equilibrium with the 2-lithiooxazoline,[29] is thus the preferred reaction partner in the nucleophilic substitution reaction with (fluorobenzene)$Cr(CO)_3$ (Scheme III).

Complexes **2** and **3** were prepared by the sequence shown in Scheme IV. (η^6-benzene)$Cr(CO)_3$ (**6**) was converted into (η^6-benzaldehyde)$Cr(CO)_3$ (**8**)[30] *via* lithiation with nBuLi/TMEDA[25] followed by quenching with DMF and hydrolysis.[31] Alternatively, heating a 1:2 mixture of $Cr(CO)_6$ and benzaldehyde dimethylacetal afforded complex **9**[19c] in 90% yield. Mild acid hydrolysis (2 N aqueous HCl/EtOH, room temperature) gave complex **8** in 95% yield. The subsequent conversion of complex **8** into **2** proceeded

Scheme III



Scheme IV



efficiently (87% yield, after crystallization) on heating a mixture of complex **8** and cyclohexylamine (1.1 equiv) in toluene in the presence of molecular sieves (4 Å). Complex **3** was readily obtained by mixing **8** and *N,N*-dimethylhydrazine (1.5 equiv) in diethyl ether at room temperature (91% yield, after crystallization).

IR Spectra. The infrared spectra of each of the complexes **1a**, **1b**, **2**, and **3** exhibited the expected pair of stretching frequencies due to the A_1 and E bands of the $Cr(CO)_3$ group. The data and the calculated Cotton–Kraihanzel force constants[32] are reported in Table I together with the values for complexes **6** and **8**, as well as for (η^6-methylbenzoate)$Cr(CO)_3$ (**10**)[33] and (η^6-anisole)$Cr(CO)_3$ (**11**),[33] which are included for comparison.

The IR stretching frequencies of the carbonyl ligands in (η^6-C_6H_5X)$Cr(CO)_3$ complexes are sensitive to the electronic effects of the arene substituent X. A π-donor group, via electron transfer from the filled π orbitals of the arene into the empty d orbitals of the metal, increases the electron density at the metal center. This, in turn, results in a more efficient π-back-bonding into the carbonyl π^* orbitals, leading to a decrease of the CO bond order and a shift of the CO stretching frequencies to lower wavenumbers (smaller k_{CO} force constants). The opposite—higher frequencies and larger k_{CO} force constants—is observed for a π-acceptor substituent X. In (arene)$Cr(CO)_3$ complexes, force constants k_{CO} have been used as a measure of the influence of the X substituent on the arene π-electron density.[33a] They have also been used to predict susceptibility of the coordinate arene to nucleophilic attack.[34] Inspection of the ν_{CO}, k_{CO}, and Δk_{CO} data

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Table I. IR Data and Cotton-Kraihanzel (k_{CO}, $k_{CO,CO}$) Force Constants for (arene)$Cr(CO)_3$ Complexes

entry no.	compd no.	ν_{CO}(A)[a] (cm^{-1})	ν_{CO}(E)[a] (cm^{-1})	k_{CO}[b] (mdyn/Å)	$k_{CO,CO}$ (mdyn/Å)	Δk_{CO} (mdyn/Å)
1	**6**	1983 (1974)	1915 (1894)	15.16 (14.90)	0.35 (0.42)	0
2	**1a**	1985 (1976)	1922 (1903)	15.25 (15.01)	0.33 (0.38)	+0.09 (+0.11)
3	**1b**	1982 (1972)	1917 (1897)	15.18 (14.92)	0.34 (0.39)	+0.02 (+0.02)
4	**2**	1983 (1973)	1917 (1899)	15.19 (14.94)	0.34 (0.38)	+0.03 (+0.04)
5	**3**	1975 (1964)	1909 (1887)	15.06 (14.78)	0.34 (0.40)	−0.10 (−0.12)
6	**8**	1996 (1987)	1940 (1919)	15.49 (15.22)	0.30 (0.36)	+0.33 (+0.32)
7	**10**	1992[c] (1985)	1930[c] (1911)	15.36 (15.14)	0.32 (0.39)	+0.20 (+0.24)[d]
8	**11**	1979 (1973)	1909 (1891)	15.08 (14.87)	0.36 (0.43)	−0.08 (−0.03)[d]

[a] In hexane; values in parentheses are for samples in CH_2Cl_2. [b] C_{3v} local symmetry was assumed. [c] In isooctane solution; data are from ref 33b. [d] ν_{CO} data (CH_2Cl_2) and $k_{CO}/k_{CO,CO}$ values are from ref 33a.

Table II. Selected ^{13}C NMR Data for (arene)$Cr(CO)_3$ Complexes[a]

complex	δ (ppm)				
	C_{ipso}	C_{ortho}	C_{meta}	C_{para}	CO
1a	93.05	93.64	93.87	95.26	232.68
2	102.52	94.14	94.14	95.31	222.15
3	109.22	90.73	95.74	92.48	234.34
6[b]	95.15	95.15	95.15	95.15	234.00
10[b]	91.05	96.04	92.47	97.46	231.98
11[b]	144.15	80.20	97.48	87.44	234.25

[a] In DMSO-d_6. [b] Data from ref 33a, included for comparison.

Table III. Chemical Shift Differences (in ppm) between the ^{13}C NMR Resonances of (benzene)$Cr(CO)_3$ and the Substituted Complexes[a]

complex	D_{ipso}	Δ_{ortho}	Δ_{meta}	Δ_{para}	Δ_π	$\Delta\delta_{CO}$
1a	−2.10	−1.51	−1.28	+0.11	+1.39	−1.32
2	+7.37	−1.01	−1.01	+0.16	+1.17	−11.85
3	+14.07	−4.42	+0.59	−2.67	−3.26	+0.34
10[b]	−4.10	+0.89	−2.68	+2.31	+4.99	−2.02
11[b]	+49.00	−14.87	+2.33	−7.71	−10.04	+0.25

[a] In DMSO-d_6. [b] Data from ref 33a, included for comparison.

in Table I shows that, as expected, the oxazoline and imine functions of complexes **1a** and **2** exhibit properties typical of a π-acceptor group. However, these are not as marked as those of the ester and aldehyde functions of complexes **10** and **8**. The data obtained for complex **1b** indicate that the electron-acceptor effect of the oxazoline group is nearly completely compensated by the π-donor methoxy group.

The IR data also show that on converting **8** into **3** the strong π-acceptor carbonyl function is replaced by a substituent with a net π-donor character. The effect of the dimethylamino group, transmitted to the arene through the conjugated C=N bond, more than compensates for the π-electron-withdrawing nature of the imine moiety.

^1H and ^{13}C NMR Spectra. The ^1H and ^{13}C spectra of complexes **1–3** show the usual upfield shift of the aromatic proton and aromatic carbon resonances (relative to the uncomplexed arenes) and the usual downfield shift of the carbonyl carbon resonances (relative to free CO). The spectra were assigned through a combination of peak multiplicities, intensities, chemical shifts, coupling constants, and DEPT and C–H correlation experiments. Selected data are listed in Table II.

^{13}C NMR chemical shifts of the carbonyl and aromatic carbons have also been used to evaluate the electronic properties of groups X in (η^6-C_6H_5X)$Cr(CO)_3$ complexes.[33] The CO resonance is deshielded when X is a π-donor group. One rationale invokes the dominant paramagnetic contribution (σ^p) to the shielding constant for the carbonyl carbons.[35] A higher electron density at the metal (relative to (η^6-C_6H_6)$Cr(CO)_3$ (**6**)) increases σ^p and, therefore, results in deshielding. In agreement with this analysis, the carbonyl carbons of the complexes containing the donor methoxy- and formylhydrazone substituents (**11** and **3**) are deshielded with respect to those of **6**. The opposite trend is found with π-acceptor substituents, i.e. in complexes **1a**, **2**, and **10**.

Δ_π values, obtained as the difference (in ppm) between the chemical shifts of the *para* and *meta* aromatic carbons in the monosubstituted complexes, are a second measure of the electronic properties of the substituent X. A negative Δ_π value corresponds to a π-donor group, while a positive Δ_π value corresponds to a π-acceptor group.[33a] Table III lists the Δ_π values calculated for complexes **1**, **2**, **3**, **10**, and **11**, along with the incremental effects Δ of the substituent X on the chemical shift of the aromatic and carbonyl carbons. These Δ values were obtained by comparing the data for the monosubstituted complexes (η^6-C_6H_5X)$Cr(CO)_3$ to those for the unsubstituted complex **6**.

The data in Tables II and III are consistent with the π-acceptor character of the oxazoline and imine functions in **1** and **2**. They also validate the conclusions reached from the IR data, which indicated that the hydrazone in complex **3** is an overall π-donor substituent.

X-ray Crystallographic Analysis of 1a. Figure 1 shows an ORTEP diagram of complex **1a** with the atom-numbering scheme. Relevant bond lengths and angles are listed in Table IV.

Complex **1a** shows the usual three-legged piano-stool structure with a η^6-bonded benzene ring. The benzene is nearly planar. The maximum deviation from the plane defined by the aromatic carbon atoms is 0.007 Å for atom C(4). C–C bond distances are between 1.392(5) and 1.425(6) Å (average value 1.403(11) Å). Bond angles are in the range 119.4(4)–120.5(5)° (average value 119.9(3)°). The oxazoline ring is also planar. Its torsion angle with respect to the benzene ring is 5.8°. C(7)–N and C(7)–O(1) bond distances are typical for C_{sp^2}=N and C_{sp^2}–O bonds. The $Cr(CO)_3$ group adopts a staggered conformation with respect to the arene carbons. This has precedence in (η^6-acetophenone)$Cr(CO)_3$,[36] while the *anti*-eclipsed conformation is found in the solid state for the ester **11**[37] and the *syn*-eclipsed conformation is favored by a π-donor X group in monosubstituted (η^6-C_6H_5X)$Cr(CO)_3$ complexes.[38] Ring carbon–Cr bond distances are between 2.203(5) and 2.225(4) Å (average value 2.211(8) Å). The $Cr(CO)_3$ group adopts the expected tripodal geometry, with C–Cr–C angles of nearly 90° (average value 89.4°). Consistent with the electron-withdrawing nature of the oxazoline group, the

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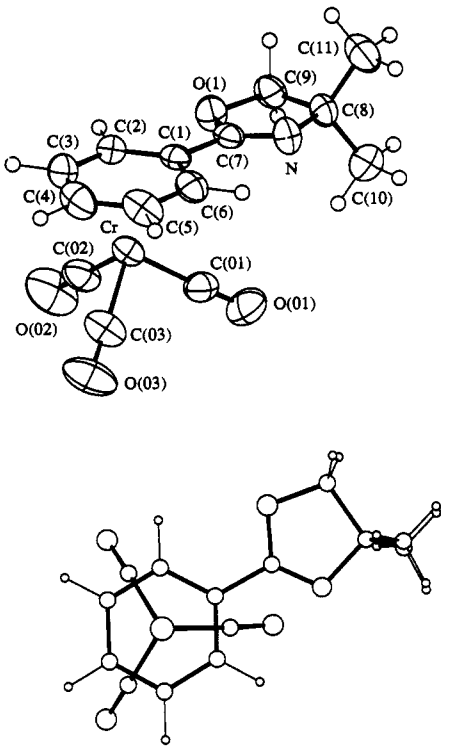


Figure 1. (Top) Perspective view of the crystal structure of complex **1a** with the atomic numbering. Ellipsoids are represented with 50% probability. (Bottom) View perpendicular to the mean plane of the arene.

Table IV. Selected Bond Lengths (Å), Bond Angles (deg), and Torsional Angles (deg) for 1a

Cr–C(1)	2.209(4)	O(1)–C(7)	1.361(5)
Cr–C(2)	2.206(4)	O(1)–C(9)	1.448(5)
Cr–C(3)	2.208(5)	N–C(7)	1.260(5)
Cr–C(4)	2.203(5)	N–C(8)	1.487(6)
Cr–C(5)	2.225(4)	C(1)–C(7)	1.470(6)
Cr–C(6)	2.217(3)	C(8)–C(9)	1.545(5)
Cr–C(01)	1.843(5)		
Cr–C(02)	1.843(4)		
Cr–C(03)	1.839(5)		
C(01)–Cr–C(02)	89.8(2)	C(7)–N–C(8)	107.0(3)
C(01)–Cr–C(03)	91.4(2)	N–C(8)–C(9)	103.5(3)
C(02)–Cr–C(03)	87.1(2)	O1–C(9)–C(8)	104.5(3)
O(1)–C(7)–N	119.0(4)	C(7)–O(1)–C(9)	105.7(3)
C(8)–N–C(7)–O(1)			–0.9(5)
C(7)–N–C(8)–C(9)			3.4(4)
N–C(8)–C(9)–O(1)			–4.6(4)
C(8)–C(9)–O(1)–C(7)			4.2(4)
C(9)–O(1)–C(7)–N			–2.4(4)
C(2)–C(1)–C(7)–O(1)			–5.8(5)
C(2)–C(1)–C(7)–N			173.4(4)
C(6)–C(1)–C(7)–O(1)			173.9(3)
C(6)–C(1)–C(7)–N			–6.8(5)

Table V. Structural and Substituent Parameters (in Å) for Complex 1a

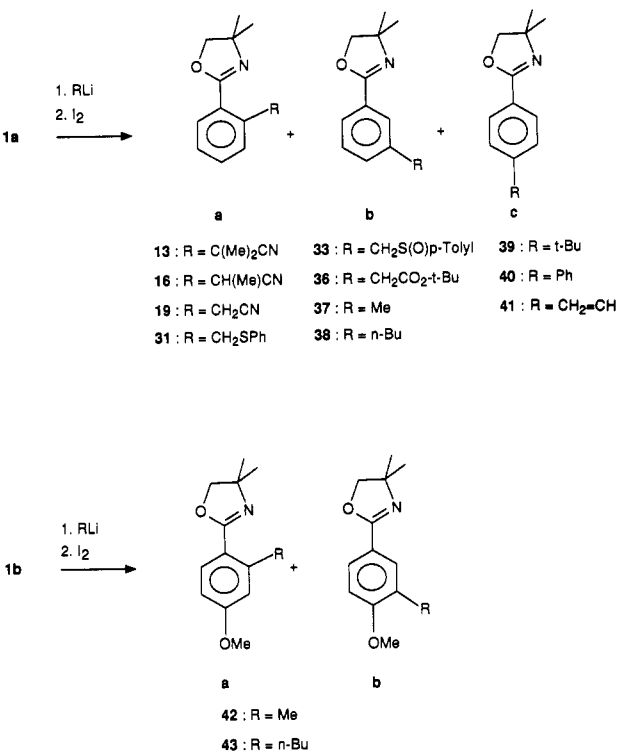
d_{C1-C7}	d_{Cr-CO}	d_{CrC-O}	D_{cent}	δ_d	δ_p	δ_{p_α}
1.470(6)	1.842(2)	1.148(5)	1.711	–0.003	–0.002	–0.001

Cr–CO bonds are significantly longer (average distance d_{Cr-CO} = 1.842(2) Å) and the C–O bonds shorter (average value d_{CrC-O} = 1.148(5) Å) than in the parent complex **6**.

Additional structural parameters D_{cent}, δ_d, δ_p, and δ_{p_α} are listed in Table V. These parameters have been defined by Hunter[38a] to measure deviations in arene planarity and the bending of the substituent X away from or toward the metal fragment. Using the atom-numbering scheme of complex **1a** in Figure 1, D_{cent} is the distance between the chromium atom and the arene centroid, δ_d is the difference between the Cr–C(1) bond length and the average of the other Cr–C(H) bond lengths, and δ_p and δ_{p_α} are the distances of C(1) and C(7), respectively, from the least-squares plane defined by C(2), C(3), C(5), and C(6).

It is seen that C(1) and C(7) are essentially in the plane of the arene, with a minimal deviation from planarity. This result is in agreement with the correlation between the structure of the arene ligand and electronic properties of the arene substituent X in other $(C_6H_5X)Cr(CO)_3$ complexes.[38a] π-Acceptor substituents and their *ipso*-carbon atoms are generally found to be in the plane of the arene or to be bent slightly toward the metal fragment. The opposite trends are observed in the case of π-donor substituents.

Scheme V



Nucleophile Addition/Oxidation Reactions with Complexes 1a and 1b. A wide variety of C-nucleophiles were found to add to complex **1a**. *In situ* oxidation with iodine afforded substituted phenyloxazolines (Scheme V). Reaction conditions, product distribution, and yields are listed in Table VI.

α-Cyano-Stabilized Carbanions. α-Cyano-stabilized carbanions are among the most widely used and efficient nucleophiles in reactions with (η^6-arene)$Cr(CO)_3$ complexes.[12a,39] They have been shown to add reversibly, and regioselectivity therefore depends on reaction time and temperature.[39a,e,g] This was confirmed anew in the reactions with **1a**, described here. Complex **1a** (1 equiv) was added to a THF solution (0.15 M) of 2-lithio-2-methylpropionitrile (**12**; 1.2 equiv) at –90 °C. The temperature was kept at –78 °C for 3 h. Oxidative decomplexation (I_2) afforded a mixture of three regioisomeric products (Table VI, entry 1). The *meta* and *para* regioisomers **13b** and

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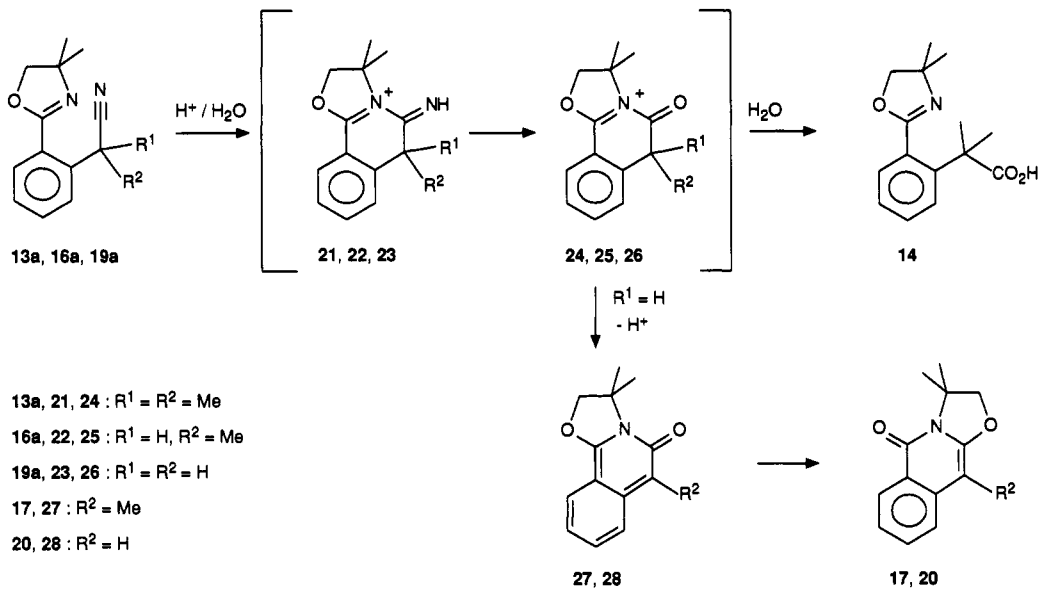
Table VI. Reaction of (phenyloxazoline)$Cr(CO)_3$ Complexes 1a and 1b with Carbon Nucleophiles Followed by Oxidative (I_2) Decomplexation

entry no.	complex	nucleophile	conditions[a]	product	distribn[b] a:b:c	a:isom	yield (%)
1	**1a**	$LiCMe_2CN$ (**12**)	−90 to −78 °C, 3 h	**13** and **14**	47[c]:11:42	0.9:1	60
2	**1a**	**12**	−90 to −20 °C, 3 h	**13** and **14**	43[c]:13:44	0.75:1	58
3	**1a**	**12**	−90 °C, 0.1 h; 0 °C, 3 h	**13** and **14**	76[c]:2:22	3.2:1	41
4	**1a**	LiCH(Me)CN (**15**)	−90 to −78 °C, 3 h	**16** and **17**	76[d]:4:20	3.2:1	68
5	**1a**	**15**	−90 °C, 0.1 h; 0 °C, 3 h	**16** and **17**	90[e]:0.5:9.5	9:1	64
6	**1a**	$LiCH_2CN$ (**18**)	−90 to −78 °C, 3 h	**19** and **20**	89:2:9	8.1:1	77
7	**1a**	**18**	−90 °C, 0.1 h; 0 °C, 3 h	**19** and **20**	98[g]:0:2	49:1	74
8	**1a**	$LiCH_2SPh$ (**30**)[h]	−78 to −20 °C, 3 h	**31**	37:19:44	0.6:1	55
9	**1a**	$LiCH_2S(O)C_6H_4$-*p*-Me (**32**)	−78 to −50 °C, 3 h	**33**	96:0:4	24:1[i]	72
10	**1a**	**32**	−78 °C, 0.1 h; 0 °C, 2 h	**33**	96:0:4	24:1[i]	71
11	**1a**	$LiCH_2COO$-*t*-Bu (**35**)[j]	−78 to −50 °C, 3 h	**36**	83:4:13	5:1	87
12	**1a**	**35**[j]	−78 °C, 0.1 h; 0 °C, 3 h	**36**	86:1:13	6:1	81
13	**1a**	MeLi	−78 to −20 °C, 3 h	**37**	100:0:0		82
14	**1a**	MeLi[h]	−78 to −20 °C, 3 h	**37**	100:0:0		81
15	**1a**	*n*-BuLi	−78 to −20 °C, 3 h	**38**	100:0:0		93
16	**1a**	*t*-BuLi	−78 to −20 °C, 3 h	**39**	100:0:0		30
17	**1a**	*t*-BuLi[k]	−78 to −20 °C, 3 h	**39**	0:14:86		57
18	**1a**	PhLi	−78 to −20 °C, 3 h	**40**	100:0:0		85
19	**1a**	PhLi[h]	−78 to −20 °C, 3 h	**40**	100:0:0		83
20	**1a**	(vinyl)Li[l]	−78 to −20 °C, 3 h	**41**	100:0:0		60
21	**1b**	MeLi	−78 to −20 °C, 3.5 h	**42**	100:0[m]		65
22	**1b**	*n*-BuLi	−78 to −20 °C, 1 h; −20 °C, 2 h	**43**	100:0[m]		67

[a] In experiments of entries 1–12 and 20, chromium complex **1a** was added as a solid or in THF solution to a solution of the nucleophile (1–1.5 equiv) in THF at −90 or −78 °C; in experiments of entries 13–19 and 21–22, a solution of the nucleophile was added to a solution of chromium complex **1a** or **1b** in THF at −78 °C. [b] Product distribution determined by GC and ^1H NMR of the crude mixture. [c] Isolated as product **14**. [d] Mixture of **16a** and **17** in the ratio 3.2:1. [e] Mixture of **16a** and **17** in the ratio 6.4:1. [f] Mixture of **19a** and **20** in the ratio 2.4:1. [g] Mixture of **19a** and **20** in the ratio 2.5:1. [h] HMPA (2.5 equiv) was used as a cosolvent. [i] Product distribution determined after purification by chromatography. [j] HMPA (2.0 equiv) was used as a cosolvent. [k] HMPA (10 equiv) was used as a cosolvent. [l] Generated *via* transmetalation from tetravinyltin and MeLi. [m] **a**:**b** ratio.

Scheme VI



13c were chromatographically separated from the third product, which was identified as the carboxylic acid **14**, derived from the *ortho* regioisomer **13a** (*vide infra*). Warming the reaction mixture from −90 °C up to −20 °C over a 3-h period before oxidation gave a similar result (entry 2). In contrast, the proportion of *ortho* product increased at the expense of both *para* and *meta* product, when **1a** and **12** were allowed to react at 0 °C for 3 h (entry 3).

With the smaller nucleophiles 2-lithiopropionitrile (**15**) and lithioacetonitrile (**18**) selectivity for *ortho* addition increases (entries 4–7). With the three nitrile-stabilized nucleophiles, and after equilibration at 0 °C, the *ortho* products were obtained with selectivities of 3.2:1 for **12**, 9:1 for **15**, and 49:1 for **18**. The *ortho* products undergo further reaction under workup conditions (I_2, then aqueous $NaHSO_3$ (10%) and aqueous NaOH). Thus, as mentioned above, **13a** is hydrolyzed to **14**. Arenes **16a** and **19a** undergo more profound changes and are, in part, transformed to the isoquinolones **17** and **20**. The intermediacy of **16a** and **19a** was established by resubmitting isolated product **19a** to the workup conditions. ^1H NMR of the crude product showed the formation of **20**.

We propose the mechanism shown in Scheme VI to account for the formation of **14**, **17**, and **20**. Oxazoline-assisted protonation of the nitrile nitrogen atom of products **13a**, **16a**, and **19a** gives intermediates **21–23**. Nucleophilic addition of water followed by loss of ammonia then results in intermediates **24–26**. With $R^1 = R^2 = Me$ as in **24**, hydrolysis affords the acid **14**. If $R^1 = H$, as in **25** and **26**, loss of a proton might generate isoquinolinones **27** and **28**.[40] A sequence of ring opening and ring closure of the oxazolidine would then lead to the more stable isoquinolones **17** and **20**.[41]

Sulfur-Stabilized Carbanions. 2-Lithio-2-methyl-1,3-dithiane (**29**) gave poor results in its addition–oxidation

reaction with complex **1a**. TLC indicated the formation of product mixtures, but all attempts to separate and purify were unsuccessful.

The smaller lithiothioanisole (**30**), as in the previously studied reactions with (1-methoxynaphthalene)$Cr(CO)_3$,[42] added with little selectivity and afforded a mixture of all three regioisomers **31a–c** in moderate yield (entry 8). The more stabilized *p*-tolyl methyl sulfoxide anion of **32**,[43] which to our knowledge has not previously been used in combination with (arene)$Cr(CO)_3$ complexes, added to **1a** to afford **33a** with excellent regioselectivity (entries 9 and 10).

Ketone and Ester Enolates. Ketone enolates have been shown to be borderline cases in addition–oxidation reactions with complex **6**.[12a] We expected the π-acceptor oxazoline function to favor nucleophilic addition of the lithium enolate of 2,2-dimethyl-2-propanone **34** to **1a**, but no addition product was isolated. The more reactive ester enolate of *tert*-butyl acetate **35** gave **36a–c** in good yield with high *ortho* regioselectivity (entries 11 and 12).

Alkyl-, Alkenyl-, and Aryllithium Nucleophiles. It is well-known that the reactivity of alkyl-, alkenyl-, and aryllithium compounds strongly depends upon their method of preparation, solvent, solution concentration, and presence of additives and cosolvents, as well as age.[44] Many of these factors affect aggregation[45] and thus reactivity. The compounds exhibit both nucleophile and base character, and the dominant one often varies with substrate and reaction condition. Several examples of their different behavior in reactions with (η^6-arene)$Cr(CO)_3$ complexes have been reported. PhLi has been shown to add to the carbonyl ligand of complex **6** in diethyl ether[46] and to the benzene ligand in THF.[12a] Nucleophilic addition to the arene ligand has been reported for *t*-BuLi,[12a,13,14] vinyllithium,[12a] allyllithium,[12a] and the lithium anion of acetylene.[12a] In contrast, with simple alkyllithium reagents, arene lithiation is the prevailing or exclusive reaction[47] (for an example, see Scheme IV). A different mechanism appears to be operative in the reaction of an excess of *n*-BuLi (at higher reaction temperatures) with **6** to yield (η^6-butylbenzene)$Cr(CO)_3$.[48]

We here report that MeLi and *n*-BuLi readily add to complex **1a**. The yellow solution of **1a** in THF turned orange within minutes following the addition of the organolithium reagent (1.2 equiv) at −78 °C and orange-red on warming to −20 °C over a 3-h period. Oxidative decomplexation gave a crude product which GC and ^1H NMR analysis showed to consist of a single regioisomer. Chromatography afforded the known *ortho*-substituted phenyloxazoline products **37a**[49] and **38a**[49] in high yield (entries 13 and 15). Note that free phenyloxazoline **4a** reacts with these alkyllithium reagents by *ortho* lithiation,[16] addition reactions being limited to pyridyl-[50] and naphthyloxazolines.[17a–e]

Exclusive *ortho* regioselectivity was also achieved in reactions of *tert*-butyllithium (entry 16), phenyllithium (entry 18), and vinyllithium (entry 20) with **1a**. Vinyllithium was generated from the corresponding tetravinyltin compounds *via* transmetalation with MeLi at −78 °C.[17c]

The addition of HMPA (2.5 equiv) had no effect on either yield or regioselectivity in reactions of MeLi and PhLi with **1a** (entries 14 and 19). Different regioselectivity was however observed when *t*-BuLi was added to **1a** in 5/1 THF/HMPA (entry 17). The *meta* and *para* regioisomers **39b** and **39c** formed in moderate yield. The *ortho* regioisomer **39a**,[49] the only product (30%) found in the reaction in THF, was notably absent. This suggests that either the change of medium accelerates the rate of addition with a concomitant preference for addition to the sterically less hindered sites and/or that chelation-controlled addition is rendered unfavorable due to the interaction between lithium and HMPA.[39d,e]

In the case of complex **1b**, reactions were not accompanied by a color change. Both MeLi and *n*-BuLi exclusively added *ortho* to the oxazoline group to give **42a**[51] and **43a**[52] (entries 21 and 22). No product derived from a *cine* nucleophilic aromatic substitution of the methoxy group by the incoming nucleophile was detected.[53]

Nucleophile Addition–Oxidation Reactions with Complexes 2 and 3. The excellent regio- and chemoselectivity of the nucleophile addition–oxidation sequence with complex **1a** made alkyl-, vinyl-, and phenyllithium the reagents of choice for analogous reactions with complexes **2** and **3**.

Indeed, nucleophilic addition, followed by oxidation and hydrolysis, gave exclusively the *ortho*-substituted benzaldehydes in all examples shown in Scheme VII and Table VII.

The set of two doublets and two triplets for the aromatic proton resonance signals in the ^1H NMR spectra were clearly consistent with the 1,2-substitution pattern. In

(40) The analytical data do not permit unambiguous assignment to structures **17** and **20**. Although we consider them less probable, structures **27** and **28** cannot be ruled out. For analytical data of 3(2*H*)-isoquinolinones, see: (a) Kappe, T.; Pocivalnik, D. *Heterocycles* **1983**, *20*, 1367. (b) Hazai, L.; Deák, G.; Tóth, G.; Volford, J.; Tamás, J. *J. Heterocycl. Chem.* **1982**, *19*, 49. For analytical data of 1(2*H*)-isoquinolones, see: Ponticelli, F.; Tedeschi, P. *Heterocycles* **1983**, *20*, 1315.

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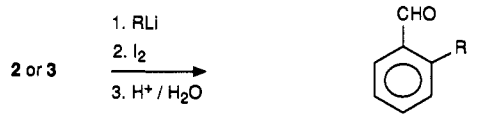
Scheme VII



44 : R = Me **45** : R = n-Bu **46** : R = t-Bu

47 : R = Ph **48** : R = CH_2=CH

Table VII. Reaction of (phenylmethanimine)$Cr(CO)_3$ (2) and (benzaldehyde hydrazone)$Cr(CO)_3$ (3) with Carbon Nucleophiles Followed by Oxidative (I_2) Decomplexation[a]

entry no.	complex	nucleophile	product[b]	yield (%)
1	**2**	MeLi	**44**	81
2	**2**	*n*-BuLi	**45**	68
3	**2**	*t*-BuLi	**46**	53
4	**2**	PhLi	**47**	78
5	**2**	(vinyl)Li[c]	**48**	78
6	**3**	MeLi	**44**	60
7	**3**	*n*-BuLi	**45**	85
8	**3**	PhLi	**47**	83

[a] Conditions: −78 to −40 °C, 2 h; 2 h; then addition of I_2 (6 equiv); −78 to +20 °C overnight. In experiments of entries 1–4 and 6–8 a solution of the nucleophile (1.1–1.2 equiv) was added to a solution of complex **2** or **3** in THF at −78 °C. In the experiment of entry 5, a solution of complex **2** in THF was added to a solution of nucleophile in THF at −78 °C. [b] GC and/or ^1H NMR analysis of the crude product showed a single regioisomer to be formed in all reactions. [c] Generated *via* transmetalation from tetravinyltin and MeLi.

the case of the *o*-vinylbenzaldehyde (**48**) assignment is based on its conversion into *o*-ethylbenzaldehyde (**51**) *via* selective hydrogenation followed by mild acid hydrolysis.

Conclusion

In this study we have shown that (arene)$Cr(CO)_3$ complexes **1a,b** and **2** undergo formal nucleophilic substitution of a hydride by C-nucleophiles *ortho* to the functional groups. The reaction is efficient, and a wide range of C-nucleophiles from primary to tertiary and from simple alkyls to carbanions α to functional groups such as nitrile, sulfoxide, and ester can be used. *ortho* regioselectivity is brought about by a combination of electron-withdrawing and lithium coordination effects. At low temperature, 2-lithio-2-methylpropionitrile adds to both *para* and *ortho* positions in roughly equal proportions. Thus, *para* selectivity becomes competitive presumably because of adverse interaction between the incoming bulky nucleophile and the *exo*-methyl substituent at C(4) of the oxazoline group in the transition state leading to *ortho* addition. However, as the addition is reversible, equilibration can be used to increase significantly the proportion of *ortho* product. Remarkably, simple alkyllithium reagents, which normally deprotonate (arene)$Cr(CO)_3$ complexes, efficiently add to complexes **1a,b**, **2**, and **3**. This finding and the high regioselectivity of this reaction significantly extend the usefulness of the arene functionalization *via* nucleophile addition–oxidation.

The spectroscopic data place the hydrazone function among π-donor substituents. The reactions of **3** with C-nucleophiles therefore demonstrate convincingly that the coordination effect, rather than an electron-withdrawing effect of a σ-bound auxiliary, is responsible for the high chemo- and regioselectivity of the addition reactions.

ortho addition holds promise for new asymmetric methodology. We have shown previously that two (or three) C-substituents can be added across an arene double bond in a regio- and stereoselective manner via a tandem nucleophile–electrophile addition to (arene)$Cr(CO)_3$ complexes.[54] Coupled with the straightforward chiral modification of the oxazoline, imine, and hydrazone functions, asymmetric addition reactions can be envisaged in which the auxiliary directs the nucleophile selectively to one of the two diastereotopic *ortho* positions. The first successful results using this methodology have recently been obtained.[55,56]

Experimental Section

All manipulations involving organometallics were carried out under an atmosphere of purified nitrogen and with an inert-gas–vacuum double manifold and standard Schlenk techniques. $Cr(CO)_6$ was obtained from Pressure Chemicals or Strem Chemicals and used as received. Tetrahydrofuran, diethyl ether, and dibutyl ether were distilled from sodium–benzophenone ketyl immediately prior to use. Hexane and acetonitrile were distilled from CaH_2. Hexamethylphosphoric triamide (HMPA, Fluka) was stirred with CaH_2 for 15 h at 60 °C before distillation under a reduced atmosphere (10 mmHg) of nitrogen. 2-Methylpropionitrile, propionitrile, *tert*-butyl acetate, and thioanisole were stirred with CaH_2, and diisopropylamine was stirred with NaOH pellets before distillation under an atmosphere of nitrogen. Benzene-d_6 was vacuum-transferred after stirring with CaH_2. DMSO-d_6 was used as received and stored over molecular sieves (4 Å). MeLi, *n*-BuLi, *t*-BuLi, and PhLi (Fluka) were titrated before use according to the method of Gilman and Cartledge.[57] Analytical and preparative TLC were carried out by using Merck silica gel 60 F_{254} plates. Column chromatography was carried out by using the flash method described by Still.[58] Gas chromatographic analyses were performed on a Hewlett-Packard capillary column instrument. ^1H and ^{13}C NMR spectra were recorded on a Bruker 400-MHz or a Varian XL-200 spectrometer. Chemical shifts (δ) are given in ppm relative to $SiMe_4$. IR spectra were recorded on a Mattson Instruments Polaris FT spectrometer and a Perkin-Elmer 1660 Series FT spectrometer by using NaCl solution cells. Electron impact (70 eV) mass spectra were obtained on a Varian CH 4 or SM 1 spectrometer; relative intensities are given in parentheses. High-resolution mass spectra were measured on a VG analytical 7070E instrument. Melting points were determined on a Büchi 510 apparatus and are not corrected. Elemental analyses were performed by H. Eder, Service de Microchimie, Institut de Chimie Pharmaceutique, Université de Genève.

[4,5-dihydro-4,4-dimethyl-2-(η^6-phenyl)oxazole]$Cr(CO)_3$ (1a). Method A. 4,5-Dihydro-4,4-dimethyl-2-phenyloxazole (**4a**;[22a,b,23] 8.75 g, 50 mmol), $Cr(CO)_6$ (5 g, 22.72 mmol), and *n*-Bu_2O (125 mL) were placed in a 250-mL flask equipped with a magnetic stirring bar and a 15 cm long glass rod of 5 mm diameter protruding into a straight, 30 cm long reflux condenser. The glass rod knocked sublimed $Cr(CO)_6$ back into the reaction mixture. The mixture was submitted to three freeze–pump–thaw cycles. THF (7.3 mL) and hexane (12 mL) were then added, and, protected from light, the mixture was heated for a period of 30 h with an oil bath set at 150 °C. After cooling to ambient temperature, volatiles were removed *in vacuo*. The residue was dissolved in dry Et_2O (50 mL) and the solution filtered over Celite and treated with hexane (20 mL). Yellow needles formed on concentrating the solution *in vacuo* and, after cooling to −78 °C overnight, 5.87 g (83%) of complex **1a** was isolated.

Method B. 4,5-Dihydro-4,4-dimethyl-2-phenyloxazole (**4a**;[22a,b,23] (7.60 g, 43.42 mmol), (η^6-naphthalene)$Cr(CO)_3$ (**5**; 5.74 g, 21.71

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mmol), and THF (60 mL) were placed in a 100-mL dry flask equipped with a reflux condenser and a magnetic stirring bar and submitted to three freeze–pump–thaw cycles. The solution was then refluxed in the dark for 24 h by means of a 80 °C oil bath. The dark reaction mixture was cooled to ambient temperature and stripped of volatiles by pumping. The residue was taken up in dry Et_2O (50 mL) and the solution filtered over Celite. After removal of solvent, the yellow-orange oil was purified by flash chromatography. After elution of a first orange-red band (mixture of naphthalene, **4a**, and **5**) with 6/1 hexane/ether, a second yellow-orange band was eluted with pure ether. After evaporation of the volatiles *in vacuo*, the yellow solid was recrystallized from hexane/ether at −78 °C to give complex **1a** (5.1 g, 75%) as yellow needles. A second crop (203 mg, 3%) was obtained after concentration of the mother liquor. Mp: 112–113 °C. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.24 (s, 6 H, $(CH_3)_2$), 4.08 (s, 2 H, OCH_2), 5.75–5.83 (m, 3 H), 6.10 (d, 2 H, J = 6.0 Hz). ^{13}C NMR (DMSO-d_6, 100 MHz): δ 27.9, 67.6, 78.9, 93.05, 93.6, 93.8, 95.2, 158.9, 232.7. IR (CH_2Cl_2): 1976 (s), 1903 (s) cm^{-1}. MS: m/z 311 (5), 255 (7), 227 (20), 155 (25), 52 (100). Anal. Calcd for $C_{14}H_{13}CrNO_4$: C, 54.02; H, 4.21; N, 4.50. Found: C, 53.94; H, 4.16; N, 4.38.

X-ray Crystal Structure Determination. Single crystals of **1a** were obtained by slow evaporation from hexane/ether solution. The cell parameters (from 25 reflections with 25° < 2θ ≤ 36°) and diffracted intensities were measured at room temperature on a Philips PW1100 diffractometer with graphite-monochromated Mo Kα ratiation (λ = 0.710 69 Å). Two reference reflections measured every 60 min showed variations less than 3.5σ(I). Data were corrected for Lorentz and polarization effects, but not for absorption. The structure was solved by direct methods using MULTAN 87;[59] all other calculations used the XTAL[60] system and ORTEP[61] programs. Atomic scattering factors and anomalous dispersion terms were taken from ref 62. All coordinates of the hydrogen atoms were calculated. A summary of crystal data, intensity measurement, and structure refinement is given in Table VIII, and final coordinates are given in Table IX.

[(2-isocyano-2-methoxypropoxy)(η^6-benzene)]Cr(CO)$_3$ (7). n-BuLi (1.6 M in hexane, 0.625 mL, 1 mmol) was added to a solution of 4,4-dimethyloxazoline (99 mg, 1 mmol) in THF (5 mL) at −78 °C. After it was warmed to −15 °C over 1 h, the solution was recooled to −78 °C and (η^6-fluorobenzene)Cr(CO)$_3$ (232 mg, 1 mmol) was added as a solid. The reaction mixture was warmed to 20 °C over 6 h and then treated with ether (5 mL), washed with degassed water (5 mL), dried over $MgSO_4$, and filtered. The solvent was removed by rotavaporation to give the crude product. Chromatography (SiO_2, ether) gave 225 mg (73%) of complex **7**. ^{1}H NMR (C_6D_6, 200 MHz): δ 1.01 (s, 6 H, $(CH_3)_2C$), 2.98 (s, 2 H, OCH_2), 3.96 (t, 1 H, J = 6.2 Hz, HC(4)), 4.17 (d, 2 H, J = 6.5 Hz, HC(2), HC(6)), 4.62 (t, 2 H, J = 6.5 Hz, HC(3), HC(5)). IR (toluene): 2125 (w), 1970 (s), 1890 (s) cm^{-1}. MS: m/z 283 (M − 28, 20), 255 (5), 227 (50), 200 (100), 175 (10), 145 (60).

{4,5-dihydro-2-[4-methoxy(η^6-phenyl)]-4,4-dimethyloxazole}Cr(CO)$_3$ (1b). 4,5-Dihydro-4,4-dimethyl-2-(4-methoxyphenyl)oxazole (**4b**;[22b,c,23] 8.20 g, 40.16 mmol), (η^6-naphthalene)Cr(CO)$_3$ (**5**; 5.31 g, 20.1 mmol), and THF (60 mL) were placed in a 100-ml dry reactor equipped with a reflux condenser and a magnetic stirring bar and submitted to three freeze–pump–thaw cycles. The solution was refluxed in the dark for 21 h by means of a 80 °C oil bath. The mixture was stripped of volatiles at room temperature. The dark residue was taken up in dry Et_2O (50 mL) and the solution filtered over Celite. Removal of solvent gave a yellow-orange oil which was purified by flash chromatography. A first orange-red band consisting of a mixture of naphthalene, **4b**, and **5** was eluted with 6/1 hexane/ether; a second yellow band was eluted with pure ether. Solvent removal gave a yellow solid which was recrystallized from hexane/ether at −78 °C (overnight) to yield 4.77 g of complex **1b** (70%) as yellow crystals. Mp: 104 °C. ^{1}H NMR (C_6D_6, 200 MHz): δ 1.11 (s, 6 H, $C(CH_3)_2$), 2.84 (s, 3 H, OCH_3), 3.59(s, 2 H, OCH_2), 4.28 (d, 2 H, J = 6.5 Hz, HC(3′) and HC(5′)), 6.02 (d, 2 H, J = 6.5 Hz, HC(2′) and HC(6′)). IR (CH_2Cl_2): 1972 (s), 1897 (s) cm^{-1}. MS: m/z 341 (2), 285 (6), 257 (28), 185 (41), 52 (100). Anal. Calcd for $C_{15}H_{15}CrNO_5$: C, 52.79; H, 4.43; N, 4.10. Found: C, 52.63; H, 4.39; N, 4.04.

(η^6-benzaldehyde)Cr(CO)$_3$ (8). Method A. (η^6-benzene)-Cr(CO)$_3$ (**6**; 48.6 g, 0.227 mol), THF (450 mL), and TMEDA (37.2 mL, 0.250 mol) were placed in a dry 1-L three-neck round-bottom flask equipped with a magnetic stirring bar and a dropping funnel. The solution was cooled to −78 °C, and n-BuLi (1.6 M in hexane, 156 mL, 0.250 mol) was transferred into the dropping funnel and added to the reaction mixture over a period of 40 min. After the

Table VIII. Summary of Crystal Data, Intensity Measurement, and Structure Refinement for 1a

formula	$Cr(C_{11}H_{13}NO)(CO)_3$
mol wt	311.3
cryst syst	triclinic
space group	$P\bar{1}$
a(Å)	6.5708(12)
b(Å)	10.4928(12)
c(Å)	10.611(1)
α (deg)	102.19(1)
β (deg)	94.92(1)
γ (deg)	97.97(1)
V (Å^3)	703.2(2)
Z	2
F(000)	320
D_c (g cm^{-3})	1.47
μ(Mo Kα) (mm^{-1})	0.803
$((\sin\theta/\lambda)_{max}$ (Å^{-1})	0.55
temp (K)	298
no. of measd rflns	1977
no. of obsd rflns	1689
criterion for observn	$\|F_o\| > 4\sigma(F_o)$
refinement (on F)	full matrix
no. of params	181
weighting scheme	$w = 1/\sigma^2(F_o)$
max and av Δ/σ	0.12×10^{-3}, 0.22×10^{-4}
max and min $\Delta\rho$ (e Å^{-3})	0.33, −0.38
S	2.60
R,[a] R_w[b]	0.043, 0.034

[a] $R = \Sigma\|\|F_o\| - \|F_c\|\|/\Sigma|F_o|$. [b] $R_w = [\Sigma(w\,|\|F_o| - |F_c|\|)^2/\Sigma w\,|F_o|^2]^{1/2}$.

Table IX. Atomic Coordinates and Equivalent Isotropic Displacement Parameters (Å^2) with Esd's in Parentheses for 1a

	x/a	y/b	z/c	U_{eq}[a]
Cr	−0.0342(1)	0.26412(7)	0.20413(6)	0.0408(3)
O(1)	−0.2643(4)	0.0263(2)	0.4250(2)	0.048(1)
N	−0.3006(5)	−0.1113(3)	0.2268(3)	0.049(1)
C(1)	−0.2929(5)	0.1233(4)	0.2405(4)	0.036(2)
C(2)	−0.2967(6)	0.2470(4)	0.3192(4)	0.044(2)
C(3)	−0.3035(7)	0.3565(4)	0.2634(5)	0.056(2)
C(4)	−0.3031(7)	0.3422(5)	0.1295(5)	0.061(2)
C(5)	−0.3006(6)	0.2178(5)	0.0488(4)	0.056(2)
C(6)	−0.2948(6)	0.1083(4)	0.1037(4)	0.044(2)
C(7)	−0.2860(5)	0.0049(4)	0.2932(4)	0.038(2)
C(8)	−0.2856(6)	−0.1986(4)	0.3198(4)	0.043(2)
C(9)	−0.2730(6)	−0.1031(4)	0.4538(4)	0.049(2)
C(10)	−0.0882(7)	−0.2590(4)	0.3045(4)	0.058(2)
C(11)	−0.4766(7)	−0.3034(4)	0.2913(5)	0.066(2)
C(01)	0.1315(6)	0.1353(4)	0.1977(4)	0.049(2)
C(02)	0.1357(7)	0.3670(4)	0.3472(4)	0.057(2)
C(03)	0.1286(7)	0.3490(4)	0.1045(4)	0.057(2)
O(01)	0.2288(5)	0.0531(3)	0.1973(3)	0.075(2)
O(02)	0.2435(5)	0.4322(4)	0.4347(3)	0.096(2)
O(03)	0.2326(5)	0.4042(4)	0.0444(3)	0.089(2)

[a] U_{eq} is the average of eigenvalues of U.

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mixture was stirred for 1 h at −78 °C, DMF (87.3 mL, 1.135 mol) was added over a period of 45 min. The cooling bath was replaced by an ice bath, and the solution was stirred for 2.5 h. The reaction was quenched by adding N_2-saturated water (100 mL) at 0 °C, which caused the solution to turn from yellow to red. The mixture was extracted with three portions of ether, and the organic extracts were washed with brine, dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Purification by flash chromatography (SiO_2, 1/1 hexane/ether) followed by crystallization (hexane/ether) afforded 40.2 g (70%) of complex **8**.[30]

Method B. A 10% aqueous HCl solution (100 mL) was added to a solution of complex **9**[19c] (6.32 g, 23.22 mmol) in MeOH (100 mL) at ambient temperature, and the mixture was stirred overnight. The red solution was extracted with three portions of ether (150 mL), and the combined extracts were dried ($MgSO_4$), filtered, and concentrated. Purification as above afforded 5.34 g (95%) of complex **8**.[30]

[*N*-(η^6-phenylmethylene)cyclohexanamine]Cr(CO)$_3$ (2). A stirred solution of complex **7** (12.0 g, 49.6 mmol) and cyclohexylamine (6.24 mL, 54.5 mmol) in toluene (100 mL) containing molecular sieves (4 Å, 24 g) was heated to 86 °C in the dark. The reaction progress was monitored by IR (disappearance of the CHO stretch). The solution was cooled to ambient temperature and filtered over Celite. Removal of volatiles and recrystallization (2/1 hexane/ether) of the crude product gave complex **2** (13.96 g, 87%). Mp: 111–112 °C. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.10–1.80 (m, 10 H, $H_{cyclohexyl}$), 3.10–3.25 (m, 1 H, NCH), 5.70–5.80 (m, 3H, HC(3), HC(4), HC(5)), 6.05–6.10 (m, 2 H, HC(2), HC(6)), 7.98 (s, 1 H, CHN). ^{13}C NMR (DMSO-d_6, 100 MHz): δ 23.9, 25.1, 34.0, 67.9, 94.1, 95.3, 102.5, 155.4, 222.1. IR (hexane): 1988 (s), 1920 (s), 1646 (m) cm^{-1}. MS: *m/z* 323 (1), 295 (2), 267 (9), 239 (56), 52 (100). Anal. Calcd for $C_{16}H_{17}CrNO_3$: C, 59.44; H, 5.30; N, 4.33. Found: C, 59.50; H, 5.49; N, 4.24.

(η^6-benzaldehyde *N,N*-dimethylhydrazone)Cr(CO)$_3$ (3). A solution of complex **8** (5.00 g, 20.7 mmol) and *N,N*-dimethylhydrazine (1.86 g, 31 mmol) in dry ether (200 mL) was stirred overnight at room temperature over molecular sieves (4 Å, 6 g). The solution was filtered over Celite, and volatiles were evaporated. The yellow oil was crystallized (1/1 hexane/ether) to give 5.33 g (91%) of complex **3**. Mp: 89–90 °C. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 2.90 (s, 6 H, $(CH_3)_2N$), 5.54 (t, 1 H, J = 6.2 Hz, HC(4)), 5.81 (t, 2 H, J = 6.6 Hz, HC(3) and HC(5)), 5.89 (d, 2 H, J = 6.3 Hz, HC(2) and HC(6)), 6.82 (s, 1 H, CHN). ^{13}C NMR (DMSO-d_6, 100 MHz): δ 42.3, 90.7, 92.5, 95.7, 109.2, 125.7, 234.3. IR (CH_2Cl_2): 1970 (vs), 1890 (vs), 1565 (s), 1400 (s), 1100 (s), 1050 (m), 1030 (m) cm^{-1}. MS: *m/z* 284 (18), 200 (15), 155 (40), 103 (50), 52 (100). High-resolution MS for $C_{12}H_{12}N_2CrO_3$: calcd for 284.0253, obsd 284.0249. Anal. Calcd for $C_{12}H_{12}N_2CrO_3$: C, 50.71; H, 4.26; N, 9.86. Found: C, 50.94; H, 4.26; N, 9.63.

Preparation of Carbon Nucleophiles 12, 15, 18, 29, 30, 32, 34, and 35. Freshly prepared solutions of the carbon nucleophiles were used in all experiments. The nucleophiles were generated as follows.

LiC(CH$_3$)$_2$CN (12). A solution of lithium diisopropylamide was prepared by dropwise addition via syringe of *n*-BuLi (1.517 M in hexane, 0.791 mL, 1.2 mmol) to diisopropylamine (0.170 mL, 1.2 mmol) in THF (10 mL) at −78 °C. After 0.5 h at 0 °C, the solution was cooled to −78 °C and 2-methylpropionitrile (0.108 mL, 1.2 mmol) was added dropwise. After being stirred for 0.3 h at 0 °C, this reagent solution was used in the addition reactions described below. The same procedure was used in the preparation of solutions of **LiCH(CH$_3$)CN (15)**, **LiCH$_2$CN (18)**, and **LiCH$_2$S(O)C$_6$H$_4$-*p*-CH$_3$ (32)**. **LiCH$_2$CC(CH$_3$)$_3$ (34)** and **LiCH$_2$COO-*t*-Bu (35)** were generated exactly as above except for the reaction temperature, which was −78 °C. If required, HMPA was then added in the quantity specified in Table VI.

LiC(CH$_3$)S(CH$_2$)$_3$S (29) was prepared by following the procedure of Corey and Seebach.[63]

LiCH$_2$SC$_6$H$_5$ (30). *t*-BuLi (1.4 M in pentane, 0.278 mL, 0.39 mmol) was added dropwise to a solution of thioanisole (0.046 mL, 0.389 mmol) in THF (3.5 mL) and HMPA (0.170 mL) at −78 °C. The temperature was maintained at −78 °C, and stirring was continued for 2 h.

General Procedure for Nucleophile Addition–Oxidation Reactions of Complex 1a with Nucleophiles 12, 15, 18, 29, 30, 32, 34, and 35. A 1-mmol aliquot of complex **1a** was added in one portion either as a solid, via a solid addition tube, or as a −78 °C solution in THF, via a Teflon transfer tube, to the −78 or −90 °C solution of the C-nucleophile (1.1–1.2 mmol). The reaction mixture was then stirred for the time and at the temperature indicated before recooling to −78 °C and treatment with a cold solution (−78 °C) of 6 mmol of I_2 in THF (10 mL). The reaction mixture was warmed to 20 °C overnight. The mixture was diluted with ether (10 mL), washed with aqueous $NaHSO_3$ (10%) to remove excess I_2. The phases were separated, and the green water phase was neutralized with aqueous NaOH solution and extracted with ether (3 × 20 mL). The organic phases were combined, dried over $MgSO_4$, and filtered. The solvent was removed in a rotavaporator to give the crude product.

Addition–Oxidation Reaction of Complex 1a with 2-Lithio-2-methylpropionitrile (12). The general procedure was followed by adding complex **1a** (311 mg, 1.0 mmol) as a solid to a solution of anion **12** in THF (10 mL) at −90 °C. The homogeneous reaction mixture was slowly warmed to −78 °C over 3 h followed by oxidation. Workup and filtration through a short plug of SiO_2 afforded 158 mg (60%) of a mixture of products **14**, **13b**, and **13c** in the ratio of 47:11:42 (analysis by ^{1}H NMR spectroscopy). A second reaction was carried out exactly as before except for warming to −20 °C. Recooling, oxidation, and workup afforded 145 mg (58%) of a mixture of **14**, **13b**, and **13c** in the ratio of 43:13:44. A third reaction was carried out exactly as before except for the reaction temperature, which was 0 °C. Recooling, oxidation, and workup afforded 104 mg (41%) of a mixture of **14**, **13b**, and **13c** in the ratio of 76:2:22. The carboxylic acid **14** was separated from the mixture of *meta* and *para* regioisomers **13b** and **13c** by flash chromatography (SiO_2, 3/1 hexane/ether). Pure *para* regioisomer **4c** was obtained by preparative TLC (9/1 hexane/ether, several elutions). **2-[2-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]-2-methylpropionic acid (14).** Mp: 104–105 °C. ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.24 (s, 3 H, CH_3), 1.60 (s, 3 H, CH_3), 1.62 (s, 3 H, CH_3), 1.74 (s, 3 H, CH_3), 2.80–3.00 (broad s, 1 H), 3.90–4.18 (AB system, 2 H, J = 8.5 Hz, OCH_2), 7.33–7.38 (m, 2 H, HC(6′) and HC(4′)), 7.48 (dt, 1 H, J = 1.5, 7.5 Hz, HC(5′)), 8.10 (dd, 1 H, J = 1.5, 7.5 Hz, HC(3′). IR (CH_2Cl_2): 3584 (w), 3500–3200 (broad, w), 3056 (w), 3047 (w), 2978 (m), 2936 (m), 2890 (w), 1656 (vs), 1604 (m), 1577 (w), 1475 (m), 1457 (m), 1406 (vs), 1384 (s), 1366 (m), 1246 (m), 1202 (m), 1173 (m), 1118 (m), 1091 (m), 1065 (s), 1055 (s), 1018 (m), 973 (w), 902 (m), 881 (m) cm^{-1}. MS: *m/z* 261 (5), 244 (11), 206 (15), 190 (12), 146 (100), 131 (76). Anal. Calcd for $C_{15}H_{19}NO_3$: C, 69.94; H, 7.33; N, 5.36. Found: C, 68.81; H, 7.37; N, 5.38. **2-[3-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]-2-methylpropanenitrile (13b).** ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.38 (s, 6 H), 1.75 (s, 6 H), 4.12 (s, 2 H, OCH_2), 7.43 (dt, 1 H, J = 0.5, 7.5 Hz, HC(5′)), 7.63 (ddd, 1 H, J = 1.5, 2.0, 7.5 Hz, HC(6′)), 7.90 (dt, 1 H, J = 1.5, 7.5 Hz, HC(4′)), 7.99 (ddd, 1 H, J = 0.5, 1.5, 2.0 Hz, HC(2′)). **2-[4-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]-2-methylpropanenitrile (13c).** Mp: 66–67 °C. ^{1}H NMR (200 MHz, $CDCl_3$): δ 1.37 (s, 6 H, $(CH_3)_2C(4'')$), 1.72 (s, 6 H, $(CH_3)_2C(2)$), 4.10 (s, 2 H, OCH_2), 7.47–4.53 (m, 2H, XX′ part of AA′XX′ system, HC(2′) and HC(6′)), 7.92–7.98 (m, 2H, AA′ part of AA′XX′ system, HC(3′) and HC(5′)). IR (CH_2Cl_2): 3054 (w), 2972 (m), 2932 (w), 2896 (w), 2238 (w), 1649 (s), 1614 (w), 1573 (w), 1514 (w), 1462 (m), 1411 (m), 1354 (m), 1320 (m), 1306 (m), 1190 (m), 1104 (m), 1068 (m), 1018 (m), 990 (w), 967 (m), 923 (m), 847 (m) cm^{-1}. MS: *m/z* 242 (10), 227 (100), 212 (18), 199 (19), 171 (25), 155 (15). High-resolution MS for $C_{15}H_{18}N_2O$: calcd 242.1419, obsd 242.1411.

Addition–Oxidation Reaction of Complex 1a with 2-Lithiopropionitrile (15). By the general procedure, complex **1a** (311 mg, 1.0 mmol) was added as a solid to a solution of **15** (1.2 mmol) in THF (10 mL) at −90 °C. The reaction mixture was slowly warmed to −78 °C over 3 h. Oxidation and workup gave 210 mg of crude product. GC analysis (initial T 150 °C, initial time 1

(63) Seebach, D.; Corey, E. J. *J. Org. Chem.* **1975**, *40*(2), 231.

min, 30 °C/min; **16a** R_f 7.3 min, **16b** R_f 8.0 min, **16c** R_f 8.4 min, **17** R_f 9.9 min) and ^{1}H NMR analysis showed four products, (**16a** + **17**):**16b**:**16c**, in the ratio of 76:4:20. Purification by flash chromatography (SiO_2, 2/1 to 1/3 hexane/ether) afforded 93 mg of **16a**, 29 mg of **17**, 6 mg of **16b**, and 27 mg of **16c** (68% total yield). A separate experiment was carried out exactly as before except for the reaction temperature, which was 0 °C. Recooling, oxidation, and workup gave 214 mg of crude product, which was shown by GC and ^{1}H NMR analysis to consist of (**16a** + **17**):**16b**:**16c** in the proportions 90:0.5:9.5. Chromatography afforded 115 mg of **16a**, 18 mg of **17**, traces (less than 1 mg) of **16b**, and 12 mg of **16c** (64% total yield). **2-[2-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]propanenitrile (16a).** Mp: 46–47 °C. ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.36 and 1.37 (two s, 6 H, $CH_3C(4'')$), 1.58 (d, 3 H, J = 7.1 Hz, $CH_3C(2)$), 4.04 (s, 2 H, OCH_2), 5.61 (q, 1 H, J = 7.1 Hz, HC(2)), 7.34 (dt, 1 H, J = 1.5, 7.5 Hz, HC(4')), 7.49 (dt, 1 H, J = 1.5, 7.5 Hz, HC(5')), 7.66 (dd, 1 H, J = 1.5, 7.5 Hz, HC(6')), 7.86 (dd, 1 H, J = 1.5, 7.5 Hz, HC(3')). IR (CH_2Cl_2): 3071 (w), 2971 (s), 2934 (m), 2895 (m), 2873 (w), 2240 (w), 1645 (vs), 1600 (w), 1578 (w), 1495 (m), 1462 (m), 1455 (m), 1446 (m), 1365 (m), 1352 (s), 1309 (s), 1284 (m), 1249 (w), 1214 (w), 1189 (m), 1126 (m), 1089 (w), 1041 v (s), 990 (m), 967 (m), 925 (w) cm^{-1}. MS: m/z 229 (M + 1, 56), 228 (56), 227 (12), 213 (9), 198 (12), 186 (23), 185 (16), 174 (18), 173 (33), 158 (20), 157 (39), 156 (59), 155 (19), 146 (40), 144 (23), 142 (21), 130 (75), 115 (52), 103 (86), 77 (100). High-resolution MS for $C_{14}H_{16}N_2O$: calcd 228.1262, obsd 228.1272. Anal. Calcd for $C_{14}H_{16}N_2O$: C, 73.66; H, 7.06; N, 12.27. Found: C, 73.61; H, 7.09; N, 12.20. **2-[3-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]propanenitrile (16b).** ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.38 (s, 6 H, $(CH_3)_2C(4'')$, 1.65 (d, 3 H, J = 7.5 Hz, $CH_3C(2)$), 3.92 (q, 1H, J = 7.5 Hz, HC(2)), 4.12 (s, 2H, OCH_2), 7.33–7.53 (m, 2 H, H_{ar}), 7.85–7.93 (m, 2H, H_{ar}). IR (CH_2Cl_2): 3043 (w), 2972 (s), 2932 (m), 2896 (m), 2243 (w), 1650 (vs), 1605 (m), 1584 (w), 1456 (m), 1383 (w), 1355 (m), 1314 (m), 1190 (m), 1085 (m), 1062 (m), 1040 (w), 990 (w), 970 (m), 926 (w), 807 (w) cm^{-1}. MS: m/z 228 (8), 213 (100), 198 (22), 185 (25), 157 (30), 141 (10), 130 (31). High-resolution MS for $C_{14}H_{16}N_2O$: calcd 228.1262, obsd 228.1257. **2-[4-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]propanenitrile (16c).** ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.37 (s, 6 H, $CH_3C(4'')$), 1.63 (d, 3 H, J = 7.5 Hz, $CH_3C(2)$), 3.92 (q, 1 H, J = 7.5 Hz, HC(2)), 4.10 (s, 2H, OCH_2), 7.35–7.42 (m, 2H, XX' part of AA'XX' system, HC(2') and HC(6')), 7.91–7.98 (m, 2 H, AA' part of AA'XX' system, HC(3') and HC(5')). IR (CH_2Cl_2): 3042 (w), 2971 (s), 2932 (m), 2897 (m), 2244 (w), 1650 (vs), 1614 (w), 1576 (w), 1513 (m), 1461 (m), 1418 (m), 1381 (w), 1365 (m), 1354 (m), 1316 (m), 1302 (m), 1215 (w), 1186 (s), 1087 (m), 1069 (m), 1019 (m), 990 (m), 966 (m), 923 (w), 846 (m) cm^{-1}. MS: m/z 228 (9), 213 (100), 198 (19), 185 (23), 157 (39), 142 (13), 130 (10), 115 (9). High-resolution MS for $C_{14}H_{16}N_2O$: calcd 228.1262, obsd 228.1259. **4*H*-2,3-Dihydro-3,3,10-trimethyloxazolo[3,2-*b*]isoquinolin-5-one (17).** ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.77 (s, 6 H, $(CH_3)_2C(3)$), 2.15 (s, 3 H, $CH_3C(10)$), 4.25 (s, 2H, $CH_2C(2)$), 7.27 (ddd, 1 H, J = 1.5, 6.9, 8.1 Hz, HC(7)), 7.47 (ddd, J = 0.6, 1.5, 8.1 Hz, HC(9)), 7.59 (ddd, 1 H, J = 1.5, 6.9, 8.1 Hz, HC(8)), 8.31 (ddd, 1 H, J = 0.6, 1.5, 8.1 Hz, HC(6)). IR (CH_2Cl_2): 3052 (w), 2975 (w), 2928 (w), 2900 (w), 2873 (w), 1679 (vs), 1631 (vs), 1605 (s), 1552 (m), 1488 (s), 1045 (m), 1400 (m), 1384 (w), 1369 (w), 1360 (w), 1339 (m), 1286 (m), 1218 (w), 1176 (m), 1152 (m), 1083 (w), 1068 (w), 1030 (m), 1012 (m), 991 (w), 967 (w), 930 (w), 904 (w), 851 (w), 818 (w). MS: m/z 229 (100), 214 (22), 201 (20), 186 (15), 175 (23), 146 (33), 128 (19), 103 (20), 77 (19), 55 (19). High-resolution MS for $C_{14}H_{15}NO_2$: calcd 229.1102, obsd 229.1088.

Addition–Oxidation Reaction of Complex 1a with 2-Lithioacetonitrile (18). By following the general procedure, complex **1a** (311 mg, 1.0 mmol) was added as a solid to a solution of **18** (1.5 mmol) in THF (10 mL) at −90 °C. The reaction mixture was slowly warmed to −78 °C over 3 h. Oxidation and workup gave 145 mg of crude product. GC analysis (initial T 150 °C, initial time 1 min, 20 °C/min; **19a** R_f 6.6 min, **19b** R_f 7.2 min, **19c** R_f 7.4 min, **20** R_f 7.9 min) and ^{1}H NMR analysis indicated four products (**19a** + **20**):**19b**:**19c** in the ratio of 89:2:9. Chromatography (SiO_2, 2/1 to 1/2 hexane/ether) afforded 101 mg of **19a**, 42 mg of **20**, 3 mg of **19b**, and 14 mg of **19c** (77% total yield). A separate experiment was carried out exactly as before except for the reaction temperature, which was 0 °C. Recooling, oxidation, and workup gave 140 mg of crude product shown by GC and ^{1}H NMR to consist of (**19a** + **20**):**19b**:**19c** in the ratio of 98:0:2. Purification afforded 111 mg of **19a** and 44 mg of **20** (74% total yield). **[2-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]acetonitrile (19a).** Mp: 46 °C. ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.39 (s, 6 H, $(CH_3)_2C(4'')$), 4.07 (s, 2 H, OCH_2), 4.35 (s, 2 H, CH_2CN), 7.39 (dt, J = 1.5, 7.5 Hz, HC(5')), 7.47 (dt, 1H, J = 1.5, 7.5 Hz, HC(4')), 7.54 (bd, 1H, J = 7.5 Hz, HC(3')), 7.91 (dd, 1H, J = 1.5, 7.5 Hz, HC(6')). IR (CH_2Cl_2): 3065 (w), 3035 (w), 2975 (s), 2935 (m), 2895 (m), 2870 (m), 2250 (w), 1652 (vs), 1605 (w), 1578 (w), 1500 (m), 1462 (m), 1448 (m), 1407 (w), 1385 (w), 1367 (m), 1352 (s), 1307 (s), 1192 (m), 1126 (m), 1044 (vs), 989 (w), 967 (m), 934 (w), 870 (w), 818 (w) cm^{-1}. MS: m/z 215 (M + 1, 35), 214 (30), 199 (63), 183 (27), 172 (12), 171 (14), 169 (15), 143 (38), 130 (31), 116 (100), 89 (63). Anal. Calcd for $C_{13}H_{14}N_2O$: C, 72.87; H, 6.58; N, 13.07. Found: C, 72.76; H, 6.62; N, 12.95. **[3-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]acetonitrile (19b).** ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.35 (s, 6 H, $(CH_3)_2C(4'')$), 4.03 (s, 2 H), 4.32 (s, 2 H), 7.33–7.60 (m, 2 H, H_{ar}), 7.93 (dd, 1 H, J = 1.6, 7.7 Hz, H_{ar}), 8.05 (bs, 1 H, H_{ar}). **[4-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]acetonitrile (19c).** ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.38 (s, 6H, $(CH_3)_2C(4'')$), 3.79 (s, 2H, CH_2CN), 4.11 (s, 2H, OCH_2), 7.34–7.39 (m, 2 H, XX' part of AA'XX' system, HC(2') and HC(6')), 7.92–7.97 (m, 2H, AA' part of AA'XX' system, HC(3') and HC(5')). IR (CH_2Cl_2): 3045 (w), 2975 (s), 2933 (m), 2896 (m), 2245 (w), 1651 (vs), 1610 (w), 1576 (w), 1510 (m), 1461 (m), 1420 (m), 1382 (w), 1365 (m), 1354 (m), 1315 (m), 1214 (w), 1185 (s), 1086 (m), 1070 (s), 990 (m), 967 (m), 924 (w), 844 (w) cm^{-1}. MS: m/z 214 (10), 199 (100), 184 (23), 171 (20), 143 (40), 116 (15). High-resolution MS for $C_{13}H_{14}N_2O$: calcd 214.1106, obsd 214.1100. **4*H*-2,3-Dihydro-3,3-dimethyloxazolo[3,2-*b*]isoquinolin-5-one (20).** Mp: 91–92 °C. ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.79 (s, 6 H, $(CH_3)_2C(3)$), 4.27 (s, 2H, OCH_2), 5.84 (s, 1H, HC(10)), 7.25 (dt, 1H, J = 1.5, 8.0 Hz, HC(7)), 7.35 (d, 1H, J = 8.0 Hz, HC(9)), 7.32 (dt, 1 H, J = 1.5, 8.0 Hz, HC(8)), 8.26 (bd, 1H, J = 8.0 Hz, HC(6)). IR (CH_2Cl_2): 3100 (w), 3065 (w), 3050 (w), 2985 (m), 2935 (m), 2900 (m), 1674 (vs), 1633 (vs), 1607 (vs), 1556 (s), 1489 (s), 1452 (s), 1418 (s), 1385 (w), 1370 (m), 1362 (m), 1342 (m), 1320 (w), 1289 (m), 1222 (m), 1192 (w), 1170 (m), 1144 (s), 1126 (m), 1120 (m), 1074 (s), 1026 (m), 1007 (s), 970 (w), 940 (w), 907 (m), 874 (w), 800 (m), 785 (w) cm^{-1}. MS: m/z 215 (57), 200 (26), 172 (13), 161 (21), 145 (14), 144 (10), 143 (26), 133 (28), 131 (17), 117 (15), 115 (34), 114 (10), 104 (14), 90 (12), 89 (73), 88 (16). Anal. Calcd for $C_{13}H_{13}NO_2$: C, 72.54; H, 6.09; N, 6.51. Found: C, 72.38; H, 6.16; N, 6.54.

Addition–Oxidation Reaction of Chromium Complex 1a with Lithiothioanisole (30). By the general procedure, a −78 °C solution of complex **1a** (110 mg, 0.354 mmol) in THF (2 mL) was added *via* cannula transfer to a solution of **30** (1.2 equiv) in THF (3 mL). The reaction mixture was slowly warmed to −20 °C over 3 h. Oxidation, workup, and filtration through a short plug of SiO_2 afforded 58 mg (55%) of crude product. GC analysis (initial T 150 °C, initial time 3 min, 20 °C/min; **31a** R_f 9.9 min; **31b** R_f 10.9 min; **31c** R_f 11.7 min) showed this to consist of three products in the ratio of 37:19:44. Analytical samples of **31a**, **31b**, and **31c** were obtained after careful purification by flash chromatography (SiO_2, CH_2Cl_2, then 40/1/1 CH_2Cl_2/ether/hexane). **4,5-Dihydro-4,4-dimethyl-2-{2-[(phenylthio)methyl]phenyl}oxazole (31a).** ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.37 (s, 6 H, $(CH_3)_2C(4)$), 4.06 (s, 2H, OCH_2), 4.59 (s, 2 H, SCH_2), 7.13–7.50 (8H, m, H_{ar}), 7.74–7.81 (m, 1H, HC(6')). IR (CH_2Cl_2): 3080 (w), 3050 (w), 2975 (s), 2930 (m) 2895 (m), 2875 (m), 1648 (s), 1581 (w), 1496 (w), 1466 (w), 1444 (m), 1351 (m), 1304 (m), 1192 (w), 1070 (m), 1051 (s), 1041 (vs), 1030 (s), 992 (w), 970 (m), 874 (w), 822 (w) cm^{-1}. MS: m/z 297 (71), 206 (100), 188 (20), 175 (16), 160 (35). High-resolution MS for $C_{18}H_{19}NOS$: calcd 297.1187, obsd 297.1182. **4,5-Dihydro-4,4-dimethyl-2-{3-[(phenylthio)methyl]phenyl}oxazole (31b).** ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.37 (s, 6 H, $(CH_3)_2C(4)$), 4.09 (s, 2 H, OCH_2), 4.12 (s, 2 H, SCH_2), 7.15–7.42 (m, 7 H, H_{ar}), 7.79 (dt, 1 H, J = 1.5, 7.5

Hz, HC(6')), 7.89 (t, 1 H, J = 2 Hz, HC(2')). IR (CH_2Cl_2): 3065 (w), 3055 (w), 2975 (m), 2935 (w), 2930 (w), 2895 (w), 2870 (w), 1653 (s), 1607 (w), 1585 (w), 1481 (m), 1460 (w), 1440 (m), 1422 (w), 1355 (m), 1315 (m), 1274 (w), 1260 (w), 1192 (m), 1077 (m), 1066 (m), 1026 (w), 985 (w), 974 (w), 911 (w), 900 (w), 811 (w) cm^{-1}. MS: m/z 297 (35), 282 (13), 188 (100). High-resolution MS for $C_{18}H_{19}NOS$: calcd 297.1187, obsd 297.1192. **4,5-Dihydro-4,4-dimethyl-2-{4-[(phenylthio)methyl]phenyl}oxazole (31c).** ^1H NMR ($CDCl_3$, 200 MHz): δ 1.37 (s, 6 H, $(CH_3)_2C(4)$), 4.08 (s, 2 H, OCH_2), 4.10 (s, 2 H, SCH_2), 7.16–7.35 (m, 7 H, H_{ar}), 7.80–7.86 (m, 2 H, HC(2') and HC(6')). IR (CH_2Cl_2): 3055 (w), 2980 (m), 2945 (w), 2895 (w), 2870 (w), 1652 (s), 1611 (w), 1574 (w), 1482 (m), 1437 (w), 1426 (w), 1363 (w), 1348 (m), 1315 (m), 1274 (w), 1185 (w), 1111 (w), 1070 (s), 1026 (w), 1022 (w), 988 (w), 970 (w), 910 (s). MS: m/z 297 (30), 282 (10), 188 (100), 173 (42). High-resolution MS for $C_{18}H_{19}NOS$: calcd 297.1187, obsd 297.1205.

Addition–Oxidation Reaction of Complex 1a with the Anion *p*-Tolyl Methyl Sulfoxide (32). By the general procedure, complex **1a** (311 mg, 1 mmol) was added as a solid to a solution of **32**[43] (1.1 mmol) in THF (10 mL) at −78 °C. The reaction mixture was warmed to −50 °C over 2 h. Oxidation, workup, and purification by radial chromatography (SiO_2, Et_2O) afforded 226 mg of **33a** and 11 mg of **33c** (72% total yield). A separate reaction was carried out exactly as before, except for warming to 0 °C in 1 h and stirring at this temperature for 2 h. Oxidation, workup, and purification afforded 228 mg of **33a** and 12 mg of **33c**. **4,5-Dihydro-4,4-dimethyl-2-{2-[((4-methylphenyl)sulfinyl)methyl]phenyl}oxazole (33a).** ^1H NMR ($CDCl_3$, 400 MHz): δ 1.40 and 1.39 (two s, 6 H, $(CH_3)_2C$)), 2.40 (s, 3 H, CH_3), 4.04–4.05 (m, 2 H, OCH_2), 4.41–4.44 (d, 1 H, B part of AB system, J = 11.6 Hz, SCH), 4.92–4.96 (d, 1 H, A part of AB system, J = 11.6 Hz, SCH), 7.10–7.12 (m, 1 H, H_{ar}), 7.20–7.30 (m, 2 H, XX' part of AA'XX' system, H_{ar}), 7.30–7.40 (m, 2 H, H_{ar}), 7.45–7.55 (m, 2 H, AA' part of AA'XX' system, H_{ar}), 7.91 (m, 1 H, Hz, HC(6)). IR ($CHCl_3$): 3024 (w), 2995 (m), 2974 (m), 2927 (w), 2882 (w), 1641 (m), 1494 (w), 1463 (w), 1445 (w), 1362 (w), 1310 (w), 1302 (w), 1084 (w), 1041 (s), 1016 (w), 967 (w), 908 (s) cm^{-1}. MS: m/z 327 (5), 311 (6), 279 (10), 252 (3), 240 (5), 218 (3), 206 (5), 188 (100), 134 (30). High-resolution MS for $C_{19}H_{21}NO_2S$: calcd 327.1293, obsd 327.1322. **4,5-Dihydro-4,4-dimethyl-2-{4-[((4-methylphenyl)sulfinyl)methyl]phenyl}oxazole (33c).** ^1H NMR ($CDCl_3$, 400 MHz): δ 1.41 (s, 6 H, $(CH_3)_2C$), 2.40 (s, 3 H, CH_3), 4.00–4.10 (m, 2 H, SCH_2), 4.11 (s, 2 H, OCH_2), 6.98–7.01 (m, 2 H, H_{ar}), 7.20–7.40 (m, 4 H, H_{ar}), 7.80–7.83 (m, 2 H, H_{ar}).

Addition–Oxidation Reaction of Complex 1a with the Lithium Enolate of *tert*-Butyl Acetate (35). By the general procedure, HMPA (0.437 mL, 2.5 mmol) and complex **1a** (311 mg, 1.0 mmol) were added to a solution of **1a** (1.2 mmol) in THF (10 mL) at −78 °C. The reaction mixture was slowly warmed to −50 °C over 3 h. After oxidation and workup, GC analysis (initial T 150 °C, initial time 5 min, 25 °C/min; **36a** R_f 8.7 min, **36b** R_f 9.2 min, **36c** R_f 9.4 min) showed three products in the ratio of 83:4:13. Purification by flash chromatography (SiO_2, 6/1 to 1/1 hexane/ether) afforded 212 mg of **36a**, 5 mg of **36b**, and 38 mg of **36c** (87% total yield). A separate reaction was carried out exactly as before except for the reaction temperature, which was 0 °C. After recooling, oxidation, and the usual workup, GC analysis showed three products in the ratio of 86:1:13. Purification by flash chromatography afforded 199 mg of **36a**, traces of **37b**, and 36 mg of **37c** (81% total yield). **[2-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]acetic Acid 1,1-Dimethylethyl Ester (36a).** Mp: 45 °C. ^1H NMR ($CDCl_3$, 400 MHz): δ 1.36 (s, 6 H, $(CH_3)_2C(4'')$), 1.43 (s, 9 H, $C(CH_3)_3$), 3.97 (s, 2 H, CH_2CO), 4.04 (s, 2 H, OCH_2), 7.23 (bd, 1H, J = 7.5 Hz, HC(3')), 7.29 (dt, 1 H, J = 1.5, 7.5 Hz, HC(5')), 7.38 (dt, 1 H, J = 1.5, 7.5 Hz, HC(4')), 7.85 (dd, 1 H, J = 1.5, 7.5 Hz, HC(6')). IR (CH_2Cl_2): 3065 (w), 2970 (m), 2935 (m), 2895 (m), 2875 (w), 1730 (s), 1652 (m), 1500 (w), 1477 (w), 1463 (w), 1455 (w), 1418 (w), 1392 (w), 1366 (m), 1352 (m), 1344 (m), 1311 (m), 1285 (m), 1255 (m), 1226 (m), 1148 (s), 1040 (m), 988 (w), 966 (w), 855 (w), 830 (w) cm^{-1}. MS: m/z 289 (1), 233 (9), 216 (9), 200 (4), 189 (4), 174 (5), 161 (15), 116 (22), 57 (100). Anal. Calcd for $C_{17}H_{23}NO_3$: C, 70.56; H, 8.01; N, 4.84. Found: C, 70.39; H, 8.00; N, 4.81. **[3-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]acetic Acid, 1,1-Dimethylethyl Ester (36b).** ^1H NMR ($CDCl_3$, 200 MHz): δ 1.38 (s, 6 H, $(CH_3)_2C(4'')$), 1.42 (s, 9 H, $C(CH_3)_3$), 3.55 (s, 2 H, CH_2CO), 4.10 (s, 2 H, OCH_2), 7.30–7.45 (m, 2 H, HC(5') and HC(6')), 7.79–8.70 (m, 2 H, HC(4') and HC(2')). IR (CH_2Cl_2): 3050 (w), 2975 (m), 2940 (w), 2890 (w), 1727 (s0, 1649 (m), 1456 (w), 1368 (m), 1148 (s), 1080 (s), 1065 (w), 975 (w). MS: m/z 289 (8), 274 (28), 218 (12), 189 (35), 57 (100). High-resolution MS for $C_{17}H_{23}NO_3$: calcd 289.1677, obsd 289.1670. **[4-(4,5-Dihydro-4,4-dimethyloxazol-2-yl)phenyl]acetic Acid, 1,1-Dimethylethyl Ester (36c).** ^1H NMR ($CDCl_3$, 200 MHz): δ 1.36 (s, 6 H, $(CH_3)_2C(4'')$), 1.40 (s, 9 H, $C(CH_3)_3$), 3.54 (s, 2 H, CH_2CO), 4.08 (s, 2 H, OCH_2), 7.26–7.33 (m, 2 H, AA' part of AA'XX' system, HC(2') and HC(6')), 7.84–7.91 (m, 2 H, XX' part of AA'XX' system, HC(3') and HC(5')). IR (CH_2Cl_2): 3050 (w), 3045 (w), 2980 (s), 2935 (m), 2900 (w), 2875 (w), 1725 (vs), 1652 (s), 1618 (w), 1515 (w), 1460 (w), 1422 (w), 1396 (w), 1370 (s), 1356 (m), 1320 (m), 1304 (m), 1285 (m), 1274 (m), 1267 (m), 1256 (m), 1181 (s), 1148 v (s), 1070 (s), 1022 (m), 970 (w) cm^{-1}. MS: m/z 289 (1), 234 (2), 232 (1), 189 (9), 57 (100). High-resolution MS for $C_{17}H_{23}NO_3$: calcd 289.1677, obsd 289.1685.

General Procedure for Nucleophile Addition/Oxidation Reactions of Complexes 1–3 with Organolithium Reagents. A commercial solution of RLi (1.1–1.2 equiv) was added dropwise via syringe to a solution of the complex (0.3–1 mmol) in THF (3–10 mL) at −78 °C. Stirring was continued for the time noted and at the temperature indicated before recooling to −78 °C. Oxidation and the usual workup afforded the crude product.

Addition/Oxidation Reaction of Complex 1a with MeLi. MeLi (1.60 M in ether, 0.750 mL, 1.2 mmol) was added to a solution of complex **1a** (311 mg, 1.0 mmol) in THF (10 mL) at −78 °C. The yellow solution turned to pale orange within minutes and became orange-red on warming to −20 °C over a period of 3 h. After oxidation and workup, GC analysis showed a single product (initial T 100 °C, initial time 5 min, 20 °C/min; R_f 9.7 min). Purification by flash chromatography (SiO_2, 2/1 hexane/ether) afforded 155 mg (82%) of **37a**. A separate reaction was carried out exactly as before, except for use of HMPA (2.5 equiv) as a cosolvent. From 71 mg (0.225 mmol) of **1a**, 35 mg (81%) of **37a** was obtained. **4,5-Dihydro-4,4-dimethyl-2-(2-methylphenyl)oxazole (37a).**[49] ^1H NMR ($CDCl_3$, 200 MHz): δ 1.40 (s, 6 H, $(CH_3)_2C(4)$), 2.54 (s, 3 H, $CH_3C(2')$), 4.06 (s, 2 H, OCH_2), 7.14–7.36 (m, 3H, HC(3'), HC(4'), HC(5')), 7.73 (dd, 1 H, J = 2.0, 7.5 Hz, HC(6')). IR (CH_2Cl_2): 3072 (w), 3044 (w), 2970 (s), 2929 (m), 2894 (m), 1648 (s), 1493 (m), 1461 (m), 1384 (w), 1365 (m), 1351 (m), 1309 (m), 1230 (m), 1189 (m), 1120 (w), 1068 (m), 1041 (s), 966 (m), 922 (w), 871 (w), 820 (w) cm^{-1}. MS: m/z 189 (100), 174 (85), 159 (25), 158 (26), 146 (58), 118 (97). High-resolution MS for $C_{12}H_{15}NO$: calcd 189.1153, obsd 189.1159.

Addition–Oxidation Reaction of Complex 1a with *n*-BuLi. *n*-BuLi (1.55 M in hexane, 0.184 mL, 0.300 mmol) was added to a solution of complex **1a** (85 mg, 0.273 mmol) in THF (3.0 mL) at −78 °C. The yellow solution turned to orange within minutes and became orange-red on warming to −20 °C over 3 h. After oxidation and workup, GC analysis showed a single product (initial T 100 °C, initial time 5 min, 20 °C/min; R_f 9.7 min). Purification by flash chromatography (SiO_2, 5/1 hexane/ether) afforded 59 mg (93%) of **38a**. **2-(2-Butylphenyl)-4,5-dihydro-4,4-dimethyloxazole (38a).**[49] ^1H NMR ($CDCl_3$, 200 MHz): δ 0.90 (t, 3 H, J = 7.5 Hz, CH_3CH_2), 1.20–1.62 (m, 4 H, $CH_3CH_2CH_2$), 1.38 (s, 6 H, $(CH_3)_2C(4)$), 2.92 (t, 2 H, J = 7.5 Hz, $CH_2C(2')$), 4.08 (s, 2 H, OCH_2), 7.14–7.38 (m, 3 H, HC(3'), HC(4'), HC(5')), 7.68 (dd, 1 H, J = 1.7, 7.8 Hz, HC(6')). IR (CH_2Cl_2): 3060 (w), 3050 (w), 2970 (s), 2935 (s), 2900 (m), 2880 (m), 1652 (s), 1600 (w), 1488 (w), 1463 (m), 1363 (w), 1348 (m), 1270 (m), 1211 (w), 1185 (w), 1074 (w), 1048 (m), 1034 (s), 985 (w), 963 (m), 907 (m) cm^{-1}. MS: m/z 231 (23), 216 (18), 202 (100), 189 (5), 148 (23), 131 (47). High-resolution MS for $C_{15}H_{21}NO$: calcd, 231.1623, obsd 231.1624.

Addition–Oxidation Reaction of Complex 1a with *t*-BuLi. *t*-BuLi (1.4 M in ether, 0.437 mL, 0.61 mmol) was added to a solution of complex **1a** (160 mg, 0.51 mmol) in THF (5 mL) at −78 °C. The solution was slowly warmed to −20 °C over 3 h.

After recooling, oxidation, and workup, GC analysis showed a single product and unreacted **4a** (initial *T* 100 °C, initial time 5 min, 20 °C/min; R_f 13.6 min). Purification by flash chromatography (SiO_2, 5/1 hexane/ether) afforded 35 mg (30%) of **39a**, with a slight impurity of **4a**. A separate experiment was carried out exactly as before except for use of HMPA (1 mL) as a cosolvent. GC analysis showed two products (R_f 14.2 and 14.63 min) and unreacted **4a** in the ratio of 1:6.1. Purification afforded 67 mg (57%) of a mixture of **39b** and **39c**. For a comparison of analytical data, product **39c** was prepared from 4-*tert*-butylbenzoyl chloride and 2-amino-2-methylethanol by following the procedure given in ref 23. **2-[2-(1,1-Dimethylethyl)phenyl]-4,5-dihydro-4,4-dimethyloxazole (39a).**[49] ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.37 (s, 6 H, $(CH_3)_2C(4)$), 1.41 (s, 9 H, $C(CH_3)_3$), 4.09 (s, 2 H, OCH_2), 7.12–7.50 (m, 4 H). **3-[4-(1,1-Dimethylethyl)phenyl]-4,5-dihydro-4,4-dimethyloxazole (39b).** ^{1}H NMR ($CDCl_3$, 200 MHz): 1.33 (s, 9 H, $C(CH_3)_3$), 1.37 (s, 6 H, $(CH_3)_2C(4)$), 4.10 (s, 2 H, OCH_2), 7.32 (dt, 1 H, *J* = 0.5, 8 Hz, HC(5)), 7.50 (ddd, 1 H, *J* = 1.2, 2.0, 8.0 Hz, HC(4')), 7.77 (ddd, 1 H, *J* = 1.2, 2.0, 8.0 Hz), 7.95 (m, 1 H, *J* = 0.5, 1.2 Hz, HC(2')). **2-[4-(1,1-Dimethylethyl)phenyl]-4,5-dihydro-4,4-dimethyloxazole (39c).** Mp: 68–70 °C. ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.32 (s, 9 H, $C(CH_3)_3$), 1.38 (s, 6 H, $(CH_3)_2C(4)$), 4.09 (s, 2 H, OCH_2), 7.37–7.45 (m, 2 H, AA' part of AA'XX' system, HC(3') and HC(5')), 7.82–7.90 (m, 2 H, XX' part of AA'XX' system, HC(2') and HC(6')). IR (CH_2Cl_2): 3060 (w), 2975 (s), 2935 (w), 2910 (w), 2875 (w), 1655 (s), 1522 (w), 1507 (w), 1474 (w), 1463 (w), 1426 (w), 1415 (w), 1400 (w), 1359 (m), 1355 (m), 1318 (m), 1307 (m), 1274 (w), 1188 (m), 1111 (w), 1066 (m), 1019 (m), 967 (w), 852 (m) cm^{-1}. MS: *m/z* 231 (9), 216 (100), 201 (20), 160 (26), 144 (28), 116 (30). High-resolution MS for $C_{14}H_{18}NO$ (M − 15): calcd 216.1388, obsd 216.1370.

Addition–Oxidation Reaction of Complex 1a with PhLi. PhLi (1.98 M in cyclohexane/ether, 0.137 mL, 0.271 mmol) was added to a solution of complex **1a** (77 mg, 0.246 mmol) in THF (2.5 mL) at −78 °C. After warming to −20 °C over 3 h, recooling, oxidation, and workup, GC analysis showed a single product (initial *T* 70 °C, 20 °C/min; R_f 11.1 min). Purification by flash chromatography (SiO_2, 5/1 hexane/ether) afforded 53 mg (85%) of **40a**. A separate experiment was carried out exactly as before except for use of HMPA (0.108 mL, 2.5 equiv) as a cosolvent. GC analysis of the crude mixture showed again a single product. Purification gave 51 mg (83%) of **40a**. **2-(1,1'-Biphenyl-2-yl)-4,5-dihydro-4,4-dimethyloxazole (40a).**[64] Mp: 39–40 °C (lit.[64] mp 38.5–40.5 °C). ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.29 (s, 6 H, $(CH_3)_2C(4)$), 3.79 (s, 2 H, OCH_2), 7.30–7.53 (m, 8 H, H_{ar}), 7.69–7.75 (m, 1 H, HC(6')). IR (CH_2Cl_2): 3050 (w), 2980 (s), 2930 (m), 2895 (w), 2870 (w), 1655 (s), 1477 (w), 1470 (w), 1463 (w), 1455 (w), 1440 (w), 1367 (w), 1352 (m), 1310 (s), 1074 (m), 1040 (s), 962 (m), 920 (m) cm^{-1}. MS: *m/z* 251 (14), 250 (100), 236 (6), 180 (36), 165 (88), 152 (43). Anal. Calcd for $C_{17}H_{17}NO$: C, 81.24; H, 6.82; N, 5.57. Found: C, 81.19; H, 6.80; N, 5.40.

Addition–Oxidation Reaction of Complex 1a with Vinyllithium. MeLi (1.76 M in ether, 0.310 mL, 0.547 mmol) was added to a stirred solution of tetravinyltin (0.028 mL, 0.153 mmol) in THF (1.5 mL) at −78 °C. The red solution was slowly warmed to −40 °C over a period of 2 h and then recooled to −78 °C. A −78 °C solution of complex **1a** (114 mg, 0.365 mmol) in THF (5 mL) was added *via* cannula. The solution was slowly warmed to −20 °C over 4 h. After recooling, oxidation, and workup, GC analysis showed a single product (initial *T* 100 °C, initial time 3 min, 20 °C/min; R_f 8.1 min). Purification by flash chromatography (SiO_2, 5/1 hexane/ether) afforded 46 mg (63%) of **41a**. **2-(2-Ethenylphenyl)-4,5-dihydro-4,4-dimethyloxazole (41a).** Mp: 65–66 °C. ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.40 (s, 6 H, $(CH_3)_2C(4)$), 4.09 (s, 2 H, OCH_2), 5.27–5.36 (dd, 1 H, *J* = 1.3, 11.0 Hz, $H_{vinylic}$), 5.65–5.76 (dd, 1 H, *J* = 1.3, 17.5 Hz, $H_{vinylic}$), 7.27 (dt, 1 H, *J* = 1.4, 7.6 Hz, HC(5')), 7.40 (dt, 1 H, *J* = 1.4, 7.6 Hz, HC(4')), 7.45 (dd, 1 H, *J* = 11.0, 17.5 Hz, $H_{vinylic}$), 7.61 (dd, 1 H, *J* = 1.4, 7.6 Hz, HC(3')), 7.74 (dd, 1 H, *J* = 1.4, 7.6 Hz, HC(6')). IR (CH_2Cl_2): 3090 (w), 3070 (w), 3055 (w), 3045 (w), 2970 (s), 2930 (m), 2895 (m), 2870 (w), 1652 (s), 1596 (w), 1567 (w), 1488 (m), 14674 (m), 1422 (w), 1385 (w), 1367 (m), 1352 (m), 1307 (m), 1278 (w), 1259 (w), 1215 (w), 1188 (w), 1107 (w), 1044 (s), 988 (m), 967 (m), 922 (m), 896 (w), 870 (w), 818 (w) cm^{-1}. MS: *m/z* 201 (22), 200 (100), 186 (5), 146 (71), 130 (26), 129 (16), 128 (37), 115 (44), 103 (39). Anal. Calcd for $C_{13}H_{15}NO$: C, 77.58; H, 7.51; N, 6.96. Found: C, 77.43; H, 7.60; N, 6.80.

Addition–Oxidation Reaction of Complex 1b with MeLi. MeLi (1.60 M in ether, 0.197 mL, 1.1 mmol) was added dropwise to a solution of complex **1b** (98 mg, 0.286 mmol) in THF (3 mL) at −78 °C. After warming to −20 °C over a period of 3 h, oxidation, and workup, GC analysis showed a single product (initial *T* 70 °C, initial time 3 min, 20 °C/min; R_f 10.4 min). Purification by flash chromatography (SiO_2, 3/1 hexane/ether) gave 40 mg (64%) of **42a**. **4,5-Dihydro-2-(4-methoxy-2-methylphenyl)-4,4-dimethyloxazole (42a).**[51] ^{1}H NMR ($CDCl_3$, 200 MHz): δ 1.36 (s, 6 H, $(CH_3)_2C(4)$), 2.55 (s, 3 H, $CH_3C(2')$), 3.70 (s, 3 H, OCH_3), 4.02 (s, 2 H, OCH_2), 6.67–6.76 (m, 2 H, HC(3'), HC(5')), 7.67–7.75 (m, 1H, HC(6')). IR (CH_2Cl_2): 3050 (w), 2971 (m), 2935 (m), 2889 (w), 2864 (w), 2840 (w), 1648 (s), 1611 (s), 1505 (m), 1296 (m), 1266 (s), 1263 (s), 1248 (s), 1033 (s), 755 (s), 750 (s), 710 (s). MS: *m/z* 219 (62), 204 (100), 176 (54), 148 (55). High-resolution MS for $C_{13}H_{17}NO_2$: calcd 219.1259, obsd 219.1261.

Addition–Oxidation Reaction of Complex 1b with *n*-BuLi. *n*-BuLi (1.5 M in hexane, 0.182 mL, 0.273 mmol) was added to a solution of complex **1b** (85 mg, 0.248 mmol) in THF (3.0 mL) at −78 °C. After warming to −20 °C over a period of 3 h, recooling, oxidation, and workup, GC analysis showed a single product (initial *T* 100 °C; initial time 5 min, 20 °C/min; R_f 11.6 min). Purification by flash chromatography (SiO_2, 5/1 hexane/ether) gave 43 mg (67%) of **43a**. **2-(2-Butyl-4-methoxyphenyl)-4,5-dihydro-4,4-dimethyloxazole (43a).**[52] ^{1}H NMR ($CDCl_3$, 200 MHz): δ 0.90 (t, 3 H, *J* = 7.5 Hz, CH_3CH_2), 1.15–1.65 (m, 4 H, $CH_3CH_2CH_2$), 1.35 (s, 6 H, $(CH_3)_2C(4)$), 2.94 (t, 2 H, *J* = 7.5 Hz, $CH_2C(2')$), 3.79 (s, 3 H, OCH_3), 4.01 (s, 2 H, OCH_2), 6.66–6.74 (m, 2 H, HC(3') and HC(5')), 7.62–7.69 (m, 1 H, HC(6')). IR (CH_2Cl_2): 3055 (w), 2966 (s), 2933 (m), 2870 (m), 1648 (s), 1607 (s), 1574 (m), 1500 (m), 1463 (m), 1352 (m), 1305 (m), 1266 (s), 1252 (s), 1242 (s), 1026 (s), 755 (s), 720 (s) cm^{-1}. MS: *m/z* 261 (17), 246 (8), 232 (100), 161 (32). High-resolution MS for $C_{16}H_{23}NO_2$: calcd 261.1729, obsd 261.1746.

Addition–Oxidation Reaction of Complex 2 with MeLi. MeLi (1.6 M in ether, 0.213 mL, 0.34 mmol) was added to a solution of complex **2** (100 mg, 0.31 mmol) in THF (5 mL) at −78 °C. After warming to −40 °C over 2 h and stirring at this temperature for 2 h, recooling, oxidation, and workup gave the crude product. GC analysis showed a single product. Purification by flash chromatography (SiO_2, 25/1 hexane/ether) gave 30 mg (81%) of *o*-tolualdehyde **44**.[9g]

Addition–Oxidation Reaction of Complex 2 with *n*-BuLi. *n*-BuLi (1.62 M in hexane, 0.210 mL, 0.34 mmol) was added dropwise to a solution of complex **2** (100 mg, 0.31 mmol) in THF (5 mL) at −78 °C. Following the usual procedure, 34 mg (68%) of 2-butylbenzaldehyde **45**[9g] was isolated.

Addition–Oxidation Reaction of Complex 2 with *t*-BuLi. *t*-BuLi (1.4 M in ether, 0.786 mL, 1.1 mmol) was added dropwise to a solution of complex **2** (1 mmol) in THF (10 mL) at −78 °C. By the usual procedure, 86 mg (53%) of **46** was obtained. **2-(1,1-Dimethylethyl)benzaldehyde (46).** ^{1}H NMR ($CDCl_3$, 400 MHz): δ 1.53 (s, 9 H, $(CH_3)_3C$), 7.30–7.53 (m, 3 H, HC(3), HC(4), HC(5)), 7.93 (d, 1 H, *J* = 8.2 Hz, HC(6)), 10.85 (s, 1 H, CHO). IR (hexane): 1716 (m), 1693 (s), 1600 (m), 1460 (m), 1450 (m), 1440 (m), 1380 (m), 1280 (w), 1250 (w), 1180 (m), 820 (w), 770 (m), 720 (w). MS: *m/z* 162 (7), 147 (89), 129 (100), 91 (60).

Addition–Oxidation Reaction of Complex 2 with PhLi. PhLi (2.18 M in cyclohexane/ether, 156 mL, 0.34 mmol) was added dropwise to a solution of **2** (100 mg, 0.34 mmol) in THF (5 mL) at −78 °C. By the usual procedure, 48 mg (78%) of 2-phenylbenzaldehyde (**47**)[9g] was obtained.

Addition–Oxidation Reaction of Complex 2 with Vinyllithium. MeLi (1.6 M in ether, 0.425 mL, 0.68 mmol) was added to a stirred solution of tetravinyltin (0.041 mL, 0.73 mmol) in THF (5 mL) at −78 °C. After 1 h a precooled (−78 °C) solution

(64) Ellefson, C. R. *J. Org. Chem.* **1979**, *44*, 1533.

of **2** (100 mg, 0.31 mmol) in THF (5 mL) was added *via* cannula technique. By the usual procedure, 32 mg (78%) of 2-vinylbenzaldehyde (**48**)[9g] was obtained.

Hydrogenation of 2-Vinylbenzaldehyde. A pressure-resistant Schlenk vessel was charged with 2-vinylbenzaldehyde (80 mg, 0.604 mmol), Pd/C (5 mg), and MeOH (20 mL). The mixture was submitted to three freeze–pump–thaw cycles, and then the atmosphere was changed to 2 atm of H_2. After the mixture was stirred at room temperature for 2.5 h, excess H_2 was vented and the solvent evaporated. Purification by flash chromatography (SiO_2, hexane, then 20/1 to 1/1 hexane/ether) afforded 80 mg (73%) of **49** and 12 mg (14%) of **50**. **2-Ethylbenzaldehyde Dimethylacetal (49).** ^1H NMR ($CDCl_3$, 200 MHz): δ 1.23 (t, 3 H, J = 7.5 Hz, CH_3), 2.75 (q, 2 H, J = 7.5 Hz, CH_2), 3.33 (s, 6 H, OCH_3), 5.51 (s, 1 H, CH), 7.15–7.33 (m, 3 H, HC(3), HC(4), HC(5)), 7.50–7.58 (m, 1 H, HC(6)). IR (CH_2Cl_2): 1700 (m), 1440 (m), 1380 (m), 1375 (m), 1100 (s), 1080 (s), 1060 (s) cm^{-1}. MS: m/z 179 (15), 149 (100), 133 (25), 117 (70), 105 (15), 91 (28). **2-Ethylbenzylic Alcohol (50).** ^1H NMR ($CDCl_3$, 200 MHz): δ 1.25 (t, 3 H, J = 7.6 Hz, CH_3), 1.55 (s, 1 H, OH), 2.72 (q, 2 H, J = 7.6 Hz, CH_2), 4.74 (s, 2H, CH_2OH), 7.18–7.30 (m, 3 H, HC(3), HC(4), HC(5)), 7.33–7.40 (m, 1 H, HC(6)). IR ($CHCl_3$): 3690 (s), 3608 (s), 1707 (w), 1602 (s), 1488 (w), 1450 (w), 997 (s) cm^{-1}. MS: m/z 136 (5), 118 (100), 117 (55), 107 (15), 91 (25).

Hydrolysis of Acetal 49. A 1 N aqueous HCl solution (3 mL) was added to a solution of 2-ethylbenzaldehyde dimethylacetal (**49**; 29 mg, 0.16 mmol) in Et_2O (6 mL) at room temperature. After the mixture was stirred for 30 min, the phases were separated and the aqueous phase was extracted with Et_2O. The organic extracts were combined, dried ($MgSO_4$), filtered, and evaporated. Purification by flash chromatography (SiO_2, 20/1 hexane/ether) afforded 20 mg (94%) of **51**. **2-Ethylbenzaldehyde (51).** ^1H NMR ($CDCl_3$, 200 MHz): δ 1.27 (t, 3 H, J = 7.5 Hz, CH_3), 3.07 (q, 2 H, J = 7.5 Hz, CH_2), 7.29 (d, 1 H, J = 7.9 Hz, HC(3)), 7.36 (dt, 1 H, J = 1.4, 7.6 Hz, HC(5)), 7.52 (dt, 1 H, J = 1.3, 7.5 Hz, HC(4)), 7.82 (dd, 1 H, J = 1.4, 7.6 Hz, HC(6)), 10.29 (s, 1 H, CHO). IR (CH_2Cl_2): 1693 (vs), 1600 (m), 1570 (w), 1475 (w), 1450 (m) cm^{-1}. MS: m/z 134 (96), 133 (100), 119 (62), 105 (84), 91 (88).

Addition–Oxidation Reaction of Complex 3 with MeLi. MeLi (1.6 M in ether, 0.688 mL, 1.1 mmol) was added to a solution of complex **3** (284 mg, 1 mmol) in THF (15 mL) at −78 °C. The solution was slowly warmed to −40 °C (2 h) and kept at this temperature for an additional 2 h before recooling to −78 °C. After oxidation and workup, HCl (10 M water, 20 mL) was added to the solution of crude product in Et_2O/THF. After the mixture was stirred for 2 h at room temperature, the phases were separated, and the aqueous phase was extracted with three portions of Et_2O (20 mL). The organic extracts were combined, dried ($MgSO_4$), filtered, and evaporated. Purification by flash chromatography afforded 73 mg (60%) of *o*-tolualdehyde (**44**).[9g]

Addition–Oxidation Reaction of Complex 3 with *n*-BuLi. *n*-BuLi (1.53 M in hexane, 0.506 mL, 0.774 mmol) was added to a solution of complex **3** (200 mg, 0.704 mmol) in THF (10 mL) at −78 °C. By the above procedure, 92 mg (80%) of 2-butylbenzaldehyde (**45**)[9g] was obtained.

Addition–Oxidation Reaction of Complex 3 with PhLi. PhLi (2.0 M in cyclohexane/ether, 1.250 mL, 2.5 mmol) was added to a solution of complex **3** (284 mg, 1 mmol) in THF (15 mL). By the above procedure, 144.3 mg (79%) of 2-phenylbenzaldehyde (**47**)[9g] was obtained.

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Supplementary Material Available: Tables of positional parameters for H atoms, thermal parameters for non-H atoms, additional bond distances and angles, and least-squares planes and deviations therefrom for **1a** (5 pages). Ordering information is given on any current masthead page.

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