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Stereodivergent C−C Bond Formation on Arene−Chromium Template: *Endo*-Selective Allylation by Hosomi−Sakurai Reaction[†]

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Introduction

In arene−tricarbonylchromium complexes, excellent diastereocontrol at benzylic or homobenzylic sites can be achieved since the $Cr(CO)_3$ group effectively blocks one face of the molecule and prevents approach of reagents from this direction.[1] This feature has been widely utilized in designing useful synthetic strategies.[2] Suitably structured substrates allow almost total diastereoselectivity even three carbons away from the complexed aromatic ring.[3] In most of these instances, the reaction occurs from the *exo* face, i.e., the face opposite to the metal; *endo*-selective reactions are particularly rare.[4] Herein we wish to report a completely *endo*-selective Hosomi−Sakurai allylation[5] on the 2-arylidene-1-tetralone−$Cr(CO)_3$ complex. The corresponding *exo*-adduct was obtained by an alternative sequence of reactions. In addition to displaying an unusual stereochemical preference, the $TiCl_4$-catalyzed allylation reaction provides a *prima facie* evidence of out-of-plane coordination of titanium to the ketone dictating steric course of the reaction.

Results and Discussion

The enones **1a**,**b** were prepared by condensation of appropriate aldehydes with 1-tetralone−$Cr(CO)_3$ complex as reported earlier.[3a] The *trans*-stereochemistry was established from the low-field olefinic proton at 7.8 ppm, the proton being deshielded by the anisotropy of the carbonyl group.[6]

Allylmagnesium bromide readily added to the complexed enone **1a** in THF to furnish the allylic alcohol **2a** as a single diastereomer (Scheme 1). Since addition of Grignard reagents is known to occur with complete *exo* selectivity[7] in these substrates, the orientation of the hydroxy group has been depicted as *endo* in the product. Treatment of **2a** with potassium hydride and a catalytic amount of 18-crown-6 in ether at room temperature resulted in smooth anionic oxy-Cope rearrangement[8] to produce the ketone **3a** as a single diastereoisomer, in nearly quantitative yield. Equilibration of **3a** with DBU/CH_2Cl_2 yielded a minor isomer **3a′** (**3a**:**3a′** = 85:15), which must be epimeric at the carbon adjacent to the ketone. The relative stereochemistry of complex **3a** was conclusively established from the crystal structure. The structure revealed that the complex **3a** had the expected stereochemistry; *i.e.*, the allyl group was delivered from the *exo* face of the molecule during the anionic oxy-Cope rearrangement from an *exo*-allyl carbinol. The same results were obtained with complex **1b**.

When the complex **1a** (or **1b**) was treated with allyltrimethylsilane and $TiCl_4$ at −78 °C, the product **4a** (or **4b**) was obtained as a single diastereomer (Scheme 2). The structural features of the 1,4-adduct were readily deduced from its ^1H NMR spectral characteristics. A minor isomer **4a′** was obtained from equilibration of the complex **4a** (**4a**:**4a′** = 89:11). The ^1H NMR spectrum of complex **4a** was similar to but not identical with that of complex **4a′**, indicating isomerism (epimeric at C-2).

The ^1H NMR spectra of all these stereoisomers derived from the same precursor *via* different routes were different. Since the isomers **3a** and **3a′** are epimeric at C-2 of tetralone—so are **4a** and **4a′**—the two sets must differ in the relative configuration at the site of allyl addition. The crystal structure of complex **4a** confirmed this fact. It was evident that the allyl group was appended from the *endo*-face of the substrate, contrary to normal expectation. These structures also established that proton quench of the enolate resulting from both the Hosomi−Sakurai allylation as well as the anionic oxy-Cope rearrangement took place from the *exo* face preferentially (**3a** and **4a** are major isomers after equilibration).

The origin of this unusual stereochemical preference in the Hosomi−Sakurai reaction is probably inherent in the mode of binding of the Lewis acidic metal to the carbonyl group.[9] The first step of this reaction is complexation of the strong Lewis acid $TiCl_4$ to the enone carbonyl, which should normally take place from the direction of the nonbonded electron pair on oxygen.[10] In this case, the chromium-complexed aromatic ring and the enone functionality are coplanar and the array of sp^2 carbons form part of a rigid bicyclic system. The oxygen

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(6) On photolysis at 350 nm for 5 h in chloroform-*d*, 2-(*p*-tolylidene)-1-tetralone afforded a mixture of stereoisomers. The olefinic proton in each appears at 6.8 and 7.85 ppm, confirming the assignment of olefin geometry in complexes **1a** and **1b**. In rigid and stereochemically defined structures such as isomeric α-benzylidenecamphors, the chemical shift of the *syn* (with respect to the carbonyl group) olefinic proton is 7.4 ppm while that of the *anti* olefinic proton is 6.45 ppm: Kossanyi, J.; Furth, B.; Morizur, J. P. *Tetrahedron* **1970**, *26*, 395. The deshielding of the *syn* olefinic proton is ascribed to the deshielding effect of the carbonyl group anisotropy.

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(9) For a discussion of Lewis acid complexation directing stereochemical outcome in arene−chromium complexes, see ref 3b,c.

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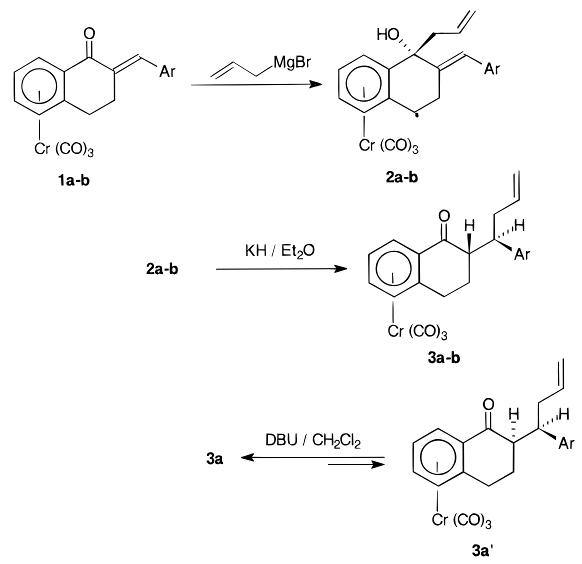
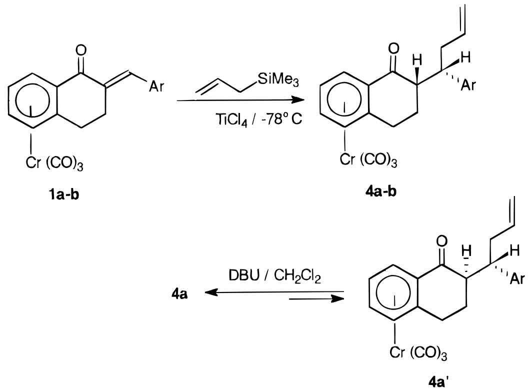
Scheme 1



Ar	Complex	Yield (%)	Complex	Yield (%)
4- $CH_3C_6H_4$	**2a**	80	**3a**	92
C_6H_5	**2b**	79	**3b**	89

Scheme 2



Ar	Complex	Yield (%)
4- $CH_3C_6H_4$	**4a**	86
C_6H_5	**4b**	76

atom is also sp^2-hybridized, and hence, the two nonbonded electron pairs on oxygen are coplanar with these carbons. In this situation, the *peri* proton of the aromatic ring as well as the olefinic proton can shield the oxygen electron pairs from approach of the Lewis acid from either end (Figure 1).

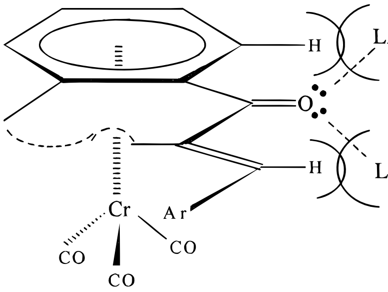


Figure 1.

Out-of-plane coordination of titanium with the CO π-bond has been structurally characterized.[11,12] Although such coordination has sometimes been described as η^2, in reality, the Ti−O distance is evidently shorter than the Ti−C bond. One should more appropriately consider a bond between Ti and a sp^3 oxygen, which in turn implies that the carbonyl center is rendered cationic and thus the enone function is activated for reaction with allyltrimethylsilane.[13] It is then likely that $TiCl_4$ (which may exist as aggregates) would occupy the *exo* face (away from the tricarbonylchromium) and force the allyltrimethylsilane to approach from the *endo* face of the molecule[14] at C-3.

Summary

In summary, we have presented a rare example of *endo*-selectivity in arene−chromium chemistry, as observed in conjugate allylation of 2-arylidene-1-tetralone $Cr(CO)_3$ complex using the Hosomi−Sakurai reaction. Normal *exo*-selectivity is observed for a similar functionalization *via* a Grignard−anionic oxy-Cope sequence. Such stereodivergence adds greater flexibility to the design of stereoselective strategies using arene−chromium complexes. The origin of this unusual stereochemical preference may be traced to an out-of-plane coordination of titanium with the carbonyl oxygen. We are currently exploring this theme in the context of π-facial selectivity in a number of varied structures, especially conformationally flexible acyclic substrates.

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Supporting Information Available: Experimental details and full characterization of complexes **1a**,**b**, **2a**,**b**, **3a**,**b**, and **4a**,**b**, ORTEP diagrams for complexes **3a** and **4a**, and ^{1}H NMR spectral comparisons of **3a**, **3a′**, **4a**, and **4a′** (6 pages).

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(12) A study, with extensive references, on the importance of out-of-plane complexation of titanium in promoting organic reactions recently appeared: Singh, D. K.; Springer, J. B.; Goodson, P. A.; Corcoran, R. C. *J. Org. Chem.* **1996**, *61*, 1436. Reference 21a−i in this paper provides a collection of relevant dihedral angle data from CSD.

(13) With Lewis acids like BF_3−etherate and $SnCl_4$, no reaction took place between allyltrimethylsilane and the substrate, and the starting material was quantitatively recovered. Thus, the dependence of selectivity on Lewis acid could not be addressed.

(14) This possibility has been suggested in the context of Lewis acid carbonyl complexation: ref 13a, p 283.