Diastereoselective Formation of an [η^4-(1*Z*)-Sulfinyl diene]iron(0) Tricarbonyl Complex. Diastereoselective Allylation of the Derived Iron Dienal

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*Summary: An enantiomerically pure (1Z,3E)-sulfinyl diene exhibited a high degree of facial selectivity (α:β = 16:1) upon complexation to an iron(0) tricarbonyl fragment, producing a [η⁴-(1Z)-sulfinyl diene]iron(0) tricarbonyl complex (**2**; 80%). The iron(0)−dienal complex derived from **2** can undergo a highly diastereoselective allylation with allyltri-n-butylstannane and $BF_3{\cdot}Et_2O$ (diastereomer ratio 95:5); the absolute stereochemistry of the homoallylic alcohol product (**4**) was established by X-ray crystallography.*

The use of enantiomerically pure sulfoxides to direct the absolute stereochemistry of emerging substrate chiral centers has been the primary feature of numerous publications[1] (e.g., diastereoselective Diels−Alder reactions,[2] additive Pummerer reactions,[3] and reductions of β-keto sulfoxides).[4] However, there have been only isolated examples of asymmetric processes in which sulfoxide chemistry has been used in combination with organotransition-metal-based transformations.[5] We have initiated a research program which seeks to explore the feasibility and diastereoselectivity of metal-catalyzed cycloisomerizations of unsaturated enantiopure sulfoxides. Having developed methodology for the preparation of stereodefined sulfinyldienes,[6] we found it necessary to determine if these substrates would exhibit a high degree of facial selectivity in a reaction with a metal fragment. Since facial recognition of the sulfinyl diene by the metal would likely be the origin of diastereoselectivity in a metal-catalyzed cycloisomerization, we chose to examine the easily isolable (η^4-diene)$Fe(CO)_3$ complexes[7,8] as a model. Here we report the diastereoselective formation of a [(1*Z*,3*E*)-1-sulfinyl diene]iron tricarbonyl complex, and furthermore, we discuss the unusually high degree of diastereoselectivity obtained via allylation of a derived iron 1-sulfinyl dienal.

Previously we reported the development of methodology for the stereocontrolled synthesis of enantiopure 1- and 2-sulfinyl dienes which was based on the Stille coupling of halovinyl sulfoxides and (*E*)-vinylstannanes.[6] Although complexation of unsubstituted racemic sulfinyl dienes to an iron tricarbonyl fragment had been reported, the diastereomeric ratio of the corresponding iron complexes had not been revealed.[7] We anticipated that, in particular, a 1-sulfinyl (1*Z*,3*E*)-diene should exhibit significant diastereofacial selectivity upon complexation as a result of allylic 1,3-strain. Thus, enantiomerically pure sulfinyl diene **1** was prepared in the usual manner.[6a] Subsequent complexation (Scheme 1) using $Fe(CO)_5$/NMO afforded the sulfinyl diene−$Fe(CO)_3$ complex **2** with excellent diastereoselectivity (α:β = 16:1)[9] and in good overall yield (80%).[10] Undoubtedly the origin of this diastereoselectivity is allylic 1,3-

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(9) We are defining the diene plane, oriented as depicted in Figure 1, as the separation between the α (lower) face from the β (upper) face.

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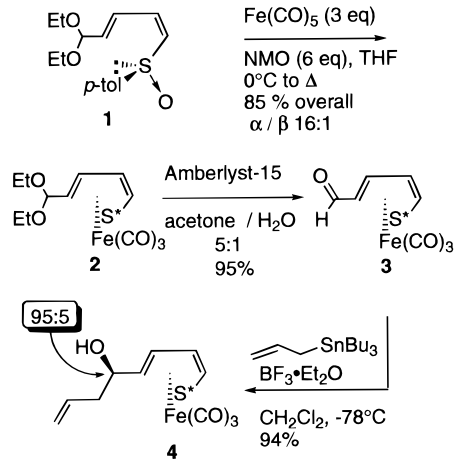
Scheme 1



strain,[11] which would force the sulfoxide to adopt a conformation that would place the bulky *p*-tolyl group directly over the β-face of the diene system. As expected, these sulfinyl diene−$Fe(CO)_3$ complexes were easily manipulated and readily purified by silica gel chromatography. Indeed, chromatographic separation of the major and minor diastereomeric complexes of **2** was trivial. Verification that the $Fe(CO)_3$ fragment was situated on the α-face of the diene was ultimately established by X-ray crystallography of a derived (sulfinyl dienol)iron(0) complex (*vide infra*).

While there have been numerous reported examples of nucleophilic addition to aldehydes adjacent to diene−$Fe(CO)_3$ complexes,[8b] most result in the formation of alcohol products with only modest diastereoselectivity (60:40 to 85:15 ratios are typical). That is, the iron tricarbonyl fragment alone is not a particularly efficient stereodirecting group. We were intrigued by the possibility that the *cis* positioning of the sulfoxide (*i.e.*, projecting toward the opposite end of the diene system) could influence the stereochemical outcome of a nucleophilic addition to the aldehyde group of **3**. Therefore, we chose to examine Lewis-acid-promoted aldehyde allylation[12] using allylstannanes in order to test this theory. Aldehyde **3** was easily obtained by deprotection of the acetal of **2** (Scheme 1).[13] We were pleased to discover that treatment of **3** (CH_2Cl_2, −78 °C) with allyltri-*n*-butylstannane (1.1 equiv) and $BF_3{\cdot}Et_2O$ (1.3 equiv) afforded the expected homoallylic alcohol **4** as a 95:5 mixture of diastereomers which were separable by careful column chromatography (Scheme 1). The absolute stereochemistry at the carbon bearing the alcohol was unambiguously established by X-ray crystallography (Figure 1).[14] Significantly, this also made it possible to establish that the major diastereomer produced in the complexation of **1** possessed an iron tricarbonyl fragment situated on the α-face of the diene, *anti* to the bulky *p*-tolyl group of the sulfoxide.

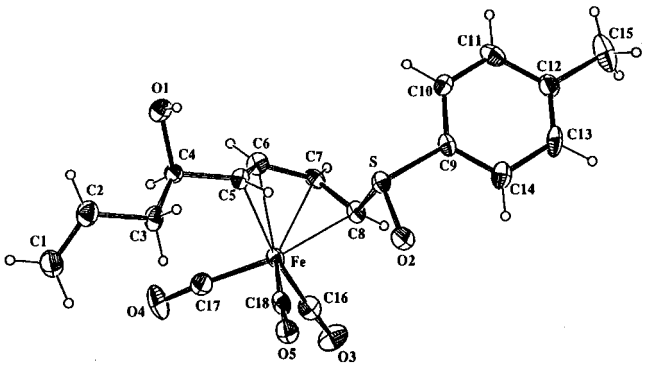
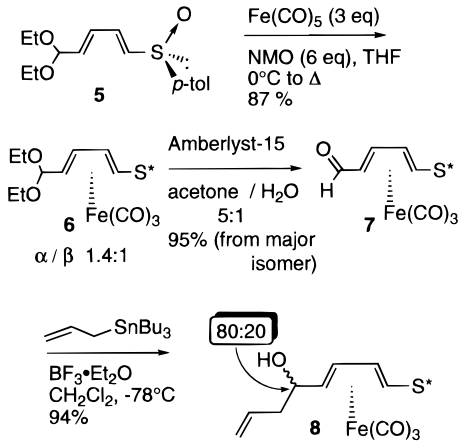


Figure 1. Final X-ray model of **4** showing the absolute chirality and the atom labels.

Scheme 2



Verification that the *cis* positioning of the sulfoxide did indeed play a role in directing the absolute stereochemistry of **4** was required; this could be most readily ascertained by preparing an isomer in which the sulfoxide would no longer exert a significant influence in the allylation transition state. Thus, the 1*E*,3*E* isomer of **1** was prepared by an analogous route (Scheme 2); as expected, the complexation of (1*E*,3*E*)-sulfinyl diene **5**[6a] was only marginally diastereoselective due to the lack of allylic 1,3-strain. Nevertheless, the major isomer **6**, tentatively assigned as having the iron tricarbonyl unit on the diene α-face,[15] was separated and readily deprotected to afford aldehyde **7**, which was subjected to the $BF_3{\cdot}Et_2O$-promoted allylation conditions previously employed. This time, the homoallylic alcohol **8** was produced as a 80:20 mixture of diastereomers (Scheme 2), implying, as anticipated, that the $Fe(CO)_3$ fragment in the (1*E*,3*E*)-diene system was ineffective at exerting a high level of stereocontrol.

There are two factors which should control the selectivity of allylstannane addition to aldehyde **3**: (1) the relative amounts of *s-cis* and *s-trans* conformers at −78 °C and (2) steric factors affecting the approach of the allylstannane, especially the proximity of the alde-

(10) Similar yield (70%) and diastereoselectivity (*ca.* 20:1) could be obtained by treatment with (bda)$Fe(CO)_3$. This reagent was prepared according to a literature procedure: Alcock, N. W.; Danks, T. N.; Richards, C. J.; Thomas, S. E. *Organometallics* **1991**, *10*, 231−238.

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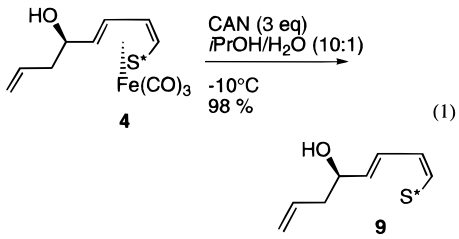
(13) Attempted conversion of the acetal to the aldehyde prior to complexation led to substantial isomerization about the *Z* double bond.

(14) The atomic coordinates for this structure have been deposited with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, U.K.

(15) This tentative assignment was made on the basis of polarity (the R_f values of the major isomers obtained from the complexation of both **1** and **5** were higher than those of the corresponding minor isomers) and the expected lower energy conformation of the *trans*-dienyl sulfoxide, which places the *p*-tolyl group above the β-face of the diene.[11]

hyde to the iron tricarbonyl unit occupying the α-face of the diene. The stereochemistry of the major diastereomer of alcohol **4** corresponds to a transition state which would place the allylstannane *anti* to the $Fe(CO)_3$ fragment[8b] of **3**, with the aldehyde in the *s-cis* conformation.[16] However, at this time, in the absence of further structural information pertaining to the aldehyde−BF_3 complex, any explanation for the enhanced diastereoselectivity observed for the allylstannane addition to **3** would be highly speculative.

Finally, decomplexation[17] of the $Fe(CO)_3$ fragment from the major diastereomer of sulfinyl diene **4** has been achieved to produce **9** (eq 1) as a single diastereomer. We anticipate that additional diastereoselective functionalization of **9** will be possible[18] and may lead to a unique approach for addressing issues of acyclic stereocontrol.



(1)

In summary, we have demonstrated that a (1*Z*,3*E*)-sulfinyl diene is capable of exhibiting a high degree of facial selectivity in a reaction with a metal fragment, and the iron dienal complex derived from this functionalized sulfinyl diene can undergo a highly diastereoselective allylation. Since diastereoselective installation of the iron tricarbonyl fragment was initially achieved as a result of the influence of the sulfoxide, to the best of our knowledge, this is the first example of an "indirect" 1,6-asymmetric induction process which originates with the chiral center of a sulfoxide. Because a high degree of facial selectivity appears to be a general process for the complexation of (1*Z*)-sulfinyl dienes, we are currently exploring the scope of this allylation using substrates related to **3** while also examining other intermolecular (as well as intramolecular) addition reactions. The results of these studies will be reported in due course.

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Supporting Information Available: Text giving experimental procedures and characterization data for compounds **2**−**4** and **6**−**9** (6 pages). Ordering information is given on any current masthead page.

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(16) Preliminary results from our laboratories indicate that allylation of a related aldehyde which bears a butyl substituent at C_6 (X-ray structure numbering) proceeds with poor diastereoselectivity (2:1). (Paley, R. S.; McCulley, D. J. Unpublished results). Since this outcome appears to be a result of an increase in *s-trans* conformer population due to steric strain between the aldehyde-BF_3 complex and the butyl group, the argument that the aldehyde−BF_3 complex derived from **3** prefers the *s-cis* conformation would seem to be strengthened.

(17) Grée, R.; Laabassi, M.; Mosset, P.; Carrié, R. *Tetrahedron Lett.* **1985**, *26*, 2317−2318.

(18) For example, highly diastereoselective epoxidation of vinyl sulfoxides is possible: Fernández de la Pradilla, R.; Castro, S.; Manzano, P.; Priego, J.; Viso, A. *J. Org. Chem.* **1996**, *61*, 3586−3587.