chiral auxiliary with sodium methoxide in methanol[6] (4 equiv, reflux, 2.5 h), *concomitant cyclization occurred to give enone* **7** *from* **6** *in 84% yield*. The chiral auxiliary was recovered as its methyl carbonate in 94% yield. Treatment of **7** [mp 90–91 °C; $[\alpha]^{23}_{D}$ +535° (*c* 0.89, $CHCl_3$)] with LDA (2 equiv, THF, −78 °C) and dimethylcarbamyl chloride (4 equiv) gave a 92% yield of amide **8**, mp 136–138 °C, and the corresponding cis diastereomer in a ratio of 97:3. The triisopropylsilyl (TIPS) group of **8** was removed with oxalic acid in methanol to provide **9** [mp 122–124 °C; $[\alpha]^{23}_{D}$ +1072° (*c* 1.1, $CHCl_3$)] in 96% yield. The enantiomeric purity of **9** was determined to be >98% by chiral column GC analysis.[10] The next step of the synthesis required a stereoselective reduction of the enaminone moiety of **9** to give amino alcohol **10a**. This was accomplished in one step using catalytic hydrogenation over washed[11] PtO_2. In this manner a 95:5 mixture of **10a** and **10b** was obtained in 96% yield. The last step of our elaeokanine C synthesis called for converting the *N*,*N*-dimethylamide group of **10a** to an *n*-propyl ketone. Although organocerium reagents are known to convert amides to ketones,[12] no examples of the analogous conversion with *β*-hydroxy amides were reported. Treatment of **10a** with anhydrous cerium chloride (2.5 equiv) and *n*-propylmagnesium chloride (3 equiv, 0 °C, 4 h) gave a 66% yield of elaeokanine C (**2**) [$[\alpha]^{23}_{D}$ +47° (*c* 0.4, $CHCl_3$)]. In the absence of cerium chloride, the analogous reaction gave only recovered starting material. Our synthetic **2** was determined to be >95% optically pure by chiral column GC analysis.[10] The literature optical rotation value for natural elaeokanine C is $[\alpha]_D$ −14° (*c* 1.0, $CHCl_3$).[1] On the basis of the literature rotation value and the work described in this communication, the isolated *natural* (−)-elaeokanine C was only 29% optically pure, with the major enantiomer having the absolute configuration 7*R*,8*S*,9*S*.[13] Treatment of (+)-elaeokanine C (**2**) with NaOH/MeOH[2e] gave (+)-elaeokanine A (**1**) in 30% yield;[14] $[\alpha]^{23}_{D}$ +47° (*c* 0.31, $CHCl_3$) [lit.[1] $[\alpha]_D$ +13° (*c* 0.9, $CHCl_3$); lit.[3] $[\alpha]^{22}_{D}$ +49° (*c* 0.5, $CHCl_3$)].

Interestingly, application of our dihydropyridone asymmetric synthesis in the above syntheses led to the enantioselective preparation of natural (+)-elaeokanine A and unnatural (+)-elaeokanine C. We have determined that these two closely related alkaloids have *opposite* absolute stereochemistry at C-9 of their indolizidine ring system. Our enantioselective synthesis[15] of (+)-elaeokanine C was accomplished with a high degree of regio- and stereocontrol in seven steps from readily available 4-methoxy-3-(triisopropylsilyl)pyridine. This approach to alkaloid synthesis is attractive from a practical standpoint as the chiral auxiliary is introduced in situ, removed during the cyclization step, and easily recovered in high yield. This synthesis clearly demonstrates the potential of enantiopure dihydropyridones as chiral building blocks. The syntheses of (−)-elaeokanine C and other naturally occurring *Elaeocarpus* alkaloids are under investigation and will be reported in due course.

Acknowledgment. We gratefully acknowledge support of this work by the National Institutes of Health (Grant GM 34442).

Supplementary Material Available: Listings giving full spectroscopic and analytical characterization of **2**, **5–9**, and **10a** (7 pages). Ordering information is given on any current masthead page.

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(10) The enantiomeric purity was determined by capillary gas chromatography using a Chirasil-Val column (Alltech Associates, Inc., Deerfield, IL). A derivative of alcohol **2** was prepared prior to GC analysis; see: König, W.; Francke, W.; Benecke, I. *J. Chromatogr.* **1982**, *239*, 227.

(11) Mitsui, S.; Saito, H.; Yamashita, Y.; Kaminaga, M.; Senda, Y. *Tetrahedron* **1973**, *29*, 1531.

(12) Imamoto, T.; Takiyama, N.; Nakamura, K.; Hatajima, T.; Kamiya, Y. *J. Am. Chem. Soc.* **1989**, *111*, 4392.

(13) Structure **2** is depicted with the absolute stereochemistry found in our synthetic (+)-elaeokanine C.

(14) The spectral properties of (+)-**1** were identical with those reported.[2]

(15) All new compounds were spectroscopically characterized and furnished satisfactory elemental analyses (C,H,N ±0.4%) or high-resolution mass spectra. Details are provided in the supplementary material.

Reduction and Chain Extension of the Carbene Ligand of Rhenium Carbene Complexes

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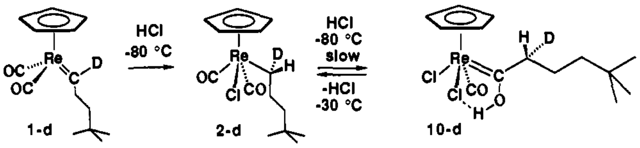
Recently we reported that stereospecific addition of HCl to the amphiphilic carbene complex $C_5H_5(CO)_2Re{=}CDCH_2CH_2CMe_3$ (**1**-*d*) produced the alkylchlororhenium complex *cis*-$C_5H_5(CO)_2ClReCHDCH_2CH_2CMe_3$ (**2**-*d*).[1] Upon warming to −13 °C for 2 h, the initially formed diastereomer of **2** rearranged to a 1:1 mixture of the two possible diastereomers of **2**. Upon further warming to room temperature, **2** lost HCl to form the rhenium–alkene complex $C_5H_5(CO)_2Re(CHD{=}CHCH_2CMe_3)$ (**3**-*d*). Possible mechanisms that we considered for interconversion of the diastereomers of **2**-*d* included (1) reversible, partially nonstereospecific loss of HCl from **2**-*d* to reform carbene complex **1**-*d*, (2) intramolecular rearrangement of **2**-*d* via a pseudorotation process, and (3) ionization of halide.



In the course of studying the possible reversible loss of HCl from **2**, we looked for exchange of deuterium from **2**-*d* with excess HCl. No loss of deuterium label was observed, but we noted the formation of a single new species whose ^1H NMR spectrum was too complex to be readily assigned.

Concurrent studies of the reaction of HCl with the related carbene complex $C_5Me_5(CO)_2Re{=}CHCH_3$ (**4**) clarified the situation. Here we report that reaction of **4** with excess HCl leads to reduction and chain extension of the carbene ligand and formation of the hydroxycarbene complex *cis*-$C_5Me_5(CO)Cl_2Re{=}C(OH)CH_2CH_3$ (**5**).

Rhenium carbene complex **4** was prepared by a route similar to that employed in the preparation of **1**;[2] reaction of $Cp_2Zr(\eta^2\text{-}COCH_3)Cl$ with $C_5Me_5(CO)_2ReH^-K^+$ led to the isolation of $C_5Me_5(CO)_2Re{=}CHCH_3$ (**4**)[3] in 84% yield. Reaction of **4** with 2 equiv of HCl in pentane at −80 °C, followed by workup at 0 °C, led to the formation of *cis*-$C_5Me_5(CO)_2ClReCH_2CH_3$ (**6**)[3] in 80% yield. Reaction of either **4** or **6** with excess HCl in CD_2Cl_2 at −80 °C led to the formation of a single new species, which was characterized spectroscopically at low temperature as the hydroxycarbene complex *cis*-$C_5Me_5(CO)Cl_2Re{=}C(OH)CH_2CH_3$ (**5**).[3] The ^{13}C NMR spectrum of **5** exhibited a 1:1 intensity ratio of peaks due to a CO ligand at δ 213.6 and a carbene ligand at δ 283.2. The IR spectrum of **5** in CH_2Cl_2 at −80 °C had a single carbonyl band at 1964 cm^{-1} and a broad weak absorption in the region >3000 cm^{-1} possibly due to the hydroxyl group. In the ^1H NMR spectrum of **5**, a far downfield doublet at δ 14.34 (*J* = 1.4 Hz) was assigned to a hydroxyl proton coupled to a single diastereotopic methylene proton of the ethyl side chain.[4] Treatment of a CD_2Cl_2 solution of **5** with excess CH_3OD washed out the doublet at δ 14.34. The presence of an intramolecular hydrogen bond between chlorine and the OH group is consistent with the far downfield ^1H NMR chemical shift of the OH signal

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(3) See the supplementary material for experimental details and full characterization.

(4) *cis*-$(CO)_4BrMn{=}C(OH)CH_3$,[4a] *cis*-$(CO)_4BrRe{=}C(OH)CH_3$,[4b] and $(PPh_3)_2(CO)(N_2)ClRe{=}C(OH)CH_3$[4c] are three examples of hydroxycarbene metal halides, having intramolecular hydrogen bonds, that were prepared by addition of organolithium reagents to metal carbonyl halides. (a) Moss, J. R.; Green, M.; Stone, F. G. A. *J. Chem. Soc., Dalton Trans.* **1973**, 975. (b) Darst, K. P.; Lukehart, C. M. *J. Organomet. Chem.* **1979**, *171*, 65. (c) Chatt, J.; Leigh, G. J.; Pickett, C. J.; Stanley, D. R. *J. Organomet. Chem.* **1980**, *184*, C64.

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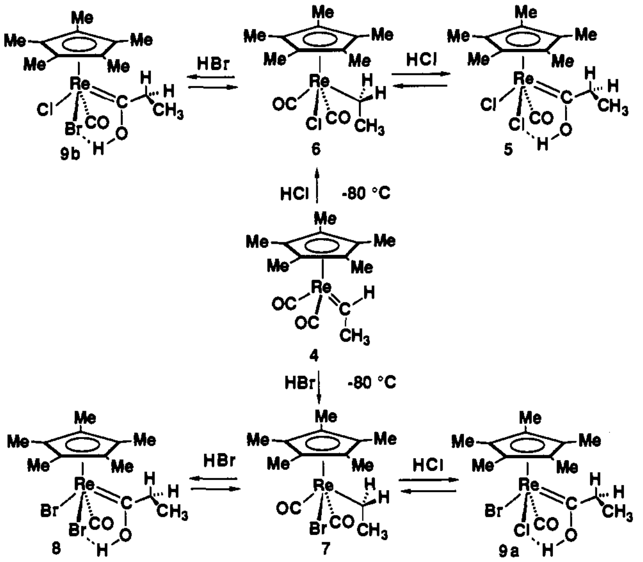
at δ 14.34, with a preferred conformation of the complex that results in long-range coupling of the OH proton to a single diastereotopic methylene proton of the ethyl group, and with the slow exchange of the OH group with excess HCl in CD_2Cl_2. The diastereotopic methylene protons of **5** establish the cis geometry of the complex.



The formation of hydroxycarbene complex **5** is reversible, and the equilibrium is shifted toward ethylchlororhenium complex **6** upon either warming or removal of HCl under high vacuum.

Reaction of **4** with 1.3 equiv of HBr led to the isolation of alkylbromo complex *cis*-$C_5Me_5(CO)_2BrReCH_2CH_3$ (**7**).[3] Reaction of excess HBr with either **4** or **7** at −80 °C led to the formation of the somewhat more stable hydroxycarbene complex $C_5Me_5(CO)Br_2Re{=}C(CO)CH_2CH_3$ (**8**),[3] which exhibits a doublet (J = 1.4 Hz) at δ 13.79 for the hydroxycarbene proton.

Remarkably, the reaction of HCl with *cis*-$C_5Me_5(CO)_2BrReCH_2CH_3$ (**7**) was stereospecific and produced a single diastereomer of $C_5Me_5(CO)BrClRe{=}C(OH)CH_2CH_3$ (**9a**)[3] with a hydroxy doublet at δ 14.30. The reaction of HBr with *cis*-$C_5Me_5(CO)_2ClReCH_2CH_3$ (**6**) produced a different diastereomer of $C_5Me_5(CO)BrClRe{=}C(OH)CH_2CH_3$ (**9b**)[3] with a hydroxy doublet at δ 13.83 in addition to a small amount of dibromo hydroxycarbene complex **8**. Synthesis of a mixture containing all four hydroxycarbene complexes **5**, **8**, **9a**, and **9b** showed four separate doublets for the hydroxycarbene protons.[5] On the basis of the hypothesis that the chemical shift of the OH proton is largely determined by the halogen to which it is hydrogen bonded, we have tentatively assigned the stereochemistry of the reaction as involving entry of the new halide ligand at a position cis to the hydroxycarbene ligand. The formation of these hydroxycarbene complexes is proposed to occur by migration of an alkyl group to a protonated carbonyl ligand with concerted attack of halide at rhenium. While Lewis acid[6] and Bronsted acid[7] induced alkyl migrations to CO are well known, the only prior example of Bronsted acid induced formation of a hydroxycarbene complex is the reaction of $(CO)_2(Ph_3P)_2Os(Cl)CH_2CH_3$ with HCl reported by Roper.[8]

In light of these findings, reinvestigation of the reaction of **1**-*d* with excess HCl in CD_2Cl_2 at −80 °C showed the formation of hydroxycarbene complex *cis*-$C_5H_5(CO)_2Cl_2Re{=}C(OH)CHDCH_2CH_2CMe_3$ (**10**-*d*).[3] The deuterated alkyl group migrated with retention of stereochemical integrity to give one diastereomer of **10**-*d*. Upon warming to −30 °C, the equilibrium shifted back toward a single diastereomer of alkylrhenium complex **2**-*d*. This experiment demonstrates that the reversible formation of hydroxycarbene complexes is not related to the mechanism for loss of stereochemistry of **2**-*d*, which remains unresolved.

Acknowledgment. Financial support from the National Science Foundation and from the Department of Energy, Division of Basic Energy Sciences, is gratefully acknowledged.

Supplementary Material Available: Experimental details for the preparation and characterization of $C_5Me_5(CO)_2ReH^-K^+$ and compounds **4** to **10**-*d* (5 pages). Ordering information is given on any current masthead page.

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(5) Reaction of a 1:1 mixture of **6** and **7** with 0.5 equiv of HBr at −80 °C, followed by reaction with 3 equiv of HCl at −80 °C, produced a mixture of four hydroxycarbene complexes with distinct doublets in the ^1H NMR spectra at δ 14.34 (**5**), 14.30 (**9a**), 13.83 (**9b**), and 13.79 (**8**).

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Carbon–Carbon Bond Formation in Aqueous Ethanol: Diastereoselective Transformation of Unprotected Carbohydrates to Higher Carbon Sugars Using Allyl Bromide and Tin Metal[1]

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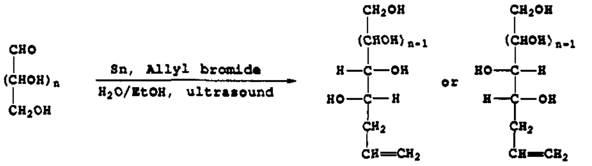
This report describes the "nucleophilic" addition of allyl groups to the carbonyl moieties of unprotected carbohydrates in aqueous/organic solvents (eq 1). These reactions are based on procedures developed and applied to non-sugar aldehydes and ketones by Luche,[3-6] Nokami,[7] Benezra,[8] and others[9,10] using reaction of allylic halides with zinc or tin metal in the presence of the carbonyl acceptor. When applied to carbohydrates, the reactions proceed with useful diastereoselectivity and permit the synthetic utilization of these water-soluble substrates directly in aqueous solutions without protection. The adducts were converted to higher carbon aldoses by ozonolysis of the deprotected polyols followed by suitable derivatization.



(1)

The yields reported in Table I were obtained in ethanol/water mixtures. Using tetrahydofuran instead of ethanol did not improve the yield but did slow the rate. Commercially available tin powder (Alfa company; 100 mesh) was used, and the suspension of the reactants was sonicated for 12–18 h in an ultrasonic cleaning bath (Cole-Parmer 8852).[11] Although the pH drops sharply during the course of the reaction (typically to a value of "pH" = 1), we did not run the reaction under positive pH control. The polyols generated were acetylated to simplify the purification procedure.

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(1) This work was supported by the NIH, Grant GM 30367.

(2) Erwin Schrödinger Postdoctoral Fellow of the Fonds zur Förderung der wissenschaftlichen Forschung in Österreich (Austrian Science Foundation).

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