Registry No.—**1**, 52786-55-7; **2a**, 55606-65-0; **2b**, 55648-91-4; **3a**, 52786-44-4; **3b**, 55606-66-1; **3c**, 55606-67-2; *tert*-butyl carbamate, 543-28-2; hexafluoroacetone, 684-16-2; imidazole, 288-32-4; methanol, 67-56-1; *tert*-butyl mercaptan, 513-44-0; N^{α}-Z-L-his-OCH_3, 15545-10-5.

References and Notes

(1) We acknowledge the support of the U.S. Public Health Service (Grant AM 12970) and the Department of Chemistry in providing a teaching fellowship for H.H S.
(2) Abbreviations used: *t*-Boc, *tert*-butoxycarbonyl; Z, benzyloxycarbonyl; THF, tetrahydrofuran; TFA, trifluoroacetic acid; his-OCH_3, histidine methyl ester.
(3) H. H Seltzman and T. M. Chapman, *Tetrahedron Lett.*, 2637 (1974).
(4) I. L. Knunyants, C. Ching-yun, and N. P. Gambaryan, *Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 647 (1960).
(5) H. E. Simmons and D. W. Wiley, *J. Am. Chem. Soc.*, **82**, 2288 (1960).
(6) F. Weygand, W. Steglich, and P. Pietta, *Tetrahedron Lett.*, 3751 (1966); Chem. Ber., **100**, 3841 (1967).
(7) Yu. V. Zeifman, N. P. Gambaryan, and I. L. Knunyants, *Dokl. Chem. (Engl. Transl.)*, **153**, 1032 (1963).
(8) H. Pauley, *Hoppe-Seyler's Z. Physiol. Chem.*, **64**, 75 (1910).
(9) Compound **1b** gives a Pauly positive spot at higher R_f if present. See Experimental Section.
(10) Yu. V. Zeifman, N. P. Gambaryan, and I. L. Knunyants, *Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 2011 (1965).
(11) W. J. Middleton and C. G. Krespan, *J. Org. Chem.*, **30**, 1398 (1965).
(12) Compound **1** adds water to give **3a**.
(13) J. R. Mohrig, K. Keegstra, A. Maverick, R. Roberts, and S. Wells, *J. Chem. Soc., Chem. Commun.*, 780 (1974).
(14) J. E. Banfield, G. M. Brown, F. H. Davey, W. Davies, and T. H. Ramsay, *Aust. J. Sci. Res., Ser. A*, **1**, 330 (1948).
(15) T. C. Bruice and S. Benkovic, "Bioorganic Mechanisms", Vol. 1, W. A. Benjamin, New York, N.Y., 1966, pp 60–66.
(16) J. A. Pople, W. G. Schneider, and H. J. Bernstein, "High Resolution Nuclear Magnetic Resonance", McGraw-Hill, New York, N.Y., 1959, p 366.

Directive Effects in the Hydroboration of Vinylferrocenes

Timothy A. Woods, Thomas E. Boyd, Edward R. Biehl, and Perry C. Reeves*

Department of Chemistry, Southern Methodist University, Dallas, Texas 75275

Received February 11, 1975

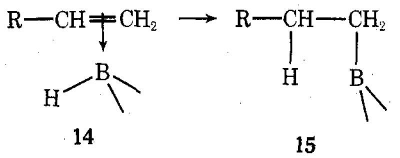
While examining possible synthetic applications of the hydroboration reaction in organometallic systems,[1] we observed that certain vinylmetallocenes, upon hydroboration–oxidation, were converted to a single alcohol product. By contrast, most aryl- and alkyl-substituted alkenes yield a mixture of two isomeric alcohols under similar reaction conditions. Since the positional selectivity of this reaction was so pronounced, a study was initiated in order to probe the nature of this directive ability.

Results and Discussion

A series of ferrocenyl-substituted alkenes (**1–6**, Table I) was prepared and allowed to react with borane in tetrahydrofuran. These alkenes reacted normally and produced the corresponding alcohols in high yields. The alcohols were isolated by column chromatography,[2] and percent yields of isolated products ranged from 60% with **4** to 79% with **3**. In addition, approximately 5% yields of the corresponding alkanes were obtained.

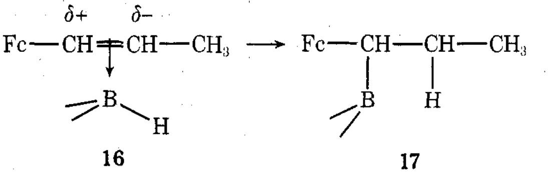
The distributions of the isomeric alcohols are indicated in Table I. By way of comparison, distributions in similar aryl- and alkyl-substituted alkenes are also shown. The distribution of ferrocenyl-substituted alcohols was determined by NMR analysis. The NMR spectra of the purified alcohol fractions from the hydroboration–oxidation procedure were recorded and unique areas of absorption for each of the possible alcohols were integrated repeatedly. Even though the accuracy of the distributions is limited by the accuracy of the integration procedure, these values are the average of several experiments. Variations in distribution among several experiments were found to be quite small (±3%).

The various isomer distributions can be accounted for in terms of the presently accepted hydroboration mechanism. This mechanism, which is based on stereochemical[3] and thermodynamic[4] considerations, involves the formation of a triangular π complex (**14**) and its collapse via a concerted process[5] to product (**15**). Both steric and electronic factors are involved in determining the carbon to which the boron moiety will become attached.[5] Upon hydroboration–oxidation the terminal alkenes **1** and **2** produce preponderant amounts of the terminal alcohols. In fact, vinylferrocene (**1**) produces a significantly greater amount of the terminal alcohol than does styrene (**7**) or *tert*-butylethylene (**10**). It is likely that the steric bulk of ferrocene and its powerful electron-releasing ability[6] combine to produce this increased preferential attachment of boron to the terminal carbon.



14 **15**

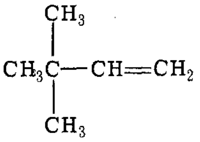
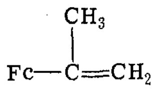
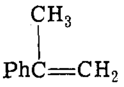
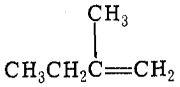
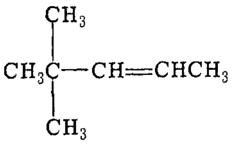
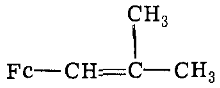
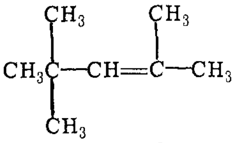
With disubstituted internal alkyl-substituted alkenes, Brown and Zweifel[7] observed that the boron moiety becomes attached in approximately equal amounts to each carbon of the double bond. When one of the substituents is the very bulky *tert*-butyl group (**12**) the distribution becomes 42:58 (Table I). However, the case of 1-phenylpropene (**9**) *demonstrates the importance of electronic factors* in the hydroboration reaction. Further, when substantial amounts of both isomers are formed one must consider the extent of hydroboration. Reactions of stoichiometric amounts of borane and of disubstituted alkenes such as **3**, **4**, or **5** indicate that these reactions proceed to the dialkylborane stage while with the trisubstituted alkene **6**, hydroboration apparently stops at the monoalkylborane stage. In the hydroboration of **3**, control by steric factors should cause a small preference for boron addition to the carbon β to the ferrocenyl group; however, the opposite result is observed. This suggests that some type of electronic control must also be involved. Ferrocene is generally regarded as a very strong electron-releasing group;[8] however, electron release by ferrocene would not favor the formation of the observed major product. An electron-withdrawing tendency (similar to the phenyl group's behavior in **9**) would lead to an intermediate such as **16**, but this tendency must be considerably less significant than in the phenyl case, since there is not a large deviation from the usual 50:50 distribution.



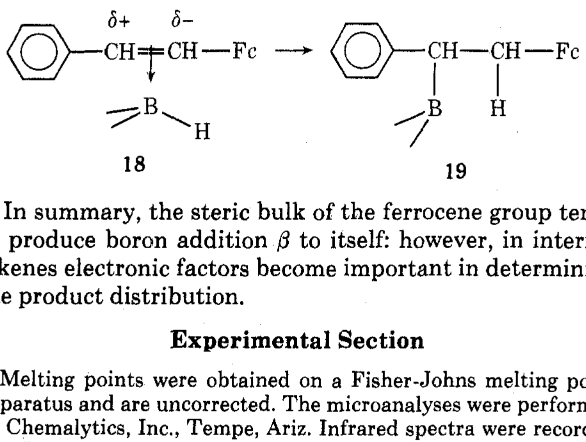
16 **17**

When the two substituents are the phenyl and the ferrocenyl systems (**4**), the boron displays a great preference for attachment to the carbon α to the phenyl group. This result occurs because of the very favorable combination of electronic factors in the intermediate (**18**) in which the ferrocenyl system is electron releasing and the phenyl group is

Table I
Distribution of Alcohol Products from Hydroboration-Oxidation

Ferrocenyl alkenes	Aryl alkenes[9]	Alkyl alkenes[9]
	Monosubstituted	
(1) $Fc—CH{=}CH_2$ 2 98	(7) $PhCH{=}CH_2$ 20 80	(10)  $\mathrm{CH_3\overset{CH_3}{\underset{CH_3}{C}}—CH{=}CH_2}$ 6 94
	Disubstituted	
(2)  $\mathrm{Fc—\overset{CH_3}{C}{=}CH_2}$ 1 99	(8)  $\mathrm{Ph\overset{CH_3}{C}{=}CH_2}$ 100	(11)  $\mathrm{CH_3CH_2\overset{CH_3}{C}{=}CH_2}$ 1 99
(3) $Fc—CH{=}CHCH_3$ 63 37	(9) $PhCH{=}CHCH_3$ 85 15	(12)  $\mathrm{CH_3\overset{CH_3}{\underset{CH_3}{C}}—CH{=}CHCH_3}$ 42 58
(4) $Fc—CH{=}CHPh$ 10 90 (5) $Fc—CH{=}CHC_6H_4\text{-}p\text{-}OCH_3$ 28 72		
	Trisubstituted	
(6)  $\mathrm{Fc—CH{=}\overset{CH_3}{C}—CH_3}$ 95 5		(13)  $\mathrm{CH_3\overset{CH_3}{\underset{CH_3}{C}}—CH{=}\overset{CH_3}{C}—CH_3}$ 98 2

electron withdrawing. This distribution can be distorted by appropriate substitution on the benzene ring (5). In this case, the p-methoxy group lessens the ability of the phenyl system to withdraw electron density from the adjacent carbon.



18 19

In summary, the steric bulk of the ferrocene group tends to produce boron addition β to itself: however, in internal alkenes electronic factors become important in determining the product distribution.

Experimental Section

Melting points were obtained on a Fisher-Johns melting point apparatus and are uncorrected. The microanalyses were performed by Chemalytics, Inc., Tempe, Ariz. Infrared spectra were recorded on a Perkin-Elmer Model 457 spectrophotometer, and NMR spectra were determined with a Perkin-Elmer R12B spectrometer using tetramethylsilane as an internal standard.

Most of the alkenes and alcohols used in this study have been previously prepared and their physical and spectra properties fully described. The preparations of previously unreported compounds are described below.

Preparation of Ferrocenyl-p-methoxybenzyl Ketone. Ferrocene (7.4 g, 40 mmol) and p-methoxyphenylacetyl chloride (7.4 g, 40 mmol) were dissolved in 100 ml of CH_2Cl_2 under a nitrogen atmosphere at 0°. To this stirred mixture was added anhydrous $AlCl_3$ (5.4 g, 40 mmol) in small portions. The purple-colored mixture was then stirred for 0.5 hr at 0° and 2 hr at room temperature. At that time water was added and the mixture was extracted with CH_2Cl_2. . The combined CH_2Cl_2 extracts were washed with 5% $NaHCO_3$ and H_2O, and finally dried over $MgSO_4$. After filtration and solvent evaporation, 8.6 g (65%) of the desired compound was obtained. Recrystallization from hexane produced bright orange needles: mp 91–92°; NMR ($CDCl_3$) τ 2.9 (4 H, m), 5.2 (2 H, m), 5.5 (2 H, m), 5.86 (5 H, s), 6.08 (2 H, s), 6.21 (3 H, s); ir (CCl_4), 1663 cm^{-1} (s, ketone carbonyl).

Anal. Calcd for $C_{19}H_{18}O_2Fe$: C, 68.28; H, 5.44. Found: C, 68.28; H, 5.79.

Preparation of 1-Ferrocenyl-2-(p-methoxyphenyl)ethanol. A mixture of 8.0 g (24 mmol) of ferrocenyl-p-methoxybenzyl ketone and 1.5 g (38 mmol) of $LiAlH_4$ in 100 ml of anhydrous ether was refluxed for 2 hr. The reaction mixture was then cooled in an ice bath while 100 ml of ice water was cautiously added. The layers were separated and the aqueous layer was further extracted with ether. The combined ether layers were washed with water and dried over $MgSO_4$. Solvent removal revealed the crude product (4.8 g, 60%) as a dark orange solid. An analytical sample was produced by recrystallization from hexane; yellow crystals, mp 62–63°; NMR ($CDCl_3$) τ 3.05 (4 H, m), 5.25 (1 H, m), 5.85 (9 H, s), 6.24 (3 H, s), 7.08 (2 H, d), 8.08 (1 H, s).

Anal. Calcd for $C_{19}H_{20}O_2Fe$: C, 67.87; H, 6.01. Found: C, 67.70; H, 6.03.

Preparation of 1-Ferrocenyl-2-(p-methoxyphenyl)ethene (5). A mixture of 2.6 g of 1-ferrocenyl-2-(p-methoxyphenyl)ethanol, 3 g of acidic alumina, and 75 ml of benzene was stirred under reflux for 2 hr with continued removal of water by a Dean-Stark trap. The mixture was filtered and the solvent was evaporated. The crude residue was chromatographed over alumina and elution with pentane removed the desired product. The red-orange crystals (1.6 g, 65%) melted at 95–97° and appear to represent a cis–trans mixture; NMR (CCl_4) τ 3.0 (4 H, m), 3.4 (2 H, m), 5.70 (2 H, m), 5.88 (2 H, m), 6.00 (5 H, s), 6.26 (3 H, s).

Anal. Calcd for $C_{19}H_{18}CFe$: C, 71.71; H, 5.71. Found: C, 71.75; H, 5.58.

Preparation of 2-Ferrocenyl-1-(p-methoxyphenyl)ethanol. To a stirred suspension of ferrocenylmethyltriphenylphosphonium iodide (5.88 g, 10 mmol) in 100 ml of anhydrous ether was added 11 mmol of butyllithium. The resultant red solution was stirred for 1.5 hr and then 5.12 g (30 mmol) of anisoyl chloride was added. An immediate precipitate formed. The mixture was stirred for an additional 2 hr and then filtered. The crude (α-ferrocenyl-*p*-methoxyphenacyl)triphenylphosphonium iodide weighed 7.0 g. A 250-ml three-necked flask was then equipped with a stirring bar, addition funnel, and condenser. Into the flask was placed 2.5 g of the iodide, 50 ml of chloroform, and 20 g of zinc dust. The reaction mixture was heated to boiling and 75 ml of glacial acetic acid added dropwise. After 1 hr the mixture was poured into water and the organic layer was separated, washed with water, dried ($MgSO_4$), and evaporated. The residue was chromatographed in pentane over alumina. Pentane removed triphenylphosphine and ether removed 0.16 g of *p*-methoxyphenacylferrocene as an orange solid (mp 96–101°). The crude ketone was dissolved in ether (25 ml) and treated with 0.2 g of $LiAlH_4$. This mixture was refluxed for 1.5 hr and then excess $LiAlH_4$ was removed by dropwise addition of water. The resultant two-phase system was poured into water and the organic layer was separated. The aqueous phase was extracted with ether and the combined extract was dried ($MgSO_4$) and evaporated. The residue was recrystallized from hexane to produce the desired alcohol as pale yellow crystals: mp 52–54° (yield, 0.11 g); NMR ($CDCl_3$) τ 2.95 (4 H, m), 5.20 (1 H, m), 5.93 (9 H, s), 6.21 (3 H, s), 7.24 (2 H, d), 7.80 (1 H, s).

Anal. Calcd for $C_{19}H_{20}O_2Fe$: C, 67.87; H, 6.01. Found: C, 67.35; H, 5.94.

Preparation of 1-Ferrocenyl-2-methyl-2-propanol. A solution of 5.4 g (22 mmol) of 1-ferrocenyl-2-propanone in ether was prepared according to literature procedures[10] and added to a solution of 50 mmol of methylmagnesium iodide in 50 ml of ether. The solution was stirred for 1 hr at room temperature and then poured into water. The ether layer was separated and the aqueous phase was extracted with ether. The combined ether extracts were dried ($MgSO_4$) and concentrated to yield a dark red oil. This viscous oil was repeatedly chromatographed over alumina and eluted with ether. The resultant dark red oil weighed 1.3 g (24%); NMR ($CDCl_3$) τ 5.90 (9 H, s), 7.45 (2 H, s), 8.50 (1 H, s), 8.86 (6 H, s).

Anal. Calcd for $C_{14}H_{18}OFe$: C, 65.13; H, 7.08. Found: C, 65.04; H, 7.06.

Hydroboration–Oxidation of Substituted Vinyl Ferrocenes. A. Excess Borane. The alkene (2.5 g), 50 ml of tetrahydrofuran, and 0.85 g of $NaBH_4$ were placed in a three-neck, 100-ml flask equipped with a condenser, addition funnel, and nitrogen inlet-outlet tube. The flask was placed in a water bath and the solution was magnetically stirred. Into the addition funnel was placed 4.2 g of boron trifluoride etherate and 10 ml of THF. This solution was added to the alkene solution over a period of 20 min and after the addition was complete, stirring was continued for 1 hr. The solution was cooled in an ice bath and 5 ml of H_2O was added dropwise to destroy excess diborane.

Enough 3 *N* NaOH was then added to raise the pH of the solution to 8.0. An equal volume of 30% H_2O_2 was added and the solution was stirred for 1 hr after which it was poured into 100 ml of water and extracted with three 50-ml portions of ether. The combined ether extracts were washed with 5% $NaHCO_3$ and four 100-ml portions of water. The ether solutions were then dried over $MgSO_4$. Removal of the solvent left the crude product, which was chromotographed over alumina. Pentane removed unreacted alkene and any reduction products. Ether eluted the alcohol fractions.

B. Stoichiometric Borane. The alkene (4.5 mmol) was dissolved in 10 ml of tetrahydrofuran (distilled from $LiAlH_4$) and a commercial solution of $BH_3 \cdot THF$ (1.7 mmol) diluted with 5 ml of THF was added dropwise over a period of 20 min. All operations were conducted at room temperature under a N_2 atmosphere. After addition of the borane, stirring was continued for 1.25 hr and then the reaction mixture was worked up as before.

The extent of alkylation of the borane was estimated from the amount of recovered unreacted alkene. With terminal and disubstituted internal alkenes used in this study, hydroboration apparently terminates at the dialkylborane stage. Trisubstituted alkene **6** proceeded to the monoalkylborane stage. The distribution of isomeric alcohols was found to be insensitive to the hydroboration procedure followed.

Acknowledgments. The authors thank the Robert A. Welch Foundation, Gulf Oil Corp., and the Sherwin-Williams Co. for generous financial support of this project.

Registry No.—*cis*-**5**, 55648-58-3; *trans*-**5**, 55700-24-8; ferrocenyl-*p*-methoxybenzyl ketone, 55648-59-4; ferrocene, 102-54-5; *p*-methoxyphenylacetyl chloride, 4693-91-8; 1-ferrocenyl-2-(*p*-methoxyphenyl)ethanol, 55648-86-7; 2-ferrocenyl-1-(*p*-methoxyphenyl)ethanol, 55648-87-8; ferrocenylmethyltriphenylphosphonium iodide, 32914-67-3; (α-ferrocenyl-*p*-methoxyphenacyl)triphenylphosphonium iodide, 55648-88-9; *p*-methoxyphenacylferrocene, 55648-89-0; 1-ferrocenyl-2-methyl-2-propanol, 55648-90-3; 1-ferrocenyl-2-propanone, 12215-52-0.

References and Notes

(1) C. H. Mauldin, E. R. Biehl, and P. C. Reeves, *Tetrahedron Lett.*, 2955 (1973).

(2) These alcohols did not undergo isomerization when chromatographed over alumina (Alcoa F-20 chromatographic alumina, 80–200 mesh).

(3) A. Streitwieser, Jr., L. Verbit, and R. Bittman, *J. Org. Chem.*, **32**, 1530 (1967).

(4) T. P. Fehlner, *J. Am. Chem. Soc.*, **93**, 6366 (1971).

(5) P. R. Jones, *J. Org. Chem.*, **37**, 1886 (1972).

(6) M. Rosenblum, "Chemistry of the Iron Group Metallocenes", Wiley, New York, N.Y., 1965, pp 84, 210.

(7) H. C. Brown and G. Zweifel, *J. Am. Chem. Soc.*, **82**, 4708 (1960).

(8) D. W. Slocum and C. R. Ernst, *Adv. Organomet. Chem.*, **10**, 108–109 (1972).

(9) Distribution values were taken from literature ref 7.

(10) M. J. Nugent, R. E. Carter, and J. H. Richards, *J. Am. Chem. Soc.*, **91**, 6145 (1969).