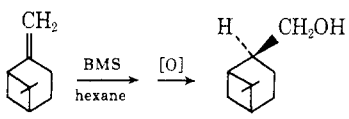
Table II
Hydroboration–Oxidation of Alkenes Using BMS[a]

Alkene	Time, hr[b]	Alcohol products	Relative amounts, %[c]	Total yield, %[d]
1-Hexene	1	1-Hexanol	93.6	100
		2-Hexanol	6.4	
2-Methyl-1-pentene	1	3-Methyl-1-pentanol		99.8
trans-3-Hexene	1	3-Hexanol		88.4
	3			100
Styrene	1	2-Phenylethanol	86.3	100
		1-Phenylethanol	13.7	
Cyclopentene	1	Cyclopentanol		96.5
Cyclohexene	1	Cyclohexanol		78.7
	1[e]			100
Norbornene	1	*exo*-Norborneol		87
	1[e]			94
1-Methyl-cyclopentene	1	*trans*-2-Methyl-cyclopentanol	>99[f]	86.4
	1[e]		>99[f]	100

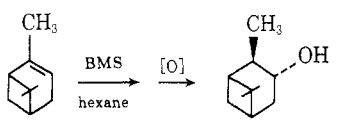
[a] All reactions involved the addition of BMS (11 mmol) to the alkene (30 mmol) dissolved in 10 ml of hexane at 0–5°. After an appropriate interval, ethanol (10 ml) was added and the reaction mixture was oxidized using 3 *N* aqueous NaOH (11 mmol) and 30% aqueous H_2O_2 (33 mmol). [b] Time for hydroboration at 20–25°. [c] By gc analysis. [d] By gc analysis using an internal standard. [e] Reaction mixture was heated to reflux for 1 hr to ensure complete hydroboration. [f] <1% cis isomer.

was obtained (eq 2), while *dl*-α-pinene gave *dl*-isopinocampheol in 92% isolated yield (eq 3).



(2)

85% isolated



(3)

92% isolated

It is now apparent that BMS is indeed a very useful reagent for the preparation of organoboranes *via* hydroboration of alkenes. The stability, commercial availability in pure form, and solubility in a wide variety of solvents should make BMS the reagent of choice for preparative hydroborations.

Experimental Section

All starting materials, including BMS, were used directly as obtained from the Aldrich Chemical Co. Since BMS is decomposed by atmospheric moisture, all manipulations of liquid BMS and the hydroboration reactions were carried out in dry glassware under a nitrogen atmosphere. A detailed description of the techniques necessary in handling air-sensitive solutions has been given elsewhere.[3]

(−)-*cis*-Myrtanol. A dry 2-l. flask equipped with a mechanical stirrer, pressure-equalizing dropping funnel, and reflux condenser was flushed with dry nitrogen and maintained under a positive nitrogen pressure. The flask was then charged with 238 ml (1.5 mol) of (−)-β-pinene and 500 ml of hexane and cooled to 0–5° with an ice–water bath. Hydroboration was achieved by the dropwise addition of 52.5 ml (0.55 mol) of BMS. Following the addition of the hydride (0.5 hr), the cooling bath was removed and the solution was stirred for 3 hr at 20–25°. Ethanol (500 ml) was then added followed by 165 ml of 3 *N* aqueous sodium hydroxide. After cooling to 0–5° in an ice–water bath, hydrogen peroxide (185 ml of a 30% aqueous solution) was added dropwise at such a rate that the reaction mixture warmed to 25–35°. Immediately following the addition of the peroxide (1 hr), the cooling bath was removed and the reaction mixture was heated at reflux for 1 hr. The reaction mixture was then poured into 6 l. of ice water. After adding 2 l. of ether and mixing thoroughly, the lower aqueous layer was removed and discarded. The upper organic layer was washed with water (2 × 1 l.), washed with saturated aqueous sodium chloride, dried over anhydrous potassium carbonate, filtered, and concentrated on a rotary evaporator to give 230 g of a light yellow oil. Short-path vacuum distillation of this oil gave 196 g (85%) of (−)-*cis*-myrtanol: purity >98% by gc analysis; bp 65–67° (0.2 mm); $n^{20}D$ 1.4911; $[\alpha]^{22}D$ −19.5° [lit.[4] bp 70–72° (1 mm); $n^{20}D$ 1.4910; $[\alpha]^{25}D$ −21°].

***dl*-Isopinocampheol.** Hydroboration–oxidation was carried out as described for *cis*-myrtanol using 500 ml of hexane, 160 ml (1.0 mol) of *dl*-α-pinene,[5] 52.5 ml (0.55 mol) of BMS, 500 ml of ethanol, 165 ml of 3 *N* aqueous sodium hydroxide, and 125 ml of 30% aqueous hydrogen peroxide. Isolation gave 154 g of a light yellow oil. Short-path vacuum distillation of this oil gave 141 g (92%) of *dl*-isopinocampheol, which crystallized upon cooling in the receiver, purity ~99% by gc analysis, bp 62–63° (0.25 mm), mp 39–41°. The sublimed alcohol exhibited mp 41–42° (lit.[4] for *l*-isopinocampheol, mp 54–56°).

Registry No.—Borane–methyl sulfide, 13292-87-0; 1-hexene, 592-41-6; (−)-*cis*-myrtanol, 51152-12-6; (−)-β-pinene, 18172-67-3; *dl*-isopinocampheol, 51152-11-5; *dl*-α-pinene, 2437-95-8.

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Relative Stabilities of α-Phenyl and α-Ferrocenyl Cations

Don Kaufman* and Robert Kupper

Department of Chemistry, Kearney State College, Kearney, Nebraska 68847

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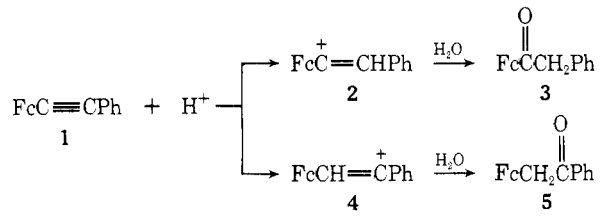
The existence of vinyl cations has now been demonstrated to the extent that these species are no longer hesitantly proposed as reaction intermediates. The first vinyl cations observed were generated in systems in which the positive charge could be delocalized as in substituted di- and triphenylethylenes. More recently, vinyl cations have been produced from a large number of compounds *via* a variety of reactions.[1-7]

In the course of our continued work with vinyl cations, the unusual stability of α-ferrocenyl alkyl cations was noted[8] and it appeared that the presence of an α-ferrocenyl moiety might also permit the ready generation of very stable vinyl cations. After exploratory work showed that various electrophilic additions to ethynylferrocene proceeded facilely, we sought to determine the relative abilities of ferrocenyl and phenyl groups to stabilize vinyl cations, *i.e.*, the relative stabilities of $FcC^+{=}CR_2$ and $PhC^+{=}CR_2$.

A qualitative answer to this question was ascertained by employing a type of intramolecular competition reaction in which either an α-phenyl or α-ferrocenyl vinyl cation could form as an intermediate as shown in Scheme I. When a dilute ethanolic solution of 1 was stirred at room temperature with a catalytic amount of 25% sulfuric acid, ferrocenylbenzyl ketone (3) was quantitatively produced. This result indicates that carbonium ion 2 was formed in preference to 4 and suggests that the α-ferrocenyl vinyl

cation is more stable than the analogous α-phenyl vinyl cation.

Scheme I



Consistent with the qualitative results just described are the kinetic data obtained for the acid-catalyzed hydrations of the compounds shown in Table I.

Table I
Relative Rates of Acid-Catalyzed Hydrations

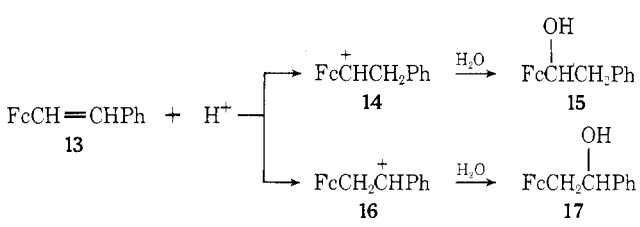
Compd	Reaction product	Relative rate[a,b]
FcC≡CH (**6**)	FcCCH$_3$ (**10**)	1.0
PhC≡CH (**7**)	PhCCH$_3$ (**11**)	10^{-5}
FcCH=CH$_2$ (**8**)	FcCHCH$_3$ (**12**)	0.11
PhCH=CH$_2$ (**9**)		No perceptible reaction

[a] Rates were determined by using uv spectroscopy to follow the disappearance of starting material. [b] First-order kinetics for longer than 5 half-lives were found for the three reactions which proceeded.

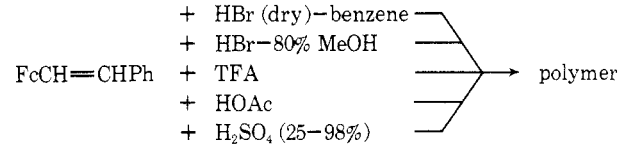
The first-order kinetics observed and the products yielded by compounds **6**, **7**, and **8** indicate an initial rate-determining protonation step for the hydration reactions. Thus, the relative reaction rates for **6** and **7** confirm the greater ease of formation for those vinyl cations stabilized by the α-ferrocenyl group.

To extend the present discussion to alkyl carbonium ions, a comparison of the relative rates of hydration of compounds **8** and **9** is used. On the basis of a faster reaction rate for **8**, it is seen that, just as was true for vinyl cations, alkyl cations are also generated more easily when α to the ferrocene ring. This result is in agreement with the work of Buell, *et al.*,[9] who noted the ready addition of weak electrophiles to vinylferrocene. Styrylferrocene (**13**) was synthesized and allowed to react as the model compound to see which of the two alkyl cations, **14** or **16** would intervene as shown in Scheme II.

Scheme II

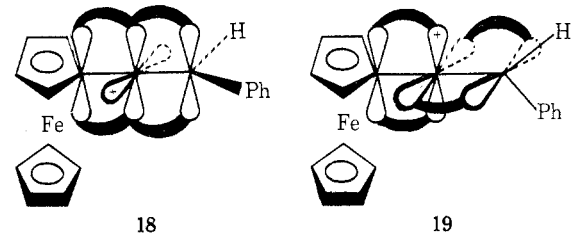


When allowed to react under the mild conditions used to effect the hydration of **1**, styrylferrocene did not react. In order to achieve any addition to styrylferrocene, it was necessary to employ much more drastic reaction conditions. However, under these severe conditions, only polymeric addition products were obtained and not the expected simple hydration products. For example



Based upon the ease of the acid-catalyzed hydration of vinylferrocene, the unreactivity of styrylferrocene in electrophilic additions was not expected. This lack of reactivity for **13**, however, can most likely be attributed to its unusual ground-state stability, which arises from the extended conjugation of the molecule. The reluctant addition to the conjugated system of **13** is not without parallel. For example, whereas bromine adds readily to styrene, it adds only slowly to stilbene. It is also of interest to note that Yates[10] found that electrophilic additions of Br_2, Cl_2, and ArSCl occurred significantly faster with alkyl-substituted olefins than with aryl-substituted olefins. This observation is not likely explained in terms of the relative energies of the carbonium ions. The greater ground-state stability of the conjugated aryl olefins could account for their lower reactivity in a fashion similar to that which is invoked above to explain the lack of reactivity of styrylferrocene.

The question still remains as to why compound **1** was hydrated more readily than **13**. If the unreactively of **13** is due to the loss of extended conjugation in going from the ground state to the intermediate carbonium ion, then it perhaps follows that, since FcC≡CPh (**1**) was seen to be quite reactive, its intermediate carbonium ion still retains the extended conjugation of the ground state. Such would require a structure similar to **18** rather than **19**.



18 **19**

If now the positive charge in **18** is to be delocalized, it would apparently have to be through direct participation of iron, since resonance with the ring would be impossible because of the orthogonality of the vacant p orbital on the vinyl carbon and the ring carbon to which it is attached. The origin of the stabilizing effect of the ferrocene ring in α-ferrocenyl alkyl cations has been the subject of much controversy, with some authors invoking direct participation of iron through its d orbitals while others promote direct conjugation with the ferrocene ring.[8]

The relative hydration rates of compounds **1** and **13** can be regarded as a specific example of the general question as to whether olefinic or acetylenic compounds will react more easily in electrophilic addition reactions. When the relative rates of reaction of compounds **6** *vs.* **8** and **7** *vs.* **9** are compared (Table I), it is seen that in each case the acetylenic compound has reacted appreciably faster than the analogous olefin. If an initial rate-determining protonation is assumed, these comparisons indicate that vinyl cations have formed more quickly than the corresponding alkyl carbonium ions. Finally, reference to the work of Yates[10] is again pertinent. He has shown that the relative reactivities of olefins and acetylenes in electrophilic addition reactions are very dependent upon solvent polarity. In solvent systems of relatively low polarity, olefins reacted significantly faster than the analogous acetylenes. However, acid-catalyzed hydrations, conducted in a polar medium of 48% aqueous sulfuric acid, proceeded at comparable rates for the olefins and acetylenes, with a slightly

faster rate being observed in several cases for the acetylene. An extension of this solvent polarity-olefin/acetylene relative reactivity relationship to the present work shows that our acetylenes were even more relatively reactive than would be expected, for the polarity of the solvent, ethanol, is substantially less than that of the aqueous sulfuric acid used by Yates. Thus, although solvent effects have been demonstrated to play an important role in determining olefin/acetylene relative reactivities, it would seem that other factors are also operative.

Experimental Section

General. Melting points were taken on an Electrothermal melting point apparatus and are uncorrected. Kinetic data were obtained on a Beckman DB spectrophotometer. Ir spectra were run on a Beckman IR-10 while nmr spectra were run on a Varian A-60 instrument.

Ferrocenylphenylacetylene (1). This compound was synthesized in 85% yield according to the method of Rausch, *et al.*,[11] mp 128–129° (lit.[11] mp 127–128°).

Iodoferrocene. Iodoferrocene, utilized in the synthesis of **1**, was initially prepared according to the method of Nesmeyanov.[12] This method, which involves the preparation of the intermediate compound chloromercuriferrocene,[13] proved to be very time consuming and gave us at best a 35% yield based upon starting ferrocene. A new method, patterned after the synthesis of halobenzenes utilizing thallic trifluoracetate (TTFA),[14] was improvised. To a solution of 3.82 g of ferrocene in 500 ml of glyme at 40° was added 5 g of TTFA in small increments over the period of 1 hr. The resulting solution was stirred at 40° for 4 hr,[15] after which time it was shaken with 250 ml of a saturated solution of aqueous potassium iodide. The organic layer was separated, dried over calcium chloride, and evaporated to yield crude iodoferrocene as a viscous, red-orange oil which was purified *via* silica gel column chromatography. The purified iodoferrocene was obtained in 88% yield, mp 50–51° (lit.[16] mp 49–49.5°). It should be stressed that subsequent attempts to prepare iodoferrocene *via* this new method have not duplicated the high yield obtained on the first run. Efforts to ascertain what was done differently on the initial trial have not met with success. However, it is suggested that freshly prepared TTFA[17] be used.

Reaction of Ferrocenylphenylacetylene (1). A 100-ml portion of a 5×10^{-2} *M* ethanolic solution of **1** was stirred at room temperature with 0.2 ml of 25% sulfuric acid. The solution was neutralized and stripped of solvent on a rotary evaporator to yield a viscous red-brown oil, which when recrystallized from benzene–hexane (75:25) gave a quantitative yield of ferrocenyl benzyl ketone (**3**), mp 129–130° (lit.[18] mp 128°). **3** was identified by comparing its melting point, ir, and nmr spectra with those of an independently prepared sample.[18]

Ethynylferrocene (6). This compound was prepared from acetylferrocene using the method of Rosenblum, *et al.*[19] An 82% yield of **6** was obtained, mp 53–54° (lit.[19] mp 51–53°).

Vinylferrocene (8). This compound was prepared in 20% yield by dehydrating α-hydroxyethylferrocene according to the method of Arimoto and Haven,[20] mp 45–47° (lit.[20] mp 48–49°).

Phenylacetylene (7). This compound was purchased from Aldrich Chemical Co. (No. 11, 770-6) and was used without further purification.

Styrene (9). This compound was purchased from Aldrich Chemical Co. (No. S497-2) and fractionally distilled prior to use.

Kinetic Data. Rates for the acid-catalyzed hydration reactions were obtained by using uv spectroscopy[21] to follow the disappearance of starting material. In each run, 3 ml of a 5×10^{-3} *M* ethanolic solution of compound was placed in the cuvette in the spectrophotometer and allowed to reach an equilibrium temperature of 31°, after which 0.1 ml of 25% H_2SO_4 was added.

Identification of Hydration Products. The hydration products listed in Table I were identified by comparing melting points and ir and nmr spectra with those of an authentic sample of the compound in question. Acetylferrocene was prepared according to the method of Broadhead, *et al.*,[22] with a 45% yield being obtained, mp 83–84° (lit.[23] mp 83–85°). α-Hydroxyethylferrocene (**12**) was prepared by $LiAlH_4$ reduction of acetylferrocene according to the method of Arimoto and Haven[20] to obtain an 80% yield, mp 70–71° (lit.[20] mp 69–72°).

Styrylferrocene (13). This compound was prepared according to the general method of Arimoto and Haven by which vinylferrocene was prepared. Ferrocene carboxaldehyde was treated with the Grignard reagent of benzyl bromide to give α-ferrocenyl-β-phenylethanol (**15**) in 80% yield, mp 80–81° (lit.[18] mp 82.3°). A 1-g portion of **15** was dissolved in a minimum amount of dry benzene to which sufficient alumina (Baker, acid washed, activity 1) was added to form a thick slurry. After standing over the alumina for 24 hr in a nitrogen atmosphere, the solution was eluted and stripped of solvent to yield crude styrylferrocene in 75% yield. After recrystallization from hexane a melting point of 123–124° was found (lit.[18] mp 120–121.5°).

Registry No.—**1**, 51108-02-2; **6**, 12764-67-9; **7**, 536-74-3; **8**, 1271-51-8; **9**, 100-42-5.

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Syntheses of Potential Antimetabolites. XV. Syntheses of a Sulfonate Analog of Adenosine 5′-Phosphate and an Alternative Synthesis of 5′,8-*S*-Anhydroadenine Nucleosides and 5′-Deoxyspongoadenosine and Its Isomers[1]

Yoshihisa Mizuno,* Chisato Kaneko, and Yuji Oikawa

Faculty of Pharmaceutical Sciences, Hokkaido University, Sapporo, Japan 060

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It has been well documented that *S*-anhydropurine nucleosides[2,4] as well as anhydropyrimidine nucleosides[3] are versatile intermediates for the interconversion of the nucleoside. In the preparation of 5′,8-*S*-anhydropurine nucleosides by a general procedure starting with preformed purine nucleosides, N^3,5′-cyclopurine nucleoside forma-