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Ionic Hydrogenations Using $BF_3 \cdot OH_2$. Reductions of Polycyclic Aromatics

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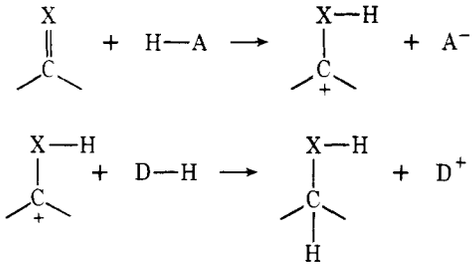
Received July 31, 1978

The hydrogenation of organic compounds can be accomplished by protonation to generate a cation followed by hydride abstraction by the cation from some hydride source (eq 1). A variety of acid–hydride donor pairs have been used. The



(1)

most well-developed system is a mixture of CF_3COOH and Et_3SiH,[1] although several other acids have also been used with Et_3SiH.[2-4] Recently, aromatics have been hydrogenated using strong acids such as HF–TaF_5 and molecular hydrogen as the hydride donor.[5] Similar reductions of aliphatic hydrocarbons are also known.[6,7] It has not been possible to use very strong acids with triethylsilane due to reaction of the acids with the silane. Both neat sulfuric and chlorosulfonic acids react with triethylsilane,[8] but aqueous sulfuric acid has been used to carry out reductions.[9] It is clear that the discovery of stronger acids which do not react directly with triethylsilane will increase the scope of this reaction.

The variety of organic compounds which can be reduced by ionic hydrogenation with triethylsilane is not large.[10] Only hydrocarbons giving tertiary or benzylic carbonium ions react with this reagent in protic media. Secondary alcohols have been reduced with BF_3 in methylene chloride[4] and the reduction of carbonyls to methylene has recently been reported.[11] There are no reports of the reduction of aromatics using the CF_3COOH–Et_3SiH pair except for the formation of 9,10-dihydroanthracene from anthracene.[12]

In this paper results obtained using the $F_3B \cdot OH_2$–Et_3SiH pair are reported. Such strong acids as $F_3B \cdot OH_2$ and HF do not react rapidly with triethylsilane, suggesting that the reactions of neat sulfuric and chlorosulfonic acids[8] are due to their high oxidizing power rather than their strength as proton donors. The acid prepared by dissolving BF_3 in water is a fascinating, useful material whose chemistry has not been much explored. The acidity of the monohydrate is comparable to anhydrous sulfuric and hydrofluoric acids.[13] The work described here was carried out in boron trifluoride monohydrate, a stable conducting material (mp 6.0 °C) which has been characterized by Greenwood and Martin.[14] Their work has been summarized together with the most of the known chemistry of the BF_3 hydrates in a good review[15a] and a book[15b] which is out of date. This acid has been little used for organic reactions. Eastham and co-workers studied boron trifluoride hydrate in ethylene dichloride as an initiator for cationic polymerizations.[16] Recently it was shown that it could be used to generate carbonium ions from diphenylethylene in methylene chloride.[17] It has also been used to prepare deuterated aromatics by proton exchange.[18]

Results and Discussion

The following compounds are not reduced by triethylsilane and $F_3B \cdot OH_2$ at 25 °C: naphthalene, phenanthrene, 1-methylnaphthalene, β-naphthalenethiol, phenol, anisole, toluene, and benzene. Compounds reduced and their products are shown in Table I.

Since anthracene is hydrogenated and phenanthrene is not, a carbonium ion stabilized by a pair of phenyls is required for reduction; conjugation with a single ring is not sufficient. The naphthalene nucleus is attacked when strongly activated, but is inert without such activation. As expected,[1] aryl ketones are easily reduced to the hydrocarbons. Some aliphatic ketones can be converted to the corresponding hydrocarbons using this reaction as shown by the formation of adamantane from adamantanone. Reductions of aliphatic ketones to hydrocarbons are quite sensitive to the reaction conditions.

Formally, the mechanism of this reduction is protonation followed by hydride abstraction. In nucleophilic media, a synchronous mechanism involving simultaneous hydride transfer and nucleophilic attack on silicon has been proposed,[19,20] while siliconium ion formation has been proposed in nonnucleophilic media.[21] Earlier we reported that naphthalene, benzene, and activated benzenes readily exchanged hydrogen with $F_3B \cdot OD_2$, presumably by a protonation–deprotonation sequence.[18] These compounds are not reduced by $F_3B \cdot OH_2$–Et_3SiH mixtures. This clearly demonstrates that the second step of the reaction, which is formally a hydride abstraction, must be rate determining. Boron trifluoride monohydrate is the strongest acid known to be compatible with triethylsilane. We hope that the utility of this reducing system with other functional groups will be explored.

Experimental Section

All compounds studied were commercially available and were used without further purification. A 6 ft × 0.125 in. 5% SE-30 on Chromosorb W column was used for GLC work, and decane was used as a GLC internal standard.

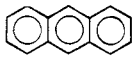
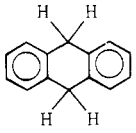
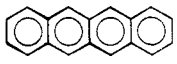
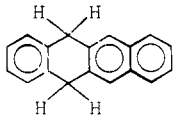
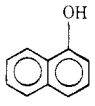
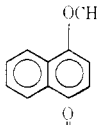
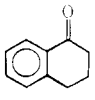
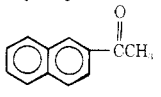
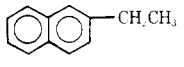
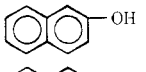
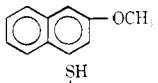
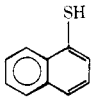
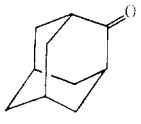
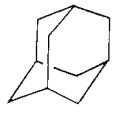
Preparation of $BF_3 \cdot H_2O$. A weighed amount of H_2O was cooled in an ice–water bath and BF_3 was bubbled into the liquid until a 1:1 mole ratio was reached as measured by the weight increase. $BF_3 \cdot H_2O$ is a dense fuming liquid and was stored in a polyethylene bottle.

Reduction of Anthracene. To a flask containing 15 g (0.175 mol) of $BF_3 \cdot H_2O$ and cooled in a water bath, 3 g (0.017 mol) of anthracene and 20 mL of methylene chloride were added. The mixture was stirred for 1 min, and 2.5 g (0.022 mol) of triethylsilane was added dropwise. After stirring for 1 h, the reaction mixture was extracted with methylene chloride several times. The methylene chloride extracts were combined, washed with water, and dried ($MgSO_4$). After methylene chloride was evaporated, 2.7 g of 9,10-dihydroanthracene was obtained; mp 108–109 °C; yield 89%; NMR (CCl_4) δ 3.75 (4 H, s), 7.0 (8H, s).

Reduction of Naphthacene. To a flask containing 10 g (0.117 mol) of $BF_3 \cdot H_2O$ and cooled in a water bath, 0.2 g (0.876 m mol) of naphthacene and 10 mL of methylene chloride were added. The mixture was stirred for 5 min followed by the dropwise addition of 1.7 g (14.6 mmol) of triethylsilane. The reaction mixture was stirred for 4 h and was extracted several times with methylene chloride. The methylene chloride extracts were combined, washed with water, dried ($MgSO_4$), and evaporated. The residue was 180 mg of a white solid:

0022-3263/79/1944-1168$01.00/0

Table I. Reduction with Triethylsilane and $F_3B{\cdot}OH_2$ at 25 °C

compd	registry no.	product	registry no.	isolated yield, %	recovered starting material, %	reaction time, h
	120-12-7		613-31-0	89	0	1
	92-24-0		959-02-4	88	0	4
	90-15-3		119-64-2	52	13	4
	2216-69-5			37	10	10
	529-34-0			67	9	3.5
	93-08-3		939-27-5	70	0	10
	135-19-3			37[a,b]	5	7
	93-04-9			26[a,c]	12	10
	529-36-2			13[a,d]		6
	700-58-3		281-23-2	78	0	1

[a] Yields determined by GLC. Naphthalene is a minor product. [b] The yield of naphthalene is 12%. [c] The yield of naphthalene is 2.5%. [d] The yield of naphthalene is 5.5%.

mp 207–209 °C; yield 88%; NMR ($CDCl_3$) δ 4.07 (4 H, s), 7.0–7.9 (10 H, m).

Reduction of 1-Hydroxynaphthalene, 2-Hydroxynaphthalene, 1-Methoxynaphthalene, 2-Methoxynaphthalene, 1-Naphthalenethiol, α-Tetralone, 2-Acetonaphthalene, and Adamantanone. The reduction of these compounds was carried out as follows. To a flask containing a 4–6 molar excess of $BF_3{\cdot}H_2O$ and cooled in a water bath, an aromatic compound was added. The mixture was stirred for 5 min and 30% molar excess of triethylsilane was added dropwise. The reaction was stirred at room temperature and then extracted with methylene chloride. The methylene chloride solution was washed with water, dried over $MgSO_4$, and distilled at atmosphere pressure. Two fractions were collected at atmosphere pressure. Fraction I, bp 39–45 °C, was methylene chloride. Fraction II, bp 100–107 °C, was composed of triethylsilane and triethylfluorosilane, as determined by GLC and GLC/mass spectrometry: mass spectrum of Et_3SiF 134 (M^+), 115, 105, 87, 77, 59. After these two fractions had been collected, the remaining material was distilled under vacuum. Pure tetralin and pure 2-ethylnaphthalene were collected from the reactions of 1-hydroxynaphthalene, 1-methoxynaphthalene, and α-tetralone and 2′-acetonaphthone, respectively, as indicated by NMR and GLC analyses. A small amount of naphthalene was formed in the reactions of 2-hydroxynaphthalene, 2-methoxynaphthalene, and 1-naphthalenethiol, while none was observed with α-naphthol and its derivatives. The naphthalene came over with tetralin in the vacuum distillation. The residue remaining in the distillation flask after the vacuum distillation was a yellow gummy material. The amount of tetralin and naphthalene isolated from 2-hydroxynaphthalene and 2-methoxynaphthalene was determined by GLC analyses. In the reduction of 1-naphthalenethiol the methylene chloride extract was not distilled, and the yield of naphthalene and tetralin formed in the reaction was obtained by GLC. Adamantane formed in the reduction of adamantanone was isolated by removal of the methylene chloride solvent.

Attempts to Reduce Naphthalene, Phenanthrene, 1-Methylnaphthalene, 2-Naphthalenethiol, Phenol, Anisole, Toluene, and Benzene. The reaction procedures were similar to those of 1-hydroxynaphthalene, etc., except methylene chloride was used as solvent for the reduction of phenathrene, naphthalene, and 2-naphthalenethiol. The organic layer was checked with NMR and GLC, and no hydrogenation products could be found.

Acknowledgment. We are grateful to the Office of Basic Energy Sciences of the Department of Energy for support of this work. This research was sponsored by the Office of Basic Energy Sciences, U. S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

Registry No.—Boron trifluoride hydrate, 15799-89-0; triethylsilane, 617-86-7; naphthalene, 91-20-3; phenanthrene, 85-01-8; 1-methylnaphthalene, 90-12-0; 2-naphthalenethiol, 91-60-1; phenol, 108-95-2; anisole, 100-66-3; toluene, 108-88-3; benzene, 71-43-2.

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Rearrangement Approaches to Polycyclic Skeletons. 2. Synthesis of the Gibberellin Skeleton[1]

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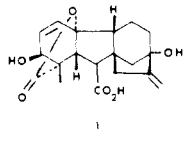
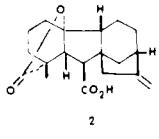
Received September 6, 1978

The intriguing and challenging synthetic objectives presented by the gibberellins,[2] represented in their full structural complexity by gibberillic acid, GA_3 (**1**), have received considerable attention. These efforts include model studies directed toward preparation of the sensitive array of functionality in ring A[3] as well as the total syntheses of gibberellins GA_4[4a] and GA_{15}.[4b] We now wish to describe an efficient, convergent method to prepare the tetracyclic carbon skeleton characteristic of gibberellins such as GA_9 (**2**).[2] The overall



1

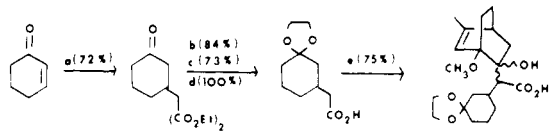


2

synthetic strategy employed in this work involves initial formation of a bridgehead-substituted bicyclo[3.2.1]octenone derivative followed by elaboration of the fused-ring framework.[1b]

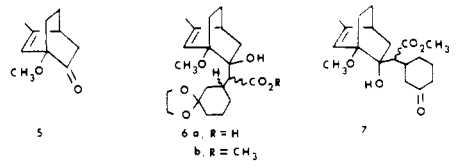
The A/B ring precursor, ketal acid **3**, was prepared from 2-cyclohexenone as shown in Scheme I. Conversion of ketal acid **3** into its lithium dianion by sequential treatment with lithium hydride and lithium diisopropylamide, followed by addition of the C/D ring precursor, the Diels–Alder derived 1-methoxy-5-methylbicyclo[2.2.2]oct-5-en-2-one (**5**),[1b] furnished a mixture of epimeric β-hydroxy acids **4** in 75% yield. This reaction mixture was crystallized to furnish pure exo alcohol acid **6a** in 27% yield. Aqueous acid hydrolysis of the resulting mother liquors, followed by esterification with diazomethane, yielded the crystalline endo alcohol ester **7** in 20% yield. Based on the expected shielding effect[1b] of the C_5–C_6

Scheme I



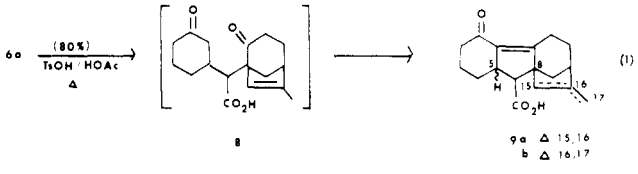
[a] Diethyl malonate, EtONa, EtOH, −5 to 25 °C, 6 h. [b] Ethylene glycol, TsOH, benzene, Δ, 12 h. [c] NaCN, Me_2SO, 155 °C, 16 h. [d] KOH, H_2O, 100 °C, 2 h. [e] (i) LiH, THF; (ii) LDA, THF, −40 to 40 °C; (iii) addition of ketone **5**, 0 to 25 °C, 12 h.

double bond of the bicyclo[3.2.1]octene nucleus, the exo/endo stereochemical assignments for these products were made by comparing the chemical shifts of the methyl esters, δ 3.67 for the exo alcohol ester **6b** and δ 3.73 for the endo alcohol ester **7**. The relative stereochemistry of the remaining chiral centers in **6** and **7** has not been assigned.



5 **6a**, R = H; **b**, R = CH_3 **7**

Treatment of exo alcohol acid **6a** with a catalytic amount of *p*-toluenesulfonic acid in acetic acid furnished a nonseparable mixture (4:1) of crystalline acid products in 80% yield (eq 1). The major product was assigned the tetracyclic structure **9a** on the basis of spectra data while the minor isomer was identified as the exocyclic methylene isomer **9b** (see Experimental Section for details). The formation of these products is consistent with the intermediacy of the expected[1b] 1-substituted bicyclo[3.2.1]oct-6-en-2-one **8** followed by acid-catalyzed Aldol cyclization and, in the case of **9b**, concomitant

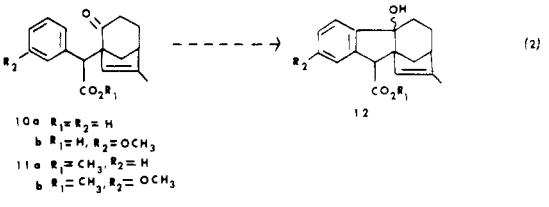


(1)

8 **9a** Δ 15,16; **b** Δ 16,17

isomerization of the isolated double bond. Although the relative stereochemistry of the C-5 and C-8 centers in **9a** has not been assigned, a single isomer appears to have been formed which, in turn, suggests that the starting exo alcohol acid **6a** is a single diastereomer. Since both the A/B and C/D ring precursor units can be readily modified to incorporate a variety of functionalities, this convergent route involving closure of the B ring via an Aldol cyclization constitutes a promising method to prepare a number of naturally occurring gibberellins.

A second synthetic approach to the tetracyclic gibberellin skeleton was also evaluated. As shown in eq 2 this sequence



(2)

10a $R_1 = R_2 = H$; **b** $R_1 = H$, $R_2 = OCH_3$
11a $R_1 = CH_3$, $R_2 = H$; **b** $R_1 = CH_3$, $R_2 = OCH_3$ **12**

involved attempted formation of the five-membered B ring by intramolecular electrophilic cyclization[5] of the 1-aryl-substituted bicyclo[3.2.1]octenones **10** and **11** to give the aromatic A ring gibberellin derivatives **12**.

Treatment of keto acid **10a**[1b] with *p*-toluenesulfonic acid (0.5 equiv) in benzene at reflux for 6 h yielded a single product in 71% yield which was assigned as the α,β-unsaturated δ-lactone **13** on the basis of spectral data (see Experimental

0022-3263/79/1944-1170$01.00/0