2 H, *E,E* and *E,Z*), 5.90–6.15 (m, 1.78 H, *E,E* and *E,Z*), 6.20–6.45 (m, 0.22 H, *E,Z*); ^{13}C NMR of (*E,E*) δ 171.2, 132.7, 131.7, 130.6, 130.1, 64.5, 32.5, 32.4, 31.4, 29.1, 29.0, 28.4, 25.4, 22.5, 21.0, 14.0. Anal. Calcd for $C_{16}H_{28}O_2$: C, 76.14; H, 11.18. Found: C, 75.93; H, 11.27.

11,13-Nonadecadien-2-one (21c): (*E,E*):(*E,Z*) = 92:8; GC (column temperature = 170 °C, carrier gas pressure = 1.45 kg/cm^2) t_R = 11.12 (*E,E*), 9.69 (*E,Z*) min; IR (neat) 3008, 2926, 2850, 1718, 1465, 1370, 986 cm^{-1}; ^{1}H NMR δ 0.88 (t, *J* = 6.0 Hz, 3 H), 1.10–1.70 (m, 17 H), 1.90–2.10 (m, 4 H), 2.14 (s, 3 H), 2.41 (t, *J* = 7.3 Hz, 2 H), 5.25–5.40 (m, 0.08 H, *E,Z*), 5.45–5.80 (m, 1.92 H, *E,E* and *E,Z*), 5.90–6.10 (m, 1.92 H, *E,E* and *E,Z*), 6.25–6.40 (m, 0.08 H, *E,Z*); HRMS calcd for $C_{19}H_{34}O$ 278.2611, found 278.2677.

6,8-Tetradecadien-1-yne (21d): (*E,E*):(*E,Z*) = 88:12; GC (column temperature = 140 °C, carrier gas pressure = 0.75 kg/cm^2) t_R = 8.40 (*E,E*), 7.35 (*E,Z*) min; IR (neat) 3306, 3012, 2924, 2854, 1437, 1433, 987 cm^{-1}; ^{1}H NMR δ 0.88 (t, *J* = 6.0 Hz, 3 H), 1.15–1.50 (m, 6 H), 1.50–1.80 (m, 2 H), 1.95 (t, *J* = 2.5 Hz, 1 H), 1.90–2.40 (m, 4 H), 2.16 (dt, *J* = 2.5, 7.5 Hz, 2 H), 5.25–5.40 (m, 0.12 H, *E,Z*), 5.40–5.80 (m, 1.88 H, *E,E* and *E,Z*), 5.90–6.20 (m, 1.88 H, *E,E* and *E,Z*), 6.25–6.40 (m, 0.12 H, *E,Z*); ^{13}C NMR of (*E,E*) δ 14.1, 17.8, 22.6, 28.2, 29.1, 31.5, 32.6, 68.4, 84.4, 130.1, 130.6, 131.4, 133.1. Anal. Calcd for $C_{14}H_{22}$: C, 88.35, H, 11.65. Found: C, 88.47, H, 11.91.

Cobalt(II)-Catalyzed Reaction between Polycyclic Aromatic Aldehydes and Acetic Anhydride. Formation of Acylals, Not 1,2-Diketones

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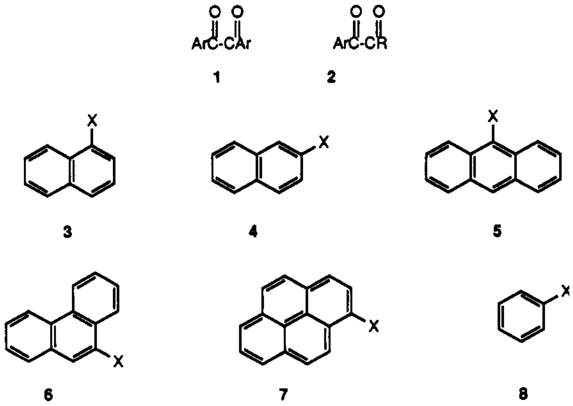
Several polycyclic aromatic aldehydes were found to react with acetic anhydride in acetonitrile in the presence of excess $CoCl_2$ to afford the corresponding acylals [ArCH(OAc)$_2$]. The results are not consistent with the literature report (Ahmad, S.; Iqbal, J. *J. Chem. Soc., Chem. Commun.* **1987**, 692) that substituted benzaldehydes afford 1,2-diketones under similar conditions. The cobalt(II) chloride probably promotes acylal formation through its weakly Lewis acid character.

In connection with other work,[1] we needed a series of diaryl and aryl alkyl 1,2-diketones (**1** and **2**). The literature contains a variety of methods for the synthesis of such substances.[2] However, it happened that our need for these compounds coincided with a report by Ahmad and Iqbal[3] concerning the reaction between acetic anhydride (Ac_2O) and a number of substituted benzaldehydes in acetonitrile in the presence of anhydrous cobalt(II) chloride ($CoCl_2$). They indicated that the reaction could be made to produce either **1** or **2** (Chart I), depending upon the ratio of Ac_2O to aldehyde employed in the reaction. In view of the apparent simplicity and versatility of this reaction, we decided to use it with a series of polycyclic aromatic aldehydes to prepare the corresponding diketones. In our hands, using somewhat different conditions, the reaction takes a considerably different course.

Chart I



a, X = CHO
b, X = $CH(OAc)_2$
c, X = $CON(CH_3)OCH_3$
d, X = CDO
e, X = $CD(OAc)_2$

Results

Syntheses of Acylals. When we subjected either benzaldehyde or 4-nitrobenzaldehyde to the conditions of ref 3, we isolated only unreacted starting aldehyde. However, when 1-naphthaldehyde (**3a**) was allowed to react for 24 h at room temperature with acetic anhydride in dry CH_3CN containing excess $CoCl_2$, in the proportion Ac_2O/aldehyde/$CoCl_2$ = 3:1:1.5 (we refer to these proportions, temperature, and time throughout the following discussion as our "standard conditions"), a reaction did take place. The product was a white crystalline solid, mp 105 °C. It was clearly not the diketone 1,1′-naphthil, which is a yellow substance, mp 188–189 °C.[4] The white solid was identified as the acylal α,α-diacetoxy-1-methylnaphthalene (**3b**) by its ^{1}H NMR spectrum (s, δ 2.15, 6 H and mult δ 7.4–8.3, 8 H), mass spectrum (peaks at 258 [parent], 156 (base), and 127), IR spectrum(1745 and 1760 cm^{-1}), and combustion analysis. This structural assignment was confirmed through an independent synthesis by the reaction between **3a** and Ac_2O under BF_3 catalysis.[5]

The generality of this acylal-forming reaction was then tested by subjecting a series of polycyclic aromatic aldehydes to similar conditions. The other aldehydes examined were 2-naphthaldehyde (**4a**), 9-anthraldehyde (**5a**), 9-phenanthraldehyde (**6a**), and 1-formylpyrene (**7a**). While **3a** and **4a** reacted completely in 24 h at room temperature under the standard conditions, the other aldehydes were only partly converted under these conditions and required higher temperatures and/or longer reaction times to go to completion. In every case, the product was the corresponding acylal (**3–7b**). There was no evidence for the

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(1) Fry, A. J.; Sherman, L. R.; Beaulieu, A. R.; Sherwin, C. *J. Org. Chem.* **1990**, *55*, 389.

(2) Waring, A. J. In *Comprehensive Organic Chemistry, Vol.* 1; Stoddart, J. F., Ed.; Pergamon: Oxford, 1979; pp 1056–1057.

(3) Ahmad, S.; Iqbal, J. *J. Chem. Soc., Chem. Commun.* **1987**, 692.

(4) Gomberg, M.; Van Natta, F. J. *J. Am. Chem. Soc.* **1929**, *51*, 2238.

(5) Mann, E. H.; Sanderson, J. J.; Hauser, C. R. *J. Am. Chem. Soc.* **1950**, *72*, 847.

0022-3263/91/1956-3283$02.50/0

formation of 1,2-diketones in any of these reactions.

Other Experiments. Several attempts were made to explore the generality of the reaction. 2-Naphthaldehyde was subjected to the standard conditions, except that acetic anhydride was replaced by succinic and glutaric anhydrides. However, in each case, TLC analysis showed only the presence of the unreacted components after a 2-week reaction time. 2-Naphthaldehyde also proved to be unreactive with these two anhydrides under the original conditions of Ahmad and Iqbal[3] (which employ much less cobalt chloride than we have customarily used). Finally, 2-acetylnaphthalene failed to react with acetic anhydride even in 2 weeks under our conditions.

Our standard conditions involve a much higher ratio of $CoCl_2$ to aldehyde (1.5:1) than that (0.05:1) used in the original report.[3] We have carried out some experiments using the original ratio for comparison. 4-Nitrobenzaldehyde and benzaldehyde were recovered unchanged both under our conditions and those used in the original report,[3] except that under our conditions benzaldehyde (**8a**) produced after 3 days a very small amount of material whose mass spectrum corresponds to that expected for the acylal (**8b**). 1-Naphthaldehyde (**3a**) was converted into **3b** under the original conditions of Ahamd and Iqbal,[3] although more slowly than when our standard conditions were used.

To test the hypothesis of Ahmad and Iqbal[3] that the first step in the reaction is an electron transfer from Co(II) to Ac_2O, we made up two reaction mixtures. One was a mixture of 1-naphthaldehyde, Ac_2O, and $CoCl_2$ in the proportions used in our standard conditions. The other was identical, except that nitrobenzene, a good electron scavenger,[6] was added to the mixture in equimolar proportion to 1-naphthaldehyde. NMR analysis showed that acylal formation proceeded at about the same rate in the latter mixture as in the control mixture.

Full analysis of the ^1H NMR spectra[7] of certain of the acylals required synthesis of the corresponding deuterated analogues [Ar*C*D(OAc)$_2$ (**3–5e**)] from the corresponding deuterio aldehydes [Ar*C*DO (*D*-**3**-**5d**)]. The latter were prepared in turn by converting the carboxylic acids into their *N*,*O*-dimethylamides (**3–5c**) and reducing the latter immediately with $LiAlD_4$.[8]

Mechanism of Acylal Formation. Ahmad and Iqbal[3] suggested that diketone formation is initiated by electron transfer from $CoCl_2$ to Ac_2O. It is known, however, that a variety of Bronsted and Lewis acids promote the reaction between aldehydes and Ac_2O to form acylals.[5,9] In fact, $ZnCl_2$ and $FeCl_3$, which cannot transfer electrons to aldehydes but are good Lewis acids, have been shown to effect this conversion.[9b] Formation of acylals **3–7b** is almost certainly acid catalyzed. There are two potential sources of acid catalysis in our system. The $CoCl_2$ used in most of our work was used as received without drying in most experiments.[10] It might contain small amounts of water (the original report states that "anhydrous $CoCl_2$" was used, but not details were provided). If so, then not only could Co(II) itself promote reaction by acting as a weak Lewis acid[11] but protic impurities in the system might also act as Bronsted acid catalysts and could also produce acetic acid by attack on Ac_2O. In fact,[10] formation of acylals is slow (but 1,2-diketones are still not formed) when very dry reagents are used. We presume that the reaction proceeds by formation of a complex between the aldehyde and an electrophile (the metal ion or a proton). Nucleophilic attack by acetic acid upon the complex would then afford a hemiacylal, which could then be acylated again to produce the acylal. Slow formation of acylals under very dry conditions[10] could occur by a route analogous to that suggested to explain the catalytic effect of $FeCl_3$.[9b]

Table I. Correlation between Aldehyde Carbonyl Frequency and Ease of Acylal Formation

aldehyde	carbonyl frequency (cm^{-1})	acylal formation[a]
4-nitrobenzaldehyde	1701	no
benzaldehyde	1703	trace
2-naphthaldehyde	1686	yes
1-naphthaldehyde	1685	yes
9-phenanthraldehyde	1681	yes
1-formylpyrene	1672	yes
9-anthraldehyde	1664	yes

[a] Reaction carried out for 24 h at room temperature with acetic anhydride in dry acetonitrile containing Ac_2O, aldehyde, and cobalt(II) chloride, in the proportions Ac_2O/aldehyde/$CoCl_2$ = 3:1:1.5.

Benzaldehyde and 4-nitrobenzaldehyde are unreactive under our conditions, whereas the polycyclic aromatic aldehydes (**3–7a**) form acylals relatively readily. We suggest that this is because the latter aldehydes are more nucleophilic. The IR carbonyl frequency, which is a measure of carbon–oxygen single-bond character and therefore of the degree of charge separation in the carbonyl group, should be correlated with carbonyl nucleophilicity. The latter should increase as the carbonyl frequency decreases.[12a] The carbonyl frequencies of these aldehydes do indeed correlate with ease of acylal formation (Table I). All of the aldehydes that undergo conversion to acylals

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(6) Fry, A. J. *Synthetic Organic Electrochemistry*, 2nd ed.; Wiley: New York, 1989; pp 96 and 104.

(7) (a) It is not immediately obvious what the effect of a $CH(OAc)_2$ group should be on the chemical shift of protons ortho or peri to it. On the one hand, the group is inductively electron-withdrawing and should exert a downfield shift on neighboring protons; on the other hand, the diamagnetic anisotropy of the two carbonyl groups might in principle result in either upfield or downfield shifts on neighboring protons, depending upon the average distance and orientation of the two carbonyl groups with respect to the ortho and peri protons. In order to obtain information on this point, the spectra of acylals **3–5b** were analyzed in detail, employing a combination of techniques including nuclear Overhauser enhancement (NOE) spectroscopy, spin decoupling experiments, aromatic solvent–induced shifts (ASIS), T_1 measurements, and synthesis of deuterated analogues. Assignments were aided by the usual generalization[7b] that naphthalene protons at positions 1, 4, 5, and 8 appear at lower field than those at 2, 3, 6, and 7 (and similarly for higher hydrocarbons such as anthracene). Complete spectral assignments for acylals **3–5b** are given in the Experimental Section. It was found that in general the $CH(OAc)_2$ exerts a downfield effect upon its neighbors. Furthermore, since irradiation of H_α in the acylals creates NOE enhancements of both of the protons ortho and peri to the $CH(OAc)_2$ group, we conclude that this group is freely rotating on the NMR time scale; (b) Memory, J. D.; Wilson, N. K. *NMR of Aromatic Compounds*; Wiley: New York, 1982; p 42.

(8) Nahm, S.; Weinreb, S. M. *Tetrahedron Lett.* 1981, *22*, 3815.

(9) (a) Thiele, J.; Winter, E. *Liebigs Ann. Chem.* 1960, *311*, 355. (b) Kochhar, K. S.; Bal, B. S.; Deshpande, R. P.; Rajadhyaksha, S. N.; Pinnick, H. W. *J. Org. Chem.* 1983, *48*, 1765. (c) Michie, J. K.; Miller, J. A. *Synthesis* 1981, 824.

(10) A referee requested that we carry out a series of reactions under anhydrous conditions. No reaction was observed after 48 h when either **3a** or 4-nitrobenzaldehyde was allowed to react with Ac_2O (1:1) in dry CH_3CN in the presence of 5 mol % anhydrous $CoCl_2$, the conditions of ref 3. The salt had been dried in vacuo at 110 °C for 72 h; the solvent was dried for 1 week over molecular sieves. Under the same conditions, and using a 1.5:1 ratio of $CoCl_2$ to **3a**, a small amount of the acylal **3b** was formed.

(11) The other applications of $CoCl_2$ in organic chemistry reported by Iqbal and co-workers all involve it acting as a Lewis acid: (a) Iqbal, J.; Khan, M. A. *Chem. Lett.* 1988, 1157. (b) Ahmad, S.; Iqbal, J. *Chem. Lett.* 1987, 953.

(12) (a) Berthier, G.; Serre, J. In *The Chemistry of the Carbonyl Group, Vol.* 1; Patai, S., Ed.; Interscience-Wiley: New York, 1966, p 1. (b) Ogata, Y.; Kawasaki, A. In *The Chemistry of the Carbonyl Group*; Zabicky, J., Ed.; Interscience-Wiley: New York, 1970; p 1.

exhibit carbonyl frequencies less than 1685 cm^{-1}; steric effects are undoubtedly also involved in the differences in reactivity among the various polycyclic aldehydes.

2-Acetylnaphthalene fails to react under our conditions. This could be because acylal formation is initiated by complexation of the carbonyl component to Co(II). It is known that aldehydes complex much more readily to metal ions than do ketones,[13] apparently for steric reasons. This could explain the decreased reactivity of ketones. On the other hand, it may be that acylals from ketones are too sterically hindered to form readily. It is known that ketones generally form tetrahedral products such as *gem*-diols much less readily than do aldehydes.[11b] The failure of succinic and glutaric anhydrides to afford acylals has precedent; it has been reported that succinic anhydride is unreactive under conditions where BF_3 readily catalyzes the reaction between propionaldehyde and acetic anhydride to afford an acylal.[5]

The formation of 1,2-diketones by the Co(II)-catalyzed reaction between aldehydes and Ac_2O was explained by a mechanism involving initial electron transfer from Co(II) to Ac_2O.[3] Granted that under some conditions this reaction may well proceed as reported, it still seems very unlikely that Ac_2O could compete successfully for an electron in the presence of an aromatic aldehyde. The polarographic reduction potentials ($E_{1/2}$) of benzaldehyde and Ac_2O are −1.80 and −2.8 V vs SCE, respectively.[14] This difference of 1 V corresponds to a very large (23 kcal/mol) factor favoring electron transfer to the aldehyde. 4-Nitrobenzaldehyde, which is said to afford the highest yield of 1,2-diketones,[3] represents an even more dramatic case: its $E_{1/2}$ is −0.86 V,[15] corresponding to an even more dramatic 45 kcal/mol thermodynamic preference for electron transfer to this aldehyde in the presence of Ac_2O. The conclusion seems inescapable that diketone formation, where it occurs and whatever the mechanism, is not initiated by electron transfer to Ac_2O.

In general, $CoCl_2$ is a milder Lewis acid catalyst for acylal formation than BF_3, $FeCl_3$, or $ZnCl_2$, all of which have previously been advocated for this purpose.[9] It reacts only with the most reactive aromatic aldehydes and may therefore have utility for selective functionalization of polycarbonyl compounds.

Experimental Section

General. NMR spectra were recorded in $CDCl_3$. Microanalyses were performed by the Robertson Laboratory, Madison, NJ. Flash chromatography was carried out over 100–300-mesh silica gel, using 25:75 ethyl acetate/hexane.

***α,α*-Diacetoxy-1-methylnaphthalene (3b).** 1-Naphthaldehyde (**3a**) (4.34 mL, 0.032 mol) and Ac_2O (3.02 mL, 0.035 mol) were cooled to 0 °C, one drop of $BF_3{\cdot}Et_2O$ was added, and the mixture was stirred overnight. Aqueous 10% NaOAc (100 mL) was then added, and the mixture was stirred for 20 min. The mixture was extracted twice with ether. The ether extracts were washed twice with saturated $NaHCO_3$, dried over Na_2SO_4, and evaporated in vacuo to afford *α,α*-diacetoxy-1-methylnaphthalene (**3b**) as a white solid. Recrystallization of the white solid from hexane afforded **3b** as fine white crystals (5.94 g, 72%): mp 99–100 °C; ^1H NMR δ 2.15 (s, 6 H), 8.23 (s, 1 H, H_α), 8.24 (d, J = 8.2 Hz, 1 H, H_8), 7.88 (m, 2 H, $H_{4,5}$), 7.74 (d, J = 6.1 Hz, 1 H, H_2), 7.5 (m, 1 H, H_3) and 7.6 (m, 2 H, $H_{6,7}$) H_α and H_8 were resolved cleanly in C_6D_6 (H_α at δ 8.84; H_8 doublet at δ 8.71), making decoupling and NOE experiments possible in this region of the spectrum. Anal. Calcd for $C_{15}H_{14}O_4$: C, 69.75; H, 5.46. Found: C, 69.56, H, 5.45.

General Procedure for Synthesis of Acylals. *α,α*-Diacetoxy-1-methylnaphthalene (3b). $CoCl_2$ (6.5 g, 0.05 mol) was dissolved in 50 mL of dry CH_3CN. It was necessary to add the salt slowly to avoid formation of an insoluble granular mass. To this solution was added 8.96 mL of Ac_2O (0.096 mol), whereupon slight warming occurred. Aldehyde **3a** (4.34 mL, 0.032 mol) was then added and the deep blue mixture was stirred at room temperature for 24 h. The solvent was then evaporated in vacuo. The resulting mixture was washed with water and then extracted with two 50-mL portions of CH_2Cl_2, which were then combined and washed with water. Drying over $MgSO_4$ and evaporation afforded a yellow liquid. Upon standing overnight, this liquid deposited *α,α*-diacetoxy-1-methylnaphthalene (**3b**) as fine white crystals (5.54 g, 67%), mp 98–99 °C, identical in physical and spectral properties with the substance prepared above by the BF_3 route.

***α,α*-Diacetoxy-2-methylnaphthalene (4b).** 2-Naphthaldehyde (5.0 g, 0.032 mol) was substituted for **3a** in the previous procedure. White crystals separated during the initial wash with water. These were filtered and the remainder worked up as usual. Evaporation afforded a second crop of white crystals. The combined weight of *α,α*-diacetoxy-2-methyl-naphthalene (**4b**) was 6.1 g (74%): mp 101–102 °C; ^1H NMR δ 2.15 (s, 6 H), 7.52 (t, 2 H, $H_{6,7}$), 7.61 (br d, 1 H, H_3), 7.83 (s, 1 H, H_α), 7.87–7.91 (m, 3 H, $H_{4,5,8}$), 8.01 (br s, 1 H, H_1). Anal. Calcd for $C_{15}H_{14}O_4$: C, 69.66; H, 5.49. Found: C, 69.56, H, 5.45.

***α,α*-Diacetoxy-9-methylanthracene (5b).** 9-Anthraldehyde (1.0 g, 3.56 mmol) was substituted for **5a** in the general procedure, with amounts of other reagents scaled appropriately, except that the Ac_2O/**5a** ratio was 6:1. Reaction was carried out for 7 days at reflux. The usual workup afforded a brown solid, which was recrystallized from EtOH and then subjected to flash chromatography to afford *α,α*-diacetoxy-9-methylanthracene (**5b**) as yellow crystals (0.73 g, 49%): mp 197–198 °C (Lit.[16] mp 199–200 °C); ^1H NMR δ 2.15 (s, 6 H), 7.50 (t, 2 H, H_3), 7.58 (t, 2 H, H_2), 8.00 (d, J = 8.3 Hz, 2 H, H_4), 8.52 (s, 1 H, H_{10}), 8.68 (d, J = 7.9 Hz, 2 H, H_1), 9.21 (s, 1 H, H_α) (the singlets were assigned by comparison with the spectrum of the corresponding deuterated acylal).

***α,α*-Diacetoxy-9-methylphenanthrene (6b).** 9-Phenanthraldehyde (0.5 g, 2.42 mmol) was substituted for **3a** in the geneal procedure, with amounts of other reagents scaled appropriately. Reaction was carried out for 96 h at reflux. The usual workup afforded *α,α*-diacetoxy-9-methylphenanthrene (**6b**) (0.45 g, 58%) as a light tan solid, mp 102–104 °C. Flash chromatography afforded an off-white solid: mp 104–105 °C; ^1H NMR δ 2.15 (s, 6 H), 7.58–7.74 (m, 4 H), 7.90 (d, 1 H, H), 7.98 (s, 1 H, H), 8.25 (s, 1 H, H), 8.29 (d, 1 H, H), 8.66 (d, 1 H, H), 8.73 (d, 1 H, H). Anal. Calcd for $C_{19}H_{16}O_4$: C, 74.01; H, 5.23. Found: C, 74.30, H, 5.43.

***α,α*-Diacetoxy-1-methylpyrene (7b).** 1-Formylpyrene[17] (0.5 g, 2.17 mmol) was substituted for **3a** in the general procedure, with amounts of other reagents scaled appropriately. The reaction was carried out for 10 days. The crude product was a brown granular material. Flash chromatography afforded *α,α*-diacetoxy-1-methylpyrene (**7b**) as yellow crystals, 0.52 g, 72%, mp 147–149 °C: ^1H NMR δ 2.15 (s, 6 H), 8.01–8.12 (m, 3 H), 8.17–8.24 (m, 5 H), 8.53 (d, 1 H, H), 8.55 (s, 1 H, H). Anal. Calcd for $C_{21}H_{16}O_4$: C, 75.89; H, 4.85. Found: C, 75.71, H, 4.99.

General Procedure for Synthesis of Deuterated Aldehydes (ArC*D*O). The same procedure was used for synthesis of *α-deuterio*-**3a**, *α-deuterio*-**4a**, and *α-deuterio*-**6a**. Details are given only for the first of these compounds. 1-Naphthoic acid (1.0 g, 5.8 mmol) and $SOCl_2$ (1 mL, 13.7 mmol) were refluxed for 1 h in 25 mL of dry benzene and then stirred overnight at room temperature (caution: with 9-anthroic acid, the mixture had to be protected from light to prevent photodimerization[18]). The

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[13] (a) Luche, J.-L.; Gemal, A. L. *Chem. Commun.* **1978**, 976. (b) Luche, J.-L.; Gemal, A. L. *J. Am. Chem. Soc.* **1979**, *101*, 5848. (c) Gemal, A. L.; Luche, J.-L. *Tetrahedron Lett.* **1981**, *22*, 4077. (c) Maruoka, K.; Nagahara, S.; Yamamoto, H. *Tetrahedron Lett.* **1990**, *31*, 5475.

[14] Benzaldehyde: Mann, C. K.; Barnes, K. K. *Electrochemical Reactions in Nonaqueous Systems*; Dekker: New York, 1970; p 184. Acetic anhydride: ref 6, p 96.

[15] Maki, A. H.; Geske, D. H. *J. Am. Chem. Soc.* **1961**, *83*, 1852.

[16] Rio, G.; Sillion, B. *Compt. Rend.* **1957**, *244*, 623.

[17] Vollmann, H.; Becker, H.; Corell, M.; Streeck, H. *Leibigs Ann. Chem.* **1937**, *531*, 107.

[18] Turro, N. *Modern Molecular Photochemistry*; Benjamin/Cummings: Menlo Park, CA, 1978; p 457.

volatile components were then removed by distillation. *N,O*-Dimethylhydroxylamine hydrochloride (0.62 g, 6.4 mmol) was added, and the resulting mixture was dissolved in 40 mL of CH_2Cl_2. The purple solution was cooled to 0 °C and pyridine (1.04 mL, 12.9 mmol) was added, upon which the mixture changed to a light orange color. The mixture was stirred overnight and evaporated in vacuo. The residue was partitioned between brine and a 1:1 mixture of Et_2O and CH_2Cl_2, washed with 5% HCl, dried over Na_2SO_4, and evaporated. The crude amide was dissolved in 30 mL of dry THF, 0.7 g of $LiAlD_4$ was added, and the solution was refluxed for 3 h. After stirring overnight, the mixture was quenched at 0 °C with 5% HCl and was extracted with a 1:1 mixture of Et_2O and CH_2Cl_2. The organic layer was dried over Na_2SO_4 and evaporated to afford *α-deuterio*-**3a** (0.46 g, 51%). The ^1H NMR spectrum of the acylal prepared from this material was identical with that of **3b** except for the absence of the singlet at δ 8.23.

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Chiral Synthesis via Organoboranes. 30. Facile Synthesis, by the Matteson Asymmetric Homologation Procedure, of α-Methyl Boronic Acids Not Available from Asymmetric Hydroboration and Their Conversion into the Corresponding Aldehydes, Ketones, Carboxylic Acids, and Amines of High Enantiomeric Purity

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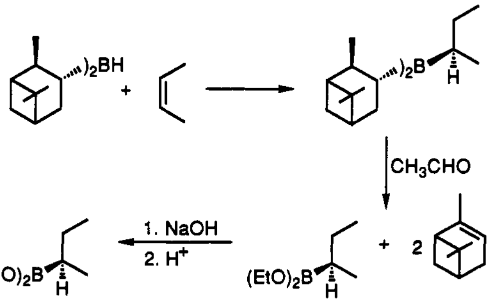
2-(α-Methylalkyl)- or 2-(α-arylethyl)-1,3,2-dioxaborinanes, $RMeHC^*BO_2(CH_2)_3$ (R = alkyl or aryl), of very high enantiomeric purity, not available from asymmetric hydroboration, can be prepared by the Matteson asymmetric homologation procedure of optically pure pinanediol or 2,3-butanediol boronate esters with (dichloromethyl)lithium, $LiCHCl_2$, conveniently generated in situ in THF at −78 °C, followed by reaction with either a Grignard reagent or an alkyllithium, with subsequent removal of the chiral auxiliaries. α-Methyl boronic esters thus obtained are readily converted into the corresponding aldehydes by the reaction with [methoxy(phenylthio)methyl]lithium [LiCH(OMe)SPh] (MPML) and mercuric chloride, followed by oxidation with hydrogen peroxide in a pH 8 buffer medium. The two-phase aqueous chromic acid procedure can be used to oxidize these aldehydes to the corresponding α-methyl carboxylic acids of very high enantiomeric purity without significant racemization. Additionally, pinanediol or 2,3-butanediol α-methylorganylboronate esters can be conveniently converted into borinic ester derivatives, RMeHC*BMe(OMe), of very high enantiomeric purity by reaction with methyllithium, followed by treatment with methanolic hydrogen chloride and subsequent recovery of the valuable chiral auxiliaries. These borinic ester derivatives are converted into α-methyl ketones and α-methyl primary amines of known absolute configuration by the α,α-dichloromethyl methyl ether (DCME) reaction and the reaction with hydroxylamine-*O*-sulfonic acid, respectively. The present synthesis of chiral 2-organyl-1,3,2-dioxaborinanes by the Matteson route, together with our direct asymmetric hydroboration procedure, makes it possible to synthesize many chiral boronic acid derivatives in very high enantiomeric purities. These complementary procedures greatly expand the scope of asymmetric synthesis via chiral organoboranes.

The synthesis of enantiomerically pure compounds has always presented a considerable challenge to organic chemists. Recently intense interest has been aroused in the development of efficient methods for asymmetric synthesis.[1] Of these procedures, asymmetric hydroboration is especially promising for providing a general synthesis of pure enantiomers.[2] For example, diisopinocampheylborane (Ipc_2BH) hydroborates *cis*-alkenes, resulting in asymmetric induction in the range of 80–99% ee.[3] Similarly, monoisopinocampheylborane ($IpcBH_2$) hydroborates *trans*-alkenes and trisubstituted alkenes with optical inductions ranging from 53% to 98% ee.[4] It was later established in our laboratory[5] that the treatment with acetaldehyde of the trialkylborane derived via the asymmetric hydroboration of prochiral olefin with Ipc_2BH resulted in the selective, facile elimination of the pinanyl groups, providing the corresponding boronic ester in very high enantiomeric purity (Scheme I). Such chiral boronic esters and acids are exceptionally promising intermediates

Scheme I



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(1) *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: New York, 1983; Vol. 2.

(2) Brown, H. C.; Jadhav, P. K.; Mandal, A. K. *Tetrahedron* **1981**, *37*, 3547.

0022-3263/91/1956-3286$02.50/0