trideoxy-β-D-*ribo*-hexopyranoside (**6**)[7] in 88% yield. If, however, the reaction mixture containing the triflate was allowed to stand at room temperature without bromide addition, the triflate **5** rearranged completely to a new compound in 4 h. The new compound was stable only in solution in the presence of the hindered base **4** under anhydrous conditions. Even under these conditions it showed evidence of decomposition after 8 h (purple color began to develop) and had polymerized after 24 h; nevertheless, it was possible to obtain $^1H$ and $^{13}C$ NMR spectra on this unstable material.[7] These spectra had several revealing features. In the $^{13}C$ NMR spectrum there was no signal for a carbonyl carbon, and those for C-3 and C-4 were unusually far downfield (δ 87.57 and 85.92). In the $^1H$ NMR spectrum H-3 and H-4 also were quite far downfield (δ 6.35 and 5.88, respectively). The coupling constants for H-3 indicated that the C-3 configuration was not the same as in the triflate **5**. These NMR spectra indicated that the unstable rearrangement product was compound **7**. Confirmation of this structure was made by chemical reaction. First, reaction of **7** with tetrabutylammonium bromide occurred with inversion of configuration at C-3 to give methyl 4-*O*-benzoyl-3-bromo-2,3,6-trideoxy-β-D-*arabino*-hexopyranoside (**8**), a product of double inversion at C-3. Second, water was added to a solution of **7** in anticipation that it would react directly with the cation produced by ionization of the triflate. The product from this reaction was methyl 3-*O*-benzoyl-2,6-dideoxy-β-D-*ribo*-hexopyranoside (**9**), the expected product from ring opening of the ortho acid 10.[8-10] These chemical reactions confirmed the structure suggested by the NMR spectra.

There are a number of questions about the formation and reactions of compound **7** which are of interest. From a synthetic point of view, the most important of these concerns the manner in which nucleophiles other than bromide react with **7**. If other nucleophiles react to give good yields of substitution products, a second question of interest relates to the generality of formation of compounds such as **7**. While a considerable amount of study will be needed to answer these questions, two experiments were conducted to provide some preliminary information. First, compound **7** was reacted with tetrabutylammonium nitrate to give methyl 4-*O*-benzoyl-2,6-dideoxy-3-*O*-nitro-β-D-*arabino*-hexopyranoside (**11**); thus, displacement with an oxygen nucleophile can occur. Second, methyl 3-*O*-benzoyl-2,6-dideoxy-β-D-*lyxo*-hexopyranoside (**12**) was treated with triflic anhydride, allowed to stand for 4 h, and then reacted with water to give methyl 4-*O*-benzoyl-2,6-dideoxy-β-D-*ribo*-hexopyranoside (**13**). The formation of compound **13** suggests that another, although quite similar, hydroxybenzoate experiences the same type of reaction as **3**.

**Acknowledgment.** We appreciate the financial support for this work by the Standard Oil Company (Ohio).

(7) Characterizing data for new compounds is given as follows. Compound number: melting point; $^1H$ and $^{13}C$ NMR data ($CDCl_3$). Compounds **3**, **6**, **8**, **9**, and **11** were analyzed and gave satisfactory analysis. Compound **3**: mp 54–57 °C; $^1H$ NMR δ 1.30 (d, H-6, $J_{5,6}$ = 6.2 Hz), 1.73 (ddd, H-2$_a$, $J_{1,2a}$ = 9.5 Hz, $J_{2a,2e}$ = 12.7 Hz, $J_{2a,3}$ = 11.7 Hz), 2.34 (ddd, H-2$_e$, $J_{1,2e}$ = 2.1 Hz, $J_{2e,3}$ = 5.2), 3.51 (s, $OCH_3$), 4.05–3.48 (m, H-3, H-5), 4.46 (dd, H-1), 4.74 (dd, H-4, $J_{3,4}$ = $J_{4,5}$ = 9.1 Hz), 7.43–7.55 and 7.98–8.10 (m, Ar); $^{13}C$ NMR δ 17.80 (C-6), 39.36 (C-2), 56.42 (OMe), 69.84, 69.99 (C-3, C-5), 79.04 (C-4), 100.59 (C-1), 128.43, 129.03, 129.78, 133.32 (Ar), 166.85 (C=O). Compound **5**: $^1H$ NMR δ 1.30 (H-6, d, $J_{5,6}$ = 6.3 Hz), 1.88–2.07 (m, H-2$_a$, 2.55 (ddd, H-2$_e$, $J_{2,2}$ = 12.6 Hz, $J_{2e,1}$ = 2.0 Hz, $J_{2e,3}$ = 4.8 Hz), 3.51 (s, $OCH_3$), 3.80 (dq, $J_{4,5}$ = 9.0 Hz), 4.52 (dd, H-1, $J_{1,2a}$ = 9.5 Hz), 5.01–5.21 (H-3, H-4), 7.43–7.54 and 7.99–8.10 (Ar); $^{13}C$ NMR δ 17.59 (C-6), 37.70 (C-2), 56.87 ($OCH_3$), 69.96 (C-5), 73.53 (C-4), 84.44 (C-3), 99.53 (C-1), 128.55, 129.67, 129.87, 133.67 (Ar). Resonances from the base **4** were also present. Compound **6**: liquid; $^1H$ NMR δ 1.33 (d, H-6, $J_{5,6}$ = 6.2 Hz), 1.85–2.60 (m, H-2$_a$, H-2$_e$), 3.51 (s, $OCH_3$), 4.21 (dt, H-5, $J_{4,5}$ = 8.6 Hz), 4.67 (dd, H-4, $J_{3,4}$ = 3.4 Hz, $J_{4,5}$ = 8.7 Hz), 4.80–4.89 (m, H-3), 4.92 (dd, H-1, $J_{1,2}$ = 3.5 Hz, $J_{1,2e}$ = 7.7 Hz), 7.42–7.54 and 8.00–8.12 (Ar); $^{13}C$ NMR δ 17.69 (C-6), 38.85 (C-2), 50.16 (C-3), 56.51 ($OCH_3$), 69.07 (C-5), 73.25 (C-4), 99.08 (C-1), 128.52, 129.53, 129.85, 133.46 (Ar), 165.50 (C=O). Compound **7**: $^1H$ NMR δ 1.28 (d, H-6, $J_{5,6}$ = 7.1 Hz), 2.29–2.61 (m, H-2a), 2.93 (ddd, H-2e, $J_{2a,2e}$ = 16.9 Hz, $J_{2e,3}$ = 4.3 Hz, $J_{2e,1}$ = 4.6 Hz), 3.40 (s, 3 H, $OCH_3$), 4.33 (dt, H-5, $J_{4,5}$ = 8.6 Hz), 4.86 (dd, H-1, $J_{1,2e}$ = 5.2 Hz), 5.88 (dd, H-4, $J_{3,4}$ = 4.3 Hz), 6.35 (ddd, H-3, $J_{2,3a}$ = 4.3 Hz), 7.44–8.32 (m, Ar); $^{13}C$ NMR δ 18.64 (C-6), 37.00 (C-2), 55.57 ($OCH_3$), 68.42 (C-5), 85.92, 87.57 (C-3, C-4), 96.06 (C-1), 129.89 ($PhCO_3$) 130.21, 134.00, 141.17 (Ar). Resonances from the base **4** also were present. Compound **8**: mp 119 °C; $^1H$ NMR δ 1.29 (d, H-6, $J_{5,6}$ = 6.3 Hz), 2.20 (ddd, H-2$_a$, $J_{2a,2e}$ = 12.9 Hz, $J_{2a,1}$ = $J_{2a,3}$ = 9.3 Hz), 2.61 (ddd, H-2$_e$, $J_{2e,1}$ = 2.1 Hz, $J_{2e,3}$ = 5.1 Hz), 3.51 (s, $OCH_3$), 3.59 (dt, H-5, $J_{4,5}$ = 9.6 Hz), 4.16 (ddd, H-3, $J_{3,4}$ = 9.6 Hz), 4.44 (dd, H-1), 5.10 (dd, H-4), 7.43–7.55 and 8.00–8.12 (Ar); $^{13}C$ NMR: δ 18.11 (C-6), 41.93 (C-2), 46.58 (C-3), 56.64 ($OCH_3$), 72.29 (C-5), 77.06 (C-4), 101.13 (C-1), 128.48, 129.84, 133.36 (Ar), 166.00 (C=O). Compound **9**: mp 97–98 °C; $^1H$ NMR δ 1.35 (d, H-6, $J_{5,6}$ = 6.2 Hz), 1.82 (ddd, H-2$_a$, $J_{1,2a}$ = 9.3 Hz, $J_{2a,2e}$ = 14.4 Hz, $J_{2a,3}$ = 2.9 Hz), 2.10 (ddd, H-2$_e$, $J_{1,2e}$ = 2.2 Hz, $J_{2e,3}$ = 3.0 Hz), 3.45 (H-4), 3.86 (dq, H-5, $J_{4,5}$ = 9.1 Hz), 4.65 (dd, H-1), 5.49 (ddd, H-3, $J_{3,4}$ = 2.7 Hz) 7.40–7.57 and 7.96–8.08 (m, Ar); $^{13}C$ NMR: δ 18.23 (C-6), 35.83 (C-2), 56.25 (OMe), 70.65, 71.59, 72.25 (C-3, C-4, C-5), 99.09 (C-1), 128.50, 129.00, 130.16, 133.25 (Ar), 166.33 (C=O). Compound **11**: mp 132–134 °C; $^1H$ NMR δ 1.32 (d, H-6, $J_{5,6}$ = 6.2 Hz), 1.65–2.03 (m, H-2$_a$), 2.51 (ddd, H-2$_e$, $J_{2a,2e}$ = 11.7 Hz, $J_{2e,1}$ = 2.0 Hz, $J_{2e,3}$ = 5.0 Hz) 3.53 (s, $OCH_3$), 3.69 (dt, H-5, $J_{4,5}$ = 9.4 Hz), 4.58 (dd, H-1, $J_{1,2a}$ = 2.0 Hz), 5.03 (dd, H-4, $J_{3,4}$ = 9.4 Hz), 5.33 (ddd, H-3), 7.43–7.55 and 7.94–8.06 (m, Ar); $^{13}C$ NMR: δ 17.69 (C-6), 35.49 (C-2), 56.78 ($OCH_3$), 70.44 (C-5), 72.75 (C-3), 79.46 (C-4), 99.97 (C-1), 128.59, 129.10, 129.79, 133.60 (Ar), 165.32 (C=O).

(8) King, J. F.; Allbutt, A. D. *Can. J. Chem.* **1969**, *47*, 1445; **1970**, *48* 1754.

(9) (a) Deslongchamps. P.: Atlani, P.; Frehel, D.; Malaval, A. *Can. J. Chem.* **1972**, *50*, 3405. (b) Deslongchamps, P.; Moreau, C.; Frehel, D.; Chenevert, R. *Ibid.* **1975**, *53*, 1204.

(10) Benzoxonium ions similar to those generated by the Hanessian–Hullar reaction (compound **2**, Scheme I) and by triflate ionization (compound **7a**, Scheme II) are believed to be intermediates in a number of reactions involving carbohydrates. For a recent review of the formation and reactions of many of these ions, see: Gelas, J. *Adv. Carbohydr. Chem. Biochem.* **1981**, *39*, 71.

**Roger W. Binkley,* Matthew R. Sivik**
*Department of Chemistry*
*Cleveland State University*
*Cleveland, Ohio 44115*
*Received February 3, 1986*

## A Total Synthesis of (−)-Sesbanimide A

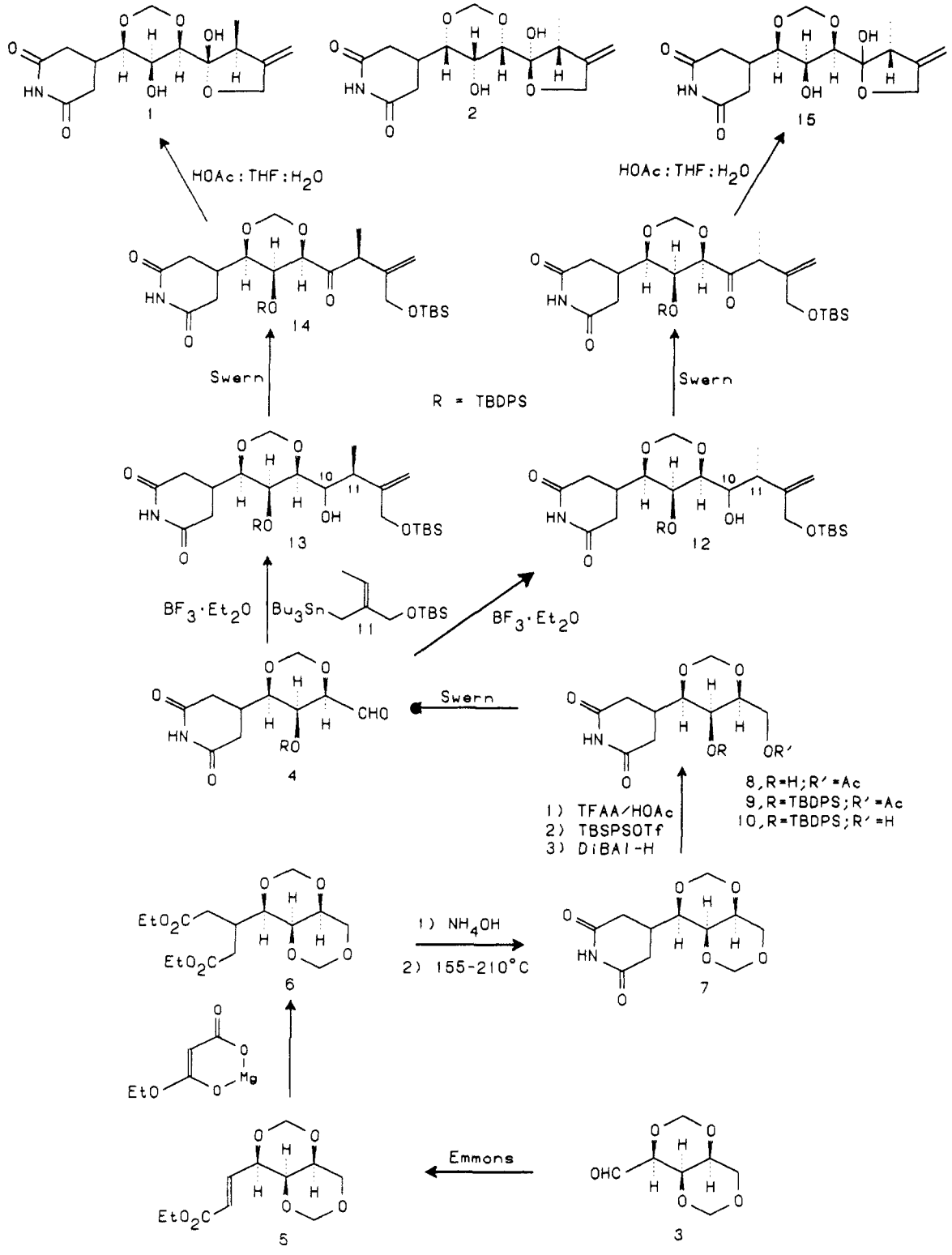
*Summary:* The molecule (−)-sesbanimide A (**1**), the optical antipode of the potent cytotoxic natural product (+)-sesbanimide A (**2**), has been prepared starting from the aldehyde **3** via a brief and efficient reaction pathway.

*Sir:* Herein, we wish to report a brief and efficient total synthesis of (−)-sesbanimide A (**1**), a molecule which is the optical antipode of the potent cytotoxic natural product (+)-sesbanimide A (**2**).[1] The stereochemistry depicted for

(1) (a) For the original report on the isolation and structural determination (X-ray) of (+)-sesbanimide A from the seed of *Sesbania drummondii*, see: Powell, R. G.; Smith, C. R., Jr.; Weisleder, D.; Matsumoto, G. K.; Clardy, J.; Kozlowski, J. *J. Am. Chem. Soc.* **1983**, *105*, 3739. (b) For the isolation and structural characterization (NMR) of (+)-sesbanimide A from *Sesbania punicea*, see: Gorst-Allman, C. P.; Steyn, P. S.; Vleggaar, R.; Grobelaar, N. *J. Chem. Soc., Perkin Trans 1* **1984**, 1311. (c) For complete NMR data on (+)-sesbanimide A together with the characterization of sesbanimide B and sesbanimide C, see: Powell, R. G.; Smith, C. R., Jr.; Weisleder, D. *Phytochemistry* **1984**, *23*, 2789. (d) After this manuscript had been submitted for publication, a report of a total synthesis of (−)-sesbanimide A was reported by: Wanner, M. J.; Willard, N. P.; Koomen, G.-J.; Pandit, U. K. *J. Chem. Soc., Chem. Commun.* **1986**, 396. This synthesis and that described herein, while similar in strategy, differ notably in their overall length and efficiency.

0022-3263/86/1951-2621$01.50/0 

**Scheme I**




(+)-sesbanimide A prompted us to commence our synthetic exercise[2] starting from the known aldehyde **3**, a substance readily available from D-(−)-sorbitol.[3] The synthesis proceeds by elaboration of **3** into compound **4**, the second aldehyde encountered in the reaction sequence (see Scheme I). An expeditious conclusion to the synthesis was fashioned via stannyl mediated addition of a $C_5$ unit onto **4**.

(2) For approaches to the A–B ring system of sesbanimide A, see: (a) Tomioka, K.; Koga, K. *Tetrahedron Lett.* **1984**, *25*, 1599. (b) Fleet, G. W. J.; Shing, T. K. M. *J. Chem. Soc., Chem. Commun.* **1984**, 835. (c) Wanner, M. J.; Koomen, G.-J.; Pandit, U. K. *Heterocycles* **1984**, *22*, 1483. (d) Shibuya, M. *Heterocycles* **1985** *23*, 61. (e) Matsuda, F.; Kawasaki, M.; Terashima, S. *Tetrahedron Lett.* **1985**, *26*, 4639. (f) Sacripante, G.; Tan, C.; Just, G. *Tetrahedron Lett.* **1985**, *26*, 5643.

(3) (a) For the preparation of **3**, see: Ness, A. T.; Hann, R. M.; Hudson, C. S. *J. Am. Chem. Soc.* **1944**, *66*, 665. (b) Bourne, E. J.; Wiggins, L. F. *J. Chem. Soc.* **1944**, 517. The use of continuous extraction techniques allows for a considerably higher overall yield in the preparation of **3** from D-(−)-sorbitol.

Freshly sublimed **3**,[3] reacted with the sodium salt of diisopropyl (carboethoxy)methylphosphonate [$(i\text{-}C_3H_7O)_2POCH_2CO_2CH_2CH_3$], gave (87% yield) the unsaturated ester **5**, mp 135–137 °C, $[\alpha]_D$ −10.8° (*c* 1.96, $CHCl_3$).[4] On treatment with magnesium monoethyl malonate,[5] **5** was smoothly converted (77% yield) into the diester **6**, mp 48–49 °C, $[\alpha]_D$ −9.5° (*c* 0.71, $CHCl_3$). The required imide ring was then readily introduced by reaction of diester **6** with ammonium hydroxide (50 °C, 24 h) followed by removal of the solvent and pyrolysis (155 °C, 35 min; 210 °C, 15 min)[6] to give (68% yield) the imide **7**, mp 261–262 °C, $[\alpha]_D$ −34.4° (*c* 0.64, $H_2O$).

We then turned our attention to selective hydrolysis of that acetal ring derived from a combination of primary and secondary alcohols. This was carried out by reacting **7** with a mixture of trifluoroacetic anhydride (TFAA, 3.0 equiv) and acetic acid (3.0 equiv) at 22 °C for 6 h.[7] After addition of saturated sodium bicarbonate and stirring and adjusting the pH of the reaction mixture to 6.5, the primary acetate **8** (87% yield) could be isolated, mp 188–189 °C, $[\alpha]_D$ −13.0° (*c* 1.44, $H_2O$). The secondary hydroxyl group of **8** was then protected with *tert*-butyldiphenylsilyl triflate, (TBDPSOTf, 4.0 equiv)[8] in $CH_2Cl_2$ solution containing 2,6-lutidine (5.0 equiv) to afford (100% yield) compound **9**, mp 181–182 °C, $[\alpha]_D$ +7.3° (*c* 1.01, $CHCl_3$). Reduction of the primary acetate residue of **9** with diisobutylaluminum hydride (1.0 equiv of DiBAl-H, −78 °C, THF, 5 min; then 3.0 equiv of additional DiBAl-H, −78 to 0 °C, 2 h) gave (97% yield) the corresponding alcohol **10**, mp 144–145 °C, $[\alpha]_D$ +7.8° (*c* 1.02, $CHCl_3$), without competing reduction of the imide residue. Finally, Swern oxidation[9] of **10** gave (97% crude yield) the aldehyde **4**.[10]

At this juncture, it was our intention to add the readily fabricated crotylstannane derivative **11**[11] to the aldehyde **4** in the presence of a Lewis acid.[12] To this end, we treated a $CH_2Cl_2$ solution of **4** containing magnesium bromide etherate (2.0 equiv) with the stannane **11** (2.0 equiv) at −78 °C followed by warming to −40 °C and stirring for 48 h. Much to our disappointment, this reaction gave a 4:1 mixture (83% yield) of compounds **12** and **13**, respectively. These substances were identified as epimers about the C-11 carbon atom; the major constituent, **12**, being the unwanted $\alpha$-methyl isomer.[13]

After an exhaustive examination of the effect of various Lewis acids on the stereochemistry of this reaction, it was found that an acceptable yield of the desired $\beta$-methyl epimer at C-11 was obtained with borontrifluoride etherate ($BF_3{\cdot}Et_2O$). Thus, to a mixture of **4** (1.0 equiv) and **11** (2.0 equiv) in $CH_2Cl_2$ (0.1 M) at −78 °C was added $BF_3{\cdot}Et_2O$ (1.5 equiv, −78 °C, 5.5 h). Hydrolysis of this reaction at −78 °C with saturated aqueous $NaHCO_3$ gave (51% yield) the C-11 $\beta$-methyl compound **13** (mixture of alcohol epimers at C-10) together with (32% yield) its $\alpha$-methyl isomer, compound **12** (single alcohol epimer at C-10). These substances, **13** and **12**, were readily separated by chromatography and independently carried forward.[14]

Swern oxidation of **13** (C-10 alcohol epimers) gave (63% yield, 89% yield based on recovered **13**) a single ketone **14**, mp 73–76 °C, $[\alpha]_D$ +73.4° (*c* 1.40, $CHCl_3$), which on treatment with a 3:1:1 mixture of HOAc–THF–$H_2O$ (22 °C, 4.3 h)[15] afforded (100% yield) compound **1**, as a white solid from $CH_2Cl_2/Et_2O$, mp 154.5–155.5 °C, $[\alpha]_D$ −56.9° (*c* 0.21, $CHCl_3$) and $[\alpha]_D$ +6.0° (*c* 0.27, $CH_3OH$). Naturally occuring sesbanimide A (compound **2**), as obtained from Dr. R. G. Powell (USDA), mp 154.5–156 °C, exhibited the following optical rotations: $[\alpha]_D$ +52.6° (*c* 0.26, $CHCl_3$) and $[\alpha]_D$ −6.3° (*c* 0.32, $CH_3OH$).[16] The same two-step sequence carried out on **12** gave (89% overall yield) **15**, as white amorphous solid, mp 78–86 °C, $[\alpha]_D$ +15.7° (*c* 2.68, $CHCl_3$).[17] The synthetic sequence to (−)-sesbanimide A (**1**) requires 10 steps from the known aldehyde **3**[18] and occurs in an overall yield of 12% (17% based on recovered starting material, Swern oxidation **13** to **14**).

**Acknowledgment.** Financial support from the NIH and the Merck Corp. are gratefully acknowledged.

(4) Satisfactory spectral ($^1H$, $^{13}C$, IR, MS, and HRMS) and physical data were collected, except in cases of instability, for all new compounds.
(5) McMurry, J. E.; Andrus, W. A.; Musser, J. H. *Synth. Commun.* **1978**, *8*, 53.
(6) Bailey, A. S.; Robinson, R. *J. Chem. Soc.* **1950**, 1375.
(7) Bourne, E. J.; Burdon, J.; Tatlow, J. C. *J. Chem. Soc.* **1959**, 1864.
(8) (a) Riediker, M.; Graf, W. *Helv. Chim. Acta* **1979**, *62*, 205. (b) Corey, E. J.; Cho, H.; Rucker, C.; Hua, D. H. *Tetrahedron Lett.* **1981**, *22*, 3455.
(9) Mancuso, A. J.; Huang, S.-L.; Swern, D. *J. Org. Chem.* **1978**, *43*, 2480.
(10) The crude aldehyde formed in this reaction was quite pure, as determined by $^1H$ NMR. However, this substance decomposed on chromatography, and, hence, its optical rotation was not measured.
(11) The preparation of **11** requires three steps starting from methyl-2-methylene-3-acetoxybutyrate, a substance described, as its ethyl ester analogue, by: Drewes, S. E.; Emslie, N. D. *J. Chem. Soc., Perkin Trans 1* **1982**, 2079. These steps are: (a) treatment of the ester with $Bu_3SnCu{\cdot}DMS{\cdot}LiBr$ (1.2 equiv); (b) reduction of the ester residue with DiBAl-H (2.5 equiv, −78 °C); (c) protection of the alcohol residue with TBSCl.
(12) For pertinent references see: (a) Yamamoto, Y.; Yatagai, H.; Naruta, Y.; Maruyama, K. *J. Am. Chem. Soc.* **1980**, *102*, 7107. (b) Keck, G. E.; Abbott, D. E.; Boden, E. P.; Enholm, E. J. *Tetrahedron Lett.* **1984**, *25*, 3927 and references cited therein. (c) Trost, B. M.; Bonk, P. J. *J. Am. Chem. Soc.* **1985**, *107*, 1778.
(13) The ultimate proof for the structures assigned to compounds **12** and **13** came not from their NMR spectra but rather from their two-step conversion into sesbanimide B and sesbanimide A, respectively.
(14) The major and minor C-10 alcohol epimers of **13** could be separated upon additional chromatography, although this was not usually done. Physical characteristics for these compounds are: major isomer, mp 182–188 °C; $[\alpha]_D$ +29.4° (*c* 2.57, $CHCl_3$); minor isomer, mp 53–58 °C; $[\alpha]_D$ −5.8° (*c* 0.80, $CHCl_3$).
(15) Corey, E. J.; Venkateswarlu, A. *J. Am. Chem. Soc.* **1972**, *94*, 6190.
(16) We thank Dr. R. G. Powell (USDA) for a generous sample of (+)-sesbanimide A.
(17) Compound **15**, according to its $^1H$ and $^{13}C$ spectra, is sesbanimide B as described in ref 1c.
(18) The optical antipode of **3** is an unknown compound. We are currently working on a short synthesis of this substance starting from D-(+)-xylose.

**R. H. Schlessinger,* J. L. Wood**
*Department of Chemistry*
*University of Rochester*
*Rochester, New York 14627*
*Received February 20, 1986*

## Mercury in Organic Chemistry. 33. A Convenient Synthesis of Allenic and Propargylic Ketones via Acylation of Propargylic and Allenic Organomercurials, Respectively[1]

*Summary:* The low-temperature reaction of carboxylic acid chlorides, aluminum halides, and propargylic and allenic organomercurials affords the corresponding rearranged allenic and propargylic ketones, respectively, in high yields. The propargylic ketones rearrange smoothly to the corresponding allenic ketones when passed through a column of aluminum oxide.

(1) For "Mercury in Organic Chemistry. 32. Bromination and Iodination of Allenic and Propargylic Organomercurials: A Convenient Synthesis of 3-Halo-1,2-alkadienes", see: Larock, R. C.; Chow, M. S. *Organometallics* **1986**, *5*, 603.

0022-3263/86/1951-2623$01.50/0 