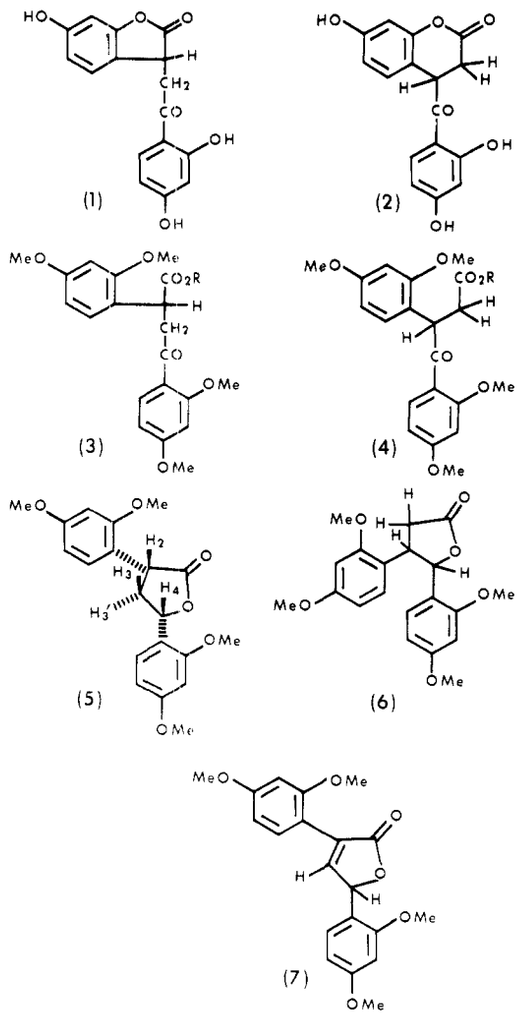

Figure 1.

the cis configuration, as determined for related δ-butyrolactones.[6]

The precursor of the latter is thus the acid **3**, R = H, which on heating under reflux in acetic anhydride gave the dehydro derivative of the lactone **5**, namely 2,4-bis(2′,4′-dimethoxyphenyl)but-2-en-4-olide (**7**). The infrared spectrum of the latter showed the expected α,β-unsaturated lactone carbonyl band at 1750 cm^{-1}, while the NMR spectrum exhibited doublets due to the H_3 and H_4 protons at δ 7.87 and 6.33 (J = 2 Hz),[7] respectively.

The synthesis of the lactones **5** and **7** via the acid **3**, R = H, and its corresponding ester **3**, R = Me, from the resorcinol–maleic anhydride condensation product therefore unequivocally establishes the structure of the latter as 3-(2′,4′-dihydroxybenzoylmethyl)-6-hydroxybenzofuran-2-one (**1**).

Experimental Section[8]

Melting points are uncorrected. The ^1H NMR spectra were obtained with a Varian HA-100 spectrometer in $CDCl_3$ solution. Infrared spectra were recorded with a Perkin-Elmer Model 237B spectrophotometer in $CHCl_3$ solution.

Methyl 2,4-Bis(2′,4′-dimethoxyphenyl)-4-oxobutyrate Oxime. The ester **3**, R = Me (0.5 g), hydroxylamine hydrochloride (1.0 g), and NaOAc (1.0 g) were heated together at 100 °C in 50% aq EtOH (40 mL) for 1 h. The mixture was poured into H_2O and the precipitated solid was filtered off and recrystallized from aqueous MeOH as white prisms: mp 139–141 °C; NMR δ 3.29 (dd, J = 14, 9 Hz, 1 H, CH_2), 3.52 (dd, J = 14, 6 Hz, 1 H, CH_2), 4.16 (dd, J = 9, 6 Hz, 1 H, CH), 3.55 (s, 3 H, OCH_3), 3.62 (s, 3 H, CO_2CH_3), 3.77 (s, 3 H, OCH_3), 3.78 (s, 6 H, 2 × OCH_3), 6.24–6.54 (m, 4 H, ArH), 6.76 (d, J = 8 Hz, 1 H, ArH), 7.05 (d, J = 8 Hz, 1 H, ArH). Anal. Calcd for $C_{21}H_{25}NO_7$: C, 62.5; H, 6.25; N, 3.47. Found: C, 62.6; H, 6.32; N, 3.44.

2,4-Bis(2′,4′-dimethoxyphenyl)-γ-butyrolactone (5). The acid **3**, R = H (1.5 g), in MeOH (100 mL) was treated with $NaBH_4$ (2.0 g), added in portions, and the solution was stirred at room temperature overnight. The mixture was poured into H_2O and the precipitated solid was filtered off, washed, air dried, and recrystallized from MeOH as white needles (0.6 g), mp 119–121 °C. The aqueous solution was extracted with Et_2O, acidified with dilute hydrochloric acid, and extracted with $CHCl_3$. The extract was washed, dried, and evaporated and the residue was recrystallized from MeOH to give a further quantity of the lactone (0.75 g): mp 119–121 °C; IR 1770 cm^{-1} (lactone C=O); NMR δ 2.30 (m, $J_{2,3\beta}$ = 12.5, $J_{3\beta,4}$ = 10.5, and $J_{3\alpha,3\beta}$ = 13.0 Hz, 1 H, H-3 β), 2.92 (m, $J_{2,3\alpha}$ = 9.0, $J_{3\alpha,4}$ = 6.0 Hz, and $J_{3\alpha,3\beta}$ = 13.0 Hz, 1 H, H-3α), 3.80 (s, 6 H, 2 × OMe), 3.82 (s, 6 H, 2 × OMe), 4.05 (q, $J_{2,3\alpha}$ = 9.0, $J_{2,3\beta}$ = 12.5 Hz, 1 H, H_2), 5.74 (q, $J_{3\alpha,4}$ = 6.0, $J_{3\beta,4}$ = 10.5 Hz, 1 H, H_4), 6.38–6.60 (m, 4 H, ArH), 7.11 (d, J = 9 Hz, 1 H, ArH), 7.42 (d, J = 8 Hz, 1 H, ArH); MS m/e 358 (M^+), 314 ($M - CO_2$). Anal. Calcd for $C_{20}H_{22}O_6$: C, 67.04; H, 6.15. Found: C, 67.1; H, 6.19.

2,4-Bis(2′,4′-dimethoxyphenyl)but-2-en-4-olide (7). The acid **3**, R = H (0.75 g), in Ac_2O (10 mL) was heated under reflux for 3 h[6] and the solution was allowed to cool and was poured into ice–water. The precipitate was filtered off, washed with H_2O, air dried, and recrystallized from Me_2CO–MeOH as pale yellow prisms: mp 150–151 °C (0.5 g); IR 1750 cm^{-1} (α,β-unsaturated lactone C=O); NMR δ 3.81 (s, 3 H, OMe), 3.84 (s, 6 H, 2 × OMe), 3.87 (s, 3 H, OMe), 6.32 (d, J = 2 Hz, 1 H, H_4), 6.38–6.63 (m, 4 H, ArH), 7.11 (d, J = 9 Hz, 1 H, ArH), 7.87 (d, J = 2 Hz, 1 H, H_3), 8.26 (d, J = 8 Hz, 1 H, ArH). Anal. Calcd for $C_{20}H_{20}O_6$: C, 67.40; H, 5.66. Found. C, 67.4; H, 5.63.

Acknowledgments. The author wishes to thank Dr. Leonard Jurd and Dr. Kenneth Stevens of this Laboratory for helpful discussions.

Registry No.—**1**, 15833-58-6; **3** (R = Me), 15833-60-0; **3** (R = Me) oxime, 66239-92-7; **3** (R = H), 66239-93-8; **5**, 66239-94-9; **7**, 66239-95-0; resorcinol, 108-46-3; maleic anhydride, 103-31-6.

References and Notes

(1) N. V. C. Rao, T. R. Seshadri and V. Venkateswarlu, *Proc. Indian Acad. Sci., Sect. A*, **26**, 299 (1947).
(2) Y. Graff, J. Calando, and M. Gardin, *Bull. Soc. Chim. Fr.*, 1106 (1961).
(3) C. W. Bird and P. Molton, *Tetrahedron*, **23**, 4117 (1967).
(4) R. J. Molyneux and L. Jurd, *Aust. J. Chem.*, **27**, 2697 (1974).
(5) G. P. Rice, *J. Am. Chem. Soc.*, **53**, 3153 (1931).
(6) S. A. M. T. Hussain, W. D. Ollis, C. Smith, and J. F. Stoddart, *J. Chem. Soc., Perkin Trans. 1*, 1480 (1975).
(7) E. Yoshisato, M. Ryang, and S. Tsutsumi, *J. Org. Chem.*, **34**, 1500 (1969).
(8) References to a company and/or product named by the Department is only for purposes of information and does not imply approval or recommendation of the product to the exclusion of others which may also be suitable.

Facile Reaction of Alcohols and Phenols with Borane–Methyl Sulfide. A New, General, and Convenient Synthesis of Borate Esters

Charles Allan Brown* and S. Krishnamurthy

Department of Molecular and Chemical Dynamics K34-281, IBM Research Laboratory, San Jose, California 95193

Received September 27, 1977

In our exploratory studies involving the synthesis and reduction characteristics of alkoxyborohydrides,[1] we required a simple and direct route to alkyl and aryl borates of varying structures, applicable to preparation of fractional molar quantities.

Existing routes of borate esters[2] can be broadly classified into three types: (1) direct esterification of boric acid or anhydride with azeotropic distillation of water; (2) transesterification with a low boiling borate (usually methyl or ethyl borate); and (3) reaction of sodium borohydride with acetic acid in the presence of excess alcohol (eq 1).

$$NaBH_4 + CH_3COOH + ROH \text{ (excess)} \rightarrow CH_3COONa + B(OR)_3 + 4H_2\uparrow \quad (1)$$

0022-3263/78/1943-2731$01.00/0

Table I. Synthesis of Borate Esters by the Reaction of Alcohols and Phenols with Borane–Methyl Sulfide

Registry no.	Borate	Procedure	Isolated yield, %	Bp, °C (mm)	Mp, °C	n_D^{20}	^{11}B NMR (ppm)[a,b]
2467-15-4	*n*-Dodecyl	A	99			1.4470	+17.8
22238-17-1	*sec*-Butyl	B	91[c]	85 (14)		1.3951	+17.4
5419-55-6	Isopropyl	B	83[c]	60 (12)		1.3868	
22238-21-7	3-Pentyl	B	90[c]	85–87 (2)		1.4100	
40589-09-1	3-Methyl-2-butyl	B	82[c]	82–83 (2)		1.4068	
2467-16-5	Cyclohexyl	C	86[c]	145–150 (0.4)	58–60		
21105-05-5	*l*-Menthyl	C	81[c]		155–158		+17.9
7397-43-5	*tert*-Butyl	B	83[c]	60 (12)		1.3872	+15.3
22238-22-8	*tert*-Amyl	B	87[c]	85 (6)		1.4110	
1095-03-0	Phenyl	C	84[c]	172 (0.35)	98–100		

[a] For a new sign convention in ^{11}B NMR spectroscopy, see *J. Organomet. Chem.*, **131**, C43 (1977). [b] F. H. Davis, I. J. Terchi, and D. N. Gheeley, *J. Org. Chem.*, **36**, 1300 (1971). [c] Yield after distillation or recrystallization from suitable solvent systems.

Each of these methods possesses certain drawbacks such as the need for careful fractional distillation and/or excess alcohol, contamination of the products with inorganic materials, moderate yields, etc. These problems become especially significant in preparation of borate esters which are solids or high boiling liquids[3] or in which the alcohol component is expensive.

Accordingly, the development of a general procedure for the synthesis of borate esters appeared highly desirable. Recently, borane–methyl sulfide has emerged as an attractive reagent for the hydroboration of olefins and the reduction of organic functional groups.[4,5]

The complex reacts with alcohols and phenols to yield borates (eq 2).

$$3ROH + BH_3 \cdot SMe_2 \rightarrow B(OR)_3 + SMe_2 + 3H_2\uparrow \quad (2)$$

Straight-chain primary alcohols and unhindered phenols react vigorously evolving all of the three hydrogens at room temperature. With secondary and tertiary alcohols, the first two of the three hydrogens are evolved rapidly and instantly, whereas the evolution of the third hydrogen is quite sluggish. However, subsequent heating of the reaction mixture at gentle reflux results in complete hydrogen evolution.

The reactions were carried out by the dropwise addition of an essentially stoichiometric quantity of the alcohol to the BMS complex stirred at 25 °C. With alcohols and phenols which are solids, the BMS was added dropwise to the neat material previously weighed into the reaction flask (the reaction can be carried out with the precise stoichiometric quantities of the reagents as in synthesis of tri-*n*-dodecyl borate). Hydrogen evolution was quantitative and no residual hydride was found upon hydrolysis; the borate esters, produced in quantitative yield after removal of volatile dimethyl sulfide under aspirator vacuum, were >98% pure as determined by refractive index, ^{1}H and ^{11}B NMR, and boron analysis. Variations in substrate structure were readily accommodated (see Table I). These results show that direct stoichiometric reaction of borane–methyl sulfide with hydroxy compounds provides a clean, convenient, general route to analytically pure borate esters of widely varying structures.[6]

Experimental Section

Alcohols and phenols utilized in this study are the commercial products of the highest purity. They were further purified by distillation over calcium hydride or recrystallization when necessary. Neat borane–methyl sulfide, approximately 10 M, was utilized as received from Aldrich Chemical Co., Milwaukee, Wis.

All reactions were carried out under dry nitrogen atmosphere, using oven dried (150 °C) or flamed glassware.

^{11}B NMR spectra were recorded on a Varian XL-100 spectrometer equipped with a Nicolet 1080 data acquisition system. ^{1}H NMR spectra were recorded on a Varian T-60 spectrometer.

Procedure A. A dry 100-mL flask (equipped with an injection port, poly-TFE covered magnetic stirring bar, and a reflux condenser connected to a bubbler) was purged with nitrogen. Then 5.2 mL (52 mmol) of $BH_3 \cdot SMe_2$ was introduced and, with stirring and cooling with a water bath, 35.4 mL (156 mmol) of *n*-dodecyl alcohol was added dropwise over 10 min. After 1 h (hydrogen evolution was quantitative) dimethyl sulfide was removed under reduced pressure to constant weight. Tri-*n*-dodecyl borate, 29.15 g (99%), was obtained as a clear viscous liquid. Hydrolysis of a sample of the ester and titration of liberated boric acid indicated purity to be 99%.

Procedure B. Apparatus and the reaction conditions were as in procedure A except that when hydrogen evolution ceased at room temperature, the mixture was heated gently under reflux to complete the hydrogen evolution.

Procedure C. Apparatus and reaction conditions were as in procedure B except that BH_3·SMe_2 was added to the solid substrate. The results are summarized in Table I.

Registry No.—BH_3·SMe_2, 13292-87-0; dodecanol, 112-53-8; 2-butanol, 78-92-2; 2-propanol, 67-63-0; 3-pentanol, 584-02-1; 3-methylbutan-2-ol, 598-75-4; cyclohexanol, 108-93-0; *l*-menthyl alcohol, 2216-51-5; *tert*-butyl alcohol, 75-65-0; *tert*-amyl alcohol, 75-85-4; phenol, 108-95-2.

References and Notes

(1) (a) C. A. Brown, *J. Am. Chem. Soc.*, **95**, 4100 (1973); (b) C. A. Brown, S. Krishnamurthy, and S. C. Kim, *J. Chem. Soc., Chem. Commun.*, 391 (1973).

(2) (a) H. Steinberg and D. L. Hunter, *Ind. Eng. Chem.*, **49**, 174 (1957), and the references cited therein; (b) H. Schiff, *Ann. Suppl.*, **5**, 154 (1867); (c) P. D. Geroge and J. R. Ladd, *J. Am. Chem. Soc.*, **77**, 1900 (1955); (d) H. C. Brown, E. J. Mead, and C. J. Shoaf, *ibid.*, **78**, 3613 (1956); (e) J.-M. Lalancette and Y. Beauregard, *Can. J. Chem.*, **46**, 659 (1968).

(3) B. Rickborn and M. T. Wuesthoff, *J. Am. Chem. Soc.*, **92**, 6894 (1970). They reported their inability to distill hindered alkylborates. We have observed that olefin formation or trialkylboroxine formation frequently accompany distillation of higher borates, especially those derived from tertiary alcohols.

(4) (a) C. F. Lane, *J. Org. Chem.*, **39**, 1437 (1974); (b) C. F. Lane, H. L. Myatt, J. Daniels, and H. B. Hopps, *ibid.*, **39**, 3052 (1974); (c) C. F. Lane, *Aldrichimica Acta*, **8**, 20 (1975).

(5) Borane–methyl sulfide complex (~10.0 M) is commercially available from Aldrich Chemical Co., Milwaukee, Wis.

(6) The crude borate esters may be readily hydrolyzed with D_2O to pure deuterated alcohols. Hydrolysis is accomplished by adding 3.5 equiv of D_2O in which 0.5 equiv of sodium has been dissolved. After warming to ~75 °C for several hours, a borate glass appears from which the alcohols may be decanted under inert atmosphere.