dithiane 1-oxide (19),[18] 2-methyl-2,3-dihydrobenzothiophene 1-oxide (20),[8] thiochroman 1-oxide (21),[8] 2-methyl-1-thiochroman 1-oxide (22),[8] *sec*-butyl *p*-tolyl sulfoxide (23),[19] *tert*-butyl 1-(*p*-tolylsulfinyl)acetate (24),[1] and 2,3-dihydrobenzothiophene 1-oxide (26)[8] were all known in the optically active form, and the physical properties of our specimens were in agreement with those reported. Yields and optical rotation are reported in Tables I and II.

Sulfoxides 16, 27, and 28 were known in the racemic form. 1-(Methylsulfinyl)dodecane (16) had mp 53 °C (lit.[20] mp, 59–61 °C): ^{1}H NMR δ 0.9 (brt, 3 H), 1.1–1.9 (m, 20 H), 2.55 (s, 3 H), 2.65 (dt, 2 H).

1-Nitro-4-(phenylsulfinyl)benzene (27) had mp 100–101 °C (lit.[21] mp 107–107.5 °C): ^{1}H NMR δ 7.4–7.7 (m, 5 H), 7.8 (d, 2 H), 8.3 (d, 2 H).

2-(Phenylsulfinyl)-1-phenyl-1-ethanol (28).[22] Only the threo isomer having the major R_f has been isolated by flash chromatrography on silica gel, using petrol/ether (9/1) as eluant. It had mp 115–118 °C; ^{1}H NMR δ 2.8 (dd, 1 H), 3.15 (dd, 1 H), 4.05 (brs, 1 H), 5.3 (dd, 1 H), 7.2–7.7 (m, 10 H). The erythro isomer, isolated as a mixture with the threo diastereoisomer, had the following: ^{1}H NMR δ 2.9 (dd, 1 H), 3.2 (dd, 1 H), 4.2 (brs, 1 H), 5.15 (brd, 1 H), 7.2–7.7 (m, 10 H).

2,4,6-Trimethyl-1-(phenylsulfinyl)benzene (17) was a wax: ^{1}H NMR δ 2.25 (s, 3 H), 2.40 (s, 6 H), 6.85 (s, 2 H), 7.4 (m, 5 H). Anal. Calcd for $C_{15}H_{16}OS$: C, 73.8; H, 6.5. Found C, 73.5; H, 6.4.

***tert*-Butyl 1-[(*p*-nitrophenyl)sulfinyl]acetate (25)** had mp 137–139 °C; H NMR δ 1.5 (s, 9 H), 3.8 (t, 2 H), 7.9 (d, 2 H), 8.4 (d, 2 H). Anal. Calcd for $C_{12}H_{15}NO_5S$: C, 50.5; H, 5.3; N, 4.9. Found C, 50.1; H, 5.5; N, 4.8.

Preparation of the Solutions of BSA/*p*-Nitrophenyl Sulfides for Electronic and CD Spectral Measurements. Electronic and CD spectra of binary mixtures of BSA/11 or BSA/13 were recorded on solutions prepared according to the following procedure. The sulfide (1 mmol) and BSA (5×10^{-2} mmol) were magnetically stirred in aqueous borate buffer solution at pH 9 (12.5 mL) at room temperature. After 2 h a sample of the mixture (2 mL) was withdrawn and centrifugated at 20000 rpm for 15 min (36 000 g). The resulting clear solution (0.5 mL) was diluted with water as needed for the observation of the electronic and CD spectra. The spectra of ternary mixtures of BSA/*p*-nitrophenyl sulfide/oxidizing agent were obtained from samples withdrawn at different times after the addition of the oxidizing agent to the mixture BSA/sulfide and treated as above.

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Hydroboration. 77. Revision of the Regioselectivity of the Hydroboration of Alkenes with Dihaloborane–Dimethyl Sulfide Complexes

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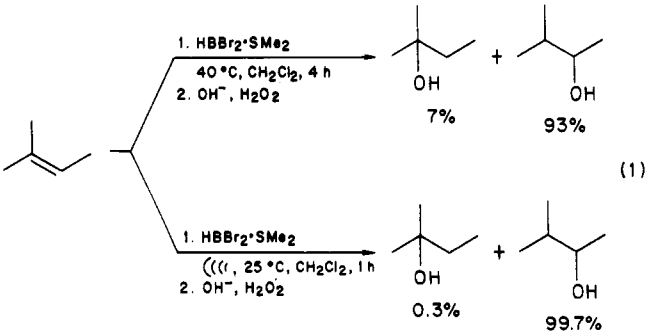
The hydroboration of alkenes with dihaloborane–dimethyl sulfide complexes ($HBX_2{\cdot}SMe_2$, X = Cl, Br, and I) was systematically reexamined to establish the true regioselectivities in hydroboration with these reagents. Hydrogen halides (HX, X = Cl, Br, and I) liberated during the hydrolysis–oxidation of the alkyldihaloborane–dimethyl sulfide complexes ($RBX_2{\cdot}SMe_2$) add to the residual alkene and hydrolyze to alcohols, thus introducing a significant error in the regioselectivity of such hydroborations. The true regioselectivities in the hydroboration of alkenes with $HBX_2{\cdot}SMe_2$ reveal considerably smaller formation of secondary and tertiary derivatives than previously reported, a result that should significantly enhance the value of these hydroborating agents.

Recently we reported that ultrasound remarkably improves the rates of heterogeneous hydroborations and has a modest accelerating influence on the rates of homogeneous hydroborations.[1] In the course of these studies, we unexpectedly discovered remarkable changes in the regioselectivities of hydroboration of certain alkenes with $HBBr_2{\cdot}SMe_2$. For example, while the hydroboration of 2-methyl-2-butene with $HBBr_2{\cdot}SMe_2$ under the usual conditions (40 °C, CH_2Cl_2, 4 h) followed by hydrolysis–oxidation affords[2] 7% of 2-methyl-2-butanol and 93% of 3-methyl-2-butanol, the same hydroboration done under ultrasound conditions ((((, 25 °C, CH_2Cl_2, 1 h) gave after oxidation 0.3% of 2-methyl-2-butanol and 99.7% of 3-methyl-2-butanol (eq 1).



(1)

Intrigued by this change, we decided to reexamine the hydroboration of 2-methyl-2-butene with $HBBr_2{\cdot}SMe_2$ at 25 °C in CH_2Cl_2 (in the absence of ultrasound). Accordingly, we followed the hydroboration with time by hydrolyzing and oxidizing aliquots (withdrawn at regular intervals of time) and analyzing the alcohols by GC.

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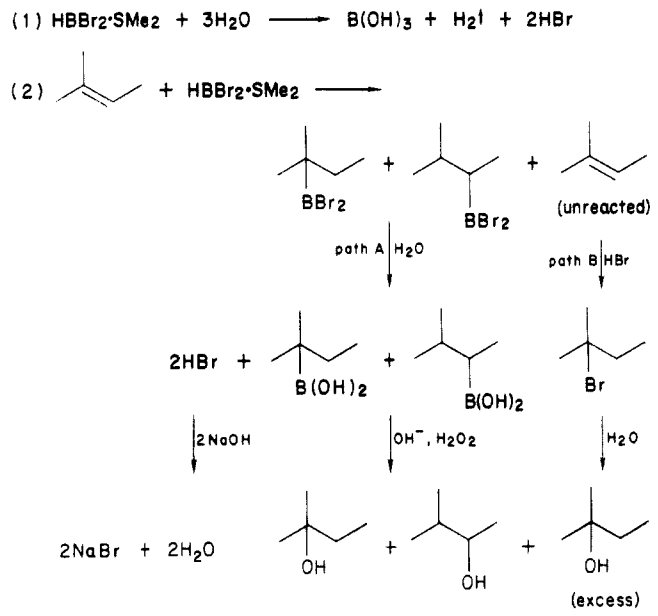
Table I. Hydroboration of 2-Methyl-2-butene with $HBBr_2 \cdot SMe_2$ at 25 °C in CH_2Cl_2[a,b]

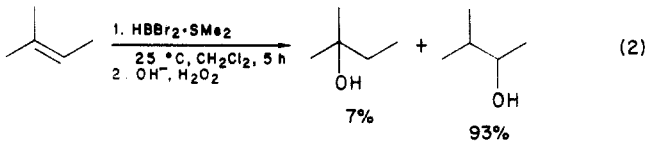
	yield,[c] mmol			% regioselectivity		
time, h			total yield, mmol			reactn, %
0.08	0.5	2.0	2.5	20	80	25
0.25	0.8	4.0	4.8	18	82	48
0.50	0.7	5.3	6.0	12	88	60
1	0.8	7.5	8.3	10	90	83
3	0.7	7.7	8.4	8	92	84
5	0.7	8.8	9.5	7	93	95
24	0.7	8.9	9.6	7	93	96

[a] The reaction was done on a 10-mmol scale. [b] Oxidation procedure was the same as in ref 2. [c] The GC analyses were performed on a 5% glycerol column isothermally at 65 °C.

Scheme I



Surprisingly, our experimental results showed a significant difference in the regioselectivities of hydroboration with time (Table I), although the final value agreed with the earlier result[2] (eq 2).



(2)

We suspected that this apparent change in the regioselectivity of hydroboration (Table I) might arise from hydrogen bromide produced by the hydrolysis of the reagent (Scheme I): $HBBr_2 \cdot SMe_2$ is extremely moisture-sensitive and could liberate HBr by reacting with traces of moisture (eq 1). This HBr could then add to the olefin (path B), producing secondary or tertiary bromide and, subsequently, the alcohol, modifying the apparent regioselectivity, as shown in Scheme I. As the reaction proceeds, the regioselectivity would then show an apparent improvement because the amount of residual alkene available for HBr addition (path B) gradually decreases.

Therefore, on this basis, we hoped that freshly crystallized $HBBr_2 \cdot SMe_2$ (absolutely free of any HBr) would produce a consistent regioselectivity for the hydroboration of 2-methyl-2-butene. However, even with such freshly crystallized $HBBr_2 \cdot SMe_2$, the hydroboration of 2-methyl-2-butene (freshly distilled over $LiAlH_4$) in CH_2Cl_2 (Spectral Grade, anhydrous) at 25 °C yielded precisely the same results (Table I). It was then clear to us that the source of the HBr must be not $HBBr_2 \cdot SMe_2$ but HBr, liberated during the hydrolysis–oxidation step (path A, Scheme I).

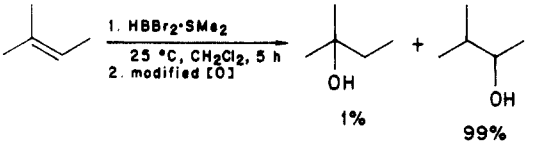
Table II. Hydroboration of 2-Methyl-2-butane with $HBBr_2 \cdot SMe_2$ at 25 °C in CH_2Cl_2[a] Using Modified Oxidation Procedure[b]

	yield, mmol			% regioselectivity		
time, h			total yield, mmol			reactn, %
0.08	0.04	3.40	3.4	1	99	34
0.50	0.08	7.30	7.4	1	99	74
1	0.09	8.20	8.3	1	99	83
3	0.09	8.70	8.8	1	99	88
5	0.10	8.80	8.9	1	99	90
24	0.10	8.90	9.0	1	99	90

[a] 10-mmol scale. [b] Excess unreacted olefin was pumped off under vacuum before each oxidation.

A puzzling feature is the fact that the absolute yield of tertiary alcohol remains essentially constant throughout the hydroboration, even though the amount of residual alkene decreases with the progress of hydroboration. Possibly this arises as a result of the heterogeneous condition of the reaction mixture during the hydrolysis–oxidation stage. However, we did not attempt to explore the cause of the apparent constancy.

It then occurred to us that if HBr, liberated during the hydrolysis–oxidation stage, is the problem, then pumping off under vacuum the unreacted 2-methyl-2-butene (bp 35–38 °C) before each hydrolysis–oxidation should completely close off path B (Scheme I) and provide the true regioselectivity for the hydroboration step. Indeed, with such a modified oxidation procedure the hydroboration of 2-methyl-2-butene with $HBBr_2 \cdot SMe_2$ at 25 °C in CH_2Cl_2 finally afforded highly consistent results for the regioselectivity of hydroboration (Table II), essentially the same as under ultrasound (eq 3).

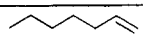


(3)

It should be pointed out that the hydroboration under ultrasound was conducted using only the stoichiometric amount of alkene. The resioselectivity of hydroboration was determined after the hydroboration was essentially 100% complete. In the previous procedure,[2] a slight excess (10%) of alkene was routinely employed to favor completion of the last stages of this relatively slow hydroboration.

For the above reasons, we felt that the previously reported directive effects in the hydroboration of alkenes with all of the $HBX_2 \cdot SMe_2$ reagents (X = Cl, Br, and I) required reexamination. However, we realized that pumping off excess unreacted olefin would not be practical for the less volatile alkenes. This problem could be circumvented by using a modest excess of the hydroborating agent and allowing the reaction to proceed to essential utilization of the alkenes. Accordingly, we systematically examined the directive effects in the hydroboration of representative alkenes with $HBCl_2 \cdot SMe_2$, $HBBr_2 \cdot SMe_2$, and $HBI_2 \cdot SMe_2$ at 40 °C in CH_2Cl_2 using a 20% excess of hydroborating agent and allowing the reactions to go to

Table III. Directive Effects in the Hydroboration of Alkenes with $HBX_2 \cdot SMe_2$[a]

olefin	alcohol[b]	isomer distribution,[c] % $HBCl_2 \cdot SMe_2$	$HBBr_2 \cdot SMe_2$	$HBI_2 \cdot SMe_2$
	1-hexanol	99	99.6	98 (96)
	2-hexanol	1	0.4	2 (4)
	2-phenylethanol	98	99 (96)	97
	1-phenylethanol	2	1 (4)	3
	2-methyl-1-pentanol	99.5 (96)	99	97 (92)
	2-methyl-2-pentanol	0.5 (4)	1	3 (8)
	3-methyl-2-butanol	99.2 (97)	99 (93)	97 (75)
	2-methyl-2-butanol	0.8 (3)	1 (7)	3 (25)
	*trans*-2-methylcyclopentanol	99.6	99.7 (98)	99.8 (86)
	1-methylcyclopentanol	0.4	0.3 (2)	0.2 (14)

[a] All reactions were performed on a 5-mmol scale. [b] Overall yields were 90 ± 5% in all cases. [c] The numbers in parentheses are taken from ref 2.

100% completion. Table III summarizes our results.[3]

In this way we observed major improvements in the directive effects of hydroboration of alkenes with $HBX_2 \cdot SMe_2$. Table III explicitly shows cases where remarkable improvements in the regioselectivity was observed. It is now very clear that the regioselectivities of hydroboration of trisubstituted alkenes with $HBX_2 \cdot SMe_2$ (X = Cl, Br, and I) are far better than those earlier reported[2] and this should further enhance the value of these hydroborating agents.

Experimental Section

Materials. All glassware and syringes used for the experiments were oven-dried (150 °C) for at least 6 h and assembled under nitrogen. The alkenes (+99% pure) were distilled over $LiAlH_4$ prior to use. Methylene chloride (99.9%, Phototrex, J. T. Baker Chemical Company) was stored over 3-Å molecular sieves under nitrogen. $HBCl_2 \cdot SMe_2$ and $HBI_2 \cdot SMe_2$ were prepared according to literature procedures.[4,5] $HBBr_2 \cdot SMe_2$ was purchased from Aldrich Chemical Company. The solutions of $HBX_2 \cdot SMe_2$ (X = Cl, Br, and I) in methylene chloride were all standardized by hydride estimation[6] prior to use.

Analyses. All hydroborations were followed by ^{11}B NMR on a Varian FT-80 instrument. The GC analyses of alcohols were done on a Varian 1200 Model gas chromatograph, equipped with a flame ionization detector. The regioselectivity of hydroboration was determined in every case by the GC analysis of the alcohols using a suitable internal standard (*n*-undecane or *n*-dodecane). The columns used for GC analyses were 5% Carbowax 20M on Chromosorb W ($^1/_8$ in. × 12 ft) and 5% Glycerol on Firebrick ($^1/_8$ in. × 12 ft).

Recrystallization of $HBBr_2 \cdot SMe_2$. Commercial $HBBr_2 \cdot SMe_2$ (100 g, 0.43 mol) was dissolved in methylene chloride (100 mL) and cooled under nitrogen to −40 °C by using dry ice. After 5 h at −40 °C, $HBBr_2 \cdot SMe_2$ crystallized out as a white solid. The supernatant layer of methylene chloride (containing small amounts of $BBr_3 \cdot SMe_2$ and any other impurities) was separated. The crystalline $HBBr_2 \cdot SMe_2$ was then redissolved in methylene chloride (500 mL) and its molarity estimated.[6] The purity of $HBBr_2 \cdot SMe_2$ was checked by ^{11}B NMR.

Hydroboration of 2-Methyl-2-butene with $HBBr_2 \cdot SMe_2$. (a) Procedure A. To a solution of 2-methyl-2-butene (0.707 g, 10 mmol) in CH_2Cl_2 (5 mL) was added *n*-undecane (0.782 g, 5 mmol), followed by a dropwise addition of $HBBr_2 \cdot SMe_2$ (2.9 mL, 3.5 M, 10 mmol) at 25 °C. The reaction mixture was stirred at 25 °C for 5 h.

At regular intervals of time, small aliquots were withdrawn, and the excess unreacted olefin was pumped off under aspirator vacuum and oxidized with 3 N NaOH and 30% H_2O_2 according to reported procedure.[2] The alcohols were analyzed on a 5% Glycerol column and the regioselectivity of hydroboration was established.

(b) Procedure B. To a stirred solution of 2-methyl-2-butene (0.707 g, 10 mmol) in methylene chloride (5 mL) were added *n*-undecane (0.782 g, 5 mmol) and $HBBr_2 \cdot SMe_2$ 3.4 mL, 3.5 M, 12 mmol) at 25 °C. The reaction mixture was refluxed (40 °C) for 4 h and then oxidized according to known procedure,[2] using 3 N NaOH and 30% H_2O_2. The regioselectivity in hydroboration, determined by this method, was the same as that obtained in procedure A, viz., 1% of 2-methyl-2-butanol and 99% of 3-methyl-2-butanol.

Hydroboration of Alkenes with $HBBr_2 \cdot SMe_2$. The hydroboration of other alkenes was done exactly as described in procedure B. A suitable internal standard was, however, used in each case. The regioselectivity of hydroboration was established in every case by GC analysis of the alcohols on a 5% Carbowax 20M column.

Hydroboration of Alkenes with $HBCl_2 \cdot SMe_2$ Using BCl_3. The hydroboration of 2-methyl-1-pentene with $HBCl_2 \cdot SMe_2$ is representative. To a solution of 2-methyl-1-pentene (0.42 g, 5 mmol) in pentane (4.0 mL) were added *n*-dodecane (0.426 g, 2.5 mmol) and $HBCl_2 \cdot SMe_2$ (0.7 mL, 8.74 M, 6 mmol). While stirring the reaction mixture at 0 °C, BCl_3 in pentane (6 mL, 1.0 M, 6 mmol) was added dropwise, and the reaction continued for 3 h at 0 °C. The reaction mixture was then oxidized with 3 N NaOH and 30% H_2O_2 according to the literature procedure[2] and the alcohols were analyzed by GC on a 5% Carbowax 20M column.

Hydroboration of Alkenes with $HBI_2 \cdot SMe_2$. The hydroboration of 1-hexene with $HBI_2 \cdot SMe_2$ is representative. To a stirred solution of 1-hexene (0.42 g, 5 mmol) in CH_2Cl_2 (5.0 mL) were added *n*-undecane (0.39 g, 2.5 mmol) and $HBI_2 \cdot SMe_2$ (12 mL, 0.5 M, 6 mmol) in CH_2Cl_2 at 25 °C. The reaction mixture was refluxed (40 °C) for 6 h to ensure completion and then oxidized with 3 N NaOH and 30% H_2O_2.[2] The alcohols were analyzed on a 5% Carbowax 20M column.

Acknowledgment. We thank the National Science Foundation (Grant CHE 841471) for the financial support of this research.

(3) An alternative way of handling the problem is described by Hasner, A.; Soderquist, J. A. *J. Organomet. Chem.* **1977**, *131*, C1. They methanolyzed the dichloroborane adduct of certain vinyltrimethylsilanes using excess trimethylamine to deactivate the hydrogen chloride liberated in the hydrolysis.

(4) Brown, H. C.; Ravindran, N. *Inorg. Chem.* **1977**, *16*, 2938.

(5) $HBI_2 \cdot SMe_2$ was prepared from BI_3 and $BH_3 \cdot SMe_2$. For procedure, see: Kinberger, K.; Siebert, W. *Z. Naturforsch. B* **1975**, *30*, 55.

(6) Brown, H. C.; Kramer, G. W.; Levy, A. B.; Midland, M. M. "Organic Syntheses via Boranes"; Wiley-Interscience: New York, 1975.