JOC Article

Studies on the Regio- and Stereoselectivity of Halohydroxylation of 1,2-Allenyl Sulfides or Selenides

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It was observed that the halohydroxylation of 1,2-allenyl sulfides or selenides with Br_2 ($CuBr_2$ or NBS) or I_2 and water demonstrated a fairly good regioselectivity (i.e., the C═C bond that is remote from the S or Se atom was halohydroxylated with the halogen atom connecting to the middle carbon atom and the hydroxyl group connecting to the non-S terminal carbon or Se-substituted terminal carbon atom of the allene moiety), leading to the synthesis of synthetically important 3-organosulfur or seleno-2-haloallylic alcohols. The stereoselectivity depends on the nature of X^+ and S or Se, showing a Z-selectivity with the matched Lewis acid−base pair.

Introduction

Allenes show unique reactivity in organic synthesis due to the presence of the cumulated C═C double bonds.[1] Recently, much attention has been paid to the study on their reactivity, especially the control of the related selectivity.[2,3] An addition reaction of a carbon−carbon multiple bond is synthetically attractive because two functional groups are introduced within one operation.[4] However, reports on the addition reactions of allenes[5] are limited, probably because of the problem of controlling the regio- and stereoselectivity.[6] Recently, we observed the following: (1) The electron-withdrawing group of the electron-deficient allenes determines the regioselectivity of the corresponding hydrohalogenation reaction, leading to β,γ unsaturated functionalized alkenes.[7] (2) The excellent regioselectivity and E-stereoselectivity of the iodohydroxylation reaction of 1,2-allenyl sulfoxides was determined by the participation of the sulfinyl group, because of the formation of a five-membered cyclic intermediate.[8]

In a preliminary communication, we have demonstrated that the iodohydroxylation reaction of 1,2-allenyl sulfides is high-yielding with excellent Z-selectivity, which is opposite to what was observed with 1,2-allenyl sulfoxides.[9] In this paper, we wish to report the scope, regioselectivity, and stereoselectivity of the halohydroxylation of 1,2-allenyl sulfides or selenides. The combination of a different X^+ with S or Se showed that the Z-selectivity may be controlled by the nature of Lewis basicity of the S or Se atom and the Lewis acidity of X^+.

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† Zhejiang University.
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(1) (a) *The Chemistry of Allenes*; Landor, S. R., Ed.; Academic Press: New York, 1982; Vols. 1−3. (b) *The Chemistry of Ketenes, Allenes and Related Compounds*; Patai, S., Ed.; Wiley: New York, 1980; Vols. 1 and 2. (c) Brandsma, L.; Verkruijsee, H. D. *Synthesis of Acetylenes, Allenes and Cumulenes*; Elsevier: New York, 1980. (d) Bruneau, C.; Dixneuf, P. H. *Compr. Org. Funct. Group Transform.* **1995**, *1*, 953. (e) Marshall, J. A. *Chem. Rev.* **1996**, *96*, 31. (f) Schuster, H. F.; Coppola, G. M. *Allenes in Organic Synthesis*; Wiley: New York, 1984. (g) Taylor, D. R. *Chem. Rev.* **1967**, *67*, 317. (h) Aso, M.; Kanematsu, K. *Trends Org. Chem.* **1995**, *5*, 157. (i) Zimmer, R. *Synthesis* **1993**, 165.

(2) For recent reviews, see: (a) Zimmer, R.; Dinesh, C. U.; Nandanan, E.; Khan, F. A. *Chem. Rev.* **2000**, *100*, 3067. (b) Hashmi, A. S. K. *Angew. Chem., Int. Ed.* **2000**, *39*, 3590. (c) Lu, X.; Zhang, C.; Xu, Z. *Acc. Chem. Res.* **2001**, *34*, 535.

(3) For some of our recent work, see: (a) Ma, S.; Zhao, S. *J. Am. Chem. Soc.* **2001**, *123*, 5578. (b) Ma, S.; Wu, S. *Chem. Commun.* **2001**, 441. (c) Ma, S.; Wu, S. *Tetrahedron Lett.* **2001**, *42*, 4075. (d) Ma, S.; Shi, Z.; Wu, S. *Tetrahedron: Asymmetry* **2001**, *12*, 193. (e) Ma, S.; Shi, Z. *Chem. Commun.* **2002**, 540. (f) Ma, S.; Jiao, N.; Zhao, S.; Hou, H. *J. Org. Chem.* **2002**, *67*, 2837. (g) Ma, S.; Duan, D.; Wang, Y. *J. Comb. Chem.* **2002**, *4*, 239. (h) Ma, S.; Yu, Z. *Angew. Chem., Int. Ed.* **2002**, *41*, 1775.

(4) (a) Nakhmanovich, A. S.; Komarova, T. N.; Lopyrev, V. A. *Russ. J. Org. Chem.* **2000**, *11*, 1551. (b) *Chemistry of Dienes & Polyenes*; Rappoport, Z., Ed.; John Wiley & Sons Ltd.: New York, 2000; Vol. 2, pp 545−663. (c) Beletskaya, I.; Moberg, C. *Chem. Rev.* **1999**, *99*, 3435. (d) *Organoselenium Chemistry*; Back, T. G., Ed.; Oxford University Press: New York, 1999; pp 35−66. (e) Mascavage, L. M.; Dalton, D. R. *Trends Org. Chem.* **1993**, *1*, 303. (f) *Chemistry of Double-Bonded Functional Groups*; Patai, S., Ed.; Wiley: New York, 1997; Vol. 3, pp 1135−1222. (g) Han, L.; Tanaka, M. *Chem. Commun.* **1999**, *5*, 395.

(5) (a) Weiss, H. M.; Touchette, K. M. *J. Chem. Soc., Perkin Trans. 2* **1998**, *6*, 1523. (b) Breuer, K.; Teles, J. H.; Demuth, D.; Hibst, H.; Schafer, A.; Brode, S.; Domgorgen, H. *Angew. Chem., Int. Ed.* **1999**, *39*, 1401. (c) Barbero, A.; Garcia, C.; Pulido, F. J. *Tetrahedron Lett.* **1999**, *36*, 6649. (d) Yang, F.; Wu, M.; Cheng, C. *J. Am. Chem. Soc.* **2000**, *122*, 7122. (e) Grigg, R.; MacLachlan, W.; Rasparini, M. *Chem. Commun.* **2000**, 2241. (f) Suginome, M.; Ohmori, Y.; Ito, Y. *J. Organomet. Chem.* **2000**, *611*, 403.

(6) For intramolecular haloalkoxylation of 2-phenythio-2,3-allenols leading to 2,5-dihydrofurans, see: (a) Yano, Y.; Ohshima, M.; Sutoh, S. *J. Chem. Soc., Chem. Commun.* **1984**, 695. (b) Florio, S.; Ronzini, L.; Epifani, E.; Sgarra, R. *Tetrahedron* **1993**, *49*, 10413.

(7) (a) Ma, S.; Shi, Z.; Li, L. *J. Org. Chem.* **1998**, *63*, 4522. (b) Ma, S.; Wei, Q. *J. Org. Chem.* **1999**, *64*, 1026. (c) Ma, S.; Li, L.; Xie, H. *J. Org. Chem.* **1999**, *64*, 5325. (d) Ma, S.; Wei, Q. *Eur. J. Org. Chem.* **2000**, 1939. (e) Ma, S.; Li, L. *Synlett* **2001**, 1206. (f) Ma, S.; Li, L.; Wei, Q.; Xie, H.; Wang, G.; Shi, Z.; Zhang, J. *Pure Appl. Chem.* **2000**, *72*, 1739. (g) Ma, S.; Xie, H.; Wang, G.; Zhang, J.; Shi, Z. *Synthesis* **2001**, 713. (h) Ma, S.; Yin, S.; Li, L.; Tao, F. *Org. Lett.* **2002**, *4*, 505.

(8) (a) Ma, S.; Wei, Q.; Wang, H. *Org. Lett.* **2000**, *2*, 3893. (b) Ma, S.; Ren, H.; Wei, Q. *J. Am. Chem. Soc.* **2003**, *125*, 4817.

(9) Ma, S.; Hao, X.; Huang, X. *Org. Lett.* **2003**, *5*, 1217.

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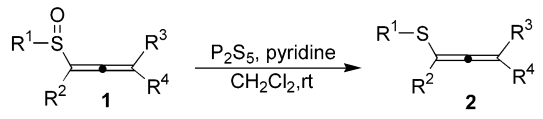
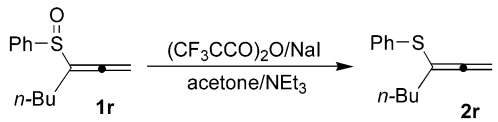
SCHEME 1



1a, 2a: R^1 = Ph, R^2 = H, R^3 = Bn, R^4 = CH_3;
1b, 2b: R^1 = Ph, R^2 = H, R^3 = H, R^4 = H;
1c, 2c: R^1 = Ph, R^2 = H, R^3 = H, R^4 = CH_3;
1d, 2d: R^1 = Ph, R^2 = H, R^3 = H, R^4 = *i*-Pr;
1e, 2e: R^1 = Ph, R^2 = H, R^3 = H, R^4 = n-C_4H_9;
1f, 2f: R^1 = Ph, R^2= H, R^3 = H, R^4 = n-C_7H_{15};
1g, 2g: R^1 = Ph, R^2 = H, R^3 = H, R^4 = Bn;
1h, 2h: R^1 = Ph, R^2 = H, R^3 = CH_3, R^4 = CH_3;
1i, 2i: R^1 = Ph, R^2 = H, R^3 = CH_3, R^4 = C_2H_5;
1j 2j: R^1 = Ph, R^2 = H, R^3 = CH_3, R^4= *i*-Bu;
1k, 2k: R^1 = Ph, R^2= H, R^3 = CH_3, R^4 = *t*-C_4H_9;
1l, 2l: R^1 = Ph, R^2 = H, R^3 = C_2H_5, R^4 = C_2H_5;
1m, 2m: R^1 = Ph, R^2 = H, R^3 = n-C_4H_9, R^4 = n-C_4H_9;
1n, 2n: R^1 = Ph, R^2 = H, R^3 = n-C_5H_{11}, R^4 = n-C_5H_{11};
1o, 2o: R^1 = Ph, R^2 = H, R^3, R^4 = -$(CH_2)_4$-;
1p, 2p: R^1 = Ph, R^2 = H, R^3, R^4 = -$(CH_2)_5$-;
1q, 2q: R^1 = *p*-Br-Ph, R^2 = H, R^3 = H, R^4 = n-C_4H_9



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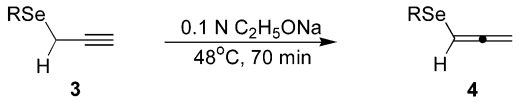
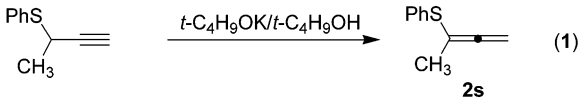


3a; 4a: R = Ph;
3b; 4b: R = *p*-$CH_3C_6H_4$;
3c; 4c: R = *o*-$CH_3C_6H_4$;
3d; 4d: R= *m*-$CH_3C_6H_4$;
3e; 4e: R = *p*-BrC_6H_4;
3f; 4f: R = *p*-ClC_6H_4;
3g; 4g: R = *p*-$CH_3OC_6H_4$;
3h; 4h: R = $PhCH_2$;
3i; 4i: R = n-C_7H_{15};
3j; 4j: R = n-$C_{12}H_{25}$

Results and Discussion

Synthesis of the Starting Materials. The starting 1,2-allenylic sulfides (**2**) were prepared via the reduction of 1,2-allenylic sulfoxides (**1**), which are easily available from the reaction of the readily available propargylic alcohols with PhSCl (Scheme 1).[10,11]

1,2-Butadienyl-3-yl phenyl sulfide (**2s**) was prepared via the rearrangement of 3-phenylthio-1-butyne (eq 1).[12]



(1)

1,2-Allenylic selenides (**4**) were prepared similarly via the rearrangement of propargyl aryl selenides (**3**) (Scheme 2).[13]

Iodohydroxylation of 1,2-Allenylic Sulfides (2). We started this research with the iodohydroxylation of 3-benzyl-1,2-butadienyl phenyl sulfide (**2a**) with I_2 and H_2O. When we performed the iodohydroxylation under the same reaction conditions as those for 1,2-allenyl sulfoxides,[8] only a Z/E mixture of 2-iodo-2-propenal (**5a**) was formed via the intermediacy of **7a** (Scheme 3), indicating a different regioselectivity with the OH group attacking the carbon atom connected with the PhS group. The configuration of the C=C bond in **5a** was determined by the NOE study. However, after some trial and error, we were pleased to note that the regioselectivity of this reaction can be reversed to a fairly high extent, leading to the formation of synthetically useful 2,3-iodohydroxylation product *Z*-**6a** in 68% yield, with 99/1 E/Z-selectivity, along with 16% yield of **5a** when the reaction was conducted in aqueous acetone (acetone/H_2O = 4:1) (Scheme 3).

Some typical results of the Z-iodohydroxylation of 1,2-allenyl sulfides are summarized in Table 1.[9] *Z*-2-Iodo-3-(organosulfur)-2-alkenols (**6**) were formed in moderate-to-high yields highly stereoselectively: Both 3-mono- and 3,3-disubstituted allenyl sulfides reacted smoothly with I_2 in aqueous acetone. The stereoselectivity, which was determined by the NOE experiment of *Z*-**6e** and the

SCHEME 3

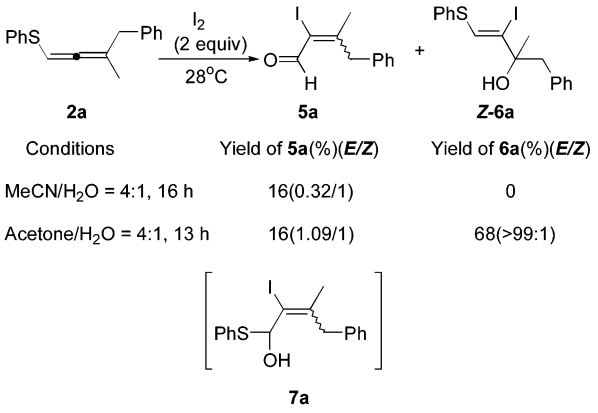
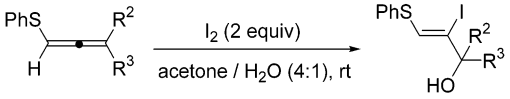


TABLE 1. Iodohydroxylation of 1,2-Allenyl Sulfides

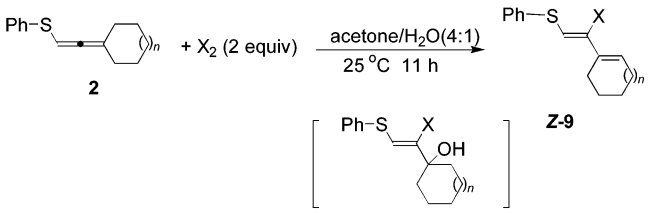


entry	2 R^2	2 R^3	time (h)	yield of **6**[a] (%)	Z/E of **6**
1	Bn	CH_3 (**2a**)	13	68 (**6a**)	99/1
2	H	H (**2b**)	9	41 (**6b**)	99/1
3	H	CH_3 (**2c**)	9	61 (**6c**)	97/3
4	H	*i*-Pr (**2d**)	10	56 (**6d**)	96/4
5	H	n-C_4H_9 (**2e**)	13.5	74 (**6e**)[b]	98/2
6	H	n-C_7H_{15} (**2f**)	9.5	67 (**6f**)[c]	96/4
7	H	Bn (**2g**)	9.5	65 (**6g**)[d]	96/4
8	CH_3	CH_3 (**2h**)	10.5	63 (**6h**)	94/6
9	CH_3	C_2H_5 (**2i**)	10	94 (**6i**)	94/6
10	CH_3	*i*-Bu (**2j**)	12	53 (**6j**)[e]	99/1
11	CH_3	*t*-C_4H_9 (**2k**)	9	85 (**6k**)	97/3
12	C_2H_5	C_2H_5 (**2l**)	8	72 (**6l**)	98/2
13	n-C_4H_9	n-C_4H_9 (**2m**)	10	93 (**6m**)	95/5
14	n-C_5H_{11}	n-C_5H_{11} (**2n**)	10	80 (**6n**)	97/3

[a] Unless otherwise stated, the corresponding aldehyde **5** was isolated in trace amount. [b] 14% of **5e** was isolated. [c] 18% of **5f** was isolated. [d] 18% of **5g** was isolated. [e] 14% of **5j** was isolated.

(10) (a) Cookson, R. C.; Parsons, P. J. *J. Chem. Soc., Chem. Commun.* **1978**, 822. (b) Taing, M.; Moore, H. W. *J. Org. Chem.* **1996**, *61*, 329−340. (c) Conrads, M.; Mattay, J. *Synthesis* **1991**, *1*, 111.
(11) Conrads, M.; Mattay, J. *Synthesis* **1991**, *1*, 11.
(12) Pourcelot, G. *C. R. Seances. Acad. Sci. Fr.* **1965**, *260*, 2847.
(13) (a) Pourcelot, G.; Cadiot, P. *Bull. Soc. Chim. Fr.* **1966**, 3016−3024. (b) Saito, S.; Hamano, S.; Inaba, M.; Moriwake, T. *Synth. Commun.* **1984**, *14*, 1105.

SCHEME 4

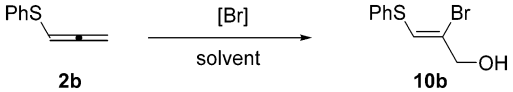


2o: n = 0, X = I — **9o:** (35%, *Z*/*E*>99/1)

2p: n = 1, X = I — **9p:** (85%, *Z*/*E*=97/3)

2p: n = 1, X = Br — **11p:** (65%, *Z*/*E*>99:1)

TABLE 2. Bromohydroxylation of 1,2-Propdienyl Phenyl Sulfide (2b)



entry	[Br] (equiv)	solvent[a]	T (°C)	time (h)	yield of **10b** (%)	Z/E[b]
1	$CuBr_2$ (2)	4:1	15	9	34	1.83/1
2	$CuBr_2$ (2)	4:1	25	7.5	39	2.88/1
3	$CuBr_2$ (10)	4:1	25	6	30	99/1
4	NBS (2)	4:1	50	3	10	99/1
5	NBS (2)	4:1	25	9	31	99/1
6	NBS (2)	4:1	0	7	49	4.38/1
7	Br_2 (2)	4:1	0	7	26	21/1
8	Br_2 (2)	4:1	50	3	29	99/1
9	Br_2 (2)	4:1	25	9	47	99/1
10	Br_2 (2)	4:1[c]	25	13	12	3.94/1
11	Br_2 (2)	2:2:1[d]	25	13	17	16/1

[a] Unless otherwise noted, solvents are CH_3CN/H_2O in the volume ratio indicated. [b] The Z/E ratio determined by 300 MHz ^1H NMR spectra. [c] CH_2Cl_2/H_2O were used as the solvents. [d] MeCN/CH_2Cl_2/H_2O were used as the solvents.

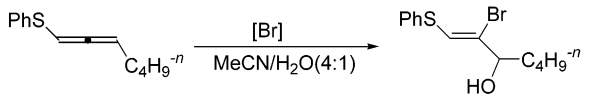
oxidation of *Z*-**6e** with *m*-CPBA in CH_2Cl_2 or H_2O_2 in HOAc to the corresponding sulfoxide *Z*-**8e**,[9] is completely opposite to that for the corresponding sulfoxides.[8]

When **2o** and **2p** were used as the starting allenyl sulfides, *Z*-(1-iodo-2-phenylthioethenyl)cycloalkenes **9o** and **9p**[9] were formed via the dehydration of the iodohydroxylation product (Scheme 4).

Bromohydroxylation of 1,2-Allenylic Sulfides. Some typical results of the bromohydroxylation of 1,2-propadienyl phenyl sulfide (**2b**) under different conditions are summarized in Table 2, from which it can be seen that, under similar conditions used for the halohydroxylation of allenylsulfoxides,[8] the bromohydroxylation reaction of 1,2-allenyl sulfides can occur to afford **10b** with different stereoselectivities when NBS, Br_2, or $CuBr_2$ was chosen as the halogen source. With $CuBr_2$, the stereoselectivity was high and the yield was as low as 30%, even with 10 equiv of $CuBr_2$ (entries 1−3, Table 2). The yield was higher when the reaction was conducted with NBS at a lower temperature, but the reaction was less stereoselective (entries 4−6, Table 2). The stereoselectivity was improved when Br_2 was used, with the highest yield (**10b**) at 47% and a Z/E ratio of 99/1 (entry 9, Table 2). The results in other solvents were poor (entries 10 and 11, Table 2). The stereoselectivity of this reaction was established by the NOE experiment of *Z*-**10b**.

Similar results were also observed with 1,2-heptadienyl phenyl sulfide (**2e**) (entries 1−6, Table 3). It is obvious

TABLE 3. Bromohydroxylation of 1,2-Heptadienyl Phenyl Sulfide (2e)



entry	[Br] (equiv)	additive (equiv)	T (°C)	time (h)	yield of **10d** (%)	Z/E[a]
1	NBS (2)		25	12	34	27/1
2	NBS (2)		0	7	46	34/1
3	Br_2 (1)		25	15	45	99/1
4	Br_2 (1)		0	6	54	99/1
5	Br_2 (1.5)		25	12	30	99/1
7	Br_2 (2)		25	12	39	99/1
8	Br_2 (2)	Na_2CO_3 (1)	25	10	51	99/1
9	Br_2 (2)	$NaHCO_3$ (1)	25	6.5	52	99/1
10	Br_2 (2)	K_2CO_3 (1)	25	9	50	99/1
11	Br_2 (2)	$LiOAc\cdot 2H_2O$ (1)	25	9	41	99/1
12	Br_2 (2)	Na_2CO_3 (1)	25	10	51	99/1
14	Br_2 (2)	Na_2CO_3 (1)	0	2	58	96/1
15	Br_2 (2)	Na_2CO_3 (1)	−10	13	52	99/1
16	Br_2 (2)	Na_2CO_3 (1.5)	0	7	46	99/1
17	Br_2 (2)	Na_2CO_3 (2)	0	16	53	99/1
18	Br_2 (2.5)	Na_2CO_3 (1)	0	6	45	99/1

[a] The Z/E ratio was determined by 300 MHz ^1H NMR spectra of the crude product.

that, in terms of both yield and stereoselectivity, the reaction proceeded more efficiently with Br_2 than with NBS (compare entries 1−2 with 3−4, Table 3). To avoid the influence of the in-situ-formed HBr on stereoselectivity, the effect of different bases on stereoselectivity was studied. The yield increased slightly when Na_2CO_3 (1 equiv) was added (entry 8, Table 3). $NaHCO_3$, K_2CO_3, or $LiOAc\cdot 2H_2O$ can also be applied (entries 9−11, Table 3). The best results were realized when the reaction was run with Br_2 (2 equiv) with the addition of Na_2CO_3 at 0 °C to afford **10e** in 58% yield and a Z/E ratio of 99/1 (entry 14, Table 3). Increasing the amount of Br_2 or base did not yield better results (entries 16−18, Table 3).

Some typical results of Z-bromohydroxylation of 1,2-allenyl sulfides are summarized in Table 4, showing that both 3-mono- and 3,3-disubstituted allenyl sulfides (**2**) reacted smoothly with Br_2 in aqueous acetonitrile to give the products *Z*-**10** in reasonably high yields with excellent Z-selectivity.

When 1-alkyl-substituted 1,2-allenyl phenyl sulfides (**2r**−**s**) were used, **10r**−**s** were produced with fairly high Z/E ratios (Scheme 5).

When sulfide **2p** was treated with Br_2 in aqueous acetone, *Z*-**11p** was formed in 65% yield with a ratio of Z/E > 99/1 (Scheme 4).

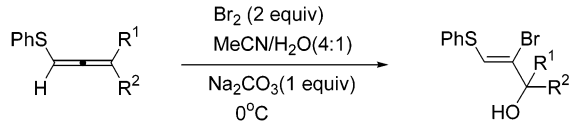
Iodohydroxylation of 1,2-Allenylic Selenides. Several selenium-substituted allenes are known as isolable compounds or reactive intermediates;[14] however, there is only very limited study on their reactivities.[15,16] According to our results on allenyl sulfides, we wish to expand this reaction to 1,2-allenyl selenides. Some typical

(14) (a) Yamazaki, S.; Fujitsuka, H.; Yamabe, S.; Tamura, H. *J. Org. Chem.* **1992**, *57*, 5610−5619. (b) Reich, H. J.; Shah, S. K.; Gold, P. M.; Olson, R. E. *J. Am. Chem. Soc.* **1981**, *103*, 3112.

(15) (a) Yamazaki, S.; Fujitsuka, H.; Yamabe, S.; Tamura, H. *J. Org. Chem.* **1992**, *57*, 5610−5619. (b) Reich, H. J.; Ringer, J. W. *J. Org. Chem.* **1988**, *53*, 455. (c) Brown, R. F. C.; Coulston, K. J.; Eastwood, F. W.; Hill, M. P. *Aust. J. Chem.* **1988**, *2*, 215.

(16) Ma, S.; Hao, X.; Huang, X. *Chem. Commun.* **2003**, 1082.

TABLE 4. Bromohydroxylation of Allenyl Sulfides with Br_2 in Aqueous MeCN in the Presence of Na_2CO_3

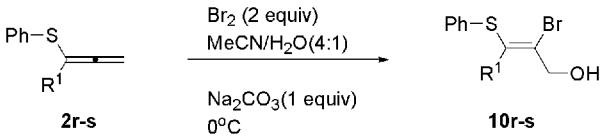


2 **10**

entry	2 R^1	2 R^2	time (h)	yield of **10** (%)	Z/E[a]
1[b]	H	H (**2b**)	9	47 (**10b**)	99/1
2	H	CH_3 (**2c**)	3	60 (**10c**)	72/1
3	H	*i*-Pr (**2d**)	4	61 (**10d**)	77/1
4	H	*n*-C_4H_9 (**2e**)	2	58 (**10e**)	96/1
6	H	*n*-C_7H_{15} (**2f**)	5	72 (**10f**)	99/1
7	CH_3	CH_3 (**2h**)	6	86 (**10h**)	99/1
8	CH_3	C_2H_5 (**2i**)	3	86 (**10i**)	99/1
9	CH_3	*i*-Bu (**2j**)	5.5	68 (**10j**)	56/1
10	CH_3	*t*-C_4H_9 (**2k**)	4.5	85 (**10k**)	99/1
11	C_2H_5	C_2H_5 (**2l**)	3	70 (**10l**)	31/1
12	*n*-C_4H_9	*n*-C_4H_9 (**2m**)	3	54 (**10m**)	99/1
13	*n*-C_5H_{11}	*n*-C_5H_{11} (**2n**)	3	68 (**10n**)	99/1
14[c]	H	*n*-C_4H_9 (**2q**)	3	64 (**10q**)	36/1

[a] The Z/E ratio was determined by 300 MHz ^{1}H NMR spectra of the crude product; [b] No Na_2CO_3 was used. [c] *p*-Bromophenyl sulfide was used instead of phenyl sulfide.

SCHEME 5



2r-s **10r-s**

2r: R^1 = *n*-C_4H_9, **10r**: (35%, *Z*/*E* = 43:1)

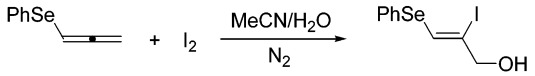
2s: R^1 = CH_3, **10s**: (44%, *Z*/*E* = 36:1)

results of iodohydroxylation of 1,2-propadienyl phenyl selenide (**4a**) with I_2 and H_2O are summarized in Table 5. When the iodohydroxylation of **4a** with I_2 and H_2O was carried out under the same conditions as those employed for 1,2-allenyl sulfoxides,[8] the expected product (**11a**) was isolated in only 28% yield with a Z/E ratio of 12.5:1 (entry 1, Table 5).[16] The stereoselectivity was determined unambiguously by the X-ray diffraction study of *Z*-**11e**.[17] We explored the effect of the ratio of nitrile/water on the reaction. The reaction could not proceed when there was too much water in the mixed solvent (entry 10, Table 5). The stereoselectivity can be tuned by reaction temperature: The reaction at 0 °C in MeCN/H_2O (4:1) afforded **11a** in 70% yield with a Z/E ratio of 99/1 (entry 18, Table 5). Some typical results of Z-iodohydroxylation of 1,2-allenyl selenides are summarized in Table 6.

The bromohydroxylation of 1,2-allenyl selenides **4a**, **4b**, or **4o** with Br_2 under similar reaction conditions as those for sulfides failed to yield the expected products (**12**) (Scheme 6).

(17) Crystal data for *Z*-**11e**: $C_9H_8BrIOSe$, Mw = 417.92, monoclinic, space group $P2_1/c$, Mo Kα, final *R* indices [$I > 2\sigma(I)$] $R_1 = 0.0592$, $wR_2 = 0.1428$, $a = 11.6887(17)$ Å, $b = 4.4071(7)$ Å, $c = 12.1232(18)$ Å, $\beta = 110.230(2)°$, $V = 585.98(15)$ Å^3, $T = 20.0$ °C, $Z = 2$, reflections collected/total 3559/unique 2201 ($R_{int} = 0.1447$), no. observation [$I > 2.00\sigma(I)$] 1671, parameters126. CCDC 186926 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Center, 12 Union Road, Cambridge CB2 1EZ, U.K.; fax (+44) 1223-336-033; or deposit@ccdc.cam.ac.uk).

TABLE 5. Addition Reaction of 4a with I_2 under Different Conditions[a]

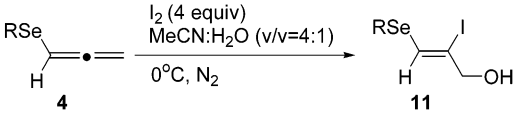


4a **11a**

entry	I_2 (equiv)	MeCN/H_2O	*T* (°C)	time (h)	yield of **11a** (%)	Z/E[d]
1[b]	2	7:1	21	10	28	12.5/1
2	1.2	4:1	27	5.5	26	*e*
3	1.5	4:1	27	5.5	49	*e*
4[c]	2	4:1	−10	10.5	54	26/1
5	2	4:1	−5	10	70	41/1
6	2	4:1	0	20	68	35/1
7	2	4:1	13	17	66	13.5/1
8	2	4:1	25	15	46	22/1
9	2	1:1	9	11	37	32/1
10	2	1:4	5	11	trace	*e*
11	2	7:1	22	20	75	16/1
12	2	7:1	21	10	28	12.5/1
13	3	4:1	0	17	73	52/1
14	4	4:1	27	7.5	61	3.50/1
15	4	4:1	14	7	75	10/1
16	2	4:1	0	7.5	61	3.5/1
17	4	4:1	0	10.5	69	99/1
18	5	1:1	0	17.5	70	99/1

[a] **4a** was added into the solution of I_2/nitrile/H_2O within a minute. [b] 2 equiv of LiOAc·$2H_2O$ was used. [c] **4a** was added into a solution of I_2/nitrile/H_2O over 30 min. [d] Determined by 300 MHz ^{1}H NMR spectra of the crude product. [e] Not determined.

TABLE 6. Iodohydroxylation of Allenyl Selenides

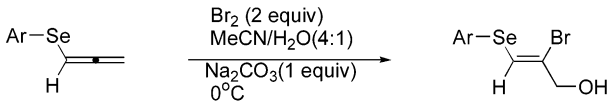


4 **11**

entry	R	time (h)	yield of **11** (%)	Z/E[a]
1	Ph (**4a**)	17.5	69 (**11a**)	99/1
2	*p*-$CH_3C_6H_4$ (**4b**)	20.5	72 (**11b**)	99/1
3	*o*-$CH_3C_6H_4$ (**4c**)	10	72 (**11c**)	99/1
4	*m*-$CH_3C_6H_4$ (**4d**)	19.5	74 (**11d**)	28/1
5	*p*-BrC_6H_4 (**4e**)	19	66 (**11e**)	99/1
6	*p*-ClC_6H_4 (**4f**)	19	72 (**11f**)	99/1
7	*p*-$CH_3OC_6H_4$ (**4g**)	11.5	74 (**11g**)	25/1
8	$PhCH_2$ (**4h**)	11.5	58 (**11h**)	99/1
9	*n*-C_7H_{15} (**4i**)	10.5	64 (**11i**)	99/1
10	*n*-$C_{12}H_{25}$ (**4j**)	8	33 (**11j**)	64/1

[a] Determined by 300 MHz ^{1}H NMR spectra of the crude product.

SCHEME 6

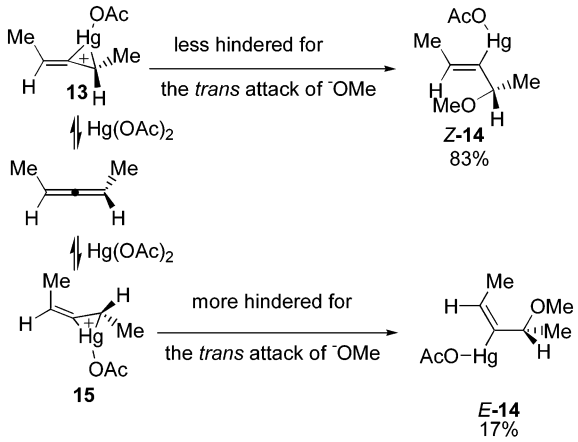


4 **12**

4a: Ph trace
4b: *p*-$CH_3C_6H_4$ trace
4o: *o*-$CH_3C_6H_4$ trace

It has been reported that $Hg(OAc)_2$ can react easily with an allene to yield methoxy-mercuration products, i.e., vinylic Hg derivatives *Z*/*E*-**14** with *Z*-**14** as the major product. The stereoselectivity was determined by the relative stability of the σ-bridged mercurinium ions and

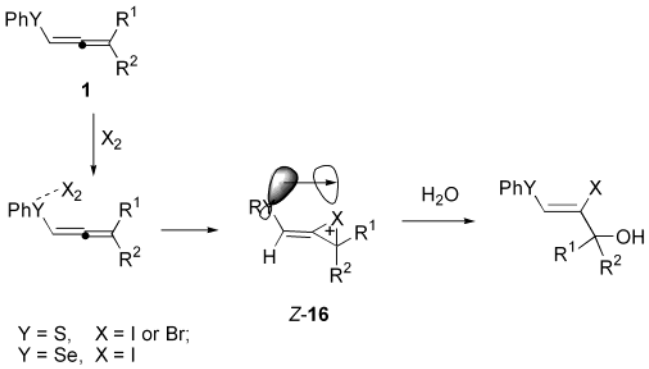
SCHEME 7



the steric hindrance of the incoming methoxy group (Scheme 7).[18]

However, even with 1,2-allenyl sulfides **2r** and **2s**, the bromohydroxylation products **10r**−**s** were formed in 35% yield (Z/E = 43:1) and 43% yield (Z/E = 36:1), respectively, indicating that the methyl or butyl group is not playing a critical role in determining the stereoselectivity (Scheme 5). Thus, a rationale for this reaction was shown in Scheme 8. The Z-stereoselectivity for these reactions may be explained by the soft Lewis base−acid interaction between the sulfur or selenium atom and the positively charged X^+ in *Z*-**16**.[19,20] The regioselectivity in these reactions may be controlled by the combined steric and electronic effects of the substituents at the two terminal positions of the allenes.

SCHEME 8



In conclusion, we have developed a highly regio- and stereoselective addition reaction of 1,2-allenyl sulfides or selenides. Although the real nature controlling the stereoselectivity needs further attention, this reaction provides an efficient route to the isomers of the Z-3-organosulfur- or seleno-group-substituted 2-halo-allylic alcohols in a highly stereoselective manner, and it may open up a new area for the control of selectivity in addition reactions of allenes. Further studies in this area are currently being carried out in our laboratory.

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Supporting Information Available: Experimental section, analytical data for compounds not listed in the text, and ^{1}H NMR and ^{13}C NMR spectra of those compounds. Crystallographic data in CIF format. This material is available free of charge via the Internet at http://pubs.acs.org.

JO049593C

(18) Waters, W. L.; Linn, W. S.; Caserio, M. C. *J. Am. Chem. Soc.* **1968**, *90*, 6741.
(19) Lowry, T. H.; Richardson, K. S. *Mechanism and Theory in Organic Chemistry*, 3rd ed.; Harper & Row Publishers: New York, 1987; p 319.
(20) For the intermolecular interaction between I and O, see: Chu, Q.; Zhu, S. *J. Am. Chem. Soc.* **2001**, *123*, 11069.