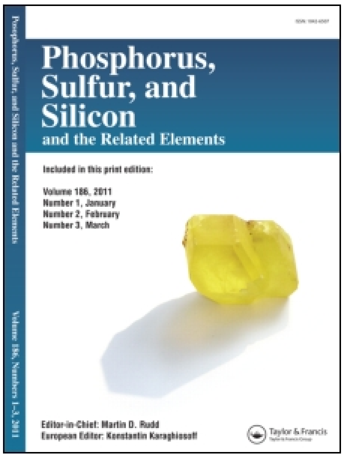


Phosphorus, Sulfur, and Silicon and the Related Elements
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713618290

Thermal Reactions of β-Hydroxysulfides Bearing Benzothiazole: Sulfenic Acid Trapping via a Spiro Intermediate

Nobuhiko Yamada[a]; Takanori Koyasu[a]; Mayumi Sonami[a]; Michiko Aoi[a]; Shintaro Tashiro[a]; Md. Chanmiya Sheikh[a]; Yusuke Ishida[a]; Wataru Kawashima[a]; Toshiaki Yoshimura[b]; Hiroyuki Morita[a]
[a] Department of Material Systems Engineering and Life Science, Faculty of Engineering, University of Toyama, Japan [b] Department of Environmental Applied Chemistry, Faculty of Engineering, University of Toyama, Japan

To cite this Article Yamada, Nobuhiko , Koyasu, Takanori , Sonami, Mayumi , Aoi, Michiko , Tashiro, Shintaro , Sheikh, Md. Chanmiya , Ishida, Yusuke , Kawashima, Wataru , Yoshimura, Toshiaki and Morita, Hiroyuki(2010) 'Thermal Reactions of β-Hydroxysulfides Bearing Benzothiazole: Sulfenic Acid Trapping via a Spiro Intermediate', Phosphorus, Sulfur, and Silicon and the Related Elements, 185: 5, 1142 — 1153

To link to this Article: DOI: 10.1080/10426501003773480
URL: http://dx.doi.org/10.1080/10426501003773480

Phosphorus, Sulfur, and Silicon, 185:1142–1153, 2010
Copyright © Taylor & Francis Group, LLC
ISSN: 1042-6507 print / 1563-5325 online
DOI: 10.1080/10426501003773480

THERMAL REACTIONS OF β-HYDROXYSULFIDES BEARING BENZOTHIAZOLE: SULFENIC ACID TRAPPING VIA A SPIRO INTERMEDIATE

Nobuhiko Yamada,[1] Takanori Koyasu,[1] Mayumi Sonami,[1] Michiko Aoi,[1] Shintaro Tashiro,[1] Md. Chanmiya Sheikh,[1] Yusuke Ishida,[1] Wataru Kawashima,[1] Toshiaki Yoshimura,[2] and Hiroyuki Morita[1]
[1]*Department of Material Systems Engineering and Life Science, Faculty of Engineering, University of Toyama, Japan*
[2]*Department of Environmental Applied Chemistry, Faculty of Engineering, University of Toyama, Japan*

Benzothiazolyl 2-hydroxyethyl sulfoxide (1a) was found to afford bis[2-(2-oxobenzotiazolyl)-ethyl] disulfide (2a) in the presence of DBU at rt. 2a was formed by the condensation of corresponding sulfenic acid intermediate. Thermolyses of 1a in the presence of ethyl propiolate at 60–140° C were carried out to succeed to trap sulfenic acid 6a as an intermediate. Trapping of 2-benzothiazolyloxyenthanesulfenic acid (6a) revealed that the thermal reaction proceeded via a five-membered spiro intermediate 5a.

Keywords Benzothiazole derivatives; β-hydroxysulfoxides; spiro intermediate; sulfenic acid; thermal reaction

INTRODUCTION

Considerable attention has been focused on organosulfur compounds bearing heterocycles, because of their interesting properties and a variety of reaction behaviors. Previously, we reported that β-phenacyl sulfoxides bearing several heteroaromatics undergo thermolytic reactions to give the corresponding thioaldehydes or sulfines, depending on the nature of heteroaromatics.[1,2] Very recently, we reported thermolysis of β-hydroxysulfides bearing several heteroaromatics that afforded the corresponding substituted olefins in excellent yields.

From the results of the formation of sulfur–oxygen exchange products, i.e., hydroxy heteroaromatics, and other mechanistic studies, the olefin product was considered to be formed via the five-membered spiro intermediates.[3] In the continuing studies, we prepared β-hydroxysulfoxides bearing benzothiazole and studied their thermal behavior in the presence or absence of a base.

Received 26 December 2008; accepted 19 January 2009.

Dedicated to Professor Naomichi Furukawa on the occasion of his 70th birthday.

Address correspondence to Hiroyuki Morita, Department of Material Systems Engineering and Life Science, Faculty of Engineering, University of Toyama, 3190 Gofuku, Toyama 930-8555, Japan. E-mail: morita@eng.u-toyama.ac.jp

RESULTS AND DISCUSSION

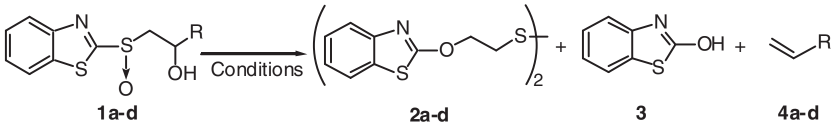
β-Hydroxysulfoxides bearing benzothiazole were prepared by the oxidation of corresponding sulfides with *m*CPBA in good yields. First, we carried out the thermal reaction of **1a** in THF in sealed tubes. The results are summarized in Table I. The reaction proceeded slowly after 24 h to afforded bis[2-(2-oxobenzotiazolyl)-ethyl] disulfide (**2a**) and 2-hydrovybenzothiazole (**3**) in low yields, respectively. We also confirmed the control experiments of the thermal reaction of **1a**. Disulfide **2a** was kept at 80°C in dioxane for 24 h to reveal that the decomposition of **2a** to afford **3**. In addition, in the case of 140°C, **2a** gave the quantitative yield of **3** after 24 h. In the case of **1c**–**1d**, which has several substituents at the β-position, the results were different. The reactions proceeded more smoothly than in the case of **1a**, and the main product was 2-hydroxybenzothiazole, and the small amount of corresponding olefins was also confirmed.

From these results, we presumed that the reactions proceeded via five-membered spiro intermediate **5a** by *ipso*-addition of hydroxy group at β-position to the 2-position of benzothiazole. Successively, in the case of **1a**, sulfenic acid **6a** was formed by the ring opening of **5a**, followed by the formation of disulfides **2a**[4] (Scheme 1).

However, the result in entries 2–4 (Table I) seems to indicate that **3** was formed by the elimination reaction of **5b–d** as shown in Scheme 2. In these cases, the reactions of **5b**–**d** to **3** and **7b–d** are probably faster than reactions of **5b**–**5d** to **6b**–**d** under the high temperature conditions.

It is known that sulfenic acids are generally unstable, and hence their isolation is usually difficult in the cases of nonstabilization effects.[5] Therefore, trapping experiments of the sulfenic acid intermediate are quite useful and important. In order to obtain a clue for the existence of a sulfenic acid **6a** via the initially formed five-membered spiro intermediate, we carried out the thermolysis of **1a** in ethyl propiolate under several conditions. The results are shown in Table II. The thermolyses at 60°C and 80°C proceeded very slowly to afford sulfenic acid trapped product 2-(2-oxy-2-benzothiazolyl)ethyl 2-(ethoxycarbonyl)ethenyl sulfoxide **8a** in low yields, 20% and 34% after 192 h, respectively (entries 2 and 6). The yields of target **8a** increased as reaction times were prolonged (entries 3–7 and 9–11). The geometry of **8a** was found to be *E*-form by comparison of the ^{1}H NMR data with reported similar compounds having -SOCHCHCO- moiety.[6] In the thermolysis at higher

Table I Thermal reactions of hydroxyuslfoxides (**1a**)



			Yield (%) [a]		
Entry	R	Conditions	2a	3	4a–d
1	R = H (**1a**)	THF, 80°C, 24 h[b]	6	11	—
2	R = H (**1a**)	THF, 100°C, 24 h[b]	10	20	—
3	R = Ph (**1c**)	CDCl3 100°C, 4 h[b]	—	83	11
4	R = 2-Nap (**1d**)	CDCl3, 100°C, 4 h[b]	—	89	14

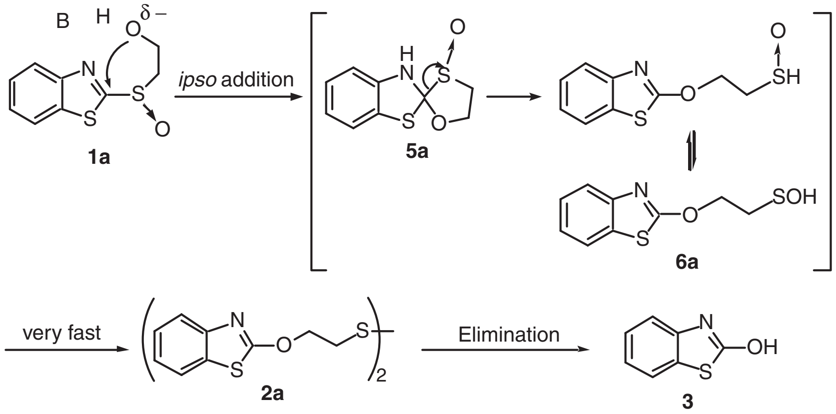
[a] Isolated yields.

[b] In a sealed tube.

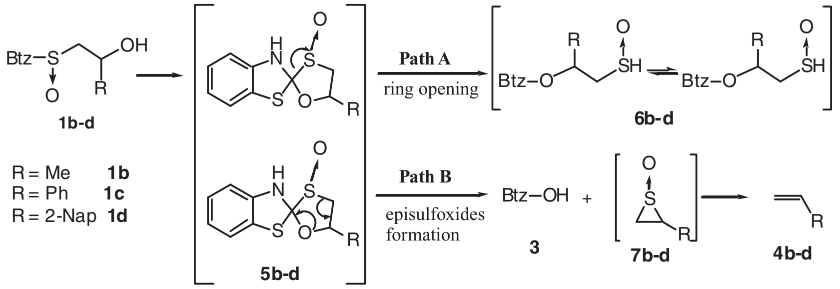
Table II Thermal reactions of **1a** in ethyl propiolate under several conditions

Entry	Conditions[b]	Yield (%)[a]			
		8a	**3**	**11**	recover (**1**)
1	60°C, 72 h	12	5	0	61
2	60°C, 192 h	20	7	0	56
3	80°C, 12 h	12	6	0	72
4	80°C, 24 h	17	6	0	65
5	80°C, 72 h	23	7	0	54
6	80°C, 192 h	34	10	0	48
7	100°C, 12 h	25	8	0	64
8	100°C, 24 h	38	10	0	42
9	100°C, 72 h	59	24	0	0
10	120°C, 5 h	16	15	trace	43
11	120°C, 12 h	44	24	trace	10
12	120°C, 24 h	50	33	7	0
13	140°C, 3 h	33	trace	10	52
14	140°C, 5 h	51	10	15	22
15	140°C, 7 h	44	18	17	6
16	140°C, 12 h	24	22	25	0

[a] Isolated yields.
[b] In a sealed tube.

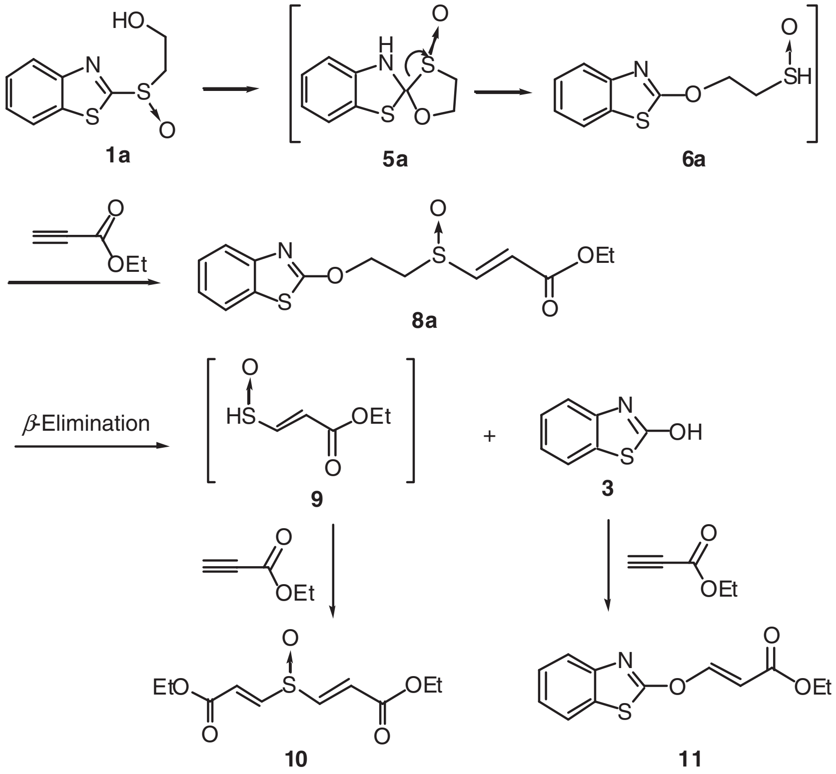


Scheme 1



Scheme 2

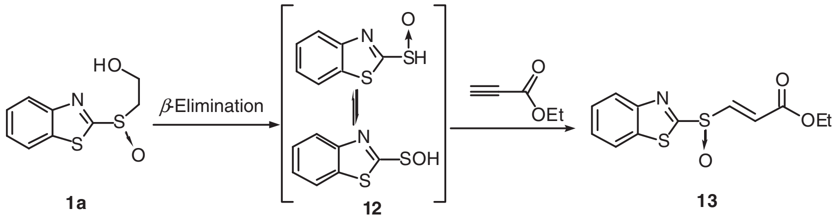
temperature than 120°C, starting material **1a** itself revealed to be decomposed by *β*-elimination. Trapping of sulfenic acid **12** was also preformed by ethyl propiolate to afford 2-benzothiazolyl 2-(ethoxycarbonyl)ethenyl sulfoxide **13** (Scheme 3). In the case at 120°C and 140°C, bis[2-(ethoxycarbonyl)ethyl]ethenyl sulfoxide (**10**) was found to be formed in a trace amount by trapping experiment of 2-(ethoxycarbonyl)ethenesulfenic acid **9** in the presence of ethyl propiolate, indicating that the further *β*-elimination of **8a** initially formed was concurrently taking place.



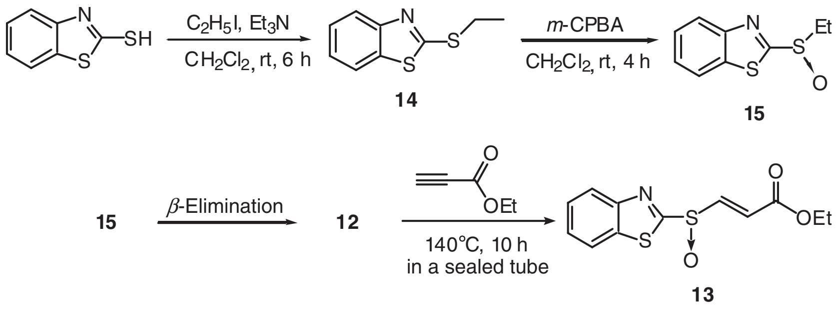
Scheme 3

Further, the Michael addition of **3** to ethyl propiolate also formed 2-(2-oxy-2-benzothiazolyl) acrylic acid ethyl ester (**9**) slowly in a trace amount. According to the systematic control and trapping experiments, the thermal reaction of **1a** and concomitant generation of sulfenic acids **6a**, **9**, and **12** revealed to proceed as is shown in Schemes 4 and 5. The same product was obtained in 64% yield in the thermal reaction of **15** in the presence of ethyl propiolate 140°C.

To study the reaction mechanism in detail, we also carried out the thermal reaction of **1b–d** in ethyl propiolate under several conditions. The results are summarized in Table III. In the thermal reaction of **1b**, it was confirmed that sulfoxide **8b,** which was formed by the reaction of sulfenic acid **6b** with ethyl propiolate, was isolated in a low yield. This result is one of the clues to reveal the reaction mechanism of the thermal reaction. In the case of the thermal reaction of **1b**, the reaction proceeded via the formation of spiro intermediate and then via the ring opening sulfenic acid formation (Scheme 2, Path A). **3** was also formed



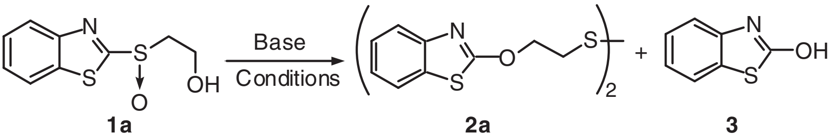
Scheme 4



Scheme 5

via the elimination of **8b** because the yield of **8b** was not improved even under longer reaction time (Table III, entries 1 and 2). At the higher temperature, the reaction proceeded more quickly, and the yield of **8b** was a little improved. On the other hand, in the thermal reaction of **1c–d**, the separable product was only **3** and other expected compounds **7c–d** or corresponding olefin **4c–d** were not confirmed to give inseparable complicated mixture (entries 5 and 6). It is likely that the reaction proceeded via mainly Path B or via both Paths A and B. **4c** has a benzyl proton, and the direct episulfoxide formation proceeded more

Table III Reactions of hydroxysulfoxides (**1**) under several conditions



Entry	Conditions	Base	Yield (%)[a] 2a	3
1	THF, rt, 3.0 h	*tert*-BuOK (1.0 equiv.)	34	30
2	THF, rt, 10 min.	DBU (1.0 equiv.)	84	trace
3	THF, rt, 1 h	DBU (1.0 equiv.)	55	36
4	THF, rt, 2 h	DBN (1.0 equiv.)	36	30
5	THF, 65°C, 4.0[b]	DABCO (2.0 equiv.)	14	8
6	THF, 65°C, 4.0[b]	DMAP (2.0 equiv.)	3	3
7	THF, 65°C, 4.0[b]	Et$_3$N (2.0 equiv.)	0	0

[a] Isolated yields.
[b] In a sealed tube.

Table IV The reaction of hydroxysulfoxides having several substituents at β-positon under various conditions

Entry	R	Conditions	Yield (%)[b] **3**	Yield (%)[b] **8b–d**
1	Me (**1b**)	ethyl propiolate, 100°C, 12 h[a]	11	9
2	Me (**1b**)	ethyl propiolate, 100°C, 24 h[a]	40	9
3	Me (**1b**)	ethyl propiolate, 120°C, 12 h[a]	57	17
4	Me (**1b**)	ethyl propiolate, 140°C, 5.0 h[a]	43	34
5	Ph (**1c**)	ethyl propiolate, 80°C, 12 h[a]	89	0
6	Ph (**1c**)	ethyl propiolate, 100°C, 12 h[a]	90	0
7	Me (**1b**)	DBU (1.0 equiv.), THF, rt, 1.0 h	50	10
8	Ph (**1c**)	t-BuOK (1.0 equiv.), THF, rt, 1.0 h	85	—
9	2-Nap (**Id**)	DBU (1.0 equiv.), THF, rt, 1.0 h	70	—

[a] In a sealed tube.
[b] Isolated yields.

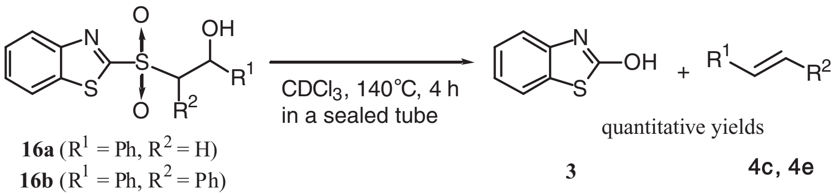
easily than **4a** and **4b**. If the reaction proceeded via path A, elimination of BtzO group is easier because of the benzyl proton of **5c** or **5c′.** These are the reasons why the sulfenic acids **6c** or **6c**′ were not trapped with ethyl propiolate.

The thermolysis in the presence of bases is also very interesting, since all the reaction steps, for example, in Table IV **1a–d** to **6a–d**, are considered to be catalyzed by bases. Therefore, we carried out the reactions of **1a–d** with several bases. Expectedly, the reaction of **1a** with bases proceed smoothly even at room temperature to afford disulfide **2a** in a good yield. The best results were obtained in the case of DBU. The starting material **1a** was consumed within 10 min to afford **2a** in 84% yield. It was confirmed that the control reaction of **1a** with bases for a long time afforded 2-hydroxybenzothiazole in a higher yield. However, when weaker bases DABCO and DMAP were used, the reaction proceeded very slowly, and the staring material was recovered in good yields even at higher temperature. In addition, the reaction of **1a** did not proceed at all in the presence of triethylamine.

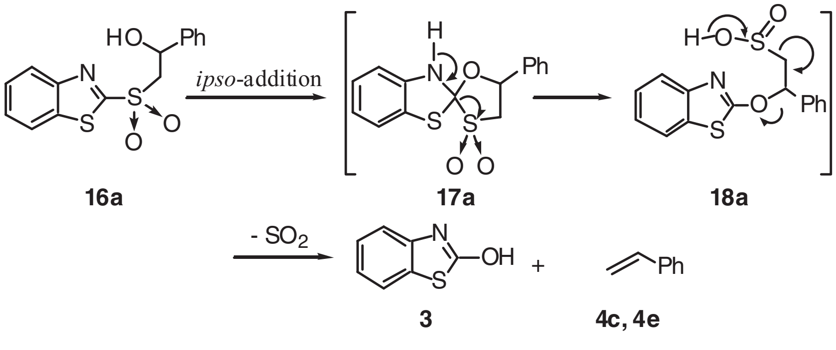
In the thermal reaction of **1b**, it was confirmed that sulfoxide **8b,** which was formed by the reaction of sulfenic acid **5b** or **5d** with ethyl propiolate, was isolated in a low yields. This result is one of the clues to reveal the reaction mechanism of the thermal reaction. In the case of the thermal reactions of **1a** and **1b**, the reaction proceeded via the formation of spiro intermediate and then via sulfenic acid formation (Path A) as shown in Scheme 4. **3** was also formed via the elimination of **8b**, because the yield of **6b** was not improved even under longer reaction times (Table IV, entries 1 and 2). At the higher temperature, the reaction proceeded faster, and the yield of **8b** was a little improved. On the other hand, the results of thermal reaction of **1c** were unexpected. The separable product was only **3**, and other expected compounds **7c** or corresponding olefin stylene were not identified to give inseparable complicated mixture (entries 5 and 6). It is likely that the reaction proceeded via Path B or via both Paths A and B. **4c** has a benzyl proton, and the direct episulfoxide formation proceeded more easily than **4a** and **4b**. If the reaction proceeded via path A, elimination of the BtzO group is easier because of benzyl proton of **5c** or **5c**′. These are the reasons why the sulfenic acid **5c** or **5c**′ were not trapped with ethyl propiolate. The reactions under milder conditions were carried out with several bases at room temperature. The reaction of **1b**, **1c**, and **1d** with 1.0 equiv. of DBU or *t*BuOK proceeded smoothly to afford **3** as only separable product in good yields. In addition, in the case of **1b**, the trace amount of corresponding disulfide **2b** was obtained. However, corresponding episulfoxides **7b–d** and disulfides **2c–d** were not isolated at all. As the result, the possible reaction mechanism of thermal reaction seems to be path A in the case of **1a** and **1b**, and path A and/or path B in the cases of **1c** and **1d**.

The thermal reactions of hydroxysulfides were also studied as our associated work. The β-hydroxysulfones were prepared by the oxidation of corresponding β-hydroxysulfides with *m*CPBA. The thermolysis of 2-benzothiazolyl 2-hydroxyphenetyl sulfone (**16a**) at 140°C was carried out in $CDCl_3$. The reaction mixture was directly measured by ^{1}H NMR to reveal the formation of **3** and corresponding **4c** in quantitative yield, respectively. The thermolysis of β-hydroxysulfone having substituents at α- and β-position were also used to study **16b**, and the same product **3** and corresponding olefin **4e** were also obtained quantitatively with the formation of other products. Stilbene (**4e**) was obtained as only *trans*-isomer, which was compared with ^{1}H NMR of authentic *trans*-stilbene and *cis*-stilbene (Scheme 6).

The plausible formation pathway of **3** and **4** is illustrated in Scheme 7. β-Hydroxysulfide (**1a**) leads to spiro intermediate **17a** by the internal *ipso*-addition of the hydroxy group at β-position. The possible decomposition route of this intermediate to **3** and **4a** will be the concerted ring-opening route, followed by the elimination of **18a** to form **3** and **4a**. In this case, the good leaving ability of hydroxy benzothiazole group seems to operate the crucial role. The results also show the clue of the mechanism of modified Julia olefination. The isolation of olefins is also easy by using silica gel flash column; therefore these thermal reactions are expected to be useful in olefin synthesis.



Scheme 6



Scheme 7 Probable mechanism of thermolysis of β-hydroxysulfide **16a**.

In conclusion, we found the reactions **1** in the presence of bases (DBU and *tert*-butoxide) proceeded via five-membered spiro intermediate **4**, and resulted in the formation of sulfenic acid **5**. The key compound **5** was successfully trapped with ethyl propiolate. We expect that the thermal reaction of β-hydroxysulfoxides and the reaction of β-hydroxysulfoxides with DBU are simple sulfenic acid preparation procedures in the field of organic synthesis. Thermal reactions of β-hydroxysulfones are useful in olefin synthesis, and in addition, further purification of olefins is very easy by simple silica flash column chromatography. Additionally, this methodology does not require any strong acid, unstable toxic metallic reagents, or other expensive reagents.

EXPERIMENTAL

All the melting points were uncorrected using micro melting point apparatus. ^{1}H NMR (400 MHz) and ^{13}C NMR (100 MHz) spectra were recorded in $CDCl_3$ using TMS as an internal standard. The elemental analyses were performed at the Microanalytical Laboratory of the Department of Material Systems Engineering and Life Science, University of Toyama. All the reactions were monitored with TLC, and the products were separated by column chromatography using silica gel 60 and also by preparative layer chromatography using silica gel 60 PF_{254} with UV detection. All the reagents were of the highest quality and were further purified by distillation or recrystallization. The solvents were further purified by general method.

General Procedure for the Preparation of β-Hydroxysulfoxides 1a–d

To a solution of β-hydroxysulfides (3.00 mmol) in distilled dichloromethane (30 mL), a solution of *m*-chloroperbenzoic acid in dichloromethane was added slowly with stirring at 0°C under N_2. After the addition, the reaction mixture was stirred at room temperature. After the starting materials were consumed, the mixture was washed with saturated $NaHCO_3$ aq four times. The organic layer was dried over anhydrous $MgSO_4$. Then the solvent was removed to afford crude β-hydroxysulfoxides **1a–d**, which were purified by silica flash column chromatography and recrystallization.

2-Benzothiazolyl 2-hydroxyethyl sulfoxide (1a). Yield 70% (white solid from dichloromethane-hexane-hexane); mp 110–112°C; ^{1}H NMR ($CDCl_3$): δ 8.06–8.08 (m, 1H), 8.01–8.03 (m, 1H), 7.56–7.66 (m, 1H), 7.49–7.53 (m, 1H), 4.24–4.30 (m, 1H), 4.14–4.20 (m, 1H), 3.60–3.66 (m, 1H), 3.37–3.43 (m, 1H), 2.60 (br, 1H),; ^{13}C NMR ($CDCl_3$): δ 176.9, 153.8, 136.0, 127.1, 126.3, 124.0, 122.3, 57.8, 56.; IR (KBr): $\nu = 3408$, 3086, 3060, 2920, 1476, 1426, 1387, 1311, 1134, 1048, 990, 766 cm^{-1}; Anal. Calcd. For $C_9H_9NO_2S_2$: C, 47.56; H, 3.9; N, 6.16. Found. C, 47.54; H, 4.05; N, 6.20.

2-Benzothiazolyl 2-hydroxypropyl sulfoxide (1b). Inseparable mixture of diastereomers (the ration of major:minor isomer was 1.4:1); yield 65%; mp 81–83°C (white solid from CH_2Cl_2, diethyl ether and hexane); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.06–8.09 (m, 2H), 8.00–8.04 (m, 2H), 7.56–7.61 (m, 2H), 7.49–7.54 (m, 2H), 4.58–4.66 (m, 1H), 4.45–4.53 (m, 1H), 3.49 (dd, $J = 13.6$, 10.0 Hz, 1H), 3.35–3.44 (m, 2H), 3.23 (dd, $J = 2.0$, 13.6 Hz, 1H), 1.40 (d, $J = 6.4$ Hz, 1H), 1.31 (d, $J = 6.4$ Hz, 1H), ^{13}C NMR ($CDCl_3$):δ 177.3, 176.8, 153.9, 153.7, 136.1, 135.9, 127.03 (2C), 126.30, 126.26, 123.94 (2C), 122.28, 122.26, 63.8, 63.7, 63.3, 62.4, 23.3, 23.3; IR (KBr): $\nu = 3365$, 1455, 1424, 1073, 1060, 1021; Anal. Calcd. For $C_9H_9NO_2S_2$: C, 49.77; H, 4.59; N, 5.80. Found. C, 49.80; H, 4.92; N, 5,82.

2-Benzothiazolyl 2–hydroxyphenethyl sulfoxide (1c). An inseparable mixture of diastereomers (the ration of major:minor isomer was 2.6:1.0); yield 72%; mp 146–160°C (dec.) (white soft solid from CH_2Cl_2, diethyl ether and hexane); ^{1}H NMR

($CDCl_3$): δ 8.03–8.07 (m, 2H), 7.98–8.02 (m, 2H), 7.54–7.59 (m, 2H), 7.47–7.53 (m, 2H), 7.24–7.42 (m, 10H), 5.49–5.52 (m, 1H), 5.37–5.39 (m, 1H), 3.86 (d, J = 3.2 Hz, 2H), 3.63–3.70 (m, 2H), 3.56 (dd, J = 13.2, 3.2 Hz, 1H), 3.41 (dd, J = 13.2, 3.2 Hz, 1H),^{13}C NMR ($CDCl_3$, major isomer): δ 176.7, 153.9, 141.4, 136.0, 128.7, 128.3, 127.1, 126.3, 125.7, 124.0, 122.3, 68.9, 63.2; IR (KBr): ν = 3374, 1052 cm^{-1}; Anal. Calcd. For $C_9H_9NO_2S_2$: C, 59.38; H, 4.32; N, 4.62. Found. C, 59.19; H, 4.73; N, 4.60.

2-Benzothiazolyl 2-(2-naphthyl)-2-hydroxyethyl sulfoxide (1d). Inseparable mixture of diastereomers (the ration of major:minor isomer was 1.7:1.0); Yield 77%; mp 115–116°C (white solid from CH_2Cl_2, diethyl ether and hexane); ^{1}H NMR ($CDCl_3$): δ 8.02–8.07 (m, 2H), 7.95–8.00(m, 2H), 7.77–7.89 (m, 8H), 7.41–7.58 (m, 10H), 5.66 (dd, J = 9.2, 3.6 Hz, 1H), 5.54 (dd, J = 9.6, 2.0 Hz, 1H), 3.74 (dd, 13.6, 10.0 Hz, 2H), 3.65 (dd, J = 13.6, 3.6 Hz, 1H), 3.49 (dd, J = 9.6, 2.0 Hz, 1H), 3.63–3.70 (m, 2H), 3.56 (dd, J = 13.2, 3.2 Hz, 1H), 3.41 (dd, J = 13.2, 3.2 Hz, 1H),^{13}C NMR ($CDCl_3$): δ 177.1, 176.6, 153.9, 153.7, 138.72, 138.67, 136.0, 135.97, 133.19 (2C), 133.16, 133.11, 128.7, 128.6, 128.03, 128.00, 127.6, 127.65, 127.1, 127.0, 126.39, 126.37, 126.30, 126.29, 126.26, 126.21, 124.9, 124.7, 123.97, 123.95, 123.44, 123.37, 126.3 (2C), 69.4, 69.0, 63.6, 63.1, IR (KBr): ν = 3374, 1052 cm^{-1}; Anal. Calcd. For $C_9H_9NO_2S_2$: C, 64.56; H, 4.28; N, 3.96. Found. C, 64.56; H, 4.13; N, 4.05

Bus [2-(2-oxy-2-benzothiazolyl) ethyl] disulfide (2a). Mp 112–114°C (white solid from dichloromethane-diethyl ether-hexane); ^{1}H NMR ($CDCl_3$): δ. 3.20 (t, J = 6.8 Hz, 2H), 4.84 (t, J = 6.4 Hz, 2H), 7.20–7.26 (m, 1H), 7.33–7.37 (m, 1H) 7.61–7.68 (m, 2H); ^{13}C NMR ($CDCl_3$): δ. 37.26, 69.28, 120.89, 121.28, 123.62, 126.00, 131.97, 149.14, 172.28; IR (KBr): ν = 2958, 1550, 1540, 1443, 1243, 1212, 1073, 1017, 954, 758 cm^{-1}; MS (EI): *m/z* 421.0 (M+1); Anal. Calcd. For $C_{18}H_{16}N_2O_2S_4$: C, 51.40; H, 3.83; N, 6.66. Found. C, 51.25; H, 3.83; N, 6.66.

2-Hydroxybenzothiazole (3). [7] ^{1}H NMR ($CDCl_3$): δ 9.56 (br, 1H), 7.41 (d, 8.0 Hz, 1H), 7.26–7.30 (m, 2H), 7.14–7.18 (m, 2H); ^{13}C NMR ($CDCl_3$): δ 172.85, 135.28, 126.50, 123.90, 123.26, 123.26, 122.55, 111.68.

2-(2-Oxy-2-benzothiazolyl)ethyl 2-(ethoxycarbonyl)ethenyl sulfoxide (8a). Mp 82–84°C (pale yellow solid from dichloromethane-diethyl ether-hexane); ^{1}H-NMR ($CDCl_3$): δ 7.69 (d, J = 6.8 Hz, 1H), 7.65 (d, J = 8.4 Hz, 1H), 7.38 (t, J = 7.2 Hz, 2H), 7.25 (t, J = 7.6 Hz, 2H), 6.70 (d, J = 14.8 Hz, 1H), 5.04–5.10 (m, 1H), 4,92–4.99 (m, 1H), 4.24 (q, J = 7.6 Hz, 2H), 3.45–3.51 (m, 1H), 3.21–3.27 (m, 1H), 31 (t, J = 3.2 Hz, 3H); ^{13}C-NMR ($CDCl_3$): δ 171.56, 163.50, 148.89, 132.05, 126.79, 126.15, 126.14, 123.90, 121.34, 121.07, 62.96, 61.42, 51.83, 14.07; IR (KBr): ν = 3018, 2926, 1711, 1535, 1445, 1370, 1298, 1249, 1217, 1158, 1042, 754 cm^{-1}; Anal. Calcd. For $C_{14}H_{15}NO_4S_2$: C, 51,67; H, 4.65; N, 4.30%. Found. C, 51.57; H, 4.66; N, 4.32%.

2-(2-Oxy-2-benzothiazolyl)ethyl 2-(ethoxycarbonyl)ethenyl sulfoxide (8b). Clear yellow oil (unstable compound), ^{1}H-NMR ($CDCl_3$): δ 7.62–7.77 (m, 3H), 7.34 (t, J = 7.6 Hz, 1H), 7.24 (t, J = 7.6 Hz, 1H), 7.71 (d, J = 15.6 Hz, 1H), 5.76–5.84 (m, 1H), 4.26 (q, J = 7.2 Hz, 2H), 3,38 (dd, J = 13.2, 7.2 Hz, 1H), 3.04 (dd, J = 13.2, 4.0 Hz, 1H), 1.67 (d, J = 6.4 Hz, 3H), 1.32 (t, J = 7,2 Hz, 3H), HRMS (EI) Calcd for $C_{15}H_{17}NO_4S_2$ 339.0599, found *m/z* 339.0590 (M^+)

Bis[2-(ethoxycarbonyl)ethyl]ethenyl sulfoxide (10). Clear yellow oil;^{1} H NMR ($CDCl_3$): δ 7.54 (d, J = 15.2 Hz, 1H), 6.64 (d, J = 14.8 Hz, 1H), 4.26 (q, J = 7.2 Hz, 3H), 1.32 (t, J = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$): δ 163.41, 146.35, 126.08, 61.6, 14.1; IR (NaCl): ν = 1723, 1293, 1265, 1219, 1084, 1031 cm^{-1}; HRMS (EI) Calcd for $C_{10}H_{14}O_5S$ 246,0562, found *m/z* 246.0562.

2-(2-Oxy-2-benzothiazolyl) acrylic acid ethyl ester (11). Mp 51–53°C (white solid from dichloromethane-hexane); ^{1}H NMR ($CDCl_3$): δ 7.93 (d, J = 14.4 Hz, 1H), 7.44–7.46 (m, 1H), 7.35–7.39 (m, 2H), 7.25–7.29 (m, 1H), 6.92 (d, J = 14.4 Hz, 1H), 4.29 (q, J = 7.2 Hz, 2H), 1.34 (t, J = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$): δ 168.88, 167.20, 134.92, 133.59, 126.90, 124.82, 122.95, 122.06, 111.55, 110.48, 60.79, 14.28; IR (KBr) ν = 1712, 1700, 1634, 1471, 1272, 1150 cm^{-1}; HRMS (EI) Calcd for $C_{12}H_{11}NO_3S$ 249.0460, found *m/z* 294.0463 (M^+).

2-Benzothiazolyl 2-(ethoxycarbonyl)ethyl sulfoxide (11). Clear pale yellow oil; ^{1}H NMR ($CDCl_3$): δ 8.10 (d, J = 7.6 Hz, 1H), 7.99 (d, J = 7.6 Hz, 1H), 7.80 (d, J = 15.6 Hz, 1H), 7.57 (t, J = 7.6 Hz, 1H), 7.51 (t, J = 7.6 Hz, 1H), 6.83 (d, J = 15.6 Hz, 1H), 4.23 (q, J = 7.2 Hz, 3H), 1.30 (t, J = 7.2 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 173.8, 163.2, 153.5, 148.5, 135.7, 127.1, 126.6, 126.3, 124.2, 122.3, 61.6, 14.0; HRMS (EI) Calcd for $C_{12}H_{11}NO_3S_2$ 281.0180, found *m/z* 281.0198 (M^+).

Reactions of 2-Benzothiazolyl 2-Hydroxyethyl Sulfoxide (1a) with Several Bases at Room Temperature

To a solution of 2-benzothiazolyl 2-hydroxyethyl sulfoxide (**1a**) (50.0 mg, 0.220 mmol) in anhydrous THF, a solution of several bases dissolved into THF was added with stirring at room temperature under nitrogen. The reaction was monitored by TLC. After the reaction, the mixture was washed with ethyl acetate, and saturated ammonium hydrochloride solution removed the bases. Each product was isolated with general methods.

Reactions of 2-Benzothiazolyl 2-Hydroxyethyl Sulfoxide (1) with Several Bases at 65°C in a Sealed Tube

To a 2 mL Pyrex tube, 2-benzothiazolyl 2-hydroxyethyl sulfoxide (**1**) (50 mg, 0.220 mmol) and several bases (0.440mmol) were added, and this tube was sealed after the replacement with N_2. After the reaction, the mixture was washed with ethyl acetate, and saturated ammonium hydrochloride solution removed the bases. Each product was isolated with silica flash column using hexane:AcOEt (2:1).

Thermal Reactions of 2-Benzothiazolyl 2-Hydroxyethyl Sulfoxide (1) in Ethyl Propiolate

To a 2 mL Pyrex tube, 2-benzothiazolyl 2-hydroxyethyl sulfoxide (**1**) (50 mg, 0.220 mmol) and ethyl propiolate (250 μL, 2.47 mmol) were added, and this tube was sealed after the replacement with N_2. After the reaction, excess ethyl propiolate was evaporated off in vacuo, and the residue was purified by silica short flash column. Each product was isolated by PTLC using hexane:AcOEt (3:1).

Thermal Reaction of 2-Hydroxybenzothiazole (3) with Ethyl Propiolate

A mixture of 2-hydroxybenzothiazole (50.6 mg, 0.335 mmol) and ethyl propiolate (500 μL, 2.94 mmol) was warmed in a Pyrex tube, and then this tube was sealed under nitrogen atmosphere. Heating at 140°C for 6 h afforded 2-(2-oxy-2-benzothiazolyl) acrylic acid ethyl ester (**9**) (27.4 mg, 0.110 mmol) in 33% yield.

Thermal Reaction of Bis[2-(2-oxy-2-benzothiazolyl)ethyl] Disulfide (2)

A solution of **2** (60.0 mg, 0.143 mmol) in 1.0 mL anhydrous 1,4-dioxane was warmed to 140°C in a sealed tube. After 24 h, the solvent was evaporated off, and the product was purified by silica flash column using dichloromethane to afford **3** in 82% yield.

2-Benzothiazolyl Ethyl Sulfide (14)[8]

To a mixture of 2-mercaptobenzothiazole (1.10 g, 6.59 mmol) and ethyl iodide (630 μL, 7.91 mmol) in distilled dichloromethane (30 mL), anhydrous triethylamine (3.0 mL) was added with stirring at room temperature. After the starting materials were consumed, the solvent and excess triethylamine were evaporated off in vacuo. The residue was washed with dichloromethane (20 mL) and pure water (20 mL × 3), and the organic layer was dried over anhydrous magnesium sulfate. After removal of the solvent, the residue was purified by silica short flash column using dichloromethane:hexane (1:1) to afford 2-benzothiazolyl ethyl sulfide in a quantitative yield.

^{1}H NMR (CDCl$_3$, 400MHz) δ 7.87 (d, $J = 8.4$ Hz, 1H), 7.76 (d, $J = 8.4$ Hz, 1H), 7.39–7.43 (m, 1H), 7.27–7.31 (m, 1H), 3.36 (q, $J = 7.2$ Hz, 2H), 1.50 (t, $J = 7.2$ Hz, 3H); HRMS (EI) Calcd for $C_9H_9NS_2$ 195.0176, found *m/z* 195.0176 (M$^+$).

2-Benzothiazolyl Ethyl Sulfoxide (15)

To a solution of 2-benzothiazolyl ethyl sulfide (473 mg, 2.42 mmol) in distilled dichloromethane (20 mL), a dichloromethane solution of *m*-chloroperbenzoic acid (70%) (597 mg, 2.42 mmol) was added with stirring at room temperature under nitrogen. The reaction was monitored by TLC. After 4 h, the starting material was consumed smoothly. The reaction mixture was washed with 5% aqueous potassium carbonate solution (20 mL × 5) to remove formed *m*-chlorobenzoic acid. The organic phase was dried over anhydrous magnesium sulfate. After removal of the solvent, 2-benzothiazolyl ethyl sulfoxide was obtained. Yield 81%; mp 41–43°C (white solid from dichloromethane-diethylether-hexane); ^{1}H NMR (CDCl$_3$): δ 8.07 (d, $J = 8.0$ Hz, 1H), 8.01 (d, $J = 8.0$ Hz, 1H), 7.57 (dd, $J = 8.0, 1.2$ Hz, 1H), 7.50 (dd, $J = 8.0, 1.2$ Hz, 1H), 3.16–3.25 (m, 1H), 3.29–3.38 (m, 1H), 1.36 (t, $J = 7.6$ Hz, 1H); ^{13}C NMR (CDCl$_3$): δ 177.2, 166.7, 153.4, 126.1, 123.9, 122.4, 50.1, 5.5; IR (KBr): $\nu = 3062, 2973, 2957, 1472, 1062, 1025, 766$ cm^{-1}; Anal. Calcd. For $C_9H_9NOS_2$: C, 51.16; H, 4.29; N, 6.63. Found. C, 51.14; H, 4.28; N, 6.69.

Thermal Reaction of 2-Benzothiazolyl Ethyl Sulfoxide in Ethyl Propiolate

To a 2 mL Pyrex tube, 2-benzothiazolyl ethyl sulfoxide (**1**) (50.0 mg, 0.237 mmol) and ethyl propiolate (250 μL, 2.47 mmol) were added, and this tube was sealed after the replacement with N_2. After the reaction, excess ethyl propiolate was evaporated off in vacuo, and 2-benzothiazolyl 2-(ethoxycarbonyl)ethyl sulfoxide (**13**) was isolated by PTLC using hexane:AcOEt (3:1) as a clear yellow oil (42.6 mg, 64%).

REFERENCES

1. (a) H. Morita, M. Takeda, H. Kamiyama, T. Hashimoto, T. Yoshimura, C. Shimazaki, and E. Tsukurimichi, *Tetrahedron Lett.*, **37,** 3739 (1996); (b) H. Morita, M. Takeda, H. Kamiyama, T. Yoshimura, T. Fujii, S. Ono, and C. Shimasaki, *J. Org. Chem.*, **62,** 9018 (1997).
2. H. Morita, M. Takeda, H. Kamiyama, T. Yoshimura, T. Fujii, S. Ono, and C. Shimasaki, *J. Org. Chem.*, **64,** 6730 (1999).
3. (a) N. Yamada, M. Mizuochi, and H. Morita, *Tetrahedron*, **63,** 3408 (2007); (b) N. Yamada, M. Mizuochi, M. Takeda, H. Kawaguchi, and H. Morita, *Tetrahedron Lett.*, **49,** 1166 (2008).
4. F. A. Davis, A. J. Friedman, and U. K. Nadir, *J. Am. Chem. Soc.*, **100,** 2844 (1978).
5. (a) T. C. Bruice and R. T. Markiw, *J. Am. Chem. Soc.*, **79,** 3150 (1957); (b) T. C. Bruice and Q. B. Sayigh, *J. Am. Chem. Soc.*, **81,** 3416 (1959); (c) W. C. Hamilton and S. J. LaPlaca, *J. Am. Chem. Soc.*, **86,** 2289 (1964); (d) B. C. Pal, M. Uziel, D. G. Doherty, and W. E. Cohn, *J. Am. Chem. Soc.*, **91,** 3634 (1969); (e) T. S. Chou, J. R. Burgtorf, A. L. Ellis, S. R. Lammert, and S. P. Kukolja, *J. Am. Chem. Soc.*, **96,** 1609 (1974); (f) M. D. Bachi and A. J. Gross, *Org. Chem.*, **47,** 897 (1982); (g) A. Heckel and W. Pfleiderer, *Tetrahedron Lett.*, **24,** 5047 (1983); (h) N. Nakamura, *J. Am. Chem. Soc.*, **105,** 7172 (1983); (i) M. Mikołajczyk, P. Łyzwa, J. Drabowicz, M. Wieczorek, and G. Bujacz, *Angew. Chem., Int. Ed. Engl.*, **28,** 97 (1989); (j) T. Yoshimura, E. Tsukurimichi, S. Yamazaki, S. Soga, C. Shimasaki, and K. Hasegawa, *J. Chem. Soc., Chem. Commun.*, 1337 (1992); (k) T. Yoshimura, K. Hamada, S. Yamazaki, C. Shimasaki, S. Ono, and E. Tsukurimichi, *Bull. Chem. Soc. Jpn.*, **68,** 211 (1995); (l) K. Goto, N. Tokitoh, and R. Okazaki, *Angew. Chem., Int. Ed. Engl.*, **34,** 1124 (1995); (m) T. Saiki, K. Goto, N. Tokitoh, and R. Okazaki, *J. Org. Chem.*, **61,** 2924 (1996).
6. F. A. Davis, L. A. Jenkins, and R. L. Billmers, *J. Org. Chem.*, **51,** 1033 (1966).
7. Y. Yatsumonji, O. Okada, T. Tsubouchi, and T. Takeda, *Tetrahedron*, **62,** 9981 (2006).
8. (a) K. Takeda and H. Ogura, *Synth. Commun.*, **12,** 213 (1982); (b) H. J. M. Dou, P. Hassanaly, J. Kister, G. Vernin, and, J. Metzger, *Helv. Chim. Acta*, **61,** 3143 (1978).