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Novel Photoinduced Reduction of Conjugate Dienes by the Combination of Benzenethiol and Diphenyl Diselenide

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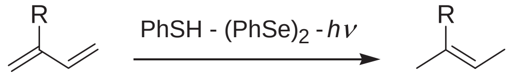
By using a binary system that consisted of benzenethiol and diphenyl diselenide under photoirradiation through a Pyrex vessel with a xenon lamp ($\lambda > 300$ nm), a variety of conjugate dienes could be reduced to the corresponding internal alkenes under mild conditions.

Glutathione peroxidase (GPx), which has –SeH groups at its active sites, catalyzes in vivo the reduction of hydroperoxides (ROOH) with cysteine or glutathione (GSH), which has an –SH group (Fig. 1).[1]

In this reduction system, selenol (RSeH), thiol (R′SH), and selenosulfide (RSeSR′) play important roles, and therefore, it is of great importance to clarify the reducing behavior of chalcogen compounds bearing a Ch–H or Ch–Ch bond (Ch = S and Se) under radical conditions, especially, in the mixed systems of them. In view of our biological and synthetical interest involving mixed systems of such chalcogen compounds,[2] we examined the photoinduced reduction of several unsaturated compounds using PhSH–$(PhSe)_2$ as a model system by combining a Ch–H compound and a Ch–Ch compound. This attempt led to a new reduction reaction of conjugate dienes **1** to the corresponding alkenes **2** by using the PhSH–$(PhSe)_2$ mixed system under photoirradiation conditions (Eq. 1).



1 **2** (1)

Results and Discussion

The reaction of 2,3-dimethyl-1,3-butadiene (**1a**) with PhSH (10 mol. amt.) in $CDCl_3$ was conducted at room temperature in the presence/absence of $(PhSe)_2$ (0.30 mol. amt.) under irradiation with a xenon lamp through a Pyrex vessel ($\lambda > 300$ nm), and was monitored by taking the ^1H NMR spectra of the reaction solution (Fig. 2).

As can be seen from Fig. 2, in the absence of $(PhSe)_2$, a conjugate addition product, i.e., allyl sulfide derivative **3a**, was obtained in excellent yield within 6 h. On the other hand, in the presence of $(PhSe)_2$, 2,3-dimethyl-2-butene (**2a**), as a reduction product, was formed gradually with a decrease in the yield of **3a** by continuous photoirradiation. To increase the yield of the reduced product **2a**, the reaction of **1a** with PhSH in the presence of $(PhSe)_2$ under photoirradiation for 24 h was examined under several reaction conditions (Table 1).

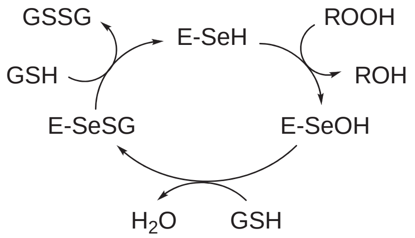


Fig. 1. Catalytic cycle for the glutathione peroxidase-catalyzed reduction of hydroperoxides with glutathione.

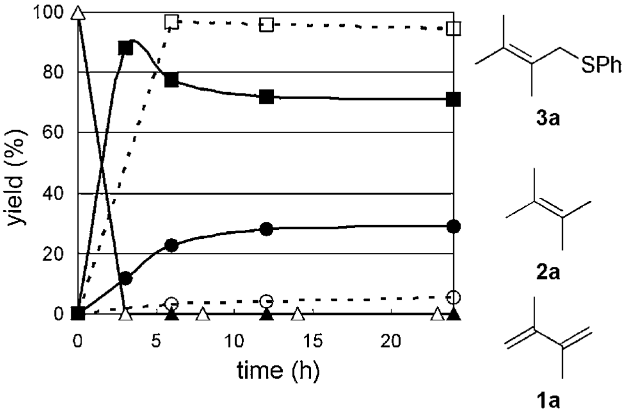
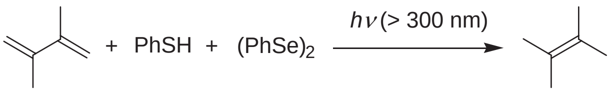


Fig. 2. Photoinduced reduction of **1a**. — presence of $(PhSe)_2$, ▲: yield of **1a**; ●: yield of **2a**; ■: yield of **3a**. --- absence of $(PhSe)_2$, △: yield of **1a**; ○: yield of **2a**; □: yield of **3a**.

Table 1. Photoinduced Reduction of 2,3-Dimethyl-1,3-butadiene (**1a**)[a)]



1a **2a**

Entry	PhSH /mol. amt.	$(PhSe)_2$ /mol. amt.	Yield[b)]/%
1	10	0.30	29
2	2.0	1.0	45
3	2.0	10	33
4	3.0	2.0	50
5	3.0	5.0	49

a) Reaction conditions: 2,3-dimethyl-1,3-butadiene (**1a**, 0.1 mmol), PhSH, $(PhSe)_2$, $CDCl_3$ (0.5 mL), rt, $h\nu$: xenon lamp (through Pyrex). b) Determined by ^1H NMR.

The use of excess amounts of PhSH and $(PhSe)_2$ improved the yield of the reduction product **2a** (Entries 4 and 5). Thus,

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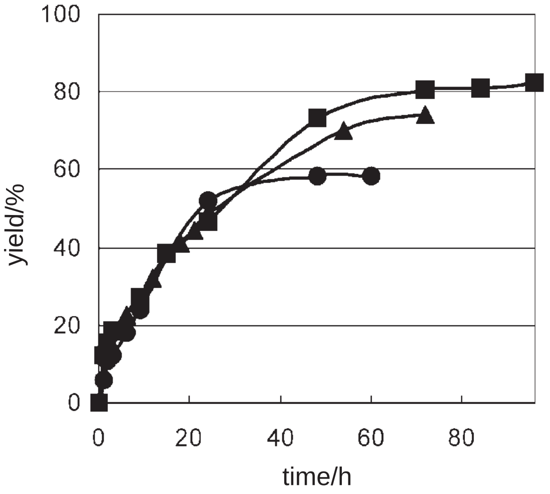
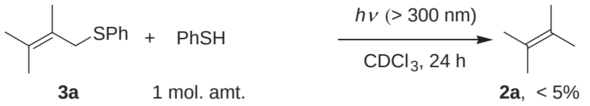


Fig. 3. Photoinduced reduction of **1a**. —■—: 3 mol. amt. of PhSH; 2 mol. amt. of $(PhSe)_2$, —▲—: 3 mol. amt. of PhSH; 5 mol. amt. of $(PhSe)_2$, —●—: 2 mol. amt. of PhSH; 1 mol. amt. of $(PhSe)_2$.

we examined the reaction by prolonging irradiation time, and the results are summarized in Fig. 3. A 3/2 molar ratio of PhSH/$(PhSe)_2$ provided **2a** in more than 80% yield.

The results of the reduction of various dienes using the PhSH/$(PhSe)_2$ mixed system are summarized in Table 2. Similar conditions could be employed with isoprene (**1b**) and 1,3-pentadiene (**1c**) (Entries 2 and 3). On the other hand, 1,4-diphenyl-1,3-butadiene (**1d**) did not undergo reduction, probably due to the bulkiness of the phenyl groups at the terminal positions (Entry 4). The reduction of cyclic dienes **1e**, **1f**, and **1g** proceeded successfully, affording the corresponding cyclic alkenes **2e**, **2f**, and **2g**, respectively, in high yields (Entries 5–7). With β-myrcene (**1h**), the reduction took place only at the conjugate double bond (Entry 8). When benzeneselenol was employed in place of $(PhSe)_2$, the reduction of diene took place smoothly (1 h) (Entry 9).[3] Next, we examined the recycling of $(PhSe)_2$ for this diene reduction. After the reduction of diene **1a** was complete, $(PhSe)_2$ was recovered as a dichalcogenide mixture ($(PhSe)_2$:$(PhS)_2$:PhSSePh = 4:2:1). Using this dichalcogenide mixture, the reduction of diene **1a** was attempted and **2a** was obtained in 74% yield (Entry 10).

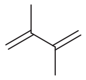
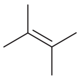
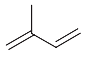
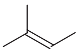
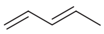
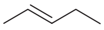
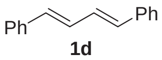
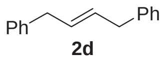
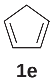
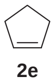
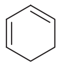
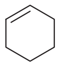
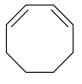
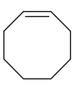
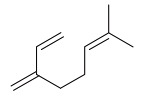
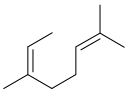
To clarify the reaction pathway for this reduction, 2,3-dimethyl-2-butenyl phenyl sulfide (**3a**)[4] and selenide (**4a**) as plausible intermediates were synthesized by the reaction of the corresponding diene **1a** with PhSH and PhSeH, respectively. Thus, we examined the reduction of these adducts under several conditions, as shown in Eqs. 2–4. When the reaction of allyl sulfide derivative (**3a**) with 1 molar amount of benzenethiol was conducted with photoirradiation, the reduction did not occur efficiently (Eq. 2).



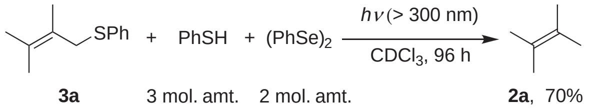
(2)

However, addition of $(PhSe)_2$ to this reaction system and prolonged photoirradiation (96 h) resulted in the formation of the reduction product **2a** in 70% yield (Eq. 3).

Table 2. Photoinduced Reduction of Conjugate Dienes with PhSH/$(PhSe)_2$[a)]

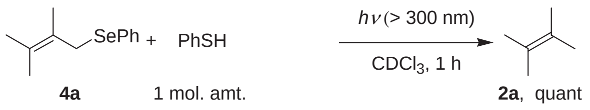
Entry	Diene	Time /h	Product	Yield /%[b)]	Recovered $(PhSe)_2$/%[e)]
1	 **1a**	96	 **2a**	82	88
2	 **1b**	100	 **2b**	45	77
3	 **1c**	70	 **2c**	78	86
4	 **1d**	100	 **2d**	0	80
5	 **1e**	96	 **2e**	62	83
6	 **1f**	72	 **2f**	73	74
7	 **1g**	96	 **2g**	81	79
8	 **1h**	110	 **2h**	70	90
9[c)]	**1a**	1	**2a**	>95	—
10[d)]	**1a**	72	**2a**	74	58

a) Reaction conditions: conjugate diene (0.1 mmol), PhSH (0.3 mmol), $(PhSe)_2$ (0.2 mmol), $CDCl_3$ (0.5 mL), rt, $h\nu$: xenon lamp (through Pyrex). b) Determined by ^{1}H NMR. c) Use of PhSeH (0.4 mmol) in place of $(PhSe)_2$ (0.2 mmol). d) Use of recovered $(PhSe)_2$ instead of pure $(PhSe)_2$. e) Along with 10%–20% of PhSSePh.



(3)

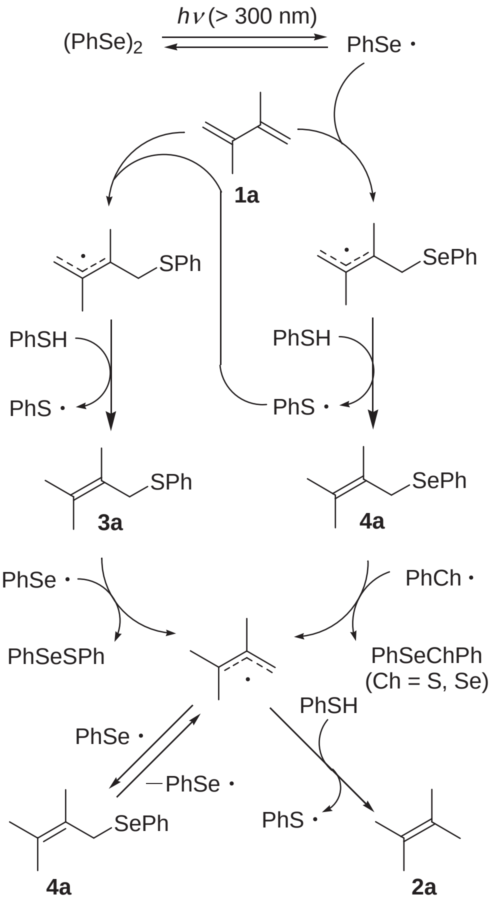
In the case of allyl selenide derivative **4a**, the photoinduced reduction took place very smoothly (1 h) to afford **2a** quantitatively (Eq. 4).



(4)

These results prompted us to propose a possible pathway for this photoinduced reduction using a PhSH–$(PhSe)_2$ binary system (Scheme 1).

Under irradiation with a xenon lamp through a Pyrex vessel ($\lambda > 300$ nm), $(PhSe)_2$ ($\lambda_{axi} = 330$ nm) mainly undergoes homolytic dissociation to generate PhSe•,[5] which adds to conjugate diene **1a**, forming seleno group-substituted allyl radical. The allyl radical abstracts a hydrogen from PhSH[6] to produce an allyl selenide derivative **4a** with the generation of phenyl-



Scheme 1.

thio radical, which adds to diene **1a**. Similar hydrogen abstraction by the thio group-substituted allyl radical yields an allyl sulfide derivative **3a**. Both allyl chalcogenide derivatives **3a** and **4a** undergo a S_H2 reaction with seleno and/or thio radical(s) to generate an allyl radical, which is captured by thiol affording the reduction product **2a**. In this reaction system, $(PhSe)_2$, which has excellent carbon radical capturing ability,[7] inhibits the polymerization of dienes.[8]

In summary, a new reduction system by combining PhSH and $(PhSe)_2$ was developed, which is useful for the reduction of conjugate dienes. We are now investigating the reduction behavior of this system in the presence of oxidizing reagents, such as H_2O_2 or O_2.

Experimental

General Procedure for the Photoinduced Reduction of Conjugate Dienes with Benzenethiol and Diphenyl Diselenide. In a Pyrex glass tube ($\phi = 5$ mm, length = 180 mm) were placed 2,3-dimethyl-1,3-butadiene (**1a**, 11 µL, 0.1 mmol), benzenethiol (31 µL, 0.3 mmol), diphenyl diselenide (62.4 mg, 0.2 mmol), and $CDCl_3$ (0.5 mL) under nitrogen atmosphere. After irradiation with a xenon lamp (500 W) at ambient temperature for 96 h, 2,3-dimethyl-2-butene (**2a**) was obtained in 82% yield.

Synthesis of 2,3-Dimethyl-2-butenyl Phenyl Selenide (4a). In a two-necked flask (30 mL) were placed 2,3-dimethyl-1,3-butadiene (**1a**, 1.2 mL, 11 mmol) and benzeneselenol (1.1 mL, 5.0 mmol), and then the solution was stirred for 10 min under the atmosphere at ambient temperature. The resulting solution was path through the silica pad (eluent: hexane) and concentrated in vacuo, yielding 2.90 g (85%) of 2,3-dimethyl-2-butenyl phenyl selenide (**4a**) as a yellow oil.

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References

1 *Selenium in Biology and Human Health*, ed. by R. F. Burk, Springer-Verlag, New York, **1994**.

2 a) A. Ogawa, H. Tanaka, H. Yokoyama, R. Obayashi, K. Yokoyama, N. Sonoda, *J. Org. Chem.* **1992**, *57*, 111. b) A. Ogawa, R. Obayashi, N. Sonoda, T. Hirao, *Tetrahedron Lett.* **1998**, *39*, 1577. c) A. Ogawa, R. Obayashi, H. Ine, Y. Tsuboi, N. Sonoda, T. Hirao, *J. Org. Chem.* **1998**, *63*, 881. d) A. Ogawa, R. Obayashi, M. Doi, N. Sonoda, T. Hirao, *J. Org. Chem.* **1998**, *63*, 4277. e) A. Ogawa, I. Ogawa, R. Obayashi, K. Umezu, M. Doi, T. Hirao, *J. Org. Chem.* **1999**, *64*, 86. f) K. Tsuchii, Y. Tsuboi, S. Kawaguchi, J. Takahashi, N. Sonoda, A. Nomoto, A. Ogawa, *J. Org. Chem.* **2007**, *72*, 415. g) Y. Takaguchi, Y. Katayose, Y. Yanagimoto, J. Motoyoshiya, H. Aoyama, T. Wakahara, Y. Maeda, T. Akasaka, *Chem. Lett.* **2003**, *32*, 1124. h) A. Ogawa, T. Hirao, *Rev. Heteroat. Chem.* **1998**, *18*, 1. i) A. Ogawa, in *Main Group Metals in Organic Synthesis*, ed. by H. Yamamoto, K. Oshima, Wiley-VCH, Weinheim, **2004**, Vol. 2, p. 813.

3 The diene reduction using PhSeH may proceed via (i) the addition of the selenol to diene to form allylic selenide; (ii) the generation of allylic radical from allylic selenide upon photoirradiation or by the attack of seleno radical; (iii) hydrogen abstraction from PhSe–H. For the radical trapping abilities of PhSe–H: $k_{\mathrm{PhSe\text{–}H}} = 2.0 \times 10^9\ \mathrm{M^{-1}\,s^{-1}}$, see: M. Newcomb, M. B. Manek, *J. Am. Chem. Soc.* **1990**, *112*, 9662.

4 For the synthesis of 2,3-dimethyl-2-butenyl phenyl sulfide (**3a**), see for example: A. A. Oswald, K. Griesbaum, W. A. Thaler, B. E. Hudson, Jr., *J. Am. Chem. Soc.* **1962**, *84*, 3897.

5 U. Schmidt, A. Müller, K. Markau, *Chem. Ber.* **1964**, *97*, 405.

6 The capturing rate constant of PhSH to Barton PTOC ester: $k_{\mathrm{PhS\text{–}H}} = 1.1 \times 10^8\ \mathrm{M^{-1}\,s^{-1}}$. See for example: J. A. Franz, B. A. Bushaw, M. S. Alnajjar, *J. Am. Chem. Soc.* **1989**, *111*, 268.

7 The rate constants for the S_H2 reaction of 5-hexenyl radical with $(PhS)_2$ and $(PhSe)_2$ are 7.6×10^4 and $1.2 \times 10^7\ \mathrm{M^{-1}\,s^{-1}}$, respectively. See for example: a) G. A. Russell, H. Tashtoush, *J. Am. Chem. Soc.* **1983**, *105*, 1398. b) M. J. Perkins, E. S. Turner, *J. Chem. Soc., Chem. Commun.* **1981**, 139. c) G. A. Russell, P. Ngoviwatchai, H. I. Tashtoush, A. Pla-Dalmau, R. K. Khanna, *J. Am. Chem. Soc.* **1988**, *110*, 3530.

8 The photoinduced reaction of conjugate dienes with $(PhS)_2$ causes the polymerization of dienes, whereas the same reaction in the presence of $(PhSe)_2$ successfully afforded the thioselenated dienes without the formation of any polymerization products (see: Ref. 2b).