A New Route to Dihydrodithiins by a Catalytic Reaction of Vinylthiiranes with W(CO)$_5$(NCMe)

Richard D. Adams,* J. W. Long, IV, and Joseph L. Perrin

Department of Chemistry and Biochemistry
University of South Carolina
Columbia, South Carolina 29208

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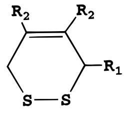
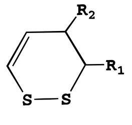
Dihydrodithiins **A** and **B** are a family of naturally occurring compounds that have been found to exhibit a range of antiviral, antifungal, and antibiotic properties.[1]

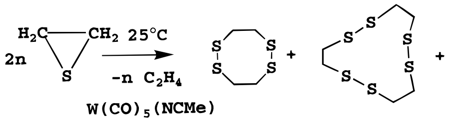


A



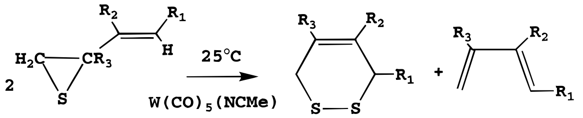
B

In recent investigations, we have found that simple thiiranes can be converted into cyclic *poly*disulfides catalytically in the presence of the catalyst W(CO)$_5$, eq 1.[2]



(1)

We have now found that vinylthiiranes[3−5] are readily and catalytically converted into a 1/1 mixture of the 3,6-dihydro-1,2-dithiins **A** and the corresponding butadiene under unusually mild conditions in the presence of W(CO)$_5$(NCMe),[6] **1**, eq 2.[7] Using the parent SCH$_2$CH(CH=CH$_2$), **2** (R$_1$ = R$_2$ = H), the 3,6-dihydro-1,2-dithiin **7**, was obtained in 82% yield at a turnover frequency of 15/h at 25 °C.



(2)

2 R$_1$=R$_2$=R$_3$=H
3 R$_1$=R$_3$=H,R$_2$=Me
4 R$_1$=Me,R$_2$=R$_3$=H
5 R$_1$=R$_2$=Me,R$_3$=H
6 R$_1$=R$_2$=H,R$_3$=Me

7 R$_1$=R$_2$=R$_3$=H
8 R$_1$=R$_3$=H,R$_2$=Me
9 R$_1$=Me,R$_2$=R$_3$=H
10 R$_1$=R$_2$=Me,R$_3$=H
8 R$_1$=R$_2$=H,R$_3$=Me

Table 1. Results of Catalytic Transformations of Vinylthiiranes to Dihydrodithiins by Compound **1**

reagent	product	yield (%)[a]	TON[b](24 h)	TOF[c]
2	**7**	82	212	15
3	**8**	84	141	29
4	**9**	86	149	24
5	**10**	80	146	19
6	**8**	34[d]	53	2

[a] Yields based on eq 2 at 24 h. [b] Number of moles product per mole of catalyst (**1** = W(CO)$_5$NCMe). [c] Number of moles product per mole catalyst per hour (based on the amount of product formed after 4 h). [d] 85% yield after 72 h.

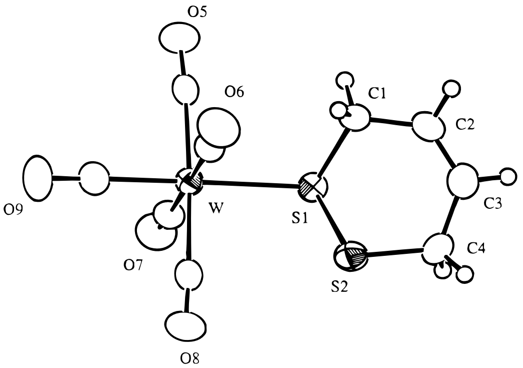


Figure 1. An ORTEP diagram of W(CO)$_5$(SSCH$_2$CH=CHCH$_2$), **11**, showing 40% probability thermal ellipsoids. Selected interatomic distances (Å) and angles (deg): W−S(1) = 2.549(2), S(1)−S(2) = 2.062(2), S(1)−C(1) = 1.820(7), S(2)−C(4) = 1.811(7), C(1)−C(2) = 1.487(9), C(2)−C(3) = 1.323(8), C(3)−C(4) = 1.49(1); W−S(1)−S(2) = 105.32(8).

In the absence of catalyst or in the presence of W(CO)$_6$, only traces of the dithiin products (<1%) were formed under the same conditions. Table 1 provides the yields, turnover numbers, and turnover frequencies for the various vinylthiiranes that have been studied. On the basis of the turnover frequencies for product formation, the addition of methyl substituents to the vinyl group clearly increases the rate of reaction. On the other hand, placement of a methyl group on the thiirane ring drastically reduces the rate of reaction as shown by the reaction of thiirane **6**.

Small amounts of a tungsten complex, W(CO)$_5$(SSCH$_2$CH=CHCH$_2$), **11**, were obtained from the reaction of **2** after removal of the volatiles and purification of the residue by TLC on silica gel.[8] Compound **11** was characterized by single-crystal X-ray diffraction analysis,[9] and an ORTEP diagram of its molecular structure is shown in Figure 1. The molecule contains a W(CO)$_5$ grouping with a 3,6-dihydro-1,2-dithiin ligand coordinated to the tungsten atom through one of its two sulfur atoms, W−S(1) = 2.549(2) Å and S(1)−S(2) = 2.062(2) Å.

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(1) (a) Block, E. *Angew. Chem., Int. Ed. Engl.* **1992**, *31*, 1135. (b) Steliou, K.; Folkins, P. L.; Harpp, D. N. *Adv. Sulfur Chem.* **1994**, *1*, 97. (c) Steliou, K.; Gareau, Y.; Milot, G.; Salama, P. *Phosphorus, Sulfur, Silicon* **1989**, *43*, 209.

(2) (a) Adams, R. D.; Queisser, J. A.; Yamamoto, J. H. *Organometallics* **1997**, *16*, 1430. (b) Adams, R. D.; Queisser, J. A.; Yamamoto, J. H. *J. Am. Chem. Soc.* **1996**, *118*, 10674.

(3) Vinyl epoxide was obtained from Eastman Chemical Co. Substituted vinylthiiranes were prepared by conversion of the appropriate α,*β*-unsaturated aldehydes to the corresponding vinyl epoxides by known procedures.[4] All vinyl epoxides were converted to the corresponding vinylthiiranes by treatment with KSCN.[5]

(4) Trost, B. M.; Melvin, L. S., Jr. *Sulfur Ylides. Emerging Synthetic Intermediates*; Academic Press: New York, 1975.

(5) Snyder, H. R.; Stewart, J. M.; Ziegler, J. B. *J. Am. Chem. Soc.* **1947**, *69*, 2672.

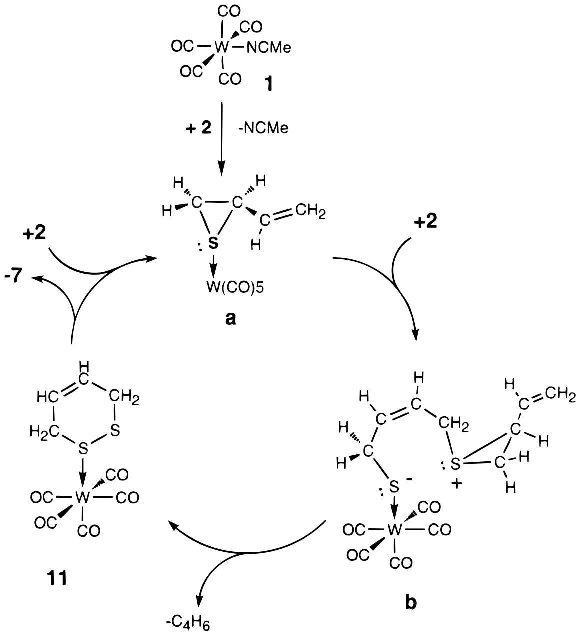
(6) Ross, B. F.; Grasselli, J. G.; Ritchey, W. M.; Kaesz, H. D. *Inorg. Chem.* **1963**, *2*, 1023.

(7) A typical reaction is as follows: A 5.0 mg amount of **1** was placed into an NMR tube with 0.5 mL of the selected vinylthiirane[5] and 0.5 mL of CD$_2$Cl$_2$. C$_6$Me$_6$ (10.0 mg) was added to serve as a quantitative reference. The solution was shaken and maintained at room temperature for 24 h. During this time there was a progressive transformation to a 1/1 mixture of the dithiin and the corresponding diene. For 3,6-dihydrodithiin, **2**: ^{1}H NMR (δ in CDCl$_3$) 5.97 (t, ^3J = 2.1 Hz, 2H), 3.26 (d, ^3J = 2.2 Hz, 4H); ^{13}C NMR (δ in CDCl$_3$) 125.50 (2C), 28.23 (2C). The mass spectrum shows the parent ion at 118 *m/e*, as well as additional ions with weights of 103, 85, and 64 m^+/e.

(8) Only small quantities of **11** were obtained from the catalytic reactions (e.g., 2.5 mg) due to the small amounts of **1** (5.0 mg) initially used. Compound **11** was obtained in 48% yield from the reaction of 50.0 mg of **1** (0.137 mmol) with 0.17 mL of **2** (2.74 mmol) in 5 mL of methylene chloride at 25 °C for 24 h. The product was isolated by TLC on silica gel using a hexane/methylene chloride 3/1 solvent mixture to yield 29.1 mg of **11**. Spectral data for **11**: IR ν_{CO} (cm^{-1} in hexane) 2078 (w), 1986 (w), 1949 (vs), 1939 (m); ^{1}H NMR (δ in CDCl$_3$) 6.08 (m, 1H), 6.00 (m, 1H), 3.62 (m, 2H), 3.43 (m, 2H); ^{13}C NMR (δ in C$_6$D$_6$) 199.42 (1C), 196.67 (4C), 124.89 (1C), 124.26 (1C), 41.23 (1C), 30.48 (1C). Anal. Calcd for C$_9$H$_6$O$_5$S$_2$W: C, 24.45, H, 1.37. Found: C, 24.12; H, 1.47.

S0002-7863(97)03880-8 CCC: $15.00

Scheme 1 Catalytic Cycle for the Transformation of Vinylthiirane (**2**) to 3,6-Dihydro-1,2-dithiin (**7**)



The catalytic activity of **11** for reaction 2 is the same as that of **1** which suggests that **11** is a species in the catalytic cycle (Scheme 1). It has been shown that **1** reacts with certain thiiranes to form stable complexes with $W(CO)_5$ by coordination of the sulfur atom.[2,10] Although we have not observed a vinylthiiraneW-$(CO)_5$ complex, we believe that the first step in these reactions is the formation of a (thiirane)$W(CO)_5$ intermediate (**a**) by displacement of the labile NCMe ligand from **1**. The addition of an equivalent of vinylthiirane to the CH_2 terminus of the vinyl group in **a** could lead to formation of a zwitterionic intermediate (**b**) with opening of the ring of the coordinated thiirane and a shift of the unsaturation to the position between the two CH groups. Elimination of butadiene from the positively charged sulfur atom in **b**, followed by neutralization of the charges on the two sulfur atoms with formation of a S−S single bond, would yield the product **11**. Substitution of the dihydrodithiin ligand in **11** by another equivalent of vinylthiirane results in regeneration of intermediate **a** and closes the catalytic cycle.

The reactions of vinylthiirane with strong Lewis acids and Lewis bases (e.g., $ZnEt_2$, LiBu; $BF_3 \cdot OEt_2 \cdot H_2O$, $TiCl_4$) have been reported to yield mixtures of 1,3 and 1,5 polymers by opening of the thiirane rings.[11] 3,6-Dihydrodithiins have been synthesized by the reaction of butadienes with suitable sources of S_2.[12] The conversion of vinylthiiranes into 3,6-dihydro-1,2-dithiins and the corresponding desulfurized butadiene by $W(CO)_5$ appears to be a most efficient and convenient method for the preparation of a range of dihydro-1,2-dithiins and further illustrates the value of this metal carbonyl in promoting transformations of strained ring thioethers into new sulfur containing compounds.[13]

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Supporting Information Available: Details of the synthesis and characterizations of the products and tables of final atomic positional parameters, intramolecular bond distances and angles, and anisotropic thermal parameters (11 pages). See any current masthead page for ordering information and Web access instructions.

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[9] Crystal data for **11**: space group = *Pbca*, $a = 15.688(2)$ Å, $b = 17.534(3)$ Å, $c = 9.305(1)$ Å, $Z = 8$, 1638 reflections, $R = 0.022$, $R_w = 0.023$. Diffraction data were collected on a Rigaku AFC6S diffractometer using Mo $K\alpha$ radiation. The structure was solved by direct methods using the Texsan structure solving program library obtained from the Molecular Structure Corp., The Woodlands, TX.

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