A above. Products were isolated by ether extraction, and purification was accomplished by column chromatography on 230–400-mesh silica gel (Merck) with hexane/ethyl acetate (10:1) as solvent.

3,4,5,6-Tetrahydro-1(2*H*)-naphthalenone (1): oil (unstable; gradually rearomatizes, and so microanalysis was not possible); IR (CCl_4) 1680 cm^{-1}; NMR (CCl_4) δ 1.8–2.5 (m, 10 H), 5.75 (1 H, vinyl), 6.45 (1 H, vinyl); mass spectrum, m/e 148 (M^+).

1,1′,2,2′,3,3′,4,4′-Octahydro-1,1′-binaphthyl-1,1′-diol (4): mp 189–191 °C (lit.[12] mp 191 °C); NMR (CCl_4) δ 1.0–1.8 (m, 8 H), 2.4–2.8 (m, 4 H), 3.1 (s, 2 H), 7.0–7.4 (m, 6 H), 8.0–8.35 (m, 2 H).

1,1′,2,2′,3,3′,4,4′-Octahydro-1,1′-binaphthyl-1-ol (5): mp 92–94 °C (hexane); NMR (CCl_4) δ 1.0–1.75 (m, 8 H), 1.8 (s, 1 H), 2.45–2.70 (m, 4 H), 3.65 (t, 1 H), 6.85–7.15 (m, 6 H), 7.35–7.60 (m, 1 H), 7.7–7.9 (m, 1 H); mass spectrum, m/e 278 (M^+).

Anal. Calcd for $C_{20}H_{22}O$: C, 86.28; H, 7.96. Found: C, 86.13; H, 7.88.

1,1′,2,2′,3,3′,4,4′-Octahydro-1,1′-binaphthyl (6): oil;[13] NMR (CCl_4) δ 1.2–2.0 (m, 8 H), 2.6 (t, 4 H), 3.3 (m, 2 H), 6.7–7.0 (m, 8 H); mass spectrum, m/e 262 (M^+).

1,1′,2,2′,3,3′,4,4′,5,8-Decahydro-1,1′-binaphthyl (7): colorless oil; NMR (CCl_4) δ 1.15–2.05 (m, 10 H), 2.6 (m, 7 H), 3.1 (m, 1 H), 5.65 (br s, 2 H), 6.8–7.35 (m, 4 H); mass spectrum, m/e 264 (M^+).

Anal. Calcd for $C_{20}H_{24}$: C, 90.85; H, 9.15. Found: C, 90.35; H, 9.07.

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Registry No. 1, 113668-50-1; 2, 529-33-9; 3, 119-64-2; 4, 3073-53-8; 5, 113668-51-2; 6, 1154-13-8; 7, 113668-52-3; α-tetralone, 529-34-0.

(12) Barnett, E. B.; Lawrence, C. A. *J. Chem. Soc.* **1935**, 1104.
(13) Ruehle, P. H.; Dobbs, T. K.; Ansell, L. L.; van der Helm, D.; Eisenbraum, E. J. *J. Org. Chem.* **1977**, *42*, 1098.

Diethyldithiocarbamic Acid *S*-Oxide: A New Class of Sulfine

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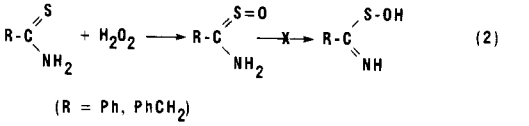
Sodium diethyldithiocarabamate (**1a**) has been widely used as a copper trapping reagent. Thus, the inhibition of an enzymatic reaction by **1a** has been regarded as a proof of the participation of copper in the reaction.[1] However, we previously noted that the inhibitory effect of **1a** on the oxygenase activity of L-tryptophan 2,3-dioxygenase was caused by its rapid reaction with hydrogen peroxide, the activator of the enzyme, instead of the chelation with copper.[2] While the oxidation product(s) of **1a** with hydrogen peroxide has never been characterized, compounds bearing a dithiocarboxylic acid group are known as strong reducing reagents;[3] even sulfoxides are readily reduced to give the corresponding sulfides (eq 1).[4]

(1)

Since thiols and dithiocarboxylic acids show similar reactivity to give the corresponding disulfides in oxidation reactions,[5] the dimeric form of **1a** can be a candidate for the product in the reaction of **1a** with hydrogen peroxide. On the other hand, the oxidation of thioamides by hydrogen peroxide is known to afford thioamide *S*-oxides (eq 2).[6] Accordingly, sodium diethyldithiocarbamate *S*-oxide

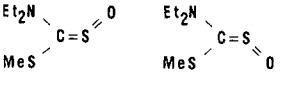


(2)

(R = Ph, $PhCH_2$)

might be an alternative for the oxidation product. Despite many examples of sulfines[7] such as the *S*-oxides of thioketones,[8] thioaldehydes,[9] and dithiocarboxylic esters,[10] a dithiocarboxylic acid *S*-oxide has not been observed. In this paper, we report the first example of a new class of sulfine; i.e., a dithiocarbamic acid *S*-oxide formed in the oxidation of either **1a** or the corresponding acid **1b** by hydrogen peroxide.

The reaction of **1a** and 1 equiv of hydrogen peroxide proceeded instantaneously in methanol at 0 °C to afford a sole product (**2a**). A time course of the UV spectral changes observed for the reaction was very similar to those observed in a phosphate buffer solution (pH 7.5).[2] When a mass spectroscopic measurement of **2a** was made, nothing was detected. This suggested that **2a** could still be a sodium salt, since **1a** itself was silent in mass spectroscopy, whereas its acid form (**1b**) gave a good spectrum ($M + 1 = 150$ by CI method). This was also consistent with TLC (Al_2O_3) analysis of **2a** (R_f 0, by $CHCl_3$). Therefore, the reaction mixture was washed with an ice-cold buffer (pH 3.3, 0.02 M) and then extracted with methylene chloride to yield **2b**, the acid form of **2a**. The mass spectrum of **2b** indicated that it was a monooxide of **1b** ($Et_2NCS_2H + O$: $M + 1 = 166$ by CI method). Oxidation of **1b** by hydrogen peroxide directly produced **2b** in good yield. Since **2b** was not stable enough to give a high-resolution mass spectrum by the EI method, it was treated with methyl iodide, and the formation of a new compound (**3**) having R_f 0.2 on TLC (Al_2O_3, $Bz/CHCl_3 = 3$) was observed. **3** was assigned as methyl diethyldithiocarbamate *S*-oxide on the basis of the following observations: (i) A high-resolution mass spectroscopic measurement of the derivative indicated the monooxide formula of methyl diethyldithiocarbamate. (ii) An IR spectrum of the derivative showed two strong bands at 960 and 1025 cm^{-1} characteristic of a sulfine (C=S=O).[11] (iii) Two distinguishable methyl resonances (2.23 and 2.83 ppm, 0.63 Me: 0.37 Me) were observed in the ^1H NMR spectrum of **3** due to the *E* and *Z* sulfine isomers.[10,12] (iv) An independent



(E)-3 (Z)-3

(1) For example: Brady, F. O.; Monaco, M. E.; Forman, H. J.; Schutz, G.; Feigelson, P. *J. Biol. Chem.* **1972**, *247*, 7915–7922.
(2) Ishimura, Y.; Hayaishi, O. *J. Biol. Chem.* **1973**, *248*, 8610–8612.
(3) (a) Wuyts, H.; Koek, H. *Bull. Soc. Chim. Belg.* **1932**, *41*, 196–201. (b) Allinger, G.; Smith, G. E. P., Jr. *J. Org. Chem.* **1949**, *14*, 962–966. (c) Oae, S.; Tsujimoto, N.; Nakanishi, A. *Bull. Chem. Soc. Jpn.* **1973**, *46*, 535–539.
(4) Oae, S.; Yagihara, T.; Okabe, T. *Tetrahedron* **1972**, *28*, 3203–3216.
(5) For example: Oae, S. In *Organic Sulfur Chemistry*; Kagaku-dojin: Kyoto, Japan, 1982; Vol. 2, pp 263–365.
(6) (a) Kitamura, R. *J. Pharm. Soc. Jpn.* **1938**, *58*, 246; *Chem. Abstr.* **1939**, *33*, 1726. (b) Walter, W. *Justus Liebigs Ann. Chem.* **1960**, *633*, 35–49.
(7) Zwanenburg, B. *Recl. Trav. Chim. Pays-Bas* **1982**, *101*, 1–27.
(8) (a) Sheppard, W. A.; Diekmann, J. *J. Am. Chem. Soc.* **1964**, *86*, 1891–1892. (b) Buter, J.; Kellogg, R. M. *J. Org. Chem.* **1977**, *42*, 973–976. (c) Strating, J.; Thijs, L.; Zwanenburg, B. *Tetrahedron Lett.* **1966**, 65–67.
(9) Strating, J.; Thijs, L.; Zwanenburg, B. *Recl. Trav. Chim. Pays-Bas* **1964**, *83*, 631–636.
(10) (a) Zwanenburg, B.; Thijs, L.; Strating, J. *Tetrahedron Lett.* **1967**, 3453–3456. (b) *Recl. Trav. Chim. Pays-Bas* **1971**, *90*, 614–629. (c) Veenstra, G. E.; Zwanenburg, B. *Tetrahedron* **1978**, *34*, 1585–1592.
(11) Duus, F. In *Comprehensive Organic Chemistry*; Neville Jones, D., Ed.; Pergamon: Oxford, England, 1979; Vol. 3, pp 373–487.

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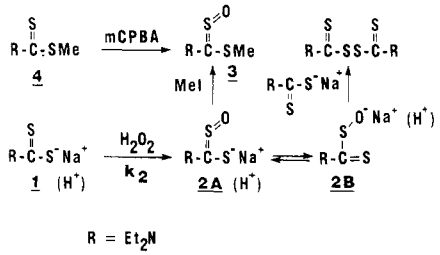
Scheme I



synthesis of **3** was carried out according to the method of Zwanenburg;[10a] i.e., the oxidation of methyl diethyldithiocarbamate (**4**) with 1 equiv of *m*-CPBA.

These results, especially ii–iv, clearly eliminate the possible formation of diethyldithiocarbamic acid *N*-oxide. Many aminosulfines have been prepared by the oxidation of tertiary thioamides with hydrogen peroxide without forming *N*-oxides.[13] Consequently, it seems clear that the oxidation of **1a** and **1b** by hydrogen peroxide took place on sulfur atom to afford the corresponding *S*-oxides.

A kinetic study showed the oxidation of **1a,b** by hydrogen peroxide is first order in both [**1**] and [hydrogen peroxide]. No effect of sodium salt on the rate constant was observed (k_2: **1a**, 6.67 M^{-1} s^{-1}; **1b**, 6.47 M^{-1} s^{-1}, at 22.5 °C).

There are two tautomers available for **2**. Appearance of the C=S=O bands at 965 and 1005 cm^{-1} for **2b** and disappearance of the S–H bands at 2310 and 2420 cm^{-1}, observed for **1b**, suggest certain interaction between oxygen and hydrogen. The formation of the methyl ester by the treatment of **2a** with methyl iodide indicates involvement of the structure of **2A**. On the other hand, exclusive formation of disulfiram in the reaction of **1a** with **2a** suggests participation of sulfenic acid form **2B**. All these observations are summarized in Scheme I.

Finally, one must be very careful to interpret the inhibitory effect of **1a** when used as a copper trapping reagent in redox-related enzymatic reactions.[14] Further study on the structure and reactivity of **2** is under way in this laboratory.

Experimental Section

^1H NMR spectra were determined on Hitachi R-40 (90 MHz) and JEOL FX-90 spectrophotometers in $CDCl_3$ solvent using tetramethylsilane as internal standard. Mass spectra were recorded on a JEOL JMS-D300 mass spectrometer. IR spectra were obtained on a JASCO IR-810 spectrophotometer. UV spectra were obtained on a Hitachi U-3200 spectrophotometer. Solvents and reagents were commercially available and, unless otherwise noted, were used without further purification.

Oxidation of Sodium Diethyldithiocarbamate (1a) by Hydrogen Peroxide. A solution of **1a** (trihydrate, 100 mg, 0.44 mmol) in methanol (10 mL) at 0 °C was treated with 50 μL of hydrogen peroxide (30% in H_2O) for a minute. UV spectrum of the reaction mixture showed complete conversion of **1a** to **2a**. Evaporation of the solvent gave 95 mg of **2a** (89%): TLC (Al_2O_3) R_f 0 (by $CHCl_3$); UV (MeOH) 265 nm (log ε 4.31), 330 (3.89); IR_{neat} 3400, 1480, 1410, 1375, 1355, 1260, 1210, 1140, 1010 (sh), 990, 920 cm^{-1}.

Acidification of 2a. The residue, **2a**, obtained above was dissolved in an ice-cold phosphate buffer solution (pH 3.3, 0.02 M) and extracted by methylene chloride. Only one spot (**2b**) on SiO_2–TLC (R_f 0.75, by AcOEt) was observed. Visible spectrum of **2b** was identical with that of **2a**. Evaporation of the solvent gave 92 mg of **2b**: IR_{neat} 3400, 1585, 1410, 1375, 1350, 1265, 1195, 1140, 1005, 965, 910 cm^{-1}; ^1H NMR 4.03 (q, 4 H, J = 7.0 Hz), 1.33 ppm (t, 6 H, J = 7.0 Hz); MS (CI), m/e (relative intensity) 166 (M^+ + 1, 15), 150, 148, 118, 116, 104 (base).

Oxidation of diethyldithiocarbamic acid (**1b**) was carried out by the procedure employed for the oxidation of **1a** to give **2b** in 92% isolated yield.

Methylation of 1b by Methyl Iodide. A methanol solution (10 mL) of **1b** (100 mg, 0.44 mmol) was treated with 1.5 equiv of methyl iodide at 0 °C for 12 h. After the usual workup, the product **3** was isolated by Al_3O_2–PTLC (Bz) in 80% yield: ^1H NMR 3.90 (q, 4 H, J = 7.2 Hz), 2.83 (s, 1.1 H), 2.22 (s, 1.9 H), 1.26 ppm (t, 6 H, J = 7.2 Hz); IR_{neat} 3400, 1490, 1425, 1200, 1150, 1025, 1000 (sh), 960, 900 cm^{-1}; HRMS for $C_6H_{13}NOS_2$ requires 179.0418, found, 179.0426.

Preparation of Methyl Diethyldithiocarbamate (4). Methyl iodide (500 mg, 3.3 mmol) was added to an acetone solution (12 mL) of **1a** (500 mg, 2.2 mmol) at 0 °C, and the reaction mixture was stirred for 12 h at 0 °C. The solvent was evaporated in vacuo, and the residue was dissolved in CH_2Cl_2. The solution was washed with water and the product **4** was isolated by Al_2O_3 column chromatography (Bz/$CHCl_3$ = 3, R_f 0.2) in 82% yield: ^1H NMR 4.05 (q, 2 H, J = 7.1 Hz), 3.75 (q, 2 H, J = 7.1 Hz), 1.59 (s, 3 H), 1.29 (t, 6 H, J = 7.1 Hz); IR_{neat} 1480, 1410, 1260, 1200, 1140, 910 cm^{-1}; MS (EI), m/e 163 (M^+, base), 116, 91, 88, 60; HRMS for $C_6H_{13}NS_2$ requires 163.0406, found, 163.0446.

Oxidation of Methyl Diethyldithiocarbamate (4). A methylene chloride solution (15 mL) containing **4** (50 mg, 0.30 mmol) and *m*-chloroperbenzoic acid (50 mg, 0.28 mmol) was stirred for 24 h at 0 °C. Methyl diethyldithiocarbamate *S*-oxide was isolated by Al_2O_3–PTLC (CH_2Cl_2) in 32% yield. All physical properties are consistent with those of **3**.

Reaction of 1a and 2a. Hydrogen peroxide (30% in H_2O, 25 μL) was introduced to a methanol solution (10 mL) containing **1a** (50 mg, 0.22 mmol) at 0 °C in one portion and stirred for a minute followed by addition of **1a** (50 mg, 0.22 mmol). The resulting was evaporated, and the residue was dissolved in CH_2Cl_2 and washed with water. The product, disulfiram, was isolated by column chromatography on silica gel Bz) in 78% yield: ^1H NMR 4.03 (q, 8 H, J = 7.4 Hz), 1.6–1.2 ppm (m, 12 H).

Kinetics. A methanol solution (1.8 mL) of **1a** (or **1b**) (1.88 × 10^{-4} M) in UV cuvette was placed to a spectrophotometer at 22.5 ± 0.5 °C. The reaction was initiated by addition of 3 equiv of hydrogen peroxide and monitored by absorbance changes at 330 nm. Second-order rate constants for the oxidation of **1a** and **1b** were 6.67 ± 0.19 and 6.47 ± 0.09 M^{-1} s^{-1}, respectively.

Acknowledgment. We are grateful to Professors Shigeru Oae (Okayama University of Science, Japan) and Tokuji Kimura (Wayne State University) for their helpful discussions.

(12) (a) Zwanenburg, B.; Thijs, L.; Tangerman, A. *Tetrahedron* **1971**, *27*, 1731–1735. (b) Veenstra, G. E.; Zwanenburg, B. *Recl. Trav. Chim. Pays-Bas* **1976**, *95*, 37–39.

(13) Walter, W.; Bauer, O. H. *Justus Liebigs Ann. Chem.* **1976**, 1584–1597.

(14) For example: Tsunawaki, S.; Nathan, C. F. *J. Biol. Chem.* **1984**, *259*, 4305–4312.

Syntheses of 9,10-Disubstituted Anthracenes Derived from 9,10-Dilithioanthracene

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The class of anthracenes disubstituted at the central ring (the 9- and 10-positions) has been proven useful in studies ranging from ESR[1] to artificial receptor design[2] to polymer synthesis.[3] As a part of our studies of structural effects on the retro-Diels–Alder reaction,[4] we required several

(1) Grampp, G.; Pluschke, P. *Gazz. Chim. Ital.* **1984**, *114*, 463.

(2) Herrmann, U.; Tummler, B.; Maass, G.; Mew, P. K.; Vogtle, F. *Biochemistry* **1984**, *23*, 4059.

(3) Beck, H. W. *J. Appl. Polym. Sci.* **1967**, *2*, 673.

(4) For example, see: Nanjappan, P.; Czarnik, A. W. *J. Org. Chem.* **1986**, *51*, 2851.

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