Heteroatom Chemistry
Volume 6, Number 2, 1995

Conformational Features and Chemical Behavior of 5*H*, 7*H*-Dibenzo[*b*,*g*][1,5]dithiocin Oxides: 1,5-Oxygen Shift via a Dithiodication Intermediate

Katsuo Ohkata, Keiji Okada, and Kin-ya Akiba*

Department of Chemistry, Faculty of Science, Hiroshima University, 1-3-1 Kagamiyama, Higashi-Hiroshima 724, Japan

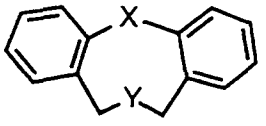
Received 11 October 1994

ABSTRACT

*Some 5H,7H-dibenzo[b,g][1,5]dithiocin oxides (**4–8**) and their related compounds **9–13** were prepared and the assignment of the most favorable conformation was carried out on the basis of the characteristic ^1H NMR spectral data. Only a single conformer (BC: boat-chair form) exists for **4**, **5**, and **8–13**, while two conformers (BC and TB: twist-boat form) are apparent for **6** and **7**. Oxidation and methylation of **4** gave exclusively a single geometrical isomer (**8** and **13**, respectively). These results are interpreted as a sterically preferential attack of electrophiles on the BC conformer of the starting material. A 1,5-oxygen shift of **4** occurred smoothly to give **6** in the presence of trifluoroacetic acid in $CDCl_3$ solution. The mechanistic investigation is described briefly. Differences in chemical behavior between dibenzodithiocin 12-oxide **4** and dibenzothiazocine 12-oxide **2** are also discussed on the basis of the conformational features.*

INTRODUCTION

Various heterocyclic analogues of 5,6,7,12-tetrahydrodibenzo[*a*,*d*]cyclooctatetraene have been synthesized and their chemical properties investigated from many points of view [1,2]. In 1976, Ollis and co-workers discussed the conformational behavior of 5*H*,7*H*-dibenzo[*b*,*g*][1,5]dithiocin (**3**) and some heterocyclic analogues [2a]. The compounds demonstrated temperature dependence in their NMR spectra, which could be associated with the boat-chair (BC) and twist-boat (TB) conformations



	X	Y
1	S	NMe
2	SO	NMe
3	S	S
4	SO	S
5	SO_2	S
6	S	SO
7	S	SO_2
8	SO	SO
9	S	O
10	SO	O
11	SO_2	O
12a	S	$S^+Me\ BF_4^-$
12b	S	$S^+Me\ SbCl_6^-$
13	SO	$S^+Me\ SbCl_6^-$
14	MeOS—$N^+Me\ SbCl_6^-$	

Dedicated to Professor Shigeru Oae on the occasion of his seventy-fifth birthday.

*To whom correspondence should be addressed.

1042-7163/95/$5.00 + .25

undergoing ring inversion and interconversion [3]. In 1983, we reported transannular bond formation (hypervalent bond) between the sulfur and the nitrogen atoms in dibenzo[*b*,*g*][1,5]thiazocine derivatives such as **14** along with some interesting chemical behavior of other derivatives [1a–d]. This article describes the relationship between the conformational feature and chemical behavior of the title compounds (**4–8**) and related compounds (**1–3** and **9–14**). Furthermore, the kinetics of the rearrangement of **4** into **6** under acidic conditions, which involves a 1,5-oxygen shift, have been studied [1e].

RESULTS AND DISCUSSION

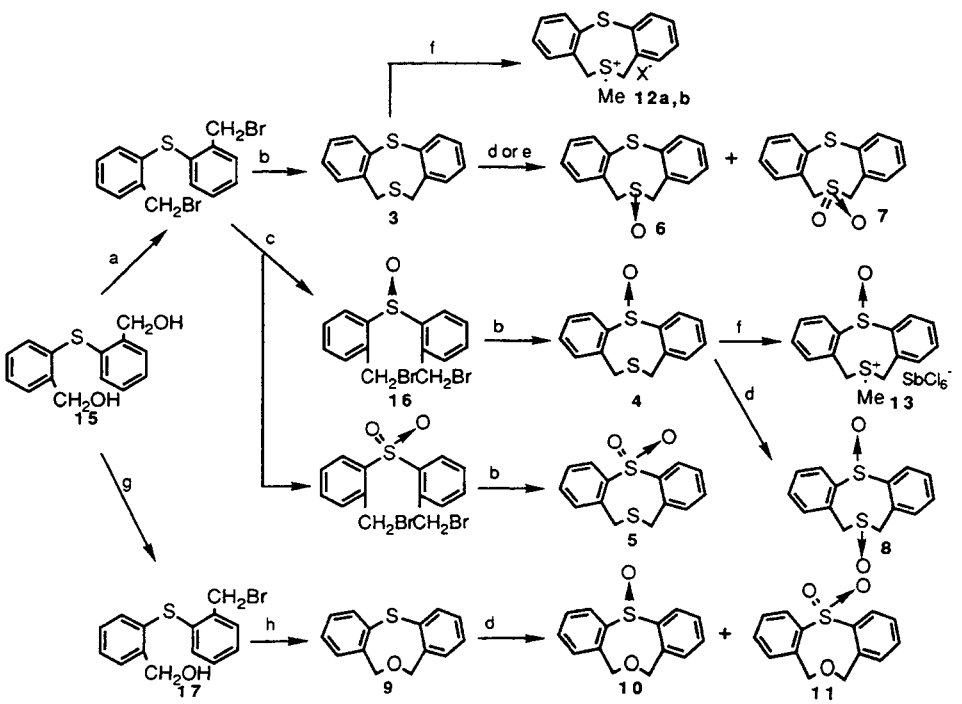
Preparation of the Title Compound **3** *and Its Related Derivatives*

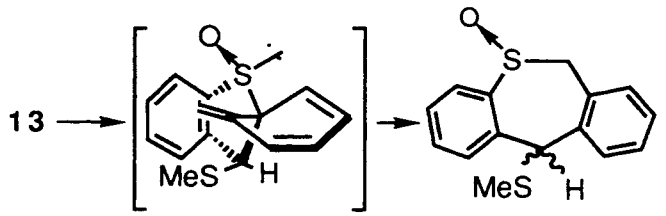
The syntheses and interconversions of the dithiocin series are outlined in Scheme 1. 5*H*,7*H*-Dibenzo[*b*,*g*][1,5]dithiocin (**3**) was prepared from diol **15** by a procedure developed by Ollis and co-workers [2a]. Oxidation of **3** with *m*-chloroperbenzoic acid (*m*CPBA) afforded the 6-oxide **6** in quantitative yield. On the other hand, oxidation of dithiocin **3** with sodium hypochlorite in aqueous methanol afforded the 6,6-dioxide **7** in 23% yield along with the 6-oxide **6** in 34% yield. The isomeric oxide **4** was obtained by an alternative route, i.e., via cyclization of the corresponding bis(2-bromomethylphenyl) sulfoxide (**16**) with sodium sulfide in 82% yield. Further oxidation of **4** with *m*CPBA furnished the 6,12-dioxide **8**, which was isomeric with **7** and also with the 12,12-dioxide **5** prepared by Ollis et al. [2a]. As expected from the oxidation of **3**, methylation of **3** with Meerwein's reagent occurred at the benzyl sulfide moiety to give **12a,b**. In order to confirm these structures concretely, oxathiocin derivatives (**9–11**) were prepared by similar methodology. Monobromination of diol **15** with CCl_3Br/Ph_3P afforded the monobromide **17** which, on treatment with sodium hydride, gave 5*H*,7*H*-dibenzo[*c*,*f*][1,5]oxathiocin (**9**) in 76% yield. Oxidation of **9** with *m*CPBA furnished a mixture of the sulfoxide **10** and the sulfone **11**, the ratio being 82:18.

Each structure was determined on the basis of its elemental analyses and spectral data. Conformational assignments for these oxides together with the methylated derivatives are discussed subsequently.

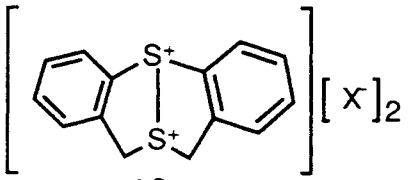
Heating a solution of **4** in acetic anhydride in the presence of sodium acetate reduced it to dithiocin **3** in moderate yield. Although the reaction mechanism was not clarified in detail at the present stage, it might be effected via an intermolecular oxidation-reduction mechanism [4]. Methylation of **4** with Meerwein's reagent (Me_3O^+ $SbCl_6^-$) gave a crystalline product **13** whose structural assignment was based on the ^1H NMR and IR spectral data and its chemical properties. The benzyl protons appear in the ^1H NMR spectrum as an AB

SCHEME 1

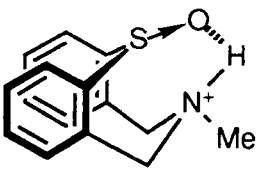




18a,b

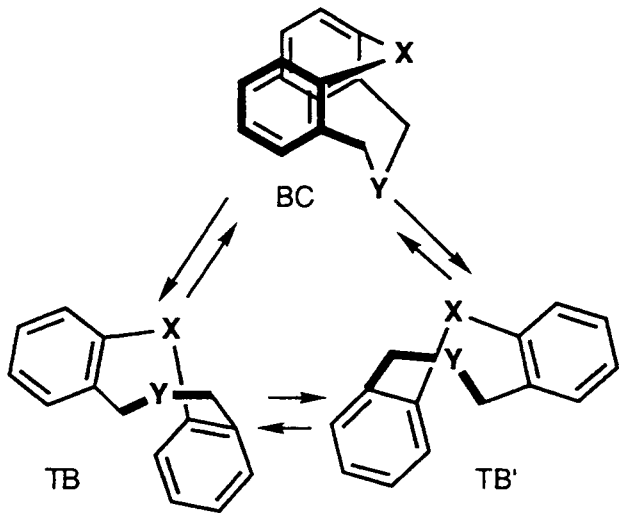


19



20

SCHEME 2



SCHEME 3

quartet (J = 14.1 Hz) at δ 4.77 and 5.35 in $CDCl_3$ solution. In the IR spectrum, a characteristic band was observed at ν_{max} = 1030 cm^{-1} assignable to the stretching vibration band of the sulfoxide group. Treatment of **13** with methanolic potassium hydroxide gave rise to a mixture of two isomeric sulfoxides in the ratio of 70:30, which were isolated by thin layer chromatography. The sulfoxides were determined to be **18a,b**, produced by way of a Sommelet–Hauser rearrangement of **13**, as shown in Scheme 2 [5]. Selective rearrangement of **4** into **6** proceeded very smoothly in chloroform solution in the presence of trifluoroacetic acid. The 1,5-oxygen shift observed in the rearrangement of **4** to **6** should proceed via the intermediate dithiodication **19** [6]. This result is very different from that of the amino sulfoxide **2**, where protonation occurred exclusively at the amino group, such as illustrated in structural formula **20**.

The structure of **20** was assigned from its ^1H NMR spectral data and analogous data for the protonated 1,5-thiazocine 5-oxide [7]. In the ^1H NMR spectrum of **20** in CF_3CO_2H-$CDCl_3$ solution, there are the following characteristic signals: δ 2.50 (d, J = 5 Hz, 3H), 4.83 (dd, J = 5 and 14 Hz, 2H), and 5.40 (d, J = 14 Hz, 2H), together with the signals for aromatic protons. This shows that the conformation is fixed by hydrogen bonding, as shown in **20**.

Structural Considerations of Dibenzodithiocin Derivatives

In these dibenzodithiocin derivatives, the conformations adopted by the eight-membered ring in each of the new compounds are of interest (Scheme 3). From conformational analyses of 1,4-cyclooctadiene systems, it is believed that generally the BC conformer is significantly more stable than the TB and/or boat-boat (BB) conformers due to transannular repulsive interactions [2a–c]. However, the TB (BB) conformer is preferred to the BC conformer in the heteroatom-containing systems or in the presence of transannular attractive interaction such as in **14** [1a,b].

The elucidation of conformational properties of such dibenzodithiocin analogues was possible as a result of distinctive differences in the ^1H NMR spectral properties of the BC and TB forms. One of the conformers shows the nonequivalent methylenes as a distinct AB quartet due to rigidity of the conformer, while the other has a singlet or AB quartet with a small difference of chemical shifts for the methylene peak due to flexibility of the conformer. The former signals are assignable to the rigid BC conformer and the latter to the TB conformer. Such structural assignments were used and confirmed to be eligible for dibenzodithiocin (**3**) and its related compounds by Ollis et al. [2a–c].

The characteristic ^1H NMR spectral data for benzyl protons are summarized in Table 1. Two kinds of AB systems are seen, at δ 4.19, 5.61 (J = 12.5 Hz) and at δ 3.88, 3.95 (J = 13.0 Hz) in the ^1H NMR spectrum of the benzyl protons of **6** in $CDCl_3$ solution at ambient temperature. The proton-de-

TABLE 1 Characteristic ^{1}H NMR Spectral Data for Benzyl Protons of **1–14** and **19**

			Chemical Shift of Benzyl Protons (δ)			
Compound	*Solvent*	*Temperature (°C)*	*BC Conformer (ABq)*	$\Delta\delta$[a]	*TB Conformer (s or ABq)*	*BC/TB*
1[b]	CD_3OD	−49.5	3.84, 5.02 (J = 14.0 Hz)	1.18	3.67 (s)	67/33
2[b]	$CDCl_3$	35	—		3.88 (s)	0/100
3	$CDCl_3$	35	3.76, 5.00 (J = 14.1 Hz)	1.24	3.68 (s)	80/20[e]
4	$CDCl_3$	35	3.88, 4.55 (J = 15.0 Hz)	0.67	—	100/0
5	$CDCl_3$	35	3.72, 5.54 (J = 14.9 Hz)	1.82	3.50 (s)	100/0[e]
6	$CDCl_3$	35	4.19, 5.61 (J = 12.5 Hz)	1.42	3.83, 3.95[c] (ABq, J = 13.0 Hz)	20/80
7	$CDCl_3$	35	4.21, 5.63 (J = 13.5 Hz)	1.42	3.76 (s)	50/50
8	$CDCl_3$	35	4.34, 5.11 (J = 13.4 Hz)	0.77	—	100/0
9	$CDCl_3$	35	4.86, 5.56 (J = 12.4 Hz)	0.70	—	100/0
10	$CDCl_3$	35	4.63, 5.20 (J = 14.8 Hz)	0.57	—	100/0
11	$CDCl_3$	35	4.81, 5.97 (J = 12.1 Hz)	1.16	—	100/0
12a	CD_3CN	35	4.56, 5.72 (J = 13.0 Hz)	1.16	—	100/0
13[b]	CD_3CN	35	4.77, 5.35 (J = 14.1 Hz)	0.58	—	100/0
14[b]	CD_3CN	35	—		4.25 (s)	0/100
19	D_2SO_4	35	—		5.26, 5.55[d] (ABq, J = 15.6 Hz)	0/100

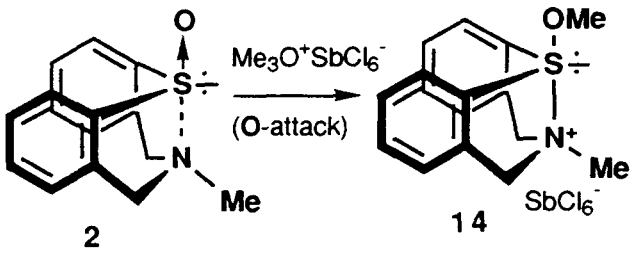
[a] $\Delta\delta = \delta_B - \delta_A$.
[b] Ref. [1bc].
[c] $\Delta\delta$ = 0.12
[d] $\Delta\delta$ = 0.29; the reasonable conformer seems to be the considerably rigid BB form; Ref. [3].
[e] Ref. [2a].

coupled carbon spectrum features two lines (δ 51.2, 64.4) assigned to the benzyl carbons along with 12 lines. The spectral data indicate the presence of two stable conformers in the ratio of 20:80. The major conformer gives an AB quartet at δ 3.83 and 3.95 for benzyl protons. This represents the TB conformer judging from the previous criteria [2a–c]. The minor conformer is assignable to the BC form.

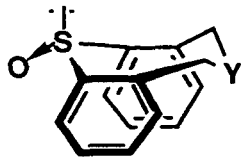
On the other hand, the ^{1}H NMR spectra of the other derivatives (**4**, **5**, and **8–13**) indicate that these compounds exist as single conformers in $CDCl_3$ solution. Each spectrum shows a characteristic AB quartet for benzyl protons consistent with the BC form. In the ^{1}H NMR spectra of all the present 12-oxides (**4**, **8**, **10**, and **13**), the protons ortho to the sulfoxide group appear at δ ca. 8; the downfield shift relative to the other aromatic protons is a direct consequence of its projection into a region of the molecule where the deshielding anisotropies of the sulfoxide group are exerting the effect. Therefore, the most favorable conformer in these compounds can be concluded to be the BC conformer, and the sulfoxide oxygen should be close to the ortho hydrogen of the phenylene group, as illustrated in **4**, **8**, **10**, and **13**.

In the ^{1}H NMR spectrum of 6-methyldithiocinium derivative **12** in CD_3CN solution there are observed only one singlet for the methyl protons at δ 3.19 and an AB quartet at δ 4.65, 5.72 (J = 13 Hz) for benzyl protons along with the other aromatic multiplet. The chemical shift of the methyl protons appears to be downfield with respect to that (δ 2.60) of dibenzylmethyl sulfonium salt (**21**) [8]. This result indicates that the methyl group must be located at a quasi-equatorial position; methyl protons in the quasi-axial positions are more shielded than that of **21** due to the ring current anisotropic effects of the two aromatic rings in the BC conformation [2]. The BC conformer as shown in **12** is considered to be the most reasonable structure, one in which steric repulsion between the methyl group and the π-electrons of the benzene ring is minimized.

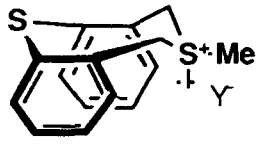
Although the formation of two geometric isomers is expected for **8** and **13**, only a single isomer was produced by oxidation and methylation, respectively. In the ^{1}H NMR spectrum of **13**, there are observed only one singlet for the methyl protons at δ 3.20 along with the other signals. Judging from the preceding considerations and the steric preferences during attack of an electrophile at the benzyl sulfide moiety in **4**, it can be expected that the geometry is *trans* with respect to the substituents in **8** and **13**. This geometry of **13** is consistent with that expected from inspection of the Dreiding model.



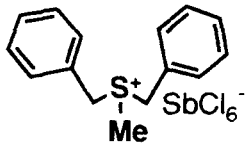
SCHEME 4



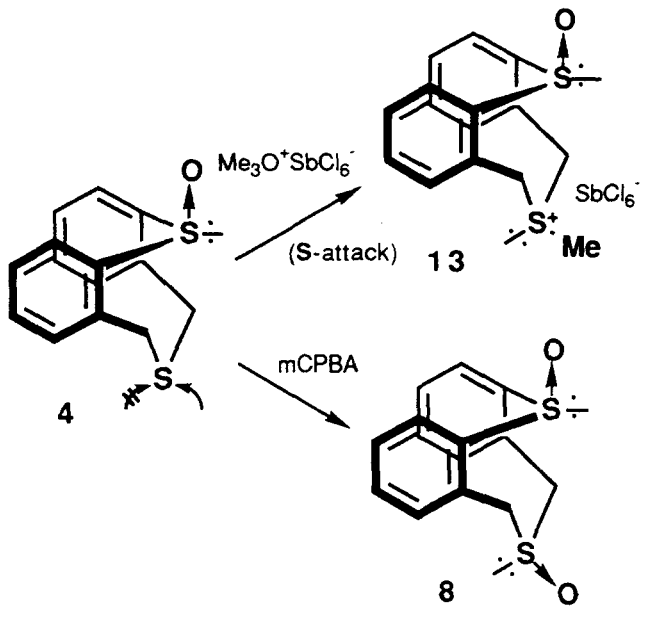
4,8,10, and 13



12a,b



21



SCHEME 5

It is noteworthy that, in electrophilic attack on **2** and **4**, methylation of **4** resulted in only *S*-methylated product **13**, while dibenzothiazocine 12-oxide **2** reacted to give solely O-methylated compound **14** under the same conditions [1]. The differences in chemical behavior between **2** and **4** can be explained by considering the most favorable ground state conformer of each in solution. Thus, the sulfoxide group of **2** should become very reactive as a consequence of the transannular participation of the amino group in the TB conformer. Such activation is unlikely in **4** since the BC conformer is preferred to the TB conformer, as noted previously.

Mechanistic Considerations of the 1,5-Oxygen Shift in Dibenzodithiocin 12-Oxide

In order to clarify the mechanism of the 1,5-oxygen shift in dibenzodithiocin 12-oxide **4** to give 6-oxide **6**, several mechanistic investigations were carried out. The rate constants (k_{obsd}) were measured spectrometrically by means of ^{1}H NMR spectroscopy under pseudo-first-order conditions. In each run, the first-order rate law was obeyed; the values of k_{obsd} are shown in Table 2. The reaction rate constants are increased on raising the concentration of CF_3CO_2H. In the acid-catalyzed reactions of sulfoxides, which involve sulfur–oxygen bond breaking, the kinetics are found to be first order in sulfoxide and second order in acid [9]. In fact, the present kinetic data apparently correspond to an oxygen atom exchange between sulfoxides and sulfides in the presence of acid. On the other hand, the 1,5-oxygen migration in **4** proceeded more slowly than that in the acyclic model compound (**22**) bearing two ortho methylthiomethyl groups, which was converted into the isomeric sulfoxide **23** under identical conditions (Table 2). The difference of reactivity may be ascribed in part to the more flexible conformations of two sulfide groups in **22** or the intermediacy of a trithiodication such as **24** during the 1,5-oxygen shift in **22**.

Reaction of **4** with CF_3CO_2H was conducted in $H_2^{18}O$ saturated chloroform solution to give the

TABLE 2 Kinetic Data for 1,5-Oxygen Shift in **4** and **22**[a]

Compound	*[CF_3CO_2H], mol/L*	*10^5 k_{obsd}, s^{-1}*
4	0.657	0.794 ± 0.016
4	0.788	1.33 ± 0.037
4	1.38	7.00 ± 0.12
22	0.788	15.8 ± 0.62

[a]Concentration of **4** and **22** was 3.85×10^{-2} mol/L, and the temperature was 33.0°C.

rearranged sulfoxide **6** in which oxygen-18 was incorporated to the extent of 30.6%, while **6** was not incorporated with ^{18}O under similar conditions. These results are presented as direct evidence that at least 70% of the rearrangement occurred either intramolecularly or by coupling of the ion pair in the solvent cage. Conversely, intermolecular oxygen migration from diphenyl sulfoxide to dibenzyl sulfide did not proceed under the same acidic conditions.

Addition of either **4** or **6** to D_2SO_4 at room temperature resulted in their conversion into the dithiodication **19**. Subsequent quenching of the reaction by pouring the solution into aqueous sodium carbonate solution gave **6**.

Formation of the dithiodication **19** is accompanied by a pronounced downfield shift of benzyl and aromatic protons. A substantial increase in the chemical shift separation of the branches of the AB quartet for the benzylic protons (δ 5.26, 5.55) suggests a considerably more rigid TB or BB conformer for **19**, according to the criteria for such conformers, which have been investigated in detail by Ollis et al. and Renaud et al. [2a,b].

EXPERIMENTAL

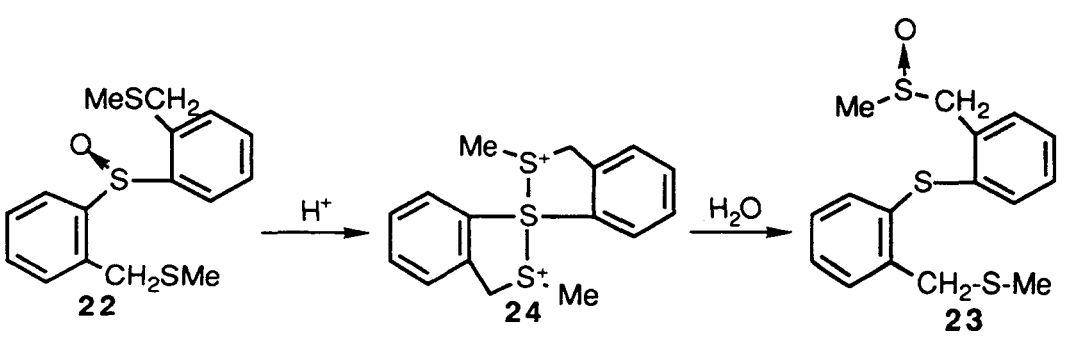
All the melting points are uncorrected. IR spectra were obtained with a Hitachi 215 grating IR spectrophotometer. ^1H NMR measurements were carried out on Varian T-60 and Hitachi R-90H instruments, using tetramethylsilane as the internal reference.

Preparations of the thiazocine derivatives **1**, **2**, and **14** are reported in the preceding articles [1b,c]. The dithiocin derivatives **3** and **5** were prepared by the procedure developed by Ollis and co-workers [2a].

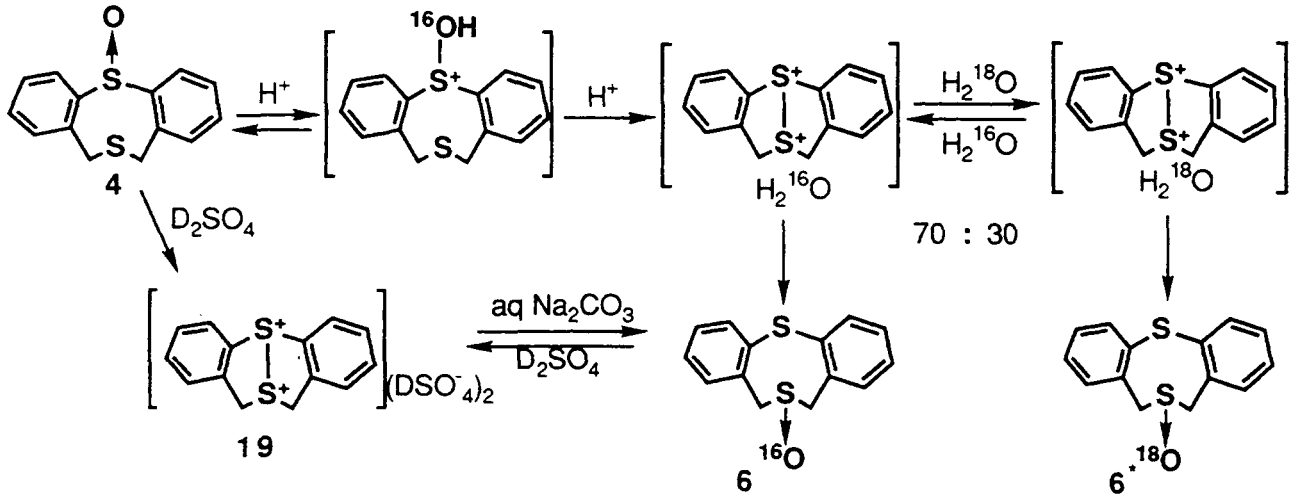
5H,7H-Dibenzo[b,g][1,5]dithiocin 12-Oxide (**4**). A mixture of bis-(2-bromomethylphenyl) sulfoxide (**16**) [1b] (0.588 g, 1.52 mmol) and sodium sulfide nonahydrate (0.91 g, 3.8 mmol) in 95% aqueous methanol (50 mL) was heated under reflux for 40 hours. The mixture was concentrated and the product was extracted into dichloromethane before drying. After evaporation of the organic layers, the residue was purified by column chromatography on silica gel (ethyl acetate). Recrystallization from ethanol gave colorless crystals (321 mg, 82%) as a pure sample **4**: mp 202.5–204.5°C; IR (KBr) 1070, 1035, 1025 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.88, 4.55 (ABq, J = 15 Hz, 4H), 7.00–7.50 (m, 6H), 8.00–8.12 (m, 2H); Mass (m/z) 260 (M^+, 13%), 243 ($M^+ - 17$, 100%), 197 ($M^+ - 63$, 48%), 170 ($M^+ - 90$, 58%), 169 ($M^+ - 91$, 90%). Anal. calcd for $C_{14}H_{12}OS_2$: C, 64.58; H, 6.65. Found: C, 64.54; H, 6.65.

5H,7H-Dibenzo[b,g][1,5]dithiocin 6-Oxide (**6**). A mixture of 5*H*,7*H*-dibenzo[*b*,*g*][1,5]dithiocin (**3**) [2a] (40.0 mg, 0.15 mmol) and *m*-chloroperbenzoic acid (30 mg, 0.17 mmol) in dichloromethane (3 mL) was stirred at room temperature for 25 hours. The mixture was evaporated and the residue was purified by thin layer chromatographic separation on silica gel (*n*-hexane-dichloromethane; 9:1). Recrystallization from *n*-hexane-dichloromethane gave a pure sample **6** (42 mg, 99%): mp 184.5–187.0°C; IR (KBr) 1055, 1045 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.88, 3.95 (ABq, J = 13 Hz), 4.19, 5.61 (ABq, J = 1 2.5 Hz), 7.17–7.59 (m, 8H); ^{13}C NMR ($CDCl_3$) δ 51.2 (TB), 64.4 (BC), 127.1, 127.6, 128.6, 129.0, 129.2, 130.1, 132.4, 133.6, 133.9, 136.0, 136.7, 138.5. Mass (m/z) 260 (M^+, 29%), 242 ($M^+ - 18$, 5%), 211 ($M^+ - 49$, 100%), 178 ($M^+ - 88$, 34%). BC/TB = 20/80 at 35°C. Anal. calcd for $C_{14}H_{12}OS_2$: C, 64.58; H, 4.65. Found: C, 64.45; H, 4.57.

5H,7H-Dibenzo[b,g][1,5]dithiocin 6,12-Dioxide (**8**). A 53.7 mg (0.207 mmol) sample of **4** was stirred at room temperature for 24 hours with *m*-chloroperbenzoic acid (37 mg) in dichloromethane (3 mL). After usual workup, recrystallization of the residue from dichloromethane-*n*-hexane gave colorless crystals as a pure sample (**8**, 54.9 mg, 96%): mp 282–285°C; IR (KBr) 1035, 1070 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.34, 5.11 (ABq, J = 13.4 Hz, 4H), 7.25–7.52 (m, 6H), 7.95–8.13 (m, 2H). Anal. calcd for



SCHEME 6



SCHEME 7

$C_{14}H_{12}O_2S_2$: C, 60.84; H, 4.38. Found: C, 60.58; H, 4.11.

Oxidation of **3** *with Sodium Hypochlorite.* To a solution of **4** (40 mg, 0.17 mmol) in 5 mL of methanol was added 0.3 mL of 10% aqueous sodium hypochlorite at −78°C. The mixture was stirred at 0°C for 1 hour. The mixture was poured into ice and water and extracted into dichloromethane before drying. Solvent removal left a yellow solid. Thin layer chromatographic separation on silica gel (*n*-hexane-ethyl acetate; 7:3) gave 14.6 mg (34%) of **6** and 10.5 mg (23%) of 5*H*, 7*H*-dibenzo[*b*,*g*][1,5]dithiocin 6,6-dioxide (**7**) as a sticky oil. Spectral data for **7**: ^{1}H NMR ($CDCl_3$) δ 3.76 (s), 4.21, 5.63 (ABq, J = 13.5 Hz, 4H), 7.20–7.90 (m, 8H); mass (*m*/*z*) 276 (M^+, 23%), 212 (M^+ − 64, 63%), 197 (M^+ − 79, 100%).

5H,7H-Dibenzo[c,f][1,5]oxathiocin (**9**). To a solution of diol **15** (2.00 g, 8.13 mmol) in acetonitrile (30 mL) was added 7 g (26.7 mmol) of triphenylphosphine and 3 mL of bromotrichloromethane at room temperature. The mixture was stirred for 1 day and concentrated. The resultant residue was purified by preparative TLC on silica gel (*n*-hexane-ethyl acetate; 7:3) to give 1.12 g (44%) of **17** as a colorless oil: ^{1}H NMR ($CDCl_3$) δ 2.18 (s, 1H), 4.66 (s, 2H), 4.75 (s, 2H), 6.9–7.7 (m, 8H). A 0.20 g sample of 66% sodium hydride in oil was washed with *n*-hexane and dried under nitrogen. A solution of **17** (0.78 g, 2.51 mmol) in 80 mL of acetonitrile was introduced, and the mixture was stirred under reflux for 10 hours. After removal of the solvent, the remaining suspension was poured into 1N hydrochloric acid and extracted with dichloromethane. The organic layers were washed with water, dried, and evaporated. Chromatography of the residue on silica gel gave a colorless solid. Recrystallization from *n*-hexane-ether gave 436 mg (76%) of **9**: mp 99–100°C; IR (KBr) 1440, 1230, 1200, 1060 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 5.11 (brs, 4H), 7.1–7.3 (m, 6H), 7.6–7.8 (m, 2H); mass (*m*/*z*) 228 (M^+, 100%), 195 (M^+ − 33, 40%). Anal. calcd for $C_{14}H_{12}OS$: C, 73.65; H, 5.30. Found: C, 73.50; H, 5.26.

Oxidation of **9** *with m-Chloroperbenzoic Acid.* By means of the previous procedure, **9** (160 mg, 0.70 mmol) in 3 mL dichloromethane was oxidized with *m*-chloroperbenzoic acid (125 mg, 0.72 mmol) to a mixture of **10** (107 mg, 71%) and **11** (22 mg, 16%).

Physical data for **10**: mp 150–153°C (*n*-hexane-dichloromethane); IR (KBr) 1095, 1070, 1020 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 4.63, 5.20 (ABq, J = 14.8 Hz, 4H), 7.0–7.6 (m, 6H), 8.0–8.2 (m, 2H). Anal calcd for $C_{14}H_{12}O_2S$: C, 68.83; H, 4.95. Found: C, 69.01; H, 4.96.

For **11**: mp 161–163°C (*n*-hexane-dichloromethane); IR (KBr) 1315, 1200, 1155, 1075 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 4.81, 5.97 (ABq, J = 12.1 Hz, 4H), 7.1–7.6 (m, 6H), 8.0–8.3 (m, 2H). Anal. calcd for $C_{14}H_{12}O_3S$: C, 64.60; H, 4.65. Found: C, 64.38; H, 4.61.

6-Methyl-5H,7H-dibenzo[b,g][1,5]dithiocinium Tetrafluoroborate (**12a**). To a solution of disulfide **3** (139 mg, 0.57 mmol) in acetonitrile (3 mL) was added excess methyl iodide (0.8 g) and silver tetrafluoroborate (120 mg, 0.62 mmol) successively. After filtration and concentration, a colorless solid (140 mg, 86%) of **12a** was obtained. Recrystallization from CH_3CN gave a pure sample: mp 212.5–214°C; IR (KBr) 1050 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.19 (s, 3H), 4.56, 5.72 (ABq, J = 13 Hz), 7.33–7.65 (m, 6H), 7.85–8.06 (m, 2H). Anal. calcd for $C_{15}H_{15}S_2BF_4$: C, 52.04; H, 4.37. Found: C, 52.15; H, 4.49.

6-Methyl-5H,7H-dibenzo[b,g][1,5]dithiocinium Hexachloroantimonate (**12b**). A mixture of disulfide **3** (30.2 mg, 0.124 mmol) and trimethyloxonium hexachloroantimonate (60 mg, 0.152 mmol) in dichloromethane (3 mL) was stirred at −78°C for 15 hours under nitrogen atmosphere. The mixture was filtered and the solid was washed with dichloromethane. A pure sample (33.9 mg, 46.1%) of **12b** was obtained by recrystallization from acetonitrile-ether: ^{1}H NMR (CD_3CN) δ 3.19 (s, 3H), 4.56, 5.72 (ABq, J = 13 Hz, 4H), 7.33–7.65 (m, 6H), 7.85–8.06 (m, 2H).

6-Methyl-12-oxo-5H,7H-dibenzo[b,g][1,5]dithiocinium Hexachloroantimonate (**13**). By means of the procedure used for **12b**, treatment of **4** (47.4 mg, 0.182 mmol) with 73 mg (0.19 mmol) of trimethyloxonium hexachloroantimonate in 3 mL of dichloromethane at −78°C and then room temperature afforded a yellow solid. Recrystallization from acetonitrile-hexane gave a pure sample of **13** (72.6 mg, 65%): mp 178–181.5°C; IR (KBr) 1070, 1030 cm^{-1}; ^{1}H NMR (CD_3CN) δ 3.20 (s, 3H), 4.77, 5.35 (ABq, J = 14.1 Hz, 4H), 7.50–7.73 (m, 6H), 8.03–8.18 (m, 2H). Anal. calcd for $C_{15}H_{15}OS_2SbCl_6$: C, 29.52; H, 2.48. Found: C, 29.48; H, 2.37.

Reduction of Dithiocin 12-Oxide **4** *with Acetic Anhydride in the Presence of Sodium Acetate.* A mixture of **4** (64.1 mg, 0.247 mmol) and 0.3 g of sodium acetate in 7 mL of acetic anhydride was heated under reflux for 30 hours. The mixture was poured into aqueous sodium hydrogencarbonate solution, and the product was extracted into dichloromethane before drying. Solvent removal left a yellowish oil. Thin layer chromatographic separation on silica gel (*n*-hexane-ethyl acetate; 85:15) gave 20.6 mg (34%) of disulfide **3**.

Rearrangement of **13** *with Methanolic Potassium Hydroxide.* A mixture of **13** (81.5 mg, 0.225 mmol) and 690 mg of potassium hydroxide in 15 mL of methanol was stirred at room temperature for 6 hours. After solvent removal, the residue was dissolved in dichloromethane and was washed with water before drying. The organic solution was concentrated and thin layer chromatographic separation on silica gel (*n*-hexane-ethyl acetate; 1:1) gave 27.2 mg (44.1%) of **18a** and 11.7 mg (19.0%) of **18b**.

Physical data for **18a**: colorless oil; IR (neat) 1020 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.94 (s, 3H), 4.25, 4.94 (ABq, J = 14.5 Hz, 2H), 5.12 (s, 1H), 7.15–7.60 (m, 7H), 7.89–8.10 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 16.5 (q), 57.4 (d), 58.5 (t), 127.5, 128.1, 128.3, 128.8, 129.3, 130.4, 131.1, 132.3, 132.4; mass (*m/z*) 274 (M^+, 9%), 241 (M^+ − 33, 16%), 228 (M^+ − 46, 78%), 211 (M^+ − 63, 44%), and 178 (M^+ − 96, 100%). Anal. calcd for $C_{15}H_{14}OS_2$: C, 65.66; H, 5.14. Found: C, 65.48, H, 5.22.

Physical data for **18b**: colorless oil; IR (neat) 1020 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.96 (s, 3H), 4.37, 5.82 (ABq, J = 13.0 Hz), 5.09 (s, 1H), 7.20–7.50 (m, 7H), 7.83–7.97 (m, 1H); mass (*m/z*) 274 (M^+) and the same fragments as that of **18a**.

Bis(2-methylthiomethylphenyl) Sulfoxide (**22**). A mixture of **16** (1.32 g, 3.4 mmol) and 15% aqueous sodium methanethiolate (2 mL) in methanol (50 mL) was heated under reflux for 8 hours. The mixture was concentrated and the product was extracted into dichloromethane before drying. After evaporation of the organic layers, the residue was purified by column chromatography on silica gel (*n*-hexane-ethyl acetate; 1:1) to give **22** as a yellow oil (0.70 g, 80%): IR (neat) 1025 and 1065 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.99 (s, 6H), 3.85 (s, 4H), 7.3–7.5 (m, 6H), 7.6–7.9 (m, 2H); mass (*m/z*) 322 (M^+). Anal. calcd for $C_{16}H_{18}OS_2$: C, 59.58; H, 5.63. Found: C, 59.46; H, 5.54.

Acid Catalyzed 1,5-Oxygen Rearrangement of **4** *and* **22**. A solution of **4** (30 mg, 0.12 mmol) and trifluoroacetic acid (150 mg, 1.3 mmol) in 0.5 mL of $CDCl_3$ was allowed to stand at room temperature for 25 hours. The mixture was poured into 5% aqueous sodium hydrogencarbonate solution and the product was extracted into dichloromethane. Ordinary workup gave 29 mg (97%) of **6** as a colorless solid.

By the same method described previously, treatment of **22** with trifluoroacetic acid in $CHCl_3$ solution gave **23** in quantitative yield. Physical data for **23** (oil): IR 1040 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.06 (s, 3H), 2.53 (s, 3H), 3.83 (s, 2H), 4.15, 4.24 (ABq, J = 12.8 Hz, 2H), 7.1–7.5 (m, 8H); mass (*m/z*) 322 (M^+, 6%), 259 (M^+ − 63, 54%), 211 (M^+ − 111, 100%). Anal. calcd for $C_{16}H_{18}OS_2$: C, 59.58; H, 5.63. Found: C, 59.44; H, 5.51.

1,5-Oxygen Rearrangement of **4** *with Concentrated Sulfuric Acid.* A 101 mg (0.39 mmol) sample of **4** was dissolved in 98% sulfuric acid to give a yellow solution. After several minutes, the reaction was quenched by addition of an ice and water mixture containing sodium carbonate. Workup in the predescribed manner gave 100 mg of **6** (99%) as a colorless solid. The intermediate in D_2SO_4 solution was assigned to be **19** on the basis of the ^{1}H NMR spectrum; δ 5.26, 5.55 (ABq, J = 15.6 Hz, 4H), 7.15–7.75 (m, 8H).

^{1}H NMR Spectral Data of Protonated **2**. ^{1}H NMR (CF_3CO_2H (0.5 mL) + $CDCl_3$ (0.5 mL)) δ 2.50 (d, J = 5 Hz, 3H), 4.83 (dd, J = 5 and 14 Hz, 2H), 5.40 (d, J = 14 Hz, 2H), 7.27–7.83 (m, 6H), 8.00–8.33 (m, 2H).

Kinetic Studies

The Hitachi R-90H FT NMR instrument was used for all measurements. For each run, 3–15 mg of **4**

was dissolved into 0.3 mL of $CDCl_3$ solution containing CF_3CO_2H (0.657–3.39 mol/L) in a 5 mm NMR tube, which was placed at the instrument probe. At appropriate intervals, the integral ratios of benzyl protons for **4** and **6** were monitored. The apparent first-order rate constants, k_{obsd}, were calculated from the slope of the linear plots of ln (integral ratio) vs. time by using the least-squares method. The results are summarized in Table 2. By the same procedure, the pseudo-first-order rate constants for **22** were determined, as shown in Table 2.

Oxygen-18 Incorporation in the 1,5-Oxygen Shift of **4**. A sample of CF_3CO_2H (0.7875 g, 6.907 mmol) was placed in a 5 mL volumetric flask, which was subsequently made up to the mark with $CHCl_3$. A measured volume (2.10 mL) of the CF_3CO_2H–$CHCl_3$ solution (1.38 mol/L) was placed in a round-bottom flask, and 20.0 μL of $H_2^{18}O$ (97% enrichment) was introduced into the solution. To the solution was added 21.0 mg of **4**, and the mixture was stirred at room temperature for 28 hours. Workup in the predescribed manner gave 20 mg of **6**.

In the mass spectrum of the sample **6**, the relative peak intensity of $M^+ + 2$ to M^+ was observed to be 41.1%. Since the theoretical value for $C_{14}H_{12}OS_2$ is 10.5% (experimental value; 11.7% for **6**), the mass spectrum of **6** indicated that the level of incorporation was 30.6%.

After the similar treatment of **6** under the preceding conditions, the mass spectrum of the resulting sample showed that $M^+ + 2/M^+$ was 13.3%. The value indicated only 1.6% incorporation of ^{18}O in this treatment.

REFERENCES

[1] (a) K.-y. Akiba, K. Takee, K. Ohkata, F. Iwasaki, *J. Am. Chem. Soc., 105*, 1983, 6965; (b) K.-y. Akiba, K. Takee, Y. Shimizu, K. Ohkata, *J. Am. Chem. Soc., 108*, 1986, 6320; (c) K. Ohkata, K. Takee, K.-y. Akiba, *Bull. Chem. Soc. Jpn., 58*, 1985, 1946; (d) K. Ohkata, M. Ohnishi, K. Yoshinaga, K.-y. Akiba, J. C. Rongione, J. C. Martin, *J. Am. Chem. Soc., 113*, 1991, 9270; (e) Preliminary report: K. Ohkata, K. Okada, K.-y. Akiba, *Tetrahedron Lett., 26*, 1987, 4491.

[2] (a) R. P. Gellatly, W. D. Ollis, I. O. Sutherland, *J. Chem. Soc., Perkin Trans., 1*, 1976, 913; (b) R. R. Fraser, M. A. Raza, R. N. Renaud, R. B. Layton, *Can. J. Chem., 53*, 1975, 167; (c) L. E. Brieaddy, R. S. Hurlbert, N. B. Mehta, *J. Org. Chem., 46*, 1984, 1630; (d) H. Fujihara, A. Kawada, N. Furukawa, *Heterocycles, 24*, 1986, 17; (e) T. Akasaka, W. Ando, *Tetrahedron Lett., 26*, 1985, 5049.

[3] In accordance with the nomenclature used in the literature [2c], the description BC and TB refer to boat-chair and twist-boat conformations in an eight-membered ring.

[4] F. G. Bordwell, R. M. Pitt, *J. Am. Chem. Soc., 77*, 1955, 572.

[5] K. Ohkata, K. Okada, K. Maruyama, K.-y., Akiba, *Tetrahedron Lett., 27*, 1986, 3257.

[6] (a) T. Numata, S. Oae, *Int. J. Sulfur. Chem., 1*, 1971, 6; (b) J. T. Doi, K. Musker, *J. Am. Chem. Soc., 103*, 1981, 1159; (c) N. Furukawa, A. Kawada, T. Kawai, *J. Chem. Soc. Commun.*, 1984, 1151; (d) H. Fujihara, A. Kawada, N. Furukawa, *J. Org. Chem., 52*, 1987, 4254.

[7] N. J. Leonard, A. E. Yethon, *Tetrahedron Lett.*, 1965, 4259 and references therein.

[8] R. H. Mitchell, V. Boekelheide, *J. Am. Chem. Soc., 96*, 1974, 1548.

[9] A. Bovio, U. Miotti, *J. Chem. Soc., Perkin Trans., 2*, 1978, 172.