

calculated geometries. Although the results presented here are not in uniform agreement with experiment, it is felt that some encouragement may be taken from them. It also is of interest to note, in the cases of triphenylene and perylene, that the calculated lengths of the long bonds are in accord with present theory.

**Registry No.**—I, 85-01-8; II, 218-01-9; III, 217-59-4; IV, 198-55-0.

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### Correlation of the Chirality of the Disulfide Group with Its Molecular Ellipticity

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In molecules possessing a C-S-S-C group in the vicinity of one or more asymmetric centers, an unequal distribution of the M and P<sup>1</sup> chiral C-S-S-C groups (left-handed helix, M, and right-handed helix, P) may be maintained. It has been shown that the electronic transitions associated with this chiral C-S-S-C group are optically active.<sup>2</sup> The ORD and CD spectra of gliotoxin,<sup>3</sup> a compound possessing a C-S-S-C group of known absolute configuration (chirality M), have been studied. In gliotoxin the negative CD peak at 340 m $\mu$  was associated with the left-handed (M) chirality of the disulfide group. However, the authors were not certain whether the sign of the CD peak was dominated by the skew sense of the disulfide. That this is the case was shown very recently by Carmack and Neubert.<sup>4</sup> Here, we confirm and extend these previous observations and provide further evidence for the predominantly chair conformation of 1,2-dithianes.

2,5-Hexanediol was separated into the *meso* and *dl* isomers by crystallization of the bis(hydrogen phthalate) esters. The higher melting bis(hydrogen phthalate) was partially resolved by crystallization of the dibrucine salt. The 2,5-hexanediol, obtained from the dibrucine salt, was chromatographed on alumina. Its rotation,  $[\alpha]^{29D} -17.6^\circ$  (ethanol), indicated that it was predominantly (2*R*,5*R*)-2,5-hexanediol.<sup>5</sup> The optically active diol was converted into the di-*p*-toluenesulfonate which, in turn, was converted with sodium disulfide into the desired *trans*-3,6-dimethyl-1,2-dithiane<sup>6</sup> (I).

(1) R. S. Cahn, C. Ingold, and V. Prelog, *Angew. Chem. Intern. Ed. Engl.*, **5**, 385 (1966).

(2) A. Fredga, *Acta Chem. Scand.*, **4**, 1307 (1950); C. Djerassi, H. Wolf, and E. Bunnenberg, *J. Amer. Chem. Soc.*, **84**, 4552 (1962).

(3) A. F. Beecham, J. Fridrichsons, and A. Mc L. Mathieson, *Tetrahedron Lett.*, 3131 (1966); A. F. Beecham and A. Mc L. Mathieson, *ibid.*, 3139 (1966).

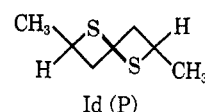
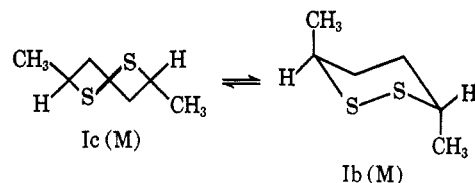
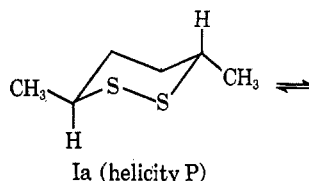
(4) M. Carmack and L. A. Neubert, *J. Amer. Chem. Soc.*, **89**, 7134 (1967). The work reported here was practically completed when the communication from Dr. Carmack appeared.

(5) K. Serck-Hanssen, S. Stållberg-Stenhagen, and E. Stenhagen, *Ark. Kemi*, **5**, 203 (1953).

(6) N. Isenberg and H. F. Herbrandson, *Tetrahedron*, 1067 (1965).

This compound was separated from an accompanying 12% *cis*-3,6-dimethyl-1,2-dithiane by preparative vapor phase chromatography. If one assumes that the displacement reaction went with 100% inversion of configuration and that the *cis*-3,6-dimethyldithiane resulted from a small quantity of the *meso*-2,5-hexanediol still present, then the (3*S*,6*S*)-(+)-*trans*-3,6-dimethyl-1,2-dithiane (IaP) so obtained should be 85% optically pure.

(2*S*,5*S*)-2,5-Hexanediol,  $[\alpha]^{29D} +14.0^\circ$  (ethanol), was obtained by hydrolysis of the mother liquors from the above resolution. This diol was converted into the di-*p*-toluenesulfonate which was crystallized to constant melting point and constant rotation. Reaction of this di-*p*-toluenesulfonate, which we believe to be optically pure, with sodium disulfide yielded (3*R*,6*R*)-(-)-*trans*-3,6-dimethyl-1,2-dithiane (IaM),  $[\alpha]^{29D}$



$-276^\circ$  (ethanol). Comparison of the rotation of this (3*R*,6*R*) enantiomer with that of the optically impure (3*S*,6*S*) enantiomer indicates that the (3*S*,6*S*)-(+)-*trans*-3,6-dimethyl-1,2-dithiane (IaP) was 84% optically pure. This agrees within experimental error with the optical purity calculated from the rotation of the (2*R*,5*R*)-2,5-hexanediol. Vapor phase chromatography of the (-)-3,6-dimethyl-1,2-dithiane showed none of the *meso* isomer. This provides good evidence that our initial assumption of 100% inversion of configuration in the displacement reaction is probably correct.

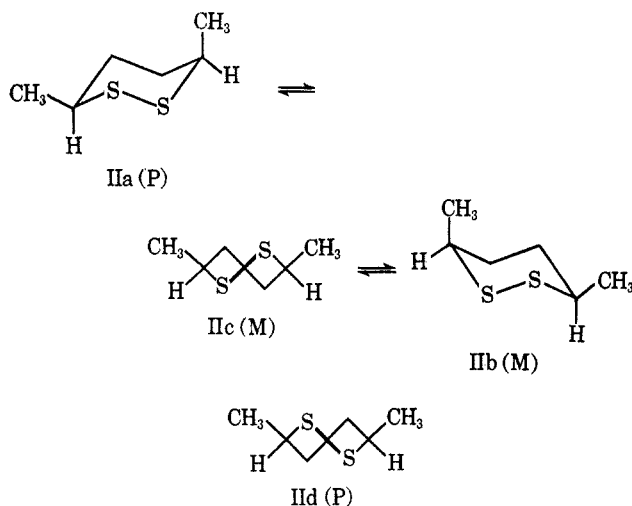
The corresponding *cis*-3,6-dimethyl-1,2-dithiane (II) was synthesized from the *meso*-2,5-hexanediol and was purified by chromatography on a silica gel column. Purity was confirmed by gas chromatography.

Kalf and Havinga<sup>7</sup> have shown that the dipole moment of 1,2-dithiane is in agreement with that calculated for the chair conformation for the compound. The nmr spectra<sup>8</sup> of 1,2-dithiane and substituted 1,2-dithianes provide good evidence for the chair conformation of these compounds. An X-ray analysis of the structure of *trans*-1,2-dithiane-3,6-dicarboxylic acid has shown that the dithiane ring has the chair conformation with the substituents in equatorial positions.<sup>9</sup> To provide further evidence for the chair conformation of

(7) H. T. Kalf and E. Havinga, *Rec. Trav. Chim. Pays-Bas*, **81**, 282 (1962).

(8) G. Claeson, G. Androes, and M. Calvin, *J. Amer. Chem. Soc.*, **83**, 4357 (1961); A. Luettringhaus, S. Kabuss, W. Maier, and H. Freiburg, *Z. Naturforsch.*, **16B**, 761 (1961).

(9) O. Foss and L. Schotte, *Acta Chem. Scand.*, **11**, 1424 (1957); O. Foss and T. Reistad, *ibid.*, 1427 (1957).



the 3,6-dimethyl-1,2-dithianes, the nmr spectra of I and II were determined at  $-60^\circ$  and at  $+90^\circ$ . The chemical shifts of the methyl groups are listed in Table I. The difference between the chemical shift of the

TABLE I<sup>a</sup>

Compd	$-60^\circ$	$+90^\circ$
I	72.82	70.41
II	72.17 and 97.60 (av 84.89)	82.58

<sup>a</sup> Chemical shifts of the methyl groups are given in hertz downfield from tetramethylsilane and were measured at 60 MHz in  $\text{CDCl}_3$ .

equatorial methyl groups in I and the average chemical shift of the equatorial and axial methyl groups in II remained practically constant over a  $150^\circ$  temperature range [ $\Delta = -12.07$  Hz ( $-60^\circ$ );  $\Delta = -12.17$  Hz ( $+90^\circ$ )]. Whereas contributions of the twist forms Iic and Iid could possibly result in little change in the average chemical shift of the methyl groups in II, any appreciable contribution of conformers Ib and/or Ic, Id should probably result in a decrease in the difference between the average chemical shifts of the methyl groups in I and II. It should be noted that the slight decreases in the chemical shift of the methyl groups in I and of the average chemical shift of the methyl groups in II at high temperature are of comparable magnitude ( $-2.41$  and  $-2.31$  Hz, respectively) and may have resulted from changes of concentration with temperature. All of the above evidence firmly establishes the principal conformation of (3*S*,6*S*)-(+) *trans*-3,6-dimethyl-1,2-dithiane as Ia with only very minor contributions from conformations Ib, c, and d.

Data from uv, CD, and ORD spectra for compounds IaP and IaM and for (2*S*,5*S*)-2,5-hexanedithiol, prepared from IaP by reduction with lithium aluminum hydride, are listed in Table II. It is readily apparent that the uv and CD absorption bands of IaP are those of the chiral disulfide group and not those corresponding to a mercaptan. The positive CD band at  $285\text{ m}\mu$  and the negative CD band at  $243\text{ m}\mu$  are associated with a C-S-S-C group with right-handed (P) helicity. This conclusion is in complete agreement with those previously published.<sup>3,4</sup> It should be noted that the sign of rotation of the (2*S*,5*S*)-2,5-hexanedithiol cor-

relates with that found for (2*S*)-2-butanethiol,<sup>10</sup>  $[\alpha]^{25\text{D}} + 18.13^\circ$  (heptane).

### Experimental Section

**(2*R*,5*R*)-2,5-Hexanediol.**—A solution of 230 g (1.94 mol) of a mixture of *meso*- and *dl*-2,5-hexanediol and 574 g (3.88 mol) of phthalic anhydride in 500 ml of toluene was stirred at  $120^\circ$  for 11 hr. The mixture was then stirred with aqueous sodium carbonate solution, and the crude bismonophthalate was isolated by acidification. Most of the lower melting *meso* isomer was removed by washing the product four times with hot chloroform. The remaining solid was crystallized from aqueous ethanol and then from acetone-methanol. From these crystallizations 230 g of *dl*-2,5-hexanediol bis(hydrogen phthalate), mp  $182\text{--}187^\circ$ , was obtained. Further crystallization from acetone-methanol failed to raise this melting point. The chloroform mother liquors were concentrated, petroleum ether (bp  $60\text{--}68^\circ$ ) was added, and the resulting solution was cooled. Impure *meso*-2,5-hexanediol bis(hydrogen phthalate) (107 g, mp  $159\text{--}167^\circ$ ) crystallized from the solution.

The *dl*-2,5-hexanediol bis(hydrogen phthalate) was resolved using the method of Pickard and Kenyon.<sup>11</sup> To a boiling solution of 228 g (0.55 mol) of the *dl*-2,5-hexanediol bis(hydrogen phthalate) in 1.5 l. of acetone and 400 ml of methanol was added 513 g (1.10 mol) of brucine. The hot solution was filtered through Celite and refrigerated for three weeks. It was then warmed to room temperature and recooled to digest the precipitate and thus make the crystals larger and more filterable. The solid was isolated by filtration and crystallized five additional times from acetone. The 174 g of salt, so obtained, was converted back into 53.8 g of 2,5-hexanediol bis(hydrogen phthalate) with methanol and concentrated hydrochloric acid. The ester was saponified by heating it under reflux for 1.5 hr with 25.9 g of sodium hydroxide and 300 ml of water. The 2,5-hexanediol was isolated by extraction with ether and was further purified by chromatography (twice) on alumina. Elution with 90% chloroform-10% methanol yielded 9.7 g of 2,5-hexanediol,  $[\alpha]^{25\text{D}} - 17.6^\circ$  (*c* 6.08, 95% ethanol) and  $-26.6^\circ$  ( $\text{CHCl}_3$ ). The reported rotation of optically pure (2*R*,5*R*)-2,5-hexanediol is  $[\alpha]^{25\text{D}} - 35.6^\circ$  (*c* 8.29,  $\text{CHCl}_3$ ).<sup>5</sup>

**(3*S*,6*S*)-(+) *trans*-3,6-Dimethyl-1,2-dithiane (IaP).**—(2*R*,5*R*)-2,5-Hexanediol (9.7 g, 0.082 mol) was dissolved in 105 ml of pyridine and stirred in an ice bath while 37.5 g (0.197 mol) of *p*-toluenesulfonyl chloride was added to the solution. The resulting solution was stirred for 4.5 hr at low temperature, then for 1 hr at room temperature. The solution was diluted with ice water and the ditosylate was isolated by filtration. The ditosylate was dissolved in acetone; the acetone solution was dried by filtration through anhydrous magnesium sulfate, then evaporated. The 2,5-hexanediol di-*p*-toluenesulfonate (31.9 g, 91%, mp  $81\text{--}91^\circ$ ) was converted directly into the dithiane.

The ditosylate (31.9 g, 0.075 mol) was added to a solution of 5.94 g (0.075 mol) of anhydrous sodium sulfide and 2.41 g (0.075 g-atom) of sulfur in 300 ml of anhydrous *N,N*-dimethylformamide. The resulting solution was stirred at  $70^\circ$  for 21 hr. It was then poured into 600 ml of water and 100 g of ice. The suspension was extracted four times with ether. The ether extracts were washed three times with water, filtered through anhydrous magnesium sulfate, and evaporated. The 7.2 g of product, so obtained, was chromatographed on 200 g of silica gel. The 3,6-dimethyl-1,2-dithiane was eluted with petroleum ether (bp  $30\text{--}60^\circ$ ). The *trans*-3,6-dimethyl-1,2-dithiane was separated from 12% of the *cis* isomer by preparative vpc on a 0.75 in.  $\times$  10 ft Carbowax column heated to  $115^\circ$ . Nitrogen (flow rate 0.1 l./min) was used as the eluent. A sample of the pure *trans*-3,6-dimethyl-1,2-dithiane was also distilled through a short-path distillation apparatus. The nmr spectrum of this material was identical with that previously reported.<sup>6</sup>

The (3*S*,6*S*)-(+) *trans*-3,6-dimethyl-1,2-dithiane (IaP), now completely free of *cis* isomer, should be ca. 85% optically pure: bp  $88\text{--}89^\circ$  (18 mm);  $[\alpha]^{25\text{D}} + 232^\circ$  ( $[\alpha]_{\text{D}} + 273^\circ$ , calculated for optically pure material); ORD (*c* 0.179, 95% ethanol),  $28^\circ$ ,  $[\phi]_{600} + 327^\circ$ ,  $[\phi]_{310} + 5590^\circ$ ,  $[\phi]_{288} 0.0^\circ$ ,  $[\phi]_{260} - 8890^\circ$ ,  $[\phi]_{248} 0.0^\circ$ ,  $[\phi]_{228} + 20,400^\circ$ ,  $[\phi]_{220} + 18,600^\circ$ .

(10) (a) P. Salvadori, L. Lardicci, G. Consiglio, and P. Pino, *Tetrahedron Lett.*, **44**, 5343 (1966); (b) P. A. Levene, A. Rothen, and M. Kuna, *J. Biol. Chem.*, **121**, 757 (1937).

(11) R. H. Pickard and J. Kenyon, *J. Chem. Soc.*, **99**, 45 (1911).

TABLE II<sup>a</sup>  
 UV, CD, AND ORD DATA FOR (3*S*,6*S*)(+)-*trans*-3,6-DIMETHYL-1,2-DITHIANE (IaP)  
 AND (3*R*,6*R*)(-)-*trans*-3,6-DIMETHYL-1,2-DITHIANE (IaM)

		IaP <sup>b</sup> (ethanol)	IaM (ethanol)	IaM (isooctane)	(2 <i>S</i> ,5 <i>S</i> )-2,5-Hexane- dithiol <sup>c</sup> (ethanol)
UV	$\lambda_1$ m $\mu$ ( $\epsilon$ )	285 (243)		284 (233)	224 sh (275)
	$\lambda_2$	241 (158)		242 (174)	
CD	$\lambda_1$ m $\mu$	285	286	286	
	$[\theta]$ , deg	+9050 (+10,800) <sup>c</sup>	-11,000	-12,100	
	$\lambda_2$ m $\mu$	243	243	243	
	$[\theta]$ , deg	-13,100 (-15,600) <sup>c</sup>	+15,700	+17,800	
ORD <sup>d</sup>	$\lambda$ m $\mu$ $[\phi]$	310; +5,590 (+6,650) <sup>c</sup>	310; -6,740	310; -6,640	238; +1,310
	$\lambda$ m $\mu$ $[\phi]$	260; -8,890 (-10,600) <sup>c</sup>	260; +12,100	262; +12,300	208; -324
	$\lambda$ m $\mu$ $[\phi]$	228; +20,400 (+24,300) <sup>c</sup>	227; -25,300	222; -31,200	

<sup>a</sup> Measurements were made at 28° in 95% ethanol and in isooctane on a Cary 60 spectropolarimeter. <sup>b</sup> Approximately 84% optically pure. <sup>c</sup> Calculated for 100% optically pure material, assuming IaP to be 84% optically pure. <sup>d</sup> The maxima or minima are given in parentheses.

(3*R*,6*R*)(-)-*trans*-3,6-Dimethyl-1,2-dithiane (IaM).—The combined mother liquors from the brucine resolution were concentrated and acidified with dilute hydrochloric acid. The solid bis(hydrogen phthalate) ester (51.5 g, mp 184–186°) which precipitated was recovered by filtration. When this material was saponified as described above, 14.6 g of 2,5-hexanediol,  $[\alpha]_{25}^{20} +1.0^\circ$  (*c* 10.32, CHCl<sub>3</sub>), was recovered.

The filtrate from the isolation of the bis(hydrogen phthalate) ester was extracted three times with ether. Evaporation of the combined extracts yielded additional bis(hydrogen phthalate) ester as a thick oil which did not solidify. This material was saponified in the usual way. Distillation of the glycol yielded 9.09 g of 2,5-hexanediol: bp 119–120.5° (15 mm);  $[\alpha]_{25}^{20} +14.0^\circ$  (*c* 7.93, ethanol) and +21.2° (*c* 9.74, CHCl<sub>3</sub>).

This diol was converted into the di-*p*-toluenesulfonate as described above. By crystallization from acetone-petroleum ether (bp 60–68°), 11.0 g of the di-*p*-toluenesulfonate, mp 85–95°, was obtained. This material was crystallized to constant melting point (100–101°, yield 5.17 g) and constant rotation,  $[\alpha]_{25}^{20} 6.8^\circ$  (*c* 0.776, ethanol), by three additional crystallizations from acetone-petroleum ether (bp 60–68°).

Anal. Calcd for C<sub>20</sub>H<sub>26</sub>O<sub>6</sub>S<sub>2</sub>: C, 56.31; H, 6.14. Found: C, 56.46; H, 6.18.

The 2,5-hexanediol di-*p*-toluenesulfonate was converted into the dithiane (IaM) (1.13 g) in the manner described for the dextrorotatory isomer. Purification of this material with preparative vpc gave the (3*R*,6*R*)(-)-*trans*-3,6-dimethyl-1,2-dithiane (IaM): mp 26–30°;  $[\alpha]_{25}^{20} -276^\circ$  (*c* 0.0718, ethanol), -269° (*c* 0.0201, isooctane); ORD (*c* 0.0718, ethanol) 28°,  $[\phi]_{600} -394^\circ$ ,  $[\phi]_{310} -6740^\circ$ ,  $[\phi]_{237} 0.0^\circ$ ,  $[\phi]_{260} +12,100^\circ$ ,  $[\phi]_{246} 0.0^\circ$ ,  $[\phi]_{227} -25,300^\circ$ ,  $[\phi]_{220} -22,700^\circ$ , (*c* 0.0201, isooctane) 28°,  $[\phi]_{600} -384^\circ$ ,  $[\phi]_{310} -6640^\circ$ ,  $[\phi]_{237} 0.0^\circ$ ,  $[\phi]_{262} +12,300^\circ$ ,  $[\phi]_{246} 0.0^\circ$ ,  $[\phi]_{222} -31,200^\circ$ ,  $[\phi]_{220} -30,600^\circ$ .

*cis*-3,6-Dimethyl-1,2-dithiane (II) was prepared using a similar sequence of reactions to those above and starting with the low melting 2,5-hexanediol bis(hydrogen phthalate). In this sequence, the 2,5-hexanediol di-*p*-toluenesulfonate, mp 112–115°, was purified by crystallization from acetone-petroleum ether, then from acetone-MeOH. The nmr spectrum of the *cis*-3,6-dimethyl-1,2-dithiane was identical with that previously reported.<sup>6</sup> Vpc indicated that the compound was pure.

The nmr spectra of I and II were run at -60 ± 5.0° and +90 ± 1.0° on a Varian A-60 spectrometer at 50-Hz sweep width. The spectra were calibrated using two side bands of TMS, generated with a Hewlett-Packard function generator, No. 3300A. Frequency was monitored with a Hewlett-Packard electronic counter, No. 3734A. The spectra were determined in triplicate on 20% (wt/v) solutions of I and II in 95% CDCl<sub>3</sub>-5% TMS. At 90°, so much of the TMS evaporated into the free space in the nmr tube that adequate reference bands were not obtainable. The tubes were opened and an additional 10% (v/v) TMS was added to them. The data, so obtained, should be accurate to ±0.07 Hz.

(2*S*,5*S*)-2,5-Hexanedithiol,  $[\alpha]_{25}^{20} +54.1^\circ$  (*c* 0.0594, 95% ethanol), was prepared by the reduction of the (+)-*trans*-3,6-dimethyl-1,2-dithiane with lithium aluminum hydride in tetrahydrofuran.<sup>12</sup> The dithiol should be ca. 84% optically pure:

(12) R. C. Arnold, A. P. Lien, and R. M. Alm, *J. Amer. Chem. Soc.*, **72**, 731 (1950).

ORD (*c* 0.0594, 95% ethanol) 28°,  $[\phi]_{600} +89^\circ$ ,  $[\phi]_{238} +1310^\circ$ ,  $[\phi]_{214} 0.0^\circ$ ,  $[\phi]_{208} -324^\circ$ , (*c* 0.0762, isooctane), 28°,  $[\phi]_{600} +83^\circ$ ,  $[\phi]_{243} +1320^\circ$ ,  $[\phi]_{221} 0.0^\circ$ .

Registry No.—IaM, 17299-08-0; IaP, 17299-01-3; *dl*-2,5-hexanediol bis(hydrogen phthalate), 17299-02-4; *meso*-2,5-hexanediol bis(hydrogen phthalate), 17299-03-5; 2,5-hexanediol, 17299-07-9; 2,5-hexanediol di-*p*-toluenesulfonate, 17299-04-6; II, 17299-05-7; (2*S*,5*S*)-2,5-hexanedithiol, 17299-06-8.

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### Charge-Transfer Properties and Electrochemistry of Quinones with Donor Substituents<sup>1a</sup>

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Whereas charge-transfer (CT) complexes have been investigated extensively, seldom have both donor and acceptor roles been ascribed to a single compound. The theory underlying these complexes intimates that a compound may display dual behavior provided that there is a good balance between its ionization potential and its electron affinity. We have already described the dual CT abilities of a series of nitro-*p*-terphenyls.<sup>2</sup> We have now extended our studies to the *p*-benzoquinone series in the hope of uncovering donor abilities to complement their well known CT acceptor properties. Consequently, we found that 2,5-diethoxy-*p*-benzoquinone (DEQ) and 2,5-bis-*N*-methylamino-*p*-benzoquinone (BAQ) can function as CT donors as well as playing traditional electron acceptor roles. As a corollary, these quinones also undergo electrochemical oxidation. Although the electrochemical reduction

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(2) R. L. Hansen, *J. Phys. Chem.*, **70**, 1646 (1966).