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Stereochemistry of 9-Arylthioxanthene 10-Oxides and 10,10-Dioxides

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The stereochemistry of 9-arylthioxanthene 10-oxides and 10,10-dioxides was determined by detailed investigation of the ^{1}H-NMR spectra. These sulfoxides and sulfones were synthesized by oxidation of the corresponding 9-arylthioxanthenes with *m*-chloroperbenzoic acid in dichloromethane or with hydrogen peroxide in acetic acid.

Keywords——stereochemistry; conformational analysis; 9-arylthioxanthene; 9-arylthioxanthene 10-oxide; 9-arylthioxanthene 10,10-dioxide; ^{1}H-NMR spectroscopy

We have synthesized many 9-arylthioxanthene 10-oxides and 10,10-dioxides in connection with studies on 9,10-disubstituted 10-thiaanthracenes.[1] There are four possible stereoisomers of 9-substituted thioxanthene 10-oxides and two stereoisomers of 9-substituted thioxanthene 10,10-dioxides. Ternay *et al.* reported extensive studies on the stereochemistry of 9-alkylthioxanthene 10-oxides and 10,10-dioxides.[2] However, little work has been done on the stereochemistry of 9-arylthioxanthene 10-oxides and 10,10-dioxides. We have investigated the stereochemistry of these sulfoxides and sulfones by the use of proton nuclear magnetic resonance (^{1}H-NMR) spectroscopy. The present paper describes in detail the synthesis and stereochemistry of 9-arylthioxanthene 10-oxides and 10,10-dioxides.[3]

Results and Discussion

Stereochemistry of 9-Arylthioxanthene 10-Oxides

Four possible stereoisomers (A—D) of 9-arylthioxanthene 10-oxides may exist from a configurational and conformational standpoint, as shown in Chart 1. We determined the conformation of 9-arylthioxanthene 10-oxides by detailed studies of the ^{1}H-NMR spectra. The ^{1}H-NMR spectral data and the results of conformational assignment are summarized in Table I.

The conformation of the 9-aryl group was determined by making use of the facts that the anisotropic effects of the 9-aryl group occupying the pseudo-equatorial (e′) position causes an upfield shift of the signals due to the peri-protons (H_1 and H_8), and that the thioxanthene ring shields the protons or the substituents of the 9-aryl group in a pseudo-axial (a′) position. On the other hand, the conformation of the sulfinyl oxygen atom at the 10-position was determined mainly by aromatic solvent-induced shifts (ASIS) studies and partly by making use of the fact that the anisotropic effect of the sulfinyl group occupying a pseudo-axial position caused a significant downfield shift of the signals due to the 9-proton or 9-substituent in the a′-position compared with those in the e′-position. This strong anisotropic effect of a′-sulfinyl oxygen on the 9a′-proton was used in the conformational determination of 9-alkylthioxanthene 10-oxides by Ternary *et al.*[2] In conformer C, in which the 9-aryl group

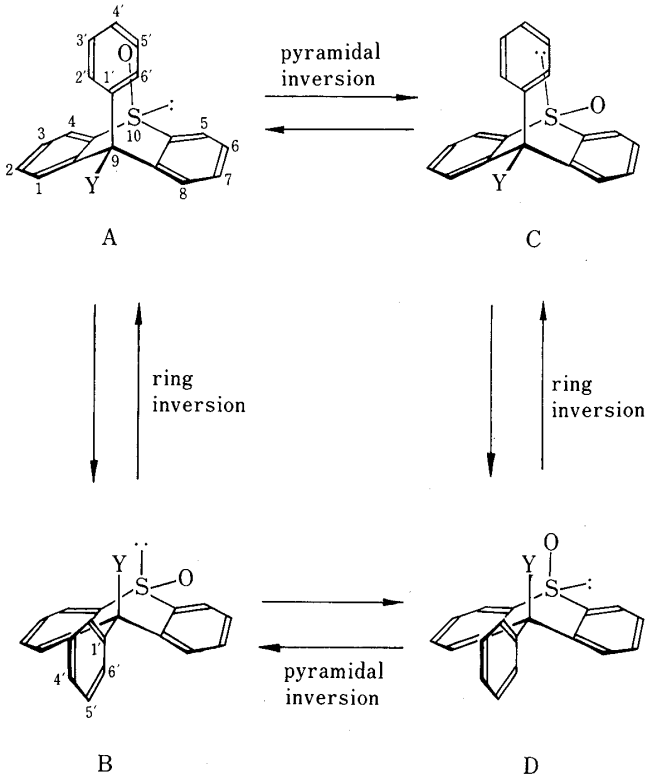


Chart 1

occupies the a′-position and sulfinyl oxygen takes the e′-position, protons of the 9-aryl group, especially the 2′- and 6′-protons (closer to the thioxanthene ring), are considered to be shielded by the anisotropy of the two benzene rings of the thioxanthene molecule. Compound **1** showed multiplet signals corresponding to the 2′- and 6′-protons and 3′-, 4′- and 5′-protons at δ 6.78—7.02 and δ 7.02—7.29, respectively, at higher field than other aromatic protons. The assignment of these signals was based on the spectrum of 9-pentadeuteriophenylthioxanthene 10-oxide (**3**) which has the same conformation as **1**. When both the 9-phenyl group and the sulfinyl oxygen atom occupy the a′ conformation (conformer A), the sulfinyl group deshields the protons of the 9-aryl group, and consequently definite upfield shifts of the protons of the 9-aryl group could not be observed, as in the case of compounds **8** and **13** (Table I). In conformers B and D, where the 9-aryl group takes the e′-position, peri-protons (H_1 and H_8) of the thioxanthene ring are expected to be shielded by the 9-aryl group. For example, the signals of H_1 and H_8 of compound **2** appeared at δ 6.90—7.13 as a separate multiplet at higher field than those of other aromatic protons. These upfield shifts of H_1 and H_8 were also observed in compounds **4**, **6**, **7**, **9** and **11**. When the sulfinyl oxygen atom occupies the a′-position, the 9a′-proton is highly deshielded by the anisotropic effect of the sulfinyl group and is shifted downfield compared with the 9e′-proton. Compounds **6**, **7** and **9** showed this downfield shift. The 9e′-protons of compounds **5** and **10** showed strong downfield shifts in spite of the e′ conformation, but this downfield shift is considered to be due to the large electronegativity of the electron-withdrawing pentafluorophenyl group. The conformation of the sulfinyl oxygen atom was also determined by the effective use of ASIS of H_4 and H_5 of the thioxanthene molecule, which were applied to determine the conformation of the sulfinyl oxygen atom of 9-alkylthioxanthene 10-oxides by Ternary *et al.*[2] In these thioxanthene 10-oxides, the ASIS value ($\Delta H_{4,5} = \delta_{CDCl_3} - \delta_{C_6D_6}$) was negative for the e′ sulfinyl conformation and positive for the a′ sulfinyl conformation. From these ASIS values, it was established that compounds **6**, **7**, **8**, **9** and **13** have the a′ sulfinyl oxygen atom and compounds **1**, **2**, **3**, **4**, **5**, **10**, **11** and **12** have the e′ sulfinyl oxygen atom, as shown in Table I. Furthermore, the ^{1}H-NMR spectra measured in

TABLE I. ^{1}H-NMR Spectral Data for 9-Arylthioxanthene 10-Oxides (**1**—**13**) in $CDCl_3$[a]

Compd.	R^1 [b]	R^2 [c]	R^3	X^1 [b]	X^2 [c]	$H_{1,8}$ (mc)[d]	$H_{4,5}$ (mc)[d]	$H_{4,5}$ in C_6D_6[e] (mc)[d]	$\Delta H_{4,5}$[f]	H_9 ($W_{1/2}$ Hz)	Other absorptions	Conformer
1	Ph	H	H	:	O	[g]	7.83—8.15 (7.99)	7.92—8.22 (8.07)	−0.08	5.52 (2.1)	6.78—7.02 (m, $H_{2',6'}$), 7.02—7.29 (m, $H_{3',5'}$), 7.35—7.76 (m, ArH)[m]	C[i]
2	H	Ph	H	:	O	6.90—7.13 (7.02)	7.85—8.17 (8.01)	8.00—8.29 (8.15)	−0.14	4.83 (2.8)	7.13—7.63 (m, ArH)	B[i]
3	C_6D_6	H	H	:	O	[g]	7.81—8.14 (7.98)	7.93—8.22 (8.08)	−0.10	5.52 (1.5)	7.22—7.66 (m, ArH)	C
4	H	C_6D_6	H	:	O	6.86—7.13	7.82—8.15 (7.99)	8.01—8.31 (8.16)	−0.17	4.83 (2.7)	7.13—7.65 (m, ArH)	B
5	C_6F_5	H	H	:	O	[g]	7.91—8.25 (8.08)	8.07—8.36 (8.22)	−0.14	6.22 (2.1)	7.20—7.75 (m, ArH)	C
6	H	Mes[h]	H	O	:	6.94—7.23 (7.09)	7.90—8.20 (8.05)	7.70—7.97 (7.84)	0.21	6.28 (3.8)	7.28—7.64 (m, ArH), 1.88 (s, 2′-,6′-Me), 2.39 (s, 4′-Me), 7.03 (s, $H_{3',5'}$)	D
7	H	Dur[j]	H	O	:	6.92—7.23[k] (7.08)	7.91—8.20 (8.06)	7.70—7.97 (7.84)	0.22	6.43 (2.9)	7.25—7.65 (m, ArH), 1.77 (br s, 2′-, 6′-Me), 2.32 (s, 3′-,5′-Me)	D
8	Ph	H	4-Me	O	:	[g]	7.72—8.10 (7.91)	7.55—7.85 (7.70)	0.21	5.37 (2.1)	2.85 (s, Me), 7.00—8.10 (m, ArH)	A
9	H	Dur[j]	4-Me	O	:	6.73—[l]	7.90—8.19 (8.05)	7.68—7.92 (7.80)	0.25	6.46 (3.5)	1.18 (br, $W_{1/2}$=0.12 ppm, 6′-Me), 2.21 (br, 2′-Me), 2.37 (s, 3′-,5′-Me), 2.91 (s, 4-Me), 6.73—7.63 (m, ArH)	D
10	C_6F_5	H	1-Me	:	O	[g]	7.96—8.25 (8.11)	8.09—8.37 (8.23)	−0.12	6.12 (1.8)	2.40 (s, 1-Me), 7.39—7.80 (m, ArH)	C
11	iso-Pr	Ph	H	:	O	6.60—6.80 (6.70)	7.90—8.13 (8.02)	8.10—8.35 (8.23)	−0.11		0.85 (d, J=6.9 Hz, $CHC\underline{H}_3$), 2.62 (h, J=6.9 Hz, $C\underline{H}CH_3$), 6.95—7.56 (m, ArH)	B
12	Ph	iso-Pr	H	:	O	[g]	7.79—8.06 (7.93)	7.87—8.22 (8.05)	−0.12		1.23 (d, J=6.9 Hz, $CHC\underline{H}_3$), 3.08 (h, J=6.9 Hz, $C\underline{H}CH_3$), 6.49—6.84 (m, $H_{2',6'}$), 6.88—7.21 (m, $H_{3',5'}$), 7.22—7.79 (m, ArH)	C
13	Ph	H	1,4-Me_2	O	:	[g]	7.73—8.01 (7.87)	7.50—7.88 (7.69)	0.18	5.50 (1.7)	2.28 (s, 1-Me), 2.86 (s, 4-Me), 7.02—8.01 (m, ArH)	A

a) Chemical shifts are reported in ppm downfield from tetramethylsilane as an internal standard. *b*) Pseudo-axial (a′) substituent.
c) Pseudo-equatorial (e′) substituent. *d*) The center of the multiplet signals resulting from these protons.
e) H_4 and/or H_5 signals of the thioxanthene ring in benzene-d_6 for the determination of (ASIS) value. *f*) Δ=ASIS value ($\delta_{CDCl_3}-\delta_{C_6D_6}$).
g) The upfield shifts of $H_{1,8}$ were not observed. *h*) Mes: mesityl. *i*) Reference 2*a*. *j*) Dur: 2,3,5,6-tetramethylphenyl.
k) The signals of $H_{4'}$ of the duryl group are included. *l*) The downfield side of the absorption was obscured by the absorption of the other aromatic protons.
m) ArH means all aromatic protons other than those specifically indicated for each compound.

TABLE II. ^{1}H-NMR Spectral Data for 9-Arylthioxanthene 10,10-Dioxides (**14**—**22**) in $CDCl_3$[a]

Compd.	R^1 [b]	R^2 [c]	R^3	$H_{1,8}$ (mc)[d]	$H_{4,5}$ (mc)[d]	Other absorptions	Conformer
14	H	Ph	H	7.09—[e]	7.98—8.30 (8.14)	7.35 (s, 9-C_6H_5), 7.09—7.63 (m, ArH),[f] 5.52 (s, H_9)	F
15	H	C_6D_5	H	7.09—[e]	7.98—8.30 (8.14)	7.09—7.63 (m, ArH), 5.52 (s, H_9)	F
16	H	Mes	H	6.87—7.21 (7.04)[g]	8.13—8.43 (8.28)	7.27—7.74 (m, ArH), 5.95 (s, H_9), 1.33 (br, 6′-Me), 2.40 (s, 4′-Me), 2.45 (s, 2′-Me)	F
17[h]	H	Mes	3-Et	6.89 (H_1, d, J=8.3 Hz) 6.86—[e]	8.11 (H_4, d, J=1.6 Hz) 8.17—8.40 (8.29)	6.86—7.74 (m, ArH), 5.91 (s, H_9), 2.76 (q, J=7 Hz, $C\underline{H}_2CH_3$) 2.45 (s, 2′-Me), 2.40 (s, 4′-Me), 1.36 (br s, 6′-Me), 1.28 (t, J=7 Hz, $CH_2C\underline{H}_3$)	F
18[h]	H	Mes	3-Pr	6.88 (H_1, d, J=8.3 Hz) 6.85—[e]	8.08 (H_4, d, J=1.5 Hz) 8.13—8.42 (8.28)	6.85—7.70 (m, ArH), 5.91 (s, H_9), 2.70 (t, J=7.7 Hz, $C\underline{H}_2CH_2CH_3$), 2.45 (s, 2′-Me), 2.40 (s, 4′-Me), 1.69 (m, $CH_2C\underline{H}_2CH_3$), 1.35 (s, 6′-Me), 0.95 (t, J=6.6 Hz, $CH_2CH_2C\underline{H}_3$)	F
19[h]	OH	Mes	H	7.03—7.35 (7.19)	8.04—8.35 (8.20)	7.37—7.73 (m, ArH), 6.88 (br, $H_{3',5'}$), 2.76 (br, OH), 2.33 (s, 4′-Me), 1.97 (br, 2′,6′-Me)	F
20[h]	H	Dur	3-Pr	6.88 (H_1, d, J=8.0 Hz) 6.84—[e]	8.13 (H_4, d, J=1.9 Hz) 8.18—8.44 (8.31)	6.84—7.77 (m, ArH), 6.08 (s, H_9), 2.71 (t, J=8 Hz, $C\underline{H}_2CH_2CH_3$), 2.43 (s, 3′-Me), 2.37 (s, 5′-Me), 2.21 (s, 2′-Me), 1.69 (m, $CH_2C\underline{H}_2CH_3$), 1.23 (s, 6′-Me), 0.95 (t, J=7 Hz, $CH_2CH_2C\underline{H}_3$)	F
21	H	C_6F_5	H	6.83—7.23 (7.03)	8.07—8.46 (8.27)	7.30—7.88 (m, ArH), 6.19 (s, H_9)	F
22	C_6F_5	H	1-Me	[i]	7.85—8.20 (8.03)	5.84 (s, H_9), 7.15—7.61 (m, ArH)	E

a) Chemical shifts are reported in parts per million downfield from tetramethylsilane as an internal standard.
b) Pseudo-axial (a′) substituent. *c*) Pseudo-equatorial (e′) substituent.
d) The center of the multiplet signals resulting from these protons.
e) The downfield side of the absorption was obscured by the absorption of the other aromatic protons.
f) ArH means all aromatic protons other than those specifically indicated for each compound.
g) The absorption of $H_{3',5'}$ is included. *h*) Reference 8.
i) The upfield shifts of $H_{1,8}$ were not observed.

C_6D_6 also showed the absorptions of the H_4 and H_5 protons at higher field than 7.9 (δ: the center of the multiplet signals) for the 10a′ conformers and at lower field than 8.0 (δ) for the 10e′ conformers, respectively, due to the different degrees of aromatic solvent effect around the conformationally different polar sulfinyl groups.[4] In the compounds having a phenyl group at the 9-position, the bulkier substituent at the 9-position tends to occupy the a′ position to decrease the steric repulsion between the 9e′-substituent and peri-protons (H_1 and H_8) of the thioxanthene ring. This is apparent from the higher yields of **1**, **3** and **11** than of the corresponding isomers **2**, **4** and **12**, respectively, reflecting increasing bulkiness in the order of iso-Pr > Ph > H.

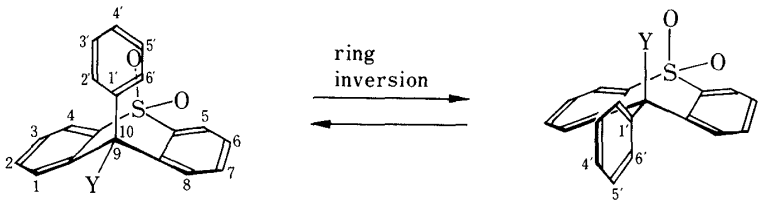
9-Arylthioxanthene 10-oxides **8**, **9** and **13**, which have a methyl group at the 4-position of the thioxanthene ring have the a′ conformation of the sulfinyl oxygen atom because of the steric interaction between the 4-methyl group and sulfinyl oxygen atom, as described by Ternay *et al.*[2] When the 2′- and 6′-protons of the 9-aryl group were both replaced by methyl groups, the 9-aryl group took the e′ position to avoid steric repulsion with the thioxanthene ring; rotation about the C_9–$C_{1'}$ bond is hindered and the 6′-methyl group is located just under the thioxanthene ring, and hence might be affected by the strong anisotropy of the thioxanthene ring. In fact, the signal of the 6′-methyl group appeared at quite high field compared to those of other methyl groups, as observed in compounds **6**, **7** and **9**. For example, in compound **9** the 6′-methyl signal appeared at δ 1.18, while the other methyl signals were observed at δ 2.21 (2′-Me) and δ 2.37 (3′- and 5′-Me). In addition, a considerable rotational barrier of the 2′- and 6′-methyl groups was inferred from the broadness of the signals.

When pairs of stereoisomers of 9-arylthioxanthene 10-oxides were isolated, they were configurational isomers in all cases, not conformational isomers.

Stereochemistry of 9-Arylthioxanthene 10,10-Dioxides

In connection with the stereochemical studies of 9-arylthioxanthene 10-oxides, we next investigated the stereochemistry of 9-arylthioxanthene 10,10-dioxides by ^{1}H-NMR spectroscopy. The ^{1}H-NMR data and the results of conformational assignment are listed in Table II.

Two stereoisomers (E and F) are possible for the conformers of 9-arylthioxanthene 10,10-dioxides as shown in Chart 2.



E F

Chart 2

In conformer F, the signals of H_1 and H_8 should be shifted upfield because of the anisotropic effect of the 9e′-aryl group, while this upfield shift might not be observed in conformer E, just as in the case of 9-arylthioxanthene 10-oxides, which were discussed above. These upfield shifts of H_1 and H_8 were observed in compounds **14**—**21**, although compound **22** did not show upfield shifts of these protons.

On the basis of the ^{1}H-NMR spectral data, all of the sulfones were established to exist in conformer F, except for compound **22**, which has a methyl group at the 1-position of the thioxanthene ring, and hence presumably exists in the 9a′ conformation (conformer E).

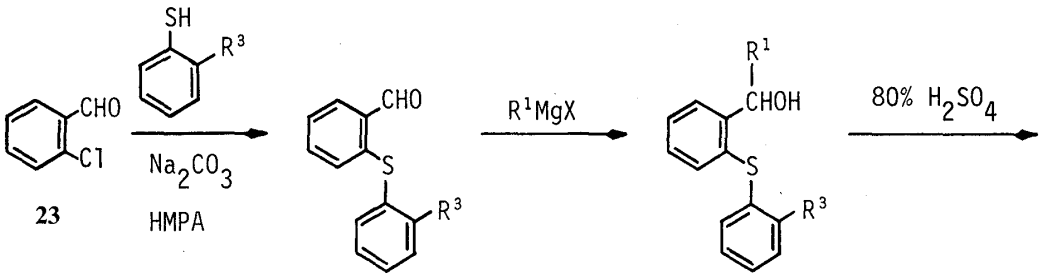
9-Mesityl- and 9-(2,3,5,6-tetramethylphenyl)thioxanthene **10**, 10-dioxides showed 6′-methyl signals at quite high field (δ 1.23—1.97), as observed in the corresponding sulfoxides.

Thus, we have established the utility of the ^{1}H-NMR method for the identification of the conformers of 9-arylthioxanthene 10-oxides and 10,10-dioxides. The application of this ^{1}H-NMR method for the conformational analysis of 10-alkyl-9-arylthioxanthenium salts will be the subject of a forthcoming publication.

Synthesis of 9-Arylthioxanthene 10-Oxides and 10,10-Dioxides

9-Arylthioxanthenes, precursors of 9-arylthioxanthene 10-oxides, were synthesized by the following methods (Charts 3 and 5).

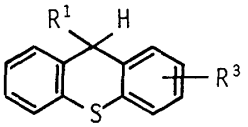
2-Chlorobenzaldehyde (**23**) was allowed to react with 2-methylbenzenethiol in hexamethylphosphoramide (HMPA) in the presence of sodium carbonate to afford 2-(2-methylphenyl)benzaldehyde (**25**). Similarly, 2-phenylthiobenzaldehyde (**24**)[5] was also synthesized in high yield by the reaction of **23** with benzenethiol. Treatment of **24** with aryl Grignard reagents gave the corresponding 1-aryl-1-(2-phenylthiophenyl)methanols **26**,[5] **27**, **28**, **29** and **30**. The aldehyde **25** gave the corresponding 1-aryl-1-[2-(methylphenylthio)phenyl]methanols **31**, **32** and **33**. Cyclization of the methanol derivatives **26**—**32** with 80% H_2SO_4 yielded the



23

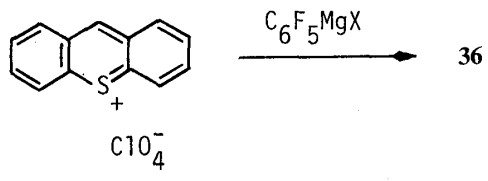
24: R^3=H
25: R^3=Me

26: R^1=Ph, R^3=H
27: R^1=C_6D_5, R^3=H
28: R^1=C_6F_5, R^3=H
29: R^1=Mes,[a] R^3=H
30: R^1=Dur,[b] R^3=H
31: R^1=Ph, R^3=Me
32: R^1=Dur,[b] R^3=Me
33: R^1=C_6F_5, R^3=Me



34: R^1=Ph, R^3=H
35: R^1=C_6D_5, R^3=H
36: R^1=C_6F_5, R^3=H
37: R^1=Mes,[a] R^3=H
38: R^1=Dur,[b] R^3=H
39: R^1=Ph, R^3=4-Me
40: R^1=Dur,[b] R^3=4-Me
41: R^1=C_6F_5, R^3=1-Me

a) mesityl
b) 2,3,5,6-tetramethylphenyl (duryl)



36

42

Chart 3

corresponding 9-arylthioxanthenes **34**,[6,7] **35**—**40** in yields of 67—95%. In the cyclization of compound **33** under the same reaction conditions, an unusual 1,2-shift occurred to give 1-methyl-9-pentafluorophenylthioxanthene (**41**). The position of the methyl group in compound **41** was elucidated by leading **41** to the corresponding sulfoxide **9**. The ^{1}H-NMR spectrum of **9** showed the signals of the two aromatic protons corresponding to H_4 and H_5 of the thioxanthene ring shifted downfield (δ 7.96—8.25) and considerably separated from other aromatic protons due to the electronic effects of the sulfinyl group; this result indicates the absence of a substituent at the 4-position. In contrast, multiplet signals due to one aromatic proton shifted downfield were observed in the case of the sulfoxides derived from normally cyclized thioxanthenes **39** and **40** which have a methyl group at the 4-position of the thioxanthene ring. The formation of **41** can be explained by a mechanism involving an ipso-attack of the carbenium ion **43** derived from the protonated alcohol to form the spiro-intermediate **44**, which undergoes 1,2-sulfur shift to afford the isomerized thioxanthene **41**, as illustrated in Chart 4. A similar abnormal cyclization *via* a spiro-intermediate was observed in the acid-catalyzed cyclization of 2-(4-methylphenylthio)phenylmethanol derivatives by Capozzi.[6] 9-Pentafluorophenylthioxanthene (**36**) was also synthesized in high yield by the reaction of thioxanthylium perchlorate (**42**)[7a] with pentafluorophenylmagnesium iodide. 9-Isopropyl-9-phenylthioxanthene (**46**) was prepared by the reaction of 9-phenylthioxanthylium perchlorate (**45**)[7a] with isopropylmagnesium bromide in 26% yield, along with 12% of the reduction product **34**. 1,4-Dimethyl-9-phenylthioxanthene (**49**) was prepared by Grignard reaction between phenylmagnesium bromide and 1,4-dimethylthioxanthylium perchlorate (**48**), which was prepared by reduction of 1,4-dimethylthioxanthone (**47**) with sodium borohydride in methanol followed by treatment with 70% perchloric acid.

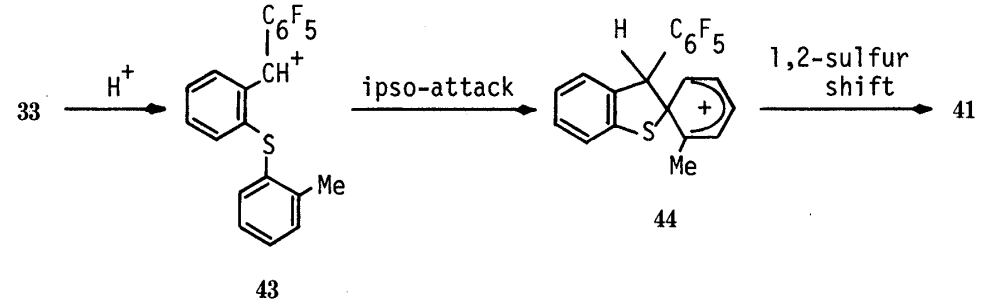


Chart 4

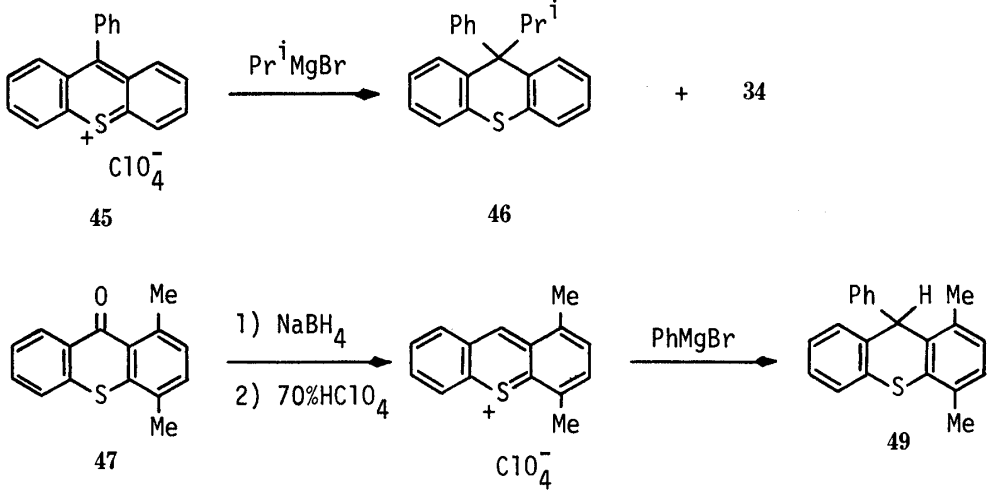


Chart 5

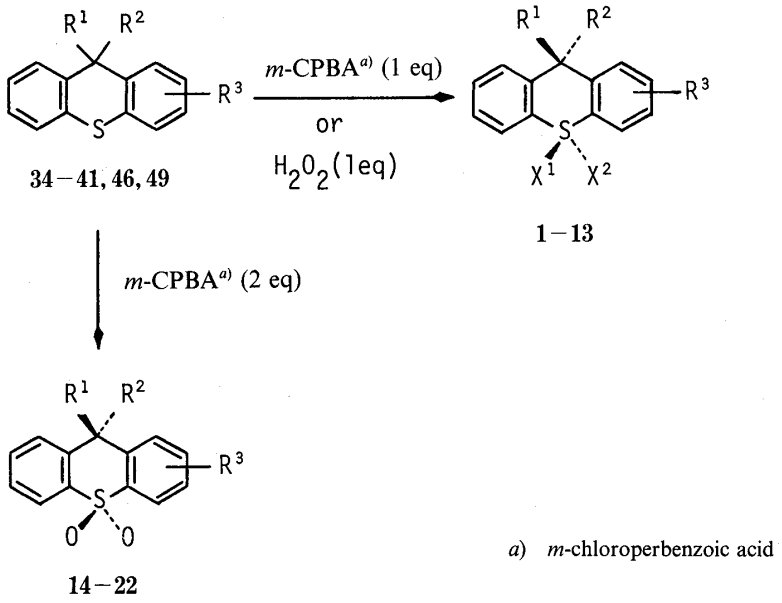


Chart 6

Thus, oxidation of the 9-arylthioxanthenes **34**—**41**, **46** and **49** prepared above with *m*-chloroperbenzoic acid in dichloromethane or with hydrogen peroxide in acetic acid afforded the required 9-arylthioxanthene 10-oxides **1**—**13** (Chart 6).

9-Arylthioxanthene 10,10-dioxides **14**—**22** were prepared by oxidation of the corresponding 9-arylthioxanthenes with 2 eq of *m*-chloroperbenzoic acid in dichloromethane (Chart 6).

Experimental

Melting points were taken on a Yanagimoto micromelting point apparatus and are uncorrected. ^{1}H-NMR spectra were determined with a Hitachi R-20B spectrometer and chemical shifts are given in parts per million relative to tetramethylsilane as an internal standard. Infrared (IR) spectra were recorded with a JASCO IRA-1 spectrometer.

The following compounds were previously synthesized by us, using a procedure similar to that shown in Chart 3:[8] 2-phenylthiobenzaldehyde (**24**), 1-mesityl-1-(2-phenylthiophenyl)methanol (**29**), 1-(2-phenylthiophenyl)-1-(2,3,5,6-tetramethylphenyl)methanol (**30**), 9-mesitylthioxanthene (**37**), and 9-(2,3,5,6-tetramethylphenyl)thioxanthene (**38**).

2-(2-Methylphenylthio)benzaldehyde (25)——A mixture of 2-chlorobenzaldehyde (**23**, 25 g), 2-methylbenzenethiol (25 ml), sodium carbonate (35 g) and HMPA (50 ml) was heated at 100 °C for 5 h with stirring. After cooling, the reaction mixture was poured into water and extracted with ether. The organic layer was washed with water and dried over anhydrous $MgSO_4$. Removal of the solvent gave an oil, which crystallized by adding hexane. Recrystallization from hexane afforded 36.6 g (90%) of **25** as colorless prisms, mp 58—59 °C. IR (KBr): 2758 (CHO), 1692 and 1671 cm^{-1} (CO). ^{1}H-NMR ($CDCl_3$) δ: 2.42 (3H, s, CH_3), 6.84—7.62 (7H, m, ArH), 7.78—8.12 (1H, m, ArH), 10.49 (1H, s, CHO). *Anal.* Calcd for $C_{14}H_{12}OS$: C, 73.65; H, 5.30. Found: C, 73.65; H, 5.29.

Preparation of 1-Aryl-1-(2-phenylthiophenyl)methanols 26—30. 1-Phenyl-1-(2-phenylthiophenyl)methanol (26)——A solution of 2-phenylthiobenzaldehyde (**24**, 10 g)[5,8] in anhydrous ether (60 ml) was added dropwise to a solution of Grignard reagent, prepared from bromobenzene (12 g), Mg (2 g) and anhydrous ether (40 ml). The mixture was refluxed for 1 h, and then treated with NH_4Cl solution. The organic layer was separated, washed with water and dried over anhydrous $MgSO_4$. Removal of the solvent gave an oil, which was crystallized by adding pet. ether. Recrystallization from pet. ether gave 13.6 g (91%) of **26** as colorless needles, mp 49—51 °C (lit.[6] 45—46 °C). IR (KBr): 3390 cm^{-1} (OH). ^{1}H-NMR ($CDCl_3$) δ: 2.51 (1H, br, OH), 6.41 (1H, br s, CHOH), 7.17—7.74 (14H, m, ArH). *Anal.* Calcd for $C_{19}H_{16}OS$: C, 78.05; H, 5.52. Found: C, 77.80; H, 5.42.

The following compounds were prepared in a manner analogous to that described above.

1-Pentadeuteriophenyl-1-(2-phenylthiophenyl)methanol (27)——A solution of **24** (10 g) in anhydrous ether (50 ml) was added dropwise with stirring to an ethereal solution of pentadeuteriophenylmagnesium bromide, prepared from pentadeuteriobromobenzene (11.5 g), Mg (1.7 g) and anhydrous ether (30 ml), and the mixture was heated under reflux for 30 min. Work-up as above gave 13.3 g (91%) of **27**, which was recrystallized from hexane to afford colorless

needles, mp 49—52 °C. IR (KBr): 3429 (OH), 2278 cm^{-1} (CD). ^{1}H-NMR ($CDCl_3$) δ 2.46 (1H, br, OH), 6.33 (1H, s, CHOH), 7.09—7.66 (9H, m, ArH). *Anal.* Calcd for $C_{19}H_{11}D_5OS \cdot 1/4C_6H_{14}$: C, 77.19; H, 4.58. Found: C, 77.16; H, 4.45.

1-Pentafluorophenyl-1-(2-phenylthiophenyl)methanol (28)——This compound was prepared by the reaction of **24** (10 g) and pentafluorophenylmagnesium iodide [prepared from pentafluoroiodobenzene (14 g), Mg (1.2 g) and anhydrous ether (80 ml)] as above in a yield of 17.8 g (80%), colorless needles (pet. ether–chloroform), mp 117—119 °C. IR (KBr): 3460 cm^{-1} (OH). ^{1}H-NMR ($CDCl_3$) δ: 2.86 (1H, d, J=5.3 Hz, OH), 6.59 (1H, d, J=5.3 Hz, CHOH), 6.78—7.71 (8H, m, ArH), 7.78—8.08 (1H, m, ArH). *Anal.* Calcd for $C_{19}H_{11}F_5OS$: C, 59.69; H, 2.90. Found: C, 59.68; H, 2.80.

Preparation of 1-Aryl-1-[2-(2-methylphenylthio)phenyl]methanols 31—33. 1-Phenyl-1-[2-(2-methylphenylthio)phenyl]methanol (31)——A solution of **25** (10 g) in anhydrous ether (50 ml) was added to a solution of phenylmagnesium bromide [prepared from bromobenzene (7.6 g), Mg (1.1 g) and anhydrous ether (50 ml)], and the mixture was refluxed for 1 h. Work-up as usual yielded 12 g (100%) of **31** as an oil, bp 142 °C (0.15 mmHg). IR (neat): 3400 cm^{-1} (OH). ^{1}H-NMR ($CDCl_3$) δ: 2.34 (3H, s, CH_3), 2.53 (1H, br, OH), 6.48 (1H, br s, CHOH), 7.13—7.78 (13H, m, ArH). *Anal.* Calcd for $C_{20}H_{18}OS$: C, 78.39; H, 5.92. Found: C, 78.69; H, 6.00.

1-[2-(2-Methylphenylthio)phenyl]-1-(2,3,5,6-tetramethylphenyl)methanol (32)——The reaction was performed with 2,3,5,6-tetramethylphenylmagnesium bromide [prepared from 2,3,5,6-tetramethylbromobenzene (12 g), Mg (1.8 g) and anhydrous tetrahydrofuran (50 ml)] and **25** (10 g) in anhydrous ether (50 ml) as above. The crude product was recrystallized from pet. ether–dichloromethane to afford 14.2 g (90%) of **32** as colorless prisms, mp 100—102 °C. IR (KBr): 3330 cm^{-1} (OH). ^{1}H-NMR ($CDCl_3$) δ: 2.16 (6H, s, 2 × CH_3), 2.25 (6H, s, 2 × CH_3), 2.36 (3H, s, CH_3 of tolyl group), 2.98 (1H, br, OH), 6.59 (1H, br, CHOH), 7.02 (1H, br s, H_4 of duryl group), 7.12—7.38 (8H, m, ArH). *Anal.* Calcd for $C_{24}H_{26}OS$: C, 79.51; H, 7.23. Found: C, 79.41; H, 7.40.

1-[2-(2-Methylphenylthio)phenyl]-1-pentafluorophenylmethanol (33)——The reaction was performed with pentafluorophenylmagnesium iodide [prepared from pentafluoroiodobenzene (8.5 g), Mg (0.7 g) and anhydrous ether (20 ml)] and **25** (5 g) in anhydrous ether (50 ml) as above. The crude product was recrystallized from pet. ether–dichloromethane to afford 7.2 g (83%) of **33** as colorless prisms, mp 136—138 °C. IR (KBr): 3287 cm^{-1} (OH). ^{1}H-NMR ($CDCl_3$) δ: 2.31 (3H, s, CH_3), 2.73 (1H, d, J=5.9 Hz, OH), 6.60 (1H, d, J=5.9 Hz, CHOH), 6.39—8.12 (8H, m, ArH). *Anal.* Calcd for $C_{20}H_{13}F_5OS$: C, 60.60; H, 3.31. Found: C, 60.66; H, 3.32.

General Procedure for Acid-Catalyzed Cyclization of 1-Aryl-1-(2-arylthiophenyl)methanols to 9-Arylthioxanthene. 9-Phenylthioxanthene (34)——A mixture of **26** (13.6 g) and 80% H_2SO_4 (50 ml) was heated on a water bath for 40 min with occasional shaking. The reaction mixture was carefully poured into cold water and extracted with dichloromethane. The extract was washed with water, dried over silica gel and concentrated to dryness. The residue was recrystallized from MeOH to give 10.3 g (89%) of **34** as colorless needles, mp 97—99 °C (lit.[6] 97—98 °C).

The following compounds were prepared in a manner analogous to that described above.

9-Pentadeuteriophenylthioxanthene (35)——Yield 91%, colorless needles (CH_2Cl_2–MeOH). mp 100—102 °C. ^{1}H-NMR ($CDCl_3$) δ: 5.29 (1H, s, H_9), 7.00—7.58 (8H, m, ArH). *Anal.* Calcd for $C_{19}H_9D_5S$: C, 81.67; H, 3.25. Found: C, 81.61; H, 3.18.

9-Pentafluorophenylthioxanthene (36)——Yield 71%, colorless scales (EtOH). mp 90—91 °C. ^{1}H-NMR ($CDCl_3$) δ: 5.64 (1H, s, H_9), 6.83—7.68 (8H, m, ArH). *Anal.* Calcd for $C_{19}H_9F_5S$: C, 62.64; H, 2.49. Found: C, 62.90; H, 2.47.

4-Methyl-9-phenylthioxanthene (39)——Yield 67%, colorless needles (MeOH). mp 122—125 °C. ^{1}H-NMR ($CDCl_3$) δ: 2.43 (3H, s, CH_3), 5.36 (1H, s, H_9), 6.90—7.63 (12H, m, ArH). *Anal.* Calcd for $C_{20}H_{16}S$: C, 83.29; H, 5.59. Found: C, 83.09; H, 5.54.

4-Methyl-9-(2,3,5,6-tetramethylphenyl)thioxanthene (40)——Yield 90%, colorless prisms (CH_2Cl_2–pet. ether). mp 175—177 °C. ^{1}H-NMR ($CDCl_3$) δ: 1.96 (6H, br, $W_{1/2}$=0.3 ppm, 2′- and 6′-CH_3), 2.32 (6H, s, 3′- and 5′-CH_3), 2.50 (3H, s, CH_3), 5.52 (1H, br s, H_9), 6.50—7.61 (8H, m, ArH). *Anal.* Calcd for $C_{24}H_{24}S$: C, 83.67; H, 7.02. Found: C, 83.39; H, 7.03.

1-Methyl-9-pentafluorophenylthioxanthene (41)——Yield 92%, colorless plates (CH_2Cl_2–MeOH). mp 103—105 °C. ^{1}H-NMR ($CDCl_3$) δ: 2.28 (3H, s, CH_3), 6.13 (1H, s, H_9), 6.91—7.54 (7H, m, ArH). *Anal.* Calcd for $C_{20}H_{11}F_5S$: C, 63.49; H, 2.93. Found: C, 63.50; H, 2.96.

Another Method for the Preparation of 36——Thioxanthylium perchlorate (**42**, 10 g)[7a] was added in small amounts with stirring to a solution of Grignard reagent, prepared from pentafluoroiodobenzene (13 g), Mg (1.05 g) and anhydrous ether (60 ml). The mixture was refluxed for 30 min, and then treated with NH_4Cl solution. The organic layer was separated, washed with water and dried over anhydrous $MgSO_4$. Removal of the solvent gave an oil, which was crystallized by adding EtOH. Recrystallization from EtOH gave 8.5 g (71%) of **36** as colorless scales.

9-Isopropyl-9-phenylthioxanthene (46)——9-Phenylthioxanthylium perchlorate (**45**, 5 g)[7a] was added in small amounts with stirring to a solution of Grignard reagent, prepared from isopropyl bromide (5 g), Mg (1 g) and anhydrous ether (30 ml). The mixture was refluxed for 30 min and treated with NH_4Cl solution. The organic layer was separated and dried over anhydous $MgSO_4$. Removal of the solvent gave an oil, which was purified by column chromatography on silica gel with hexane to give 0.45 g (12%) of **34** and 1.1 g (26%) of **46**. Recrystallization of the crude **46** from CH_2Cl_2–MeOH afforded colorless needles, mp 115—117 °C. ^{1}H-NMR ($CDCl_3$) δ: 0.93 (6H, d, J=

TABLE III. Preparation of 9-Arylthioxanthene 10-Oxides (**1**—**13**)[a]

Compd.	Appearance	Recryst. solvent	mp (°C)	Yield (%)	IR (KBr) cm^{-1} (SO)	Formula	Analysis (%) Calcd (Found)	
							C	H
1	Needles	MeOH	143—144	94[b]	1030	$C_{19}H_{14}OS$	78.58	4.86
							(78.31	5.11)
2	Prisms	MeOH	184—189[c]		1032	$C_{19}H_{14}OS$	78.58	4.86
							(78.68	4.93)
3	Needles	MeOH	142—144	93[d]	1036	$C_{19}H_9D_5OS$	77.25	3.07
							(77.27	2.94)
4	Plates	MeOH	185—189[c]		1030	$C_{19}H_9D_5OS$	77.25	3.07
							(77.18	2.92)
5	Prisms	CH_2Cl_2–ether	145—154[c]	83	1022	$C_{19}H_9F_5OS$	60.00	2.39
							(60.04	2.39)
6	Scales	CH_2Cl_2–ether	162—173[c]	93	1016	$C_{22}H_{20}OS$	79.48	6.06
							(79.37	5.99)
7	Prisms	CH_2Cl_2–MeOH	>145[c]	94	1020	$C_{23}H_{22}OS$	79.73	6.40
							(79.47	6.41)
8	Prisms	CH_2Cl_2–pet. ether	233—234	84	1013	$C_{20}H_{16}OS$	78.91	5.30
							(78.95	5.37)
9	Plates	CH_2Cl_2–hexane	>155[c]	89	1013	$C_{24}H_{24}OS$	79.96	6.71
							(79.69	6.72)
10	Prisms	CH_2Cl_2–MeOH	219—222[c]	91	1040	$C_{20}H_{11}F_5OS$	60.91	2.81
							(60.65	2.75)
11	Needles	CH_2Cl_2–hexane	183—185	92[e]	1029	$C_{22}H_{20}OS$	79.48	6.06
							(79.23	6.07)
12	Rhombs	CH_2Cl_2–hexane	185—187		1035	$C_{22}H_{20}OS$	79.48	6.06
							(79.39	6.04)
13[f]	Prisms	Benzene	230—232	23	1007	$C_{21}H_{18}OS$	79.21	5.70
							(79.43	5.76)

a) See Table I for the substituents at the 9- and 10-positions and on the benzene ring of the thioxanthene skeleton.
b) The ratio of **1** to **2**=3 (by NMR).
c) Melting point with decomposition.
d) The ratio of **3** to **4**=3 (by NMR).
e) The ratio of **11** to **12**=2.8 (by NMR).
f) Prepared by oxidation of **49** with hydrogen peroxide in acetic acid.

6.8 Hz, 2 × CH_3), 2.80 (1H, h, J=6.8 Hz, $CH(CH_3)_2$), 6.43—7.83 (13H, m, ArH). *Anal.* Calcd for $C_{22}H_{20}S$: C, 83.50; H, 6.37. Found: C, 83.30; H, 6.58.

1,4-Dimethylthioxanthylium Perchlorate (48)——Sodium borohydride (8 g) was added in small amounts to a stirred suspension of 1,4-dimethylthioxanthone (**47**, 20 g)[1b] in MeOH (200 ml), and the mixture was refluxed for 1 h, then cooled. Water was added, and the mixture was extracted with ether. The ethereal layer was washed with water and dried over anhydrous $MgSO_4$. Removal of the solvent gave an oil, and a solution of this oil in AcOH (100 ml) was treated dropwise with 70% perchloric acid (10 ml). The precipitate was collected and washed with ether to afford 23 g (85%) of crude **48**. Recrystallization from AcOH containing trace amounts of 70% perchloric acid gave dark violet needles, mp 240—260 °C (dec.). IR (KBr): 1100 cm^{-1} (ClO_4^-). ^{1}H-NMR (CF_3CO_2H) δ: 3.09 (3H, s, CH_3), 3.24 (3H, s, CH_3), 8.03—9.08 (7H, m, ArH). *Anal.* Calcd for $C_{15}H_{13}ClO_4S$: C, 55.47; H, 4.03. Found: C, 55.68; H, 3.89.

1,4-Dimethyl-9-phenylthioxanthene (49)——Anhydrous THF (10 ml) was added to phenylmagnesium bromide [prepared from bromobenzene (5 g), Mg (0.8 g) and ether (20 ml)] and then **48** (6 g) was added in small amounts to the stirred solution. The mixture was refluxed for 1 h, then the reaction mixture was treated with NH_4Cl solution and extracted with ether. The extract was washed with water, dried over anhydrous $MgSO_4$ and evaporated *in vacuo*. The residual solid was recrystallized from MeOH to afford 3.6 g (55%) of **49** as colorless needles, mp 131—134 °C. ^{1}H-NMR ($CDCl_3$) δ: 2.43 (3H, s, CH_3), 2.46 (3H, s, CH_3), 5.67 (1H, s, H_9), 6.82—7.66 (11H, m, ArH). *Anal.* Calcd for $C_{21}H_{18}S$: C, 83.40; H, 6.00. Found: C, 83.17; H, 5.91.

General Procedure for the Preparation of 9-Arylthioxanthene 10-Oxides 1—12. *cis*- and *trans*-9-Phenylthioxanthene 10-Oxide (2 and 1)——*m*-Chloroperbenzoic acid (85% purity, 1.48 g) was added in small amounts to a solution of **34** (2 g) in dichloromethane (30 ml), and the mixture was stirred for 12 h. The reaction mixture was

TABLE IV. Preparation of 9-Arylthioxanthene 10,10-Dioxides[a)]

Compd.	Appearance	Recryst. solvent	mp (°C)	Yield (%)	IR (KBr) cm^{-1} (SO_2)	Formula	Analysis (%) Calcd (Found) C	H
14	Needles	CH_2Cl_2–hexane	197—199	91	1299 1161	$C_{19}H_{14}O_2S$	74.48 (74.25	4.61 4.58)
15	Needles	CH_2Cl_2–hexane	197—199	89	1298 1166	$C_{19}H_9D_5O_2S$	73.28 (73.10	2.91 2.81)
16	Needles	CH_2Cl_2–pet. ether	212—214	87	1322 1304 1165	$C_{19}H_9F_5O_2S$	57.58 (57.58	2.29 2.30)
21	Needles	CH_2Cl_2–MeOH	177—179	87	1313 1161	$C_{20}H_{11}F_5O_2S \cdot 1/4CH_2Cl_2 \cdot 1/4CH_3OH$	56.01 (55.94	2.87 2.67)
22	Leaflets	CH_2Cl_2–pet. ether	239—242	89	1299 1164 1156	$C_{20}H_{11}F_5O_2S$	58.53 (58.26	2.70 2.66)

a) See Table II for the substituents at the 9- and 10-positions and on the benzene ring of the thioxanthene skeleton.

washed with sodium carbonate solution and then with water, and dried over $MgSO_4$. Evaporation of the solvent *in vacuo* at room temperature gave 1.99 g (94%) of 9-phenylthioxanthene 10-oxide as a mixture of *cis* and *trans* isomers (the ratio of **1** to **2** was 3 as determined from the ^{1}H-NMR spectrum). Recrystallization from MeOH gave colorless needles of **1** and colorless prisms of **2**, which were mechanically separated.

The other sulfoxides **3**—**12** were prepared from **35**—**41** in a manner analogous to that described above. The results are summarized in Tables I and III.

1,4-Dimethyl-9-phenylthioxanthene 10-Oxide (13)——A mixture of AcOH (60 ml) and 35% H_2O_2 (0.64 g) was added to a solution of **49** (2 g) in dichloromethane (60 ml). The mixture was stirred for 5 d, then poured into water. The organic layer was separated, washed with sodium bicarbonate solution and then water, and dried over anhydrous $MgSO_4$. Removal of the solvent gave a residue, which was purified by preparative thin layer chromatography on silica gel with chloroform. Recrystallization from benzene yielded 0.474 g (23%) of **13** as colorless prisms, mp 230—232 °C. The results are listed with those for the other sulfoxides in Tables I and III.

General Procedure for the Preparation of 9-Arylthioxanthene 10,10-Dioxides. 9-Phenylthioxanthene 10,10-Dioxide (14)——*m*-Chloroperbenzoic acid (85% purity, 0.89 g) was added portionwise to a well-stirred solution of **34** (0.5 g) in dichloromethane (20 ml), and the mixture was stirred at room temperature overnight. The reaction mixture was extracted with sodium carbonate solution, then with water, dried over anhydrous $MgSO_4$ and evaporated. The residue was recrystallized from CH_2Cl_2–hexane to afford 0.507 g (91%) of **14** as colorless needles, mp 197—199 °C. The other sulfones **15**, **21** and **22** were prepared in a manner analogous to that described above. The results are summarized in Tables II and IV.

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