Stereospecific Desulfinylation of Sulfinylaziridines with Alkylmetals: A Novel Synthesis Including Asymmetric Synthesis of (*Z*)-*N*-Arylaziridines and Some Mechanistic Studies[1]

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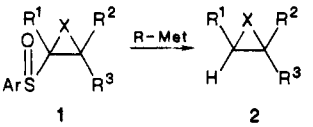
Addition of the anion derived from 1-chloroalkyl *p*-tolyl sulfoxides **3** to *N*-arylimines **4** afforded chloro amines **5** in high yields with complete 1,2- and 1,3-asymmetric induction. Treatment of these chloro amines **5** with potassium *tert*-butoxide gave sulfinylaziridines **6** in good yield. Displacement of aziridines from the sulfinylaziridines **6** was most effectively conducted with excess ethylmagnesium bromide to give the desired aziridines **7** with high stereospecificity in good yields. When optically active **3** were used as starting materials, an asymmetric synthesis of optically active *N*-arylaziridines was realized. In the displacement reaction, it was found that the intermediate, aziridine Grignard reagent, was relatively stable, and it was possible to trap the intermediate with D_2O and acetaldehyde.

Sulfoxides are extensively used in modern synthetic organic chemistry.[2] The sulfinyl group is usually used as an auxiliary for activation of the α-carbon. After several chemical transformations the group must be removed to get the final desired compounds. Reduction, thermal elimination, sulfoxide–sulfenate rearrangement, Pummerer rearrangement, and some other methods are known to be useful for the chemical transformations and/or removal of the sulfinyl group.

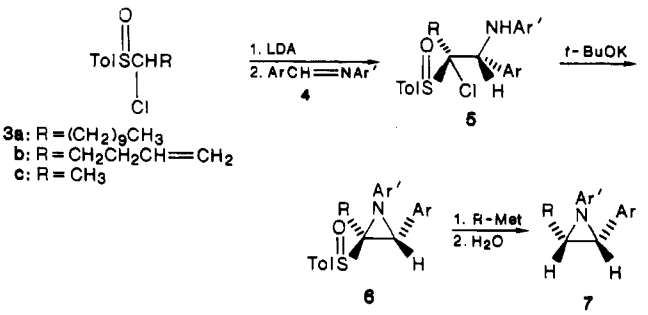
Displacement of aryl groups from diaryl or alkyl aryl sulfoxides by alkylmetals has been known,[3] and recently this reaction was used to prepare pyridyl and quinolyl Grignard reagents by Furukawa et al.[4] These reactions are thought to be useful to new chemistry for conversion of sulfoxides to other compounds; however, few reports have been published so far.[5]

We recently reported a desulfinylation of α,β-epoxy sulfoxides (**1**: X = O) with butyllithium giving epoxides (**2**: X = O)[6] (Scheme I). This displacement of the epoxy group from α,β-epoxy sulfoxides was found to be stereospecific, and the reaction was used in a novel asymmetric synthesis of optically active epoxides and allylic alcohols.[7] In continuation of this chemistry, the technology was extended to the nitrogen analogue of α,β-epoxy sulfoxides, sulfinylaziridines (**1**: X = NAr′), and we found that the reaction worked excellently to give *N*-arylaziridines (**2**: X = NAr′).[8] In this paper we report the details of the displacement of aziridines from sulfinylaziridines and a novel asymmetric synthesis of optically active (*Z*)-*N*-arylaziridines. We also refer to the intermediate of this reaction, aziridine Grignard reagent, and some trials to trap the Grignard reagent with electrophiles.

Scheme I



Scheme II



Results and Discussion

Stereospecific Desulfinylation of Sulfinylaziridines with Alkylmetals Giving *N*-Arylaziridines. Sulfinylaziridines (**1**: X = NAr′), the nitrogen analogues of α,β-epoxy sulfoxides, are little-known compounds. These rare compounds were once reported by Reutrakul et al. and were used in the synthesis of pyroles.[9]

1-Chloroundecyl *p*-tolyl sulfoxide **3a** was treated with 1.1 equiv of lithium diisopropylamide (LDA) in THF at −60 °C followed by 1.3 equiv of benzalaniline **4** (Ar = Ar′ = Ph)[10] to give the chloro amine (**5a**: R = $(CH_2)_9CH_3$; Ar = Ar′ = Ph) as colorless crystals in 94% yield. Somewhat surprising is the observation that the reaction gave only one product, though the chloro amine has three chiral centers. This fact indicates that in the reaction of the α-carbanion of the sulfoxide **3a** with the imine 1,2- and

(1) α,β-Epoxy sulfoxides as useful intermediates in organic synthesis. 22. Part 21: Satoh, T.; Oohara, T.; Ueda, Y.; Yamakawa, K. *J. Org. Chem.*, in press.

(2) Trost, B. M. *Chem. Rev.* **1978**, *78*, 363. Block, E. *Reactions of Organosulfur Compounds*; Academic Press: New York, 1978. *The Chemistry of Sulphones and Sulphoxides*; Patai, S., Rappoport, Z., Stirling, C., Eds.; John Wiley and Sons: Chichester, 1988.

(3) Lockard, J. P.; Schroeck, C. W.; Johnson, C. R. *Synthesis* **1973**, 485. Durst, T.; LeBelle, M. J.; Van den Elzen, R.; Tin, K.-C. *Can. J. Chem.* **1974**, *52*, 761. Hojo, M.; Masuda, R.; Saeki, T.; Fujimori, K.; Tsutsumi, S. *Synthesis* **1977**, 789.

(4) Furukawa, N.; Shibutani, T.; Matsumura, K.; Fujihara, H.; Oae, S. *Tetrahedron Lett.* **1986**, *27*, 3899.

(5) Nokami, J.; Kunieda, N.; Kinoshita, M. *Chem. Lett.* **1977**, 249. Furukawa, N.; Shibutani, T.; Fujihara, H. *Tetrahedron Lett.* **1987**, *28*, 2727.

(6) (a) Satoh, T.; Kaneko, Y.; Yamakawa, K. *Tetrahedron Lett.* **1986**, *27*, 2379. (b) *Bull. Chem. Soc. Jpn.* **1986**, *59*, 2463.

(7) Satoh, T.; Oohara, T.; Ueda, Y.; Yamakawa, K. *Tetrahedron Lett.* **1988**, *29*, 313. Satoh, T.; Oohara, T.; Yamakawa, K. Ibid. **1988**, *29*, 2851.

(8) Satoh, T.; Oohara, T.; Yamakawa, K. *Tetrahedron Lett.* **1988**, *29*, 4093.

(9) Mahidol, C.; Reutrakul, V.; Prapansiri, V.; Panyachotipun, C. *Chem. Lett.* **1984**, 969.

(10) Bigelow, L. A.; Eatough, H. *Organic Synthesis*; Wiley: New York, 1967; Collect. Vol. I, p 80. All imines **4** used in this study were prepared according to the method described in this literature.

0022-3263/89/1954-3973$01.50/0

Table I. Desulfinylation of Sulfinylaziridine (6a: R = $CH_3(CH_2)_9$, Ar = Ar′ = Ph) with Alkylmetals

alkylmetal (equiv)	temp, °C	time	yield,[a] %
BuLi (1.1)	−100	10 min	69
MeLi (1.1)	−70	5 min	trace[b]
(3.0)	−70	5 min	75
MeMgBr (3.5)	−55 to 0	2 h	0
EtMgBr (1.7)	−70 to −50	40 min	79
(3.5)	−55 to −35	2 h	95
PhMgBr (3.5)	−55 to −30	2 h	trace[b]

[a] Isolated yield. [b] Detected on TLC.

1,3-chiral induction took place simultaneously. This chemical property was used in the chiral synthesis of aziridenes (see below). The chloro amine **5a** was heated at 70 °C with 2.4 equiv of potassium *tert*-butoxide (*t*-BuOK) in a 1:1 mixture of THF and 2-methyl-2-propanol (*t*-BuOH) for 15 min to afford the desired sulfinylaziridine **6a** as colorless prisms in 87% yield. The stereochemistry of the sulfinylaziridine **6a** was easily determined to be *E* from its ^1H NMR spectrum. The proton on the aziridine ring showed quite low resonance (δ 4.62), and after removal of the sulfinyl group (giving **7a**: see below) this signal shifted to δ 3.29. These data unambiguously indicate the proton to be *cis* to the sulfinyl group.

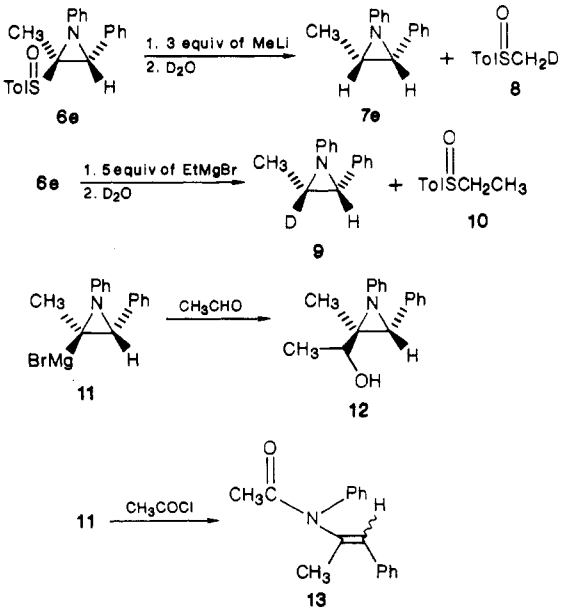
Firstly, the desulfinylation was studied with butyllithium (*n*-BuLi) based on the experience gained from the study with α,β-epoxy sulfoxides.[6] The sulfinylaziridine **6a** was treated with 1.1 equiv of *n*-BuLi at −100 °C in THF for 10 min. The desired desulfinylation took place to afford (*Z*)-*N*-phenylaziridine **7a** in 69% yield; however, this reaction always gave some unknown byproducts. We studied this reaction with other alkylmetals, and the results are summarized in Table I. As shown in Table I, the reaction was most effectively conducted with excess ethylmagnesium bromide (EtMgBr). Excess methyllithium (MeLi) was also effective. Somewhat surprisingly, methylmagnesium bromide (MeMgBr) showed a sharp contrast with EtMgBr; even at room temperature **6a** did not react at all with MeMgBr.

The stereochemical assignment of **7a** was made to be *Z* from an inspection of the coupling constants between adjacent ring protons. The proton on the ring bearing the phenyl group showed at δ 3.29 with a coupling constant of 6 Hz, which indicated that the protons on the ring were cis to each other.[11] These results also showed that the desulfinylation proceeded with high stereospecificity on the aziridine ring.

The results of the synthesis of (*Z*)-*N*-arylaziridines **7** from 1-chloroalkyl *p*-tolyl sulfoxides **3** and *N*-arylimines **4** are summarized in Table II. The overall yields were uniformly quite good. Aziridines have recently received considerable attention with interest concerning their use as versatile intermediates in organic synthesis.[12] The results described above offer a novel and very short method for the synthesis of *N*-arylaziridines.

Proof of the Aziridine Grignard Reagent as the Intermediate of the Desulfinylation. The intermediate of the desulfinylation reaction of the sulfinylaziridines is worthy to be considered. If the intermediates are the organometals of aziridines, it can be assumed that they could be trapped by electrophiles to give new aziridines.

Scheme III



Sulfinylaziridine **6e** was treated with 3 equiv of MeLi in THF at −60 °C for 3 min. The reaction was then quenched with excess D_2O to give aziridine **7e** and monodeutrated methyl *p*-tolyl sulfoxide **8** in 82% and 36% yields, respectively. No deutrated aziridine was observed (Scheme III). On the other hand, treatment of **6e** with 5 equiv of EtMgBr in THF at 0 °C for 3 min followed by excess D_2O gave monodeutrated aziridine **9** and ethyl *p*-tolyl sulfoxide **10** in 94% and 76% yields, respectively. These results indicated that the intermediate of the reaction of **6e** with EtMgBr must be the Grignard reagent of aziridine **11**. The reason why the reaction of **6e** with MeLi did not give deuterated aziridine is explained as follows. The intermediate of the reaction with MeLi is thought to give the lithium compound of the aziridine and methyl *p*-tolyl sulfoxide. However, the lithium compound picks up the acidic proton of the displaced methyl *p*-tolyl sulfoxide to give **7e** very quickly. On the other hand, because the aziridine Grignard reagent **11** does not have enough basicity to pick up the acidic proton of **10** no protonated aziridine was observed. In fact, though excess EtMgBr was used in this reaction, no deuterated ethyl *p*-tolyl sulfoxide was observed. The aziridine Grignard reagent **11** was found to be relatively stable; after standing for 1 h at 0 °C followed by quenching with D_2O, the reagent gave **9** with no reduction in the yield.

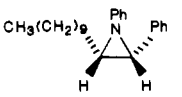
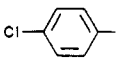
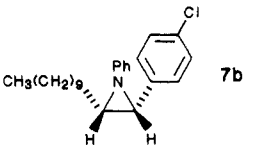
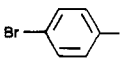
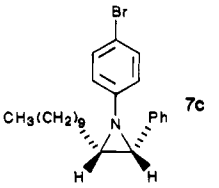
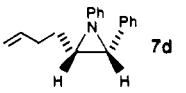
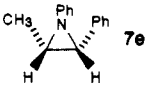
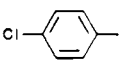
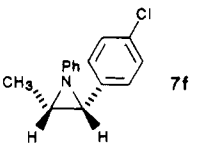
Trapping the Grignard reagent with electrophiles was attempted with iodomethane, acetaldehyde, benzaldehyde, acetone, and acetyl chloride; however, these reactions were not productive. With acetaldehyde, adduct **12** (unstable compound) was obtained in 85% yield as a mixture of diastereomers. The reaction of **11** with acetyl chloride gave enamide **13** in 38% yield as the only one isolable product. All other reactions gave a complex mixture.

Asymmetric Synthesis of (*Z*)-*N*-Arylaziridines. The growing importance of optically active aziridines in organic synthesis[13] requires their chiral synthesis from

(11) Deyrup, J. A.; Greenwald, R. B. *J. Am. Chem. Soc.* **1965**, *87*, 4538.
(12) Some recent papers: Kametani, T.; Honda, T. *Advances in Heterocyclic Chemistry*; Katritzky, A. R., Ed.; Academic Press: New York, 1986; Vol. 39, p 181. Alper, H.; Hamel, N. *Tetrahedron Lett.* **1987**, *28*, 3237. Torii, S.; Inokuchi, T.; Takagishi, S.; Sato, E.; Tsujiyama, H. *Chem. Lett.* **1987**, 1469. Dureault, A.; Tranchepain, I.; Greck, C.; Depezay, J.-C. *Tetrahedron Lett.* **1987**, *28*, 3341. Hata, Y.; Watanabe, M. *Tetrahedron* **1987**, *43*, 3881. Vedejs, E.; Dax, S.; Martinez, G. R.; McClure, C. K. *J. Org. Chem.* **1987**, *52*, 3470. Vedejs, E.; Grissom, J. W.; Preston, J. K. Ibid. **1987**, *52*, 3487.

(13) Some recent papers: Duggan, M. E.; Karanewsky, D. S. *Tetrahedron Lett.* **1983**, *24*, 2935. Dureault, A.; Tranchepain, I.; Greck, C.; Depezay, J.-C. Ibid. **1987**, *28*, 3341. Hata, Y.; Watanabe, M. *Tetrahedron* **1987**, *43*, 3881. Baldwin, J. E.; Adlington, R. M.; Robinson, N. G. J. *Chem. Soc., Chem. Commun.* **1987**, 153.

Table II. Synthesis of (*Z*)-*N*-Arylaziridines 7 from 1-Chloroalkyl *p*-Tolyl Sulfoxides 3 and *N*-Arylimines 4 through Sulfinylaziridines 6

	4					7	
3 R	Ar	Ar′	5 (yield, %)[a]	6 (yield, %)[a]	condn[b]		yield,[a] %
$CH_3(CH_2)_9$	Ph	Ph	**5a** (94)	**6a** (87)	A	 **7a**	95
		Ph	**5b** (84)	**6b** (92)	B	 **7b**	88
	Ph		**5c** (88)	**6c** (98)	C	 **7c**	85
$CH_2{=}CHCH_2CH_2$	Ph	Ph	**5d** (76)	**6d** (83)	D	 **7d**	90
CH_3	Ph	Ph	**5e** (91)	**6e** (92)	E	 **7e**	89
		Ph	**5f** (74)	**6f** (90)	F	 **7f**	91

[a] Isolated yield. [b] All reactions were conducted with EtMgBr in THF. A: 3.5 equiv, −55 to −35 °C, 2 h. B: 5 equiv, −60 to −50 °C, 1 h, then room temperature for 20 min. C: 3.5 equiv, −55 to −20 °C, 1 h, then room temperature for 10 min. D: 5 equiv, −55 to −30 °C, then room temperature for 10 min. E: 5 equiv, −55 to −40 °C, 1 h. F: 3.5 equiv, −55 to −25 °C, 2 h.

readily available starting materials. Usually, optically active aziridines are synthesized by the dehydrative cyclization of 2-amino alcohols[14] derived from optically active amino acids or sugars. Atkinson and Tughan[15] recently reported an asymmetric induction of 2-(chiral)substituted benzimidazol-derived *N*-nitrene to α-methylene-γ-butyrolactone, giving the aziridines in high diastereomeric excess. To our knowledge, no other asymmetric synthesis of aziridines has been reported so far. As described above, the addition of the anion of **3** with **4** took place with complete asymmetric induction from the sulfur chiral center. By the use of optically active **3** in these reactions, it was thought that they would give optically active aziridines **7** in high overall yields.

Optically active (−)-**3a** (97% ee)[1,7] reacted with **4a** to give optically active (−)-**5a**, which was recrystallized from $CHCl_3$–hexane to afford colorless needles ($[\alpha]^{25}_D$ −217.4° (*c* 0.2, $CHCl_3$)). The absolute stereochemistry of the carbon bearing the chlorine atom of (−)-**5a** was deduced to be *R* from the experiences of the study with chiral α,β-epoxy sulfoxides.[7] This deduction has been subsequently verified (see below). Treatment of (−)-**5a** with *t*-BuOK at 70 °C gave (*E*)-(*N*-phenyl)sulfinylaziridine (−)-**6a** ($[\alpha]^{25}_D$ −301.4° (*c* 0.1, acetone)) as colorless prisms. At this stage it was suspected that the isomerization or racemization of the sulfinylaziridine took place through azomethine ylide[16] by heating; however, this did not prove to be the case. Optical purity of (−)-**6a** was measured by ^1H NMR using $Eu(hfc)_3$ as a chiral shift reagent. With 50–100 mol % of $Eu(hfc)_3$ in $CDCl_3$ the proton of the *p*-tolyl group of **6a** showed clear separation of the signals, and (−)-**6a** was found to be optically pure.[17]

At this stage, the absolute stereochemistry of the carbon bearing the nitrogen atom of (−)-**5a** was determined to be *R* as follows. Reduction of the chlorine atom of (−)-**5a** was carried out under radical dehalogenation conditions[18] (2 equiv of Bu_3SnH; 0.2 equiv of α,α′-azobisisobutyronitrile (AIBN); in refluxing benzene for 20 min) to afford **14** in 99% yield as a mixture of inseparable diastereomers in equal amounts. The mixture **14** was treated with Raney Ni (W-2) in refluxing EtOH for 15 min to give the amine **15** as a colorless oil in 83% yield, which showed $[\alpha]^{25}_D$ +10.5° (*c* 2.1, MeOH). Comparing the sign of the specific rotation of **15** with that of (*R*)-(−)-*N*-phenyl-α-phenethylamine ($[\alpha]^{25}_D$ −18.1° (MeOH))[19] the absolute config-

(14) Suzuki, H.; Tani, H. *Chem. Lett.* **1984**, 2129. Pfister, J. R. *Synthesis* **1984**, 969. Kelly, J. W.; Eskew, N. L.; Evans, S. A., Jr. *J. Org. Chem.* **1986**, *51*, 95.

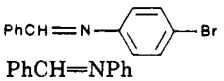
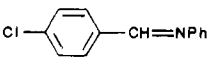
(15) Atkinson, R. S.; Tughan, G. *J. Chem. Soc., Perkin Trans. 1* **1987**, 2787; **1987**, 2797; **1987**, 2803.

(16) Huisgen, R.; Scheer, W.; Szeimies, G.; Huber, H. *Tetrahedron Lett.* **1966**, 397. Huisgen, R.; Scheer, W.; Huber, H. *J. Am. Chem. Soc.* **1967**, *89*, 1753. Huisgen, R.; Scheer, W.; Mader, M. *Angew. Chem., Int. Ed. Engl.* **1969**, *8*, 602. Vedejs, E.; Dax, S.; Martinez, G. R.; McClure, C. K. *J. Org. Chem.* **1987**, *52*, 3470. Vedejs, E.; Grissom, W.; Preston, J. K. Ibid. **1987**, *52*, 3487.

(17) Though the optical purity of the starting material (−)-**3** is 97% ee, the optical purity of (−)-**5** was upgraded to 100% ee by recrystallization from $CHCl_3$–hexane. The optical purity of all (−)-**6** were measured to be 100% ee by this technique.

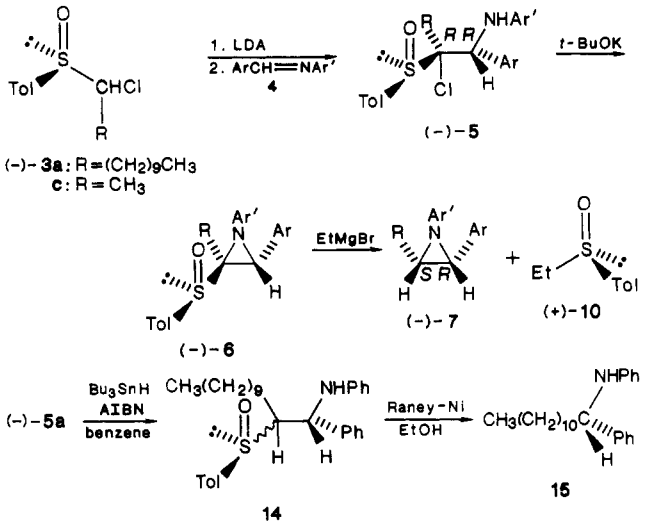
(18) Ramaiah, M. *Tetrahedron* **1987**, *47*, 3541.

Table III. Specific Rotations (deg) of Optically Active 5, 6, and 7

R	4	5[a]	6[b]	7[b]
$CH_3(CH_2)_9$	PhCH=NPh	-217.4[b]	-301.4	-159.5
$CH_3(CH_2)_9$		-250.5	-277.4	-132.6
CH_3	PhCH=NPh	-177.6	-385.2	-271.3
CH_3		-196.1	-384.8	-313.3

[a] $[\alpha]_D$; measured in $CHCl_3$ at 25 °C. [b] $[\alpha]_D$; measured in acetone at 25 °C.

Scheme IV



uration of **15** was unambiguously *S*.

Stereospecific desulfinylation of (-)-**6a** was carried out with 5 equiv of EtMgBr in THF to give the desired optically active (-)-(*Z*)-*N*-phenylaziridine **7a** ($[\alpha]^{25}_D$ -159.5° (*c* 1.2, acetone)) as an oil in almost quantitative yield with (+)-ethyl *p*-tolyl sulfoxide **10** (87% yield). Unfortunately, we were not able to determine the optical purity of (-)-**7a**; however, partial racemization of (-)-**6a** and/or (-)-**7a** under the conditions was quite unlikely. The specific rotation of the products obtained in this study are summarized in Table III.

We were interested in the absolute configuration of the produced ethyl *p*-tolyl sulfoxide (+)-**10** ($[\alpha]^{25}_D$ +194.8° (*c* 1.0, acetone)).[20] The sign of the specific rotation of (+)-**10** showed that it has *R* absolute configuration. This result indicated that the reaction proceeded with almost complete inversion on the sulfur chiral center. The stereochemistry of this displacement reaction is consistent with the reaction of pyridyl sulfoxides with Grignard reagents reported by Furukawa et al.[4]

In conclusion, because of its overall simplicity and the high overall yields obtainable, we believe that the presented method will prove valuable in the synthesis of *N*-arylaziridines, including the optically active form.

Experimental Section

All melting points are uncorrected. Infrared (IR) spectra were measured directly on a NaCl plate or in KBr disks with a Hitachi 215 spectrometer. ^1H Nuclear magnetic resonance (NMR) spectra were measured in $CDCl_3$ solution with a JEOL FX-100 spectrometer using Me_4Si as an internal standard. Electron-impact mass spectra (MS) were obtained on a Hitachi M-80 double-focusing spectrometer at 70 eV by direct insertion. Optical rotation was measured on a JASCO DIP-360 polarimeter. Silica gel BW-127 ZH (Fuji-Devison) containing 2% fluorescence 254 and a quartz column were used for column chromatography, and the products having UV absorption were detected by UV irradiation. In experiments requiring dry solvent, THF and ether were distilled from benzophenone ketyl; diisopropylamine and benzene were dried over CaH_2 and distilled.

1-Chloro-4-pentenyl *p*-tolyl sulfoxide (3b) was synthesized from chloromethyl *p*-tolyl sulfoxide and 4-bromo-1-butene using LDA as a base in a similar way to that described previously[6b] in 61% yield: colorless oil; IR (neat) 1650, 1090, 1060 cm^{-1}; ^1H NMR δ 1.9–2.4 (4 H, m), 2.42 (3 H, s), 4.3–4.6 (1 H, m), 4.9–5.2 (2 H, m), 5.5–5.9 (1 H, m), 7.2–7.7 (4 H, m); MS *m/z* (relative intensity) 242 (M^+, 3), 190 (1), 140 (100).

General Procedure for Synthesis of Chloro Amine 5. A synthesis of **5a** is described. A solution of **3a** (560 mg; 1.7 mmol) in 1 mL of dry THF was added dropwise with stirring to a solution of LDA (2 mmol) in 4 mL of THF in a flame-dried flask at -60 °C. After 15 min, a solution of 400 mg of benzalaniline (**4**; Ar = Ar′ = Ph) in 1 mL of THF was added to the reaction mixture, and the stirring was continued for 5 min. The reaction was quenched with saturated aqueous NH_4Cl, and the solution was extracted with $CHCl_3$. The organic layer was dried over Na_2SO_4, and the solvent was evaporated to give crystals, which were washed with a mixture of hexane–AcOEt (10:1). Yield 831 mg (94%). Recrystallization of the product from $CHCl_3$–hexane gave colorless needles: mp 144–146 °C; IR (KBr) 3325 (NH), 1610, 1045 cm^{-1}; ^1H NMR δ 0.89 (3 H, t, *J* = 7 Hz), 1.1–2.1 (18 H, m), 2.34 (3 H, s), 4.10 (1 H, s), 6.1–7.7 (15 H, m); MS *m/z* (relative intensity) 509 (M^+, 0.7), 369 (39), 334 (24), 242 (67), 180 (96), 91 (100). Anal. Calcd for $C_{31}H_{40}ClNOS$: C, 72.98; H, 7.90; Cl, 6.95; N, 2.75; S, 6.28. Found: C, 72.69; H, 7.94; Cl, 7.02; N, 2.52; S, 6.44. (-)-**5a**: mp 152–153 °C; $[\alpha]^{25}_D$ -217.4° (*c* 0.2, $CHCl_3$).

Chloro amine 5b: yield 84%; colorless needles; mp 134–136 °C ($CHCl_3$–hexane); IR (KBr) 3325 (NH), 1610, 1040 cm^{-1}; ^1H NMR δ 0.88 (3 H, t, *J* = 7 Hz), 1.1–2.0 (18 H, m), 2.33 (3 H, s), 4.04 (1 H, s), 6.1–7.7 (14 H, m); MS *m/z* (relative intensity) 543 (M^+, trace), 403 (52), 368 (19), 276 (100). Anal. Calcd for $C_{31}H_{39}Cl_2NOS$: C, 68.37; H, 7.22; Cl, 13.02; N, 2.57; S, 5.89. Found: C, 68.07; H, 7.35; Cl, 13.10; N, 2.29; S, 6.01.

Chloro amine 5c: yield 88%; colorless needles; mp 144–146 °C ($CHCl_3$–hexane); IR (KBr) 3320 (NH), 1605, 1040 cm^{-1}; ^1H NMR δ 0.88 (3 H, t, *J* = 7 Hz), 1.0–2.0 (18 H, m), 2.36 (3 H, s), 4.06 (1 H, s), 6.0–6.2 (2 H, m), 6.9–7.7 (11 H, m). Anal. Calcd for $C_{31}H_{39}BrClNOS$: C, 63.21; H, 6.67; Br, 13.56; Cl, 6.02; N, 2.38; S, 5.44. Found: C, 62.95; H, 6.73; Br, 13.77; Cl, 6.03; N, 2.03; S, 5.49. (-)-**5c**: mp 148–150 °C; $[\alpha]^{25}_D$ -250.5° (*c* 0.2, $CHCl_3$).

Chloro amine 5d: yield 76%; colorless needles; mp 170–171 °C ($CHCl_3$–hexane); IR (KBr) 3340 (NH), 1615, 1045 cm^{-1}; ^1H NMR δ 1.8–3.0 (4 H, m), 2.33 (3 H, s), 4.10 (1 H, d, *J* = 2 Hz), 4.9–5.2 (2 H, m), 5.6–6.0 (1 H, m), 6.1–7.7 (15 H, m); MS *m/z* (relative intensity) 423 (M^+, 5), 284 (28), 242 (35), 206 (73), 182 (100). Anal. Calcd for $C_{25}H_{26}ClNOS$: C, 70.82; H, 6.18; Cl, 8.36; N, 3.30; S, 7.56. Found: C, 70.62; H, 6.19; Cl, 8.64; N, 3.34; S, 7.51.

Chloro amine 5e: yield 91%; colorless needles; mp 185–187 °C ($CHCl_3$–hexane); IR (KBr) 3330 (NH), 1610, 1045 cm^{-1}; ^1H NMR δ 1.81 (3 H, s), 2.35 (3 H, s), 4.38 (1 H, d, *J* = 4 Hz), 6.3–7.7 (14 H, m); MS *m/z* (relative intensity) 383 (M^+, 7), 244 (38), 208 (78), 182 (100); found *m/z* 383.1105, calcd for $C_{22}H_{22}ClNOS$ (M) 383.1109. Anal. Calcd for $C_{22}H_{22}ClNOS \cdot 0.04(CHCl_3)$: C, 68.46; H, 5.75; Cl, 9.73; N, 3.63; S, 8.23. Found: C, 68.17; H, 5.78; Cl,

(19) Tsuchihashi, G.; Iriuchijima, S.; Maniwa, K. *Tetrahedron Lett.* **1973**, 3389.

(20) (+)-Ethyl *p*-tolyl sulfoxide **10** obtained in this study was contaminated with trace amounts of unknown byproducts. Pure (*R*)-**10** shows $[\alpha]_D$ +203.6°. Cope, A. C.; Caress, E. A. *J. Am. Chem. Soc.* **1966**, *88*, 1711.

10.04; N, 3.46; S, 8.29. (−)-**5e**: mp 189–191 °C; $[\alpha]^{25}_D$ −177.6° (*c* 0.3, acetone).

Chloro amine 5f: yield 74%; colorless needles; mp 169–172 °C ($CHCl_3$–hexane); IR (KBr) 3330 (NH), 1610, 1040; ^1H NMR δ 1.84 (3 H, s), 2.36 (3 H, s), 4.29 (1 H, d, *J* = 4 Hz), 6.2–7.7 (13 H, m); MS *m/z* (relative intensity) 417 (M^+, 8), 278 (40), 242 (68), 216 (100); found: *m/z* 417.0736, calcd for $C_{22}H_{21}Cl_2NOS$ (M) 417.0720. (−)-**5f**: mp 180–182 °C; $[\alpha]^{25}_D$ −196.1° (*c* 0.2, $CHCl_3$).

General Procedure for Synthesis of Sulfinylaziridine 6. A synthesis of **6a** is described. To a solution of **5a** (800 mg; 1.57 mmol) in a 1:1 mixture of *t*-BuOH–THF (40 mL) was added 423 mg (2.4 equiv) of *t*-BuOK. The reaction mixture was stirred and heated at 70 °C for 15 min; it was then quenched with saturated aqueous NH_4Cl, and the solvent was evaporated. The residue was extracted with ether–benzene. The organic layer was washed once with saturated aqueous NH_4Cl and dried over Na_2SO_4. After the usual workup, the product was purified by silica gel column chromatography to give 646 mg (87%) of **6a** as light yellow crystals. Recrystallization of the crystals from EtOH–H_2O gave colorless prisms: mp 87–89 °C; IR (KBr) 1605, 1500, 1060 cm^{-1}; ^1H NMR δ 0.88 (3 H, t, *J* = 6 Hz), 1.0–2.0 (18 H, m), 2.41 (3 H, s), 4.62 (1 H, s), 6.9–7.7 (14 H, m); MS *m/z* (relative intensity) 473 (M^+, trace), 457 (0.8), 334 (69), 304 (12), 244 (100). Anal. Calcd for $C_{31}H_{39}NOS$: C, 78.60; H, 8.30; N, 2.96; S, 6.77. Found: C, 78.27; H, 8.30; N, 2.82; S, 6.83%. (−)-**6a**: mp 81–84 °C; $[\alpha]^{25}_D$ −301.4° (*c* 0.1, acetone).

Sulfinylaziridine 6b: yield 92%; colorless oil; IR (neat) 1610, 1500, 1095, 1065 cm^{-1}; ^1H NMR δ 0.88 (3 H, t, *J* = 6 Hz), 1.0–1.9 (18 H, m), 2.41 (3 H, s), 4.57 (1 H, s), 6.9–7.7 (13 H, m); MS *m/z* (relative intensity) 292 (9), 221 (3), 197 (20), 154 (84), 139 (100).

Sulfinylaziridine 6c: yield 98%; colorless prisms; mp 87–89 °C (AcOEt–hexane); IR (KBr) 1595, 1495, 1060 cm^{-1}; ^1H NMR δ 0.88 (3 H, t, *J* = 6 Hz), 0.9–1.9 (18 H, m), 2.42 (3 H, s), 4.58 (1 H, s), 6.8–7.7 (13 H, m); MS *m/z* (relative intensity) 553, 551 (M^+, trace), 528, 526 (0.8), 414, 412 (100). Anal. Calcd for $C_{31}H_{38}BrNOS$: C, 67.38; H, 6.93; Br, 14.46; N, 2.53; S, 5.80. Found: C, 67.65; H, 7.02; Br, 14.36; N, 2.50; S, 5.79. (−)-**6c**: mp 104–105 °C; $[\alpha]^{25}_D$ −277.4° (*c* 0.1, acetone).

Sulfinylaziridine 6d: yield 83%; light brown prisms; mp 94–96.5 °C (AcOEt–hexane); IR (KBr) 1610, 1505, 1095, 1060 cm^{-1}; ^1H NMR δ 1.05–1.35 (2 H, m), 2.2–2.6 (2 H, m), 2.41 (3 H, s), 4.63 (1 H, s), 4.78–5.05 (2 H, m), 5.44–5.88 (1 H, m), 6.8–7.7 (14 H, m); MS *m/z* (relative intensity) 387 (M^+, trace), 369 (0.2), 248 (32), 206 (100).

Sulfinylaziridine 6e: yield 92%; light yellow prisms; mp 140–142 °C (AcOEt–hexane); IR (KBr) 1065, 1500, 1095, 1070, 1050 cm^{-1}; ^1H NMR δ 1.05 (3 H, s), 2.38 (3 H, s), 4.52 (1 H, s), 6.8–7.7 (14 H, m); MS *m/z* (relative intensity) 347 (M^+, trace), 331 (trace), 208 (100), 193 (29). Anal. Calcd for $C_{22}H_{21}NOS$: C, 76.05; H, 6.09; N, 4.03; S, 9.23. Found: C, 75.85; H, 6.08; N, 4.02; S, 9.11. (−)-**6e**: light yellow oil; $[\alpha]^{25}_D$ −385.2° (*c* 0.2, acetone).

Sulfinylaziridine 6f: yield 90%; colorless plates; mp 151–153 °C (AcOEt–hexane); IR (KBr) 1605, 1500, 1095, 1065, 1050 cm^{-1}; ^1H NMR δ 1.03 (3 H, s), 2.40 (3 H, s), 4.48 (1 H, s), 6.9–7.6 (13 H, m); MS *m/z* (relative intensity) 381 (M^+, trace), 365 (5), 338 (12), 242 (100), 207 (82). Anal. Calcd for $C_{22}H_{20}ClNOS$: C, 69.12; H, 5.28; Cl, 9.28; N, 3.67; S, 8.39. Found: C, 69.42; H, 5.31; Cl, 9.37; N, 3.68; S, 8.42. (−)-**6f**: colorless oil; $[\alpha]^{25}_D$ −384.8° (*c* 0.2, acetone).

General Procedure for Desulfinylation of the Sulfinylaziridine 6. A synthesis of (*Z*)-1,2-diphenyl-3-decylaziridine **7a** from **6a** with EtMgBr is described. A solution of **6a** (71 mg; 0.15 mmol) in a small amount of dry THF was added dropwise with stirring to a solution of EtMgBr (3.5 equiv) in 1 mL of THF at −55 °C. The reaction mixture was allowed to warm to −35 °C for 2 h, and then saturated aqueous NH_4Cl was added. The solution was extracted with benzene. The usual workup gave a crude product, which was purified by silica gel column chromatography to afford 48 mg (95%) of **7a** as a colorless oil: IR (neat) 1610, 1500 cm^{-1}; ^1H NMR δ 0.87 (3 H, t, *J* = 7 Hz), 1.0–1.6 (18 H, m), 2.40 (1 H, m), 3.29 (1 H, d, *J* = 6 Hz), 6.8–7.5 (10 H, m); MS *m/z* (relative intensity) 335 (M^+, 48), 222 (57), 208 (41), 194 (20), 181 (30), 104 (100); found *m/z* 335.2615, calcd for $C_{24}H_{33}N$ (M) 335.2611. (−)-(2*R*,3*S*)-**7a**: colorless oil; $[\alpha]^{25}_D$ −159.5° (*c* 1.2, acetone).

(*Z*)-1-Phenyl-2-(4-chlorophenyl)-3-decylaziridine (7b): yield 88%; colorless oil; IR (neat) 1610, 1500 cm^{-1}; ^1H NMR δ 0.87 (3 H, t, *J* = 6 Hz), 1.0–1.6 (18 H, m), 2.40 (1 H, m), 3.24 (1 H, d, *J* = 6 Hz), 6.8–7.4 (9 H, m); MS *m/z* (relative intensity) 369 (M^+, 14), 256 (19), 215 (11), 180 (44), 151 (32), 124 (100); found *m/z* 369.2226, calcd for $C_{24}H_{32}ClN$ (M) 369.2222.

(*Z*)-1-(4-Bromophenyl)-2-phenyl-3-decylaziridine (7c): yield 85%; colorless oil; IR (neat) 1600, 1495 cm^{-1}; ^1H NMR δ 0.97 (3 H, t, *J* = 6 Hz), 1.0–1.6 (18 H, m), 2.37 (1 H, m), 3.26 (1 H, d, *J* = 6 Hz), 6.87 (2 H, m), 7.2–7.4 (7 H, m); MS *m/z* (relative intensity) 415, 413 (M^+, 33), 302, 300 (33), 184 (60), 91 (100); found *m/z* 413.1701, calcd for $C_{24}H_{32}BrN$ (M) 413.1716. (−)-(2*R*,3*S*)-**7c**: colorless oil; $[\alpha]^{25}_D$ −132.6° (*c* 1.4, acetone).

(*Z*)-1,2-Diphenyl-3-(3-butenyl)aziridine (7d): yield 90%; colorless oil; IR (neat) 1610, 1500 cm^{-1}; ^1H NMR δ 1.2–1.6 (2 H, m), 2.0–2.4 (2 H, m), 2.46 (1 H, q, *J* = 6 Hz), 3.31 (1 H, d, *J* = 6 Hz), 4.8–5.1 (2 H, m), 5.5–6.0 (1 H, m), 6.8–7.5 (10 H, m); MS *m/z* (relative intensity) 249 (M^+, 11), 220 (10), 208 (28), 104 (100); found *m/z* 249.1501, calcd for $C_{18}H_{19}N$ (M) 249.1516.

(*Z*)-1,2-Diphenyl-3-methylaziridine (7e): yield 89%; colorless oil; IR (neat) 1610, 1500 cm^{-1}; ^1H NMR δ 1.13 (3 H, d, *J* = 6 Hz), 2.52 (1 H, m), 3.27 (1 H, d, *J* = 6 Hz), 6.8–7.5 (10 H, m); MS *m/z* (relative intensity) 209 (M^+, 60), 208 (100), 194 (13), 167 (18), 118 (21), 105 (63); found *m/z* 209.1185, calcd for $C_{15}H_{15}N$ (M) 209.1203. (−)-(2*R*,3*S*)-**7e**: colorless oil; $[\alpha]^{25}_D$ −271.3° (*c* 0.6, acetone).

(*Z*)-1-Phenyl-2-(4-chlorophenyl)-3-methylaziridine (7f): yield 91%; colorless oil; IR (neat) 1605, 1495 cm^{-1}; ^1H NMR δ 1.11 (3 H, d, *J* = 6 Hz), 2.52 (1 H, m), 3.23 (1 H, d, *J* = 6 Hz), 6.8–7.4 (9 H, m); MS *m/z* (relative intensity) 243 (M^+, 67), 242 (86), 201 (14), 166 (18), 118 (41), 105 (100); found *m/z* 243.0795, calcd for $C_{15}H_{14}ClN$ (M) 243.0813. (−)-(2*R*,3*S*)-**7f**: colorless oil; $[\alpha]^{25}_D$ −313.3° (*c* 1.0, acetone).

Monodeuterated methyl *p*-tolyl sulfoxide (8): colorless oil; IR (neat) 1085, 1040, 1010 cm^{-1}; ^1H NMR δ 2.41 (3 H, s), 2.69 (2 H, m), 7.2–7.6 (4 H, m); MS *m/z* (relative intensity) 155 (M^+, 51), 139 (100); found *m/z* 155.0510, calcd for C_8H_9DOS (M) 155.0513.

Monodeuterated aziridine (9): colorless oil; IR (neat) 1590, 1480 cm^{-1}; ^1H NMR δ 1.12 (3 H, s), 3.27 (1 H, s), 6.8–7.5 (10 H, m); MS *m/z* (relative intensity) 210 (M^+, 52), 209 (100), 195 (13), 167 (19); found *m/z* 210.1267, calcd for $C_{15}H_{14}DN$ (M) 210.1267.

Acetaldehyde Adduct of Aziridine (12). EtMgBr (0.9 mmol) was added dropwise with stirring to a solution of **6e** (104 mg; 0.3 mmol) in 1 mL of dry THF at 0 °C. The reaction mixture was stirred for 5 min, and then acetaldehyde (1.8 mmol) was added. After 2 min the reaction was quenched with saturated aqueous NH_4Cl. The usual workup followed by silica gel column chromatography gave 64 mg (85%) of **12** as a colorless oil: IR (neat) 3400 (OH), 1660, 1600 cm^{-1}; ^1H NMR δ 1.06 (3 H, d, *J* = 7 Hz), 1.64 (3 H, s), 3.32, 3.48 (each s), 4.0–5.0 (m), 6.5–7.5 (10 H, m); MS *m/z* (relative intensity) 253 (M^+, 1), 209 (14), 167 (3), 118 (100); found *m/z* 253.1470, calcd for $C_{17}H_{19}NO$ (M) 253.1465.

Enamide 13. EtMgBr (0.9 mmol) was added dropwise with stirring to a solution of **6e** (104 mg; 0.3 mmol) in 1 mL of THF at 0 °C. The reaction mixture was stirred for 5 min, and then acetyl chloride (140 mg; 1.8 mmol) was added. After 5 min the reaction was quenched with saturated aqueous NH_4Cl. The usual workup followed by silica gel column chromatography afforded 30 mg (38%) of **13** as a colorless oil: IR (neat) 1675 (CO), 1495, 1370, 1300 cm^{-1}; ^1H NMR δ 2.06, 2.16 (each 3 H, broad singlet), 6.52 (1 H, broad singlet), 6.9–7.5 (10 H, m); MS *m/z* (relative intensity) 251 (M^+, 26), 209 (47), 193 (20), 167 (26), 118 (100); found *m/z* 251.1300, calcd for $C_{17}H_{17}NO$ (M) 251.1308.

(*S*)-(+)-1-Phenyl-1-(phenylamino)dodecane (15). AIBN (5 mg; 0.03 mmol) was added to a solution of (−)-**5a** (77 mg; 0.15 mmol) and Bu_3SnH (81 μL; 0.3 mmol) in 6.5 mL of dry benzene. The atmosphere in the flask was replaced with N_2, and the reaction mixture was stirred and refluxed for 20 min. The benzene was evaporated, and the residue was purified by silica gel column chromatography to give 71 mg (97%) of **14** as 1:1 mixture of diastereomers: IR (KBr) 3330 (NH), 1615, 1035; ^1H NMR δ 0.87 (3 H, t, *J* = 7 Hz), 2.37 (3 H, s), 2.68 (1 H, m), 4.51 (0.5 H, t, *J* = 3 Hz), 4.80 (0.5 H, t, *J* = 6 Hz), 5.6–5.9 (1 H, m, NH), 6.3–7.5 (10 H, m). A solution of **14** (70 mg) and about 300 mg of Raney Ni in 8 mL of EtOH was stirred and refluxed for 15 min. The Raney Ni was filtered off, and the filtrate was evaporated to give

a residue, which was purified by silic gel column chromatography to afford 41.2 mg (83%) of **15** as a colorless oil: $[\alpha]^{25}_D$ +10.5° (*c* 2.1, MeOH); IR (neat) 3450 (NH), 1610, 1510 cm^{-1}; ^1H NMR δ 0.87 (3 H, t, J = 6 Hz), 1.0–1.9 (20 H, m), 4.25 (1 H, t, J = 6 Hz), 6.4–7.4 (10 H, m); MS m/z (relative intensity) 337 (M^+, 5), 182 (100); found m/z 337.2765, calcd for $C_{24}H_{35}N$ (M) 337.2767.

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Cycloaddition Reactions of Bisallenes. Stereochemistry of the (4 + 2) Cycloaddition Process

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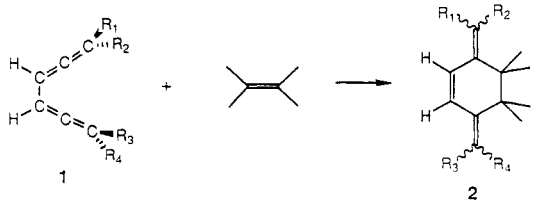
The cycloaddition of *erythro*- and *threo*-8,8-dimethyl-2,3,5,6-nonatetraene (**11e** and **11t**) with *N*-phenylmaleimide has been investigated. The (4 + 2) cycloaddition reactions are stereospecific; **11e** producing only **12**, and **11t** producing only **13**. The dienophile approaches the less sterically hindered face of the bisallene undergoing a symmetry-allowed (2 + 4) cycloaddition, with the groups at the termini of the bisallene on the opposite face of the bisallene rotating outward in a disrotatory manner. The direction of the rotatory motion of the two termini of the bisallene is not controlled by orbital symmetry. The preference for the anti outward disrotatory motion of the termini of the bisallene is attributed to the development of better overlap between the terminal 2p AO's of the interacting diene and dienophile in the transition state for the cycloaddition process and, to a lesser extent, the relief of steric congestion relative to the other rotatory processes.

Introduction

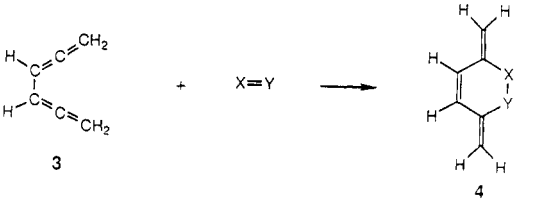
Substituted 1,2,4,5-tetraenes **1** (bisallenes)[1] are a highly reactive, intriguing class of compounds. They not only contain two allene chromophores, but they also contain a central conjugated butadiene chromophore. Thus, substituted bisallenes might be expected to exhibit chemical properties of both substituted allenes and substituted 1,3-butadienes. One such type of reaction of synthetic interest is the (4 + 2) cycloaddition across the central 1,3-butadiene chromophore. With substituted bisallenes, this is a very interesting reaction from a stereochemical point of view. The groups attached to the termini of the bisallene (illustrated in **1**) are oriented perpendicular to the general plane of the butadiene chromophore both of which, during a (4 + 2) cycloaddition process, must undergo a rotation of 90° during the formation of the product **2**. The important question is, in which directions do the



1 **2**

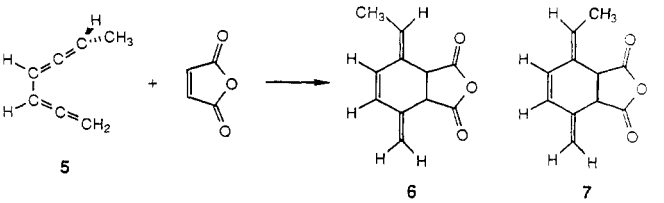
two termini rotate, and are the directions coordinated? The answer to this question does not appear to have unambiguously answered for the (4 + 2) cycloaddition reactions.

A number of cycloaddition reactions of the parent bisallene, 1,2,4,5-hexatetraene (**3**) with a wide range of substituted dienophiles has been described.[2] Apparently the



3 **4**

only concerted (4 + 2) cycloaddition reaction of an unsymmetrically substituted bisallene is that of **5** with maleic anhydride, which is reported to produce only **6**.[2] The stereochemistry of **6** was assigned on the basis of extensive NMR chemical shift studies, which showed that the effect of added chemical shift reagent on the chemical shift of the methyl groups was very small compared to the effect on the vinyl hydrogens syn to the anhydride moiety. None of the stereoisomeric cycloadduct **7** was detected in the cycloaddition reaction product mixture. It was suggested that the dienophile approached from the less sterically hindered side of the bisallene in the syn conformation, with an outward rotation of the methyl group on the opposite face of the bisallene occurring to produce the observed product.[2] The proposed disrotatory motation was based



5 **6** **7**

on the observed stereochemistry of the cheleotropic (4 + 1) addition of sulfur dioxide to a number of substituted bisallenes reported earlier which occurred by approach to the less sterically hindered face of the bisallene with

(1) Although the bisallenes are shown in their s-cis conformations, the lowest energy conformations are the s-trans conformations (D. J. Pasto, results of unpublished theoretical calculations).

(2) Hopf, H.; Schon, G. *Annalen* **1981**, 165.

0022-3263/89/1954-3978$01.50/0