Stereochemistry of Diels–Alder Reactions of Allenic Sulphones; Transfer of Asymmetry from Allenic to Norbornene Systems

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Diels–Alder reactions of chiral allenic sulphones afford as main products the diastereoisomers derived by attack of the diene from the less hindered side of the double bond α to the sulphonyl group; starting from menthyl sulphinate, asymmetry is transmitted to the allenic sulphone, and in turn to the Diels–Alder adduct, with a high degree of retention of chirality.

IN recent years a great deal of mechanistic investigations have been devoted to the cycloaddition and cyclodimerization of allenes.[1] Allenic sulphones, easily accessible, *e.g. via* rearrangement of propargyl sulphinates [2] or oxidation of the corresponding sulphoxides,[3] are suitable substrates for cycloaddition reactions, the unsaturated system being strongly activated by the adjacent sulphonyl group. We report here a study of the stereochemistry of Diels–Alder addition of cyclopentadiene (1) to the title compounds and the synthesis of optically active adducts.

A definitive proof of the structure was obtained in the case of the alkylidene derivative (9a) by X-ray analysis.[5] This not only confirms the internal consistency of the assignments based on n.m.r. data for compounds (9a)—(9d), but indirectly also confirms the conformational assignment of the other compounds examined.

These results as a whole show that the major compounds (9a, b), (10a, b), and (11a, b), obtained in the reaction of cyclopentadiene (1) with the allenic sulphones (6)—(8), have the configurations depicted.

Cycloadditions of allenic derivatives as dienophiles or dienes have been extensively investigated;[6] however, only

(2),(3) Ar = Ph, R = H
(4),(5) Ar = p-MeC₆H₄, R = Me
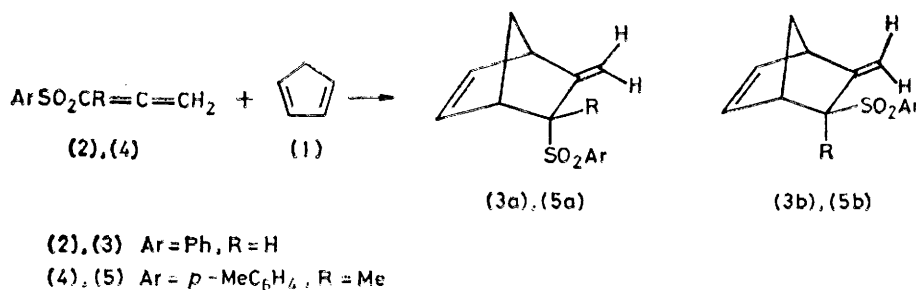
RESULTS

(Phenylsulphonyl)propadiene (2) is known [4] to react with (1) to afford a mixture of the norbornene derivatives (3a) (*endo*) and (3b) (*exo*) in the ratio 65 : 35. Reaction of 3-(*p*-tolylsulphonyl)buta-1,2-diene (4) is slower, as expected on the basis of the stereo-electronic effect of the methyl α to the sulphonyl group, and gives *endo*- (5a) and *exo*-adducts (5b) in a ratio of 20 : 80.

A more complex situation is encountered in the chiral allenic sulphones (6)—(8) which, in principle, can produce four diastereoisomeric adducts.

This is the case with 1-(*p*-tolylsulphonyl)buta-1,2-diene (6) and 3-phenyl-1-(phenylsulphonyl)propadiene(7), whereas from 1-(*p*-tolylsulphonyl)hexa-1,2-diene (8) only three isomers were formed. The process is highly stereoselective; indeed, starting from (6), (7), and (8), compounds (9a, b), (10a, b), and (11a, b), the predominant diastereoisomers, constitute 94, 80, and 96% of the reaction products, respectively (see Table 1 and Experimental section).

The *endo*- or *exo*-configuration † at C-2 of the alkylidene norbornenes (3). (5). and (9)—(11) and the *Z*- or *E*-configuration at C-8 of compounds (9)—(11) was established by ¹H and/or ¹³C n.m.r. spectroscopy (see below).

† An indication of the configuration at C-2 is given by the eluotropic sequence, *exo*-adducts preceding *endo*-adducts.

two examples involving optically active allenes, namely (−)-pentadienedioic acid,[7] and (−)-1,3-dimethylallene [1b] have hitherto been reported. A variety of optically active allenic sulphones is available,[2,3,8] *e.g. via* reaction of menthyl

TABLE 1
Diels–Alder reaction of unsaturated sulphones with cyclopentadiene in refluxing benzene

Sulphone	Reaction time/ h	Overall yield (%)	Products	Relative ratio
(2)	24	90	(3a), (3b)	65 : 35
(4)	66	32	(5a), (5b)	20 : 80
(6)	64	74	(9a), (9b), (9c). (9d)	66 : 28 : 5 : 1
(7)	90	74	(10a), (10b), (10c), (10d)	a
(8)	66	73	(11a), (11b), (11c)	61 : 35 : 4

a Product composition: (10a), 54%; (10b), 25%; mixture of (10c) and (10d). 21%.

sulphinates with propargyl Grignard reagents, and subsequent oxidation of the obtained allenic sulphoxides.[3] By this route 1-(*p*-tolylsulphonyl)buta-1,2-diene, $[\alpha]_D^{24}$ +27.4° (CHCl₃), 44% optically pure,[3] was prepared, having the (+)-(S) absolute configuration on the basis of the Brewster empirical rule. Reaction of (+)-(S)-(6) with cyclopenta-

diene afforded the optically active adducts (9), the predominant diastereoisomers (9a), $[\alpha]_D^{30}$ +36.9° (CHCl₃), and (9b), $[\alpha]_D^{30}$ +25.6° (CHCl₃), being isolated by column chromatography The absolute configuration of norbornene derivatives (9a) and (9b) derives straightforwardly from that of (+)-(S)-(6), as represented in the Scheme (see below).
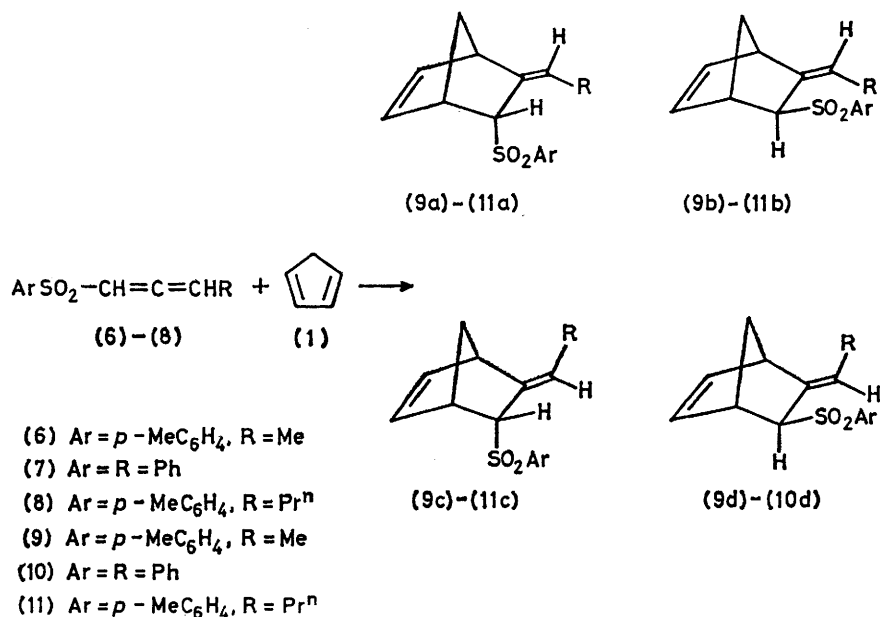
DISCUSSION

The [2 + 3] and [2 + 4] cycloadditions of allenes are concerted processes, the allenes behaving as electron-rich alkenes, even though they are much more reactive.[1,6] Reaction of the sulphones (2), (4), and (6)—(8) with cyclopentadiene is regio-selective and involves the double bond nearest to the sulphonyl group.   It leads to

molecular orbital (HOMO) of allene retains the symmetry properties of the π-HOMO of ethylene in the polarized sulphonyl derivatives.

On this basis one can reasonably assume that in the reaction of (+)-(S)-1-(p-tolysulphonyl)buta-1,2-diene (6) to give (+)-(9a) and (+)-(9b) the original enantiomeric excess of (6) is largely preserved.

In conclusion, it can be pointed out that, from an optically active alcohol, asymmetry is transmitted to centrodis-symmetric sulphur, from this to the axial dis-symmetric allene, and then to the alkylidenebicyclic system of the Diels–Alder adducts, the process as a whole involving a high degree of retention of chirality.

Assignment of Configuration to Adducts (3), (5), *and*

(9a)-(11a)   (9b)-(11b)

ArSO₂—CH=C=CHR + [cyclopentadiene] →

(6)—(8)   (1)

(6) Ar = p-MeC₆H₄, R = Me
(7) Ar = R = Ph
(8) Ar = p-MeC₆H₄, R = Pr^n
(9) Ar = p-MeC₆H₄, R = Me
(10) Ar = R = Ph
(11) Ar = p-MeC₆H₄, R = Pr^n

(9c)-(11c)   (9d)-(10d)

the preferential formation of endo-adducts (3a), (9a), (10a), and (11a), in agreement with the stereochemical course usually found in Diels–Alder reactions. The formation of the exo-sulphone (5b) as the main product starting from (4) is in line with the endo-selectivity exhibited by the methyl group.[9] The ' endo-rule ' for [2 + 4] cycloadditions is a consequence of orbital-symmetry relationship and points to a concerted process. Another stereochemical feature in the Diels–Alder reaction of the chiral allenes (6)—(8) is the configuration about the exocyclic double bond, Z-isomers (9a, b), (10a, b), and (11a, b) being largely predominant (see Table 1).   They are derived by preferential approach of cyclopentadiene from the less sterically hindered side of the double bond next to the sulphonyl group [paths (a) and (b), in the Scheme].

The stereoselectivity of the reaction suggests a concerted process for the addition of cyclopentadiene to the allenic derivative; although the π-system of the allene may conceivably be perturbed by the presence of the sulphonyl group, the reaction can be assimilated to the symmetry-allowed suprafacial addition of butadiene to ethylene, in the hypothesis that the highest-occupied

(9)—(11) *by* [1]H *and* [13]C *N.M.R. Spectroscopy.*—Due to the long-range effects of the double bonds, the proton at C-2 of the endo-isomers resonates 0.5—0.8 p.p.m. downfield from the corresponding proton of the exo-isomers.[10]   The same trend is observed for the methyl group at C-2 in (5a) which is deshielded by 0.35 p.p.m. with respect to the methyl group in (5b).

Although a complete interpretation of the C-13 pattern of these compounds is complicated by the difficulty of distinguishing between electronic and steric contributions,[11] in order to identify the different isomers only carbons γ to the 2-SO₂Ar (C-6 and C-7) or to the 8-R (C-2 and C-4) groups need be considered.

In agreement with what has been observed for several 2-substituted norbornene derivatives,[11] i.e. exo-2-groups produce an upfield shift at C-7 while endo-2-groups produce an upfield shift at C-6, compounds with an exo-2-SO₂Ar substituent have C-7 at *higher* field and C-6 at *lower* field than the corresponding isomers with an endo-2-SO₂Ar substituent.

As far as the isomerism at the exocyclic double bond is concerned, Lippmaa et al.[12] have identified the Z- and E-isomers of 5-ethylidene-2-norbornene on the basis of

the γ effect exerted on C-2 and C-4 by the methyl group at C-8.

On the same basis, we have identified the isomers having C-4 at *higher* field and C-2 at *lower* field as being of the Z-configuration [compounds (9c) and (9d)]. Consistent with such an assignment it was found that in the Z-isomers the shielding of the proton at C-8 is generally more affected when the 2-SO$_2$Ar substituent

(6)-(8)

path (a)

(9a)-(11a)

(6)-(8)

path (b)

(9b)-(11b)
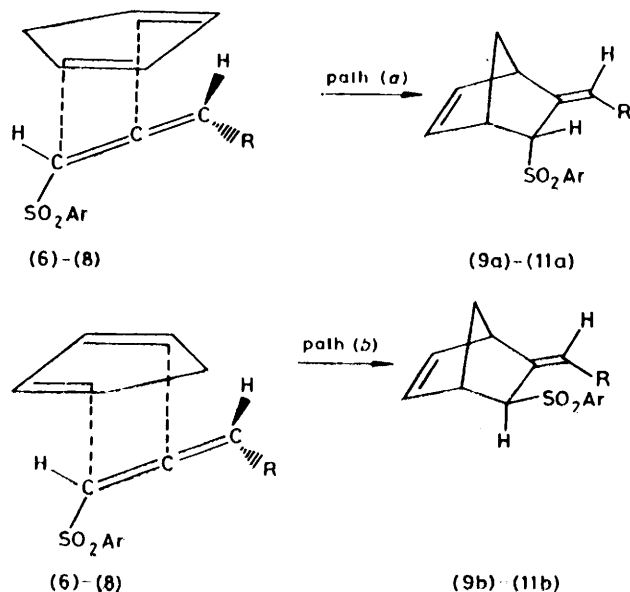
SCHEME

goes from the *endo-* to the *exo-*position than that of the same proton in the *E*-isomers.

Our approach in identifying the different isomers is illustrated by data in Table 2, in which the relevant n.m.r. parameters for compounds (9a)—(9d) are reported. It appears that although the variations of the ^{1}H or ^{13}C shieldings on going from the *exo-* to the *endo-*isomer or from the Z- to the *E*-isomers are generally small, the trend is always the expected one and the whole pattern is consistent.

TABLE 2

Relevant ^{1}H and ^{13}C chemical shifts of compounds (9a)—(9d) in CDCl$_3$ (δ, downfield from SiMe$_4$)

C or H	(9a)	(9b)	(9c)	(9d)
C-2	68.9	67.8	70.0	67.9
C-4	46.8	45.4	45.1	44.6
C-6	133.2	141.7	132.9	139.4
C-7	50.3	47.6	46.2	45.3
CH–Me	5.78	5.81	5.87	5.67
CH–Me	1.90	1.80	1.74	1.63
CH–SO$_2$Ph	4.39	3.60	4.15	3.55

EXPERIMENTAL

General.—Light petroleum had b.p. 40—60 °C. Ether and benzene were dried over sodium. ^{1}H N.m.r. spectra were recorded with Varian A-60, Varian HA 100, or Brucker WH 270 instruments; ^{13}C n.m.r. spectra were recorded with a Varian CFT-20 spectrometer; ^{13}C assignments were based on single-frequency off-resonance experiments and on shielding of known compounds.[11,12] In all cases, CDCl$_3$ was

used as solvent and SiMe$_4$ as internal reference. I.r. spectra were recorded on a Perkin-Elmer 377 spectrometer. Optical rotations were measured with a Perkin-Elmer 141 polarimeter. 3-*p*-Tolylsulphonylbuta-1,2-diene (4),[3] phenylsulphonylpropadiene (2),[13] 1-phenyl-3-phenyl-sulphonylpropadiene (7).[11] 1-*p*-tolylsulphonylhexa-1,2-diene (8),[3] and racemic[2] and (+)-(*S*)-1-*p*-tolylsulphonyl-buta-1,2-diene (6) {[α]$_D$^{21} +27.6° (CHCl$_3$)^3} were prepared according to literature methods.

Diels–Alder Reactions.—In a typical run cyclopentadiene (25 mmol) was added to a solution of allanic sulphone (10 mmol) in anhydrous benzene (50 ml) and the reaction mixture was refluxed for 24—90 h (see Table 1). After evaporation of the solvent the crude product was separated by column chromatography (silica, light petroleum-ether). Overall yields and diastereoisomeric ratios of the adducts are reported in Table 1.

Starting from (2), 2-*exo*-phenylsulphonyl-3-methylidene-bicyclo[2.2.1]hept-5-ene (3b), m.p. 58 °C (lit.,[4] m.p. 58—59 °C), and 2-*endo*-phenylsulphonyl-3-methylidenebicyclo-[2.2.1]hept-5-ene (3a), m.p. 68—69 °C (lit.,[4] m.p. 68—69 °C), were obtained. Starting from the allene (4), 2-exo-p-*tolylsulphonyl*-2-endo-*methyl-3-methylidenebicyclo*[2.2.1]-*hept-5-ene* (5b), m.p. 116—117 °C, and 2-endo-p-*tolyl-sulphonyl*-2-exo-*methyl-3-methylidenebicyclo*[2.2.1]*hept-5-ene* (5a), contaminated by 10% of (5b) (evaluated by ^{1}H n.m.r.), were obtained [Found for (5b): C, 69.7; H, 6.5. Found for (5a): C, 69.8; H, 6.6. C$_{16}$H$_{18}$O$_2$S requires C, 70.0; H, 6.6%]. Reaction of the sulphone (7) with cyclopentadiene gave (Z)-2-exo-*phenylsulphonyl-3-benzylidene-bicyclo*[2.2.1]*hept-5-ene* (10b), m.p. 121—123 °C, (Z)-2-endo-*phenylsulphonyl-3-benzylidenebicyclo*[2.2.1]*hept-5-ene* (10a), m.p. 128—130 °C, and an inseparable mixture of (E)-2-endo- (10c) and (E)-2-exo-*phenylsulphonyl-3-benzyl-idenebicyclo*[2.2.1]*hept-5-ene* (10d) [Found for (10b): C, 74.3; H, 5.7. Found for (10a): C, 74.4; H, 5.5. Found for the mixture of (10c) and (10d): C, 74.5; H, 5.6. C$_{20}$H$_{18}$O$_2$S requires C, 74.5; H, 5.6%].

Starting from the allene (8), (Z)-2-exo-p-*tolylsulphonyl-3-butylidenebicyclo*[2.2.1]*hept-5-ene* (11b), m.p. 57—58 °C, (Z)-2-endo-p-*tolylsulphonyl-3-butylidenebicyclo*[2.2.1]*hept-5-ene* (11a), m.p. 50—51 °C, and (E)-2-endo-p-*tolylsulphonyl-3-butylidenebicyclo*[2.2.1]*hept-5-ene* (11c), contaminated with (11b), were obtained [Found for (11b): C, 71.3; H, 7.2. Found for (11a): C, 71.4; H, 7.3. Found for the mixture of (11c) and (11a): C, 71.6; H, 7.3. C$_{18}$H$_{22}$O$_2$S requires C, 71.5; H, 7.3%].

Cycloaddition of the allenic sulphone (6) afforded (Z)-2-exo-p-*tolylsulphonyl-3-ethylidenebicyclo*[2.2.1]*hept-5-ene* (9b), m.p. 85—86 °C, (E)-2-exo-p-*tolylsulphonyl-3-ethylidene-bicyclo*[2.2.1]*hept-5-ene*, (9d), contaminated by (9b), (Z)-2-endo-p-*tolylsulphonyl-3-ethylidenebicyclo*[2.2.1]*hept-5-ene* (9a), m.p. 100—101 °C, and (E)-2-endo-p-*tolylsulphonyl-3-ethylidenebicyclo*[2.2.1]*hept-5-ene* (9c), contaminated by (9a) [Found for (9b): C, 69.7; H, 6.4. Found for the mixture of (9d) and (9b): C, 70.0; H, 6.6. Found for (9a): C, 69.9; H, 6.5. Found for the mixture of (9c) and (9a): C, 70.0; H, 6.5. C$_{16}$H$_{18}$O$_2$S requires: C, 70.0; H, 6.6%]. When the reaction was repeated starting from (*S*)-(6) {[α]$_D$^{24} +27.6° (*c* 1, CHCl$_3$)}, the two prevailing isomers (9b) and (9a) were isolated in pure form, [α]$_D$^{30} +25.6° and +36.9° (*c* 1, CHCl$_3$), respectively.

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