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The Reaction of Vinyl Sulfones with Iodine Azide: Synthesis and Thermal Reactions of β-Azidovinyl Sulfones

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p-Toluenesulfonylethene reacted with iodine azide (IN_3) to give 2-azido-1-iodo-1-*p*-toluenesulfonylethane which was treated with 1,4-diazabicyclo[2.2.2]octane (Dabco) to afford *trans*-2-azido-1-*p*-toluenesulfonylethene (**3a**). Similarly benzenesulfonylethene was converted to *trans*-2-azido-1-benzenesulfonylethene (**3b**). *cis*- and *trans*-2-Benzenesulfonylstyrenes also reacted with IN_3 to give *threo*- (**10**) and *erythro*-2-azido-1-iodo-2-phenyl-1-benzenesulfonylethanes (**6**), respectively. Treatment of **10** with Dabco gave α-azido-β-benzenesulfonylstyrene (**11**), whereas **6** yielded β-iodo-β-benzenesulfonylstyrene (**7**).

Heating **3** in ethanol at 50° produced dimeric compounds **13**. Refluxing **11** in methanol or irradiation of **11** in a Pyrex tube gave 3-benzenesulfonyl-2-phenyl-1-azirine (**14**).

Keywords——*anti*-addition; *anti*-elimination; *syn*-elimination; 1,3-dipolar cycloaddition; self-addition of a vinyl azide; 1-azirine

The reaction developed by Hassner for addition of iodine azide (IN_3) to double bonds has been found to be widely applicable in organic synthesis.[2] We have now investigated the reaction of vinyl sulfones with IN_3 in the hope of developing a new route to the relatively unexplored β-azidovinyl sulfones.[3,4]

Treatment of vinyl sulfone **1a** with IN_3 prepared *in situ* from iodine monochloride and sodium azide in dry acetonitrile at room temperature gave 1:1 adduct **2a** in 70% yield. The structure was based on its method of synthesis and on spectroscopic and chemical data. The infrared (IR) spectrum of **2a** showed strong absorption at 2110 cm^{-1} (N_3) and at 1330 and 1160 cm^{-1} (SO_2). The nuclear magnetic resonance (NMR) spectrum revealed a singlet at δ 2.45 (3H, CH_3), an ABX pattern consisting of a quartet (H_X) centered at δ 5.03 and an eight-line multiplet (H_A and H_B) in the region of δ 3.6—4.2 with J_{AB}=14 Hz, J_{AX}=10 Hz, and J_{BX}=3 Hz, and an AB quartet at δ_A 7.38 and δ_B 7.82 with J_{AB}=8 Hz (4H, aromatic protons). The coupling constants between two vicinal protons (J_{AX} and J_{BX}) are consistent with conformation **2-A** or **2-B**, of which the former is preferred because the bulky *p*-$CH_3C_6H_4SO_2$ and azide group are *anti*. Final confirmation of the structure **2a** was obtained by dehydroiodination; treatment of the adduct **2a** with 1,4-diazabicyclo[2.2.2]octane (Dabco) gave known *trans*-β-azidovinyl sulfone **3a**[5,6] in 79% yield.

Similar treatment of vinyl sulfone **1b** with IN_3 afforded 1:1 adduct **2b** in 86% yield, which was converted to *trans*-β-azidovinyl sulfone **3b** in 83% yield. The structures of both **2b** and **3b** were readily established by spectral comparison with those of **2a** and **3a**, respectively (see Experimental).

1) Location: *133-1, Yamada-kami, Suita, Osaka, 565, Japan.*
2) A. Hassner, *Accounts Chem. Res.*, **4**, 9 (1971), and references therein.
3) Previously only two methods for the synthesis of β-azidovinyl sulfones were known, which involve the reaction of β-chlorovinyl sulfones[5] or 1,2-di-*p*-toluene sulfonylethene[6] with sodium azide.
4) For recent reviews of vinyl azides, see G. L'abbé and A. Hassner, *Angew. Chem. Int. Ed. Engl.*, **10**, 98 (1971); G. L'abbé, *ibid.*, **14**, 775 (1975).
5) G. Modena and P.E. Todesco, *Gazz. Chim. Ital.*, **89**, 866 (1959).
6) J.S. Meek and J.S. Fowler, *J. Org. Chem.*, 33, 985 (1968).

The *trans*-olefins 3 formed from the adducts 2 are the expected products of the *anti*-E2 elimination of hydrogen iodide (Chart 1); the transition state (shown in **2-A**) leading to *trans*-olefins, in which the bulky $ArSO_2$ and the azide group are *anti*, is expected to be more stable than the other (shown in **2-C**) leading to *cis*-olefins, in which these bulky groups are *syn*.

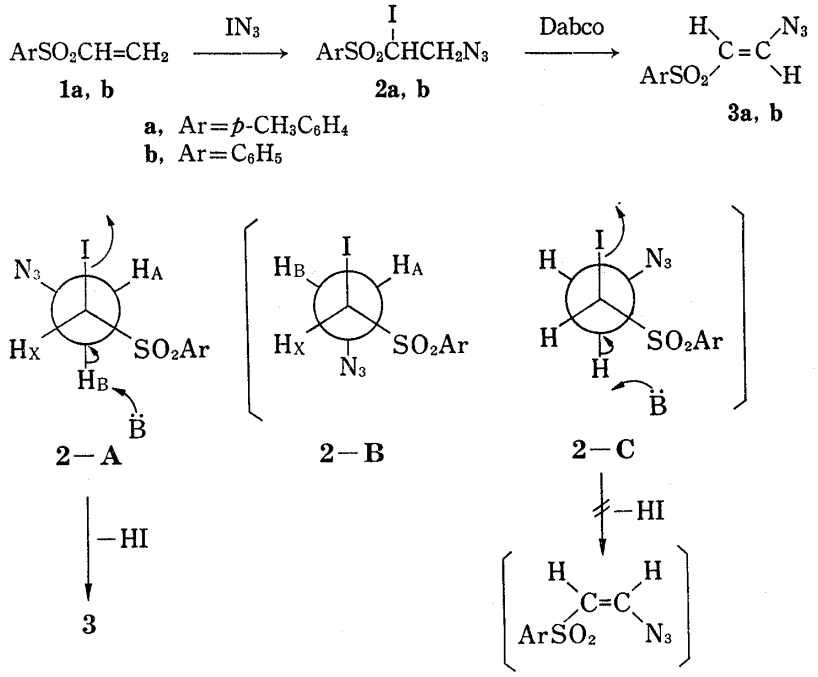

Chart 1

In order to obtain hitherto unknown β-substituted β-azidovinyl sulfones, we next investigated the reaction of IN_3 with *trans*- and *cis*-β-phenylvinyl sulfones, **4** and **8**. Treatment of the *trans*-isomer **4** with IN_3 gave exclusively *erythro*-adduct **6** in 80% yield, and the *cis*-isomer **8** afforded *threo*-adduct **10** in 60% yield, accompanied by small amounts of unidentified products. Compounds **6** and **10** are the expected products of *anti*-addition[2] to the olefins **4** and **8**, probably through iodonium ions **5** and **9**,[7] respectively (Chart 2). Nucleophilic ring opening of the iodonium ion intermediates by N_3^- should occur at β to a sulfonyl group since S_N2 reactions α to a sulfonyl group are known to be extremely slow[8] and α-sulfonyl carbonium ions would be very unstable.

The structures of the adducts were based on the spectroscopic data and elimination reactions. The IR and mass spectra (MS) of compounds **6** and **10** were strikingly similar. The IR spectra showed strong azide absorption at 2120 cm^{-1} and sulfone absorption at 1325 and 1150 cm^{-1}. The NMR spectrum of **6** revealed an AB quartet at δ_A 5.04 and δ_B 5.36 with J_{AB}=9 Hz (2H) and a multiplet (10H) in the aromatic region between δ 7.3 and 8.2, and that of **10** indicated an AB quartet at δ_A 5.00 and δ_B 5.10 with J_{AB}=2.5 Hz (2H) and a multiplet (10H) in the aromatic region between δ 7.3 and 8.1.

The preferred conformations of the adducts **6** and **10** were deduced from the observed vicinal H,H-couplings; compound **6** showed an *anti*-vicinal coupling (J=9 Hz) and **10** showed a *gauche*-vicinal coupling (J=2.5 Hz) in accord with the conformations **6-A** and **10-A**, respectively, in which the bulky $C_6H_5SO_2$ and the phenyl group are *anti*.

7) The observed stereospecificity would not be expected if addition proceeded through an initial Micheal type addition of N_3^- to vinyl sulfones, since free rotation about the C_1–C_2 single bond in the carbanionic intermediates is presumably permitted. [*c.f.*, I. Sataty and C.Y. Meyer, *Tetrahedron Lett.*, **1974**, 4161, and references therein].

8) F.G. Bordwell and W.T. Branner, Jr., *J. Am. Chem. Soc.*, **86**, 4645 (1964).

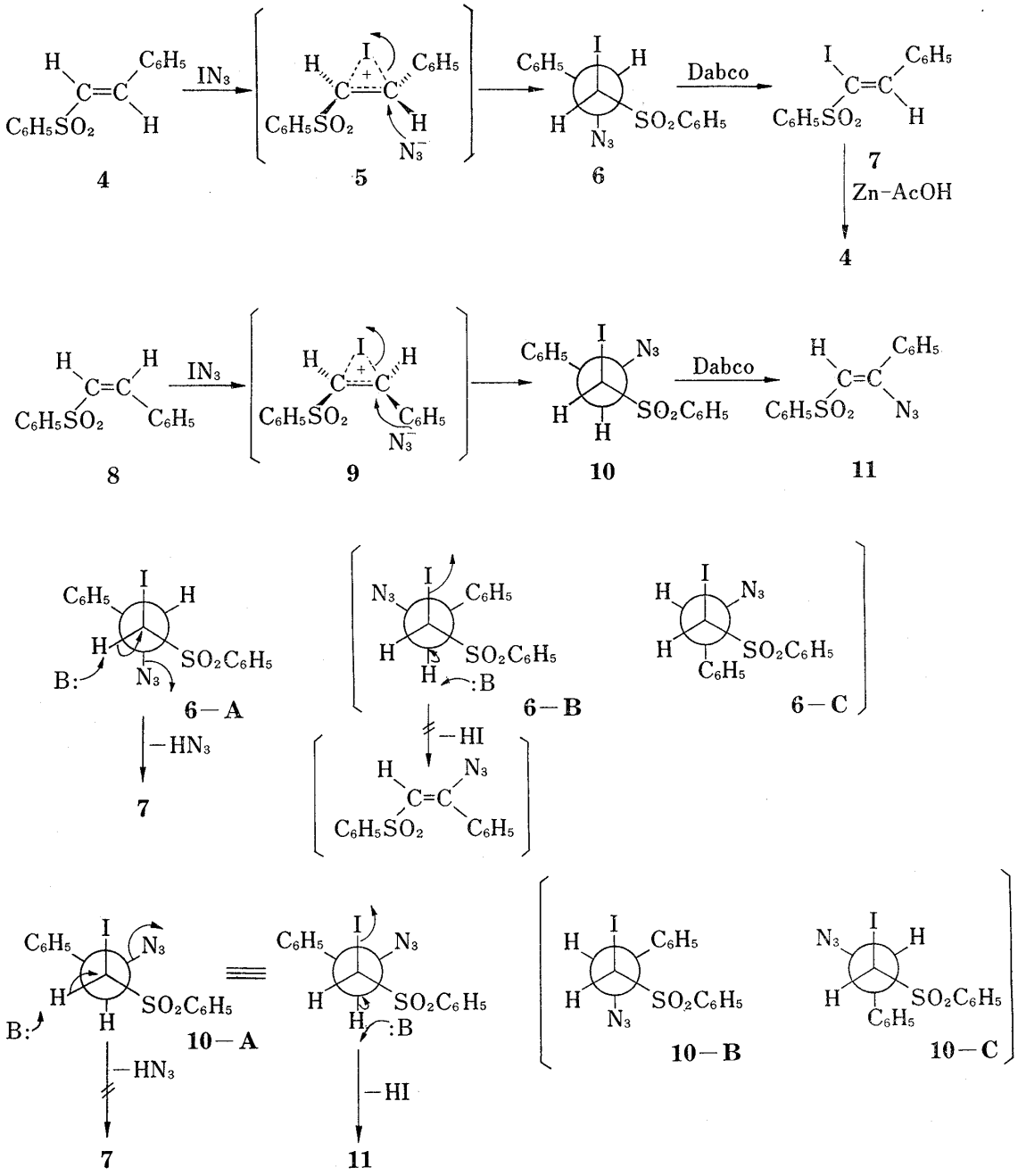

Chart 2

Treatment of **6** with Dabco at room temperature gave α-iodovinyl sulfone **7** in 66% yield. The structure of **7** showed no absorption due to an azide group in the IR spectrum and revealed a vinylic proton signal at δ 8.40 as a singlet in the NMR spectrum. The stereochemistry of **7** was derived from the reduction with zinc in acetic acid to **4**. This reduction is known to proceed with retention of configuration.[9a] In contrast, the same treatment of the adduct **10** afforded the desired β-azidovinyl sulfone **11** in 91% yield. Structure of **11** showed strong IR absorption due to an azide group at 2130 cm^{-1} and a vinylic proton signal at δ 6.00 in the NMR spectrum. The stereochemistry about the C–C double bond of **11** was tentatively assigned on the basis of the following mechanistic considerations.

The formation of **7** from the *erythro* adduct **6** may be rationalized by assuming a *syn*-elimination, presumably *via* an ElcB mechanism.[9b] In this case, *anti*-E2 transition states (shown in **6-B** and **6-C**) would be energetically unfavorable because of eclipsing between

the bulky $C_6H_5SO_2$ and the phenyl group.[9] On the other hand, since the transition states (shown in **10-A**) for two possible *anti*-E2 eliminations from the *threo* adduct **10** have no such steric interaction, compounds **7** and/or **11** would be the favored product(s). The observed exclusive formation of **11** is most likely a reflection of relative ability of the leaving group ($I^- > N_3^-$). In contrast, conformations **10-B** and **10-C** are not suitable for E2-elimination.

Thermal Reaction of β-Azidovinyl Sulfones

Fowler and coworkers[10] have noted that refluxing *trans*-β-azidovinyl sulfone **3a** in methanol leads to *p*-toluenesulfonylacetonitrile (**12a**). Indeed refluxing a solution of 200 mg of *trans*-β-azidovinyl sulfone **3b** in 10 ml of ethanol for 10 hr produced acetonitrile **12b** in 66% yield. However, when a solution of 209 mg of **3b** in 4 ml of ethanol was heated at 50° for 2 hr, dimeric compound **13b** was obtained as the sole product in 76% yield. Similar treatment of **3a** gave **13a** in 84% yield.

The structure of **12b** was assigned on the basis of the spectral data (see Experimental). The structure of **13** except for the position of the $ArSO_2$ in the triazole ring was based on the following spectral data. For example, the parent ion in the mass spectrum of **13b** appeared at *m/e* 375. The NMR spectrum of **13b** showed two vinylic protons at δ 7.24 and 8.10 with a *trans*-vicinal coupling (J=14 Hz), a triazole ring proton at δ 8.18, and aromatic protons (10H) in the δ 7.5—8.15 region.

The formation of **13** can be formulated as proceeding *via* 1,3-dipolar cycloaddition of the azide group in one molecule to the vinyl sulfone in the other followed by aromatization due to elimination of HN_3. Because the formation of **12** must be initiated by unimolecular elimination of nitrogen which requires a temperature above *ca.* 60°,[10] the dimerization becomes the favored reaction pathway at a lower temperature. The formation of **13** is the first example of self-addition of vinyl azides.[4]

Refluxing β-azidovinyl sulfone **11** in methanol produced 1-azirine **14** in 79% yield. The 1-azirine **14** was also obtained in 71% yield by irradiation of a benzene solution of **11** in a Pyrex vessel. The structure of **14** was based on the spectroscopic data. The IR spectrum showed absorption band at 1750 cm^{-1} due to a C=N of an azirine ring[11] and 1320 and 1150 cm^{-1} (SO_2). The NMR spectrum showed a singlet at δ 3.70 (1H, azirine ring proton) and aromatic protons between δ 7.4—8.1 (m, 10H).

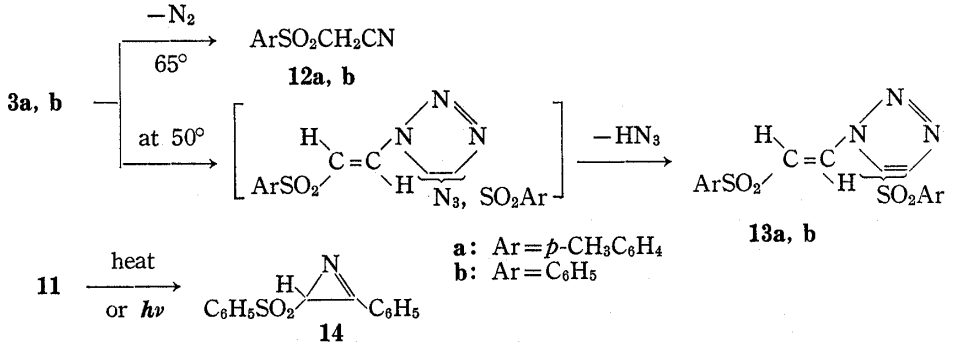

Chart 3

Experimental

All melting points are uncorrected. The NMR spectra were recorded with a Hitachi R-20A (60 MHz) or R-22 (90 MHz) spectrometer with tetramethylsilane as internal standard, IR spectra with a Hitachi EPI-G2 spectrophotometer, and mass spectra with a Hitachi RMU-6D instrument.

9) *a*) J.C. Philips, M. Aregullin, M. Oku, and A. Sierra, *Tetrahedron Lett.*, **1974**, 4157; *b*) V. Fiandaness, C.V. Maffeo, F. Naso, and L. Ronzini, *J.C.S. Perkin II*, **1976**, 1303, and references therein.

10) J.S. Meek and J.S. Fowler, *J. Org. Chem.*, 33, 3418 (1968).

11) B. Singh and E.F. Ullman, *J. Am. Chem. Soc.*, **89**, 6911 (1967); T. Nishiwaki, *Tetrahedron Lett.*, **1969**, 2049.

Material——*p*-Toluenesulfonylethene (**1a**) and benzenesulfonylethene (**1b**) were prepared according to the procedure of Smith and Davis.[12] *trans*-*β*-Benzenesulfonylstyrene (**4**) was prepared by the method of Cardillo.[13]

***cis*-*β*-Benzenesulfonylstyrene** (**8**)——To a solution of *E*-*β*-benzenesulfonyl-*α*-chlorostyrene[14] (1.3 g) in glacial AcOH (12 ml), zinc dust (0.98 g) was added portionwise with stirring. The mixture was stirred at 90° for 1 hr. After cooling, the mixture was poured into H_2O and extracted with CH_2Cl_2. The extract was washed with H_2O and dried ($MgSO_4$). The solvent was evaporated and the residual solid was recrystallized from MeOH–H_2O to give white needles of **8** (0.95 g, 79%), mp 60—61° (lit.[16] mp 62.5—63.5°), which was identified by mixed mp determination and IR spectral comparison with an authentic sample.[15]

2-Azido-1-iodo-1-*p*-toluenesulfonylethane (**2a**)——Essentially the procedure of Hassner[16] was employed for the addition of IN_3. A solution of **1a** (1.82 g, 0.01 mol) in dry acetonitrile (20 ml) was added dropwise to a stirred solution of IN_3 [prepared *in situ* from ICl (3.25 g, 0.02 mol) and NaN_3 (1.95 g, 0.03 mol)] in dry acetonitrile (20 ml) at −10° during 10 min. After stirred at room temperature for 24 hr, the reaction mixture was poured into H_2O and extracted with ether. The extract was washed with 5% $Na_2S_2O_3$ solution and saturated NaCl solution, dried ($MgSO_4$), and concentrated under reduced pressure below 20° to give white crystals of **2a** (2.46 g, 70%), mp 67° (from MeOH). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 2110 (N_3), and 1330, 1160 (SO_2). NMR ($CDCl_3$) δ: 2.45 (s, 3H, CH_3), 5.03 (q, 1H, H-1, J_{12}=10 Hz, J_{12}=3 Hz), 3.6—4.2 (m, 2H, H-2, J_{12}=10 Hz, J_{12}=3 Hz, J_{22}=14 Hz), and 7.38 and 7.82 (ABq, 2H each, J=8 Hz, arom. protons). *Anal.* Calcd. for $C_9H_{10}IN_3O_2S$: C, 30.78; H, 2.87; N, 11.97. Found: C, 30.62; H, 2.87; N, 12.02.

2-Azido-1-iodo-1-benzenesulfonylethane (**2b**)——Using a similar procedure described above for the preparation of **2a**, adduct **2b** (2.90 g, 86%) was obtained from **1b** (1.68 g) and IN_3 as white crystals, mp 57—60° (from MeOH). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 2100 (N_3), and 1325, 1150 (SO_2). NMR ($CDCl_3$) δ: 3.78 (q, 1H, H-1, J_{12}= 9 Hz, J_{12}=4 Hz), 4.3—5.05 (m, 2H, H-2, J_{12}=9 Hz, J_{12}=4 Hz, J_{22}=14 Hz), and 7.5—8.5 (m, 5H, arom. protons).

***trans*-2-Azido-1-*p*-toluenesulfonylethene** (**3a**)——To a solution of **2a** (1.93 g, 5 mmol) in anhydrous tetrahydrofuran (50 ml) was added dropwise a solution of Dabco (1.4 g, 13 mmol) in anhydrous tetrahydrofuran (20 ml). The reaction mixture was stirred at room temperature for 24 hr. The precipitated solid was removed by filtration and the filtrate was concentrated. The residue was diluted with water and extracted with ether. The extract was washed with water, 5% HCl, and water, dried ($MgSO_4$), and concentrated to give **3a** (0.98 g, 79%), mp 74—75° [lit.[6] 72—74°].

***trans*-2-Azido-1-benzenesulfonylethene** (**3b**)——Using a similar procedure described above for the preparation of **3a**, **3b** (0.72 g, 83%) was obtained from **2b** (1.4 g). An analytical sample was obtained by preparative TLC using silica gel and $CHCl_3$ as solvent, mp 69—70°. IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 2110 (N_3), and 1330, 1145 (SO_2). NMR ($CDCl_3$) δ: 6.18 (d, 1H, J=13 Hz, H-1), and 7.5—8.05 (m, 6H, arom. protons and H-2). *Anal.* Calcd. for $C_8H_7N_3O_2S$; C, 45.97; H, 3.37; N, 20.08. Found: C, 45.71; H, 3.59; N, 19.81.

***erythro*-2-Azido-1-iodo-2-phenyl-1-benzenesulfonylethane** (**6**)——Using a similar procedure described for the preparation of **2a**, **6** (1.65 g, 80%) was obtained from **4** (1.22 g) and IN_3 as white crystals, mp 149—150° (from MeOH). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 2120 (N_3), and 1325, 1150 (SO_2). NMR ($CDCl_3$) δ: 5.04 and 5.36 (ABq, 1H each, J=9 Hz, H-2 and H-1, respectively), and 7.2—8.1 (m, 10H, arom. protons). MS *m/e* (at 20 eV): 413 (2%, M^+), 370 (41), 282 (20), and 104 (100). *Anal.* Calcd. for $C_{14}H_{12}IN_3O_2S$: C, 40.69; H, 2.93; N, 10.17. Found: C, 40.70; H, 2.95; N, 10.24.

***threo*-2-Azido-1-iodo-2-phenyl-1-benzenesulfonylethane** (**10**)——Using a similar procedure described for the preparation of **2a**, **8** (2.44 g) gave a crude crystalline product, which was recrystallized from MeOH to give **10** (2.6 g, 60%), mp 71—72°. IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 2120 (N_3), and 1325, 1150 (SO_2). NMR ($CDCl_3$) δ: 5.00 and 5.10 (ABq, 1H each, J=2.5 Hz, H-2 and H-1, respectively), and 7.3—8.1 (m, 10H, arom. protons). MS *m/e* (at 20 eV): 413 (2%, M^+), 370 (5), 282 (18), and 104 (100). *Anal.* Calcd. for $C_{14}H_{12}IN_3O_2S$: C, 40.69; H, 2.93; N, 10.17. Found: C, 40.93; H, 2.96; N, 10.45.

***β*-Iodo-*β*-benzenesulfonylstyrene** (**7**)——Using a similar procedure described for the preparation of **3a**, **7** (0.53 g, 66%) was obtained from **6** (0.9 g) as white crystals, mp 78—79° (from MeOH). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1315 and 1145 (SO_2). NMR ($CDCl_3$) δ: 7.35—8.1 (m, 10H, arom. protons) and 8.40 (s, 1H, vinyl proton). *Anal.* Calcd. for $C_{14}H_{11}IO_2S$: C, 45.42; H, 3.00. Found: C, 45.60; H, 3.02.

Zinc-Acetic Acid Reduction of 7——A slurry of **7** (50 mg) and zinc dust (31 mg) in AcOH (3 ml) was heated at 90° with stirring for 10 min. The reaction mixture was poured into H_2O and extracted with CH_2Cl_2. The extract was washed with H_2O and dried ($MgSO_4$). The solvent was evaporated off *in vacuo*, and the residual solid was recrystallized from MeOH–H_2O to give white crystals (29 mg) of **4**, identified by mixed mp determination and IR spectral comparison with an authentic sample.

12) L.I. Smith and H.R. Davis, Jr., *J. Org. Chem.*, **15**, 824 (1950).
13) G. Cardillo, *Synthesis*, **1975**, 453.
14) W.E. Truce, C.T. Goralski, L.W. Christensen, and R.H. Bavry, *J. Org. Chem.*, **35**, 4217 (1970).
15) V. Baliah and T.K. Rathinasamy, *Indian J. Chem.*, **9**, 220 (1971).
16) F.W. Fowler, A. Hassner, and L.A. Levy, *J. Am. Chem. Soc.*, **89**, 2077 (1967).

α-Azido-β-benzenesulfonylstyrene (11)——Using a similar procedure described for the preparation of **3a**, **11** (0.52 g, 91%) was obtained from **10** (0.83 g) as white crystals, mp 62—63° (from MeOH). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 2130 (N_3), and 1315, 1140 (SO_2). NMR ($CDCl_3$) δ: 6.00 (s, 1H, vinyl proton) and 7.3—8.15 (m, 10H, arom. protons). *Anal.* Calcd. for $C_{14}H_{11}N_3O_2S$: C, 58.93; H, 3.89; N, 14.72. Found: C, 59.00; H, 3.88; N, 14.12.

Benzenesulfonylacetonitrile (12b)——A solution of **3b** (200 mg) in ethanol (10 ml) was refluxed until the starting material disappeared on TLC (*ca.* 10 hr) and concentrated to give pale yellow crystals. Recrystallization from MeOH gave **12b** (119 mg, 66%), mp 110—112° (lit.[17] 112.0—112.5°).

4(or 5)-*p*-Toluenesulfonyl-1-(2-*p*-toluenesulfonylvinyl)-1H-1,2,3-triazole (13a)——A solution of **3a** (166 mg) in EtOH (3 ml) was heated at 50° for 2 hr and concentrated. The resulting solid was recrystallized from MeOH to give white crystals of **13a** (139 mg, 84%), mp 142—143°. IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1330 and 1150 (SO_2). NMR (90 MHz, $CDCl_3$) δ: 2.42 (s, 6H, $2\times CH_3$), 7.20 (d, 1H, $J=14$ Hz, vinyl proton), 7.31 (d, 4H, $J=9$ Hz, arom. protons), 7.87 (d, 4H, $J=9$ Hz, arom. protons), 8.04 (d, 1H, $J=14$ Hz, vinyl proton), and 8.12 (s, 1H, triazole ring proton); MS *m/e* (at 70 eV): 403 (M^+). *Anal.* Calcd. for $C_{18}H_{17}N_3O_4S_2$: C, 53.58; H, 4.25; N, 10.42. Found: C, 53.38; H, 4.26; N, 10.53.

4(or 5)-Benzenesulfonyl-1-(2-benzenesulfonylvinyl)-1H-1,2,3-triazole (13b)——Using a similar procedure described above for the preparation **13a**, **13b** (159 mg, 76%) was obtained from **3b** (209 mg), mp 168—169° (from MeOH). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1300 and 1145 (SO_2). NMR (90 MHz, $CDCl_3$) δ: 7.24 (d, 1H, $J=14$ Hz, vinyl proton), 7.5—8.15 (m, 10H, arom. protons), 8.10 (d, 1H, $J=14$ Hz, vinyl proton), and 8.18 (s, 1H, triazole ring proton). MS *m/e* (at 70 eV): 375 (M^+). *Anal.* Calcd. for $C_{16}H_{13}N_3O_4S_2$: C, 51.20; H, 3.49; N, 11.20. Found: C, 51.11; H, 3.39; N, 11.19.

3-Benzenesulfonyl-2-phenyl-1-azirine (14)——(A) A solution of **11** (285 mg) in MeOH (20 ml) was refluxed for 3 hr. After the solvent was removed, the residual pale yellow crystals were recrystallized from MeOH to give **14** (201 mg, 79%), mp 109°. IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1750 (C=N) and 1320, 1150 (SO_2). NMR ($CDCl_3$) δ: 3.70 (s, 1H, H-3) and 7.4—8.05 (m, 10H, arom. protons). *Anal.* Calcd. for $C_{14}H_{11}NO_2S$: C, 65.35; H, 4.31; N, 5.44. Found: C, 65.06; H, 4.36; N, 5.43.

(B) A solution of **11** (285 mg) in benzene (30 ml) was irradiated in a Pyrex vessel using a 350 W high-pressure mercury lamp for 6 hr. Evaporation of the solvent and recrystallization of the residual solid from MeOH gave pale yellow crystals of **14** (182 mg, 71%), mp 109°.

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17) H. Dressle and J.E. Graham, *J. Org. Chem.*, **32**, 985 (1967).