Stereochemistry of Amine Additions to Acetylenic Sulfones[1]

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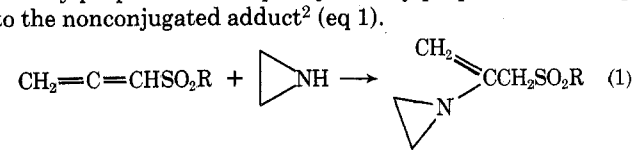
Nucleophilic addition of aziridine to sulfonylacetylenes ($RSO_2C{\equiv}CR'$) in benzene proceeds predominantly in a trans fashion. Increasing the bulk of R′ results in lowering the rate of addition as well as trans stereoselectivity. A weak solvent and temperature effect was observed in the propynyl sulfones. Postisomerization was shown to occur spontaneously during work-up of some of these 1:1 adducts and was also catalyzed by acetic acid, but was inhibited by tertiary amines.

Nucleophilic additions of amines to activated acetylenes have received considerable attention over the past several years, especially with respect to the stereochemistry of the 1:1 adducts. Aziridine has gained prominence as the amine in the recent studies[2-7] because of the reported greater resistance of its adducts to undergo postisomerization under the reaction conditions.

The early workers[4,8] in the field of amine additions to sulfonylacetylenes utilized primary and secondary amines (except aziridine), whose adducts were subject to thermodynamic equilibration under the reaction conditions. The *Z*–*E* isomer ratios for primary amine adducts were found to be solvent dependent, whereas only the *E* isomer was observed with secondary amines. Low-temperature (−25°) studies[4] of diethylamine and *n*-propylamine with *p*-tolylsulfonylacetylene demonstrated that the kinetic product (*Z* isomer) was formed initially, but gradually isomerized to the more stable *E* structure.

Aziridine additions to terminal acetylenic[4] and propynyl sulfones[2,4] appeared to be inconsistent, the terminal acetylenes undergoing ≥95% trans addition in benzene while the propynyl sulfones appeared to be nonstereoselective, giving a mixture of *Z* and *E* isomers, and exhibiting some solvent and temperature dependency. The addition of aziridine to propynyl sulfones was thought to be complicated by the intermediacy of an allene,[4,8a] followed by 1,2 or 2,3 addition; however, this was ruled out when it was found that 1,2 addition predominated in the addition of aziridine to ethylsulfonylpropadiene and *p*-tolylsulfonylpropadiene leading to the nonconjugated adduct[2] (eq 1).



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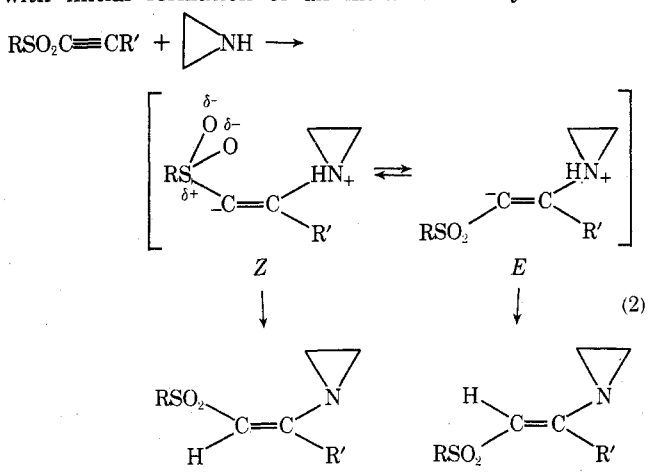
The proposed mechanism for these additions involves attack by aziridine on the β carbon of the sulfonylacetylene with initial formation of an intramolecularly stabilized



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(electrostatic or hydrogen bonded) angular dipolar *Z* intermediate (eq 2). This intermediate can then proceed to the *Z* adduct by protonation (kinetic control) or isomerize to the *E* angular intermediate. Protonation of the *E* intermediate leads to the *E* adduct and thermodynamic control.

Table I
Reaction of Aziridine with $CH_3C{\equiv}CSO_2C_6H_4R$-*p* in Benzene

R	Temp, °C	Reaction time, hr	Configuration, %[a] *Z*	*E*
H	Room temp	4	81	19
CH_3[b]	24–25	4	87	13
OCH_3[c]	24–25	4	78	22
NO_2[c]	24–25	4	83	17

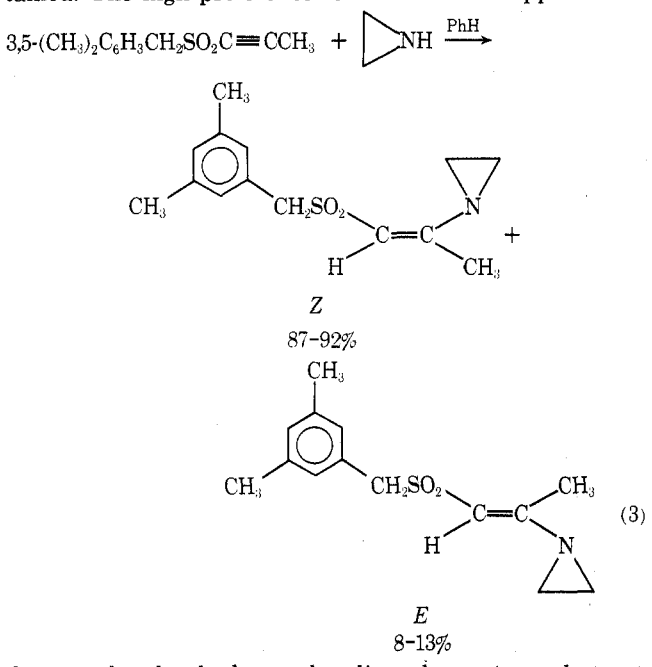
[a] The ratios of *Z* and *E* isomers were determined by NMR analysis of the crude reaction mixture. [b] Under identical conditions ref 2 reports 80% *Z* and 20% *E*. [c] Reference 9.

A modification of this mechanism was proposed[2] when there appeared to be an effect in the propynyl sulfones on the isomer ratio by an aromatic ring attached to the sulfonyl moiety or contained in an attached chain. This neighboring group participation (π hydrogen bonding of the *Z* aziridinium center to the aromatic nucleus) presumably is operative when attached directly to the sulfonyl moiety or only one carbon removed. However, two arguments may be raised concerning the feasibility of such a π hydrogen bonded intermediate. First, since the reaction is conducted in benzene solvent, it would seem that the π-electron clouds of the numerous solvent molecules would compete favorably for the aziridinium center and might be expected to have a higher electron density than the aromatic ring attached to the electron-withdrawing sulfonyl moiety. A second consideration would be the attractive force of the negative oxygens of the sulfone group toward the positively charged aziridinium center in comparison to that of the π-electron cloud of the aromatic ring.

The influence of electron-withdrawing and -donating substituents on the electron density of the aromatic ring of the sulfone should be reflected in the *Z*–*E* ratio of isomers. In the reaction of aziridine with the variously substituted phenylsulfonylpropynes (Table I) in benzene at ambient temperatures no definite trend was observed; however, it is significant that all gave a preponderance of the *Z* isomer, which arises from trans addition of the aziridine molecule across the acetylenic bond.

Hydrogen bonding to the π cloud of electrons of an aromatic ring has precedent in the literature,[10,11] as well as the effect of substituents[11] on the strength of the hydrogen bond. It has been shown that increased methyl substitution enhances the capacity of the ring to form a hydrogen bond. As a further test, 1-(3,5-dimethylbenzylsulfonyl)propyne was prepared and treated with aziridine under the reaction

conditions. 1-Benzylsulfonylpropyne had been reported[2] to give a preponderance (72%) of the Z isomer so that the dimethyl substituted compound might be expected to give a larger proportion of the Z isomer if π hydrogen bonding were involved. In a series of three runs under similar conditions (26–31°, 4–5 hr) the products shown in eq 3 were obtained. The high preference for Z isomer is supportive of



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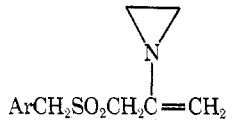
the postulated π hydrogen bonding phenomenon, but yet does not eliminate the possibility of stabilization of the Z intermediate by attractive forces between the sulfonyl oxygens and the aziridinium center. To ascertain that the Z isomer was the kinetic isomer in this system the reaction product was isomerized with potassium hydroxide in THF to give an equilibrium mixture containing 5% Z, 90% E, plus 5% of the nonconjugated isomer



As was the case with the adduct of 1-benzylsulfonylpropyne and aziridine, an upfield shift of the vinyl methyl protons of the E isomer was observed in the NMR relative to those of the Z isomer in 1-(3,5-dimethylbenzylsulfonyl)-2-aziridinopropene. It has been suggested[2] that this shift is the result of diamagnetic shielding[12] by the aromatic ring of the protons of the methyl group located on the same side of the double bond. The pertinent NMR data are given in Table IV.

An extension of the homologous series $C_6H_5(CH_2)_nSO_2C{\equiv}CCH_3$ to n = 3 could provide information concerning the π hydrogen bonding hypothesis, since, when n = 0, 1, and 2, the percent of Z isomer obtained with aziridine in benzene solvent appeared to decrease.[2] However, on repeating these experiments the product ratio shown in eq

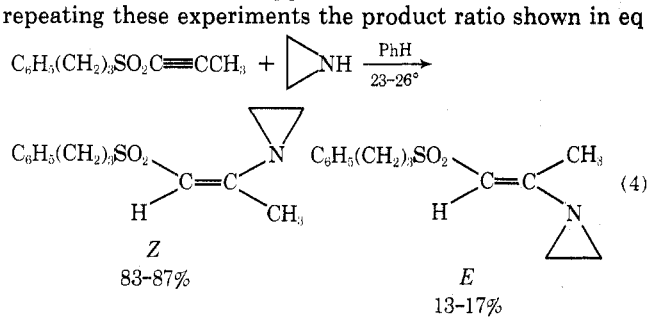


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Table II
Reaction of Aziridine with 1-Cyclopentylsulfonylpropyne in Benzene

Run	Temp, °C	Reaction time, hr	Configuration, %[a] Z	E
1[b]	29–31	4	53	47
2[b]	22–24	4	55	45
3[c]	23–24	15 min	85	15
4[b,d]	23–24	4	58	42
5[e]	24–25	2	81	19
6[f]	27–30	4	89	11

[a] The ratios of Z and E isomers were determined by NMR analysis of the crude reaction mixtures. [b] Normal run procedure: aziridine added to benzene solution of acetylene; solution stirred for specified time; solvent removed in vacuo at room temperature; residue dissolved in $CDCl_3$ for NMR. [c] Reaction carried out in NMR tube. Less than the stoichiometric amount of aziridine added to benzene solution of acetylene. [d] The aziridine was freshly distilled before use. [e] One equivalent of pyridine was added to the reaction mixture before aziridine addition. [f] One-half equivalent of tripropylamine was added after 4 hr, but before work-up.

4 was observed. The E isomer was likewise the thermodynamic product in this case. A neighboring group participation by the phenyl ring nine atoms removed seems unlikely in accounting for the preponderance of the Z isomer in this reaction; however, stabilization might be afforded by the oxygens of the sulfonyl group.

Another approach to this problem involved the replacement of the aromatic ring by a saturated ring with similar size and steric characteristics, but without the capability to form a π hydrogen bond. For this purpose 1-cyclopentylsulfonylpropyne was prepared and allowed to react with aziridine in benzene under the usual conditions.[2] Two runs under similar conditions provided 53–55% Z isomer. This result seemed inconsistent with the preceding data, so successive runs were made to determine if this was the true isomer ratio (Table II). The NMR-monitored reaction was complete in 15 min, but at 27 min elapsed time the ratio had changed slightly to 81% Z and 19% E adducts while at 43 min the ratio was 65% Z and 35% E, the E isomer increasing at the expense of the Z isomer. After standing overnight the ratio had fallen to 39% Z and 61% E adducts. Obviously, a postisomerization of the initially formed adducts is occurring in this system and likewise occurred in the two initial runs with this acetylene.

Huisgen[13] has noted that catalytic amounts of acid cause rapid isomerization of the amine adducts of methyl propiolate and dimethyl acetylenedicarboxylate. Spontaneous isomerization of these adducts occurred in benzene solution alone at 25°, the rate being very slow; however, when an equimolar amount of triethylamine was added to the solution, the rate of isomerization decreased by a factor of 27 in the case of methyl 3-cyclohexylaminoacrylate. This reduced rate of isomerization was attributed to the scavenging of any free acid in the solution by the triethylamine. Presumably the addition of base in runs 5 and 6 is functioning similarly in this system. The presence of more basic tertiary amines, e.g., triethylamine and tripropylamine, in the reaction mixture initially causes isomerization of the acetylene to the allene.[2,4]

The study of aziridine addition to 1-cyclopentylsulfonylpropyne has demonstrated that postisomerization can occur with aziridine adducts under normal reaction and work-up conditions. An, as yet unidentified, acidic impurity appears to be responsible for this isomerization, since small amounts of tertiary amine decrease the isomerization rate drastically. This postisomerization has not been observed in all systems studied; however, a reexamination of

the previously reported[2] propynyl systems, 1-ethylsulfonylpropyne and 1-(2-phenylethylsulfonyl)propyne, was necessary as well as an in-depth study of other alkylsulfonylpropynes, being alert for postisomerization and factors responsible for it.

The following propynyl sulfones were prepared and treated with aziridine in benzene (with the results recorded in Table III): 1-methylsulfonylpropyne, 1-(2-propylsulfonyl)propyne, 1-(2-methyl-2-propylsulfonyl)propyne, and 1-(2-phenylethylsulfonyl)propyne. In all of the propynyl sulfones studied a high degree of stereoselectivity for formation of the *Z* isomer by trans addition of aziridine was observed. Only with 1-methylsulfonylpropyne was it necessary to utilize a tertiary amine to decrease the postisomerization rate. In the absence of tripropylamine, postisomerization occurred so rapidly under normal reaction and work-up conditions that a ratio of 7% *Z* and 93% *E* adducts was obtained.

As noted in Table III, both 1-ethylsulfonylpropyne and 1-(2-phenylethylsulfonyl)propyne were shown to undergo addition of aziridine to give a preponderance of the *Z* isomer from trans addition. Obviously, the earlier reported[2,4] ratios of isomers for these compounds were those in which postisomerization had already occurred, presumably during work-up, and thus gave an erroneous trend which led to a postulation of a neighboring group participation (π hydrogen bonding) by an aromatic group attached to the sulfonyl moiety. The data in Table III do not support the published trend nor the π hydrogen bonding modification of the proposed mechanism.

Table III
Reaction of Aziridine with $RSO_2C{\equiv}CCH_3$ in Benzene

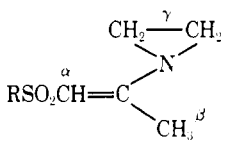
R	Temp, °C	Reaction time, hr	Configuration, %[a] *Z*	*E*
C_6H_5	Room temp	4	81	19
p-$CH_3C_6H_4$	24–25	4	87	13
p-$CH_3OC_6H_4$[b]	24–25	4	78	22
p-$NO_2C_6H_4$[b]	24–25	4	83	17
$C_6H_5CH_2$[c]	28–29	4	72	28
3,5-$(CH_3)_2C_6H_3CH_2$	29–31	4	92	8
$C_6H_5CH_2CH_2$	27–31	4.3	84	16
$C_6H_5CH_2CH_2CH_2$	23–26	4	87	13
CH_3	24–26	2	94	6
CH_3CH_2	23–25	4	96	4
$(CH_3)_2CH$	23–25	4	91	9
	27–30	4	89	11
$(CH_3)_3C$	23–25	4	96	4

[a] The ratios of *Z* and *E* isomers were determined by NMR analysis of the crude reaction mixture. These isomer ratios represent minimal values (greater than or equal to) for the *Z* isomer for this reaction. [b] Reference 9. [c] Reference 2.

Configurational assignments were based on NMR analysis of the reaction mixture and are similar to those previously published[2,4] for these compounds. The pertinent chemical shifts are given in Table IV. A downfield shift of 0.12–0.19 ppm was noted for the vinyl proton of the *E* isomer relative to that of the *Z* isomer which would be consistent with a deshielding of this proton by the electronegative nitrogen of the aziridino group on the same side of the double bond in the *E* isomer. Likewise, a downfield shift of 0.17–0.34 ppm was observed for the aziridino protons in the *Z* isomer relative to those in the *E*, as well as a downfield shift of 0.21–0.37 ppm for the vinyl methyl protons of the *E* isomer relative to those of the *Z* (with the exception of those in the two benzylsulfonyl systems as noted above), both of which can be attributed to a deshielding by the sulfonyl moiety on the same side of the double bond.

Numerous attempts were made to effect a postisomerization under the reaction conditions used with the 1-ethylsulfonylpropyne–aziridine system. Shortening the reaction time to 30 min decreased the *Z* isomer insignificantly (91% on a 70% completion of the reaction). Utilizing a mole ratio of 1.5 (acetylene:aziridine) over 4 hr reaction time caused another decrease to 88% *Z* adduct and 12% *E*. Inverse addition of the acetylene to aziridine gave 91% of the *Z* isomer. Analysis in carbon tetrachloride or $CDCl_3$[14] gave identical isomer ratios of 94–95% *Z* isomer and 5–6% *E* isomer following a 4-hr run period. A slow isomerization was observed when the crude reaction mixtures were allowed to stand in carbon tetrachloride: elapsed time 4 hr, *Z*:*E* ratio 94:6; 72 hr, 70:30; 144 hr, 61:39; 360 hr, 50:50. However, this postisomerization could be effectively reduced to zero by the addition of a small amount of tertiary amine, e.g., no isomerization was noted after 6 days when 10 mol % trieth-

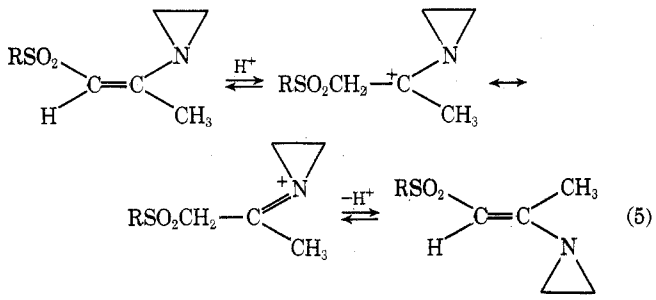
Table IV
NMR Data for



R	Solvent	α[a] *Z*	*E*	β[a] *Z*	*E*	γ[a] *Z*	*E*
C_6H_5	$CDCl_3$	5.54	5.73	1.87	2.23	2.27	1.98
p-$CH_3C_6H_4$	$CDCl_3$	5.51	5.68	1.85	2.20	2.24	1.95
$C_6H_5CH_2$[b]	$CDCl_3$	5.19	5.38	1.80	1.73	2.15	1.85
3,5-$(CH_3)_2C_6H_3CH_2$	$CDCl_3$	5.25	5.41	1.91	1.86	2.25	1.96
$C_6H_5CH_2CH_2$	$CDCl_3$	5.35	5.47	1.85	2.22	2.25	1.91
$C_6H_5CH_2CH_2CH_2$	$CDCl_3$	5.33	5.49	1.81	2.16	2.15	1.92
CH_3	CCl_4	5.47	5.63	1.92	2.19	2.26	2.02
CH_3CH_2	$CDCl_3$	5.37	5.53	1.90	2.25	2.29	2.05
$(CH_3)_2CH$	$CDCl_3$	5.26	5.39	1.94	2.21	2.23	2.06
	$CDCl_3$	5.38	5.54	1.95	2.26	2.30	2.03
$(CH_3)_3C$	CCl_4	5.20	5.35	1.97	2.18	2.23	2.02

[a] Positions given in parts per million (δ) relative to Me_4Si. The α, β, and γ peaks were all singlets. [b] Reference 2.

ylamine was added to a carbon tetrachloride solution of 94% *Z* and 6% *E* isomers. It was only after the addition of a small amount of acetic acid to one of these reaction mixtures that an exothermic reaction and a reversal in the isomer ratio was noted. Within 5 min the isomer ratio had changed from 93% *Z* and 7% *E* to 8% *Z* and 92% *E* adducts. This rapid isomerization by an organic acid is suggestive of the mode of postisomerization which may be operative in these systems (eq 5). The reaction solvent, the NMR sol-



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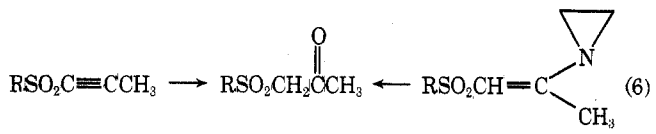
vent, and aziridine have been eliminated as sources of acidic impurities. One of the remaining suspects is the acetylenic sulfone, which could form the moderately acidic β-keto sulfone[15] through a hydrolysis step. Likewise, a hydrolysis of the adducts (enamines) could lead to the same β-keto sulfones (eq 6).



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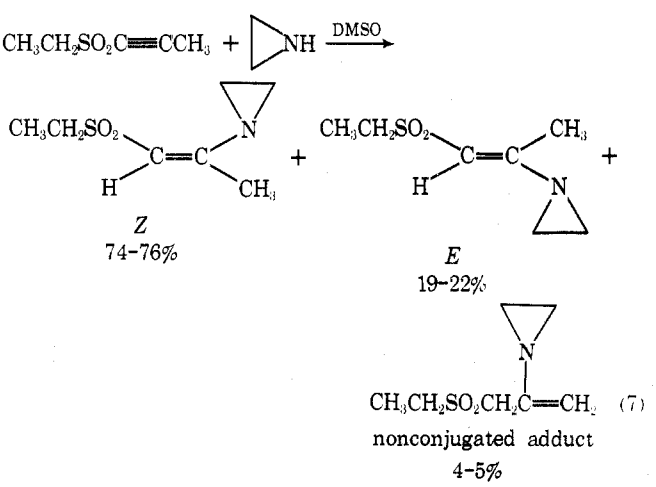
A solvent effect has been alluded to earlier in this discussion and reported previously for aziridine additions to acetylenic sulfones,[2,4] acetylenic carboxylic esters,[3,4,5a,6] and nitriles.[3] The reaction of aziridine with 1-*p*-tolylsulfonylpropyne in four different aprotic solvents gave a decreasing amount of stereoselectivity for trans addition with increasing polarity of the solvent,[2] e.g., CCl_4, 81% *Z* isomer; C_6H_6, 80%; Et_2O, 74%; Me_2SO, 68%. Since 1-ethylsulfonylpropyne had been shown to be highly stereoselective toward trans addition (96%) in benzene, it was of interest to study the addition in the polar solvent dimethyl sulfoxide. Analyzing the crude reaction mixture prior to distillation gave the results shown in eq 7. Although this solvent effect is not as



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great as that which was claimed earlier,[16] it is still significant and consistent with the proposed mechanism.[2]

This is the first instance in which the nonconjugated isomer has been observed in the product reaction mixture of aziridine addition to 1-propynyl sulfones. A possible explanation for the appearance of this isomer is that some ethylsulfonylpropadiene[17] is being formed during the reaction with subsequent addition of aziridine. Facile isomerization[2,4,8a,18] of 1-propynyl sulfones to the isomeric allenes is favored under sufficiently basic conditions. The base strength of aziridine in benzene is not sufficient to facilitate this isomerization; however, in the highly polar dimethyl sulfoxide, its base strength may be enhanced to effect such an isomerization.

A temperature effect was found to be operative in the earlier study[2] and was supportive of the mechanism (eq 2). The results indicated below with 1-ethylsulfonylpropyne and 1-*p*-tolylsulfonylpropyne substantiate the temperature effect in nonterminal acetylenes, but also suggest that the effect is considerably less than originally thought. It appears that some postisomerization clouded the picture in the earlier 1-*p*-tolylsulfonylpropyne study[2] (where 31% *Z* isomer was reported at a reaction temperature of 53–54°, in benzene), since under identical conditions, 64% *Z* isomer was observed in the present study. This isomer ratio was confirmed with two subsequent runs in which 10 mol % of a tertiary amine was added to the reaction mixture to retard any postisomerization. A run made with 10% pyridine in benzene at 55–57° showed 65% *Z* and 35% *E* isomers while the run containing 10 mol % 1,8-bis(dimethylamino)-naphthalene[19] at 53–54° gave 72% *Z* and 28% *E* isomers. These results, when compared with the 87% *Z* isomer at 24–25°, reflect an effect of temperature on the reaction.

As with 1-*p*-tolylsulfonylpropyne, the addition of aziridine to 1-ethylsulfonylpropyne at 52–57° in benzene gave a slight decrease in the amount of trans addition compared to addition at 23–24°. A series of five runs gave between 82 and 91% *Z* isomer at the higher temperature compared to 96% at room temperature.

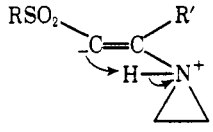
The preceding investigation of the propynyl sulfone system revealed that the alkyl and aryl groups attached to the sulfonyl moiety, as well as the temperature and solvent, had an effect, albeit relatively small, on the course of addition of aziridine to these acetylenes; however, a thorough study of the effect of substituents, R′, on the acetylenic β carbon was lacking ($RSO_2C{\equiv}CR'$). In the addition of *n*-propylamine to $CH_3CH_2SO_2C{\equiv}CR'$, it was shown[4] previously that as the steric bulk of R′ increased, the equilibrium was shifted toward the *Z* adduct, owing to greater steric effects in the *E* isomer. The addition of aziridine to this series where R′ = H,[16] CH_3,[2,4] and CH_2CH_3[2] was reported, but postisomerization appears to have complicated the picture. The results shown in Tables V and VI for the addition of aziridine to $CH_3CH_2SO_2C{\equiv}CR'$ and *p*-$CH_3C_6H_4$-$SO_2C{\equiv}CR'$ in benzene indicated a trend toward nonstereoselectivity as the bulk of R′ increases, but yet the predominance of trans addition was observed throughout (67% or greater). This trend may be explained on the basis of steric retardation of protonation in the *Z* intermediate

Table V
Reaction of Aziridine with $CH_3CH_2SO_2C{\equiv}CR'$ in Benzene

R′	Temp, °C	Reaction time, hr	Configuration, %[a] *Z*	*E*
H[b]	Room temp	4	100	
CH_3	23–24	4	96	4
$CH(CH_3)_2$[c]	26–27	6	76	24
$C(CH_3)_3$[d]	29–32	28	75	25

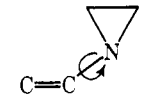
[a] The ratios of *Z* and *E* isomers were determined by NMR analysis of the crude reaction mixture. [b] Reference 16. [c] The reaction was only 83% complete at the end of 4 hr. Analysis was carried out in acetone or carbon tetrachloride since the *Z* and *E* vinyl protons overlapped in $CDCl_3$. [d] The reaction was only 14% complete at the end of 4 hr and 42% complete at 28 hr.

leading to a shift in equilibrium to the *E* intermediate, wherein protonation could occur in a four-center process from the aziridinium group as shown (or via a six-center process involving a second aziridine associated with the first).



The rate of reaction observed for both systems where R′ was *tert*-butyl was significantly diminished (14–17% complete after 4 hr) when compared to the less sterically bulky members in the series (where reaction was complete in 6 hr or less). Longer reaction times, where R′ = *tert*-butyl, improved the extent of reaction with similar isomer ratios being observed. The addition of the sterically larger secondary amine, diethylamine, to 1-(*p*-tolylsulfonyl)-3,3-dimethyl-1-butyne was unsuccessful (no adducts were present even after 38 hr in benzene), thus supporting the evidence that nucleophilic approach to the β carbon of the *tert*-butyl-substituted sulfonylacetylene is severely restricted.

The pertinent NMR data for the adducts in these series are tabulated in Table VII and support the structural assignments. However, it should be noted that the difference ($\Delta\alpha$) in chemical shift between the *Z* and *E* vinyl proton decreases as the steric bulk increases and becomes negative at *tert*-butyl. The greater downfield shift of the *Z* vinyl proton in the *tert*-butyl substituted acetylene adducts may be due to the hindrance by the bulky *tert*-butyl group to free rotation about the sp^2 carbon to nitrogen bond



thus reducing the amount of deshielding by the electronegative nitrogen on the proton in a cis relationship to it. All other shifts in the adducts are consistent with those previously published.[2,4]

Table VI
Reaction of Aziridine with *p*-$CH_3C_6H_4SO_2C{\equiv}CR'$ in Benzene

R′	Temp, °C	Reaction time, hr	Configuration, %[a] *Z*	*E*
H[b]	0, room temp	4	95	5
CH_3	24–25	4	87	13
CH_2CH_3[c]	Room temp	4	76	24
$CH(CH_3)_2$	Room temp	4	73	27
$C(CH_3)_3$[d]	Room temp	4	67	33
C_6H_5	Room temp	4	85	15

[a] The ratios of *Z* and *E* isomers were determined by NMR analysis of the crude reaction mixture. [b] Reference 4. [c] Reference 20. [d] The reaction was only 17% complete after 4 hr. After 52 hr the ratio of isomers remained the same and the reaction was 74% complete.

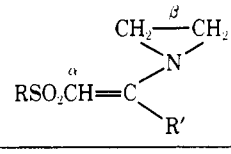
Experimental Section[21]

Materials. Aziridine was obtained from Dow Chemical Co. and stored in the cold over caustic soda pellets. Phenylacetylene, 3-methyl-1-butyne, and 3,3-dimethyl-1-butyne were purchased from Farchan Research Laboratories, methanethiol from Pennsalt Chemical Corp., cyclopentyl mercaptan from Columbia Chemical Co., sodium *p*-toluenesulfinate, propargyl bromide, 2-propanethiol, 2-methyl-2-propanethiol, 3-phenyl-1-propanethiol, and *m*-chloroperbenzoic acid from Aldrich Chemical Co., and ethanesulfonyl chloride from Eastman Chemical Co. Samples of the following chemicals were supplied by the persons indicated of this laboratory: 1-(*p*-tolylthio)propyne, J. Allison; *cis*-1,2-bis-(ethylthio)ethene, L. D. Markley; 1-(*p*-tolylsulfonyl)-3-methyl-1-butyne, G. C. Wolf; and 1-(*p*-tolylsulfonyl)-3,3-dimethyl-1-butyne, G. Tichenor.

Preparation of 3,5-Dimethylbenzyl Bromide (1). *N*-Bromosuccinimide (89 g, 0.5 mol) was added to freshly distilled mesitylene (60 g, 0.5 mol) dissolved in 3300 ml of carbon tetrachloride and refluxed for 2.5 hr under illumination.[35] After cooling, the precipitated succinimide was filtered from the solution and the filtrate concentrated in vacuo and distilled to give 58.56 g (58.9%) of **1**, bp 86° (1.85 mm), mp 39–41° [lit.[22] bp 75–77° (1.5 mm)].

Preparation of 3,5-Dimethylbenzyl Mercaptan (2). Utilizing the established method[23] for alkyl thiol synthesis, a solution of **1** (58.24 g, 0.293 mol) in 165 ml of 95% ethanol was refluxed with thiourea (22.27 g, 0.293 mol) for 4.5 hr and then allowed to cool. After the addition of aqueous sodium hydroxide (17.6 g, 0.44 mol in 150 ml of water) the mixture was again refluxed for 2 hr. The cooled solution formed two layers. The aqueous lower layer was acidified (7 ml of concentrated H_2SO_4 in 50 ml of water) and extracted with benzene. After the organic layer was combined with

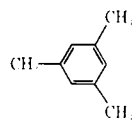
Table VII
NMR Data for



R	R′	Solvent	α[a] *Z*	α[a] *E*	Δα[b]	β[a] *Z*	β[a] *E*	Δβ[c]
p-$CH_3C_6H_4$	H	$CDCl_3$	5.59 (d, *J* = 8.8 Hz)	5.82 (d, *J* = 13 Hz)	0.23	2.23	2.00	0.23
	CH_3	$CDCl_3$	5.51	5.68	0.17	2.24	1.95	0.29
	CH_2CH_3[d]	$CDCl_3$	5.54	5.66	0.12	2.23	1.95	0.28
	$CH(CH_3)_2$	$CDCl_3$	5.51	5.55	0.04	2.28	1.97	0.31
	$C(CH_3)_3$	$CDCl_3$	5.63	5.47	−0.16	2.38	2.00	0.38
	C_6H_5	$CDCl_3$	5.92	6.03	0.11	2.35	1.89	0.46
CH_3CH_2	H[e]	$CDCl_3$	5.48 (d, *J* = 9 Hz)	5.78 (d, *J* = 13 Hz)	0.30	2.25	2.09	0.16
	CH_3	$CDCl_3$	5.37	5.53	0.16	2.29	2.05	0.24
	CH_2CH_3[e]	$CDCl_3$	5.35	5.47	0.12	2.30	2.05	0.25
	$CH(CH_3)_2$	CCl_4	5.22	5.30	0.08	2.28	2.02	0.26
	$C(CH_3)_3$	$CDCl_3$	5.50	5.34	−0.16	2.45	2.08	0.37

[a] Positions given in parts per million (δ) relative to Me_4Si. The α and β peaks appeared as singlets except for R′ = H, where the α peaks were doublets. [b] Difference in α position, *E*–*Z*. [c] Difference in β position, *Z*–*E*. [d] Reference 20. [e] Reference 16.

Table VIII
Preparation of $HC{\equiv}CCH_2SR$

R	% Yield	Bp, °C (mm)	Reaction time, hr	Note	Compd
CH_3	32.7	108–109.5 (760)	2	*a*	3
$CH(CH_3)_2$	78.4	63–65.5 (49)	Overnight	*b*	4
$C(CH_3)_3$	74	76.8–78 (52)	2	*c*	5
	80.2	124–126 (68)	2	*d*	6
	81.6	128 (2.55)	Overnight	*e*	7
$CH_2CH_2C_6H_5$	79.1	85–88 (0.3)	2	*f*	8
$CH_2CH_2CH_2C_6H_5$	59.1	88–93 (0.2)	2 (reflux)	*g*	9

[a] NMR (CCl_4) δ 2.19 (s, 3 H, CH_3S), 2.33 (t, 1 H, J = 2.7 Hz, $-C{\equiv}CH$), 3.24 (d, 2 H, J = 2.7 Hz, $-SCH_2C{\equiv}C-$). [b] Reference 24. [c] Reference 25. [d] Anal. Calcd for $C_8H_{12}S$: C, 68.51; H, 8.62; S, 22.86; mol wt, 140.25. Found: C, 68.41; H, 8.84; S, 22.61; mol wt, 144.6. [e] Anal. Calcd for $C_{12}H_{14}S$: C, 75.74; H, 7.42; S, 16.85; mol wt, 190.31. Found: C, 75.95; H, 7.21; S, 16.95; mol wt, 191.1. [f] Reference 2. [g] Reference 9.

the benzene extracts, the mixture was washed with water, dried over sodium sulfate, concentrated in vacuo and distilled to give 36.02 g (81%) of **2**: bp 97° (4.15 mm); NMR ($CDCl_3$) δ 1.68 (t, 1 H, J = 7.3 Hz, -SH), 2.26 (s, 6 H, aromatic CH_3), 3.62 (d, 2 H, J = 7.3 Hz, $-CH_2S$), 6.90 (broad singlet, 3 H, aromatic ring protons).

Anal. Calcd for $C_9H_{12}S$: C, 71.00; H, 7.94; S, 21.06; mol wt, 152.26. Found: C, 71.10; H, 7.91; S, 20.76; mol wt, 156.

General Procedure for the Preparation of 3-Propynyl Sulfides.[24] One equivalent each of sodium thiolate and propargyl bromide was combined in methanol and stirred for a specified time. The reaction mixture was diluted with water and extracted with either chloroform or methylene chloride. The extracts were dried ($MgSO_4$) and then distilled to obtain the desired product listed in Table VIII.

General Procedure for the Preparation of 1-Propynyl Sulfides.[8a] The corresponding 3-propynyl sulfides were dissolved in a tetrahydrofuran solution containing excess undissolved potassium hydroxide and stirred until isomerization was complete. The solid was removed by filtration and the filtrate distilled to obtain the 1-propynyl sulfides listed in Table IX.

Preparation of 1-(Ethylthio)propyne (18). To a cooled (−46°, Dry Ice–cyclohexane bath) solution of sodium amide (28.08 g, 0.72 mol) in 500 ml of ammonia was added, dropwise, (*Z*)-1,2-bis(ethylthio)ethene (3.28 g, 0.36 mol). After stirring for 6 hr, methyl iodide (102.6 g, 0.72 mol) was added slowly and then the ammonia was allowed to evaporate overnight. Water and diethyl ether (100 ml of each) were added to the residue, the layers separated, and the organic layer dried ($MgSO_4$) and distilled to give 21.14 g (58.7%) of **18**: bp 59.5–61° (48 mm) (lit.[28] bp 134–144°); NMR ($CDCl_3$) δ 1.34 (t, 3 H, J = 7.2 Hz, CH_3CH_2S-), 1.93 (s, 3 H, $-SC{\equiv}CCH_3$), 2.66 (q, 2 H, J = 7.2 Hz, CH_3CH_2S-).

General Procedure for the Preparation of 1-Propynyl Sulfones from Sulfides. Two equivalents of 85% m-chloroperbenzoic acid (MCPBA) in chloroform were added to a chloroform solution of the sulfide (1 equiv) maintained at 0°. After 24 hr, during which time the reaction mixture warmed to room temperature, the precipitated *m*-chlorobenzoic acid was removed. The filtrate was washed with a saturated $NaHCO_3$ solution containing a small amount of Na_2SO_3, dried over $MgSO_4$, and concentrated in vacuo. The 1-propynyl sulfone was purified by either recrystallization if it was a solid or distillation if a liquid. See Table X.

Preparation of 1-Phenylsulfonylpropyne (28). Oxidation was carried out using hydrogen peroxide in glacial acetic acid. To a solution of **17** (10.5 g, 0.071 mol) in 100 ml of glacial acetic acid was added 30% hydrogen peroxide (32.2 g, 0.284 mol). The resulting mixture was heated to reflux for 2 hr and then poured into 500 ml of ice water. The excess peroxide was destroyed with Na_2SO_3. The crude sulfone was collected, dissolved in $CHCl_3$, dried ($MgSO_4$), and concentrated to give 7.2 g; mp 63–70°. Recrystallization from pentane–chloroform afforded 4.87 g (38%) of **28**: mp 70–72° (lit.[31] mp 68.5–69.5°); NMR ($CDCl_3$) δ 2.02 (s, 3 H, $-C{\equiv}CCH_3$), 7.52–7.82 (m, 3 H, aromatic ring protons), 7.88–8.14 (m, 2 H, aromatic ring protons).

Preparation of Sodium Ethanesulfinate (29). This compound was prepared by alternately adding small portions of ethanesulfonyl chloride (47.5 g, 0.37 mol) and sodium bicarbonate (61.3 g, 0.73 mol) to an aqueous solution of sodium sulfite (92 g, 0.73 mol in 400 ml of H_2O) held at 86°. After an additional 30 min of stirring the

Table IX
Preparation of $CH_3C{\equiv}CSR$

R	% yield	Bp, °C (mm)	Note	Compd
CH_3	75	111 (760)	*a*	10
$CH(CH_3)_2$	83	67–68 (45)	*b*	11
$C(CH_3)_3$	84.8	69 (35)	*c*	12
	69.7	85–87 (12)	*d*	13
	88	100 (0.5)	*e*	14
$CH_2CH_2C_6H_5$	86.8	82.5–83 (0.27)	*f*	15
$CH_2CH_2CH_2C_6H_5$	68	91–93 (0.3)	*g*	16
C_6H_5	70	56.5–58.5 (0.2)	*h*	17

[a] Reference 26. [b] Reference 27. [c] Reference 28. [d] Anal. Calcd for $C_8H_{12}S$: C, 68.51; H, 8.62; S, 22.86; mol wt, 140.25. Found: C, 68.75; H, 8.86; S, 22.66; mol wt, 144.2. [e] Anal. Calcd for $C_{12}H_{14}S$: C, 75.74; H, 7.42; S, 16.85; mol wt, 190.31. Found: C, 75.66; H, 7.12; S, 16.57; mol wt, 188.0. [f] Reference 2. [g] Reference 9. Anal. Calcd for $C_{12}H_{14}S$: C, 75.74; H, 7.42; S, 16.85; mol wt, 190.31. Found: C, 76.02; H, 7.29; S, 16.65; mol wt, 190. [h] Reference 29, 30, and 31.

Table X
Preparation of $CH_3C{\equiv}CSO_2R$

R	% yield	Mp or bp, °C (mm)	Note	Compd
CH_3	57	75 (0.4)	*a*	19
CH_2CH_3	82.9	81.5 (0.58)	*b*	20
$CH(CH_3)_2$	84	87.5–89.5 (0.45)	*c*	21
$C(CH_3)_3$	87.3	78–79.5	*d*	22
	83.9	110 (0.23)	*e*	23
	94.4	121–122	*f*	24
$CH_2CH_2C_6H_5$	89.3	45.5–47	*g*	25
$CH_2CH_2CH_2C_6H_5$	52		*h*	26
$C_6H_4CH_3$-*p*	88.4	98–99.5	*i*	27

[a] Mp 36–39°C. Anal. Calcd for $C_4H_6O_2S$: C, 40.66; H, 5.12; S, 27.14; mol wt, 118.16. Found: C, 40.44; H, 5.14; S, 27.31; mol wt, 120.12. [b] Reference 4. [c] Anal. Calcd for $C_6H_{10}O_2S$: C, 49.29; H, 6.89; S, 21.93; mol wt, 146.21. Found: C, 49.52; H, 6.77; S, 21.83; mol wt, 148.9. [d] Anal. Calcd for $C_7H_{12}O_2S$: C, 52.47; H, 7.55; S, 20.01; mol wt, 160.24. Found: C, 52.58; H, 7.67; S, 20.19; mol wt, 162. [e] Anal. Calcd for $C_8H_{12}O_2S$: C, 55.79; H, 7.02; S, 18.62; mol wt, 172.25. Found: C, 55.96; H, 7.15; S, 18.42; mol wt, 173:91. [f] Anal. Calcd for $C_{12}H_{14}O_2S$: C, 64.83; H, 6.35; S, 14.42; mol wt, 222.31. Found: C, 64.62; H, 6.31; S, 14.62; mol wt, 224.9. [g] Reference 2. [h] Attempted distillation led to decomposition.[32] Purification was effected by elution from a column of silica gel with diethyl ether–petroleum ether (bp 35–37°). [i] Reference 8d.

solvent was removed in vacuo and the resulting dry salts leached with boiling ethanol. Solvent evaporation and vacuum drying afforded 37.12 g (86%) of **29** as a fluffy white solid.

Preparation of *p*-Tolylsulfonyl Iodide (30). To a vigorously stirred solution of sodium *p*-toluenesulfinate (17.8 g, 0.1 mol) in 1200 ml of water was added iodine (25.0 g, 0.099 mol) in 450 ml of ethanol. The resulting yellow precipitate was collected, washed with cold petroleum ether (bp 35–37°), and recrystallized from carbon tetrachloride, giving 21.75 g (78%) of **30:** mp 90–94° dec (lit.[34] mp 90–91° dec); NMR ($CDCl_3$) δ 2.48 (s, 3 H, aromatic CH_3), 7.36 (d, 2 H, J = 8.2 Hz, aromatic ring protons), 7.75 (d, 2 H, J = 8.2 Hz, aromatic ring protons).

In Situ Preparation of Ethylsulfonyl Iodide (31). This sulfonyl iodide rapidly decomposes,[33] as evidenced by the liberation of iodine, so was prepared freshly in a benzene solution for each addition and used immediately. The general procedure follows. To a vigorously stirred benzene solution of iodine was added a slight excess of sodium ethanesulfinate in water. After a short time (5 min) the benzene layer turned from purple to orange indicating the formation of **31** so the layers were separated. The benzene layer was dried briefly over anhydrous magnesium sulfate and then used in the acetylene additions.

Preparation of 1-Iodo-1-phenyl-2-(*p*-tolylsulfonyl)ethene (32). To a solution of **30** (21.15 g, 0.075 mol) in 200 ml of diethyl ether was added phenylacetylene (7.65 g, 0.075 mol) in 100 ml of Et_2O with illumination.[35] After 12 hr the solvent was removed and the residue recrystallized from ethanol–water, affording 25.9 g (90%) of **32:** mp 83–84.5° (lit.[33] mp 83–84°); NMR ($CDCl_3$) δ 2.32 (s, 3 H, aromatic CH_3), 7.0–7.61 (m, 10 H, aromatic ring protons, vinyl proton).

Preparation of 1-Ethylsulfonyl-2-iodo-3-methyl-1-butene (33). To **31** (60.91 g, 0.24 mol of I_2 and 33.64 g, 0.29 mol of $EtSO_2Na$) in benzene was added 3-methyl-1-butyne (17.68 g, 0.26 mol) with illumination[35] (4 hr) and the solution was stirred overnight. The reaction mixture was washed with sodium thiosulfate solution, dried over magnesium sulfate and decolorizing carbon, and concentrated in vacuo giving 41.02 g of yellow liquid. Distillation provided a reddish material[36] in the forerun and then 25.56 g (37%) of **33:** bp 119–123° (1 mm); NMR ($CDCl_3$) δ 1.02 [d, 6 H, J = 6.3 Hz, $-CH(CH_3)_2$], 1.39 (t, 3 H, J = 7.3 Hz, $CH_3CH_2SO_2-$), 3.02 (q, 2 H, J = 7.3 Hz, $CH_3CH_2SO_2-$), 3.13 [septet, 1 H, J = 6.3 Hz, $-CH(CH_3)_2$], 6.93 (s, 1 H, vinyl proton).

Anal. Calcd for $C_7H_{13}IO_2S$: C, 29.19; H, 4.55; I, 44.05; S, 11.13. Found: C, 29.14; H, 4.74; I, 44.21; S, 11.10

Preparation of 1-Ethylsulfonyl-2-iodo-3,3-dimethyl-1-butene (34). To a benzene solution of **31** (60.91 g, 0.24 mol of I_2 and 30.76 g, 0.26 mol of $EtSO_2Na$) was added 3,3-dimethyl-1-butyne (21.32 g, 0.26 mol) with illumination[35] (4.5 hr). The reaction mixture was washed with sodium thiosulfate solution, dried over $MgSO_4$, decolorized with carbon, and concentrated in vacuo to 44.81 g of orange liquid. NMR analysis showed two isomers,[37] cis-addition isomer predominating over the trans-addition isomer, 56:44. Pure Z isomer was obtained by cooling to −78° causing the formation of a glass; subsequent warming to room temperature and addition of petroleum ether provided 14.41 g of (*Z*)-**34.** Recrystallization from 2-propanol–water gave a white solid: mp 77–78°; NMR ($CDCl_3$) δ 1.27 [s, 9 H, $-C(CH_3)_3$], 1.37 (t, 3 H, J = 7.4 Hz, $CH_3CH_2SO_2-$), 3.26 (q, 2 H, J = 7.4 Hz, $CH_3CH_2SO_2-$), 6.91 (s, 1 H, vinyl proton).

Anal. Calcd for $C_8H_{15}IO_2S$: C, 31.80; H, 5.00; I, 42.00; S, 10.61; mol wt, 302.18. Found: C, 32.00; H, 5.07; I, 41.80; S, 10.40; mol wt, 299.4.

Distillation of the filtrate provided a reddish material[38] in the forerun, bp 37–38° (0.25 mm), and then 24.33 g of the Z and E isomers, bp 109–117.5° (0.2 mm). Pure (*E*)-**34** was obtained by adsorption chromatography using a silica gel column with benzene–diethyl ether as the eluent. Recrystallization from petroleum ether gave white platelets: mp 44.5–45.5°; NMR ($CDCl_3$) δ 1.40 (t, 3 H, J = 7.4 Hz, $CH_3CH_2SO_2-$), 1.47 [s, 9 H, $-C(CH_3)_3$], 3.11 (q, 2 H, J = 7.4 Hz, $CH_3CH_2SO_2-$), 7.14 (s, 1 H, vinyl proton).

Anal. Calcd for $C_8H_{15}IO_2S$: C, 31.80; H, 5.00; I, 42.00; S, 10.61. Found: C, 31.60; H, 5.04; I, 42.28; S, 10.49.

The combined yield of (*Z*)- and (*E*)-**34** was 38.74 g (53.4%).

General Procedure for the Dehydroiodination of Vinyl Iodides to Acetylenes.[33] A warm (50–60°) methanol solution of the vinyl iodide was treated with an equivalent amount of aqueous potassium carbonate and stirred for 0.75–1.5 hr. Water was then added to the cooled solution inducing crystallization if the acetylene was a solid. The liquid acetylenes were extracted into diethyl ether, dried with $MgSO_4$, and distilled.

***p*-Tolylsulfonylphenylacetylene (35).** **32** (25.85 g, 0.067 mol) in 250 ml of methanol and potassium carbonate (9.25 g, 0.067 mol) in 40 ml of water gave 13.03 g (76%) of **35** after recrystallization from ethanol–water: mp 84–85.5° (lit.[39] mp 80–81°); NMR ($CDCl_3$) δ 2.43 (s, 3 H, aromatic CH_3), 7.13–7.97 (m, 9 H, aromatic ring protons).

1-Ethylsulfonyl-3-methyl-1-butyne (36). To **33** (23.11 g, 0.80 mol) in 150 ml of methanol was added K_2CO_3 (11.04 g, 0.08 mol) in 75 ml of water. Work-up and distillation afforded 11.32 g, bp 78–82° (0.25 mm); however, a carbonyl[40] band at 1733 cm^{-1} was noted in the infrared spectrum as a minor impurity. After a 10% NaOH wash, which removed the impurity, the material was redistilled, giving 6.6 g (52%) of **36:** bp 86–88° (0.5 mm); NMR ($CDCl_3$) δ 1.26 [d, 6 H, J = 6.3 Hz, $-CH(CH_3)_2$], 1.44 (t, 3 H, J = 7.4 Hz, $CH_3CH_2SO_2-$), 2.80 [septet, 1 H, J = 6.3 Hz, $-CH(CH_3)_2$], 3.18 (q, 2 H, J = 7.4 Hz, $CH_3CH_2SO_2-$).

Anal. Calcd for $C_7H_{12}O_2S$: C, 52.47; H, 7.55; S, 20.01; mol wt, 160.237. Found: C, 52.72; H, 7.48; S, 20.22 mol wt, 160.4.

1-Ethylsulfonyl-3,3-dimethyl-1-butyne (37). To 52% (*E*)-: 48% (*Z*)-**34** (30.2 g, 0.1 mol) in 250 ml of methanol was added K_2CO_3 (13.8 g, 0.1 mol) in 100 ml of water. Work-up and distillation provided 14.37 g (82.6%) of **37:** bp 78–86° (0.38 mm); NMR ($CDCl_3$) δ 1.31 [s, 9 H, $-C(CH_3)_3$], 1.44 (t, 3 H, J , 7.4 Hz, $CH_3CH_2SO_2-$), 3.18 (q, 2 H, J = 7.4 Hz, $CH_3CH_2SO_2-$).

Anal. Calcd for $C_8H_{14}O_2S$: C, 55.14; H, 8.10; S, 18.40; mol wt, 174.266. Found: C, 55.25; H, 8.26; S, 18.55; mol wt, 170.

General Procedure for the Addition of Aziridine to Sulfonyl Acetylenes. For most of the addition reactions 1 molar equiv of aziridine was added by means of a syringe directly into a magnetically stirred solution of the sulfonyl acetylene. After the specified length of stirring time, the solvent was removed in vacuo at room temperature with the resulting residue taken up in $CDCl_3$ or CCl_4 for NMR analysis. The ratio of Z and E isomers reported here is that of the crude reaction mixture before any purification. The yield of the crude material was essentially quantitative by NMR, except where noted. Pertinent chemical shifts are given in Tables IV and VII.

1-Methylsulfonyl-2-aziridino-1-propene (38). Runs 1 and 2. To **19** (0.51 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol). After stirring for 4 hr at 23–25°, solvent was removed at room temperature and NMR analysis in CCl_4 showed 7% (*Z*)- and 93% (*E*)-**38.** Distillation[41] of combined runs 1 and 2 gave 0.74 g (53.6%) of (*Z*)-**38** (8%), (*E*)-**38** (86%), and $CH_3SO_2CH_2C(Az)=CH_2$ (6%; Az = aziridinyl), bp 110–114.5° (0.35 mm).

Run 3. To aziridine (0.36 g, 0.0086 mol) in 10 ml of benzene was added **19** (0.51 g, 0.0043 mol) in 10 ml of benzene, followed by stirring for 2 hr at 24–26°. Tripropylamine (0.3 g) was added and the solvent removed in vacuo. NMR analysis showed 94% (*Z*)- and 6% (*E*)-**38** (Table III).

1-Ethylsulfonyl-2-aziridino-1-propene (39).[4] **Run 1.** To **20** (0.57 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol) followed by stirring for 4 hr at 23–24°. Solvent evaporation and NMR analysis gave 95% (*Z*)- and 5% (*E*)-**39.**

Run 2. To **20** (0.57 g, 0.0043 mol) in 20 ml of dimethyl sulfoxide was added aziridine (0.18 g, 0.0043 mol), and the solution was stirred for 4 hr at 22–23°. Solvent removal under vacuum (0.23 mm) and up to 52° bath temperature gave a residue, which contained 74% (*Z*)- and 22% (*E*)-**39** as well as 4% of the nonconjugated isomer, $CH_3CH_2SO_2CH_2C(Az)=CH_2$.

1-(2-Propylsulfonyl)-2-aziridino-1-propene (40). Run 1. To **21** (0.63 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol) and the solution was stirred for 4 hr at 23–25°. Solvent removal and NMR analysis of the residue showed 4% **21** and 91% (*Z*)- and 9% (*E*)-**40** (Table III).

Run 2. To **21** (1.26 g, 0.0086 mol) in 40 ml of benzene was added aziridine (0.36 g, 0.0086 mol) and the solution was stirred for 6 hr at 29–31°. Tripropylamine (0.3 g) was added and then the solvent removed in vacuo and the residue analyzed in $CDCl_3$ [89% (*Z*)- and 11% (*E*)-**40**]. Distillation[41] provided 1.10 g (67.9%) of (*Z*)-**40** (81%), (*E*)-**40** (16%), and $(CH_3)_2CHSO_2CH_2C(Az)=CH_2$ (3%), bp 117° (0.4 mm).

1-(2-Methyl-2-propylsulfonyl)-2-aziridino-1-propene (41). A solution of **22** (0.69 g, 0.0043 mol) in 20 ml of benzene and aziridine (0.18 g, 0.0043 mol) was stirred for 4 hr at 23–25°. Solvent removal and NMR analysis of the residue showed 10% of **22** and 96% (*Z*)- and 4% (*E*)-**41** (Table III).

1-Cyclopentylsulfonyl-2-aziridino-1-propene (42). Runs 1 and 2. To **23** (0.74 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol). The solution was stirred for 4 hr. The

residue after solvent removal showed 55% (*Z*)- and 45% (*E*)-**42** (Table II).

Run 6. Under conditions identical with those of runs 1 and 2, except that tripropylamine (0.3 g) was added before solvent removal, 89% (*Z*)- and 11% (*E*)-**42** were obtained. Distillation[41] provided 0.36 g (38%) of (*Z*)-**42** (50%), (*E*)-**42** (40%), and c-C_5H_9-$SO_2CH_2C(Az)=CH_2$ (10%), bp 144–146° (0.37 mm).

1-(3,5-Dimethylbenzylsulfonyl)-2-aziridino-1-propene (43). To **24** (0.95 g, 0.0043 mol) dissolved in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol). Stirring was carried out for 4 hr at 29–31°. NMR analysis showed 92% (*Z*)- and 8% (*E*)-**43.** Recrystallization from benzene–hexane gave 0.57 g of white needles, mp 107.5–110.5° [95% (*Z*)-**43**], while another 0.24 g of solid was obtained from the mother liquor, total yield 0.81 g (72%).

Anal. Calcd for $C_{14}H_{19}NO_2S$: C, 63.36; H, 7.22; N, 5.28; S, 12.08; mol wt, 265.37. Found: C, 63.23; H, 7.32, N, 5.38; S, 12.00; mol wt, 266.1.

1-(2-Phenylethylsulfonyl)-2-aziridino-1-propene (44).[2] To **25** (0.89 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol). The solution was stirred for 4.3 hr at 27–31°. Solvent evaporation and NMR analysis of the residue showed 84% (*Z*)- and 16% (*E*)-**44** (Table III).

1-(3-Phenylpropylsulfonyl)-2-aziridino-1-propene (45). To **26** (0.95 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol). Stirring for 4 hr at 23–26° and solvent removal left 1.28 g of crude oil,[42] which showed 87% (*Z*)- and 13% (*E*)-**45** as well as some benzene solvent (Table IV).

1-(*p*-Tolylsulfonyl)-2-aziridino-1-propene (46).[2] To **27** (0.83 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol). After stirring for 4 hr at 24–25°, analysis of the whole residue in $CDCl_3$ showed 87% (*Z*)- and 13% (*E*)-**46.**

1-Phenylsulfonyl-2-aziridino-1-propene (47). To **28** (1.2 g, 0.0067 mol) in 24 ml of benzene was added aziridine (0.29 g, 0.0067 mol) followed by stirring for 4 hr at room temperature. Solvent removal left 1.53 g of white solid, mp 83–89° [81% (*Z*)- and 19% (*E*)-**47**]. Recrystallization from benzene–hexane gave 0.94 g (63%) of 95% (*Z*)-**47,** mp 92.5–94°.

1-Aziridino-1-phenyl-2-(*p*-tolylsulfonyl)ethene (48). To **35** (1.1 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol) followed by stirring for 4 hr at room temperature. NMR analysis of the crude residue showed 85% (*Z*)- and 15% (*E*)-**48.** Recrystallization (benzene–hexane) gave 0.97 g (76%) of **48,** mp 87–100.5°. Successive recrystallizations provided pure (*Z*)-**48,** mp 101.5–103.5°.

Anal. Calcd for $C_{17}H_{17}NO_2S$: C, 68.20; H, 5.72; N, 4.68; S, 10.71; mol wt, 299.4. Found: C, 67.98; H, 5.63; N, 4.70; S, 10.48; mol wt, 302.7.

1-Ethylsulfonyl-2-aziridino-3-methyl-1-butene (49). To **36** (0.69 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol). Stirring was continued for 6 hr at 26–27°. NMR analysis of the residual oil (0.88 g) in CCl_4 showed 75% (*Z*)- and 25% (*E*)-**49** (Table V).

1-(*p*-Tolylsulfonyl)-2-aziridino-3-methyl-1-butene (50). To 1-(*p*-tolylsulfonyl)-3-methyl-1-butyne (0.4 g, 0.0018 mol) in 6.5 ml of benzene was added aziridine (0.07 g, 0.0018 mol); the solution was stirred for 4 hr at room temperature. Solvent evaporation provided 0.47 g (100%) of (*Z*)-**50** (73%) and (*E*)-**50** (27%), mp 88.5–94° (Table VI).

1-Ethylsulfonyl-2-aziridino-3,3-dimethyl-1-butene (51). To **37** (0.75 g, 0.0043 mol) in 20 ml of benzene was added aziridine (0.18 g, 0.0043 mol) followed by stirring for 28 hr at 29–32°. Solvent removal and NMR analysis indicated that 58% of the starting sulfonyl acetylene, **37,** remained unreacted, but also that product formation had occurred giving 75% (*Z*)- and 25% (*E*)-**51** (Table V).

1-(*p*-Tolylsulfonyl-2-aziridino-3,3-dimethyl-1-butene (52). To 1-(*p*-tolylsulfonyl)-3,3-dimethyl-1-butyne (1.01 g, 0.0043 mol) in 15.6 ml of benzene was added aziridine (0.18 g, 0.0043 mol); the solution was stirred for 4 hr at room temperature. Solvent removal and NMR analysis of the residue showed 17% completion of the reaction with a ratio of 67% (*Z*)- and 33% (*E*)-**52.** This residue was again dissolved in benzene, treated with more aziridine (0.18 g), and stirred for an additional 24 hr. Work-up and analysis indicated 62% completion with a ratio of 68% (*Z*)- and 32% (*E*)-**52.** Successive treatment with aziridine over a total of 191 hr brought the reaction to 92% completion with some postisomerization being noted at 124 hr. Final isomer ratio was 91% (*Z*)- and 9% (*E*)-**52.** Recrystallization from benzene–hexane gave pure (*Z*)-**52,** mp 109.5–111.5°.

Anal. Calcd for $C_{15}H_{21}NO_2S$: C, 64.48; H, 7.58; N, 5.01; S, 11.48; mol wt, 279.46. Found: C, 64.28; H, 7.50; N, 5.02; S, 11.66; mol wt, 282.

Equilibration of Sulfonylaziridinopropenes to the Thermodynamic Mixture. The propenyl adducts are isomerized to the thermodynamic equilibrium mixture with potassium hydroxide in tetrahydrofuran.[2]

Isomerization of 43. To **43** (0.55 g, 0.0025 mol, 95% *Z* and 5% *E*) in 50 ml of THF was added 85% KOH pellets (1.65 g, 0.025 mol); the mixture was stirred for 65 hr at room temperature. Solvent evaporation after filtration left 0.59 g of oil, which analyzed as 5% (*Z*)-**43,** 90% (*E*)-**43,** and 5% of the nonconjugated isomer, Ar-$CH_2SO_2CH_2C(Az)=CH_2$. Crystallization occurred upon the addition of petroleum ether, giving 0.33 g, mp 91–92.5° [pure (*E*)-**43**]. A second crop of 0.16 g gave a total yield of 89.1%.

Isomerization of 45. To **45** (2.09 g, 0.0079 mol, 39% *Z* and 61% *E*) in 50 ml of THF was added 85% KOH pellets (5.20 g, 0.079 mol); the mixture was stirred for 71 hr at room temperature. Filtration of the solid and solvent removal provided 1.42 g (68%) of orange oil, which analyzed as 4% (*Z*)-**45,** 87% (*E*)-**45,** and 9% of the nonconjugated isomer, $C_6H_5CH_2CH_2CH_2SO_2CH_2C(Az)=CH_2$.

Registry No.—**1,** 27129-86-8; **2,** 38360-81-5; **3,** 26842-65-9; **4,** 14272-25-4; **5,** 17277-57-5; **6,** 56480-82-1; **7,** 56480-83-2; **8,** 25558-00-3; **9,** 56480-84-3; **10,** 22174-51-2; **11,** 56480-85-4; **12,** 1595-36-4; **13,** 56480-86-5; **14,** 56480-87-6; **15,** 25558-02-5; **16,** 56480-88-7; **17,** 6212-77-7; **18,** 13597-15-4; **19,** 56480-89-8; **20,** 13596-73-1; **21,** 56480-90-1; **22,** 56480-91-2; **23,** 56480-92-3; **24,** 56480-93-4; **25,** 25558-04-7; **26,** 56480-94-5; **27,** 14027-53-3; **28,** 2525-41-9; **29,** 20035-08-9; **30,** 1950-78-3; **31,** 42790-83-0; **32,** 56480-95-6; **33,** 56480-96-7; (*Z*)-**34,** 56480-97-8; (*E*)-**34,** 56480-98-9; **35,** 28995-88-2; **36,** 56480-99-0; **37,** 52323-96-3; (*Z*)-**38,** 56481-00-6; (*E*)-**38,** 56481-01-7; (*Z*)-**39,** 13894-50-3; (*E*)-**39,** 13894-33-2; (*Z*)-**40,** 56481-02-8; (*E*)-**40,** 56481-03-9; **40** nonconjugated isomer, 56481-04-0; (*Z*)-**41,** 56481-05-1; (*E*)-**41,** 56481-06-2; (*Z*)-**42,** 56481-07-3; (*E*)-**42,** 56481-08-4; **42** nonconjugated isomer, 56481-09-5; (*Z*)-**43,** 56481-10-8; (*E*)-**43,** 56481-11-9; (*Z*)-**44,** 25558-49-0; (*E*)-**44,** 25558-44-5; (*Z*)-**45,** 56481-12-0; (*E*)-**45,** 56481-13-1; (*Z*)-**46,** 25558-47-8; (*E*)-**46,** 25558-42-3; (*Z*)-**47,** 56481-14-2; (*E*)-**47,** 56481-15-3; (*Z*)-**48,** 56481-16-4; (*E*)-**48,** 56481-17-5; (*Z*)-**49,** 56481-18-6; (*E*)-**49,** 56481-19-7; (*Z*)-**50,** 56481-20-0; (*E*)-**50,** 56481-21-1; (*Z*)-**51,** 56481-22-2; (*E*)-**51,** 56481-23-3; (*Z*)-**52,** 56481-24-4; (*E*)-**52,** 56481-25-5; propargyl bromide, 106-96-7; sodium methanethiolate, 5188-07-8; sodium 2-propanethiolate, 20607-43-6; sodium 2-methyl-2-propanethiolate, 29364-29-2; sodium cyclopentanethiolate, 56481-26-6; sodium 3,5-dimethylphenylmethanethiolate, 56481-27-7; sodium 2-phenylethanethiolate, 13423-07-9; sodium 3-phenylpropanethiolate, 56481-28-8; (*Z*)-1,2-bis(ethylthio)ethene,14044-67-8; ethanesulfonyl chloride, 594-44-5; sodium sulfite, 10579-83-6; sodium *p*-toluenesulfinate, 824-79-3; iodine, 7553-56-2; phenylacetylene, 536-74-3; 3-methyl-1-butyne, 598-23-2; 3,3-dimethyl-1-butyne, 917-92-0; aziridine, 151-56-4; 1-(*p*-tolylsulfonyl)-3-methyl-1-butyne, 28995-91-7; 1-(*p*-tolylsulfonyl)-3,3-dimethyl-1-butyne, 28995-90-6.

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Stereochemistry of β-Lactams Derived from α-Keto-γ-lactams by Ring Contraction. X-Ray Analysis and Differential Behavior with Shift Reagents of Difunctional β-Lactams

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The configurations of the α,α-disubstituted β-lactams **2**, **3**, and **4** were determined by X-ray analysis, and the results are used to explain the stereochemistry of β-lactams derived from α-keto-γ-lactams by oxidative ring contraction with periodate. The X-ray data provide indirect support for the proposed correlation of biological activity with the pyramidal nature of bonding to the β-lactam nitrogen. The behavior of the esters **7** and **8** toward the lanthanide shift reagents $Eu(dpm)_3$ and $Eu(fod)_3$ in both CCl_4 and $CDCl_3$ was also examined. Different results arose depending upon both ligand (dpm or fod) and solvent, and the differences are explained by invoking for $Eu(fod)_3$ a 2:2 bridged complex in CCl_4 and a mixture of bridged complex and 1:1 chelated complex in $CDCl_3$. In addition, $Eu(fod)_3$ was shown to be unstable to the carboxylic acids **1–4**, indicating a limitation on its utility for the characterization of carboxylic acids. Perturbation of conformational equilibria by coordination to shift reagents is illustrated.

The formation of β-lactams from α-keto-γ-lactams by oxidative ring contraction with periodate[1] can lead to two orientations for the new carboxyl group at the α carbon of the β-lactam. The mechanism of this rearrangement reaction has been investigated using 1-methyl-2,3-piperidinedione as the prototype,[2] and the proposed mechanism is illustrated in Scheme I for β-substituted α-keto-γ-lactams. It was anticipated that stereochemistry would be governed by the relative size of substituents in an orientation-determining stage approximated by structures **11** or **12**. Consistent with this view, only the trans isomer **1** was obtained when X = H.[1] When X = methyl, again only one isomer, **2**, was produced; however both isomers, **3** and **4**, occurred when X = bromine,[1] and this provided the possibility of defining the requirements for generating the isomer with the carboxyl group oriented cis (β) to the fused ring. Accordingly, we undertook the determination of the stereochemistry of β-lactams **2**, **3**, and **4** by X-ray crystallographic analysis, and we now report the results of these studies along with their mechanistic implications.

It was also anticipated that use of a lanthanide shift reagent (LSR) could lead to definition of relative stereochemistry. The shift reagent $Eu(dpm)_3$ (dpm = dipivaloylmethanato) differentiated between the bromo isomers, and the limitations on its use for determining stereochemistry are discussed. On the other hand, use of $Eu(fod)_3$ (fod = 1,1,1,2,2,3,3-heptafluoro-7,7-dimethyl-4,6-octanedionato) led to essentially no differentiation. The results of the use of both reagents in CCl_4 and $CDCl_3$ are discussed in terms of composition of LSR–substrate complexes.

In addition, perturbation of conformational equilibria by coordination to shift reagents is illustrated, and limitations on the use of chelate shift reagents with carboxylic acids are discussed.

Results and Discussion

Previously the syntheses of compounds **9** (X = H) and **10** (X = CH_3 and Br) were described along with their reaction with periodate to form the β-lactams **13**.[1] For X = H and CH_3 only one isomer was formed, but for X = Br both iso-