Cycloaddition Reactions of *N*-Sulfinylsulfonamides with Ketenimines

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N-Sulfinylsulfonamides, **1a, b**, reacted with ketenimines, **2**, in ether to give the unstable [2+2] cycloadducts, 3-ylidene-1,2,4-thiadiazetidin-1-oxides, **3**, which were then readily hydrolyzed to the *N,N'*-disubstituted amidine derivative, **4**, in good yields. The reaction of *N*-sulfinylmethanesulfonamide (**1b**) with diphenylketen-*N*-*p*-tolylimine (**2d**) at 130 °C gave the exchange product, *N*-sulfinyl-*p*-toluidine (**5**) in a 70% yield *via* the intermediate cycloadduct. In contrast to **2d**, the reaction of *N*-sulfinyl-*p*-toluenesulfonamide (**1a**) and phenylethylketen-*N*-phenylimine (**2f**), under the same conditions, led to the formation of a mixture of *N*-phenyl-*N'*-*p*-toluenesulfonyl-2-phenyl-*trans*- (**6a**) and *cis*-2-butenoamidine (**6b**) in an 81% yield.

We previously demonstrated that *N*-sulfinylamines react with heterocumulenes, such as isocyanate and isothiocyanate, to give exchange products *via* the intermediate [2+2] cycloadducts.[1,2]

However, recently we reported that, in contrast to the above heterocumulenes, carbodiimides afford the unstable [2+2] cycloadducts in reactions with *N*-sulfinylsulfonamides.[3] In the course of such studies of the chemical reactivities of *N*-sulfinylamines, we have observed that the reactions with ketenimines similarly yield the corresponding unstable cycloadducts. We wish to report here on the structures of the cycloadducts and their reactivities.

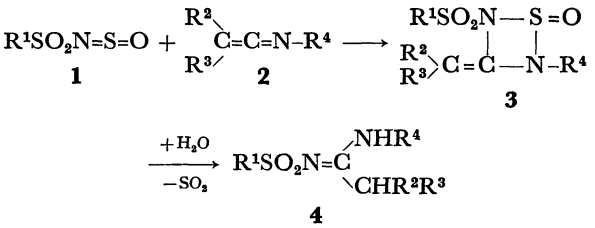
Results and Discussion

N-Sulfinyl-*p*-toluenesulfonamide (**1a**) was allowed to react with dimethylketen-*N*-phenylimine (**2a**) at the ambient temperature in ether to give, smoothly, a 1:1 cycloadduct, **3a**, which was precipitated on standing in a 79% yield. The infrared spectrum exhibits the characteristic absorption bands for the C=C group and the S=O group at 1580 and 1090 cm^{-1} respectively. The mass spectrum shows the molecular ion at *m/e* 362 and the fragment ions at 223 and 139 due to ($Me_2C{=}C{=}NTs^+$) and ($PhNSO^+$). The NMR spectrum ($CDCl_3$) indicates two singlet isopropylidene methyl (6H), *p*-methyl (3H), and phenyl protons (9H) at 1.94 and 2.00, 2.40, and 7.20—7.96 ppm respectively. Thus, the structure of **3a** was identified as 2-*p*-toluenesulfonyl-3-isopropylidene-4-phenyl-1,2,4-thiadiazetidin 1-oxide. Furthermore, this structure was confirmed by the hydrolysis of **3a** to *N*-phenyl-*N'*-*p*-toluenesulfonyl-isobutyramidine (**4a**) in a good yield.

The reaction of *N*-sulfinylmethanesulfonamide (**1b**) with **2a** similarly afforded the [2+2] cycloadduct **3b** in an 85% yield.

However, in the reactions of **1a** (or **1b**) with other ketenimines, **2b—e**, the expected cycloadducts, **3**, could not be isolated in pure forms since they are unstable and are readily hydrolyzed to the corresponding amidines, **4b—e**. The physical and analytical data and the yields of the cycloadducts and the amidines obtained above are shown in Table 1.

No 1:2-cycloadduct was obtained in any of the above reactions nor in the reactions between *N*-sulfinylsulfonamides and carbodiimides,[3] although the 1:2-cycloadducts are well known to be formed in the reactions of



1a, R^1=*p*-MeC_6H_4 **3a**, R^1=*p*-MeC_6H_4, R^2=R^3=Me, R^4=Ph
1b, R^1=Me **3b**, R^1=R^2=R^3=Me, R^4=Ph
2a, R^2=R^3=Me, R^4=Ph **4a**, R^1=*p*-MeC_6H_4, R^2=R^3=Me, R^4=Ph
2b, R^2=R^3=Me, R^4=*p*-MeC_6H_4 **4b**, R^1=*p*-MeC_6H_4, R^2=R^3=Me, R^4=*p*-MeC_6H_4
2c, R^2=R^3=Me, R^4=C_6H_{11} **4c**, R^1=*p*-MeC_6H_4, R^2=R^3=Me, R^4=C_6H_{11}
2d, R^2=R^3=Ph, R^4=*p*-MeC_6H_4 **4d**, R^1=R^4=*p*-MeC_6H_4, R^2=R^3=Ph
2e, R^2=H, R^3=Ph, R^4=C_6H_{11} **4e**, R^1=Me, R^2=H, R^3=Ph, R^4=C_6H_{11}

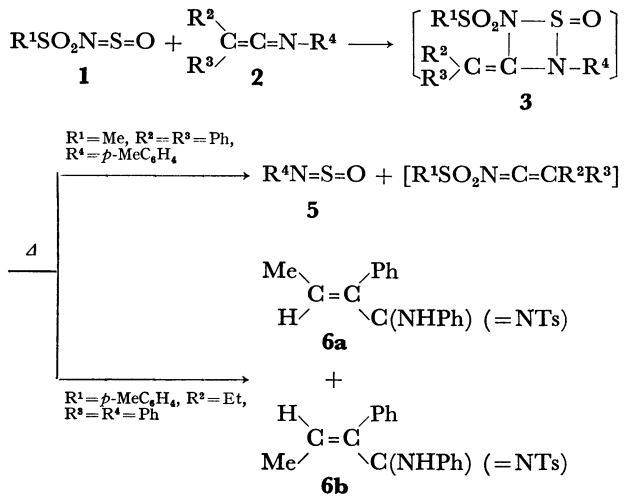
Scheme 1.

TABLE 1. 3-YLIDENE-1,2,4-THIADIAZETIDIN 1-OXIDES **3** AND AMIDINES **4** FROM *N*-SULFINYLSULFONAMIDES **1** AND KETENIMINES **2**

3 or 4	Substituents				Yield %	Mp °C	Formula	Calcd %			Found %		
	R^1	R^2	R^3	R^4				C	H	N	C	H	N
3a	*p*-MeC_6H_4	Me	Me	Ph	79	117	$C_{17}H_{18}N_2O_3S_2$	56.35	5.01	7.73	56.07	5.23	7.88
3b	Me	Me	Me	Ph	85	125	$C_{11}H_{14}N_2O_3S_2$	46.15	4.93	9.79	46.31	4.84	9.86
4a	*p*-MeC_6H_4	Me	Me	Ph	78	84	$C_{17}H_{20}N_2O_2S$	64.54	6.37	8.86	64.21	6.47	8.72
4b	*p*-MeC_6H_4	Me	Me	*p*-MeC_6H_4	78	128	$C_{18}H_{22}N_2O_2S$	65.44	6.71	8.48	65.52	6.77	8.40
4c	*p*-MeC_6H_4	Me	Me	C_6H_{11}	58	127	$C_{17}H_{26}N_2O_2S$	63.33	8.13	8.69	63.23	8.24	8.56
4d	*p*-MeC_6H_4	Ph	Ph	*p*-MeC_6H_4	85	168	$C_{28}H_{26}N_2O_2S$	73.99	5.77	6.16	74.01	5.73	6.19
4e	Me	H	Ph	C_6H_{11}	77	187	$C_{15}H_{22}N_2O_2S$	61.20	7.53	9.52	61.13	7.61	9.66

carbodiimides with isocyanates.[4] Therefore, in contrast to the reactions between carbodiimides and isocyanates, the cycloaddition reactions of *N*-sulfinylsulfonamides with heterocumulenes can be said probably to proceed *via* a concerted mechanism rather than *via* a step-by-step mechanism, although further kinetic evidence is necessary for the establishment of the mechanism.

A reaction using *N*-sulfinylarylamines or *N*-sulfinylalkylamines in place of reactive *N*-sulfinylsulfonamides afforded no cycloadduct.



Scheme 2.

On the other hand, the reaction of **1b** with diphenylketen-*N*-*p*-tolylimine (**2d**) at 130 °C for 1 hr under reduced pressure gave *N*-sulfinyl-*p*-toluidine (**5**) as a volatile liquid, which is an exchange product *via* the intermediate cycloadduct, in a 70% yield along with the residual polymeric product. However, the similar treatment of a mixture of **1a** and phenylethylketen-*N*-phenylimine (**2f**) containing hydrogen on the α carbon resulted in the formation of a mixture of *N*-phenyl-*N'*-*p*-toluenesulfonyl-2-phenyl-*trans*- (**6a**) and *cis*-2-butenoamidine (**6b**), the ratio of which was found by NMR to be approximately 5: 3, in an 81% yield. Their formations could be explained in terms of the elimination of sulfur monoxide from the [2+2] cycloadduct, **3**, which would be initially yielded from **1a** and **2f**, followed by a proton shift on the delocalized anionic nitrogen moiety. Such thermal decomposition is of interest since similar results have not been observed in the reactions of *N*-sulfinylamines with other heterocumulenes.

Experimental

All the melting points were determined with a Yanagimoto micro melting apparatus and are uncorrected. The NMR spectra were obtained on a JEOL LMM 3H-60 spectrometer, with tetramethylsilane as the internal standard. The IR spectra were recorded with a Jasco IR-E spectrometer. The mass spectra were taken with a Hitachi RMU-6E spectrometer.

Materials. The *N*-sulfinyl-*p*-toluenesulfonamide,[5] *N*-sulfinylmethanesulfonamide,[5] dimethylketen-*N*-phenyl-,[6] -*N*-*p*-tolyl-,[6] and -*N*-cyclohexyl-,[6] phenyl-*N*-cyclohexyl-,[6] and diphenyl-*N*-*p*-tolylketenimines[7] were prepared according to the established procedures.

2-p-Toluenesulfonyl-3-isopropylidene-4-phenyl-1,2,4-thiadiazetidin 1-Oxide (3a). Dimethylketen-*N*-phenylimine (**2a**, 1.02 g, 7 mmol) in 20 ml of dry ether was added, drop by drop, into a solution of 1.52 g (7 mmol) of *N*-sulfinyl-*p*-toluenesulfonamide (**1a**) in 30 ml of dry ether. After being stirred at the ambient temperature for 1 hr, the solution was allowed to stand overnight to give 2.0 g (79%) of a white solid, **3a**. Recrystallization from hexane–benzene afforded the analytical sample; mp 117—119 °C; IR (Nujol) ν 1600, 1580 (C=C), 1300 (SO_2), 1155 (SO_2), and 1090 cm^{-1} (SO); NMR ($CDCl_3$) δ 1.94 (s, 3H, $\underline{Me}>C=C<$), 2.00 (s, 3H, $\underline{Me}>C=C<$), 2.40 (s, 3H, $\underline{Me}Ar$), and 7.20—7.96 (m, 9H, phenyl protons); mass spectrum (70 eV) *m/e* 362 (M^+), 314 (M^+-SO), 223 (Me_2CCNTs^+), 145 (Me_2CCNPh^+), and 139 ($PhNSO^+$).

2-Methanesulfonyl-3-isopropylidene-4-phenyl-1,2,4-thiadiazetidin 1-Oxide (3b). This substance was prepared in the same way as **3a** by the reaction of **2a** (1.45 g, 0.01 mol) with *N*-sulfinylmethanesulfonamide (**1b**, 1.41 g, 0.01 mol). After the removal of the solvent, the resulting residue was recrystallized from hexane–benzene to give 2.45 g, (85%) of pure **3b**; mp 125—126 °C; IR (Nujol) ν 1600 (C=C), 1290 (SO_2), 1160 (SO_2), and 1130 cm^{-1} (SO); NMR ($CDCl_3$) δ 1.90 (s, 3H, $\underline{Me}>C=C<$), 1.95 (s, 3H, $\underline{Me}>C=C<$), 3.10 (s, 3H, $\underline{Me}SO_2$), and 7.25—7.75 (m, 5H, phenyl protons); mass spectrum (70 eV) *m/e* 286 (M^+), 238 (M^+-SO), 159 (M^+-MeSO_2), and 147 ($Me_2CCNSO_2Me^+$).

Base Catalyzed Hydrolysis of 3a. A solution of **3a** (1.09 g, 3 mmol) in 95% ethanol (20 ml) containing sodium hydroxide (0.12 g, 3 mmol) was refluxed for 1 hr. After the removal of the solvent, the residue was washed with water and then dried. The white solid thus obtained was recrystallized from ethanol to give pure *N*-phenyl-*N'*-*p*-toluenesulfonylisobutyramidine (**4a**, 0.74 g, 78%); mp 84—86 °C; IR (Nujol) ν 3240 (NH), 1560 (C=N), 1525 (NH), 1250 (SO_2), and 1135 cm^{-1} (SO_2); NMR ($CDCl_3$) δ 0.85—1.35 (m, 6H, methyl protons), 2.40 (s, 3H, $\underline{Me}Ar$), 3.60 (q, J=7 Hz, 1H, methine proton), 6.95—7.95 (m, 9H, phenyl protons), and 9.50—10.10 (broad, 1H, NH); mass spectrum (70 eV) *m/e* 316 (M^+), 247 ($TsNHPh^+$), and 224 (M^+-PhNH).

Reactions of N-Sulfinylsulfonamides, 1a—b, with Ketenimines, 2b—e. These reactions were carried out in a similar manner. After similar treatments, the cycloadducts corresponding to **3a** (or **3b**) could not be isolated in pure forms because of their easy hydrolysis. Therefore, the reaction products were chromatographed on alumina to give the amidine derivatives, **4b—e**, which are hydrolysis products, in good yields, as is shown in Table 1. The amidines, **4b—e**, had the following physical properties:

N-p-*Tolyl*-N'-p-*toluenesulfonyl-isobutyramidine (4b)*: IR (Nujol) ν 3280 (NH), 1560 (C=N), 1525 (NH), 1250 (SO_2), and 1135 cm^{-1} (SO_2); NMR ($CDCl_3$) δ 0.85—1.35 (broad d, 6H, methyl protons), 2.34 (s, 3H, $\underline{Me}Ar$), 2.40—2.90 (m, 4H, $\underline{Me}Ar$ and methine proton), 6.90—7.95 (m, 8H, phenyl protons), and 9.10—9.40 (broad, 1H, NH); mass spectrum (70 eV) *m/e* 330 (M^+), and 261 ($TsNHC_6H_4Me^+$).

N-*Cyclohexyl*-N'-p-*toluenesulfonyl-isobutyramidine (4c)*: IR (Nujol) ν 3290 (NH), 1570 (C=N), 1530 (NH), 1260 (SO_2), and 1130 cm^{-1} (SO_2); NMR ($CDCl_3$) δ 1.0—2.05 (m, 16H, two methyl and cyclohexyl protons), 2.40 (s, 3H, $\underline{Me}Ar$), 2.50—2.90 (m, 1H, methine proton), 3.50—3.90 (m, 1H, methine proton), 5.50—5.90 (broad, 1H, NH), and 7.05—7.85 (dd, 4H, phenyl protons); mass spectrum (70 eV) *m/e* 322 (M^+) and 241 ($TsNHC_6H_9^+$).

N-p-*Tolyl*-N'-p-*toluenesulfonyldiphenylacetamidine (4d)*: IR

(Nujol) ν 3200 (NH), 1570 (C=N), 1510 (NH), 1270 (SO_2), and 1130 cm^{-1} (SO_2); NMR ($CDCl_3$) δ 2.35 (s, 6H, methyl protons), 5.03 (s, 1H, methine proton), 6.80—7.70 (m, 18H, phenyl protons), and 9.55—9.85 (broad, 1H, NH); mass spectrum (70 eV) *m/e* 454 (M^+).

N-*Cyclohexyl*-N′-*methanesulfonyl-phenylacetamidine (4e)*: IR (Nujol) ν 3220 (NH), 1555 (C=N), 1540 (NH), 1270 (SO_2), and 1140 cm^{-1} (SO_2); NMR (DMSO-d_6) δ 1.0—2.15 (m, 12H), 2.80 (s, 3H, methyl protons), 3.25—3.40 (broad, 1H, methine proton), 3.65—4.10 (broad, 1H, NH), and 7.40—8.05 (m, 5H, phenyl protons); mass spectrum (70 eV) *m/e* 294 (M^+).

Exchange Reaction between ***1b*** *and Diphenylketen*-N-p-*tolylimine (2d)*. To 0.71 g (5 mmol) of **1b** in 20 ml of ether, we added, drop by drop, 1.42 g (5 mmol) of **2d** in 10 ml of ether. After the subsequent evaporation of the solvent under reduced pressure, the vacuum distillation of the residue at 130 °C for 1 hr under reduced pressure (15 mmHg) yielded 0.54 g (70%) of *N*-sulfinyl-*p*-tolylamine (**5**), whose structure was determined by a comparison of its IR spectrum and glpc behavior with those of an authentic sample.[8] No identification of the residue was attempted.

N-*Phenyl*-N′-p-*toluenesulfonyl-2-phenyl-2-butenoamidine (6)*.

The reaction mixture of **1a** (2.17 g, 0.01 mol) with phenylethylketen-*N*-phenylimine (**2f**, 2.21 g, 0.01 mol) was similarly thermolyzed. The crude product was recrystallized from ethanol to give a mixture (3.13 g, 81%) of *N*-phenyl-*N′*-*p*-toluenesulfonyl-2-phenyl-*trans*- (**6a**) and *cis*-2-butenoamidine (**6b**), whose ratio was determined by means of its NMR spectrum. The attempted isolation of pure samples of individual **6a** and **6b** was unsuccessful. The analytical and physical data of the product are as follows.

Mp 185—187 °C; IR (Nujol) ν 3260 (NH), 1565, 1510, 1275 (SO_2), and 1180 cm^{-1} (SO_2); NMR ($CDCl_3$) δ 1.70 (d, J=6 Hz, 3H, $\underline{\text{Me}}\rangle C{=}C\langle^{Ph}$), 1.82 (d, J=6 Hz, 3H, $\underline{\text{Me}}\rangle C{=}C\langle^{Ph}$), 2.32 (s, 3H, $\underline{\text{Me}}$Ar), 2.44 (s, 3H, $\underline{\text{Me}}$Ar), 5.80—6.25 (m, J=6 Hz, 1H, $^{\underline{H}}_{Me}\rangle C{=}C\langle_{Ph}$ and $^{Me}_{\underline{H}}\rangle C{=}C\langle_{Ph}$), 6.75—8.0 (m, 14H, phenyl protons), and 10.0—10.25 (broad, 1H, NH); mass spectrum (70 eV) *m/e* 390 (M^+), 247 ($PhNHTs^+$) and 235 (M^+-Ts).

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