

Anal. Calcd for  $C_{10}H_{16}O_2S$ : C, 59.97; H, 8.05; S, 16.01. Found: C, 59.82; H, 8.04; S, 16.04.

Ester 6: IR (neat) 1725 (C=O)  $cm^{-1}$ ;  $^1H$  NMR ( $CDCl_3$ )  $\delta$  2.15 (s, 3 H, SMe), 0.78-3.08 (m, 10 H, ring H), 3.72 (s, 3 H, OMe).

Anal. Calcd for  $C_{10}H_{16}O_2S$ : C, 59.97; H, 8.05; S, 16.01. Found: C, 59.94; H, 8.04; S, 16.01.

**6-*exo*-(Methylthio)bicyclo[2.2.1]heptane-2-*endo*-carboxylic Acid (4a).** A sample of endo ester 4b (350 mg, 1.75 mmol) was dissolved in 0.42 M potassium hydroxide solution in 95% ethanol (20 mL, 8.4 mmol). The solution was stirred at room temperature for 24 h. At the end of this time the solvent was removed by rotary evaporation and the residue dissolved in water (5 mL). After extraction with ethyl ether, the aqueous phase was acidified with 3 M hydrochloric acid solution with ice-bath cooling. The mixture was filtered and the precipitate washed with cold water and dried to give a colorless solid, 243 mg, mp 124-126.5 °C. This solid was recrystallized from ethyl acetate-petroleum ether to afford pure endo acid 4a (201 mg, 62%): mp 127-130 °C; IR (KBr) 3600-2200 (OH), 1675 (C=O)  $cm^{-1}$ ;  $^1H$  NMR ( $CDCl_3$ )  $\delta$  2.12 (s, 3 H, SMe), 0.88-3.22 (m, 10 H, ring H), 10.15-10.75 (br s, 1 H, CO<sub>2</sub>H).

Anal. Calcd for  $C_9H_{14}O_2S$ : C, 58.03; H, 7.58; S, 17.21. Found: C, 58.11; H, 7.60; S, 17.15.

**Methyl 6-*exo*-(Methylthio)bicyclo[2.2.1]heptane-2-*exo*-carboxylate (5b).** A solution of sodium methoxide was prepared by cautiously adding sodium metal (124 mg, 5.40 mmol) to freshly dried, distilled methanol (5 mL). A solution of endo ester 4b (504 mg, 2.52 mmol) in dried, distilled methanol (6 mL) was added to the sodium methoxide solution. The solution was stirred and heated at reflux under a nitrogen atmosphere for 19 h. The solution was allowed to cool to room temperature and the solvent removed by rotary evaporation under vacuum. To the residue was added ice cold 3 M hydrochloric acid solution (2-3 mL) and the resulting mixture was twice extracted with ethyl ether. The combined extracts were washed successively with water and brine and dried over anhydrous sodium sulfate, the solvent was evaporated, and the residue was distilled from bulb to bulb under oil-pump vacuum at bath temperature of 115 °C. The colorless, mobile liquid (483 mg) so obtained was analyzed by GC and found to be a 27:73 mixture of 4b and 5b. There was no change in the composition of the material on an additional 15 h of exposure to sodium methoxide in methanol. Pure *exo* ester 5b was secured by preparative GC on a 0.25 in.  $\times$  5 ft Carbowax 20M on Chromosorb W (DMCS treated) column at 220 °C: IR (neat) 1725 (C=O)  $cm^{-1}$ ;  $^1H$  NMR ( $CDCl_3$ )  $\delta$  2.15 (s, 3 H, SMe), 0.7-3.0 (m, 10 H, ring H), 3.53 (s, 3 H, OMe).

Anal. Calcd for  $C_{10}H_{16}O_2S$ : C, 59.97; H, 8.05; S, 16.01. Found: C, 59.90; H, 8.07; S, 15.95.

**6-*exo*-(Methylthio)bicyclo[2.2.1]heptane-2-*exo*-carboxylic Acid (5a).** *Exo* ester 5b (109 mg, 0.545 mmol) was dissolved in a 0.420 M solution of potassium hydroxide in 95% ethanol (8 mL, 3.36 mmol). The solution was stirred at room temperature for 20 h. The solvent was then removed on a rotary evaporator. The residue was acidified with 3-4 mL of ice-cold 3 M hydrochloric acid solution and extracted with ethyl ether. The extracts were concentrated to a liquid which was distilled from bulb to bulb under oil-pump pressure at a bath temperature of 155 °C. A colorless viscous liquid (92.5 mg, 91%) was so obtained which was greater than 99% pure by GC analysis on a 0.25 in.  $\times$  5 ft 10% SE-30 on Chromosorb W (DMCS treated) column at 220 °C: IR ( $CHCl_3$ ) 3680-2340 (OH), 1690 (C=O)  $cm^{-1}$ ;  $^1H$  NMR ( $CDCl_3$ )  $\delta$  2.17 (s, 3 H, SMe), 0.57-2.9 (m, 10 H, ring H), 11.0-11.4 (br s, 1 H, CO<sub>2</sub>H).

Anal. Calcd for  $C_9H_{14}O_2S$ : C, 58.03; H, 7.58; S, 17.21. Found: C, 58.19; H, 7.12; S, 17.25.

**Acknowledgment.** We gratefully acknowledge support of this work by the U.S. Public Health Service, National Institutes of Health, Grant No. HL 15104.

**Registry No.** 1, 38347-95-4; 2a, 64887-93-0; 2a benzylamide, 74036-64-9; 2b, 64887-94-1; 2c, 64887-95-2; 2d, 74036-60-5; 2e, 64887-96-3; 2f, 74036-61-6; 3a, 64937-41-3; 3b, 64937-42-4; 3c, 64937-43-5; 3d, 74080-75-4; 3e, 64937-44-6; 3f, 74080-76-5; 4a, 74080-77-6; 4b, 74080-78-7; 5a, 74080-79-8; 5b, 74080-80-1; 6, 74036-62-7; methyl iodide, 74-88-4; 2-*endo*-bicyclo[2.2.1]heptane-carboxylic acid, 934-28-1; *endo*-6-(isopropylthio)bicyclo[2.2.1]heptane-2-*endo*-carboxylic acid, 74036-63-8; isopropyl bromide, 75-26-3; benzylamine, 100-46-9; methanethiol, 74-93-1; methyl bicyclo[2.2.1]hept-5-ene-2-*endo*-carboxylate, 2903-75-5.

**Supplementary Material Available:** Stereoscopic view of the packing of the molecules in the unit cell of endo acid 2a and endo acid 4a; tables of additional crystal data, final atomic positional and thermal parameters, bond length, bond angle, and selected torsion angle data for endo acid 2a and endo acid 4a; listings of structure factor amplitudes for endo acid 2a and endo acid 4a; table comparing molecular structure of endo acid 2a and endo acid 4a determined by X-ray crystallographic techniques with the geometry calculated by molecular-mechanics method (12 pages). Ordering information is given on any current masthead page.

## 1,3-Dipolar Cycloadditions of Diazoalkanes with Thiete 1,1-Dioxide

Pier G. De Benedetti,<sup>1a</sup> Carlo De Micheli,<sup>\*1b</sup> Remo Gandolfi,<sup>1c</sup> Pierluigi Gariboldi,<sup>1d</sup> and Augusto Rastelli<sup>\*1a</sup>

*Institute of Physical Chemistry, 41100-Modena, Italy, Institute of Pharmaceutical Chemistry, 42-Milano, Italy, Institute of Organic Chemistry, 10-Pavia, Italy, and Laboratory of Organic Chemistry, 50-Milano, Italy*

Received January 21, 1980

Cycloadditions of diazoalkanes with thiete 1,1-dioxide have been reinvestigated; diazomethane, diazoethane, phenyldiazomethane, and 2-diazopropane yielded similar amounts of two regioisomers, whereas the reaction of diphenyldiazomethane was regioselective and gave an adduct with regiochemistry opposite to that previously reported. Structures were assigned on the basis of  $^1H$  and  $^{13}C$  NMR spectra. The mass spectra of the adducts are also briefly discussed. Results are rationalized on the basis of a simple model of perturbation theory.

### Introduction

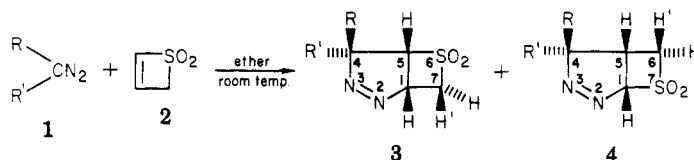
Thiete 1,1-dioxide (2) is a reactive compound and owing to its planar structure is a suitable substrate for studying endo-*exo* selectivity in reactions with dienes<sup>2</sup> and regio-

selectivity in reactions with 1,3-dipoles.<sup>3,4</sup> Nevertheless the 1,3-dipolarophilic reactivity of thiete 1,1-dioxide has been

(1) (a) Institute of Physical Chemistry. (b) Institute of Pharmaceutical Chemistry. (c) Institute of Organic Chemistry. (d) Laboratory of Organic Chemistry.

(2) Dittmer, D. C.; Christy, M. E. *J. Am. Chem. Soc.* **1962**, *84*, 399. Paquette, L. A.; Phillips, T. R. *J. Org. Chem.* **1965**, *30*, 3883. Dittmer, D. C.; Takashina, N. *Tetrahedron Lett.* **1964**, 3809. Martin, H. D.; Iden, R.; Schiwiek, H. J. *Tetrahedron Lett.* **1978**, 3337.

(3) Dalla Croce, P.; Del Buttero, P.; Maiorana, S.; Vistocco, R. *J. Heterocycl. Chem.* **1978**, *15*, 515.

Table I. Yields and Isomer Distributions for Reactions of Diazoalkanes and Thiete 1,1-Dioxide<sup>a</sup>

compd	yield, %	% of 3	mp, °C	% of 4	mp, °C
1a, R = R' = H	70	35	120-121 <sup>b</sup>	65	114-115 <sup>c</sup>
1b, R = Me; R' = H	73	52	135-136 <sup>b</sup>	48	110-111 <sup>c</sup>
1c, R = Ph; R' = H	76	70	133-134 <sup>b</sup>	30	160-161 <sup>d</sup>
1d, R = R' = Me	87	27	170 dec <sup>b</sup>	73	170 dec <sup>d</sup>
1e, R = R' = Ph	90	0	170 dec <sup>b</sup>	100	141-142 <sup>b</sup>

<sup>a</sup> Satisfactory analytical data ( $\pm 0.3\%$  for C, H, N) were reported for all new compounds listed in the table. <sup>b</sup> White needles from EtOH. <sup>c</sup> White prisms from EtOH. <sup>d</sup> White leaflets from EtOH.

Table II. <sup>1</sup>H NMR [ $\delta$  (Me<sub>2</sub>SO-*d*<sub>6</sub>)] Data for 3 and 4<sup>a</sup>

compd	chemical shifts						coupling constants, Hz			
	H-1	R'	R	H-5	H-7	H-7'	<i>J</i> <sub>1,5</sub>	<i>J</i> <sub>1,7</sub>	<i>J</i> <sub>1,7'</sub>	<i>J</i> <sub>7,7'</sub>
3a	5.45 (m)	<i>b</i>	<i>b</i>	<i>b</i>	4.23 (m)	<i>b</i>				14.0
3b	5.10-5.80 (m)		1.37 (d) <sup>c</sup>	3.80-4.90 (m)						
3c	5.89 (m)	6.50 (t) <sup>d</sup>	-	5.02 (m)	4.39 (m)	4.87 (m)	6.3	1.5	9.3	14.1
3d	5.52 (ddd)	1.81 (s)	1.11 (s)	4.76 (m)	4.34 (m)	4.76 (m)	6.5	2.5	9.5	14.0

compd	chemical shifts						coupling constants, Hz				
	H-1	R'	R	H-5	H-6	H-6'	<i>J</i> <sub>1,5</sub>	<i>J</i> <sub>1,6'</sub>	<i>J</i> <sub>5,6</sub>	<i>J</i> <sub>5,6'</sub>	<i>J</i> <sub>6,6'</sub>
4a	7.24 (m)	4.88 (m)	-	2.85 (m)	3.91 (dd)	4.43 (ddd)	8.0	2.0	5.9	10.0	14.0
4b <sup>e</sup>	6.98 (m)	4.92 (m)	1.34 (d) <sup>f</sup>	2.35 (m)	3.62 (dd)	4.31 (ddd)	7.3	2.1	5.3	9.9	13.7
4c <sup>e</sup>	7.21 (m)	5.90 (t)	-	2.74 (m)	3.81 (dd)	4.43 (ddd)	7.2	2.2	5.4	9.9	13.6
4d	7.19 (dd)	1.52 (s)	1.19 (s)	2.75 (m)	4.05 (m)		7.1	1.8			
4e	7.75 (m)	7.20-7.70 (m)		<i>g</i>	3.10 (dd)		<i>g</i>	6.0			12.0

<sup>a</sup> The spectra were analyzed as first-order spectra. <sup>b</sup>  $\delta$  4.50-5.20. <sup>c</sup>  $J_{\text{Me,H}'} = 7.8$  Hz. <sup>d</sup>  $J_{1,4} = J_{4,5} = 2.5$  Hz. <sup>e</sup> In CDCl<sub>3</sub>;  $J_{1,4} = J_{4,5} = 2.7$  Hz. <sup>f</sup>  $J_{\text{Me,H}'} = 7.3$  Hz. <sup>g</sup> In the range  $\delta$  3.90-4.60.

explored only with nitrilimines<sup>3</sup> and diazoalkanes.<sup>4</sup>

In the course of research directed toward the synthesis of thiabicyclopentane derivatives, Dittmer and co-workers<sup>4</sup> isolated the sole adducts **3b**, **3c**, and **3e** from the reactions of diazoethane, phenyldiazomethane, and diphenyldiazomethane. By contrast, in the reactions of diazomethane and 2-diazopropane the two regioisomers **4a** and **4d** were found to be the dominant adducts and minor amounts of **3a** and **3d**, respectively, were detected.

The inversion in regiochemistry on passing from diazomethane to diazoethane or from 2-diazopropane to diphenyldiazomethane seemed surprising to us as it is unexplicable on the basis of either electronic or steric effects.

An aim of the present work was to reinvestigate from a quantitative viewpoint the regiochemistry of the reactions of diazoalkanes with **2**, which have previously been only qualitatively considered.

## Results

The reactions of **2** with excess diazoalkanes **1** were carried out in ether at room temperature. The isomer ratios were determined by column chromatographic separation and in the case of **1b** and **1d** secured by NMR analysis of the crude reaction mixture.

The results reported in Table I confirm the previously assigned structures for compounds **3a-d**, **4a**, and **4d**, while the structure of the adduct derived from the reaction of diphenyldiazomethane and **2** must be reassigned as **4e** instead of **3e**;<sup>4</sup> substantial amounts of regioisomers **4b** and **4c** were isolated for the first time. The structures were

Table III. <sup>13</sup>C NMR [ $\delta$  (Me<sub>2</sub>SO-*d*<sub>6</sub>)] Data for 3a, 4a, and 4e

compd	chemical shifts				
	C-1	C-4	C-5	C-6	C-7
3a	73.7 (d)	79.7 (t)	72.9 (d)		69.6 (t)
4a	120.8 (d)	84.9 (t)	17.9 (d)	72.9 (t)	
4e	121.3 (d)	104.1 (s)	27.1 (d)	69.0 (t)	

assigned on the basis of <sup>1</sup>H and <sup>13</sup>C NMR spectra (Table II and III). Adducts **4** show resonances at low field (in the range  $\delta$  6.98-7.75) which are absent in the spectra of adducts **3**. We agree with Dittmer and co-workers in attributing this low-field signal to H-1 which in compounds **4** is strongly deshielded by the azo and sulfone groups. In **4e** the resonance of H-1 is partly overlapped by the complex signal of the aromatic protons; in fact, on irradiation at  $\delta$  7.75, the line pattern of the complex signal (two protons) at  $\delta$  3.90-4.60 was simplified and, on irradiation of this latter signal, the H-1 resonance collapses to a singlet at  $\delta$  7.75.

Conclusive evidence for the correct attribution of structure **4e** was represented by <sup>13</sup>C NMR data (Table III). All carbon atoms of **3a** resonate at a similar field ( $\delta$  69.6-79.7), whereas in **4a** and **4e** C-1 is shifted to lower field ( $\delta$  120.8 and 121.3, respectively) and C-5 (without electron-withdrawing substituent) is in the aliphatic region ( $\delta$  17.9 and 27.1, respectively) of the spectrum in full agreement with the assigned structures.

The trans relationship between H-4 and H-5 in **3c** and **4c** is supported by their low coupling constant ( $J_{4,5} \approx 3$  Hz); for **3b** and **4b** the same relationship is proposed in

(4) Dittmer, D. C.; Glassman, R., *J. Org. Chem.* 1970, 35, 999.

Table IV. Relative Abundance of Ions 5, 6, and 7<sup>a</sup>

compd	<i>m/e</i> (abundance, %)		
	5	6	7
3a <sup>b</sup>	54 (100)	53 (44)	41 (33)
4a	54 (90)	53 (82)	41 (100)
3b <sup>b</sup>	68 (89)	67 (100), 53 (82)	55 (15)
4b	68 (25)	67 (64), 53 (77)	55 (100)
3c	130 (100)	129 (51)	
4c	130 (100)	129 (81)	117 (70)
3d	82 (33)	67 (100)	69 (6)
4d	82 (22)	67 (46)	69 (100)
4e	206 (100)	129 (5)	

<sup>a</sup> The mass spectra were performed at an ionizing voltage of 20 eV. <sup>b</sup> Ionizing voltage 70 eV.

analogy. We were not able to detect in the crude reaction mixture the epimers (R = H, R' = Me or Ph; H-4 and H-5 cis) of **3c** and **4c** and **3b** and **4b** arising from the more crowded transition state with the substituent of the diazoalkane and the cyclobutene ring in a cisoid relationship. The two epimers were often isolated from the reaction of diazoalkanes with cyclobutenes.<sup>5-7</sup>

Table IV clearly shows that the mass spectral data should be used with caution in order to distinguish between regioisomers **3** and **4**. As a matter of fact compounds **3** exhibit a sole important fragmentation path (see Scheme I) corresponding to the loss of sulfur dioxide plus nitrogen to give ions **5** (base peak for **3a** and **3c**) which thereafter lose methyl or hydrogen radical to give ions **6** (base peak for **3b** and **3d**). This fragmentation path is also always present in the mass spectra of compounds **4**; however, while it is a minor process in the electron impact induced fragmentation of **4a**, **4b**, and **4d**, it becomes the major one for **4c** and the sole important fragmentation path for **4e**. In conclusion, the fragmentation pattern of compounds **4** is greatly influenced by substituents and while the presence of the intense ion **7** in the mass spectra does support structure **4** its absence cannot offer evidence for structure **3**.

### Discussion

Cycloadditions of diazoalkanes are predominantly HOMO (1,3-dipole)-LUMO (dipolarophile) controlled as shown by the fact that they are accelerated only by electron-withdrawing substituents in the dipolarophile and electron-releasing substituents in the diazoalkane.<sup>8</sup> This well-known aspect of diazoalkane reactivity has recently received further quantitative support by a very elegant and exhaustive kinetic investigation of Huisgen et al. who measured a large number of cycloaddition rate constants of diazomethane and aryl- and diaryldiazomethanes.<sup>9</sup> Moreover "ab initio" calculations of the hypersurface of the reaction diazomethane-ethylene<sup>10</sup> as well as MO semiempirical calculations<sup>11</sup> of the orbital energies of

(5) Bianchi, G.; De Micheli, C.; Gamba, A.; Gandolfi, R.; Rezzani, B. *J. Chem. Soc., Perkin Trans. 1* 1977, 2222.

(6) Gandolfi, R.; De Micheli, C. *Synthesis* 1978, 383.

(7) De Micheli, C.; Gandolfi, R., unpublished results.

(8) Bianchi, G.; De Micheli, C.; Gandolfi R.; Patai, S. "The Chemistry of Functional Groups", Supplement A; Interscience: New York, 1977, p 445, and the literature cited therein.

(9) Huisgen, R.; Geitner, J. *Heterocycles* 1978, 11, 105; Geitner, J.; Huisgen, R.; Reissig, H. U. *Heterocycles* 1978, 11, 109.

(10) Minato, T.; Yamabe, S.; Inagaki, S.; Fujimoto, H.; Fukui, K. *Bull. Chem. Soc. Jpn.* 1974, 47, 1619. Leroy, G.; Sana, M. *Tetrahedron* 1975, 31, 2091.

(11) (a) Houk, K. N.; Sims, J.; Duke, R. E., Jr.; Strozier, R. W.; George, J. K. *J. Am. Chem. Soc.* 1973, 95, 7287. (b) Houk, K. N.; Sims, J.; Watts, Ch. R.; Lusku, L. J. *Ibid.* 1973, 95, 7301. (c) Bastide, J.; Henri-Rousseau, O.; Aspart-Ascot, A. *Tetrahedron* 1974, 30, 3335.

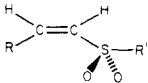
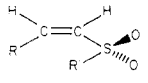
Table V. FO Energies, Coefficients, and Total and  $\pi$  Net Charges of Diazoalkanes (CNDO/2)<sup>a</sup>

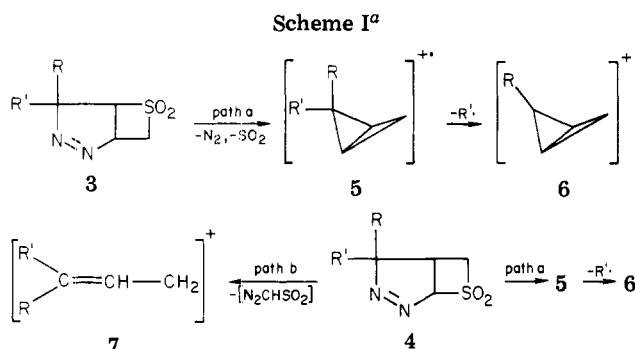
N≡N-X X =	HOMO			LUMO			total charges ( $\pi$ charges)			
	FO <sup>b</sup>	c <sub>N<sub>1</sub></sub>	c <sub>N<sub>2</sub></sub>	FO <sup>b</sup>	c <sub>N<sub>1</sub></sub>	c <sub>N<sub>2</sub></sub>	c <sub>CX</sub>	q <sub>N<sub>1</sub></sub>	q <sub>N<sub>2</sub></sub>	q <sub>CX</sub>
CH <sub>2</sub>	-0.352	0.626	-0.091	0.141	0.524	-0.687	0.504	-0.237	0.472	-0.314
CHMe	-0.322	0.589	-0.139	0.130	0.514	-0.658	0.450	-0.245	0.445	-0.230
CMe <sub>2</sub>	-0.301	0.565	-0.165	0.125	0.517	-0.645	0.413	-0.255	0.422	-0.161
CHPh	-0.321	0.591	-0.138	0.140	0.517	-0.670	0.498	-0.263	0.445	-0.260
CPh <sub>2</sub>	-0.295	0.583	-0.178	0.142	0.506	-0.655	0.497	-0.287	0.409	-0.194

<sup>a</sup> Orbital coefficients and  $\pi$  net charges refer to the  $\pi$  system perpendicular to the molecular planes of the diazoalkanes. <sup>b</sup> Frontier orbital, atomic units.

Table VI. FO Energies, Coefficients, and Total and  $\pi$  Net Charges of Vinyl Sulfones (CNDO/2)<sup>a</sup>

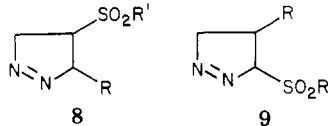
RCH=CHSO <sub>2</sub> R'		HOMO			LUMO			total charges ( $\pi$ charges)	
R	R'	FO <sup>b</sup>	c <sub><math>\alpha</math></sub>	c <sub><math>\beta</math></sub>	FO <sup>b</sup>	c <sub><math>\alpha</math></sub>	c <sub><math>\beta</math></sub>	q <sub><math>\alpha</math></sub>	q <sub><math>\beta</math></sub>
-CH <sub>2</sub> - (syn)									
H	Me (anti) <sup>c</sup>	-0.455	0.097	0.132	0.099	0.667	0.710	-0.063 (-0.040)	-0.036 (0.032)
		-0.534	0.422	0.476					
H	Ph (anti)	-0.496	0.180	0.223	0.083	0.153	-0.172	-0.077 (-0.038)	-0.035 (0.030)
		-0.549	0.486	0.512	0.100	0.648	-0.682		
Me	Me (anti)	-0.451	0.143	0.160	0.084	0.626	-0.661	-0.106 (-0.113)	0.034 (0.072)
		-0.487	0.568	0.445					
		-0.444	0.265	0.206					
Ph <sub>90°</sub>	Me (anti)	-0.458	0.216	0.101	0.096	0.628	-0.704	-0.112 (-0.125)	0.024 (0.082)
		-0.519	0.488	0.438					
		-0.434	0.221	0.130					
Ph <sub>45°</sub>	Me (anti)	-0.439	0.316	0.190	0.067	0.538	-0.525	-0.105 (-0.122)	0.021 (0.079)
		-0.532	0.307	0.385	0.144	0.311	-0.442		
		-0.555	0.319	0.418					
H	Me (syn) <sup>d</sup>	-0.585	0.484	0.446	0.067	0.688	-0.692	-0.039 (0.014)	-0.079 (-0.021)
		-0.452	0.111	0.114					
		-0.516	0.594	0.539	0.053	0.670	-0.652	-0.092 (-0.035)	-0.025 (0.021)

<sup>a</sup> c <sub>$\alpha$</sub>  and c <sub>$\beta$</sub>  are the coefficients of p <sub>$\pi$</sub>  atomic orbitals of the carbon atoms in  $\alpha$  and  $\beta$  positions with respect to the SO<sub>2</sub> substituent. <sup>b</sup> Frontier orbital, atomic units. <sup>c</sup> Anti conformation:  <sup>d</sup> Syn conformation: 



<sup>a</sup> Structures 5-7 for the ions are tentatively attributed.

diazoalkanes and several dipolarophiles support this type of predominant frontier-orbital control. The low experimental ionization potentials (IP  $\leq$  9.03 eV) of diazoalkanes<sup>12a-c</sup> and the high IP values ( $\geq$  11.10 eV) for the dipolarophiles in study<sup>12d,e</sup> offer a new strong argument in favor of HOMO (1,3-dipole)-LUMO (dipolarophile) control for the reactions under investigation. In full agreement with these findings are also the results of our CNDO/2 calculations on diazoalkanes and vinyl sulfones reported in Tables V and VI, even if, on account of the strong coupling between the ethylenic  $\pi$  bond and the sulfone group, in many cases two or more surface orbitals appear to be significant both on the grounds of orbital energies and coefficients. In Table VI the CNDO/2 results of thiete 1,1-dioxide are compared with those of a number of acyclic vinyl sulfones (cis when disubstituted) so as to test the effectiveness of the theoretical model toward discrimination between their different behaviors toward regioselectivity; in fact, these calculations are intended to be much more suited for rationalizing qualitative trends than for

Table VII. Experimental Results for Reactions of Diazomethane with  $\alpha,\beta$ -Unsaturated Sulfones<sup>13</sup>


substituent		yield, %	relative percentage	
R	R'		8	9
H	Ph	87	0	100
Me	<i>n</i> -C <sub>12</sub> H <sub>25</sub>	86	0	100
Ph	Me	86	69.8	30.2

matching single experimental results.

Together with the result (Table V) that carbon atoms in the HOMOs of diazoalkanes have higher coefficients than the nitrogen ends, inspection of Table VI reveals the following: (i) Methyl (or phenyl) vinyl sulfone and propenyl methyl sulfone, with larger coefficients on the  $\beta$  than  $\alpha$  position in their LUMOs, should add to diazoalkanes to form normal adducts 9 as the dominant adducts in agreement with experimental regioselectivity.<sup>13</sup> (ii) Conjugation in styryl methyl sulfone, evidenced in model calculations by comparing the results obtained with a molecular geometry where the phenyl  $\pi$  system is orthogonal to the ethylenic  $\pi$  systems (Ph<sub>90°</sub>) with those where some degree of  $\pi$  coupling is allowed (Ph<sub>45°</sub>), appears to be responsible for the observed loss of regioselectivity<sup>13</sup> (Table VII), as it tends to produce comparable LUMO coefficients on the  $\alpha$  and  $\beta$  carbon atoms. (iii) A mixture of two regioisomers, with a slight preference for the reversed isomer 3, is also foreseen for thiete 1,1-dioxide; this finding substantially conforms to the results obtained with diazoalkanes 1a-d. The regioselectivity observed with diphenyldiazomethane (100% of adduct 4) could be due to the steric factors operating against adduct 3. (iv) By comparing the LUMO coefficients of *syn*-vinyl methyl sulfone and thiete 1,1-dioxide, one can suggest that the different regioselectivity observed for thiete 1,1-dioxide with respect to vinyl methyl sulfone and propenyl methyl sulfone can possibly be attributed to the presence, in the

(12) The experimental IP's are reported in the following references. (a) Diazomethane: Pualett, G. S.; Ettinger, R. *J. Chem. Phys.* 1963, 39, 825. (b) 2-Diazopropane: Heilbronner, E.; Martin, H. D. *Chem. Ber.* 1973, 106, 3376. (c) Phenyl diazomethane: Bastide, J.; Maier, J. P.; Kubota, T. *J. Electron Spectrosc. Relat. Phenom.* 1976, 9, 307. (d) Phenyl vinyl sulfone: Sims, J.; Houk, K. N. *J. Am. Chem. Soc.* 1973, 95, 5798. (e) Methyl vinyl sulfone: Müller, C.; Schweig, A. *Tetrahedron* 1973, 29, 3973. Solouki, B.; Bock, H.; Appel, R. *Chem. Ber.* 1975, 108, 897. (f) The photoelectron spectrum of thiete 1,1-dioxide is insufficiently resolved for definitive assignment; it presents three peaks at 10.79, 10.93, and 11.10 eV. This spectrum was recorded by Dr. F. P. Colonna, C.N.R. Centre, Ozzano E.—Bologna.

(13) Parham, W. E.; Blake, F. D.; Theissen, D. R. *J. Org. Chem.* 1962, 27, 2415.

Table VIII. Interaction Energy (kcal/mol) of HOMO (Diazomethane) with All Unoccupied MO's of Vinyl Sulfones for Adducts 3(8) and 4(9)

	RCH=CHSO <sub>2</sub> R', R, R' =						Ph <sub>90°</sub> , Me (anti)	Ph <sub>45°</sub> , Me (anti)
	CH <sub>2</sub> <sup>a</sup> (syn)	H, Me (syn)	H, Me (anti)	H, Ph (anti)	Me, Me (anti)	Me (anti)		
ΔE <sub>3(8)</sub>	-22.50	-22.76	-21.30	-21.92	-20.16	-19.88	-20.04	
ΔE <sub>4(9)</sub>	-22.62	-22.64	-21.66	-21.28	-20.82	-20.76	-20.74	
ΔΔE	0.12	-0.12	0.36	0.36	0.66	0.88	0.70	

<sup>a</sup> Similar results were obtained for the reactions of diazoalkanes 1b-e with thiete 1,1-dioxide.

cyclic compound, of a blocked syn form, sterically unfavored<sup>14</sup> in the acyclic analogues.

The stabilization energies due to the charge-transfer interactions of the HOMO (diazomethane) with all the vacant orbitals of vinyl sulfones have been calculated<sup>15</sup> to obtain a semiquantitative treatment and to overcome the difficulty of multiple orbitals in the frontier range. Table VIII shows the interaction energies for the oriented complexes leading to adducts 3 (8) and 4 (9);<sup>16</sup> the energy differences ΔΔE are much larger for acyclic vinyl sulfones than for thiete 1,1-dioxide and indicate a preference for regioisomer 9.<sup>17</sup> Here again *syn*-vinyl methyl sulfone should behave like thiete 1,1-dioxide. It is interesting to observe that conjugation in styryl vinyl sulfone (Ph<sub>45°</sub> compared to Ph<sub>90°</sub>) increases the stabilization energy of adduct 8 but, at variance with the frontier coefficients criterion, does not succeed in matching the experimental finding of a mixture of 8 and 9.

The above reported approach ignores the contributions of closed-shell repulsion (steric effect) and charge interactions (Coulombic effects). A quantitative treatment of these terms is beyond the aims of the present work; however, the small differences in charges (see Table V and VI) between the terminal atoms of diazoalkanes indicate that the Coulombic term has little effect on regioselectivity.

The reactions of thiete 1,1-dioxide with nitrile oxides and nitrones are under investigation in order to better understand the origin of regioselectivity in the cyclo-

additions of this dipolarophile.

### Experimental Section

NMR spectra were recorded at 36 °C for Me<sub>2</sub>SO-*d*<sub>6</sub> solutions with a Varian XL-100 (100 MHz for <sup>1</sup>H and 25.18 MHz for <sup>13</sup>C) spectrometer (Me<sub>4</sub>Si as internal standard); mass spectra were recorded with a Varian MAT 112 S spectrometer at an ionizing voltage of 20 eV, unless otherwise noted; microanalyses were performed with a Carlo Erba Analyzer Model 1106.

Thiete 1,1-dioxide was prepared according to Dittmer et al.<sup>19</sup> Reaction mixtures were analyzed by TLC on silica gel GF<sub>254</sub> and the spots were detected by spraying with a 3% solution of chromic anhydride in sulfuric acid (50%) followed by charring at 120 °C.

**Molecular Orbital Calculations.** MO calculations have been performed at the Centro di Calcolo Elettronico of the University of Modena by a modified version of the library program QCPE 161. A standard CNDO/2 parametrization was chosen,<sup>20</sup> experimental geometries<sup>14</sup> or standard bond lengths and bond angles have been used. The qualitative conclusions have been checked to be largely independent of any reasonable choice of parameters and geometries.

**Reaction of Diazomethane (1a) with Thiete 1,1-Dioxide (2).** An ethereal solution of thiete 1,1-dioxide (2.1 g, 20 mmol) and a twofold excess of diazomethane was allowed to stand at room temperature until TLC analysis indicated the dipolarophile disappearance (3 or 4 days).

Evaporation of the solvent under reduced pressure at room temperature gave a residue which was at once column chromatographed on silica gel with ethyl acetate-cyclohexane (2:3) as eluant to afford, in order of elution, 0.71 g of 3a and 1.33 g of 4a. A similar workup was used for the other reactions; the adducts 3b, 3d, and 4c were characterized by a higher *R<sub>f</sub>* value than 4b, 4d, and 3c, respectively.

The adducts were found to be stable under reaction and workup conditions. The ratios 3b/4b and 3d/4d were confirmed by NMR analysis of the crude reaction mixture, considering the integrals of the methyl groups. In the reaction of 1b, the NMR spectrum of the crude reaction mixture revealed the presence (doublet at δ 1.30) of small amounts (≤5%) of an epimer of 3b or 4b.

**Acknowledgment.** We thank Dr. G. Galli and Dr. M. Sisti for the mass spectra, Dr. F. P. Colonna, CNR Centre of Ozzano E., for the thiete 1,1-dioxide IP measurement and the C.N.R. (Rome) for financial support.

**Registry No.** 1a, 334-88-3; 1b, 1117-96-0; 1c, 766-91-6; 1d, 2684-60-8; 1e, 883-40-9; 2, 7285-32-7; 3a, 73466-77-0; 3b, 73495-33-7; 3c, 73495-34-8; 3d, 73466-78-1; 4a, 73466-79-2; 4b, 73466-80-5; 4c, 73466-81-6; 4d, 73466-82-7; 4e, 73466-83-8; methyl vinyl sulfone, 3680-02-2; (ethenylsulfonyl)benzene, 5535-48-8; (*Z*)-1-(methylsulfonyl)-1-propene, 40205-25-2; (*Z*)-[2-(methylsulfonyl)ethenyl]-benzene, 37630-43-6.

(19) Nelson, T. R.; Babiarz, J. E.; Bartholomew, J. T.; Dittmer, D. C., submitted for publication in *Org. Synth.*

(20) Pfister-Guillonzo, G.; Gonbeau, D.; Deschamps, J. *J. Mol. Struct.* 1972, 14, 81.

(14) CNDO/2 results show that the anti conformations are more stable than the syn ones for both vinyl and propenyl methyl sulfone. For conformational problems in vinyl sulfones see: Hargittai, I. *Lect. Notes Chem.* 1978, 6, 50.

(15) Sustmann, R.; Wenning, E.; Huisgen, R. *Tetrahedron Lett.* 1977, 877. Sustmann, R. *Pure Appl. Chem.* 1974, 40, 569.

(16) The interaction energies were calculated with the equations

$$\Delta E_{3(8)} = -2 \sum_{\text{unocc}}^{\text{dip}} (C_{N_1} C_{i,\beta} \beta_{CN} + C_{CX} C_{i,\alpha} \beta_{CC})^2 \frac{1}{\epsilon_i - \epsilon_{\text{HOMO}}}$$

$$\Delta E_{4(9)} = -2 \sum_{\text{unocc}}^{\text{dip}} (C_{N_1} C_{i,\alpha} \beta_{CN} + C_{CX} C_{i,\beta} \beta_{CC})^2 \frac{1}{\epsilon_i - \epsilon_{\text{HOMO}}}$$

$$\Delta \Delta E = \Delta E_{3(8)} - \Delta E_{4(9)}$$

where β<sub>CN</sub> and β<sub>CC</sub> were given the values 2.14 and 2.63 eV, corresponding to a distance of 2.50 Å between the reacting centers.<sup>11b</sup>

(17) The calculated values of ΔΔE, although showing definitive trends in good agreement with experimental findings, are too small for justifying regiospecificity. This appears to be a quite general shortcoming of the procedure (approximations and parameters); some authors<sup>18</sup> have postulated a proportionality between ΔΔG<sup>‡</sup> and ΔΔE and determined, a posteriori, the proportionality constants so as to bring the differences into the correct range (>3 kcal/mol for regiospecificity).

(18) Bastide, J.; El Ghandour, N.; Henri-Rousseau, O. *Bull. Soc. Chim. Fr.* 1973, 2290.