Triflate/Mesylate Ratios and Competing C−O and S−O Bond Cleavages in Nucleophilic Vinylic Substitution

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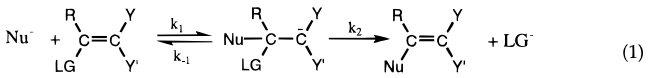
In an attempt to develop the k_{OTf}/k_{OMs} ratio as a mechanistic tool for the "addition−elimination" route in nucleophilic vinylic substitution, several pairs of vinyl mesylates and triflates were prepared. Whereas reactions of ArC(LG)═C$(CO_2Et)_2$ (LG = OTf, OMs) with piperidine and morpholine in MeCN or THF gave the normal substitution product with k_{OTf}/k_{OMs} ratios of 4.3−10.6, the reaction of the mesylates, Ar = *p*-$O_2NC_6H_4$, and of PhC(OMs)═C(Me)CN with MeS^- gave a ketone via an S−O bond cleavage. A related mesityl-substituted tosylate also reacted with *p*-$MeC_6H_4X^-$ (X = O, S) via an S−O bond cleavage. Hence, k_{OTf}/k_{OMs} ratios cannot be used as a general mechanistic tool. Several reactivity ratios in vinylic substitution are briefly discussed.

Introduction

The leaving group (LG) effect is a valuable tool in the study of nucleophilic vinylic substitution.[1] The only extensively studied tool is the k_{Br}/k_{Cl} ratio, which compares the rates of a pair of otherwise similar vinyl bromide and vinyl chloride. In reaction routes involving rate-determining C−halogen bond cleavage such as elimination−addition, S_N1, or halophilic reaction, the k_{Br}/k_{Cl} ratio should be much greater than unity. In contrast, in the two-step addition−elimination route with rate-determining nucleophilic attack (eq 1, k_1 is the slow step) the similar electronic effects of the two halogens lead to $k_{Br}/k_{Cl} \sim 1$ or slightly > 1, and this is one of the strongest arguments for the nonconcerted nature of this route.[1]

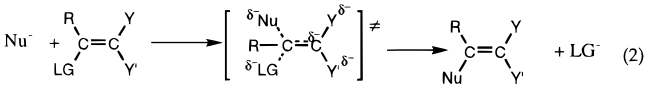


(1)

(Nu^- = nucleophile, LG = nucleofuge, Y,Y' = activating groups; charge delocalized on Y and Y')

Since the electronegativity of fluorine is higher than that of chlorine, whereas the C−Cl bond cleavage is more facile than the C−F bond cleavage, for rate-determining nucleophilic addition $k_F/k_{Cl} \gg 1$ and for rate-determining C−LG bond cleavage $k_F/k_{Cl} \ll 1$. This sharper tool than the k_{Br}/k_{Cl} ratio was used to corroborate the multistep route.[1] However, due to the different bulk of F and Cl, the ratio may contain a steric contribution. Moreover, since fluorine is not a very good nucleofuge, its expulsion can compete with the protonation of the intermediate carbanion,[2] thus reducing the utility of the k_F/k_{Cl} probe.

We are interested in the possibility of a single step "addition−elimination" type vinylic substitution. This can involve perpendicular nucleophilic attack, resulting in retention of configuration (eq 2),[1b] or an in-plane nucleophilic attack that will lead to inversion of configuration.[3] We expect a $k_{Br}/k_{Cl} > 1$, but if the transition state is early, the ratio is not expected to be very high. We therefore look for a mechanistic tool that will accentuate the differences between the two routes.



(2)

The relative reaction rates of a vinyl trifluoromethanesulfonate (triflate) ROTf, compared with the corresponding vinyl methanesulfonate (mesylate) ROMs, with a nucleophile seem appropriate for this purpose. Whereas k_{Br}/k_{Cl} ratios for aliphatic S_N2 or aliphatic or vinylic S_N1 reactions are $10-10^2$ (up to 10^3 in a few cases),[4] the k_{OTf}/k_{OMs} ratios are much higher, $10^4-(5 \times 10^5)$.[5] At the reaction site the bulk of the two groups is very similar, closer than those of Cl and Br, thus excluding the steric effect on the ratios. The two anions are structurally very similar, except for the higher stability of TfO^-, arising from the stronger electron withdrawal and therefore negative charge delocalization of the CF_3 group. Although the effect of mesylate and triflate on the stereochemistry of vinylic substitution was compared in a single system,[6] there are no kinetic data on the ratios in vinylic substitution of the addition−elimination route.

For a proper analysis of the use of the k_{OTf}/k_{OMs} tool the ratio should be first evaluated for a case of a *bona fide* two-step process (eq 1). Due to the higher electronegativity of triflate, a k_{OTf}/k_{OMs} ratio higher than the k_{Br}/k_{Cl} ratio in the same system is expected. Second, it should be investigated if the ratio depends (and to what extent) on the reactivity of the system, as determined by the activation by its electron-attracting groups Y and Y′. Note that no discernible dependency on Y,Y′ is known for the k_{Br}/k_{Cl} ratio in eq 1.[1] Finally, the substitution of a system with very low activation by Y and Y′, where both a perpendicular and an in-plane single step route may have a chance to occur,[3] should be investigated.

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(1) (a) Rappoport, Z. *Adv. Phys. Org. Chem*, **1969**, *7*, 1. (b) Rappoport, Z. *Acc. Chem. Res.* **1981**, *14*, 7.

(2) Marchese, G.; Naso, F. *Chim. Ind. (Milano)* **1971**, *53*, 760.

(3) (a) Ochiai, M.; Oshima, K.; Masaki, Y. *J. Am. Chem. Soc.* **1991**, *113*, 7059. (b) Shainyan, B.; Rappoport, Z. *J. Org. Chem.* **1993**, *58*, 3421. (c) Glukhovtsev, M. N.; Pross, A.; Radom, L.; *J. Am. Chem. Soc.* **1994**, *116*, 5961. (d) Lucchini, V.; Modena, G.; Pasquato, L. *Ibid.* **1995**, *117*, 2297.

(4) (a) Stang, P. J.; Rappoport, Z.; Hanack, M.; Subramanian, L. R. *Vinyl Cations*; Academic Press: New York, 1979. (b) For values in several reactions see: Avramovitch, B.; Weyerstahl, P.; Rappoport, Z. *J. Am. Chem. Soc.* **1987**, *109*, 6687.

(5) For a recent reference see: Bentley, T. W. In *The Chemistry of Sulphonic Acids, Esters and their Derivatives*; Patai, S., Rappoport, Z., Eds.; Wiley: Chichester, 1991; Chapter 16, pp 671−696.

(6) Avramovitch, B.; Rappoport, Z. *J. Am. Chem. Soc.* **1988**, *110*, 911.

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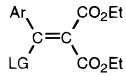
In the present paper we measured a few k_{OTf}/k_{OMs} ratios for substitution proceeding via the multistep addition−elimination route, but we found that nonaddition−elimination routes can also take place, invalidating the mechanistic generality of the k_{OTf}/k_{OMs} tool.

Results

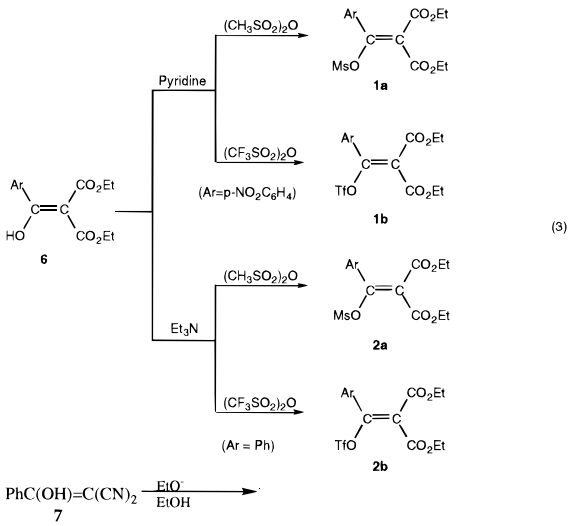
Synthesis. Compounds reacting by the multistep addition−elimination route should have at least one and preferably two electron-withdrawing groups. Hence, compounds **1**−**3** having no stereochemistry and the isomeric pairs **4** and **5**, carrying triflate and mesylate leaving groups in each case, were prepared.



1a Ar = *p*-$O_2NC_6H_4$; LG = OMs
1b Ar = *p*-$O_2NC_6H_4$; LG = OTf
2a Ar = Ph; LG = OMs
2b Ar = Ph; LG = OTf

3a Y = Y' = CN; LG = OMs
3b Y = Y' = CN; LG = OTf
4a Y = CN, Y' = Me; LG = OMs
4b Y = CN, Y' = Me; LG = OTf
5a Y = Me, Y' = CN; LG = OMs
5b Y = Me, Y' = CN; LG = OTf

The vinyl sulfonates were prepared by reaction of the enol/pyridine or triethylamine, i.e., via the corresponding enolate salt with the appropriate sulfonic anhydride (eq 3). The precursors, written as the enol **6** in eq 1, were ca. 50:50 and 85:15 ketone:enol (according to ^{1}H NMR) when Ar = *p*-$O_2NC_6H_4$ and Ph, respectively.



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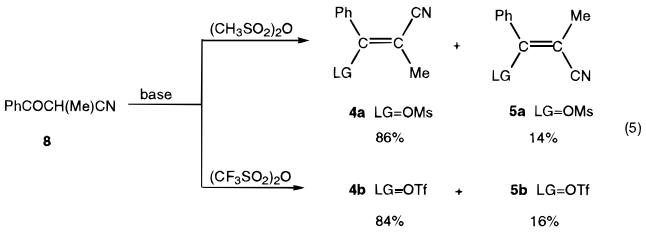


(5)

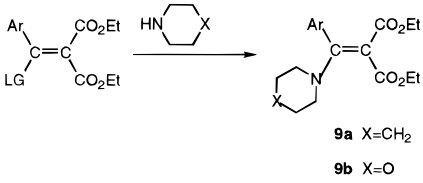
3a was prepared from the enol **7** (eq 4). Attempted preparation of **3b** in an analogous way gave a yellow oil with an appropriate ^{1}H NMR spectrum. However, the compound was unstable and turned black rapidly, so that further reaction with this system was not continued. The reaction of α-benzoylpropionitrile **8** with the two sulfonic anhydrides in the presence of base gave **4**:**5** mixtures rich in the *E* isomer (85%:15%) (eq 5). X-ray diffraction of **4a** established the stereochemistry in this case and by analogy for **5a**. Selected crystallographic data are given in Table 1.[7]

Table 1. Selected Bond Lengths and Angles for 4a

	distance, Å			deg	
bond	A	B	angle	A	B
C(1)−C(2)	1.359(6)	1.329(5)	C(1)C(2)C(3)	119.5(4)	118.3(4)
C(1)−O(1)	1.412(5)	1.410(4)	C(1)C(2)C(4)	125.7(4)	126.8(4)
C(1)−C(6)	1.478(6)	1.459(5)	C(2)C(1)C(6)	127.9(4)	128.4(4)
C(2)−C(3)	1.353(6)	1.446(7)	O(1)C(1)C(2)	117.2(4)	116.1(4)
C(2)−C(4)	1.501(6)	1.502(6)	C(3)C(2)C(4)	114.7(4)	114.9(4)
O(1)−S(1)	1.608(3)	1.618(3)	O(1)C(1)C(6)	114.5(4)	115.1(3)
O(2)−S(1)	1.415(3)	1.411(3)	N(1)C(3)C(2)	178.3(5)	176.6(5)
C-C (ring)	1.358(6)− 1.390(6)[a]	1.372(7)− 1.398(5)	O(1)C(1)C(2)C(4)	4.4(6)	−3.1(6)
			C(3)C(2)C(1)C(6)	−2.9 (7)	2.1 (6)

[a] Shorter bonds C(9)−C(10) 1.358(6) Å; C(8)−C(9) 1.364(7) Å; C(9′)−C(10′) 1.375(7) Å; C(8)−C(5) 1.372(7)Å.

Substitution. Compounds **1a, 1b, 2a** and **2b** reacted with piperidine and morpholine in both THF and MeCN to give the substitution products **9a** and **9b** (eq 6). The reactions of **1a** were studied earlier.[8] The reactions were



(6)

9a X=CH_2
9b X=O

followed spectrophotometrically at the λ_{max} of the products **9** at 303 and 313 K. The relative concentrations of the amines to the substrates were sufficiently high to ensure pseudo-first-order reactions. Five different nucleophile concentrations in the two solvents were used in each system. Clean second-order reactions, first each in the amine and the substrate, were obtained with no evidence for amine catalysis. Isosbestic points were retained during the measurements, and the infinity readings were stable for several half-lives. The second-order rate constants and the approximate activation parameters (due to the narrow temperature range, we estimate $\Delta H^{\ddagger}$ as ±1.5 kcal mol^{-1} and $\Delta S^{\ddagger}$ as ±4.5 cal K^{-1} mol^{-1}) are given in Table 2. The calculated k_{OTf}/k_{OMs} ratios are given in Table 3, and $k_{piperidine}/k_{morpholine}$, k_{MeCN}/k_{THF}, and $k_{p-O_2NC_6H_4}/k_{Ph}$ ratios are given in Table 4. The agreement with previous data[8] is very good.

When the reactions were conducted in EtOH the behavior of the triflates **1b** and **2b** with piperidine at 30 °C was identical to that described above, giving appreciably lower rate constants than in MeCN. However, the reactions of **1a** and **2a** did not show a steady isosbestic point during the reaction, and the absorption vs time plot did not reach a plateau even after long reaction times. In a quantitative determination of the products of piperidine in EtOH, **2b** gave completely the substitution product **9a**, whereas **2a** gave 95% of **9a** together with 5% of the enol/ketone **6** (Ar = Ph) (according to the ^{1}H NMR data). Reaction of **2a** with ethanol in the absence of the amine had shown that a spectral change takes places with time, and λ_{max} shifts to a longer wavelength with increase in the absorption

(7) The author has deposited atomic coordinates for this structure with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK.

(8) Rappoport, Z.; Topol, A. *J. Chem. Soc., Perkin Trans. 2* **1975**, 863.

Table 2. Second Order Rate Constants (in M^{-1} s^{-1}) for the Reaction of Systems 1 and 2 with Amines

substrate[a]	solvent	nucleophile	[Nu]	10^2k_2 at 303 K	10^2k_2 at 313 K	$\Delta H^{\ddagger}$ (kcal mol^{-1})	$\Delta S^{\ddagger}$ (cal mol^{-1} K^{-1})
1a	MeCN	piperidine	0.0014−0.035	19.7	35.1	10.3	−28
		morpholine	0.016−0.27	1.25	2.00	8.2	−40
	THF	piperidine	0.018−0.1	4.73	7.11	7.1	−41
		morpholine	0.065−0.22	0.60	0.76	3.9	−47
1b	MeCN	piperidine	0.00057−0.00528	149	234	7.9	−32
		morpholine	0.00311−0.038	8.43	13.6	8.4	−36
	THF	piperidine	0.0029−0.018	38.6	44.3	2.0	−54
		morpholine	0.065−0.2	3.64	4.19	2.0	−58
2a	MeCN	piperidine	0.0025−0.071	5.11	6.62	4.3	−50
		morpholine	0.0039−0.32	0.55	0.75	5.3	−51
	THF	piperidine	0.018−0.2	2.01	2.52	3.7	−54
		morpholine	0.2−1.0	0.37	0.46	3.6	−58
2b	MeCN	piperidine	0.00057−0.0049	54.2	60.3	1.4	−55
		morpholine	0.0075−0.081	2.60	3.87	6.9	−43
	THF	piperidine	0.0029−0.037	12.5	14.8	2.6	−54
		morpholine	0.044−1.0	1.37	2.0	6.5	−46
1b	EtOH	piperidine	0.00266−0.0133	9.31			
2b	EtOH	piperidine	0.00426−0.0213	2.99			

[a] [Substrate] = (4.7−6.3) × 10^{-5} M^{-1}.

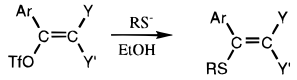
Table 3. Mesylate/Triflate Ratios in the Reaction of 1 and 2 with Amines

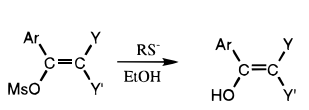
	THF				MeCN			
	piperidine		morpholine		piperidine		morpholine	
k_{OTf}/k_{OMs}	303 K	313 K	303 K	313 K	303 K	313 K	303 K	313 K
k(**1b**)/k(**1a**)	8.2	6.2	6.1	5.5	7.6	6.7	6.5	6.8
k(**2b**)/k(**2a**)	6.2	5.9	3.7	4.3	10.6	9.1	4.8	5.2

without an isosbestic point. In contrast, neither the spectrum of **2b** nor that of **4a** change in EtOH after a long time.

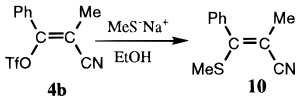
The reaction of **5a** with piperidine in MeCN is slow at moderate [amine]/[**5a**] ratios. When ratios > 100 were used the reaction is faster but the amine absorption overlaps that of **5a**, so that spectrophotometic kinetic study of the reaction becomes impossible.

Reactions with Other Nucleophiles. The reactions of **1** and **2** with MeS^-Na^+ are too fast to follow by conventional spectrophotometry.[9] The reaction of triflate **4b** with MeS^-Na^+ led to replacement of the leaving group. However, product analyses show a different reaction course for the triflates and the mesylates. Whereas the triflates give a normal nucleophilic substitution product (eq 7), the vinyl mesylates **4a** and **5a** undergo a cleavage reaction to their precursor enol (eq 8).



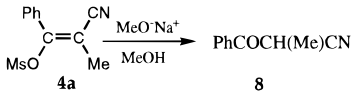


The reaction of **1b** with sodium *p*-toluenethiolate gives the substitution product and **4b** gives the retained substitution product **10** with MeS^- (eq 9). In contrast, reactions of **1a** and **4a** with MeSNa in EtOH give the ketones **11** and **8** (eq 10). Reaction of **4a** with NaOMe in MeOH gives ketone **8** (eq 11).



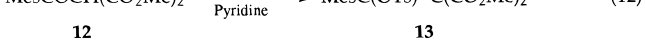
4b **10**

1a Ar = *p*-$O_2NC_6H_4$ **11** Ar = *p*-$O_2NC_6H_4$; Y = Y' = CO_2Et
4a Ar = Ph **8** Ar = Ph; Y = CN, Y' = Me

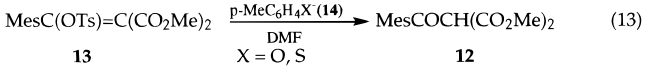


4a **8**

In order to see if a vinylic tosylate will behave similarly to a vinylic mesylate (as expected) or like a triflate, the α-mesityl [α-(tosyloxy)vinylidene]malonate (**13**) was prepared from the keto diester **12** (eq 12) and substituted by *p*-toluenethiolate and by *p*-cresolate anions (**14**). No substitution product was formed, and the only product obtained was the ketone **12**, presumably formed by S−O bond cleavage (eq 13).



12 **13**



13 **12**

Solid State Structure of 4a. Two independent molecules of **4a**, A and B, are present in the unit cell. The ORTEP drawing of A is given in Figure 1. A and B differ appreciably (by 0.03 Å) in the double bond C(1)−C(2) length and by 0.113 Å in the =C−CN bond length in a complementary way. All of the other differences are minor. Angles between geminal double bond substituents are ca. 115°, whereas bond angles C=C−C(4) and C=C−C(6) are 126−128°. The double bond torsional angle is 7.7° (A) and 6.4° (B), and the torsional angles between the Ph and C_β are 41.8° (A) or 43.0 (B).

Discussion

Competition between C−O and S−O Bond Cleavages. The desired application of k_{OTf}/k_{OMs} ratios as a

(9) The reaction of *p*-$MeC_6H_4S^-$ with **1a** in EtOH was somewhat irreproducible,[8] and this may be due to a competition between attack on =C and on S, which is sensitive to minor changes in the reaction conditions.

Table 4. Piperidine/Morpholine, MeCN/THF, and p-$O_2NC_6H_4$/Ph Rate Ratios in the Reactions of 1 and 2

		k_{pip}/k_{morp}			k_{MeCN}/k_{THF}				$k_{p\text{-}O_2NC_6H_4}/k_{Ph}$	
compd	solvent	303 K	313 K	amine	303 K	313K	amine/solvent	nucleofuge	303 K	313 K
1a	MeCN	15.6	17.5	piperidine	4.2	4.9	piperidine/MeCN	OMs	2.3	2.7
	THF	7.9	9.4	morpholine	2.1	2.6	piperidine/THF	OMs	1.6	1.7
1b	MeCN	17.7	17.2	piperidine	3.9	5.3	Morpholine/MeCN	OMs	2.3	2.7
	THF	10.6	10.6	morpholine	2.3	3.3	morpholine/THF	OMs	1.6	1.7
2a	MeCN	9.3	8.8	piperidine	2.6	2.6	piperidine/MeCN	OTf	2.7	3.9
	THF	5.4	5.5	morpholine	1.5	1.5	piperidine/THF	OTf	3.1	3.0
2b	MeCN	20.8	15.8	piperidine	4.3	4.1	morpholine/MeCN	OTf	3.2	3.6
	THF	9.1	7.4	morpholine	1.9	1.9	morpholine/THF	OTf	2.7	2.1

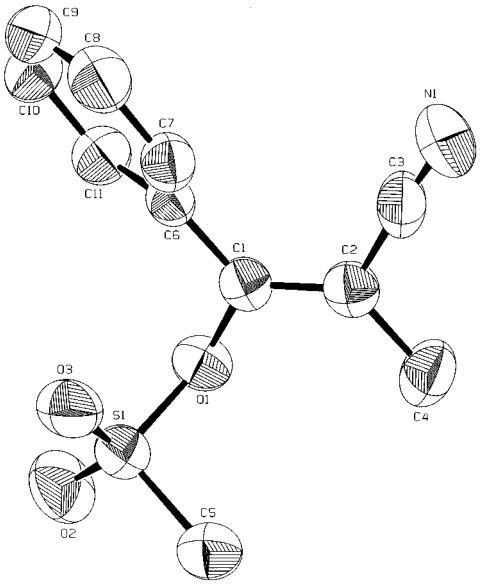


Figure 1. ORTEP drawing and numbering for **4a**.

probe to distinguish between rate-determining nucleophilic attack on the vinylic carbon and a rate-determining C−LG bond cleavage in nucleophilic vinylic substitution requires the study of a variety of substrates ranging from the most reactive to the least reactive ones. The present work had shown two major obstacles to such a study; i.e., (i) the "instability" of highly reactive triflates and (ii) the competition or predominance of nucleophilic attack on the sulfonate group rather than on the vinylic carbon.

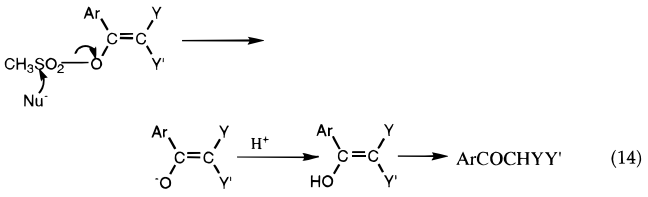
Whereas vinylic triflates of (mostly) nucleophilic olefins are usually stable species that are used extensively in synthesis,[10] especially in organometallic coupling reactions, the situation apparently differs with triflate-substituted highly electrophilic olefins. Not many of those are known, and when they are not highly activated like **1b, 2b, 4b**, or **5b** they seem sufficiently stable. However, replacing an ester by a cyano group, which moderately increases the double bond electrophilicity, as judged by previous studies,[8,11] apparently decreases the stability of the vinylic triflate. We have previously found that p-$O_2NC_6H_4C(OTf)=C(CN)CO_2Me$ is very reactive, although it was sufficiently long-lived for a stereochemical study,[6] and we observed now that the dicyano-substituted triflate **3b** blackens, i.e., deteriorates a short time after its preparation. The reason for this was not investigated, but by analogy with the low stability of highly reactive aliphatic tosylates in solvolysis[12] we assume that the higher reactivity due to the strongly electron-withdrawing triflate increases its sensitivity to reaction with nucleophiles, such as adventitious water in the solvent or in a humid atmosphere. Hence, the k_{OTf}/k_{OMs} probe will be difficult to use with highly activated systems.

This is a limitation only if there is a trend in the k_{OTf}/k_{OMs} ratios as a function of the electrophilicity of the (sulfonyloxy)alkene. If this is not the case, as found for the k_{Br}/k_{Cl} ratios that are relatively insensitive to the electrophilicity of the haloalkene in the addition−elimination regime,[1] the ratios found for **1** and **2** can be regarded as "normal" values for the addition−elimination route.

The second obstacle is more severe. Comparison with systems of differing electrophilicity should be with the same nucleophile. Whereas the reactions of **1** and **2** with piperidine and morpholine in the aprotic solvents proceed by the desired addition−elimination route, the observed rates are not very high and the rates for less activated systems, e.g., only by a singly activating group, such as **4** and **5** will be low. Compensation by higher nucleophile concentrations makes it unpractical to follow the reactions spectrophometrically, due to the end absorption of the nucleophile at the λ_{max} of the (sulfonyloxy)alkene. Moreover, the intermediate in the reaction with amino nucleophiles is a zwitterion rather than a carbanion, and the mechanistic behavior may be different. Since the transition to a single-step route should be at systems with a much lower reactivity, the amino nucleophiles are expected not to be sufficiently reactive with the systems of low reactivity.

Since the lower reactivity range is the one of the highest interest, anionic, and especially the highly reactive nonconjugated thio nucleophiles, like MeS^-, are the nucleophiles of choice. At the higher reactivity range, their rate could be followed by a fast reaction technique.

The reactions of the vinyl mesylates **1a** and **4a** with MeS^- and of **4a** and **5a** with MeO^- ions take a different reaction course than those of the triflates **1b** and **4b** with these nucleophiles or of both the vinyl mesylates and triflates with the cyclic amines. The product obtained, either completely with **1a** or **4a** with RS^- or partially in addition to the substitution product in the reaction of **2a** with piperidine in EtOH, are the enol (ketone) precursors of the mesylates. Their formation is ascribed to nucleophilic attack of the nucleophile at the mesylate sulfur by an O−S bond cleavage, displacing the enolate ion as a nucleofuge (eq 14). The latter is protonated in the protic medium or on workup.



(14)

(10) (a) Stang, P. J.; Hanack, M.; Subramanian, L. R. *Synthesis* **1982**, 85. (b) Scott, W. J.; McMurry, J. E. *Acc. Chem. Res.* **1988**, *21*, 47.

(11) Patai, S.; Rappoport, Z. *J. Chem. Soc.* **1962**, 392.

(12) H. M. R. Hoffmann, *J. Chem. Soc.* **1965**, 6748.

This reaction is not an isolated case. The structurally closely related tosylate **13** also reacts with the softer *p*-toluenethiolate and *p*-cresolate nucleophiles to give a similar S−O bond fission to the enolate. This cleavage competes, although to a lower extent, even in the reaction with piperidine in EtOH, where the C−O:S−O cleavage ratio, judged by the products, is 95:5.

Consequently, we conclude that great care should be exercised in trying to use k_{OTf}/k_{OMs} ratios as a mechanistic probe. In addition to the kinetics of the disappearance of the precursor alkene, the products should be carefully and completely identified as the substitution products.

S−O bond cleavage in nucleophilic reactions of vinyl sulfonates were previously observed for nucleophilic vinyl sulfonates.[13] Whereas most cycloalkenyl triflates solvolyze via S_N1,[4b] cyclopentenyl triflate gives [^{16}O]cyclopentanone in 50% ethanol−$H_2{}^{18}O$, excluding an S_N1 route and suggesting reaction via an S−O bond cleavage.[13b] Other cyclic triflates with geometrical constraints react similarly.[13c] The *k*(cyclohexenyl-OTf)/*k*((*E*)-MeC(OTf)=CHMe) ratios in 50% dioxane are 10^6 and ca. 4 with and without added OH^-, respectively. The high sensitivity in the absence of OH^- was ascribed to an S_N1 reaction, whereas the low value with OH^- was ascribed to reaction on sulfur, which is relatively insensitive to the effect of remote substituents.[14]

An interesting use of a sulfonate/sulfonate leaving group effect was to distinguish between rate-determining *electrophilic* attack on the C=C bond (Ad_E−E substitution route) and C−X bond cleavage (vinylic S_N1 route). *p*-Bromobenzenesulfonate (OBs) is more electron-withdrawing than *p*-methylbenzenesulfonate (tosylate, OTs), but $^-$OBs is a better nucleofuge than $^-$OTs, a situation resembling the OTf/OMs pair. Consequently, a $k_{OBs}/k_{OTs} > 1$ is expected for the S_N1 route and $k_{OBs}/k_{OTs} < 1$ for the Ad_E−E route. Indeed, for the reaction of (*E*)-MeCH=C(Me)LG, $k_{OBs}/k_{OTs} = 3.8$ in 50% MeOH (S_N1) and 0.28 in HCOOH/$HCOO^-$ (Ad_E−E).[15a] For cyclohexenyl-LG ($k_{OBs}/k_{OTs} = 0.30$ (Ad_E−E) whereas cyclohexenyl−OTf in AcOH/AcO^- reacts via S_N1.[15b]

All of these examples are for competition of reactions of nucleophilic olefins. We know of only two cases where attack on a multiatom *ester* nucleofuge predominated completely over the competing reaction at the vinylic carbon.[16] The nucleophile was OH^-/H_2O. In the analogous reaction with *p*-$MeC_6H_4S^-$ the products indicated a ca. 1:1 competition between reaction on the vinylic carbon and the carbonyl.[16]

Consequently, the reactions demonstrated by eqs 8, 10, 11, and 13 add one more variant to the multitude of reactions routes leading to or competing with vinylic substitution.[17]

Whereas triflates should be more prone than mesylates to react via a concerted route (eq 2) the possibility that the different behavior of triflates and mesylates is due to the intervention of this route for the triflates is unlikely with our moderately activated system based on what is known for nucleophilic vinylic substitutions.[1,3,6]

Electron-withdrawing CF_3 and Y,Y′ groups affect the electrophilicity of both the sulfonyloxy-substituted carbon and the sulfonyl sulfur electrophilic reaction centers. The closer the substituent is to one of these centers the higher is its effect on its electrophilicity. Hence, it is reasonable that as the electron-withdrawing effect of Y and Y′ decrease, the relative C-/S-electrophilicity also decreases and the effect of the constant and strongly electron-withdrawing CF_3 group on the sulfur electrophilicity will relatively increase with a consequently higher importance of the S−O bond cleavage. This prediction is in contrast with our observation that the mesylates rather than the triflates undergo the preferential S−O bond cleavage. Moreover, this effect cannot be dominated by hard−hard, soft−soft interactions since it takes place with the mesylates and tosylate **13** with both the harder oxygen and the softer thiolate anions. The solvent also affects the site of attack since slight S−O bond cleavage takes place in EtOH compared with MeCN or THF. We conclude that with the present limited and unsystematic data we cannot predict the =C- vs S-regioselectivity of the nucleophilic attack and why a certain combination of electrophilic sulfonyloxyalkene/nucleophile/solvent gives an Ad_N−E substitution, while other combinations lead to reaction at sulfur.

Mesylate/Triflate Reactivity Ratios. There is evidence, e.g., from stereochemistry,[5,18] that compounds such as **1** and **2** are likely to react via the stepwise nucleophilic addition−elimination route. Additional evidence are the activation parameters. Whereas the temperature span of 10 °C is insufficient to give accurate activation parameters it is clear that the $\Delta H^{\ddagger}$ values are very low and the $\Delta S^{\ddagger}$ values are highly negative. This is typical for many similar multistep reactions with amines that proceed via a polar zwitterionic intermediate.[8,19] We therefore ascribe the k_{OTf}/k_{OMs} reactivity ratios of Table 3 to a different effect of the two electron-withdrawing sulfonyloxy groups on the electrophilicity of C_α.

The clean second-order kinetics is usually ascribed to a rate-determining nucleophilic attack k_1. Indeed, no amine catalysis was observed, although this strong criterion for a multistep route was previously observed for *p*-$Me_2NC_6H_4C(LG)=C(CN)_2$ (LG = Cl, F, OR) with amines.[19,20] However, amine catalysis was never found for dicarboalkoxy-activated vinyl chlorides and bromides and is therefore not expected for the better sulfonyloxy nucleofuges.

In a previous analysis of the k_{OMs}/k_{Cl} ratios for **1a** and its corresponding chloride with piperidine and morpholine in THF and MeCN, it was suggested that the relatively high ratios should be interpreted in terms of a scheme similar to eq 1, where the rate of both an amine-catalyzed route (k_3[amine]) and the expulsion rate of the nucleofuge (k_2) are smaller than k_1. Under these conditions ($k_{-1} \gg k_2 + k_3$[amine]) the observed rate constant is given by $k_{obs} = k_1k_2/k_{-1}$. This conclusion was derived from the observation that in the substitution of system **1** with ArS^- $k_{OMs}/k_{Cl} = 1.5 \pm 0.1$[8] and since in the reaction

(13) (a) Frydman, N.; Bixon, R.; Sprecher, M.; Mazur, Y. *Chem. Commun.* **1969**, 1044. (b) Eymann, E.; Hanack, M. *Tetrahedron Lett.* **1976**, 3507. Hanack, M.; Benz, H.; Markl, R.; Subramanian, L. R. *Liebigs Ann. Chem.* **1978**, 1894. (c) Subramanian, L. R.; Hanack, M.; Chang, L. W. K.; Imhoff, M. A.; Schleyer, P.v.R.; Effenberger, F.; Kurtz, W.; Stang, P. J.; Dueber, T. E. *J. Org. Chem.* **1976**, *41*, 4099.

(14) Summerville, R. H.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1972**, *96*, 1110.

(15) (a) Peterson, P. E.; Indelicato, J. M. *J. Am. Chem. Soc.* **1969**, *91*, 6194. (b) Pfeifer, W. D.; Bahn, C. A.; Schleyer, P. v. R.; Bocher, S.; Harding, C.E.; Hummel, K.; Hanack, M.; Stang, P. J. *J. Am. Chem. Soc.* **1971**, *93*, 1513.

(16) Strauss, M. J.; Rappoport, Z. *J. Org. Chem.* **1982**, *47*, 1009.

(17) Rappoport, Z. *Recl. Trav. Chim. Pays-Bas* **1985**, *104*, 309.

(18) Rappoport, Z.; Gazit, A. *J. Am. Chem. Soc.* **1987**, *109*, 6698.

(19) E.g. (a) Rappoport, Z.; Greenzaid, P.; Horowitz, A. *J. Chem. Soc.* **1964**, 1334. (b) Rappoport, Z.; Peled, P. *J. Chem. Soc., Perkin Trans. 2* **1973**, 617.

(20) E.g., see: Rappoport, Z.; Ta-Shma, R. *J. Chem. Soc. B* **1971**, 871, 1461.

Table 5. Relative Activation of Nucleofugal Substituents LG in the Reaction of p-$O_2NC_6H_4C(LG)=C(CO_2Et)_2$ with Amino Nucleophiles

	In MeCN				In THF			
	morpholine		piperidine		morpholine		piperidine	
substituent	303 K	313 K	303 K	313 K	303 K	313 K	303 K	313 K
Cl	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
OTs	17.0	14.4	15.5	12.8	12.9	10.8	11.8	10.6
OMs	19.1	17.4	17.6	15.4	12.3	11.5	10.9	10.4
OBs	27.7	25.1	26.9	24.2	28.9	24.9	25.7	24.1
OTf	124.1	118.3	133.8	103.2	75.0	63.3	89.4	64.5

of p-cyanoaniline with $LGCH=C(CN)_2$ (LG = Cl, OMs) $k_{OMs}/k_{Cl} = 1$ in MeCN.[21]

Are the new results compatible with this interpretation? The σ constants of OMs and OTf are σ_m 0.39 and 0.56, σ_p 0.33, 0.47, σ_I 0.61 and 0.84, and σ_R −0.28 and −0.36, respectively.[5] If one uses a two-point Taft polar substituent equation $\log(k_{OTf}/k_{OMs}) = \rho_I(\sigma_{I(OTf)} - \sigma_{I(OMs)})$ and the average of all k_{OTf}/k_{OMs} ratios from Table 3, i.e., 6.5 ± 1.3, then $\rho_I = 3.5$, i.e., an appreciable sensitivity to the polar effect of the substituent. The k_{Br}/k_{Cl} ratios of ca. 1[1] in related systems are consistent with $\sigma_{I(Br)} = \sigma_{I(Cl)} = 0.47$.[22] The k_{OMs}/k_{Cl} ratios will give $\rho_I = 8 \pm 1$. The expected k_{OTf}/k_{OMs} ratios for a rate-determining $C-OS_2R$ bond cleavage are much higher than those observed, being $10^4-(5 \times 10^5)$ in solvolysis of neutral species.[5] The ratios will be, however, smaller if the precursor in the rate-determining bond cleavage will be the carbanion, as in the k_2 step. Since we find no experimental way to distinguish between $k_{obs} = k_1$ or $k_{obs} = k_1k_2/k_{-1}$ we conclude that the leaving group tool, even if it could properly be studied and in spite of the significant ratios, will be a problematic mechanistic probe to distinguish the single and multistep routes.

We see no trend in the k_{OTf}/k_{OMs} ratios as a function of the solvent and the amine, and we ascribe no significance to the difference between the numbers.

The effect of LG = Cl, OMs, OTs, and OBs on the rates of reaction of p-$O_2NC_6H_4C(LG)=C(CO_2Et)_2$ with piperidine and morpholine was previously studied.[8] The present work adds LG = OTf, and the extended data, which are the only data available for these groups in vinylic substitution, are given in Table 5. The differences between the Cl and OTf extremes are significant: 63−138. Still, these are much smaller than the ratio of 10^9 for these groups where they serve as nucleofuges in S_N1 reaction.[23]

A Few More Mechanistic Comments. As for other vinylic substitutions,[24] piperidine is a better nucleophile than morpholine: k_{pip}/k_{morp} ratios are 5.4−20.8 (Table 4), being twice as high in MeCN than in THF and higher for **1a** than for **1b**, but more similar for the **1b/2b** pair. The k_{MeCN}/k_{THF} ratios are 1.5−5.3 and are consistently higher for piperidine than for morpholine (Table 4). This is reasonable for a reaction forming a highly polar zwitterionic-like transition state, which is slightly later for piperidine than for morpholine.

The single isomer that was obtained from **4b** with MeS^- was ascribed to the retained E-product as is usually the case with substitution of mildly activated systems.[1,17] This is consistent with the lower field Me group of both **4b** and **10** than those of **5b** and the geometric isomer of **10**. The formation of 16% of the inverted product in the mainly retained substitution of **5b** is ascribed to post-isomerization since the sample was analyzed after a long reaction time.

Experimental Section

Methods and Precursors. For the kinetic studies THF (spectroscopic grade, Merck) was distilled from benzophenone/Na before use. Spectrocopic grade EtOH (Merck) and MeCN (Frutarom) were used without further purification. CCl_4 and CH_2Cl_2 were dried over $CaCl_2$ before use, and piperidine and morpholine were distilled from NaOH before use. Diethyl 2-[(methylsulfonyl)oxy]-2-(p-nitrophenyl)ethylene-1,1-dicarboxylate (**1a**) and diethyl (p-nitrobenzoyl)malonate were prepared according to Rappoport and Topol.[8] Diethyl benzoylmalonate was prepared according to Lund.[25] The triethylammonium salt of benzoylmalononitrile (**10**) was prepared according to Fleury and Libis,[26a] and the enolate salt was converted to the enol according to Dornow.[26b] α-Benzoylpropionitrile was prepared according to Hassner.[27] The substitution products diethyl 2-morpholino- (and 2-piperidino)-2-(p-nitrophenyl)ethylene-1,1-dicarboxylate are known from a previous work.[8]

Diethyl 2-(p-Nitrophenyl)-2-[[(trifluoromethyl)sulfonyl]oxy]ethylene-1,1-dicarboxylate (1b). To a solution of diethyl (p-nitrobenzoyl)malonate (2 g, 6.5 mmol) in CH_2Cl_2 (60 mL) was added pyridine (1.05 mL, 13 mmol). After being stirred for 15 min, the solution was cooled in an ice−salt bath and trifluromethanesulfonic anhydride (1.5 mL, 9 mmol) was added. The mixture was stirred for 3 days in the dark and filtered, and the solvent was evaporated. The residue was extracted with 1:1 ether−water (100 mL), the aqueous phase washed with ether (50 mL) and dried ($MgSO_4$), and the solvent was evaporated, leaving an orange oil (2.1 g). Chromatography on silica with 85:15 petroleum ether (40−60 °C): ether eluent gave **1b** admixed with acetophenone and diethyl malonate (according to GC−MS) as the main fraction (1.2 g). Chromatography of this fraction on silica with 1:1 petroleum ether: CH_2Cl_2 eluent gave **1b** (700 mg, 24%) as a colorless oil, which then crystallized to a solid, mp 58−9 °C. UV λ_{max} (MeCN): 271 nm (ϵ 22 000 M^{-1} cm^{-1}). IR ν_{max} (neat): 1742 (s, COOEt), 1654 (w, Ph) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.17, 1.38 (2 × 3H, 2t, J = 7.1 Hz), 4.15, 4.41 (2 × 2H, 2q, J = 7.1 Hz), 7.71, 8.32 (4H, AA′BB′q, J = 8.8 Hz). Mass spectrum m/z (relative abundance, assignment): 441 (2, M), 396 (4, M − OEt), 292 (10, M − CF_3SO_3), 150 (B, p-$O_2NC_6H_4CO$), 69 (28, CF_3). Anal. Calcd for $C_{15}H_{14}F_3NO_9S$: C, 40.82; H, 3.20; N, 3.17. Found: C, 40.68; H, 3.07; N, 3.16.

Diethyl 2-[(Methylsulfonyl)oxy]-2-phenylethylene-1,1-dicarboxylate (2a). To a solution of diethyl benzoylmalonate (1 g, 4 mmol) in CH_2Cl_2 (30 mL) was added triethylamine (0.64 mL, 4.6 mmol), and the mixture was stirred for 24 h. Methanesulfonic anhydride (0.8 g, 4.6 mmol) was then added, the mixture was stirred for 8 h and filtered, and the solvent was evaporated. The remainder was extracted with 1:1 ether−water (100 mL), the aqueous phase washed with ether (50 mL) and dried ($MgSO_4$), and the solvent was evaporated, leaving an orange oil (1.1 g). Chromatography on silica with 1:3 ether: petroleum ether (40−60 °C) eluent gave an oil (300 mg) impure by GC−MS. Additional chromatography on silica with 2:3 ether:petroleum ether gave **2a** (250 mg, 18%) as an oil, which on standing gave a colorless solid, mp 46−7 °C. UV λ_{max} (MeCN): 382 nm (ϵ 15 700 M^{-1} cm^{-1}). IR ν_{max} (Nujol): 1730 (s, COOEt), 1654 (w, Ph) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.06, 1.34 (2 × 3H, 2t, J = 7.1 Hz), 3.13 (3H, s), 4.10, 4.32 (2 × 2H, 2q, J = 7.1 Hz), 7.42−7.58 (5H, m). Mass spectrum m/z (relative

(21) Rappoport, Z.; Topol, A. *J. Chem. Soc., Perkin Trans. 2* **1972**, 1823.
(22) Charton, M. *Prog. Phys. Org. Chem*. **1981**, *13*, 119.
(23) Bentley, W. T.; Christl, M.; Kemmer, R.; Llewellyn, G.; Oakley, J. E. *J. Chem. Soc., Perkin Trans. 2* **1994**, 2531.
(24) For collection of data, see: Rappoport, Z. In *Nucleophilicity*; Harris, J. M., McManus, S. P. , Eds.; Advances in Chemistry Series 215; American Chemical Society: Washington, D.C., 1987; p 399.
(25) Lund, H. *Chem. Ber*. **1934**, *67*, 935.
(26) (a) Fleury, J. P.; Libis, B. *Compt. Rend*. **1962**, *254*, 2020. (b) Dornow, A.; Grabhofer, H. *Ber*. **1958**, *91*, 1824.
(27) Rasmussen, J. K.; Hassner, A. *Synthesis* **1973**, *11*, 682.

abundance, assignment): 342 (3, M), 297 (2, M − OEt), 109 (B, PhCO), 77 (20, Ph). Anal. Calcd for $C_{15}H_{18}F_3O_7S$: C, 52.62; H, 5.30. Found: C, 52.80; H, 5.16.

Diethyl 2-[[(Trifluoromethyl)sulfonyl]oxy]-2-phenylethylene-1,1-dicarboxylate (2b). To a solution of diethyl benzoylmalonate (1.5 g, 5.7 mmol) in CCl_4 (50 mL) was added triethylamine (1 mL, 7 mmol). After 3 days of stirring trifluoromethanesulfonic anhydride (1.2 mL, 7.2 mmol) was added at ice−salt bath temperature. TLC analysis after 2 days showed that the precursor did not completely disappear, additional amine and anhydride (7 mmol each) were added, and the mixture was stirred for 2 additional days. The solvent was evaporated, the remainder was extracted with 1:1 ether−water mixture (100 mL), and the aqueous phase was washed with ether (50 mL), dried ($MgSO_4$), and evaporated. The yellow liquid obtained was chromatographed with 1:4 CH_2Cl_2−petroleum ether (40−60 °C), giving **2b** (1 g, 44%) as a colorless oil that on cooling solidified to a colorless solid, mp 32−3 °C. UV λ_{max} (MeCN): 259 nm (ϵ 12 000 M^{-1} cm^{-1}). IR ν_{max} (Nujol): 1740 (s, CO_2Et), 1660 (m, Ph) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.06, 1.37 (2 × 3H, 2t, J = 7.1 Hz), 4.11, 4.38 (2 × 2H, 2q, J = 7.1 Hz), 7.43−7.53 (5H, m). Mass spectrum m/z (relative abundance, assignment): 396 (4.5, M), 351 (5, M − OEt), 247 (13, M − CF_3SO_3), 105 (B, PhCO), 77 (25, Ph). Anal. Calcd for $C_{15}H_{15}F_3O_7S$: C, 45.45; H, 3.81. Found: C, 45.52; H, 3.77.

1,1-Dicyano-2-[(methylsulfonyl)oxy]-2-phenylethylene (3). To a solution of NaOEt, prepared from Na (0.15 g, 6.5 mmol) in EtOH (75 mL), was added benzoylmalononitrile (1.19 g, 7 mmol). The mixture was stirred for 2 days, and the solvent was evaporated, leaving the sodium enolate as a white solid. To a solution of the sodium enolate (1.06 g, 5.5 mmol) in MeCN (35 mL) was added methanesulfonic anhydride (1.22 g, 7 mmol), the mixture was refluxed for 2 h and filtered, and the solvent was evaporated. The remainder was extracted with ether (30 mL) and water (20 mL), the aqueous phase was washed with ether (20 mL) and dried ($MgSO_4$), and the solvent was evaporated, leaving an oil (1.3 g). Chromatography on silica with 45:55 ether:petroleum ether (40−60 °C) gave **3a** (650 mg, 48%) as an oil, which on cooling gave a solid, mp 42−3 °C. UV λ_{max} (MeCN): 298 nm (ϵ 16 000 M^{-1} cm^{-1}); IR ν_{max} (Nujol): 2240 (s, CN), 1600 (m, C=C), 1563 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 3.47 (3H, s), 7.54−7.95 (5H, m). Mass spectrum m/z (relative abundance, assignment): 248 (16, M), 170 (8, $PhCOCH(CN)_2$), 105 (73, PhCO), 79 (B, $MeSO_2$), 77 (38, Ph). Anal. Calcd for $C_{11}H_8N_2O_3S$: C, 53.22; H, 3.25; N, 11.28. Found: C, 53.39; H, 3.21; N, 11.30.

(*E*)- and (*Z*)-2-Cyano-1-[(methylsulfonyl)oxy]-1-phenylpropene (4a and 5a). To a solution of α-benzoylpropionitrile (1 g, 6.3 mmol) in CH_2Cl_2 (50 mL) were added triethylamine (1 mL, 7.2 mmol) and methanesulfonic anhydride (1 g, 7.2 mmol). After the solution was refluxed for 26 h, 30% of the precursor was still unreacted, additional amounts (7.2 mmol each) of the amine and anhydride were added, and reflux continued for 17 h. The solvent was evaporated, and the remainder was extracted with a 1:1 ether−water mixture (100 mL). The aqueous phase was further washed with ether (2 × 50 mL), and the combined organic phase was dried ($MgSO_4$) and evaporated, leaving an oil (1.4 g). Two consecutive chromatographies on silica with 3:7 ether:petroleum ether and 3:7 CH_2Cl_2:petroleum ether gave two fractions.

(a) **4a** (600 mg, 40%) was colorless oil that solidified on cooling to a colorless solid, mp 60 °C. Identified as the E isomer by X-ray crystallography. UV λ_{max} (MeCN): 258 nm (ϵ 13 000 M^{-1} cm^{-1}). IR ν_{max} (neat): 2223 (s, C≡N), 1653 (s, Ph or C=C) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 2.19 (3H, s), 2.85 (3H, s), 7.47−7.69 (5H, m). Mass spectrum m/z (relative abundance, assignment): 237 (48, M), 159 (69, MH − $MeSO_3$), 105 (B, PhCO), 77 (80, Ph). Anal. Calcd for $C_{11}H_{11}NO_3S$: C, 55.68; H, 4.67; N, 5.90. Found: C, 55.71; H, 4.68; N, 5.87.

(b) **5a** (100 mg, 6%) was a colorless oil that was chromatographed on a PLC plate with 3:7 CH_2Cl_2:petroleum ether (40−60 °C), giving 50 mg (3%) of an oil that on cooling gave a colorless solid, mp 70 °C. UV λ_{max} (MeCN): 256 nm (ϵ 17 000 M^{-1} cm^{-1}). IR ν_{max} (Nujol): 2220 (s, C≡N), 1640 (s, Ph) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 2.07 (3H, s), 3.21 (3H, s), 7.49 (5H, s). Mass spectrum m/z (relative abundance, assignment): 237 (65, M), 159 (88, M − $MeSO_3$), 105 (B, PhCO), 77 (70, Ph). Anal. Calcd for $C_{11}H_{11}NO_3S$: C, 55.68; H, 4.67; N, 5.90. Found: C, 55.90; H, 4.80; N, 6.19.

(*E*)- and (*Z*)-2-Cyano-2-phenyl-2-[[(trifluoromethyl)sulfonyl]oxy]ethylene (4b and 5b). To a solution of α-benzoylpropionitrile (1.5 g, 10 mmol) in CH_2Cl_2 (50 mL) was added triethylamine (1.5 mL, 11 mmol), and after the mixture was cooled in an ice−salt bath trifluoromethanesulfonic anhydride (2.5 mL, 15 mmol) was added. After the mixture was stirred overnight, the reaction was incomplete, and more amine and anhydride (0.4 mL each) were added. After an additional 18 h of stirring, the solvent was evaporated, the remainder was extracted with 1:1 ether−water (60 mL), the aqueous phase washed with more ether (30 mL), and the combined ethereal phase was dried ($MgSO_4$) and evaporated, leaving an oil (2 g). Chromatography on silica with 1:9 ether:petroleum ether (40−60 °C) eluent gave two fractions.

(a) **4b** (700 mg, 24%) was a colorless oil. The assignment as the *E* isomer is based on analogy with the formation of **4a** as the major isomer. UV λ_{max} (MeCN): 257 nm (ϵ 11 000 M^{-1} cm^{-1}). IR ν_{max} (neat): 2230 (s, C≡N), 1648 (s, Ph or C=C) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 2.21 (3H, s), 7.48−7.67 (5H, m). Mass spectrum m/z (relative abundance, assignment): 291 (67, M), 142 (9, M − CF_3SO_3), 105 (B, PhCO), 77 (58, Ph). Anal. Calcd for $C_{11}H_8F_3NO_3S$: C, 45.36; H, 2.77; N, 4.81. Found: C, 45.12; H, 3.05; N, 5.13.

(b) An oil (290 mg), which was a mixture of two compounds according to ^1H NMR, was obtained. Chromatography with 3:7 CH_2Cl_2:petroleum ether (40−60 °C) eluent gave **5b** (120 mg, 4%) as a colorless oil, which on cooling gave a colorless solid, mp 35 °C. UV λ_{max} (MeCN): 256 nm (ϵ 19 000 M^{-1} cm^{-1}). IR ν_{max} (Nujol): 2235 (s, C≡N), 1654 (s, Ph or C=C) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 2.09 (3H, s), 7.46−7.54 (5H, m). Mass spectrum m/z (relative abundance, assignment): 291 (27, M), 142 (9, M − CF_3SO_3), 105 (B, PhCO), 77 (68, Ph). Anal. Calcd for $C_{11}H_8F_3NO_3S$: C, 45.36; H, 2.77; N, 4.81. Found: C, 45.43; H, 2.48; N, 4.79.

Diethyl 2-Piperidino-2-phenylethylene-1,1-dicarboxylate (9a). A solution containing diethyl 2-phenyl-2-[[(trifluoromethyl)sulfonyl]oxy]ethylene-1,1-dicarboxylate (**2b**) (200 mg, 0.5 mmol) and piperidine (0.12 mL, 1.2 mmol) in MeCN (5 mL) was stirred for 3 h. The solvent was evaporated, and the remainder was extracted with ether (40 mL) and filtered. Evaporation of the solvent left a yellow oil that solidifed on cooling. Attempted crystallizaion of the oil from EtOH, $CHCl_3$, or petroleum ether had failed due to the high solubility of the compound. Chromatography on silica with EtOH eluent, followed by evaporation of the solvent, gave an oil that after addition of petroleum ether gave yellow grains (40 mg, 25%), mp 88 °C. UV λ_{max} (MeCN): 240 nm (ϵ 18 000 M^{-1} cm^{-1}), 332 nm (12 000 M^{-1} cm^{-1}). IR ν_{max} (Nujol): 1687, 1660 (s, N−C=CCO_2Et), 1640 (w) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.02 (2 × 3H, t, J = 7 Hz), 1.69 (6H, br), 3.14 (4H, br), 3.98 (2 × 2H, q, J = 7 Hz), 7.42 (5H, m). Mass spectrum m/z (relative abundance, assignment): 331 (17, M), 286 (16, M − OEt), 258 (B, M − CO_2Et), 240 (24, M − CO_2Et − H_2O), 212 (66, M − CO_2Et − EtOH).

Diethyl 2-Morpholino-2-phenylethylene-1,1-dicarboxylate (9b). A solution containing morpholine (0.1 mL, 1.1 mmol) and diethyl 2-phenyl-2-[[(trifluoromethyl)sulfoxyl]oxy]-ethylene-1,1-dicarboxylate (**2b**) in MeCN (5 mL) was stirred for 2 h. The solvent was evaporated, and the oil obtained was chromatographed on silica with 3:7 ether:petroleum ether eluent. A yellow oil that crystallized to a solid (70 mg, 85%), mp 92 °C, was obtained. UV λ_{max} (MeCN): 237 nm (ϵ = 16 000 M^{-1} cm^{-1}), 328 nm (ϵ = 11 000 M^{-1} cm^{-1}). IR ν_{max} (Nujol): 1688, 1672 (s, N−C=CCO_2Et), 1580 (w) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.03 (2 × 3H, t, J = 7 Hz), 3.18 (4H, t, J = 5 Hz), 3.76 (4H, t, J = 5 Hz), 4.00 (2 × 2H, 2q, J = 7 Hz), 7.41 (5H, m). Mass spectrum m/z (relative abundance, assignment): 333 (53, M), 288 (74, M − OEt), 260 (77, M − CO_2Et), 242 (66, M − CO_2Et − H_2O), 214 (B, ?).

(*E*)-2-Cyano-1-(methylthio)-1-phenylpropene (10). To a solution of (*E*)-2-cyano-1-[[(trifluoromethyl)sulfonyl]oxy]-1-phenylpropene (**4b**) (200 mg, 0.86 mmol) in ethanol (5 mL) was added sodium methylthiolate (0.3 g, 1.1 mmol). A rapid

exothermic reaction took place. After 5 min the solvent was evaporated and the remainder was extracted with ether (20 mL) and water (20 mL). The organic phase was washed with water (3 × 20 mL), dried (Na_2SO_4), and evaporated. The remaining yellow ether (110 mg) was chromatographed on silica with 95:5 ether:petroleum ether eluent, giving a yellow oil (80 mg, 49%). UV λ_{max} (MeCN): 279 nm (ϵ 17 000 M^{-1} cm^{-1}). IR ν_{max} (neat): 2210 (s, C≡N) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.91 (3H, s), 2.12 (3H, s), 7.31−7.44 (5H, m). Mass spectrum *m/z* (relative abundance, assignment): 189 (B, M), 174 (45, M − Me), 147 (24, M − Me − HCN), 140 (20), 115 (55, PhC≡CMeH). Anal. Calcd for $C_{11}H_{11}NS$: C, 69.80; H, 5.86; N, 7.40. Found: C, 70.10; H, 6.11; N, 7.18.

Substitution of (Z)-2-Cyano-1-[[(trifluoromethyl)sulfonyl]oxy]-1-phenylpropene (5b) with MeS⁻. MeSNa (0.03 g, 0.26 mmol) was added with stirring to (Z)-2-cyano-1-[[(trifluoromethyl)sulfonyl]oxy]-1-phenylpropene (**5b**) (30 mg, 0.13 mmol) in ethanol (5 mL). The solvent was evaporated after 1 h, the remainder was extracted with ether (10 mL) and water (10 mL), and the etheral phase washed with water (3 × 10 mL) and dried (Na_2SO_4). The oil obtained (20 mL) was chromatographed on silica with 9:1 ether:petroleum ether (40−60 °C), giving a few mg of a yellow oil. The material was sufficient only for measuring a mass spectrum [*m/z* (relative abundance, assignment): 189 (B, M), 174 (41, M − Me), 147 (24, M − Me − HCN), 140 (31), 115 (62, PhC≡CMeH)] and ^1H NMR spectrum. The latter showed the presence of the retained substitution product [δ ($CDCl_3$): 1.92 (3H, s), 1.94 (3H, s), 7.2−7.5 (5H, m)] as the major product, admixed with 16% of the isomeric product.

Reactions of 1b with Sodium *p*-Toluenethiolate. A solution containing sodium *p*-toluenethiolate (80 mg, 0.55 mmol) and **1b** (220 mg, 0.5 mmol) in EtOH (10 mL) was stirred for 2 h. The solvent was evaporated, and the remainder was extracted with ether, which was dried ($MgSO_4$) and evaporated, giving an oil (180 mg, 77%) with an ^1H NMR [δ ($CDCl_3$): 0.96, 1.37 (2 × 3H, 2t, J = 7.1 Hz), 2.19 (3H, s), 3.94, 4.36 (2 × 2H, 2q, J = 7.1 Hz), 6.87, 7.05 (2 × 2H, 2AA′BB′q, J = 8.2 Hz), 7.19, 7.94 (2 × 2H, 2AA′BB′q)] identical with that reported for the substitution product, diethyl 2-(*p*-tolylthio)-2-(*p*-nitrophenyl)ethylene-1,1-dicarboxylate.[8]

Reactions with Thio-nucleophiles. In a typical experiment, 1 equiv of the vinyl mesylate (**1a** or **4a**) was mixed with 2 equiv of NaSMe in ethanol, and the reaction was followed by TLC. When all the precursor had disappeared the EtOH was evaporated and the remainder was extracted with 1:1 ether−water. The organic phase was separated, dried ($MgSO_4$), and evaporated, leaving very small quantities of unidentified compound. Acidification of the organic phase gave a white emulsion that was extracted with ether. The organic phase was dried ($MgSO_4$) and evaporated, giving an oil that, according to its ^1H NMR, was identical with that of the precursor enol for the preparation of the mesylate.

A similar experiment of **4a** with NaOMe in MeOH gave a similar result.

Dimethyl 2-Mesityl-2-(tosyloxy)ethylene-1,1-dicarboxylate (13). A mixture of dimethyl mesitoylmalonate (1.6 g, 6 mmol) and tosyl chloride (1.2 g, 6 mmol) in pyridine (5 mL) was kept in the refrigerator for 20 h. A solid (presumably pyridine·HCl) was obtained. The mixture was poured on 1 N HCl (50 mL), extracted with CH_2Cl_2 (2 × 100 mL), washed with dilute HCl solution and with water, and dried ($MgSO_4$), and the solvent was evaporated at 50 °C. A white solid, sparingly soluble in EtOH or hexane, was obtained. Crystallization from benzene−hexane gave a white solid, mp 120 °C (0.89 g, 32%). UV λ_{max} (EtOH): 243 nm (ϵ 8000 M^{-1} cm^{-1}), 284 (6000), 293 (6000). IR ν_{max} ($CHCl_3$): 1730 (s, CO_2R), 1640 (C=O) cm^{-1}. ^1H NMR ($CDCl_3$) δ: 2.15 (6H, s), 2.23 (3H, s), 2.38 (3H, s), 3.58 (3H, s, CO_2Me cis to Mes), 3.87 (3H, s, CO_2-Me trans to Mes), 6.69 (2H, s), 7.12, 7.39 (4H, AA′BB′ q, J = 8.4 Hz). Mass spectrum *m/z* (relative abundance, assignment): 432 (5, M), 277 (72, M − SO_2Tol), 246 (B, M − SO_2Tol − MeO), 228 (29, M− SO_2Tol − OMe − H_2O), 218 (19, M − SO_2Tol − COOMe), 201 (23, M − SO_2Tol − COOMe − H_2O), 173 (65, MesCH=CHCO), 155 (77, Tos), 147 (95, MesCO), 119 (86, Mes). Anal. Calcd for $C_{22}H_{24}SO_7$: C, 61.11; H, 5.55; S, 7.41. Found: C, 61.11; H, 5.84; S, 6.88.

Reactions of 2-Mesityl-2-(tosyloxy)ethylene-1,1-dicarboxylate with Nucleophiles. (a) With Sodium *p*-Toluenethiolate. To the tosylate **13** (0.43 g, 1 mmol) in DMF (5 mL) was added solid sodium *p*-toluenethiolate (0.19 g, 1.3 mmol). No color was developed. After the mixture was stirred for 48 h at rt and worked up as above, the product was analyzed by NMR. A 55:45 mixture of **13** to dimethyl α-mesitoylmalonate (**12**) was observed, with no trace of the substitution product. Chromatography on silica gave an oil (0.15 g, 55%), which according to the ^1H NMR and TLC is **12**, and an oil (0.15 g), which is a 4:1 mixture of **13** to **12**.

(b) With Sodium *p*-Cresolate. To a solution of **13** (0.22 g, 0.51 mmol) in DMF (3 mL) was added sodium *p*-cresolate (0.1 g, 0.8 mmol). The colorless clear solution was stirred for 47 h at rt. After the usual workup a viscous oil was obtained, which according to the ^1H NMR consists of a 15:85 mixture of **13** to **12**. The expected substitution product was not obtained. Chromatography over silica gave **12** (90 mg, 65%), which was identified by NMR and TLC.

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