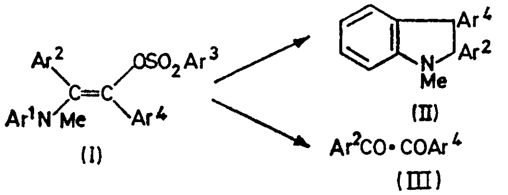
Reactivity of Vinyl Sulphonic Esters. Part XV.[1] Unimolecular Cleavage of the Sulphur–Oxygen Bond in the Ethanolysis of Aminovinyl Arenesulphonates

By **Aldo Burighel, Giorgio Modena,*** and **Umberto Tonellato,** Centro ' Meccanismi di Reazioni Organiche ' del C.N.R., Istituto di Chimica Organica, Università di Padova, 35100 Padova, Italy

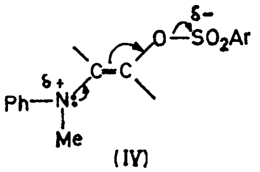
Kinetic and product analyses indicate that 1,2-diaryl-2-[aryl(methyl)amino]vinyl arenesulphonates react in dry ethanol *via* a rate-limiting heterolysis of the sulphur–oxygen bond to generate sulphinate anions and carbonyl derivatives. The behaviour in other solvolytic media is also briefly discussed.

THE investigation of the effect of β-substituents in the unimolecular reactivity[2] of vinyl sulphonic esters brought to light the rather peculiar behaviour of β-aminovinyl sulphonates of general structure (I).[3] They react in a variety of solvents to give either indole (II) or benzil (III) derivatives as major final products.



	Ar^1	Ar^2	Ar^3	Ar^4
a;	Ph	Ph	C_6H_4Br-*p*	Ph
b;	Ph	Ph	C_6H_4Br-*p*	C_6H_4Me-*p*
c;	Ph	Ph	C_6H_4Br-*p*	C_6H_4Cl-*p*
d;	Ph	C_6H_4Me-*p*	C_6H_4Br-*p*	Ph
e;	Ph	C_6H_4Cl-*p*	C_6H_4Br-*p*	Ph
f;	C_6H_4Me-*p*	Ph	C_6H_4Br-*p*	Ph
g;	C_6H_4Cl-*m*	Ph	C_6H_4Br-*p*	Ph
h;	C_6H_4Cl-*p*	Ph	C_6H_4Br-*p*	Ph
i;	Ph	Ph	C_6H_4Me-*p*	Ph

The hypothesis was advanced that products (II) and (III) derive from different reaction pathways, (a) an S_N1-type reaction through an open vinyl cation followed by cyclization to give (II) and (b) an internal redox fragmentation possibly through the transition state (IV) involving displacement of the sulphinate anion to give (III). This was, in fact, isolated as the acid in experiments carried out in inert solvents using boron trifluoride as catalyst.



(IV)

Reaction (b) is an unusual mode of decomposition for sulphonates. Although sulphinate displacements in base catalysed eliminations[4] or S_N2 processes[5] have been reported, spontaneous solvolyses involving oxygen–sulphur bond heterolysis have not, as far as we are aware, been observed even under forcing conditions. Thus, phenyl toluene-*p*-sulphonate is unreactive at 190° in acetic acid[6] and, as extreme cases, phenyl and *p*-methoxyphenyl trifluoromethanesulphonates are virtually inert in acetic acid and trifluoroethanol at high temperatures.[7] Therefore, it seemed worthwhile to investigate reaction (b) further and define its mechanistic features.

RESULTS

Esters (Ia—i) have been synthesized by a described method.[3]

Preliminary experiments showed that in most solvents reactions (a) and (b) are concurrent. Moreover, when the decomposition of esters (I) is carried out in aqueous media, a third type of reaction, *i.e.*, the enamine hydrolysis (1) (see Discussion section), may also interfere and becomes dominant in the presence of strong acids.

$$\text{(I)} \xrightarrow[-\text{NHMeAr}^1]{\text{HOH (H}^+\text{)}} \text{Ar}^2\text{CO}\cdot\text{CH(O}_3\text{SAr}^3\text{)Ar}^4 \longrightarrow \text{products} \quad (1)$$

Products from Reaction of Ester (Ia).—(a) *In* 4 : 1 *ethanol–water.* The products isolated after complete reaction at 80° were (V) (23%), (VI) (27%), (VII) (33%), and (VIII) (10%). Both *p*-bromobenzenesulphonic (55%) and *p*-bromobenzenesulphinic (32%) acids were also identified together with *N*-methylaniline. The indole derivative was absent.

PhCO·CH(OH)Ph (V)	PhCO·CH(OEt)Ph (VI)
PhCO·COPh (VII)	PhCH(NMePh)·COPh (VIII)

$PhCO\cdot CH(OSO_2C_6H_4Br$-*p*$)Ph$
(IX)

$PhCO\cdot C(OMe)_2Ph$ (X)	$PhCO\cdot C(OEt)_2Ph$ (XI)

The rate of disappearance of (Ia) in the same solvent mixture was found to be enhanced by addition of strong acids. In the presence of 0·82N-perchloric acid, after 6 h at 30°, the products isolated were (V) (23%), (VII) (33%), (IX) (20%), and *N*-methylaniline (78%). *p*-Bromobenzenesulphinic acid as well as the indole derivative were absent.

---

[1] Part XIV, P. Bassi and U. Tonellato, *J.C.S. Perkin I*, 1973, 669.

[2] A. Burighel, G. Modena, and U. Tonellato, *J.C.S. Perkin II*, 1972, 2206 and previous papers in the series; P. Bassi and U. Tonellato, *Gazzetta*, 1972, **102**, 387; G. Modena and U. Tonellato, *Adv. Phys. Org. Chem.*, 1971, **9**, 185.

[3] G. Capozzi, G. Modena, and L. Ronzini, *J.C.S. Perkin I*, 1972, 1136.

[4] J. D. Loudon and I. Wellings, *J. Chem. Soc.*, 1959, 1781.

[5] J. Ferns and A. Lapworth, *J. Chem. Soc.*, 1912, **101**, 273; S. Oae and R. Kiritani, *Bull. Chem. Soc. Japan*, 1965, **38**, 765 and references therein.

[6] J. D. Roberts and V. C. Chambers, *J. Amer. Chem. Soc.*, 1951, **73**, 5034.

[7] T. M. Su, W. F. Sliwinski, and P. v. R. Schleyer, *J. Amer. Chem. Soc.*, 1969, **91**, 5386 and references therein.

(b) *In methanol.* Ester (Ia) after 8 h at 90° afforded (VII) (31%), 1-methyl-2,3-diphenylindole (11%), and acetal (X) (41%). Both sulphonic (7%) and sulphinic acid (and its methyl ester) were found in the reaction mixture together with *N*-methylaniline.

(c) *In ethanol.* The products isolated and identified after complete solvolysis at 80° were essentially benzil (VII) (48%) and acetal (XI) (33%) together with *p*-bromobenzenesulphinic acid (93%) and possibly small amounts of its ethyl ester. *p*-Bromobenzenesulphonic acid as well as compounds (V), (VI), and (VIII), and indole derivatives were virtually absent. Control experiments have shown that *p*-bromobenzenesulphonic acid is stable under the reaction conditions.

On this basis, dry ethanol was eventually chosen as the most convenient solvent for the kinetic study of the ' sulphinate ' type (b) reaction mechanism.

Kinetics.—Esters (Ia—i) react in ethanol by first-order kinetics up to at least 60% (a modest autocatalytic effect becomes manifest as reaction proceeds further) and up to 80—90% in the presence of added base (triethylamine). The specific rate constants measured in the presence or absence of base were however coincident within the estimated experimental error (±4%). The rates were measured spectrophotometrically and data are shown in Table 1.

TABLE 1

Rate coefficients [a] (10^4 k/s^{-1}) and activation parameters for the solvolysis of esters (Ia—i) in ethanol

	Temp. (°C)			E_a [b]	$\Delta S^\ddagger$ [c]
Ester	80	90	100	kcal mol^{-1}	cal mol^{-1} K^{-1}
(Ia)	0·89	2·60	6·85	26·8	−3·2
(Ib)		2·50			
(Ic)		2·58			
(Id)		3·28			
(Ie)		1·62			
(If)	2·11	6·42	15·4	26·3	−2·8
(Ig)		0·38			
(Ih)		0·95			
(Ii)		0·88			

[a] Average of two or three kinetic runs. [Ester] = 1—2 × 10^{-4}M. [b] Estimated errors ±0·9 kcal mol^{-1}. [c] At 90° estimated error ±2·5 cal mol^{-1} K^{-1}.

The rate constants at 90° for esters (Ia—c) indicate that there is no appreciable effect of substituents on Ar^4. On the other hand, substituents on Ar^2 have a modest effect on rate whereas those on Ar^1 have a rather large one. Although the range of substituents is limited, the rate data are well correlated by the Hammett relationship [8] and ρ is virtually 0 for variation in Ar^4, −0·57 (correlation coefficient [8] r = 0·9998) for Ar^2, and −2·2 (r = 9982) for Ar^1.

DISCUSSION

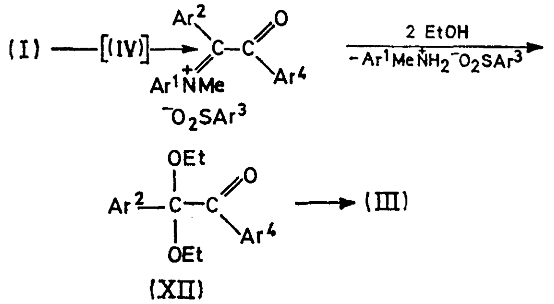
The kinetic results and the nature of the products fit the hypothesis that esters (I) in ethanol react by way of a rate-limiting heterolytic cleavage of the oxygen–sulphur bond of the sulphonate group.

The leaving group effect on rate, *p*-bromobenzenesulphonate (Ia) is 2·9 times more reactive than toluene-*p*-sulphonate (Ii), is consistent either with those reported [9] for a carbon–oxygen heterolytic rupture or with that expected for an oxygen–sulphur cleavage. However, the absence of sulphonic acid among the reaction products as well as the absence of any appreciable rate effect of variation of Ar^4 rule out the possibility of carbon–oxygen heterolysis. The ρ values measured [2,10] in S_N1 vinylic reactions for such substituents range between −3·6 and −6·6 by use of σ^+ constants.

On the other hand the ρ value relative to substituents on the Ar^1 is quite large in spite of their remote position from the reaction centre and may be compared with the value of −2·7 (25°; water) reported [11] for the protonation of substituted anilines. Since a protonation pre-equilibrium of the anilino-group of esters (I) in the conditions used is apparently excluded by the absence of any effect of added base on the rate of solvolysis, the large fraction of positive charge developing on nitrogen in the transition state is probably due to the effect of the delocalization of the nitrogen lone pair toward oxygen through the double bond [see structure (IV)]. The positive charge is only partly shared also by the β-carbon atom as reflected by the small ρ value of substituents on Ar^2.

The small negative activation entropy of the process indicates that nucleophilic assistance by the solvent is unimportant and the driving force for the oxygen–sulphur heterolysis is provided by the electronic conjugative assistance of the nitrogen end of the molecule. The reported inertness of aryl sulphonates in very drastic solvolytic conditions (see above) gives a measure of such effect.

The stoicheiometry can be reasonably defined in terms of Scheme 1 to account for the final products of type (III) and (XII).



SCHEME 1

The ' sulphinate ' mechanism prevails in ethanol over other possible routes probably by a small margin. Changing from ethanol to methanol brings forth a small but sizable incursion of reaction (a) leading to indole derivative. Changing from dry to aqueous ethanol further complicates the reaction pattern. Products analogous to (VIII) [(XIII)] conceivably derive from vinylic solvolysis following mechanism (a); moreover a

---

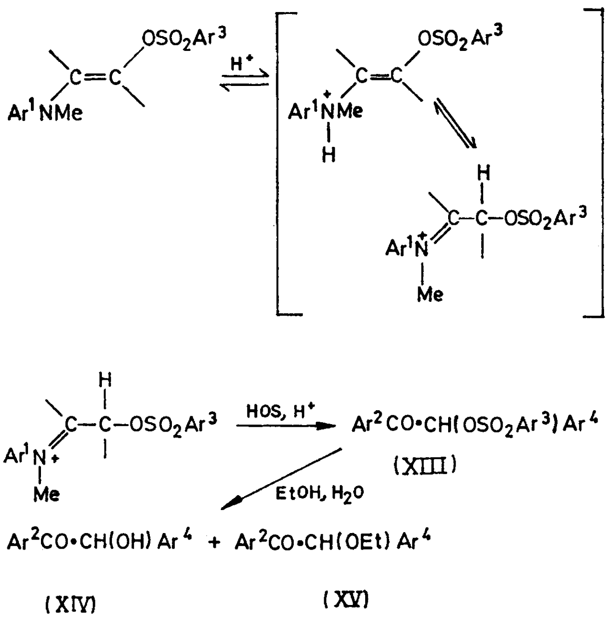
[8] H. H. Jaffé, *Chem. Rev.*, 1953, **53**, 191.

[9] P. E. Peterson and J. M. Indelicato, *J. Amer. Chem. Soc.*, 1968, **90**, 6515; Z. Rappoport and J. Kaspi, *ibid.*, 1970, **92**, 3220; *J.C.S. Perkin II*, 1972, 1102; G. Modena, and U. Tonellato, *J. Chem. Soc.* (*B*), 1971, 1569.

[10] L. L. Miller and D. A. Kaufman, *J. Amer. Chem. Soc.*, 1968, **90**, 7282; C. A. Grob and H. R. Pfaendler, *Helv. Chim. Acta*, 1971, **54**, 2060

[11] See J. E. Leffler and E. Grunwald, ' Rates and Equilibria of Organic Reactions,' Wiley, New York, 1963.

third type of reaction, which is exclusive in strongly acidic conditions must be invoked to account for products analogous to (V) and (VI) [(XIV) and (XV)] presumably deriving from solvolysis of (IX). This last reaction has the hallmarks of the enamine hydrolysis investigated in detail by other authors[12] and the suggested mechanism is outlined in Scheme 2.



SCHEME 2

EXPERIMENTAL

M.p.s are uncorrected. Chemical shifts are relative to tetramethylsilane for deuteriochloroform solutions. ' Super-dry ' ethanol and methanol were obtained following standard procedures. Esters (Ia), (Ib), (Id), and (If) were prepared as described.[3] All other esters (Ic), (Ie), and (Ig)—(Ii) were obtained (55—65% yields; analytical data are reported in Table 2) by the same method *i.e.* by sulphonylation of the corresponding α-aryl-α-[aryl(methyl)-amino]acetophenones.

TABLE 2

Analytical data for new sulphonates (I) and α-aryl-α-[aryl(methyl)amino]acetophenones (XVI)—(XIX)

		Found (%)						Required (%)					
Compound	M.p. (°C)	C	H	Br	Cl	N	S	C	H	Br	Cl	N	S
(Ic)	136—137	58·2	3·8	14·55	6·1	2·8	5·55	58·35	4·0	14·35	6·35	2·5	5·75
(Ie)	120—121	58·1	3·95	14·6	6·6	2·35	5·8	58·35	4·0	14·35	6·35	2·5	5·57
(Ig)	139—140	58·4	3·8	14·5	6·4	2·65	5·75	58·35	4·0	14·35	6·35	2·5	5·75
(Ih)	145—146	58·2	3·9	14·05	6·75	2·55	5·8	58·35	4·0	14·35	6·35	2·5	5·75
(Ii)	137—138	74·0	5·4			3·0	7·25	73·8	5·55			3·05	7·05
(XVI)	106—107	75·3	5·8		10·8	3·9		75·1	5·4		10·55	4·15	
(XVII)	100—101	75·2	5·4		10·65	4·05		75·1	5·4		10·55	4·15	
(XVIII)	118—119	75·15	5·55		10·6	4·2		75·1	5·4		10·55	4·15	
(XIX)	109	75·05	5·5		10·75	4·25		75·1	5·4		10·55	4·15	

The new α-aminoacetophenones: p-*chloro*-α-[*methyl*(*phenyl*)*amino*]-α-*phenylacetophenone* (XVI), α-m-*chlorophenyl*-α-[*methyl*(*phenyl*)*amino*]*acetophenone* (XVII), α-[p-*chlorophenyl*(*methyl*)*amino*]-α-*phenylacetophenone* (XVIII), and α-[m-*chlorophenyl*(*methyl*)*amino*]-α-*phenylacetophenone* (XIX) were obtained (80—90% yields; analytical data are shown in Table 2) by treatment[13] of the appropriate α-bromoacetophenones with *N*-methylaniline and its derivatives. α-*Bromo*-α-(m-*chlorophenyl*)*acetophenone* (93%) was synthesized by treatment of α-(*m*-chlorophenyl)acetophenone, m.p. 42—43° (lit.,[14] 43°), with an equimolar amount of bromine in carbon tetrachloride.[15] When crystallized from ligroin, it had m.p. 40—41° (Found: C, 54·4; H, 3·35; Br, 26·0; Cl, 11·7. $C_{14}H_{10}BrClO$ requires C, 54·3; H, 3·25; Br, 25·8; Cl, 11·45%).

Product Analysis: General Procedure.—A solution of ester (Ia) (1·5—2mM) in a suitable solvent (100 ml) was heated at the desired temperature in a thermostated bath. After complete reaction, the solution was poured in dichloromethane–water [containing $NaHCO_3$ (2·5—3·5mM)]. After two cross extractions, the aqueous layer was reduced to small volume (10—15 ml) under reduced pressure and chromatographed on a column packed with a strongly acid ion exchanger (Merck I, 4765). Sulphonic acid and sulphinic acids were thus effectively separated, identified (by comparing their i.r. and u.v. spectra[16] with those of authentic samples), and determination by titration. The organic layer was then treated with 0·1N-$HClO_4$ (from which the *N*-methylaniline was occasionally isolated and determined), water, dried (Na_2SO_4), and the solvent evaporated. The crude material was chromatographed on a silica gel column using the appropriate mixture of benzene, ether, and light petroleum chosen on the basis of t.l.c. tests.

(a) *In* 4 : 1 *ethanol–water*. From ester (Ia) (0·878 g) at 80° for 6 h, the following products were isolated and identified: *p*-bromobenzenesulphonic acid (55%); *p*-bromobenzenesulphinic acid (32·5%); benzoin (V) (82 mg, 23%); and benzil (VII) (117 mg, 33%), by comparing their i.r. spectra with those of commercial samples; α-[methyl-(phenyl)amino]-α-phenylacetophenone[3] (VIII) (51 mg, 10%), m.p. 98—99° (lit.,[17] 99·5—101·5°); α-ethoxy-α-phenylacetophenone (VI) (110 mg, 27%), m.p. 58—60° (lit.,[18] 62°), τ 1·7—2·2 (2H, m), 2·4—3·0 (8H, m), 4·42 (1H, s), 6·4 (2H, q), and 8·75 (3H, t); and *N*-methylaniline (148 mg, 82%).

(b) *In* 4 : 1 *ethanol–water containing* 0·82N-$HClO_4$. From ester (Ia) (0·866 g) at 30° for 6 h, the products isolated and identified were: benzoin (V) (82 mg, 23·2%) and its ethyl derivative (VI) (132 mg, 33%); α-*benzoylbenzyl* p-*bromobenzenesulphonate* (IX), m.p. 125—126° (Found: C, 55·55; H, 3·45; Br, 18·25; S, 7·25. $C_{20}H_{15}BrO_4S$ requires C,

---

[12] E. J. Stamhuis and W. Mass, *J. Org. Chem.*, 1965, **30**, 2156; P. Y. Sollenberger and R. B. Martin, *J. Amer. Chem. Soc.*, 1970, **92**, 4261.

[13] F. Brown and F. G. Mann, *J. Chem. Soc.*, 1948, 858.

[14] S. S. Jenkins, *J. Amer. Chem. Soc.*, 1933, **55**, 2896.

[15] S. S. Jenkins, *J. Amer. Chem. Soc.*, 1934, **56**, 682.

[16] See S. De Toni and D. Hadzi, *J. Chem. Soc.*, 1955, 3163.

[17] R. E. Lutz, R. H. Jordan, and W. L. Truett, *J. Amer. Chem. Soc.*, 1950, **72**, 4085.

[18] E. Bergmann and J. Hervey, *Chem. Ber.*, 1929, **62**, 896.

55·7; H, 3·5; Br, 18·5; S, 7·45%), τ 2·0—2·4 (2H, m), 2·4—3·0 (12H, m), and 3·25 (1H, s) (143 mg, 20%); and *N*-methylaniline (138 mg, 78%).

(c) *In methanol.* From ester (Ia) (0·752 g) at 90° for 8 h, the products isolated and identified were: *p*-bromobenzenesulphonic acid (7%) and *p*-bromobenzenesulphinic (72%) acids; 1-methyl-2,3-diphenylindole (45 mg, 11%), by comparing its i.r. and ^{1}H n.m.r. spectra with those of an authentic sample;[3] benzil (VII) (95 mg, 31·3%); α,α-*dimethoxy*-α-*phenylacetophenone* (X), m.p. 64—65° (Found: C, 74·65; H, 6·4. $C_{16}H_{16}O_3$ requires C, 74·95; H, 6·3%), τ 1·8—2·1 (2H, m), 2·2—2·8 (8H, m), and 6·8 (6H, s) (152 mg, 41%); and presumably methyl *p*-bromobenzenesulphinate by its i.r. spectrum,[19] $\nu_{S=O}$ 1128 cm^{-1} ($CHCl_3$), τ 2·3—2·7 (4H, m) and 6·5 (3H, s) (30 mg, 9%).

(d) *In ethanol.* From ester (Ia) (1·018 g) at 80° for 17 h: *p*-bromobenzenesulphinic acid (93%) and *N*-methylaniline (173 mg, 83%); benzil (VII) (197 mg, 48%); and α,α-*diethoxy*-α-*phenylacetophenone* (XI) (185 mg, 33%) (Found: C, 75·8; H, 6·95. $C_{18}H_{20}O_3$ requires C, 76·05; H, 7·1%), τ 1·8—2·0 (2H, m), 2·2—2·8 (8H, m), 6·56 (4H, q), and 8·82 (6H, t).

Kinetic Measurements.—The solutions of esters (*ca.* 2 × 10^{-4}M) in ethanol (100 ml) were sealed under a nitrogen atmosphere in glass vials (5 ml). These were heated at the desired temperature and taken out at appropriate intervals after thermal equilibrium was achieved (1·5—2 min). The disappearance of the substrate was followed by measuring the decrease of the absorption band at $\lambda_{max.}$ in the range 355—367 nm characteristic[12] of each ester under study. Rate constants were calculated by applying the integrated first-order equation by use of a graphic or a least-squares computer programme.

[2/2285 *Received*, 4*th October*, 1972]

[19] E. Bonini, G. Ghersetti, and G. Modena, *Gazzetta*, 1963, **93**, 1222.