Reactivity of Vinyl Sulphonic Esters. Part XI.[1] Behaviour of Aminovinyl *p*-Bromobenzenesulphonates

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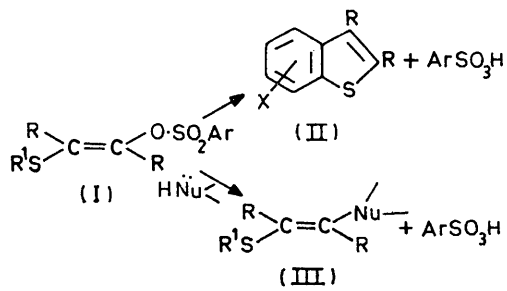
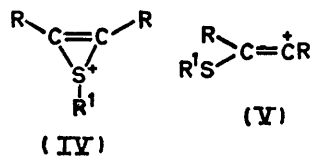
1,2-Diaryl-2-[(*N*-aryl)methylamino]vinyl *p*-bromobenzenesulphonates, prepared by reactions of α-aryl-α-[(*N*-aryl)methylamino]acetophenone derivatives with *p*-bromobenzenesulphonyl chloride and sodium hydride, undergo two kinds of reactions. One formally involves intermediate formation of β-aminovinyl cations to give substitution products and/or cyclisation to give indole derivatives along with *p*-bromobenzenesulphonic acid. The other is a novel internal redox reaction which affords benzil derivatives together with *p*-bromobenzenesulphinic acid, and is catalysed, in inert solvents, by boron trifluoride. The cyclisation to indoles, which is catalysed by aluminium trichloride, occurs without rearrangement, indicating that a β-nitrogen atom in contrast to a β-sulphur atom, does not participate in the reaction by bridging between the two ethylenic carbon atoms.

WE have recently investigated the solvolysis of arylthiovinyl sulphonic esters (I), which, by a unimolecular process, results in either cyclisation (II) or substitution (III) products, depending on the nucleophilicity of the solvent [2] (Scheme 1). Evidence has been given that a



SCHEME 1

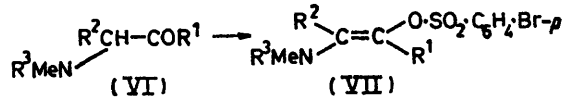
β-sulphur atom anchimerically assists the solvolysis reaction by bridging to give thiirenium ions (IV).[3] On



the other hand kinetic evidence suggests that the transition state has vinyl cation (V) character.[4] We wished to ascertain whether β-oxygen and β-nitrogen atoms could participate in the reaction in a manner similar to β-sulphur atoms. Evidence has recently been given [5] that the β-oxygen atom in aryloxyvinyl sulphonic esters does not participate to any significant extent. We report here a similar study on 1,2-diaryl-2-[(*N*-aryl)methylamino]vinyl *p*-bromobenzenesulphonates (VII). We also investigated a side reaction which under some conditions becomes dominant and gives benzil (VIII) together with the sulphinic acid (X) by an internal redox reaction.

RESULTS

1,2-Diaryl-2-[(*N*-aryl)methylamino]vinyl *p*-bromobenzenesulphonates (VIIa—d) were prepared by sulphonylation of the corresponding α-aryl-α-[(*N*-aryl)-methylamino]acetophenones (VIa—d) in the presence of sodium hydride by a reaction similar to that used for the synthesis of the analogous oxygen [5] and sulphur [3b]



(1)

Reagent NaH–*p*-BrC_6H_4·SO_2Cl.

derivatives [equation (1)]. Table 1 lists the products with their analytical data.

Solvolysis of compound (VIIa) in methanol at 100° afforded, as major products, benzil (VIII) (60%) and 1-methyl-2,3-diphenylindole (IXa) (10%) [equation (2)]. The latter may be formed either by direct cyclisation of the sulphonate (VIIa) or *via* cyclisation of the primary solvolysis product, 1,2-diphenyl-2-[(*N*-phenyl)methylamino]vinyl methyl ether. The latter, however, was not isolated from the reaction mixture.

TABLE 1

Analytical data for sulphonates (VII)

					Found (%)						Required (%)				
	R^1	R^2	R^3	M.p. (°C)	C	H	Br	N	S	Formula	C	H	Br	N	S
(VIIa)	Ph	Ph	Ph	109—111	62·5	4·25	15·25	2·75	6·25	$C_{27}H_{23}BrNO_3S$	62·3	4·25	15·35	2·7	6·15
(VIIb)	*p*-Tolyl	Ph	Ph	108—111	62·6	4·4	14·95	2·8	6·1	$C_{28}H_{25}BrNO_3S$	62·9	4·5	14·95	2·6	6·0
(VIIc)	Ph	Ph	*p*-Tolyl	132—134	62·5	4·55	15·0	2·7	6·05	$C_{28}H_{25}BrNO_3S$	62·9	4·5	14·95	2·6	6·0
(VIId)	Ph	*p*-Tolyl	Ph	120—122	62·7	4·45	14·55	2·7	6·05	$C_{28}H_{25}BrNO_3S$	62·9	4·5	14·95	2·6	6·0

[1] Part X, G. Melloni, and G. Modena, *J.C.S. Perkin I*, 1972, 218.

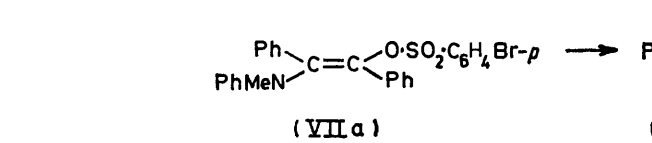
[2] G. Capozzi, G. Melloni, and G. Modena, *J. Chem. Soc.* (*C*), 1970, (*a*) 2621; (*b*) 2625.

[3] (*a*) G. Capozzi, G. Melloni, G. Modena, and U. Tonellato, *Chem. Comm.*, 1969, 1520; (*b*) G. Capozzi, G. Melloni, and G. Modena, *J. Chem. Soc.* (*C*), 1971, 3018; (*c*) G. Modena, and U. Tonellato, *J. Chem. Soc.* (*B*), 1971, 381.

[4] G. Modena and U. Tonellato, *J. Chem. Soc.* (*B*), 1971, 374.

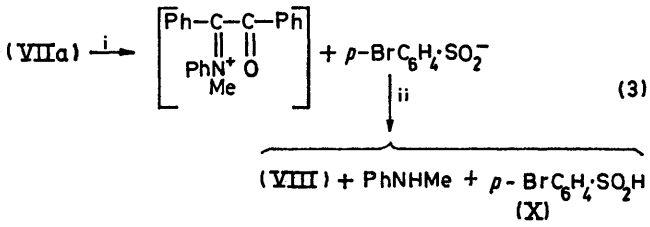
[5] G. Capozzi and G. Modena, *J.C.S. Perkin I*, 1972, 216.

In attempts to observe cyclisation to indole in the absence of a nucleophilic solvent, the reaction was carried out in nitromethane at 100°, in dimethylformamide at 152°, and in dichloromethane or benzene saturated with anhydrous boron trifluoride at room temperature. These reactions failed to give the expected indole derivate, yielding instead benzil (VIII) in 75—85% yield. In a typical experiment we identified *p*-bromobenzenesulphinic acid (X) and *N*-methylaniline in the reaction mixture. This shows that, under the conditions adopted, the main reaction of compounds (VII) is the one represented in equation (3).



(VIIa) (VIII) (IXa) (2)

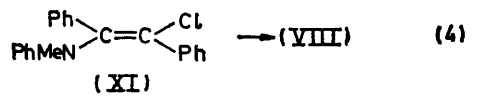
Reagent MeOH at 100°.



(VIIa) (VIII) + PhNHMe + *p*-BrC$_6$H$_4$·SO$_2$H (X) (3)

Reagents: i, BF_3 in CH_2Cl_2; ii, H_2O.

This is not necessarily the only reaction path by which benzil (VIII) may be formed from compounds like (VII). Indeed Huang and Lessard [6] have reported that 1,2-diphenyl-2-morpholinovinyl bromide and chloride furnish benzil, among other products, on hydrolysis with silver ion catalysis. In this case a mechanism like (3) cannot operate. These findings were confirmed by us with 1,2-diphenyl-2-[(*N*-phenyl)methylamino]vinyl chloride (XI), which in boiling dimethyl sulphoxide with silver oxide or in boiling nitromethane with silver tetrafluoroborate catalyst, gave benzil in yields of 95 and 60%, respectively [equation (4)].

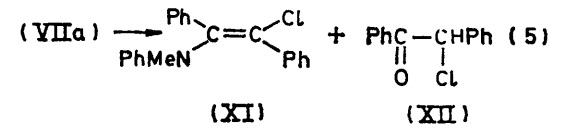


(XI) (VIII) (4)

Reagents Me_2SO–Ag_2O or $MeNO_2$–$AgBF_4$.

Esters of type (VII), however, also gave reactions like those of arylthiovinyl derivatives (I), which probably occur by a S_N1-like mechanism. The unsubstituted (VIIa) gave, in boiling benzene with added dry hydrogen chloride, 1,2-diphenyl-2-[(*N*-phenyl)methylamino]vinyl chloride (XI) together with α-chloro-α-phenylacetophenone (XII) [equation (5)]. Compound (XII) may be derived from hydrolysis of (XI), but it could also be formed by direct substitution of the amino-group by Cl^- followed by hydrolysis of the sulphonate residue.

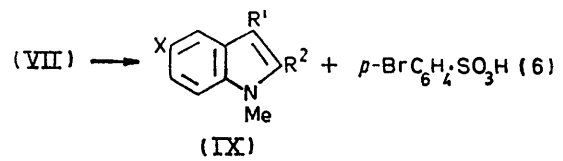
Esters (VIIa—d) in benzene containing aluminium chloride gave indoles (IX) in 60—70% yield, together



(VIIa) (XI) (XII) (5)

Reagent HCl in dry C_6H_6.

with high molecular weight compounds which probably arise from polymerisation of indoles; these were not further investigated [equation (6)].



(VII) (IX) + *p*-BrC$_6$H$_4$·SO$_3$H (6)

Reagent $AlCl_3$ in C_6H_6.

The chloro-enamine (XI) also yielded indole in 80% yield under similar conditions. The cyclisation of (VII) to indole was studied in some detail because it could provide evidence for the participation, if any, of the nitrogen atom in the above reaction. The results are summarised in Table 2. It is apparent that the cyclisation occurs without rearrangement; in particular compound (VIId) gives 1-methyl-2-*p*-tolyl-3-phenylindole (IXd). Following the hypothesis that the reaction of enamines (VII) occurs *via* a unimolecular heterolysis of the C–O·SO_2 bond to give a vinyl cation (XIII) (Scheme 2), as observed for the sulphur analogue (I), it seems that the nitrogen atom is not capable either of bridging to give an azirinium ion or of shifting to the adjacent carbon atom. In fact in the case of compound

TABLE 2

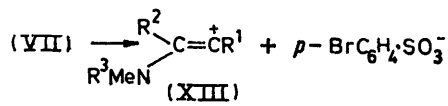
Cyclisation of sulphonates (VII) to 1-methyl-2,3-diarylindoles (IX)

(VII)	(IX)	R^1	R^2	X	M.p. (°C)	Yield (%)
(VIIa)	(IXa)	Ph	Ph	H	138—139 [a]	61
(VIIb)	(IXb)	Ph	Ph	Me	124—126 [b]	55
(VIIc)	(IXc)	*p*-Tolyl	Ph	H	155—157 [c]	50
(VIId)	(IXd)	Ph	*p*-Tolyl	H	120—122 [d]	30

[a] Lit.,[14] m.p. 139°. [b] This work. [c] Lit.,[7] m.p. 156—157° [d] Lit.,[7] m.p. 120·5—122·5°.

[6] S. J. Huang and M. V. Lessard, *J. Amer. Chem. Soc.*, 1968, **90**, 2432.

(VIId) both processes would lead to a more stable carbonium ion.



SCHEME 2

The structure of the indoles (IX) was proved by comparison with authentic samples.[7]

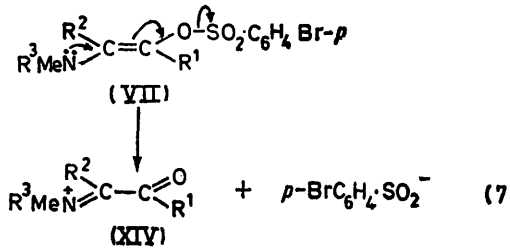
DISCUSSION

The reactivity of the sulphonic esters (VII) may be explained on the basis of competition between two different reaction mechanisms: (i) an S_N1-like reaction characterised by a rate determining heterolysis of the C–O·SO_2 bond and formation of a vinyl cation (XIII); (ii) an internal redox fragmentation [equation (3)].

Reactions which belong to group (i) include substitution of the sulphonate group by chlorine in the reaction of hydrochloric acid on (VIIa) and cyclisation to give indole derivatives either in methanol or in an inert solvent. Direct evidence for the intermediacy of a vinyl cation is lacking, but analogy with reactions of other vinyl esters is compelling. In this respect it is noteworthy that cyclisation of sulphonates (VII) to indoles (IX) occurs with no rearrangement, which implies that the nitrogen atom does not participate in the reaction. The oxygen atom in aryloxyvinyl sulphonic esters [5] behaves similarly, and the β-aryl groups in triarylvinyl sulphonates [8] and halides [9] do not show any anchimeric effect. Thus the evidence so far collected emphasises the special ability of a β-sulphur atom to act as a neighbouring participating group in the solvolysis of vinyl sulphonic esters. This is in contrast with the observed behaviour in S_N1 reactions of saturated compounds, in which case all the groups listed may interact by bridging with the incipient carbonium ion, although with varying efficiency. It is likely that the nature of the heteroatom plays an important role in determining the stability of a three-membered ring intermediate. Other heavy atoms may behave similarly to sulphur, as suggested by recent results concerning the mechanism of halogen addition to acetylenic derivatives, which show that bromine and iodine may in some cases give bridged unsaturated cations.[10,11]

The other reaction, which yields benzil and a sulphinic acid must follow a different path; vinyl cations (XIII) or benzoin derivatives presumably cannot reduce sulphonic to sulphinic acids. The reaction may well involve a displacement of the sulphinate anion by the electron pair of the nitrogen atom through the double bond [equation (7)]. Intermediate (XIV) would be hydrolysed quickly to benzil either in the reaction medium or during work-up.

A mechanism of this kind would justify the importance of this reaction in the enamine case. It is hoped that work in progress will give further insight into the reaction mechanism. In particular, it would be interesting to know why boron trifluoride catalyses the formation of benzil, and aluminium chloride the reaction *via* the vinyl cation.



EXPERIMENTAL

^{1}H N.m.r. spectra were obtained for solutions in deuteriochloroform (unless otherwise specified) with tetramethylsilane as internal standard.

α-Phenyl-α-[(*N*-phenyl)methylamino]acetophenone (VIa), m.p. 98—100° (lit.,[12] 99·5—101·5°), τ 2—3·5 (15H, m), 3·7 (1H, s), and 7·2 (3H, s); α-phenyl-α-[(*N*-phenyl)methylamino]-*p*-methylacetophenone (VIc), m.p. 152—154° (lit.,[7] 154°), τ 2·1—3·3 (14H, m), 3·65 (1H, s), 7·15 (3H, s), and 7·65 (3H, s); and α-*p*-tolyl-α[(*N*-phenyl)methylamino]-acetophenone (VId), m.p. 90—92° (lit.,[7] 92°), τ 2—3·3 (14H, m), 3·6 (1H, s), 7·15 (3H, s), and 7·68 (3H, s), were prepared by treatment of the appropriate α-bromoacetophenone with *N*-methylaniline.

α-Phenyl-α-[(N-p-tolyl)methylamino]acetophenone (VIb), obtained in 90% yield by treatment of α-bromo-α-phenylacetophenone [13] with *N*-methyl-*p*-toluidine, had m.p. 106—107° (from ethanol) (Found: C, 83·6; H, 6·5; N, 4·45. $C_{22}H_{21}NO$ requires C, 83·8; H, 6·7; N, 4·4%).

1,2-Diaryl-2-[(N-aryl)methylamino]vinyl p-Bromobenzenesulphonates (VIIa—d).—Sodium hydride (50% dispersion in oil; 0·02 mol) was added in small portions to a well stirred solution of the acetophenone (VI) (0·01 mol) in dry acetone (20 ml) at 0°. After 15 min *p*-bromobenzenesulphonyl chloride (0·01 mol) was added, and the temperature was allowed to rise gradually to 25°. The mixture was then poured into water and the oily material thus obtained solidified on treatment with a few ml of methanol. The products were recrystallised from methanol (yields 50—70%). Analytical data are reported in Table 1.

Solvolysis Reactions of 1,2-Diphenyl-2-[(N-phenyl)methylamino]vinyl p-Bromobenzenesulphonate (VIIa).—(a) *In methanol.* A solution of compound (VIIa) (0·1 g) in anhydrous methanol (10 ml) sealed in an ampoule was immersed in an oil-bath at 100° for 4 h. The ampoule was cooled and opened and the methanol was evaporated off.

[7] F. Brown and F. G. Mann, *J. Chem. Soc.*, 1948, 858.
[8] (*a*) G. Modena and U. Tonellato, *J. Chem. Soc.* (*B*), 1971, 1569; (*b*) Z. Rappoport and J. Kaspi, *J. Amer. Chem. Soc.*, 1970, **92**, 3220.
[9] Z. Rappoport and Y. Apeilog, *Tetrahedron Letters*, 1970, 1817.
[10] J. A. Pincock and K. Yates, *Canad. J. Chem.*, 1970, **48**, 3332
[11] J. W. Wilson and E. Berliner, *J. Amer. Chem. Soc.*, 1971, **93**, 208.
[12] R. E. Lutz, R. H. Jordan, and W. L. Truett, *J. Amer. Chem. Soc.*, 1950, **72**, 4085.
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The residue was chromatographed on silica gel [eluant light petroleum (b.p. 40—70°)–ether 95 : 5] to give 1-methyl-2,3-diphenylindole (IXa) (6·4 mg, 12%), m.p. 137—139° (lit.,[14] 139°), identified by comparison (i.r. spectrum) with an authentical sample, and benzil (25·2 mg, 62%), m.p. 92—94° (lit.,[15] 94—95°).

(b) *In nitromethane.* Compound (VIIa) (1·0 g) was dissolved in nitromethane (10 ml) and the solution was refluxed for 90 min. The solvent was evaporated off and the residue chromatographed on silica gel as in (a) to give benzil (0·3 g, 75%),[15] m.p. 94° and a light yellow oil (0·1 g, 49%) identified as *N*-methylaniline by comparison (i.r. spectrum) with a commercial sample.

(c) *In dimethylformamide.* A solution of compound (VIIa) (0·5 g) in dimethylformamide (20 ml) was refluxed for 3 h then poured into water and extracted with dichloromethane. Evaporation of the extract left an oil which was chromatographed on silica gel; the only product identified was benzil [15] (0·23 g, 82%), m.p. 93—94°.

(d) *In dichloromethane with boron trifluoride.* A solution of compound (VIIa) (1·0 g) in dichloromethane (100 ml) was saturated with gaseous boron trifluoride. After 24 h the solvent was partially removed by distillation and the residue was extracted with aqueous sodium hydroxide (10 ml). The organic layer, after chromatography on silica gel, gave benzil [15] (0·32 g, 81%), m.p. 94°, and *N*-methylaniline (0·05 g, 25%). The aqueous layer, after acidification with hydrochloric acid, was extracted with chloroform. The extract was dried ($CaCl_2$) and evaporated giving *p*-bromobenzenesulphinic acid (X) (0·11 g, 26%), m.p. 112—114° (lit.,[16] 114—115°), identified by comparison with an authentic sample.

1,2-*Diphenyl*-2-[(N-*phenyl*)*methylamino*]*vinyl Chloride* (XI).—α-[(*N*-Phenyl)methylamino]stilbene [17] (2·85 g) was dissolved in carbon tetrachloride (25 ml) and *N*-chlorosuccinimide (1·33 g) was added. The mixture was stirred under nitrogen for 5 h; the succinimide formed was filtered off and the solvent evaporated under reduced pressure yielding a yellow oil, which solidified upon treatment with n-hexane. Recrystallisation from n-hexane gave the *chloride* (XI) (1·6 g, 50%), m.p. 127—129° (Found: C, 79·15; H, 5·5; Cl, 11·2; N, 4·4. $C_{21}H_{18}ClN$ requires C, 78·9; H, 5·5; Cl, 11·1; N, 4·4%), τ 2·3—3·4 (15H, m) and 7·08 (3H, s).

Silver-catalysed Solvolysis of 1,2-*Diphenyl*-2-[(N-*phenyl*)-*methylamino*]*vinyl Chloride* (XI).—(a) *With silver oxide in dimethyl sulphoxide.* To a solution of the chloride (XI) (0·15 g) in dimethyl sulphoxide (50 ml), silver oxide was added; the mixture was refluxed for 90 min. The silver salt formed was filtered off and the solution was poured into water and extracted with ether. Evaporation of the extract gave benzil [15] (0·1 g, 95%), m.p. 95° (from methanol).

(b) *With silver tetrafluoroborate in nitromethane.* The chloride (XI) (0·15 g) in anhydrous nitromethane (50 ml) containing silver tetrafluoroborate (0·3 g) was refluxed for 10 h. Insoluble material was filtered off, the solvent was removed, and the residue was poured into water and extracted with dichloromethane. The organic layer was dried and evaporated; chromatography on silica gel gave benzil (0·06 g, 60%), identified by comparison (i.r. spectrum) with an authentic sample.

Reaction of 1,2-*Diphenyl*-2-[(N-*phenyl*)*methylamino*]*vinyl* p-*Bromobenzenesulphonate* (VIIa) *with Hydrogen Chloride,*—Hydrogen chloride was bubbled through a refluxing solution of compound (VIIa) (0·5 g) in anhydrous benzene (60 ml) for 2 h. The excess of hydrogen chloride was removed under reduced pressure and the solution was evaporated. The residue was chromatographed on silica gel to give 1,2-diphenyl-2-[(*N*-phenyl)methylamino]vinyl chloride (XI) (0·18 g, 59%), m.p. 127—129°, and α-chloro-α-phenylacetophenone (XII) (0·08 g, 36%), m.p. 65° (lit.,[18] 65—66°).

Cyclisation of Vinyl Sulphonates (VII) *to* 1-*Methyl*-2,3-*diarylindoles* (IX).—To a solution of compound (VII) (4 mmol) in dry benzene (80 ml), aluminium trichloride (12 mmol) was added and the mixture was refluxed for 4 h. The solution was poured in water and the organic layer separated, dried ($CaCl_2$), and evaporated to give a tarry residue, which was chromatographed on silica gel. Elution with light petroleum (b.p. 40—70°)–ether (98 : 2) gave the indole (IX) (Table 2) which was recrystallised from ethanol, and a high molecular weight compound not further investigated.

Cyclisation of 1,2-*Diphenyl*-2-[(N-*phenyl*)*methylamino*]-*vinyl Chloride* (XI) *to* 1-*Methyl*-2,3-*diphenylindole* (IXa).—To a solution of compound (XI) (0·3 g) in dry benzene (50 ml), aluminium trichloride (0·26 g) was added and the mixture was refluxed for 13 h. Work-up for the cyclisation of compounds (VII) yielded the indole (IXa) (0·14 g, 50%), m.p. 137—138° (lit.,[14] 139°).

1-Methyl-2,3-diphenylindole (IXa), m.p. 137—139° (lit.,[14] 139°); 1-methyl-2-phenyl-3-*p*-tolylindole (IXc), m.p. 155—157° (lit.,[7] 156—157°), τ 2·1—2·9 (13H, m), 6·4 (3H, s), and 7·7 (3H, s); and 1-methyl-2-*p*-tolyl-3-phenylindole (IXd), m.p. 120—122° (lit.,[7] 120·5—122·5°), τ 2·1—2·9 (13H, m), 6·4 (3H, s), and 7·65 (3H, s), were prepared according to known methods.

1,5-*Dimethyl*-2,3-*diphenylindole* (IXb).—α-Phenyl-α-[(*N*-*p*-tolyl)methylamino]acetophenone (VIb) (3·0 g) and methane sulphonic acid (0·25 ml) in anhydrous methanol (30 ml) were heated at 150° for 20 h. The solvent was evaporated off and water was added to the residue. Extraction with ether and evaporation of the extract gave, after chromatography on silica gel, the *indole* (IXb) (2·0 g, 70%), m.p. 124—126° (from ethanol) (Found: C, 88·9; H, 6·4; N, 4·7. $C_{22}H_{19}N$ requires C, 88·85; H, 6·45; N, 4·7%).

[1/2137 *Received*, 12*th November*, 1971]

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[15] H. T. Clark and E. E. Dreger, *Org. Synth.*, 1941, Coll. Vol. I, p. 87.
[16] E. Knoevenagel and J. Kenner, *Ber.*, 1908, **41**, 3315.
[17] J. Hoch, *Compt. rend.*, 1935, **20**, 200.
[18] A. M. Ward, *Org. Synth.*, 1943, Coll. Vol. II, p. 159.