

## Use of Fluoride Ion as a Reagent in Acetylene- and Allene-forming Eliminations

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The use of fluoride ion as a reagent for promoting elimination from halogenoethylenes has been investigated. Tetraethylammonium fluoride in acetonitrile and potassium fluoride in various solvents are good dehydrohalogenating reagents for systems (I)—(IV) in which the leaving groups are *anti*-related. Acetylenes can be obtained in good yields without any substitution or post-addition reactions. Elimination from the 2-halogeno-1-*p*-nitrophenylpropenes (VI) and (VII) leads to *p*-nitrophenylallene in good yields, thus indicating the potential usefulness of fluoride ion for obtaining this type of sensitive compound. The effect of dicyclohexyl-18-crown-6-ether in the reaction mixture has been briefly explored.

HALIDE ions have become useful reagents for promoting 1,2-eliminations leading to olefins.<sup>1-3</sup> On the other hand, systematic studies dealing with acetylene- and

<sup>1</sup> P. Beltrame, G. Biale, D. J. Lloyd, A. J. Parker, M. Ruane, and S. Winstein, *J. Amer. Chem. Soc.*, 1972, **94**, 2240, and previous papers of the series.

<sup>2</sup> R. A. Bartsch, *J. Org. Chem.*, 1970, **35**, 1023 and references therein.

<sup>3</sup> J. Hayami, N. Ono, and A. Kaji, *Tetrahedron Letters*, 1968, 1385; 1970, 2727; *Bull. Chem. Soc. Japan*, 1971, **44**, 1628; N. Ono, *ibid.*, p. 1369.

<sup>4</sup> For reviews concerning these problems *cf.* (a) G. Modena, *Accounts Chem. Res.*, 1971, **4**, 73; (b) Z. Rappoport, *Adv. Phys. Org. Chem.*, 1969, **7**, 1.

allene-forming reactions appear to be lacking. It was thus of particular interest to undertake a study of these processes since they are often complicated by subsequent isomerization and/or by nucleophilic additions<sup>4-8</sup> and

<sup>5</sup> G. Marchese, G. Modena, and F. Naso, *J. Chem. Soc. (B)*, 1968, 958; G. Marchese, G. Modena, F. Naso, and N. Tangari, *ibid.*, 1970, 1196; A. Giametta, G. Marchese, and F. Naso, *Gazzetta*, 1971, **101**, 247.

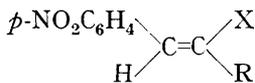
<sup>6</sup> G. Modena and L. Ronzini, *Chimica e Industria*, 1972, **54**, 617.

<sup>7</sup> A. Campagni, G. Modena, and P. E. Todesco, *Gazzetta*, 1960, **90**, 694.

<sup>8</sup> D. Landini, G. Modena, F. Montanari, and F. Naso, *J. Chem. Soc. (B)*, 1969, 243.

we hoped that these side reactions could be avoided with halide ions as nucleophiles.

The  $\beta$ -halogenostyrene system <sup>5,6</sup> [(I)—(VII)] and the  $\beta$ -bromo(sulphonyl)ethylenes <sup>7</sup> [(VIII)—(IX)] were chosen as substrates for the present investigation, because their behaviour with a variety of nucleophiles is well known <sup>5-7</sup> and this would permit straightforward comparisons.

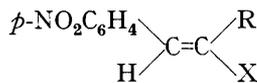


(I) X = Br, R = H

(II) X = Cl, R = H

(III) X = Br, R = Me

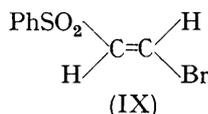
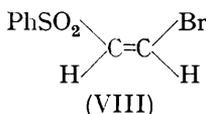
(IV) X = Cl, R = Me



(V) X = Br, R = H

(VI) X = Br, R = Me

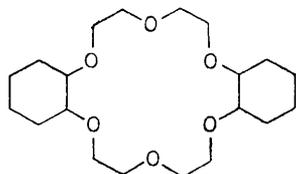
(VII) X = Cl, R = Me



Fluoride ion was suggested as a suitable reagent by some recent reports on olefin-forming eliminations.<sup>2,3</sup>

#### RESULTS AND DISCUSSION

Several fluoride ion reagents were examined for promotion of the elimination process. Tetraethylammonium fluoride in acetonitrile was first tested, since this salt is known to be a powerful species for proton abstraction reactions. In the phenylethyl series<sup>3</sup> it has been shown to be more reactive than ethoxide ion by a factor of *ca.* 10<sup>3</sup>. However, the use of this reagent presents severe



(X)

limitations since in solution or in the solid state, decomposition occurs, particularly above 80°, with formation of ethylene, triethylamine, and hydrogen fluoride.<sup>3</sup> It seemed worthwhile, therefore, to test the more familiar, but much less soluble, potassium fluoride in acetonitrile or in other dipolar aprotic solvents.

This and similar compounds<sup>9</sup> are known to be able to complex alkali and alkaline earth cations. Consequently, the solubility of the corresponding salts becomes higher, ion pair separation is favoured and, as an overall result, an increase in reactivity is achieved.

*Reactions with Tetraethylammonium Fluoride in Acetonitrile.*—When *cis*- $\beta$ -bromo- and *cis*- $\beta$ -chloro-*p*-nitrostyrenes (I) and (II) were allowed to react at 25° with the title reagent, *anti*-elimination was easily accomplished

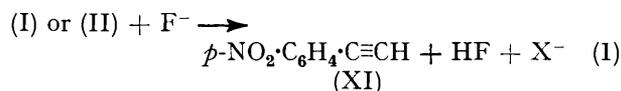
TABLE I

Reactions of various halogenostyrenes with tetraethylammonium fluoride in acetonitrile at 25°

Substrate	Concentration (M × 10)		Yield (%)		Time (h)
	Substrate	Base	Acetylene (XI) or (XIII)	Allene (XIV)	
(I)	0.6	4.4	92 <sup>a</sup>		1
(II)	0.6	4.4	97 <sup>a</sup>		9
(III)	3.0	6.0	87 <sup>b</sup>		2
(IV)	1.1	4.4	60 <sup>b</sup>		8
(V)	1.1	4.4	<i>ca.</i> 0 <sup>a</sup>		48
(VI)	1.1	4.4	<i>ca.</i> 1 <sup>c</sup>	30 <sup>c</sup>	1.5
(VII)	1.1	4.4	5 <sup>c</sup>	45 <sup>c</sup>	4
(VII)	1.1	4.4	5 <sup>c</sup>	48 <sup>c</sup>	6

<sup>a</sup> Value obtained by g.l.c. analysis using *p*-nitrotoluene as an internal standard. <sup>b</sup> Value obtained by i.r. analysis. <sup>c</sup> Average value estimated from the i.r. spectra of mixtures of reactions which, however, did not reach completion (*cf.* text).

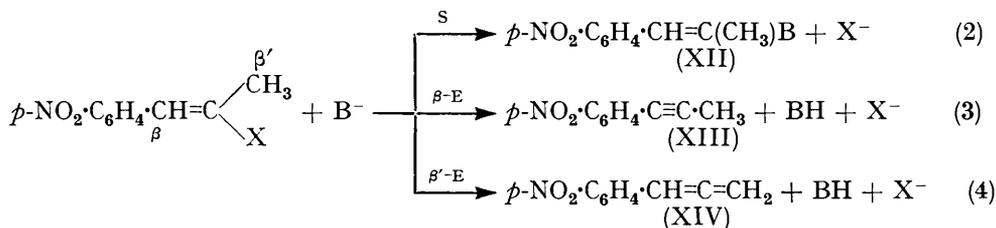
with formation of *p*-nitrophenylacetylene<sup>5</sup> (XI) in almost quantitative yields (*cf.* Table I).



G.l.c. and t.l.c. analysis of the reaction mixtures revealed that the product of nucleophilic substitution,  $\beta$ -fluoro-*p*-nitrostyrene,<sup>10</sup> was absent.

When *trans*- $\beta$ -bromo-*p*-nitrostyrene (V) was dissolved in an acetonitrile solution of tetraethylammonium fluoride, no significant reaction was detected even after 3 days at 30–50°, thus indicating the importance of *anti*-relationship between the leaving groups in order to obtain the elimination process.

In principle, when a methyl-group is present on the double bond of substrates of the type here investigated,



Finally, several reactions were performed by adding dicyclohexyl-18-crown-6-ether (X) to the reacting mix-

a competition between substitution,  $\beta$ -, and  $\beta'$ -elimination could occur (equations 2–4).

<sup>9</sup> C. J. Pedersen and H. K. Frensdorff, *Angew. Chem. Internat. Edn.*, 1972, **11**, 16.

<sup>10</sup> G. Marchese, G. Modena, and F. Naso, *J. Chem. Soc. (B)*, 1969, 290.

A recent investigation<sup>6,11</sup> performed with methoxide ion in methanol has revealed that either of the elimination pathways could predominate. The configuration of the starting material appeared to be of importance in determining the extent of the two processes, the elimination leading to acetylene being favoured by an *anti*-relationship between the vinylic hydrogen and the leaving halogen. However, when the alkoxide-alcohol pair was used the situation was complicated by isomerization and addition reactions.<sup>6</sup>

Using the fluoride ion as a promoting base *cis*-\*2-bromo- and 2-chloro-1-*p*-nitrophenylpropenes (III) and (IV) give the acetylene whereas in the corresponding *trans* isomers (VI) and (VII) the *syn*-elimination leading to the same product is of little, if any, importance relative to the allene-forming reaction. Indeed, during the first stages of the reactions the acetylene was only a small fraction of the product, particularly from the bromo-olefin. At the later stages the relative amount of compound (XIII) became larger. Control experiments suggested that a fluoride ion-catalysed prototropic rearrangement (allene  $\rightarrow$  acetylene), and a higher stability of the latter product under the reaction conditions are responsible for the observed trend. Furthermore, it was difficult to bring the reactions to completion even after long periods, presumably because of decomposition of the reagent.<sup>3</sup>

*Reactions with Potassium Fluoride in Dipolar Aprotic Solvents.*—The use of potassium fluoride in a variety of solvents including dimethyl sulphoxide (DMSO), acetonitrile, hexamethylphosphoramide, dimethylformamide (DMF), and *N*-methyl-2-pyrrolidone was tested. In all cases the salt appeared to be a good dehydrohalogenating agent particularly when DMSO was used as reaction medium. The results concerning this solvent (*cf.* Table 2) reveal that *anti*-elimination leading to acetylene can

TABLE 2

Reactions of halogenoethylenes with potassium fluoride in various solvents<sup>a</sup>

Substrate	Solvent	Time	Temp. (°C)	Product	Yield (%)
(I)	DMSO	30 min	80	(XI)	77 <sup>b</sup>
(II)	DMSO	4 h	120	(XI)	50 <sup>b</sup>
(III)	DMSO	10 min	100	(XIII)	94 <sup>c</sup>
(IV)	DMSO	45 min	120	(XIII)	85 <sup>c</sup>
(VI)	DMSO	20 min	100	(XIV)	93 <sup>c</sup>
(VII)	DMSO	35 min	100	(XIV)	70 <sup>c</sup>
(VIII) <sup>d</sup>	MeCN	7 h	30	Ph·SO <sub>2</sub> ·C≡CH	86 <sup>b</sup>
(IX) <sup>d</sup>	MeCN	16 h	30	Ph·SO <sub>2</sub> ·C≡CH	ca. 0 <sup>b</sup>
(I)	Bu-Cell <sup>e</sup>	90 min	150	(XI)	68 <sup>b</sup>

<sup>a</sup> Solutions were saturated with KF. Unless otherwise indicated the concentration of the substrate is  $3 \times 10^{-2}$  M. <sup>b</sup> G.l.c. analysis. <sup>c</sup> I.r. analysis. <sup>d</sup> The concentration of the substrate is  $2 \times 10^{-2}$  M. Pyridine  $1 \times 10^{-2}$  M was present in this run. <sup>e</sup> Butyl Cellosolve.

be easily achieved for the substrates (I)—(IV). In substrates (VI) and (VII), where the leaving halogen and

\* In order to keep the nomenclature consistent with that used in previous work,<sup>4a,5,6</sup> we refer to *trans* and *cis* with respect to the *p*-nitrophenyl and the leaving halogen. The *cis*-isomers are of (*Z*)-configuration whereas the *trans*-counterparts are of (*E*)-configuration.

the vinylic hydrogen are *syn*-related, the elimination leads to the allenic material which, particularly in the case of the bromoderivative, contains only traces of acetylene. Pure material can be easily obtained by crystallization.

Relatively low temperatures were required for the reactions of the highly-activated sulphonyl derivative (VIII) in acetonitrile. In order to obtain good yields an organic base must be present and pyridine was used since it is unreactive towards (VIII) (at least within the reaction times employed). For the purpose of comparison the reaction of the *trans*-derivative (IX) was also performed under the same conditions and once again the result points to the difficulty of obtaining the *syn*-elimination process.

The last line of Table 2 concerns the reaction of the *cis*- $\beta$ -bromo-*p*-nitrostyrene with F<sup>-</sup> in Butyl Cellosolve (ethylene glycol mono-*n*-butyl ether) and shows that the use of the fluoride ion is not restricted to the dipolar aprotic solvents. Furthermore, it is worth recalling that in diethylene glycol mono-*n*-butyl ether sodium iodide leads to the substitution product.<sup>12</sup> This behaviour is consistent with the view that in vinylic systems 'soft' nucleophiles prefer attack on carbon, whereas 'hard' reagents prefer attack on hydrogen.<sup>4,5</sup>

TABLE 3

The effect of the addition of the dicyclohexyl-18-crown-6-ether (X) in the reactions of *cis*- $\beta$ -bromo-*p*-nitrostyrene (I)<sup>a</sup>

Solvent	Temp. (°C)	Base	Time (min)	Conversion (%) <sup>b</sup>
MeCN	80	KF	60	ca. 0
MeCN	80	KF + (X)	60	53
MeCN	80	KF	90	ca. 0
MeCN	80	KF + (X)	90	71
DMF	70	KF	30	28
DMF	70	KF + (X)	30	58
DMF	70	KF	45	35
DMF	70	KF + (X)	45	68
Bu-Cellosolve	150	KF	10	15
Bu-Cellosolve	150	KF + (X)	10	43
Bu-Cellosolve	150	KF	20	22
Bu-Cellosolve	150	KF + (X)	20	80

<sup>a</sup> The concentrations of substrate and crown ether were  $3 \times 10^{-2}$  M; undissolved KF was present during the runs (see text). <sup>b</sup> The percentages of conversion were obtained from g.l.c. analysis.

'Crown Ether Catalysis'.—When dicyclohexyl-18-crown-6-ether was added to reacting mixtures of compound (I) and potassium fluoride in several solvents an increase in the rate of the reactions was observed by measuring the extent of acetylene formation at different times. The relevant data are in Table 3. The results reveal that the effect of 'crown ether catalysis' depends on the nature of the solvent. For instance, it appears

<sup>11</sup> For studies on substitution, allene- and acetylene-forming reactions *cf.* also F. Théron, *Bull. Soc. chim. France*, 1969, 278, 285; P. Beltrame, S. Carrà, P. Macchi, and M. Simonetta, *J. Chem. Soc.*, 1964, 4386; P. Beltrame, D. Pitea, A. Marzo, and M. Simonetta, *J. Chem. Soc. (B)*, 1967, 71; M. Ballabio, P. L. Beltrame, and P. Beltrame, *J.C.S. Perkin II*, 1972, 1229; S. W. Staley and R. F. Doherty, *Chem. Comm.*, 1969, 288; L. F. Hatch and H. D. Weiss, *J. Amer. Chem. Soc.*, 1955, 77, 1798.

<sup>12</sup> S. I. Miller and P. K. Yonan, *J. Amer. Chem. Soc.*, 1957, 79, 5931.

to be rather dramatic in acetonitrile, but much less important when dimethylformamide is the reaction medium. Undoubtedly, variations in solubility and ion pairing phenomena are underlying these observations. Since the aim of this work was to develop a synthetic method, we did not investigate this point fully. It was ascertained that in DMF and MeCN the solubility of potassium fluoride<sup>13</sup> increased upon adding the crown ether. In fact, in the temperature range 25–80°, solutions prepared by vigorously stirring the dry salt in the solvent for several hours were found to be  $\leq 10^{-4}\text{M}$  when the crown ether was absent, whereas solutions  $1\text{--}3 \times 10^{-3}\text{M}$  could be prepared under strictly comparable conditions upon addition of the cyclic compound ( $3 \times 10^{-2}\text{M}$ ). In Butyl Cellosolve higher concentrations ( $10^{-2}\text{M}$ ) were obtained easily at 100° in the presence or absence of the crown ether. In principle, the latter solvent seemed suitable for running experiments under homogeneous conditions. However, reactions performed at 100° using KF solutions ( $1\text{--}2 \times 10^{-2}\text{M}$ ) did not give satisfactory yields of acetylenic material thus preventing us from making accurate comparisons of reactivity.

**Conclusions.**—Further cases will have to be studied in order to extend the validity of our observations to other systems. However, the substrates we have investigated cover a wide range of reactivity; in the reactions with  $\text{MeO}^-$  in MeOH, seven orders of magnitude separate the 'slow' *cis*- $\beta$ -chloro-*p*-nitrostyrene<sup>5</sup> (II) from the 'fast' sulphonyl-derivative<sup>7</sup> (VIII) of the same configuration. Therefore, the examples reported above clearly show the ability of the fluoride ion to promote eliminations in the olefinic series.

Acetylenes can be formed easily from substrates of suitable configuration. Nucleophilic addition and substitution reactions which are observed in other instances,<sup>4,14</sup> are not of importance in the cases we have studied.

Furthermore, the possibility of obtaining in high yield a sensitive allenic compound highlights another important advantage of the fluoride ion particularly when compared with other allene forming eliminations.<sup>14,15</sup>

Finally, the use of the crown ether represents a novel application of this interesting class of compounds. In view of the results obtained the extension of the crown ether effect to the dehydrohalogenations in which olefins are formed and, also, to the dehalogenation of vicinal dihalides can be envisaged.

<sup>13</sup> T. Pavlopoulos and H. Strehlow, *Z. phys. Chem. (Leipzig)*, 1954, **202**, 474.

<sup>14</sup> W. A. Sheppard and C. M. Sharts, 'Organic Fluorine Chemistry,' W. A. Benjamin, New York, 1969; P. Beltrame, G. Favini, M. G. Cattania, and F. Guella, *Gazzetta*, 1968, **98**, 380; J. T. Maynard, *J. Org. Chem.*, 1963, **28**, 112; W. T. Miller, jun., J. H. Fried, and H. Goldwhite, *J. Amer. Chem. Soc.*, 1960, **82**, 3091.

<sup>15</sup> H. Fischer in 'The Chemistry of Alkenes,' ed. S. Patai, Interscience, London, 1964, ch. 13.

## EXPERIMENTAL

The i.r. spectra were taken in carbon tetrachloride using a Perkin-Elmer model 257 spectrophotometer.

**Materials.**—*cis*- $\beta$ -Bromo-*p*-nitrostyrene<sup>5</sup> (I), m.p. 50–51° [from light petroleum (b.p. 80–120°)], *cis*- $\beta$ -chloro-*p*-nitrostyrene<sup>5</sup> (II), m.p. 50–51° [from light petroleum (b.p. 80–120°)], *cis*-2-bromo-1-*p*-nitrophenylpropene<sup>6</sup> (III), m.p. 84–85° (from methanol), *cis*-2-chloro-1-*p*-nitrophenylpropene<sup>6</sup> (IV), m.p. 78–79° [from light petroleum (b.p. 40–70°)], *trans*- $\beta$ -bromo-*p*-nitrostyrene<sup>5</sup> (V), m.p. 160° (from methanol), *trans*-2-bromo-1-*p*-nitrophenylpropene<sup>6</sup> (VI), m.p. 69–70° (from methanol), *trans*-2-chloro-1-*p*-nitrophenylpropene<sup>6</sup> (VII), m.p. 55–56° (from methanol), *cis*-2-bromovinyl phenyl sulphone<sup>7</sup> (VIII), m.p. 41–42° [from light petroleum (b.p. 80–120°)], and *trans*-2-bromovinyl phenyl sulphone<sup>7</sup> (IX), m.p. 59–60° [from light petroleum (b.p. 80–120°)] were prepared according to known procedures. Tetraethylammonium fluoride was obtained from the reaction of the corresponding bromide with silver fluoride and purified by crystallization from acetonitrile.<sup>3</sup> Potassium fluoride was dried at 160° for 2 days. Dicyclohexyl-18-crown-6-ether was a commercial sample (Aldrich) purified by column chromatography over acid alumina. Solvents were purified by conventional methods.<sup>16</sup> Fluoride ion was titrated with thorium nitrate.

**Reactions.**—The reactions were performed at the concentrations and temperatures indicated in Tables 1–3 and were followed by g.l.c. or i.r. techniques. The g.l.c. analysis was performed with a Hewlett-Packard 5750 B instrument (column packed with SE 30 5% on Chromosorb W.A.W. D.M.C.S. 80–100 mesh) using *p*-nitrotoluene as an internal standard. The i.r. analysis was based on the bands at 2255  $\text{cm}^{-1}$  present in the acetylene (XIII) and at 1940  $\text{cm}^{-1}$  present in the allene (XIV). Standardization plots were obtained using solutions of known composition. In several experiments, beside the analysis during the reaction, isolation of the products was also accomplished. Two typical runs are described below.

**Elimination with Tetraethylammonium Fluoride.**—*cis*- $\beta$ -Bromo-*p*-nitrostyrene (I) (0.8 g) was added to a solution (20 ml) of  $\text{Et}_4\text{N}^+\text{F}^-$  (0.35M in MeCN). After 1 h at room temperature, the mixture was diluted with saturated brine and extracted with ether. After drying ( $\text{Na}_2\text{SO}_4$ ), evaporation of the solvent and crystallization from ethanol yielded *p*-nitrophenylacetylene (XI) (0.46 g, 90%), m.p. 150° (lit.,<sup>5</sup> 150°).

**Elimination with Potassium Fluoride.**—Potassium fluoride (0.2 g) was added to DMSO (150 ml) containing *trans*-2-bromo-1-*p*-nitrophenylpropene (VI) (1.1 g). The mixture was stirred for 25 min at 100°. After this period the work-up described in the previous experiment afforded *p*-nitrophenylallene (XIV) (0.58 g, 80%), m.p. 66–67° (from ethanol) (lit.,<sup>6</sup> 63–65°).

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<sup>16</sup> J. A. Riddick and W. B. Bunger, jun., in 'Techniques of Chemistry,' ed. A. Weissberger, Wiley-Interscience, New York, 1970, vol. 2.