

Thermal Cyclisation of *trans*-*o*-Fluorocinnamic Acids to Coumarins. An Apparent Similarity between Mass Spectral and Thermal Fragmentations †

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The predominant fragmentation of the molecular ion derived from *trans*-pentafluorocinnamic acid involves the initial loss of hydrogen fluoride; this process is also important in the case of *trans*-*o*-fluorocinnamic acid. Pyrolyses of the acids lead to the formation of coumarin derivatives in good yield. The photolysis of an aqueous solution of sodium pentafluorocinnamate at 100° also results in the formation of 5,6,7,8-tetrafluorocoumarin.

CONSIDERABLE recent interest has been shown in apparent similarities between pyrolytic, photolytic, and mass spectral processes.¹ Many examples involve retro-Diels–Alder reactions and have clearly justified the use

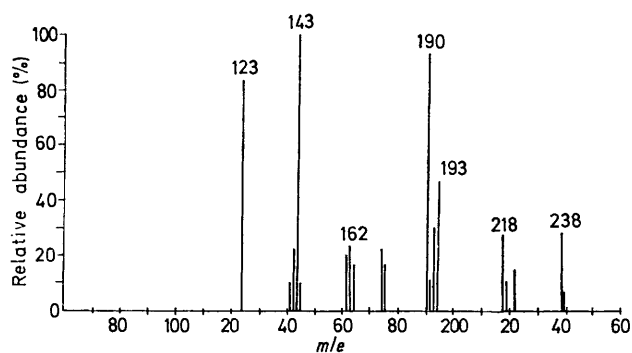


FIGURE 1 Mass spectrum of *trans*-pentafluorocinnamic acid

of this approach by synthetic organic chemists.² Similarly, potential pericyclic reactions have also been studied in some detail in an attempt to provide guidance as to whether a photochemical or a thermal analogy was likely in any given system.³

The electron-impact induced fragmentation of *trans*-cinnamic acid has been studied.⁴ The primary loss gives the cinnamoyl ion which, by loss of carbon monoxide, affords the styryl ion. The loss of acetylene then leads to the phenyl ion. We first studied the mass spectrum of *trans*-pentafluorocinnamic acid (1) and found that this fragmentation is of minor importance (Figure 1 and Table 1). High-resolution mass spectrometry established the composition of the important fragment ions (Table 2), from which it is apparent that the initial fragmentation involves the loss of hydrogen fluoride. This was confirmed by the presence of a metastable transition at *m/e* 199.7. *trans*-Pentafluorocinnamic [²H]acid also gave an ion at *m/e* 218 and a metastable transition at *m/e* 198.9 showed that the primary elimin-

ation of deuterium fluoride involves the hydroxy-deuteron, and that no hydrogen scrambling occurs prior to fragmentation is indicated by the absence of an increase in the intensity of the peak at *m/e* 219. Ions at *m/e* 190 and 162, together with the appropriate metastable transitions, reveal that the sequential loss of two molecules of carbon monoxide occurs after the initial loss of hydrogen fluoride. Thus it is necessary to postulate that the initial loss of hydrogen fluoride from the molecular ion involves a cyclisation reaction with the production of an ion with a coumarin-like structure [Scheme 1 (e)]. The isomerisation of the *trans*-acid to the *cis*-acid may occur before ionisation, since it is known⁵ that *trans*-cinnamic acid and derivatives can be isomerised both thermally and photochemically in solution. Thereafter the fragmentation of the ion at *m/e* 218 showed a qualitative similarity to the reported⁶ mass spectrum of coumarin and to the mass spectrum of 5,6,7,8-tetrafluorocoumarin (Figure 2) which we now report (Tables 1 and 2). Essentially similar spectra

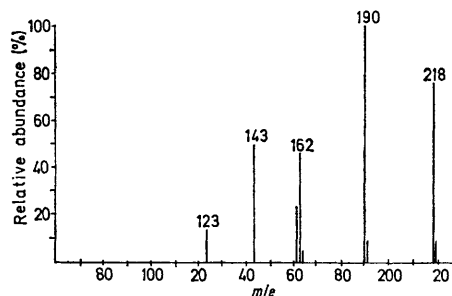


FIGURE 2 Mass spectrum of 5,6,7,8-tetrafluorocoumarin

were obtained for pentafluorocinnamic acid with a heated inlet at 68 or 160°, or by use of a direct insertion probe.

The mass spectrum of *o*-fluorocinnamic acid was also

† Preliminary communication, H. Heaney and A. P. Price, *Chem. Comm.*, 1971, 894.

¹ T. W. Bentley and R. A. W. Johnstone, *Adv. Phys. Org. Chem.*, 1970, **8**, 151; and references cited therein.

² E.g., H. Budzikiewicz, J. I. Brauman, and C. Djerassi, *Tetrahedron*, 1965, **21**, 1855; J. P. N. Brewer, I. F. Eckhard, H. Heaney, and B. A. Marples, *J. Chem. Soc. (C)*, 1968, 664; R. Bloch, R. A. Marty, and P. de Mayo, *J. Amer. Chem. Soc.*, 1971, **93**, 3071.

³ R. C. Dougherty, *J. Amer. Chem. Soc.*, 1968, **90**, 5780, 5788; R. A. W. Johnstone and S. D. Ward, *J. Chem. Soc. (C)*, 1968, 1805, 2540; M. J. Bishop and I. Fleming, *ibid.*, 1969, 1712.

⁴ J. Ronayne, D. H. Williams, and J. H. Bowie, *J. Amer. Chem. Soc.*, 1966, **88**, 4980; E. F. Brittain, J. P. Kelly, and W. L. Mead, *Org. Mass Spectrometry*, 1969, **2**, 325.

⁵ R. Stoermer, *Ber.*, 1909, **42**, 4865; W. Gruber, *Monatsh.*, 1944, **75**, 14.

⁶ C. S. Barnes and J. L. Occolowitz, *Austral. J. Chem.*, 1964, **17**, 975; J. L. Occolowitz and G. L. White, *ibid.*, 1968, **21**, 997.

recorded in order to test the generality of the fragmentation by primary loss of hydrogen fluoride. Evidently such a fragmentation competes favourably with that involving the loss of a hydroxyl fragment (Table 1). On the other hand, the mass spectrum of methyl pentafluorocinnamate (Table 1) shows that the fragmentation is similar to that of methyl cinnamate.⁷

(2) (Scheme 2) in 84% yield. The structure of the product was established from analytical and spectral data. Accurate mass measurement on the molecular ion in the mass spectrum in addition to carbon and hydrogen analysis established the molecular formula. The u.v., i.r., and ¹H and ¹⁹F n.m.r. data are also fully in accord with the assigned structure.

TABLE 1
Mass spectral data

	<i>m/e</i>	%	Ion	<i>m</i> *	Transition
Pentafluorocinnamic acid	238	28	<i>M</i> ⁺		
	221	14	<i>M</i> ⁺ - OH		
	218	28	<i>M</i> ⁺ - HF	199.7	238 → 218
	193	47	221 - CO	168.6	221 → 193
	192	31			
	190	94	218 - CO	165.6	218 → 190
	181	20			
	174	17			
	173	22			
	163	17			
	162	22	190 - CO	138.1	190 → 162
	161	20			
	143	100	162 - F	126.5	162 → 143
	142	22			
	124	20			
	123	83	143 - HF	105.8	143 → 123
Pentafluorocinnamic [² H]acid	239	28	<i>M</i> ⁺		
	218	30	<i>M</i> ⁺ - DF	198.9	239 → 218
Methyl pentafluorocinnamate	252	56	<i>M</i> ⁺		
	222	12			
	221	100	<i>M</i> ⁺ - CH ₃ O		
	193	71	221 - CO		
	192	13			
	174	10			
	173	15			
	143	47			
	123	26	143 - HF		
5,6,7,8-Tetrafluorocoumarin	218	76	<i>M</i> ⁺		
	191	9			
	190	100	<i>M</i> ⁺ - CO	165.6	218 → 190
	162	47	190 - CO	138.1	190 → 162
	161	24			
	143	49	162 - F		
<i>o</i> -Fluorocinnamic acid	123	13	143 - HF		
	166	41	<i>M</i> ⁺		
	149	19	<i>M</i> ⁺ - OH		
	146	14	<i>M</i> ⁺ - HF	128.4	166 → 146
	142	17			
	121	31	149 - CO	98.3	149 → 121
	120	24			
	118	100	146 - CO	95.4	146 → 118
	109	19			
	101	45	121 - HF	84.3	121 → 101
	95	12	121 - C ₂ H ₂		
90	10	118 - CO			

The assignment of a structure to a fragment ion on the grounds that a compound with the same molecular formula fragments in a similar fashion has been criticised.⁸ Nonetheless it is interesting that the characteristic fragmentation of coumarin and its derivatives also involves the consecutive loss of two molecules of carbon monoxide.

The pyrolysis of pentafluorocinnamic acid at 400° in a static system for 4 h gave 5,6,7,8-tetrafluorocoumarin

The photolysis of an aqueous solution of sodium *trans*-pentafluorocinnamate at room temperature gave a mixture of the *cis*- and *trans*-isomers. After 10 h the photostationary state was achieved with a ratio of *trans*- to *cis*-acids of 2 : 1. However, when the photolysis was carried out at 100°, 5,6,7,8-tetrafluorocoumarin

⁷ E. M. Emery, *Analyt. Chem.*, 1960, **32**, 1495.

⁸ P. Bommer and K. Biemann, *Ann. Rev. Phys. Chem.*, 1965, **16**, 481.

steam distilled from the reaction mixture and was isolated in 48% yield.

TABLE 2

Precision mass measurements

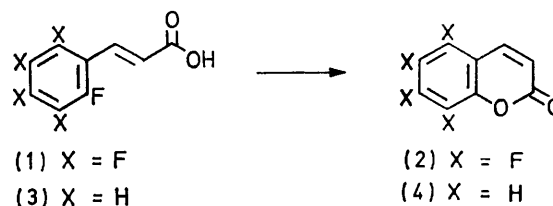
	Measured mass	Possible formula	Calculated mass
Pentafluorocinnamic acid	238-0056	C ₉ H ₃ F ₅ O ₂	238-0053
	217-9989	C ₉ H ₂ F ₄ O ₂	217-9991
	193-0075	C ₈ H ₂ F ₅	193-0076
	190-0038	C ₈ H ₂ F ₄ O	190-0042
	162-0089	C ₇ H ₂ F ₄	162-0092
	143-0108	C ₇ H ₂ F ₃	143-0107
	123-0045	C ₇ H ₂ F ₂	123-0046
	116-9949	C ₆ F ₃	116-9952
5,6,7,8-Tetrafluorocoumarin	217-9990	C ₉ H ₂ F ₄ O ₂	217-9991
	190-0038	C ₈ H ₂ F ₄ O	190-0042
	162-0090	C ₇ H ₂ F ₄	162-0092
	143-0109	C ₇ H ₂ F ₃	143-0108
	112-0124	C ₆ H ₂ F ₂	112-0124

The pyrolysis of *o*-fluorocinnamic acid (3) at 400° for 4 h gave coumarin (4) in 63% yield. However, photo-

lysis of sodium *o*-fluorocinnamate gave no coumarin at 100°. As expected⁹ the energy required for the cyclisation is greater for *o*-fluorocinnamate than for pentafluorocinnamate.

EXPERIMENTAL

Low resolution mass spectra were obtained with an A.E.I. MS 12 spectrometer [direct probe at 70 eV; the ion source at 150° (except as indicated)]. High resolution



SCHEME 2

spectra were obtained with an A.E.I. MS 902 spectrometer (direct probe at 70 eV; ion source at 150°).

Pentafluorocinnamic [³H]Acid.—Pentafluorocinnamic acid¹⁰ (100 mg) in chloroform (15 ml) was shaken with deuterium oxide (0.5 ml) for 2 h and the organic phase was separated. The process was repeated a further three times and gave pentafluorocinnamic [³H]acid (>99% ³H₁) with the mass spectrum given in Table 1.

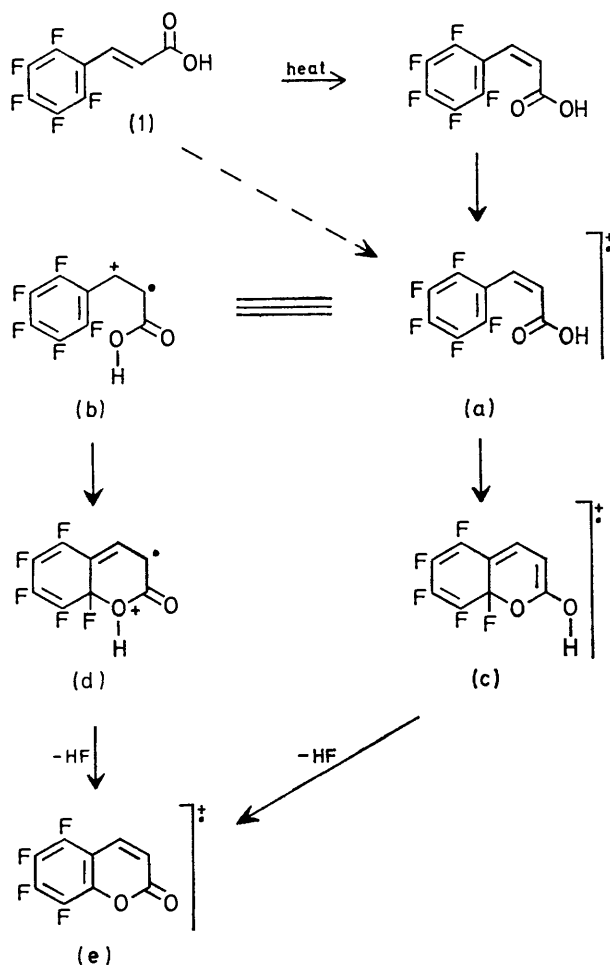
Pyrolysis of Pentafluorocinnamic Acid.—Pentafluorocinnamic acid (500 mg) was placed in a Pyrex tube (ca. 1 l); the system was evacuated, flushed with dry nitrogen, re-evacuated, sealed, and heated at 400° for 4 h. The cold tube was opened and the product dissolved in chloroform; the solution was washed with aqueous potassium hydrogen carbonate, dried (MgSO₄), and evaporated to give 5,6,7,8-tetrafluorocoumarin (390 mg, 84%), m.p. 61–62° (after sublimation) (Found: C, 49.8; H, 1.0%; M⁺, 218. C₉H₂F₄O₂ requires C, 49.6; H, 0.9%; M, 218); τ 2.73 (ABq, |J|_{AB} 10.5 Hz, δ_{AB} 1.38); δ -154.8 (1F, m), -159.7 (1F, m), -169.7 (1F, m), and -173.8 p.p.m. (1F, m); ν_{max.} (KBr) 1775, 1737, 1660, 1600, 1510, and 1485 cm⁻¹; λ_{max.} (EtOH) 275 (ε 11,690) and 210 nm (13,194).

Photolysis of Sodium trans-Pentafluorocinnamate.—Sodium hydroxide (200 mg) was added to pentafluorocinnamic acid (1.19 g) in water (100 ml) and after 0.5 h the solution was carefully adjusted to pH 7 and then made up to 500 ml with water. The solution was heated under reflux under nitrogen while being irradiated with a Hanovia medium-pressure source (450 W) internally through quartz. A white crystalline solid was deposited in the condenser and gave, after 10 h, 5,6,7,8-tetrafluorocoumarin (0.52 g, 48%), m.p. 61–62° (after sublimation), identified by mixed m.p. and i.r. spectrum.

Acidification of the aqueous solution gave a mixture of *cis*- and *trans*-pentafluorocinnamic acids (48 mg) in the ratio 1 : 1.9 (by ¹H n.m.r.).

⁹ J. Burdon, *Tetrahedron*, 1965, **21**, 3373.

¹⁰ A. K. Barbour, M. W. Buxton, P. L. Coe, R. Stephens, and J. C. Tatlow, *J. Chem. Soc.*, 1961, 808.



SCHEME 1

Pyrolysis of o-Fluorocinnamic Acid.—*o*-Fluorocinnamic acid¹¹ (156 mg) was pyrolysed at 400° for 4 h and gave coumarin (85 mg, 63%), m.p. and mixed m.p. 70° (lit.,¹² 70°).

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mouth) for a grant (to A. P. P.) and the S.R.C. for accurate mass measurements through the P.C.M.U. (Aldermaston).

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¹¹ H. Willstaldt, *Ber.*, 1931, **64**, 2689.

¹² Heilbron's 'Dictionary of Organic Compounds,' Eyre and Spottiswoode, London, 1965, vol. 2, p. 748.