# Electrophilic Aromatic Substitution. Part 25.[1] The Nitration in Aqueous Sulphuric Acid of Some Cinnamic Acids and Other Styrene Derivatives

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The rates of nitration of ethyl cinnamate, cinnamic acid, β-nitrostyrene, and trimethyl(styryl)ammonium ion in sulphuric acid of a range of concentrations have been determined. The nitrovinyl and the trimethyl(vinyl)-ammonium groups deactivate the aromatic nucleus by factors of ca. 330 and 60, respectively. The yields of products from ethyl cinnamate and β-nitrostyrene, nitrated over a range of sulphuric acid concentrations, are reported. With ethyl cinnamate the o : p-ratio falls with increasing acidity. The acidity dependences of the rates of reaction of ethyl 4-nitrocinnamate, 4-nitrocinnamic acid, ethyl 3-nitrocinnamate, and 3-nitrocinnamic acid with nitric acid in sulphuric acid show the primary reaction in each case to be attack by the nitronium ion (at the β-carbon atom). The reactions are completed by addition, giving nitroalcohols. A similar but much slower reaction occurs with β,4-dinitrostyrene. In every case the nitroalcohol decomposes in concentrated sulphuric acid to give the nitrobenzaldehyde. With absolute nitric acid, ethyl 4-nitrocinnamate gives the side-chain nitro-nitrate by formal syn-addition. Addition of nitromethane to the reaction solution leads to addition in both stereochemical modes. The nitro-nitrate gives the nitro-alcohol in sulphuric acid, but in aqueous media gives ethyl α-nitro-β-(4-nitro-phenyl)acrylates. These apparent side-chain nitrations are thus addition–elimination reactions, as suggested by van der Lee. Similar processes have been detected in the cases of 4-nitrocinnamic acid and β,4-dinitrostyrene.

THE presence of an electron-withdrawing group at the β-position of a styrene molecule deactivates the aromatic nucleus towards electrophilic attack, and causes predominantly o- and p-substitution. This behaviour is similar to that of a halogen substituent. There are few quantitative data available for the nitration of this type of compound, and for this reason we have determined the rate coefficients for nitration of the compounds (I) in sulphuric acid of various concentrations, and for some of these compounds the yields of products formed.

Nitration of some of the mononitro-compounds (II) occurs at the exocyclic double-bond, as has been observed with nitrocinnamic acids and their esters. Friedländer [2a] nitrated ethyl 4-nitrocinnamate in a mixture
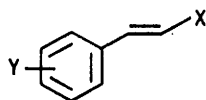
X = CO_2H, CO_2Et, NO_2, NMe_3^+

(I) Y = H

(II) Y = NO_2

containing 60% of sulphuric acid and 40% of nitric acid and isolated one form (III) of ethyl α-nitro-β-(4-nitrophenyl)acrylate [the stereoisomer (IV) was probably lost during crystallisation]. Ethyl 3-nitrocinnamate behaved similarly,[2b] but ethyl 2-nitrocinnamate gave 2-nitrobenzaldehyde. However, one form of ethyl α-nitro-β-(2-nitrophenyl)acrylate was probably obtained from nitration with fuming nitric acid and sodium nitrate.

With mixed acid 4-nitrocinnamic acid gave [2a] β,4-dinitrostyrene. When the reaction solution was poured into iced water the resulting clear solution became turbid and evolved carbon dioxide, suggesting that α-nitro-β-(4-nitrophenyl)acrylic acid was the precursor of the dinitrostyrene. Similar results were obtained with 2- and 3-nitrocinnamic acid.[2b]

van der Lee [3a] nitrated ethyl 4-nitrocinnamate with nitric acid and obtained the stereoisomers (III) and (IV), and compound (V). He regarded (V) as an intermediate in the formation of (III) and (IV), and thought compounds of the same type as (V) to be involved in the nitration of the nitrocinnamic acids.

(III)   (IV)
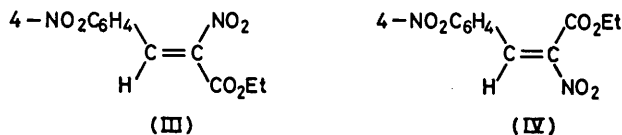
4-NO_2C_6H_4CH(OR)CH(NO_2)Z

(V)   R = NO_2, Z = CO_2Et   (VIII) R = NO_2, Z = CO_2H
(VI) R = H, Z = CO_2Et   (IX)   R = H, Z = CO_2H
(VII) R = Et, Z = CO_2Et   (X)   R = Z = NO_2
                                  (XI)   R = H, X = NO_2

Olefinic nitration has been observed with 1,5-bis-(3-nitrophenyl)- and 1,5-bis-(4-nitrophenyl)-penta-1,4-dien-3-one, 1-(3-nitrophenyl)- and 1-(4-nitrophenyl)-but-1-en-3-one, and 3',4-dinitrochalcone.[3b] Triarylethylenes have been similarly nitrated with nitric acid in acetic acid.[4] Alkenes with solutions prepared from nitric acid and acetic anhydride give nitro-acetates and nitro-nitrates, predominantly by syn-addition.[5]

EXPERIMENTAL

Materials.—Sulphuric acid and urea were AnalaR reagents. Nitric acid was purified by distillation from sulphuric acid. Concentrations of diluted deuteriated acids were determined by titration. Deuterionitric acid was prepared by gently warming potassium nitrate (25 g) in dideuteriosulphuric acid (36 g). The mixture was then distilled under reduced pressure to give pure deuterionitric acid (12 g).

Ethyl cinnamate was purified by distillation, b.p. 80.2 °C at 0.05 mmHg. 4-Nitrobenzaldehyde, m.p. 105—108 °C (EtOH), β-nitrostyrene, m.p. 56—57 °C (EtOH), and cin-

namic acid, m.p. 134—135.5 °C (AcOH), were recrystallised from the solvents indicated.

Ethyl nitrocinnamates were made from the acids, which were prepared from the corresponding benzaldehydes and malonic acid by standard methods. β-Nitrostyrenes were prepared from the corresponding benzaldehydes and nitromethane by standard methods. 2-Nitrocinnamic acid, m.p. 248—252 °C (AcOH), 3-nitrocinnamic acid, m.p. 204—206 °C (AcOH), 4-nitrocinnamic acid, m.p. 288.5 °C (AcOH), ethyl 2-nitrocinnamate, m.p. 42—43 °C (EtOH), ethyl 3-nitrocinnamate, m.p. 74.5—75.5 °C (EtOH), ethyl 4-nitrocinnamate, m.p. 138—139 °C (EtOH), β,2-dinitrostyrene, m.p. 106—107 °C (EtOH), β,3-dinitrostyrene, m.p. 126 °C (EtOH), and β, 4-dinitrostyrene, m.p. 203 °C (EtOH), were recrystallised from the solvents indicated.

Ethyl α-Nitro-β-(4-nitrophenyl)acrylates.—These were prepared by the method of van der Lee.[3a] The two isomers were separated by fractional recrystallisation, first from benzene, then from ether. The Z-isomer (III) formed plates, m.p. 109—111 °C; δ (CDCl$_3$), 8.36 (2 H, d, H-3 and -5), 7.65 (3 H, d, H-2, -6, and α-H), 4.44 (2 H, q, CH$_2$), and 1.39 (3 H, t, CH$_3$); λ$_{max.}$ (hexane) 286 nm (ε 12 900); ν$_{max.}$ (CCl$_4$), 1 732 and 1 270 (COOEt), 1 547, 1 532, and 1 354 cm^{-1} (NO$_2$). The E-isomer (IV) formed yellow needles, m.p. 86.5—87 °C; δ (CDCl$_3$) 8.39 (2 H, d, H-3 and -5), 8.18 (2 H, s, α-H), 7.77 (2 H, d, H-2 and -6), 4.46 (2 H, q, CH$_2$), and 1.36 (3 H, t, CH$_3$); λ$_{max.}$ (hexane) 288 nm (ε 12 300); ν$_{max.}$ (CCl$_4$), 1 732 and 1 225 (COOEt), 1 549, 1 532, 1 350, and 1 338 cm^{-1} (NO$_2$).

Ethyl (2RS,3RS)-2-Nitro-3-nitro-oxy-3-(4-nitrophenyl)propionate.—This was prepared by the method of van der Lee.[3a] The nitric acid solution was poured into iced water over dichloromethane, and the aqueous layer was further extracted with dichloromethane. Recrystallisation from benzene and then ether gave prisms, m.p. 73.5—74.5 °C; δ (CDCl$_3$) 8.38 (2 H, d, H-3 and -5), 7.74 (2 H, d, H-2 and -6), 6.79 (1 H, d, β-H), 5.53 (1 H, d, α-H), 4.13 (2 H, q, CH$_2$), and 1.09 (3 H, t, CH$_3$).

Ethyl 3-Hydroxy-2-nitro-3-(4-nitrophenyl)propionate.—(1) Ethyl 4-nitrocinnamate (2 g) was dissolved in absolute nitric acid (5 ml) below 0 °C. After being stirred for 1 h at 0 °C the solution was poured into 90% w/w sulphuric acid (200 ml) and left for 2 min. This solution was then poured into iced water (800 ml) over dichloromethane (100 ml) and further extracted with dichloromethane (1 × 100 + 2 × 50 ml). The dichloromethane extract was washed twice with water (2 × 50 cm^3) and dried (MgSO$_4$). Evaporation of the solvent under reduced pressure gave a yellow oil which was recrystallised from benzene–light petroleum. This gave one racemate of *ethyl 3-hydroxy-2-nitro-3-(4-nitrophenyl)-propionate* (1.1 g), as prisms, m.p. 74—75.5 °C (Found: C, 46.4; H, 4.3; N, 9.8. C$_{11}$H$_{12}$N$_2$O$_7$ requires C, 46.5; H, 4.2; N, 9.9%); δ (CDCl$_3$) 8.28 (2 H, d, H-3 and -5), 7.63 (2 H, d, H-2 and -6), 5.67 (1 H, d, β-H), 5.41 (1 H, d, α-H), 4.20 (2 H, q, CH$_2$), 3.58br (1 H, OH), and 1.17 (3 H, t, CH$_3$); ν$_{max.}$ (KBr disc) 1 750 and 1 200 (COOEt), 1 564, 1 524, and 1 349 cm^{-1} (NO$_2$).

(2) Ethyl 4-nitrocinnamate (2 g) was dissolved in a mixture of absolute nitric acid (5 ml) and nitromethane (2 ml) below 0 °C. After being stirred for 1 h at 0 °C, the solution was poured into 90% w/w sulphuric acid (200 ml) and left for 2 min. This solution was worked up as before, to give a mixture of the two racemates of *ethyl 3-hydroxy-2-nitro-3-(4-nitrophenyl)propionate* (1.2 g) as prisms, variable m.p. (Found: C, 46.4; H, 4.2; N, 9.8%); δ (CDCl$_3$) 8.29 (4 H,

d, H-3, -5, -3', and -5'), 7.65 (4 H, d, H-2, -6, -2', and -6'), 5.69 (1 H, d, β-H'), 5.66 (1 H, d, β-H), 5.41 (1 H, d, α-H), 5.37 (1 H, d, α-H'), 4.31 (2 H, q, CH$_2$'), 4.19 (2 H, q, CH$_2$), 3.98br (1 H, OH'), 3.64br (1 H, OH), 1.24 (3 H, t, CH$_3$'), and 1.16 (3 H, t, CH$_3$).

Ethyl 3-Ethoxy-2-nitro-3-(4-nitrophenyl)propionate.[2a]— Ethyl 2-nitro-3-(4-nitrophenyl)acrylate (1 g) was dissolved in ethanol (10 ml). After 18 h the ethanol was removed under reduced pressure, giving a clear liquid. Both isomers of ethyl 2-nitro-3-(4-nitrophenyl)acrylate yield the same product, as shown by n.m.r.; δ (CDCl$_3$) 8.22 (4 H, d, H-3, -5, -3', and -5'), 7.64 (1 H, d, H-2, -6, -2', and -6'), 5.41 (1 H, d, β-H'), 5.33 (1 H, d, α-H'), 5.31 (1 H, d, β-H), 5.18 (1 H, d, α-H), 4.32 (2 H, q, O=C–OCH$_2$'), 4.04 (2 H, q, O=C–O–CH$_2$), 3.49 (4 H, m, OCH$_2$ and OCH$_2$'), and 1.17 (12 H, m, CH$_3$ and CH$_3$'). Assignments are based on those for ethyl 3-hydroxy-2-nitro-3-(4-nitrophenyl)propionate.

Kinetic Measurements.—The conventional method was used substantially as described in earlier Parts.[1]

Product Studies.—When analysis was to be carried out by n.m.r. spectroscopy a weighed amount of the starting material (0.2 g) was added to the reaction mixture and after a suitable time the reaction was, if necessary, quenched in ice-cold water and extracted with dichloromethane (10 × 10 ml). After drying (MgSO$_4$) the combined extracts were evaporated under reduced pressure until 5 ml of solution remained. This was transferred to a weighed 25 ml round-bottom flask. The first flask was washed with dichloromethane (2 × 5 ml) and the combined solutions evaporated under reduced pressure. The flask was then re-weighed. N.m.r. spectra were obtained using a JEOL MH-100 spectrometer.

When analysis was to be carried out by g.l.c. the methods used were those which have been described previously in this series. The reaction mixtures were analysed on a Pye 104

TABLE 1

Gas chromatography conditions

Compound	Slope of calibration graph [a]	Column [b]	Retention time (s)
1-Nitronaphthalene [c]	1.000	3% OV17 on	316
Ethyl cinnamate	0.964 ± 0.013	Chromasorb W AW	155
Ethyl *cis*-2-nitrocinnamate	1.41 ± 0.02 [d]	D.M.C.S. (214 °C)	377
Ethyl *cis*-4-nitrocinnamate	1.42 ± 0.04 [d]		518
Ethyl *trans*-2-nitrocinnamate	1.41 ± 0.02		586
Ethyl *trans*-3-nitrocinnamate	1.33 ± 0.02		703
Ethyl *trans*-4-nitrocinnamate	1.42 ± 0.04		779
2,3,5,6-Tetrachloro-nitrobenzene [c]	1.000	As above (220 °C)	226
2-Nitrobenzaldehyde	0.589 ± 0.011		112
4-Nitrobenzaldehyde	0.642 ± 0.022		128
β-Nitrostyrene	0.704 ± 0.013		137
β,2-Dinitrostyrene	0.737 ± 0.017		519
β,3-Dinitrostyrene [e]	0.702 ± 0.026		683
β,4-Dinitrostyrene [e]	0.714 ± 0.013		730

[a] (Wt. of substance) × (Peak area for standard)/(Wt. of standard) × (Peak area for substance). [b] Pye 104 instrument with flame-ionization detector and nitrogen (40 ml min^{-1}) as carrier. [c] Standards. [d] Slope assumed to be the same as that of the *trans*-isomer. Tests on standard solutions showed that this assumption gave yields which were quantitative within the experimental error. [e] There was some overlap of these peaks.

gas chromatograph linked to a Pye 'minigrator'. Details of the g.l.c. procedures used in analysing product mixtures are given in Table 1.

Protonation Data.—A spectrophotometric method [6] was used. The extinction coefficients for the conjugate acid were plotted against H_0 and the indicator ratio calculated from the sigmoidal curve.

RESULTS

Protonation of Ethyl Cinnamate, Cinnamic Acid, and Ethyl 4-Nitrocinnamate.—In the range 71.2—86.0% H_2SO_4 plots of (log I — log [H$^+$]) *versus* M_c (the Marziano function using values calculated by Cox and Yates [7]) had slopes of 0.58 and 0.66 for cinnamic acid (pK_a —4.41) and ethyl cinnamate (pK_a —4.82), respectively. Ethyl 4-nitrocinnamate was protonated at a slightly higher acidity, but accurate determinations were not possible. 4-Nitrocinnamic acid was also protonated in this region.

Nitrations.—The second-order rate coefficients for the nitrations in sulphuric acid at 25 °C, corrected where necessary for protonation, are given in Table 2. Yields of products are given in Table 3. Product yields from cinnamic acid were not obtained because both the starting material and the products were insoluble in the extracting solvent. G.l.c. and n.m.r. spectroscopy showed that the products

TABLE 2

Second-order rate coefficients for nitration in sulphuric acid at 25.0 $\pm$ 0.1 °C

H_2SO_4 (%)	10^3[HNO$_3$]/ mol dm^{-3}	k_2/dm^3 mol^{-1} s^{-1}	k_2(fb)/dm^3 mol^{-1} s^{-1}
Ethyl cinnamate [a,b,d]			
69.1	92	1.38×10^{-2}	1.51×10^{-2}
69.3	146	1.51×10^{-2}	1.67×10^{-2}
70.0	145	1.98×10^{-2}	0.023
71.2	100	0.057	0.067
71.6	151	0.062	0.076
73.1	30	0.190	0.25
73.9	11.1	0.43	0.61
74.7	37	0.78	1.20
75.1	14	0.93	1.49
76.4	20	2.9	5.4
77.8	1.02	7.2	16.7
78.5	0.86	11.9	30
79.1	0.36	21	58
79.2	0.44	19.3	55
79.9	0.37	36	118
Cinnamic acid [a,b,d]			
69.1	92	6.3×10^{-3}	7.4×10^{-3}
71.2	100	0.027	0.034
73.1	30	0.091	0.123
75.1	14	0.43	0.67
77.8	1.02	3.8	7.8
79.2	0.44	11	27
β-Nitrostyrene [a,b,d]			
73.1	146	1.44×10^{-2}	
75.1	75	0.094	
77.8	5.2	0.89	
79.2	14.4	3.9	
80.5	1.06	15.1	
83.0	0.26	138	
Trimethyl(styryl)ammonium perchlorate [a,b,g]			
71.1	18.2	1.54×10^{-2}	
73.1	75	0.082	
74.4	29	0.32	
75.1	13.6	0.61	
77.6	1.70	9.2	
79.2	0.31	39	

TABLE 2 (continued)

H_2SO_4 (%)	10^3[HNO$_3$]/ mol dm^{-3}	k_2/dm^3 mol^{-1} s^{-1}
Ethyl 4-nitrocinnamate [a,c,e]		
78.5	210	3.7×10^{-4}
79.1	210	4.8×10^{-4}
79.9	193	8.3×10^{-4}
81.4	145	2.5×10^{-3}
82.0	156	5.8×10^{-3}
82.3	133	5.3×10^{-3}
82.5	182	6.3×10^{-3}
83.8	103	9.1×10^{-3}
85.0	200	0.023
85.3	68	0.027
86.5	101	0.039
88.3	143	0.086
88.7	113	0.094
91.4	58	0.040
93.4	118	0.024
94.1	147	0.0177
4-Nitrocinnamic acid [a,c,f]		
78.5	81	2.4×10^{-4}
79.1	134	2.3×10^{-4}
79.9	94	4.0×10^{-4}
81.4	121	9.5×10^{-4}
82.0	159	2.2×10^{-3}
82.3	101	2.1×10^{-3}
82.5	76	1.86×10^{-3}
83.8	108	5.0×10^{-3}
85.0	85	1.28×10^{-2}
86.5	46	1.54×10^{-2}
88.7	62	0.032
91.4	78	0.022
93.4	138	1.64×10^{-2}
94.1	140	1.01×10^{-2}
Ethyl 3-nitrocinnamate [a,c,g]		
80.3	29	2.5×10^{-3}
82.3	21	6.7×10^{-3}
83.1	54	1.16×10^{-2}
85.0	63	0.058
86.0	52	0.072
88.6	25	0.122
89.3	25	0.103
90.7	32	0.102
92.5	51	0.090
96.9	23	0.020
3-Nitrocinnamic acid [a,c,h]		
80.3	43	9.1×10^{-4}
82.3	36	3.2×10^{-3}
83.1	47	4.8×10^{-3}
85.0	100	1.83×10^{-2}
86.0	52	0.036
88.6	25	0.052
89.3	25	0.058
90.7	32	0.049
92.5	100	0.032
96.9	47	1.72×10^{-2}

[a] [Urea] $\approx$ 3 $\times$ 10^{-2} mol dm^{-3}. [b] [ArH] $\approx$ 4 $\times$ 10^{-5} mol dm^{-3}. [c] [ArH] $\approx$ 1 $\times$ 10^{-4} mol dm^{-3}. [d] Measurements at various wavelengths. [e] Measurements at 319 nm. [f] Measurements at 325 nm. [g] Measurements at 300 nm. [h] Measurements at 330 nm.

from ethyl cinnamate *cis–trans*-isomerised whilst dissolved in dichloromethane and in the light. The yields given are the sums of those of the *cis*- and *trans*-isomers. The loss of yield from ethyl cinnamate at lower acidities is probably due to hydrolysis of the ethyl nitrocinnamates; the acids would not be extracted. Hydrolysis is more noticeable at lower acidities because the products are in contact with the acid for longer times. If reaction was stopped after a shorter time, as when 69.03% H_2SO_4 was used (Table 3), material could be recovered quantitatively.

Yields of products from the nitration of ethyl cinnamate and β-nitrostyrene in aqueous sulphuric acid at 25.0 ± 0.1 °C

Compound	H_2SO_4 (%)	Nitro-compound (%)			Total yield (%)	$\frac{1}{2}o : p$-ratio
		(2)	(3)	(4)		
Ethyl cinnamate [a]	69.03 [c]	31.0	1.1	25.0	100.3	0.62
	69.12	47.5	1.7	39.2	88.4	0.61
	71.42	50.9	1.9	42.5	95.3	0.60
	73.06	50.9	1.9	44.0	96.8	0.58
	75.05	51.2	2.1	46.5	99.8	0.55
	77.72	50.6	2.1	50.0	102.7	0.51
	80.80	47.8	2.4	51.6	101.8	0.46
	83.04	45.7	3.1	55.3	104.1	0.41
	84.98	41.3	3.3	55.4	100.0	0.37
β-Nitrostyrene [b]	77.57	33.4	9.8	50.4	93.6	0.33
	79.17	34.1	9.5	55.7	99.3	0.31
	80.54	35.8	7.4	54.7	97.9	0.33
	83.04	33.9	8.5	57.3	99.7	0.30
	84.98	33.9	8.6	57.0	99.5	0.30
	86.03	34.5	6.8	54.4	98.6 [d]	0.32
	89.33	32.7	8.2	53.3	94.2	0.31
	90.75	28.5	9.3	59.4	97.6	0.24
	92.54	26.9	7.1	58.4	92.4	0.23
	96.88	4.8	7.2	53.3	65.3	0.05

[a] [ArH] $\approx$ 8 × 10^{-5} mol dm^{-3}. [b] [ArH] $\approx$ 6 × 10^{-5} mol dm^{-3}. [c] Stopped after one half-life (43% of starting material). [d] Including some starting material.

With β-nitrostyrene cis–trans-isomerisation was not a problem. At lower acidities the products were hydrolysed to the nitrobenzaldehydes, which could not be extracted quantitatively. Where nitrobenzaldehydes were produced the total yield of nitro-product is given (Table 3). At higher acidities β,2-dinitrostyrene decomposed whereas β,4-dinitrostyrene and β-nitrostyrene itself could be recovered quantitatively.

Nitration of ethyl 4-nitrocinnamate under Friedländer's conditions [2a] gave both (III) and (IV), with a trace of (V) and of p-nitrobenzaldehyde, the aggregate yield being almost quantitative. The isomers (III) and (IV) were separated. Structural assignments were attempted on the basis of the work of Watarai et al.[8] However, differences in the spectra were smaller than expected and complicated by the presence of two nitro-groups. The compound, m.p. 109—111 °C, was shown to be the Z-isomer by X-ray diffractional studies.*

van der Lee's compound (V), from the reaction of ethyl 4-nitrocinnamate with nitric acid, has been shown by X-ray crystallography to be ethyl (2RS,3RS)-2-nitro-3-nitro-oxy-3-(4-nitrophenyl)propionate,[9] formed by syn-addition to the presumably trans-ester. Reaction of ethyl 4-nitrocinnamate with absolute nitric acid gave almost wholly this compound, though the n.m.r. spectrum of the total extract from the reaction showed the presence of the second isomer (<5%). The n.m.r. spectrum of the reaction solution itself, using deuterionitric acid, gave the same result. Increasing the concentration of nitromethane (5—40% v/v) in a nitrating solution of nitromethane and nitric acid increased the proportion of the second isomer (up to 30%) and caused a decrease in the reaction rate.

Reaction of ethyl 4-nitrocinnamate with nitric acid ([HNO_3] < 0.1 mol dm^{-3}, [Ar] 0.01 mol dm^{-3}) in aqueous 80—98% sulphuric acid for ten half-lives gave predominantly p-nitrobenzaldehyde. This was not formed from (III) and (IV) for these react more slowly. Compound (V) is unlikely to be formed in sulphuric acid with such a low concentration of nitric acid, and the reaction was first-order with respect to the concentration of nitric acid, even

* We are grateful to Dr. J. D. Wallis for this information.

with equimolar concentrations of nitric acid and ethyl 4-nitrocinnamate. A more likely intermediate is the alcohol (VI), which we prepared by hydrolysing (V). With [HNO_3] 2 mol dm^{-3} the reaction with the ester in 90% H_2SO_4 was, of course, much faster, and could be quenched after 2 min, thus reducing decomposition of the intermediate. There were isolated the two racemates of (VI), p-nitrobenzaldehyde, (III), (IV), and a small amount of (V). A similar result was obtained by direct extraction of the aqueous sulphuric acid reaction after five half-lives.

By carrying out the reaction of ethyl 4-nitrocinnamate with nitric acid in deuteriosulphuric acid it was possible, using n.m.r. spectroscopy, to observe that as the concentration of the starting material decreased an intermediate was formed which decomposed to give benzaldehyde. Decomposition of ethyl α-nitroacetate formed from the intermediate led to the evolution of carbon dioxide. The n.m.r. spectrum of the intermediate in deuteriosulphuric acid identified it as (VI). The n.m.r. spectrum of a solution prepared by dissolving (V) in 98% deuteriosulphuric acid was identical with that of (VI), showing the ease of hydrolysis of (V). Under the conditions used interconversion of the two racemates of (VI) did not occur. Over the range 84.6—98.1% D_2SO_4 equal amounts of the two were formed.

The n.m.r. spectrum of the solution of 4-nitrocinnamic acid in deuterionitric acid revealed the presence of a compound similar to (V), probably (VIII). Only one racemate could be detected. Nitration in sulphuric acid caused the evolution of carbon dioxide, and the n.m.r. spectrum of the reaction solution in deuteriosulphuric acid showed 4-nitrobenzaldehyde to be the product, with a very small amount of an intermediate (IX), having a spectrum very similar to that of (VI).

β,4-Dinitrostyrene is much less reactive towards nitration than are 4-nitrocinnamic acid and ethyl 4-nitrocinnamate. The n.m.r. spectrum of solutions prepared from the dinitrostyrene and deuterionitric acid showed the formation of a compound very similar to (VI) and (IX), presumably (X), which was again formed in one diastereoisomeric form. Again, nitration in deuteriosulphuric acid produced 4-

nitrobenzaldehyde and an intermediate similar to (VI), presumably (XI).

Reactions of Compounds (V) *and* (VI).—These compounds can decompose in two ways. By a retro-aldol reaction they give 4-nitrobenzaldehyde, and by elimination of water or nitric acid they give (III) and (IV). In sulphuric acid the first reaction predominates, (V) being first hydrolysed to (VI). First-order rate constants for the reaction (measured by following u.v. spectroscopic changes) are given in Table 4.

TABLE 4

First-order rate coefficients for the decomposition of (V) and (VI) in aqueous sulphuric acid at 25.0 ± 0.1 °C

Compound	H_2SO_4 (%)	$10^3 k_1/s^{-1}$
(V) [a,b]	83.04	0.106
	85.36	0.241
	86.00	0.291
	92.54	0.837
	96.88	1.15
	97.51	1.57
(VI) [c]	86.00	0.277
	89.33	0.600
	90.73	0.859
	92.54	0.921
	96.88	1.33

[a] Measurements at 278 nm. [b] The pure (2RS,3RS)-compound was used. Measurements at 280 nm. [c] The pure racemate, m.p. 74—75.5 °C, was used.

In water and in aqueous ethanol elimination to give (III) and (IV) is the major reaction of (V); (III) and (IV) then gave 4-nitrobenzaldehyde, presumably *via* (VI). In ethanol elimination is slower; it is followed by addition of ethanol to give (VIII).[2] Sodium hydroxide greatly accelerated elimination from (V). The n.m.r. spectrum of the reaction solution, using trideuterionitromethane and deuterium oxide showed (V) to give equal amounts of (III) and (IV) directly without an observable intermediate.

In the decomposition of (V) in a solvent over aqueous media the proportion of (III) to (IV) was reversed in going from alkali to acid [*e.g.* reaction of (V) in ether with 10% aqueous sodium hydroxide gave (III) and (IV) in the ratio 1.8 : 1; use of ether and 23% H_2SO_4 changed the ratio to 0.72 : 1] and acid slowed the reaction.

DISCUSSION

Nuclear Nitrations.—The rate profile for the nitration of β-nitrostyrene is parallel to that of benzene (Table 5). The group CH:CHNO₂ deactivates the aromatic ring by

TABLE 5

Slopes of rate profiles for nitrations in aqueous sulphuric acid at 25 °C

Compound	H_2SO_4 (%)	$d(\log_{10}k_2)/d(\log_{10}k_2^{bz})$
β-Nitrostyrene	73—80	1.02
Ethyl cinnamate	69—80	0.81
	69—80	0.93 [a]
Cinnamic acid	69—79	0.82
	69—79	0.90 [a]
Ethyl 4-nitrocinnamate	78—82	0.55
	78—82	0.77 [a]
Ethyl 3-nitrocinnamate	78—82	0.59
3-Nitrocinnamic acid	78—82	0.56
4-Nitrocinnamic acid	78—82	0.51
Trimethyl(styryl)ammonium perchlorate	71—79	1.08

[a] Corrected for protonation.

a factor of 330. In contrast the nitro-group of nitrobenzene deactivates the ring *ca.* 2 × 10⁷ times. The attenuation of the effect of the cationic group in trimethyl(styryl)ammonium is greater, from a relative rate for phenyltrimethylammonium similar to that of nitrobenzene to *ca.* 60 (the figures are to some degree medium-dependent). The slopes of the rate profiles for the nitration of cinnamic acid and ethyl cinnamate (Table 5) are slightly lower than that for benzene, even after correction for protonation. In other compounds with oxygen-containing substituents such behaviour has been attributed to hydrogen-bonding.[10,11a]

Over the acidity range 79—89% H_2SO_4 β-nitrostyrene is quantitatively mononitrated with constant ratios of products and a $\frac{1}{2}o$: *p*-ratio of 0.31. The apparently lower $\frac{1}{2}o$: *p*-ratio at higher acidities was, in these experiments, probably due to difficulties in recovering products. The u.v. spectrum indicates that above 89% H_2SO_4 β-nitrostyrene is beginning to be protonated. The decrease in the $\frac{1}{2}o$: *p*-ratio for the nitration of ethyl cinnamate with increasing acidity (leading to the formation of a preponderance of the *p*-isomer above 78.5% H_2SO_4) is, like the slightly low slope of the rate profile (Table 5), probably due to hydrogen-bonding.[10,11a]

Side-chain Nitration.—The rate profiles for the nitration of 3- and 4-nitrocinnamic acid and ethyl 3- and 4-nitrocinnamate in sulphuric acid show the characteristic maxima at *ca.* 89% H_2SO_4 (Table 2). This and the slopes of the profiles are consistent with rate-determining attack by nitronium ion.[11b] The low slopes of the rate profiles (Table 5) even when, as in the case of ethyl 4-nitrocinnamate, corrected for protonation, are again probably due to hydrogen-bonding. Such behaviour is characteristic of nitro-compounds.[11a]

As regards the products of side-chain nitrations, it is convenient to consider first the reaction of ethyl 4-nitrocinnamate with absolute nitric acid. This reaction is highly stereoselective, though not stereospecific, but becomes less so with the increasing addition to the medium of nitromethane. The highly stereoselective reaction gives the product of formal *syn*-addition to the *trans*-ester. Such addition might occur in an ion-pair containing the carbonium ion, formed by initial attack of nitronium ion, and nitrate anion (the involvement of dinitrogen pentaoxide itself is highly unlikely: nitrations in nitric acid are nitronium ion reactions,[11b,12] and dinitrogen pentaoxide is completely ionised by dissolution in nitric acid: [11c] ethyl 4-nitrocinnamate did not react with dinitrogen pentaoxide in carbon tetrachloride) or by *anti*-addition to the nitrocarbonium ion following rotation round the central C–C bond. The effect of added nitromethane on these processes is not readily predicted.

In sulphuric acid the (2RS,3RS)-nitro-nitrate (V) gives the two racemates of the nitro-alcohol (VI). This observation would be easily understood if an S_N1 solvolysis were involved, but available knowledge of the hydrolysis of nitrate esters gives no guide to the behaviour of (V) in the conditions used. It is surprising that the nitro-alcohols are not interconverted in the strongly

acidic solutions. The nitro-alcohols (VI) were formed also by nitrating ethyl 4-nitrocinnamate with low concentrations of nitric acid in sulphuric acid. Corresponding addition reactions occur with 4-nitrocinnamic acid and β,4-dinitrostyrene. Our kinetic results (Tables 2 and 5) show that these reactions are all electrophilic additions, initiated by the nitronium ion. There is nothing in the stereochemical results to suggest that nitronium attack produces a bridged intermediate.

Friedländer's preparation [2a] of (III), by reaction of ethyl 4-nitrocinnamate with mixed acid, we have shown to produce (III), (IV), traces of (V), and 4-nitrobenzaldehyde. Friedländer's conditions employed very much larger concentrations of nitric acid than our experiments discussed above, and clearly, van der Lee's opinion [3a] that (V) was the initial product, and that it decomposed to (III) during work-up is correct. van der Lee noticed that (V) is sensitive to moisture, readily losing nitric acid to give (III) and (IV). Available results on the elimination of nitric acid from (III) are not adequate to reveal the mechanism or mechanisms operating.

Our main conclusion relating to the side-chain reactions is that they are not nitro-deprotonations, but electrophilic additions which may be followed by elimin-ations or retro-aldol reactions, depending upon the conditions and mode of work-up.

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