Aromatic Sulphonation. Part XLIV.[1] Sulphonation of Some *meta*-Substituted Benzenesulphonic Acids with Fuming Sulphuric Acid. Preparation of Arene-1,2-disulphonic Anhydrides

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Isomer distributions for the sulphonation of various 3-substituted benzenesulphonic acids in fuming sulphuric acid at 25° have been determined. The isomer distributions are dependent on the sulphuric acid concentration and approach a constant ratio below 104 and above 115% H_2SO_4. The degree of substitution at the 6-position † and the $f_6:f_5$ partial rate factor ratio run parallel with the ability of conjugative electron release of the substituent at the 3-position. The size of this substituent further determines the $f_4:f_6$ ratio. The preparation of some 4-substituted benzene-1,2-disulphonic anhydrides is described. They hydrolyse rapidly with the exception of 3,4,5,6-tetramethylbenzene-1,2-disulphonic anhydride. This compound is also formed more rapidly from the corresponding disulphonic acid than the other anhydrides, probably as a result of a decrease in overcrowding. The ^1H n.m.r. and i.r. spectral data of the intramolecular anhydrides are compared with those of some intermolecular arenesulphonic anhydrides.

Reaction of 3-fluoro- and 3-chloro-benzenesulphonic acid with oleum gives rise to sulphonation at the 4-, 5-, and 6-positions.[2] † The relative amount of 4-substitution is significantly greater with the fluoro- than with the chloro-substrate. In order to determine the factors which control the isomer distribution, we have studied the sulphonation of a series of 3-substituted and 3,5-disubstituted benzenesulphonic acids. The sulphonation products with two *ortho*-sulpho-groups, *i.e.* the 1,2-disulphoarenes, are of special interest, as they would allow the formation of intramolecular disulphonic anhydrides. This paper further deals with the formation and some of the properties of these anhydrides.

RESULTS AND DISCUSSION

Sulphonation Isomer Distribution.—The isomer ratio of the disulphoarenes formed in the sulphonation of *meta*-substituted benzenesulphonic acids with oleum was determined by multicomponent ^1H n.m.r. analysis. The results are in Table 1. For a given 3-substituted benzenesulphonic acid a constant isomer ratio is observed both at low and high fuming sulphuric acid concentration (see 3-fluoro- and 3-methyl-benzenesulphonic acid). The degree of 5-substitution is greater at high than at low sulphuric acid concentration. The substrate species undergoing substitution in weak oleum is the sulphonic acid proper.[3] It is suggested that the substrate species undergoing substitution in $\geqslant 115\%$ H_2SO_4 is the protonated (or sulphur trioxide complexed) arenesulphonic acid. The degree of *meta*-substitution will be greater for the $SO_3H_2^+$ (or S_2O_6H) than for the SO_3H substituent.

For a given sulphuric acid concentration the degree of 6-substitution and the $f_6:f_5$ partial rate factor ratio with a 3-substituted benzenesulphonic acid as substrate decreases in the order $F > Cl \simeq Br > Me > Bu^t \gg H$. This order parallels the ability of conjugative electron release by these substituents to the *para*-position and emphasizes the requirement of mesomeric electron release by the substituent at the 3-position in order to effect sulphonation at the 6-position. According to Suter, the sole product in the sulphonation of 3-aminobenzenesulphonic acid is 2-aminobenzene-1,4-disulphonic acid.[4] The absence of the 4-amino-1,2-disulpho-isomer infers that the amino-substituent in the substrate species undergoing substitution does not exhibit conjugative electron release and is apparently present in the NH_3^+ form.

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† In this paper, the position of the entering sulpho-group is numbered by reference to the numbering of the substrate.

[1] Part XLIII, C. Ris and H. Cerfontain, *J.C.S. Perkin II*, 1973, 2129.

[2] H. Cerfontain, A. Koeberg-Telder, and W. A. Zwart-Voorspuy, *Canad. J. Chem.*, 1972, **50**, 1574.

[3] C. W. F. Kort and H. Cerfontain, *Rec. Trav. chim.*, 1969, **88**, 1298.

[4] C. M. Suter, 'The Organic Chemistry of Sulphur,' Wiley, New York, 1944, p. 248.

The $f_4 : f_6$ ratio decreases in the order H > Me > Cl > Br > Bu^t = 0. This order of the rate ratios can be explained in terms of variations in f_4, as the steric hindrance for substitution at the 4-position due to the 3-substituent increases in the given order.

With the symmetrical 3,5-dialkylbenzenesulphonic acids the $f_2 : f_4$ ratio decreases in the order H ⩾ Me > Et.

TABLE 1

Sulphonation of 3-X,5-Y-disubstituted benzenesulphonic acids

				Disulphonic acid isomer distribution (%)			Partial rate factor ratios		Activation parameters for 104·0% H_2SO_4				
X	Y	H_2SO_4 (%)	Temp. (°C)	1,6 [a]	1,5	1,4	f_6/f_5 [a]	f_4/f_6 [a]	$\Delta H_6^\ddagger - \Delta H_5^\ddagger$ kcal mol^{-1}	$\Delta H_4^\ddagger - \Delta H_6^\ddagger$ kcal mol^{-1}	$\Delta S_6^\ddagger - \Delta S_5^\ddagger$ cal mol^{-1} K^{-1}	$\Delta S_4^\ddagger - \Delta S_6^\ddagger$ cal mol^{-1} K^{-1}	Ref.
H	H	101—104	25·0	≤0·5	97 ± 1	2·9 ± 0·5	≤0·005	≥5·8				≥5	7
		115	25·0	≤0·5	98 ± 1	2·0 ± 0·5	≤0·005	≥4·0					7
F	H	104·0	25·0	79 ± 2	7 ± 2	14 ± 2							
		107·2	25·0	77·8 ± 1·0	7·1 ± 1·0	15·1 ± 1·5							
		112·3	25·0	73 ± 2	13 ± 2	14 ± 2							
		115	25·0	75·1 ± 1·0	14·7 ± 1·0	10·2 ± 1·5							
		118·1	25·0	75·7 ± 1·0	14·1 ± 1·0	10·2 ± 1·5							
Cl	H	115	25·0	48 ± 2	39 ± 3	13 ± 2	1·2 ± 0·1	0·27 ± 0·05					
Br	H	115	25·0	46 ± 3	45 ± 4	9 ± 2	1·0 ± 0·2	0·20 ± 0·06					
Me	H	102—104	25·0	14 ± 2	50 ± 2	36 ± 2	0·28 ± 0·05	2·6 ± 0·5	−2·2 ± 0·1	2·9 ± 0·1	−10·1 ± 0·5	11·5 ± 1·0	7
		115—118	25·0	11 ± 2	69 ± 1	20 ± 1	0·16 ± 0·03	1·8 ± 0·4					7
Bu^t	H	104	25·0	14 ± 1	86 ± 1	0	0·16 ± 0·01	0					
NH_3^+	H	115	25·0	No reaction in 60 days									
Me	Me [a]	104·0	0	29·7 ± 0·5		70·3 ± 0·5				0·4 ± 0·1		4·5 ± 0·2	
			25·0	27·3 ± 0·5		72·7 ± 0·5		5·4 ± 0·2					
			62	26·5 ± 0·5		73·5 ± 0·5							
			98	25·6 ± 0·5		74·4 ± 0·5							
			150	24·7 ± 0·5		75·3 ± 0·5							
Et	Et [a]	104·0	0	51·4 ± 0·5		48·6 ± 0·5				1·2 ± 0·2		5·8 ± 0·2	
			25·0	46·4 ± 0·5		53·6 ± 0·5		2·34 ± 0·1					
			50	42·1 ± 0·5		57·9 ± 0·5							
			80 [b]	38·9 ± 0·5		61·1 ± 0·5							
Bu^t	Bu^t	107·2	25·0	See text									

[a] For the 3,5-dialkylbenzenesulphonic acids the 6-position should be read as the 2-position. [b] The ratio of 1,2- to 1,4-disulphonic acid is the same for reaction times of 2 and 10 min.

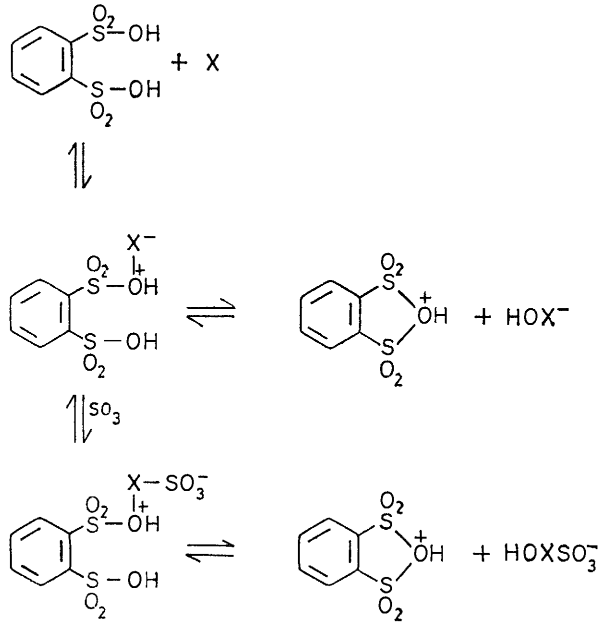
Inspection of the activation parameters shows that the order Me > Et is due to a higher activation enthalpy difference of 0·8 ± 0·3 kcal mol^{-1} for the ethyl as compared with the methyl analogue, despite a higher entropy of activation of 1·3 ± 0·4 cal mol^{-1} K^{-1}.

The reaction of 3,5-di-t-butylbenzenesulphonic acid with fuming sulphuric acid results in dealkylation and subsequent sulphonation of the resulting 3-t-butylbenzenesulphonic acid.

Arene-1,2-*disulphonic Anhydrides*.—These compounds can be obtained on reaction of a benzenesulphonic acid containing an activating substituent in the *meta*-position with an excess of fuming sulphuric acid. They are also formed on dissolving arene-1,2-disulphonic acids, or the corresponding disulphonates in >100% H_2SO_4 or chlorosulphuric acid. Some of the anhydrides can be isolated by pouring the reaction mixtures onto a large excess of ice-water, and rapidly filtering the precipitated anhydride. The 1,2-arenedisulphonic anhydrides are easily hydrolysed, some even by moist air.

3,4,5,6-Tetramethylbenzene-1,2-disulphonic anhydride behaves somewhat differently from the other anhydrides. It does not hydrolyse in boiling water. The deviation in behaviour is due in part to the very low solubility of the anhydride in water and in part to a lower degree of overcrowding[5] in the disulphonic anhydride as compared with the disulphonate dianion. In support of the first explanation, 3,4,5,6-tetramethylbenzene-1,2-disulphonic anhydride upon dissolution in aqueous dimethyl sulphoxide hydrolyses at room temperature. In support of the second explanation, a homogeneous solution of dipotassium 3,4,5,6-tetramethylbenzene-1,2-disulphonate in 98% H_2SO_4 yields a precipitate of the disulphonic anhydride, whereas for the formation of the other disulphonic anhydrides sulphuric acid more concentrated than 100% is required.

The conversion of an arene-1,2-disulphonic acid into its intramolecular anhydride proceeds in fuming sulphuric acid and in chlorosulphuric acid. It apparently requires



SCHEME

transfer of a strong electrophile, *e.g.* SO_3 or SO_3H^+ from $H_2S_2O_7$ or $H_3S_2O_7^+$ to the disulphonic acid and successive ring closure with or without interference of a molecule of SO_3 (Scheme).

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[5] M. A. M. Meester and H. Schenk, *Rec. Trav. chim.*, 1972, **91**, 213.

The physical constants of some anhydrides are collected in Table 2. The ^1H n.m.r. spectra of the arene-1,2-disulphonic anhydrides in nitromethane and fuming sulphuric acid are similar, but significantly different from those in 98% H_2SO_4 and D_2O (*cf.* the chemical shifts of H or Me at the 4- and 5-positions). The spectra of the anhydrides in D_2O, 98% H_2SO_4, and fuming sulphuric acid are identical with those obtained by dissolving the corresponding arene-1,2-disulphonates in these solvents. Accordingly arene-1,2-disulphonic acids are present as such in concentrated aqueous sulphuric acid, but as the corresponding intramolecular anhydride in fuming sulphuric acid, and *vice versa.*

TABLE 2

Physical constants of sulphonic and disulphonic anhydrides

Substituents in Benzene-1,2-disulphonic anhydride	Substituents in Benzene-sulphonic anhydride	M.p. (°C)	Solvent	δ (p.p.m.) [a] Sulphonic anhydride 2-	3-	4-	5-	6-(H or Me)	Corresponding sulphonic acid or sulphonate 2-	3-	4-	5-	6-(H or Me)	Characteristic i.r. frequencies [b,c] SO_2 $\nu_{as}/\mathrm{cm}^{-1}$	SO_2 ν_s/cm^{-1}	S–O–S $\nu_{as}/\mathrm{cm}^{-1}$	S–O–S ν_s/cm^{-1}
None		183—185	CD_3NO_2		8·24	8·24	8·24	8·24		8·28	7·93	7·93	8·28	1415	1220; 1190	795	720
			102—107% H_2SO_4		8·17	8·17	8·17	8·17									
			$ClSO_3H$		8·0	8·0	8·0	8·0									
			98% H_2SO_4							8·40	8·08	8·08	8·40				
			D_2O							8·12	7·60	7·60	8·12				
4-Me		Unstable	CD_3NO_2		Decomposes					8·07	2·54	7·70	8·12				
			104% H_2SO_4		7·96	2·64	7·93	8·05									
			98% H_2SO_4							8·20	2·63	7·83	8·24				
			D_2O							7·91	2·40	7·45	7·99				
4-Bu^t		Unstable	107% H_2SO_4		8·24	1·49	8·27	8·15									
			D_2O							8·17	1·32	7·65	8·05				
3,4,5-Me_3		203—204	CD_3NO_2		2·76	2·43	2·55	7·84		2·68	2·38	2·48	7·95	1413: 1395	1224; 1162	808	721; 710
			104% H_2SO_4		2·63	2·38	2·50	7·76									
Me_4		242—243	CD_3NO_2		2·63 [d]	2·45 [d]	2·45 [d]	2·63 [d]						1390	1180; 1170	800	730
			$(CH_3)_2SO$		2·59	2·38	2·38	2·59		2·54	2·22	2·22	2·54				
			102% H_2SO_4		2·62	2·41	2·41	2·62									
			98% H_2SO_4		2·65	2·44	2·44	2·65									
			D_2O							2·51	2·24	2·24	2·51				
4-F		Unstable	CD_3NO_2		8·04		8·0	8·36						1415 [e]	1235; 1195 [e]	800 [e]	740 [e]
			107% H_2SO_4		7·87		7·8	8·2									
			98% H_2SO_4							8·25		7·85	8·57				
			D_2O							7·86		7·36	8·16				
	4-Me													1375 [f]	1174 [f]		
	2,4,6-Me_3	145—151	CD_3NO_2	2·50	7·1	2·34	7·1	2·50	2·61	7·08	2·33	7·08	2·61	1390; 1375	1190; 1170	730; 715	655
			98% H_2SO_4						2·57	7·02	2·29	7·02	2·57				
			D_2O						2·55	6·98	2·22	6·98	2·55				
	4-I	Unstable	CD_3NO_2	7·56	8·01		8·01	7·56	7·67	8·02		8·02	7·67	1398; 1380	1193; 1174	730	
			98% H_2SO_4						7·68	8·05		8·05	7·67				
			D_2O						7·57	7·90		7·90	7·57				
	2,5-Cl_2	152—153												1400; 1390	1187	745	675

[a] The experimental error in δ for CD_3NO_2, $(CH_3)_2SO$, and D_2O as solvent is 0·03, for 107—98% H_2SO_4 0·05, and for $ClSO_3H$ 0·1 p.p.m. [b] For KBr pellets. [c] The corresponding frequencies of $H_2S_2O_7$ are 1451—1444, 1271—1221, 812—809, and 736—730 cm^{-1} (K. Stopperka, *Z. anorg. Chem.*, 1966, **345**, 264). [d] These values were also observed for acetone as solvent. [e] These bands are rapidly replaced by broad SO_3^- bands.[1] [f] S. Detoni and D. Hadzi, *Spectrochim. Acta*, 1957, **11**, 601.

The n.m.r. spectra of the intermolecular arenesulphonic anhydrides differ from those of the intramolecular arene-1,2-disulphonic anhydrides in that the chemical shifts of H and Me of the intermolecular anhydrides are now more similar to those of the corresponding sulphonic acids and sulphonates (Table 2).

The characteristic i.r. spectral frequencies of the disulphonic anhydride group are somewhat greater for the intramolecular arene-1,2-disulphonic than for the intermolecular arenesulphonic anhydrides.

EXPERIMENTAL

Materials.—The preparation of the *meta*-substituted benzenesulphonic acids or sulphonates has been described.[6] Potassium 3,5-diethylbenzenesulphonate was prepared by the procedure described for 3,4,5-trimethylbenzenesulphonate.[7] Potassium 3,5-di-t-butylbenzenesulphonate was prepared by reaction of 3,5-di-t-butylbenzenesulphonyl chloride with ethanolic potassium hydroxide followed by recrystallization from 50% aqueous ethanol. This sulphonyl chloride was obtained by the reaction of *m*-di-t-butylbenzene with chlorosulphuric acid according to Huntress and Autenrieth.[8]

The preparation of 2,5-dichloro- and 4-iodo-benzenesulphonic anhydride has been described.[9] Mesitylenesulphonic anhydride was obtained by reaction of mesitylene (1 g) in CCl_3F (50 ml) with sulphur trioxide (0·3 ml) in CCl_3F (75 ml) and filtration of the resulting precipitate.

All compounds gave satisfactory microanalysis.

Spectrometers.—^1H N.m.r. spectra were recorded with a Varian HA 100 spectrometer for solutions containing 20—100 mg of the sample per ml of solvent. For solutions in D_2O and the organic solvents sodium 4,4-dimethyl-4-silapentane-1-sulphonate and tetramethylsilane, respectively, were used as internal standards. For sulphuric acid a solution of sodium tetradeuterio-2-trimethylsilylpropionate in D_2O (200 mg ml^{-1}) was used as external standard.

I.r. spectra were recorded on Perkin-Elmer 125 and Unicam SP 200 spectrometers.

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[6] L. Vollbracht, H. Cerfontain, and F. L. J. Sixma, *Rec. Trav. chim.*, 1961, **80**, 11; A. J. Prinsen and H. Cerfontain, *ibid.*, 1965, **84**, 22; J. M. Arends and H. Cerfontain, *ibid.*, 1966, **85**, 93.

[7] A. Koeberg-Telder and H. Cerfontain, *J.C.S. Perkin II*, 1973, 633.

[8] E. H. Huntress and J. S. Autenrieth, *J. Amer. Chem. Soc.*, 1941, **63**, 3446.

[9] J. K. Bosscher, Thesis, University of Amsterdam, 1967, p. 24; N. H. Christensen, *Acta Chem. Scand.*, 1961, **15**, 219.

Preparation of Arene-1,2-*disulphonic Anhydrides*.—Either an appropriate *meta*-substituted benzenesulphonate (*ca*. 5 mmol) or an arene-1,2-disulphonate was added to 107% H_2SO_4 (10 ml), or chlorosulphuric acid (10 ml), and left at room temperature till the conversion was complete (1—10 h). Then the reaction mixture was poured onto an excess of ice–water and the precipitated anhydride filtered off, washed with an appropriate solvent, and recrystallized from nitromethane, acetone, or benzene.

Isomer Analysis.—The isomeric composition of the sulphonation products was determined by multicomponent n.m.r. analysis of the fuming sulphuric acid reaction mixture as such, and after dilution to *ca*. 98% H_2SO_4.[2,10]

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[10] H. Cerfontain, A. Koeberg-Telder, C. Kruk, and C. Ris, *Analyt. Chem.*, in the press; H. Cerfontain, Z. R. H. Nienhuis, and W. A. Zwart-Voorspuy, *J.C.S. Perkin II*, 1973, 633; H. de Vries and H. Cerfontain, *Rec. Trav. chim.*, 1967, **86**, 873.