# Protonation and Sulphonation Reactions of Anisole in Sulphuric and Fluorosulphuric Acid

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The reactions of anisole in sulphuric and fluorosulphuric acid have been examined. At room temperature sulphonation is so rapid that it is not possible to observe protonated species. $^1$H N.m.r. spectra in $D_2SO_4$ reveal that the *ortho*- and *para*-protons are rapidly exchanged. The initial product of sulphonation is *p*-methoxybenzenesulphonic acid which reacts further in concentrated acids to form 4-methoxybenzene-1,3-disulphonic acid. Anisole reacts cleanly with equivalent amounts of either sulphuric or fluorosulphuric acid in trifluoroacetic acid to form 4-methoxybenzenesulphonic acid. Our results suggest that Kresge and Hakka's suggestions may be in error.

THERE is confusion over the behaviour of anisole in sulphuric and fluorosulphuric acid. The most recent authoritative review [1] concluded that the controversy over the site of protonation, oxygen [2] or carbon,[3,4] was settled by the suggestion of Kresge and Hakka [5] that the conjugate acid of anisole would be expected to change from primarily the *O*-protonated to the *C*-protonated species in going from 60% sulphuric to 100% sulphuric acid. Despite the seemingly consistent picture presented,[1] the issue remains uncertain owing to the report by Ramsey [6] that Kresge and Hakka's u.v. assignments were incorrect and that in both solvents irreversible chemical reactions occur on dissolution at room temperature. Thus we found it necessary to reinvestigate sulphuric and fluorosulphuric acid as media for preparing solutions during our studies of the photochemistry of protonated alkyl phenyl ethers and phenols (protonated cyclohexadienones).[7] Here we report the results of $^1$H n.m.r. and product studies of anisole in strong acids and the stoicheiometric reaction of anisole with sulphuric and fluorosulphuric acid in trifluoroacetic acid.

## EXPERIMENTAL

The $^1$H n.m.r. spectra were recorded at 60 MHz on a Varian A-60A spectrometer equipped with a variable-temperature controller (V 6040). U.v. spectra were recorded on a Unicam SP 1800 spectrophotometer. The i.r. spectra were recorded on a Perkin-Elmer 337 grating spectrophotometer. Analyses were performed at the microanalytical department of this laboratory.

*Preparation of Samples at Low Temperature.*—Anisole (30 μl) was cooled to −78 °C in an n.m.r. tube. Solvent (500 μl), cooled to the same temperature, was added and the tube was transferred to a previously cooled n.m.r. probe.

4-*Methoxybenzenesulphonic Acid.*—Anisole (3·0 g) was dissolved in trifluoroacetic acid (30 ml) and concentrated sulphuric acid (1·5 ml) was added. The solution was allowed to stand for one day at room temperature. The sulphonic acid was obtained as white crystals after evaporation of the trifluoroacetic acid. The i.r. spectrum (in KBr) and the $^1$H n.m.r. spectrum (in $CDCl_3$) are in agreement with the assigned structure. An aqueous solution of the sulphonic acid was neutralised with barium hydroxide to give the *barium salt*, which was isolated by evaporation of the water (Found: C, 32·2; H, 2·8. $C_{14}H_{14}BaO_8S_2$ requires C, 32·9; H, 2·76%). 4-Methoxybenzenesulphonic acid was also prepared from equivalent amounts of fluorosulphuric acid and anisole. The compound obtained from the two preparations had identical m.p., t.l.c., i.r., and n.m.r. spectra.

4-*Methoxybenzene*-1,3-*disulphonic Acid.*—Anisole (3·0 g) was dissolved in concentrated sulphuric acid (1·5 ml) and the solution was allowed to stand at room temperature for 2 days. After being poured into ice–water, the solution was slowly added to $Ba(OH)_2,8H_2O$ (152 g) in *ca.* 700 ml of water. The mixture was filtered and the filtrate was evaporated to give the pure *barium disulphonate* in good yield. The $^1$H n.m.r. spectrum (in $D_2O$) is in agreement with the assigned structure (Found: C, 20·35; H, 1·9. $C_7H_6BaO_7S_2$ requires C, 20·8; H, 1·5%).

*Sulphuric Acid.*—The $^1$H n.m.r. spectrum of anisole recorded immediately after dissolution in 98% sulphuric acid revealed two methoxy-signals at τ 6·42 and 6·37 in the approximate ratio 4 : 1 respectively.* The most conspicuous feature in the aromatic region of the spectrum was an AA'BB' pattern with chemical shifts at τ 3·30 and 2·57 with a AB coupling constant of 9 Hz. Integration showed the methoxy-region to consist of 3 protons and the aromatic region 4 protons. The 2-proton signal expected for the methylene group of the *C*-protonated species was noticeably absent. The spectrum was very similar to that of 4-methoxybenzenesulphonic acid in trifluoroacetic acid–$CDCl_3$ (1 : 1, v/v) (Figure 1). The spectrum recorded in $D_2SO_4$ showed a single 2-proton signal in the aromatic region at the same position as the low-field doublet of the spectrum in sulphuric acid. Evidently the *ortho*- and *para*-protons of anisole are very rapidly exchanged.

The $^1$H n.m.r. spectrum of a $D_2SO_4$ solution of anisole after standing for 2 days at room temperature showed 2 one-proton doublets in the aromatic region at τ 2·24 and 2·08 with a *meta*-coupling constant of 2·5 Hz. Under the same conditions in sulphuric acid the spectrum showed the presence of a single 2,4-disubstituted anisole with doublets at τ 3·08 ($J_o$ 9 Hz) and 2·08 ($J_m$ 2 Hz) along with a doublet of doublets centred at τ 2·23 (Figure 2). Neutralisation of the latter solution with $Ba(OH)_2$ resulted in the isolation of barium 4-methoxybenzene-1,3-disulphonate.

* The signal at τ 6·37 increased in magnitude on standing at the expense of that at τ 6·42

[1] G. A. Olah, A. M. White, and D. H. O'Brien, *Chem. Rev.*, 1970, **70**, 561.
[2] E. M. Arnett and C. Y. Wu, *J. Amer. Chem. Soc.*, 1960, **82**, 5660.
[3] T. Birchall, A. N. Bourns, R. J. Gillespie, and P. J. Smith, *Canad. J. Chem.*, 1964, **42**, 1433.
[4] T. Birchall and R. J. Gillespie, *Canad. J. Chem.*, 1964, **42**, 502.
[5] A. J. Kresge and L. E. Hakka, *J. Amer. Chem. Soc.*, 1966, **88**, 3868.
[6] B. G. Ramsey, *J. Amer. Chem. Soc.*, 1966, **88**, 5358.
[7] U. Svanholm and V. D. Parker, to be published.

The $^1H$ n.m.r. spectra of the isolated mono- and di-sulphonic acids were recorded in $D_2SO_4$ and indicated that the *ortho*-protons of 4-methoxybenzenesulphonic acid exchanged with deuterium. No exchange was observed for 4-methoxybenzene-1,3-disulphonic acid.

*Fluorosulphuric Acid.*—When a solution of anisole was prepared at −60 °C in freshly distilled fluorosulphuric acid the spectrum previously assigned [4] to the *C*-protonated species was observed. On warming to 0 °C an irreversible change occurred. The aromatic region of the spectrum at 0 °C suggests the presence of two different *para*-substituted anisoles having approximately the same chemical shift for the *ortho*-protons but different shifts for the *meta*-protons, which appear as AB doublets with approximately equal

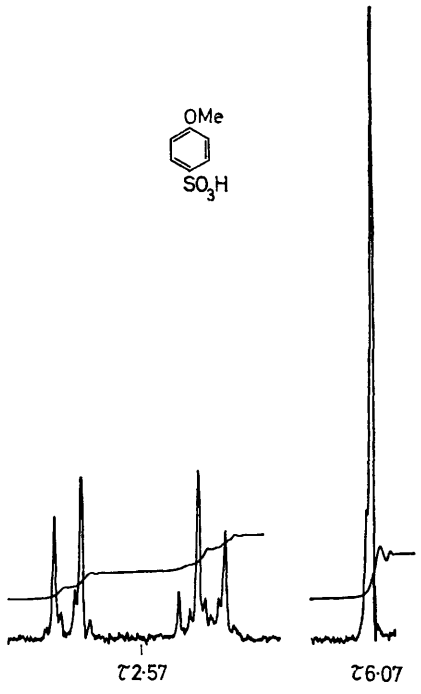



FIGURE 1 $^1H$ N.m.r. spectrum of equivalent amounts of anisole and sulphuric acid in $CDCl_3$–$CF_3CO_2H$ (1 : 1) after standing for one day at room temperature

coupling constants. The relative positions of the signals arising from the methoxy-protons, the *ortho*-protons, and the *meta*-protons (the low-field *meta*-doublet) are the same as observed for 4-methoxybenzenesulphonic acid in concentrated sulphuric acid.

The room-temperature spectrum of a freshly prepared solution of anisole in fluorosulphuric acid showed at least three different signals arising from the methoxy-protons. The aromatic region indicated the presence of a major amount of a *para*-substituted anisole, with signals at the same relative position as those observed for 4-methoxybenzenesulphonic acid, along with minor amounts of two different 2,4-disubstituted anisoles (Figure 3, A). When the solution was allowed to stand at room temperature for one day, the spectrum indicated that the mixture consisted mainly of two different 2,4-disubstituted anisoles (Figure 3, B). Signals which could be assigned to one of the 1,2,4-trisubstituted compounds were at the same position as those observed for 4-methoxybenzene-1,3-disulphonate in concentrated sulphuric acid.

*Sulphonation in Trifluoroacetic Acid.*—In a solvent mixture consisting of $CDCl_3$–trifluoroacetic acid (1 : 1, v/v) the normal anisole spectrum was observed (Figure 4).

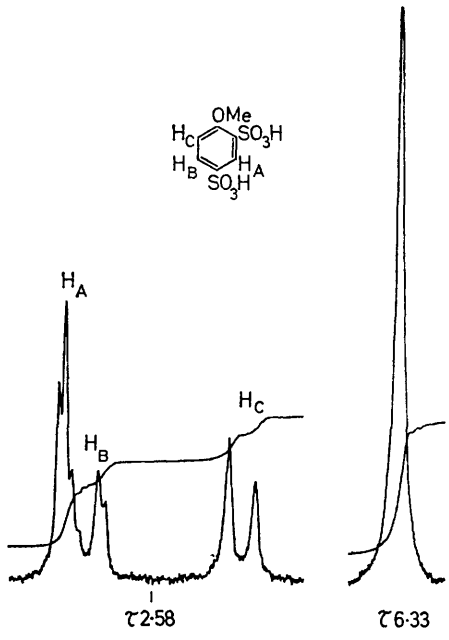



FIGURE 2 $^1H$ N.m.r. spectrum of anisole in 98% sulphuric acid after standing at room temperature for two days

Addition of an equivalent amount of sulphuric acid resulted in the slow conversion ($t_{\frac{1}{2}}$ *ca.* 3 h) into the compound showing the AA′BB′ spectrum (Figure 1). This solution exhibited the same $^1H$ n.m.r. spectrum after standing at room temperature for one week. In the same solvent system, addition of an equivalent amount of fluorosulphuric

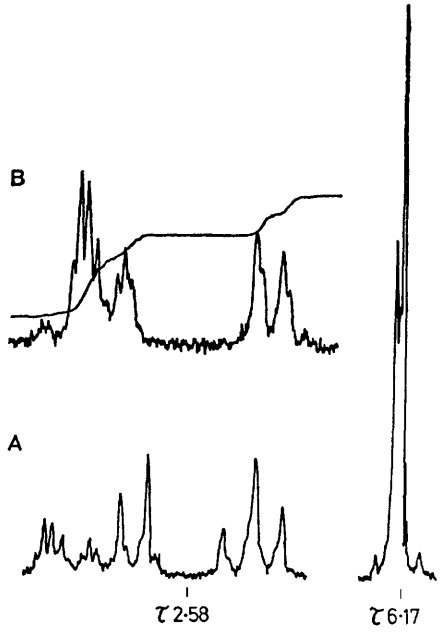



FIGURE 3 $^1H$ N.m.r. spectra of A, anisole immediately after dissolution in fluorosulphuric acid at room temperature; B, anisole in fluorosulphuric acid after standing for 1 h at room temperature

acid to anisole brought about more rapid conversion into a compound which was stable in solution indefinitely and gave a spectrum nearly identical to Figure 1. In $CDCl_3$–$CF_3{\cdot}CO_2D$ (1 : 1, v/v) the addition of an equivalent amount of $D_2SO_4$ to anisole brought about rapid exchange of the

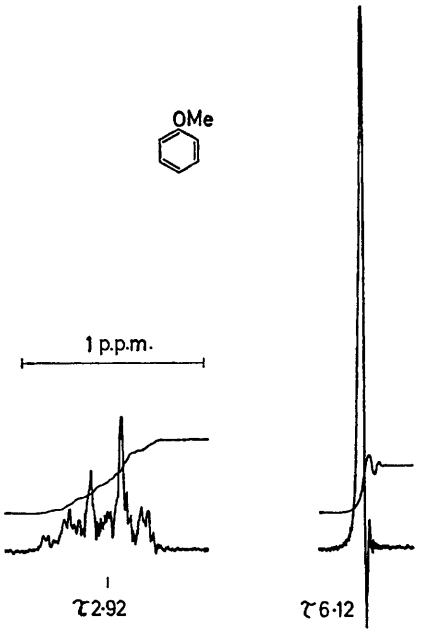



FIGURE 4 $^1H$ N.m.r. spectrum of anisole in $CDCl_3$–$CFCO_2H$ (1 : 1)

*ortho*- and *para*-protons with the eventual conversion into a compound with a single aromatic signal at τ 2·17 (Figure 5). The AA'BB' pattern was also observed for a solution of anisole in $CDCl_3$ on the addition of equivalent amounts of fluorosulphuric acid in the temperature range −60 to 15 °C. In this case the rate of conversion of anisole was quite slow at the low temperatures and on further warming the spectrum consisted of many unrecognisable signals.

When equivalent amounts of sulphuric acid and anisole were allowed to react in trifluoroacetic acid and the solvent then removed under reduced pressure in the cold a product consisting mainly of 4-methoxybenzenesulphonic acid was obtained. The $^1H$ n.m.r. spectrum (in $CDCl_3$) of the pure compound was nearly identical to Figure 1, but in addition showed a one-proton signal at τ −0·53.

## DISCUSSION

The rapid *para*-sulphonation of anisole in sulphuric acid and fluorosulphuric acid at room temperature precludes the observation of protonated species under these conditions. The decrease in intensity of the 270 nm u.v. absorption band to about half its intensity as the acidity of the medium is increased is no doubt due to consumption of anisole rather than a protonation effect as suggested by Kresge and Hakke.[5] The $^1H$ n.m.r. spectrum of anisole in 93% sulphuric acid was nearly the same as in 98% acid, but a small amount of anisole could still be detected when the spectrum was recorded immediately after mixing at room temperature. The latter solution showed a u.v. absorption band at 284 nm which increased in intensity upon standing. Further, 4-methoxybenzenesulphonic acid showed weak u.v. absorption at 284 nm in 93% sulphuric acid immediately after mixing and this band became intense after standing at room temperature for one day. The u.v. spectrum of 4-methoxybenzene-1,3-disulphonic acid in 93% sulphuric acid showed an absorption band at 284 nm. Thus, the band at 284 nm observed for a solution of anisole in 93% sulphuric acid is surely due to the formation of the disulphonic acid. Our results support Ramsey's conclusions [6] that Kresge and Hakke's [5] u.v. assignments are questionable and do not give an indication of the protonation behaviour of anisole in sulphuric acid.

When fluorosulphuric acid is used as a solvent it is reasonable to attribute sulphonations to $SO_3$ formed by hydrolysis. However, the stoicheiometric reaction of anisole with fluorosulphuric acid suggests an alternative

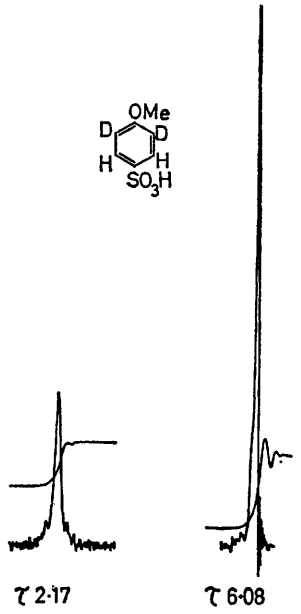
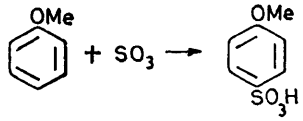



FIGURE 5 $^1H$ N.m.r. spectrum of anisole in $CDCl_3$–$CF_3CO_2H$ (1 : 1) after standing for one day in the presence of an equivalent amount of $D_2SO_4$

mechanism which could possibly involve direct dissociation according to the Scheme. It has been pointed out by Gillespie [8] that it is not possible to remove the last traces of $SO_3$ from fluorosulphuric acid and this may

$$HFSO_3 \rightleftharpoons HF + SO_3 \qquad (1)$$



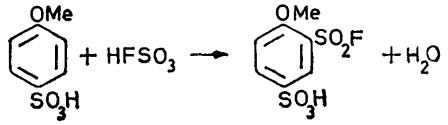

(2)

SCHEME

possibly be due to equilibrium (1). Our data show that fluorosulphuric acid is much more potent as a sulphonating agent than is sulphuric acid.

[8] R. J. Gillespie, *Accounts Chem. Res.*, 1968, **1**, 202.

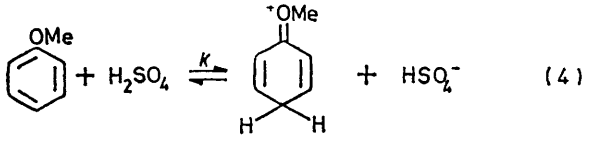
Sulphinylation of phenylium ions in fluorosulphuric acid solutions has been implicated.[9] Ramsey [6] did not identify any of the products from anisole in either sulphuric or fluorosulphuric acid but concluded that sulphonation products were formed in sulphuric acid and that a possible product in fluorosulphuric acid is *o*-anisylsulphonyl fluoride. We observe that the first




(3)

product formed in fluorosulphuric acid is 4-methoxybenzenesulphonic acid which reacts further to give a mixture of at least two different trisubstituted benzenes, one of which most surely being 4-methoxybenzene-1,3-disulphonic acid. The other could possibly be the sulphuryl fluoride [equation (3)].

The rapid hydrogen–deuterium exchange in the *ortho*- and *para*-positions of anisole in either $D_2SO_4$ or in $CDCl_3$–$CF_3{\cdot}CO_2D$–$D_2SO_4$ indicates that *C*-protonation does indeed occur at room temperature. In the latter




(4)

case the equilibrium constant [equation (4)] is small since the $^1H$ n.m.r. spectrum shows only anisole immediately after mixing with the slow formation of 4-methoxybenzenesulphonic acid. In concentrated sulphuric acid we cannot say anything about the degree of protonation at room temperature since sulphonation occurs so rapidly.

[1/2388 *Received*, 13*th December*, 1971]

[9] M. Brookhart, F. A. L. Anet, and S. Winstein, *J. Amer. Chem. Soc.*, 1966, **88**, 5657.