404. *Aromatic Polyfluoro-compounds. Part II.* Pentafluorophenol.*

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Hexafluorobenzene reacts with sodium methoxide to give pentafluoroanisole which when heated with aluminium chloride yields pentafluorophenol. This strongly acidic phenol has been fully characterised and shown to resist nucleophilic attack. Its hydrazinium salt is formed when pentafluoroanisole reacts with hydrazine hydrate.

THE interesting fluorocarbon, hexafluorobenzene, has recently been prepared in quantity by Godsell, Stacey, and Tatlow [1] and by Hellmann *et al.*[2] Both groups of workers have shown that the molecule is reactive to nucleophilic agents.[1,3,4] An earlier report [5] had indicated that the molecule was stable to electrophilic attack, which is not surprising since substitution under such conditions would require the elimination of the fluorine cation (F^+). Nucleophilic attack, however, occurs readily when hexafluorobenzene reacts with sodium methoxide in methanol alone [1] or admixed with pyridine [3] or with potassium hydroxide in pyridine.[3] The first reaction, which gives a good yield of pentafluoroanisole, was used as the starting point for the present work. The last reaction gives a poor yield (20%) of pentafluorophenol. These reactions and others [4] which involve the elimination of a fluoride ion probably occur by way of a reactive intermediate complex analogous to that proposed by Bunnett and Zahler [6] for aromatic bimolecular nucleophilic substitution.

Pentafluorophenol was obtained as a liquid in 20% yield by Pummer and Wall [3] by demethylating pentafluoroanisole with hydriodic acid. Our own experiments using hydrobromic acid were no more successful. When, however, the anisole was heated with aluminium chloride without a solvent [7] pentafluorophenol was obtained in 60% yield as a solid, m. p. 39°, which was corrosive to the skin and very acidic. Its dissociation constant ($4{\cdot}79 \times 10^{-6}$ at 17·5) showed that it was considerably more acidic than phenol itself ($1{\cdot}3 \times 10^{-10}$ at 25° [8]) though slightly less acidic than pentachlorophenol ($5{\cdot}5 \times 10^{-6}$ at 25° [9]). This order of activity can be attributed to the greater power of electron-release through back-co-ordination in the fluorine than in the chlorine atom. Similar behaviour is shown by *p*-fluorobenzoic acid and *p*-fluorophenol, which are weaker acids than the corresponding chloro-compounds. Indeed, electron-release from fluorine by this mechanism is such as to make *p*-fluorophenol a weaker acid than phenol itself, and will be shown, in a subsequent communication, to have an important bearing on the orientation of disubstitution products obtained from pentafluorophenyl derivatives.

The low boiling point of pentafluorophenol, 145—146°, has been attributed to intramolecular hydrogen-bonding,[3] and the infrared spectrum, which shows bands at 3636 and 3448 cm.$^{-1}$ (free and bonded OH), indicates that this bonding is extensive. The ultraviolet spectra of pentafluorophenol and its phenoxide ion closely resemble those of phenol and its phenoxide ion. There is, however, an additional maximum at 350 mμ in the fluorophenol spectrum which is not shown by phenol itself but is shown by picric acid.

Pentafluorophenol was characterised by a number of derivatives, all of which were prepared by the usual methods. In addition, it formed a characteristic potassium salt

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* Part I, *J.*, 1959, 166.

[1] Godsell, Tatlow, and Stacey, *Nature*, 1956, **178**, 199.

[2] Hellmann, Peters, Pummer, and Wall, *J. Amer. Chem. Soc.*, 1957, **79**, 5654.

[3] Pummer and Wall, *Science*, 1958, **127**, 643.

[4] Forbes, Richardson, and Tatlow, *Chem. and Ind.*, 1958, 630.

[5] Desirant, *Bull. Acad. roy. Belg., Classe Sci.*, 1955, **41**, 759.

[6] Bunnett and Zahler, *Chem. Rev.*, 1951, **49**, 273.

[7] Hartmann and Gattermann, *Ber.*, 1892, **25**, 3531.

[8] "Handbook of Chemistry and Physics," Chemical Rubber Publishing Co., Cleveland, Ohio, 39th edn., 1957.

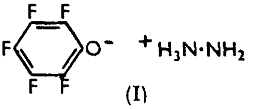
[9] Tiessens, *Rev. Trav. chim.*, 1929, **48**, 1068.

which crystallised from water as a dihydrate which could be dehydrated azeotropically with benzene. Other salts were formed with organic bases, even as weak as aniline.

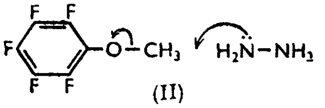
The stability of pentafluorophenol towards attack by nucleophilic agents was marked. It was recovered unchanged after prolonged heating with strong alkali, presumably owing to the presence of the phenoxide ion which would render the nucleus resistant to nucleophilic attack. It seems likely that the dihydric phenol obtained by Pummer and Wall,[3] from the reaction between potassium hydroxide and hexafluorobenzene in pyridine–ethanol–water, arises from an attack of ethoxide ion on the intermediate pentafluorophenetole, followed by hydrolysis of the ether links with hydroxyl ion. The ready hydrolysis of the pentafluorophenyl ether link by nucleophilic agents is illustrated in the sequel.

It was thought that the powerful electron-withdrawing effect of the pentafluorophenyl nucleus might confer the properties of an ester or carboxylic acid on the anisole and phenol respectively: certainly, the acidity of the phenol is comparable to that of an aromatic carboxylic acid. When attempts were made to replace the hydroxyl group of the phenol with a chlorine atom no tractable product was isolated.

The reaction between pentafluoroanisole and hydrazine hydrate gave an interesting result. We had expected a straightforward displacement of the methoxyl group by hydrazine, as occurs in the reaction with 2 : 4-dinitroanisole.[10] However, the chief product of the reaction under a variety of conditions was the hydrazine salt (I) of pentafluorophenol. It was identified by converting it into the potassium salt of pentafluorophenol and isolating the hydrazine as its sulphate. The structure was confirmed when the compound was obtained directly from pentafluorophenol and hydrazine hydrate in the cold.



(I)



(II)

This salt must be formed from the anisole by a direct displacement of phenoxide ion from the methyl group by the nucleophilic hydrazine molecule (cf. II). That the salt of hydrazine and not that of methylhydrazine is isolated must be due to the large excess of hydrazine which is usually employed in such reactions.

EXPERIMENTAL

Ultraviolet spectra were measured for ethanol solutions unless stated to the contrary.

Pentafluoroanisole.—A solution from sodium (7·1 g.) in absolute methanol (740 c.c.) was heated under reflux with hexafluorobenzene (49·8 g.). After 6 hr. the mixture was cooled and poured into a large volume of water. Pentafluoroanisole separated as an oil and was extracted with ether. The extract was dried and filtered, and the solvent removed. Distillation of the residue through a short column gave pure pentafluoroanisole (38·1 g., 72%), b. p. 138—139°, n_D^{20} 1·4090 (Found: C, 42·6; H, 1·7; F, 48·1. Calc. for $C_7H_3OF_5$: C, 42·4; H, 1·5; F, 48·0%). Godsell, Stacey, and Tatlow[1] give b. p. 155—157°, n_D^{18} 1·417, and Pummer and Wall[3] give b. p. 154—156°: these values were obtained on small samples and are too high. It had $\lambda_{max.}$ 266 mμ (ε 1023), $\nu_{max.}$ 3010 (aliphatic C–H stretching) and 1524 cm.$^{-1}$ (fluoro-aromatic ring breathing) (liquid film).

Pentafluorophenol.—(*a*) Pentafluoroanisole (8·75 g.) was heated with anhydrous aluminium chloride (8·5 g.) for 3 hr. at 120°, then cooled in iced water, and the pentafluorophenol was liberated by addition of iced water to the powdered mixture with stirring. The phenol was extracted with methylene chloride, the extract dried, and the solvent removed. Distillation of the residue gave pentafluorophenol (4·68 g., 58%), b. p. 142—144°, m. p. 38·5—39·5° (Found: F, 51·0%; equiv., 186. Calc. for C_6HOF_5: F, 51·6%; equiv., 184) [Pummer and Wall[3] give b. p. 72—73/48 mm. and 144—146° (micro-capillary)], $\lambda_{max.}$ 227, 269, and 350 mμ (ε 2640, 990, and 198, respectively): the phenoxide ion showed $\lambda_{max.}$ 228 mμ (ε 13,200) and 273 mμ (ε 2040)

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[10] Borsche, *Ber.*, 1923, **56**, 1488.

(*c* 0·012 g./l. in 80% ethanolic 0·05N-sodium hydroxide). Infrared bands (liquid film) were at 3600 cm.$^{-1}$ (OH stretching) and 1515 cm.$^{-1}$ (fluoro-aromatic ring breathing).

(*b*) Pentafluoroanisole (2·2 g.) was heated under reflux with hydrobromic acid (20 c.c.; *d* 1·47) for 17 hr. After the heterogeneous mixture had been cooled, the aqueous layer was decanted from an oil. A solution of the oil in ether was extracted with 2N-sodium hydroxide (30 c.c.). From the ether layer was then obtained unchanged pentafluoroanisole (0·5 g.), and from the alkaline extract acidification gave pentafluorophenol (0·2 g.), identified as its toluene-*p*-sulphonate, m. p. and mixed m. p. 62—63°.

Potassium pentafluorophenoxide dihydrate was obtained when 6N-potassium hydroxide (5 c.c.) was added slowly to a solution of pentafluorophenol (0·5 g.) in 6N-potassium hydroxide (3 c.c.). The precipitated salt, crystallised from a little water, had m. p. 245° (decomp.) (Found: C, 27·9; H, 1·6; F, 36·7. $C_6OF_5K,2H_2O$ requires C, 27·9; H, 1·6; F, 36·8%). The *monohydrate*, m. p. 248° (decomp.), was obtained from the dihydrate at 110°/18 mm. in 3 hr. (Found: C, 30·2; H, 1·1; F, 39·5. C_6OF_5K,H_2O requires C, 30·0; H, 1·2; F, 39·6%). The anhydrous *salt* was obtained when the dihydrate was boiled with benzene for 5 hr.: removal of the liquid phase gave a white powder which, crystallised from acetone, had m. p. 242° (decomp.) (Found: F, 42·8. C_6OF_5K requires F, 42·8%).

The *toluene-*p*-sulphonate* of pentafluorophenol was obtained when the potassium salt dihydrate (0·31 g.), toluene-*p*-sulphonyl chloride (0·28 g.), and water (2 c.c.) were heated with stirring on a steam-bath for 5 hr. A solution of the product in light petroleum (b. p. 40—60°) was washed with concentrated ammonia and then evaporated to dryness. Recrystallisation of the residue from ethanol afforded an analytical specimen, m. p. 64—65° (Found: C, 46·1; H, 2·1; F, 27·8. $C_{13}H_7O_3SF_5$ requires C, 46·2; H, 2·1; F, 28·1%). The *p-nitrobenzyl ether*, prepared by heating the potassium salt of the phenol with *p*-nitrobenzyl bromide in aqueous ethanol for 1 hr., crystallised from ethanol in pale yellow plates, m. p. 57° (Found: C, 48·5; H, 1·8. $C_{13}H_6O_3NF_5$ requires C, 48·9; H, 1·9%). The benzoate (Schotten–Baumann procedure) had m. p. 70·5—71·5° after three recrystallisations from aqueous ethanol (Found: C, 54·4; H, 1·7. Calc. for $C_{13}H_5O_2F_5$: C, 54·2; H, 1·7%) (Pummer and Wall[3] cite m. p. 76·5—78·2°). The *anilinium salt* crystallised from a little water in needles, m. p. 74° (Found: C, 51·9; H, 2·9. $C_{12}H_8ONF_5$ requires C, 52·0; H, 2·9%).

Hydrazinium Pentafluorophenoxide.—Pentafluoroanisole (5·0 g.), 80% w/w hydrazine hydrate (18·0 g.), and sufficient ethyl alcohol (*ca.* 5 ml.) to render the mixture homogeneous were heated together under reflux for 5 hr., then cooled, poured into an equal volume of water, and extracted with methylene chloride (6 × 10 ml.). The aqueous layer was continuously extracted with methylene chloride for 80 hr. From this extraction a colourless solid was obtained, which crystallised in the methylene chloride. Purification by crystallisation, or by sublimation at 80°/0·2 mm., gave *hydrazinium pentafluorophenoxide* (3·32 g., 61%), m. p. 157—158° (subl.) (Found: C, 33·3; H, 2·4. $C_6H_5ON_2F_5$ requires C, 33·4; H, 2·3%), $\lambda_{max.}$ 230 and 269 mμ (ε 7700 and 1390, respectively).

With less hydrazine hydrate and at a lower concentration the yield of hydrazine pentafluorophenoxide dropped to 31%.

Concentrated sulphuric acid was added dropwise to a solution of hydrazine pentafluorophenoxide (0·1 g.) in ethanol (2 c.c.) until no more solid was formed. The colourless precipitate was recrystallised from hot water to give large colourless crystals of hydrazine sulphate (0·03 g.), m. p. and mixed m. p. 255°. The infrared spectra of these compounds were identical.

Hydrazinium pentafluorophenoxide (0·3 g.) was warmed gently with 6N-potassium hydroxide (4 c.c.) for a few minutes. On cooling, a colourless precipitate was formed which recrystallised from a little water. Potassium pentafluorophenoxide dihydrate was thereby obtained, having m. p. and mixed m. p. 245° (decomp.).

A solution of 100% hydrazine hydrate (0·089 g.), and pentafluorophenol (0·12 g.) was continuously extracted with methylene chloride for 48 hr. The solid which was precipitated in the boiling flask was collected and sublimed at 80°/0·05 mm., to afford hydrazinium pentafluorophenoxide (0·09 g., 64%), m. p. and mixed m. p. with the product isolated from the reaction between hydrazine hydrate and pentafluoroanisole, 157—158°. The infrared spectra of the two solids were identical.

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