REACTIONS OF 4-METHOXYPHENOL AND 4-METHYLPHENOL WITH BROMINE

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The reactions of 4-methoxy- and 4-methylphenols with bromine in aqueous medium give 1,4-benzoquinone and 2-bromo-4-methylphenol respectively. In an aprotic medium (CCl_4) the electrophilic substitution takes place giving 2-bromo-4-methoxy(resp. methyl)phenol, but the ratio of the reactivities of the both phenols is reverse of that corresponding to the Brown's σ constants.

Within the studies[1] of coupling of benzenediazonium ions with 4-substituted phenols it was found that the coupling rate of 4-methoxyphenol is substantially higher than it should be according to the Hammett relations valid for these cases. We decided to study in more detail the reactions of 4-methoxyphenol and 4-methylphenols with bromine in aqueous and non-polar media in order that we might find the extent to which the above anomaly, found for the reaction of diazonium ion with phenolate ion (*i.e.* a weak electrophilic reagent with a highly reactive substrate), will make itself felt in a reaction with a more strongly electrophilic reagent.

Older papers dealt with brominations of various phenols in water[2-4], acetic acid[5-8] and tetrachloromethane[7,8]. It was found that the bromination rates of undissociated phenols and those of phenolate anions extended as high as the values 3.10^4 and 8.10^9 l mol^{-1} s^{-1} respectively. Even the tribromoamide reacted with the anions, its reactivity being about $1-3\%$ of the reactivity of molecular bromine[4].

In the present paper we have, therefore, studied the reactions of 4-methoxyphenol with bromine in aqueous medium and compared them with the bromination of 4-methylphenol. Further we have studied the behaviour of the both phenols during their reactions with bromine in non-polar medium (CCl_4). As the bromination proceeds very quickly in water, we used the method of competing reactions for the comparison of the reaction rates in this medium, whereas the reaction rate in tetrachloromethane was directly measurable. We have focused our attention to the identification of some bromination products of the both phenols, too.

EXPERIMENTAL

Reagents. 4-Methylphenol — a commercial sample — was purified by distillation, m.p. 34—35°C (ref.[9] 34.5°C). 4-Methoxyphenol was obtained by methylation of hydroquinone with dimethyl sulphate in alkaline medium[10]. The raw product was purified by two vacuum distillations and a crystallization from light petroleum, m.p. 55—56°C (ref.[10] 56°C). It was checked for the ab-

sence of unreacted hydroquinone by gas–liquid and paper chromatography. 2-Bromo-4-methyl-phenol and 2-bromo-4-methoxyphenol were prepared by bromination of the respective phenols with the equimolar amount of bromine in carbon disulphide and chloroform[11,12]. 2-Bromo-4-methylphenol and 2-bromo-4-methoxyphenol were purified by distillation and crystallization from light petroleum respectively, m.p. of the latter 44°C (ref.[12] 44—45°C). Their homogeneity was verified by gas chromatography. The anorganic chemicals used were of p.a. purity grade. pH was controlled by acetate and phosphate buffers and measured by means of a Radiometer apparatus. The concentration changes of 4-methylphenol, 4-methoxyphenol and the products formed during the competing brominations were measured with the use of a VSU-2P spectrophotometer (Zeiss, Jena), the UV spectra necessary for determination of the respective analytical wavelengths being obtained with a Unicam SP 800 spectrophotometer.

Brominations of 4-Methoxyphenol

a) *With equimolar bromine amount in water.* 5 g 4-Methoxyphenol was inferred portionwise into 50 ml water in a 100 ml flask with continuous stirring, 6·45 g bromine being added drop by drop simultaneously. A solid precipitated after several hours cooling. It was found that it contains the rest of 4-methoxyphenol and 1,4-benzoquinone. A part of the solid was sublimated, and benzoquinone was proved in the sublimate by means of the colour reaction with cyanoacetate[13,14] and identified by its melting point 115°C (ref.[15] 115—116°C). In the reaction mixture, methanol was identified as 3,5-dinitrobenzoate[16]. b) *With excess bromine in water.* 7·5 g 4-Methoxyphenol was dissolved in 500 ml water and a solution of 120 g bromine and 100 g KBr in 250 ml water was added drop by drop with continuous stirring. The orange precipitate formed was crystallized from a benzene–hexane mixture to give two compounds; one of them was identified to be 2,3,5,6-tetrabromo-1,4-benzoquinone (m.p. 296—298°C, ref.[17] 300°C), the other was not investigated. c) *With excess bromine in acetic acid.* 5 g 4-Methoxyphenol was dissolved in 50 ml acetic acid, and 80 g bromine was added. The solution was boiled 45 min, diluted with 50 ml acetic acid and cooled to give a crystalline solid which was collected by suction; after crystallization from benzene and sublimation it melted at 142—144°C which corresponds to 2,3,6-tribromo-4-methoxyphenol (ref.[18] 145°C). d) *With equimolar bromine amount in methanol.* 5 g 4-Methoxyphenol was dissolved in 50 ml methanol and 6·45 g bromine was added drop by drop with stirring. The solution was stirred for another 30 min, methanol was distilled off, and the oily residue was crystallized from methanol to give 2-bromo-4-methoxyphenol, m.p. 44°C (ref.[12] 44—45°C).

Reaction Stoichiometry

During the addition of bromine the concentration increase of 1,4-benzoquinone and decrease of 4-methoxyphenol were measured spectrophotometrically at the wavelengths of 250 and 285 nm respectively. The initial 4-methoxyphenol concentration was $2 \cdot 10^{-4}$M, bromine was added up to a 1·8 fold excess. With respect to 1,4-benzoquinone absorbing partially at 285 nm, too, the extinction values measured for 4-methoxyphenol were corrected for the extinction of 1,4-benzoquinone just formed. The absorption of 4-methoxyphenol at 250 nm, *i.e.* in the range of measurement of 1,4-benzoquinone extinction, was small and diminishing during the reaction course, so that its influence could be neglected. The stoichiometric coefficient was unity for each of the two components.

Competition Reactions of 4-Methoxyphenol and 4-Methylphenol with Bromine in Water

$2 . 10^{-4}$M Solutions of 4-methoxyphenol, 4-methylphenol, 1,4-benzoquinone and 2-bromo-4-methylphenol were prepared and their extinction measured at two wavelengths. The wavelengths chosen were 290 and 285 nm for the measurements in acid and neutral region and 305 and 300 nm for those in alkaline region. Equimolar mixture of the both phenols having the total concentration $4 . 10^{-4}$M was treated with 1/8 equivalents of bromine and the extinction was measured at the abovementioned wavelengths. The concentration of the both phenols after the reaction was calculated according to Eqs (1) and (2), where E_1 and E_2 are the extinctions measured

$$E_{1A}X + E_{1B}(1 - X) + E_{1C}Y + E_{1D}(1 - Y) = E_{1E} , \qquad (1)$$

$$E_{2A}X + E_{2B}(1 - X) + E_{2C}Y + E_{2D}(1 - Y) = E_{2E} \qquad (2)$$

at the individual wavelengths, A, B, C, D, and E denote 4-methylphenol, 2-bromo-4-methylphenol, 4-methoxyphenol, 1,4-benzoquinone and the mixture of these compounds after the reaction respectively, and X and Y stand for the concentrations of 4-methylphenol and 4-methoxyphenol after the reaction respectively. The ratio of rate constants was obtained from Eq. (3),

$$k_A/k_C = ([A]/[C])/([A]_0/[C]_0) \qquad (3)$$

where $[A]_0$, $[C]_0$ and $[A]$, $[C]$ are the concentrations of 4-methyl(resp. methoxy)phenol before and after the reaction respectively. All the measurements were carried out at the ionic strength 0·3 and at various pH values maintained by acetate or phosphate buffers[13]. The resulting k_A/k_C ratios of the competition brominations of the phenols are the average values from five measurements each.

Bromination of 4-Methylphenol and 4-Methoxyphenol in Tetrachloromethane

Bromination kinetics of 4-methyl- and 4-methoxyphenols in CCl_4 could be measured directly under the conditions of a 1st-order reaction. The bromine decrease was followed spectrophotometrically at the wavelength of 410 nm. The concentrations of the phenols and bromine were $2 . 10^{-2}$M and $1·45 . 10^{-3}$M respectively. The bromination rate constants of 4-methyl- and 4-methoxyphenols were 5·05 and 11·21 l mol^{-1} s^{-1} respectively.

RESULTS AND DISCUSSION

From the results it follows that the reaction of 4-methoxyphenol with bromine proceeds in various ways according to the polarity of reaction medium. In the medium of acetic acid and methanol the electrophilic substitution takes place, 2-bromo-4-methoxyphenol or the respective polybromo derivatives being formed according to the bromine amount used. These results stand in accord with the literature data[11,12,19] concerning the bromination of 4-methoxyphenol in carbon disulphide or chloroform. In aqueous medium, however, 4-methoxyphenol reacts with bromine to give 1,4-benzoquinone or, with excess bromine, 2,3,5,6-tetrabromo-1,4-benzoquinone. In methanol, acetic acid and further still less polar solvents, 4-methoxyphenol (I) reacts probably in its undissociated form, and the intermediate Ia gives the product of electrophilic substitution on splitting off of the proton (Eq. (A)).

In aqueous medium, 4-methoxyphenol is partially dissociated[20] (pK 10·20). With respect to the bromination of phenoxide being faster than that of the undissociated

$$(A)$$

$$(B)$$
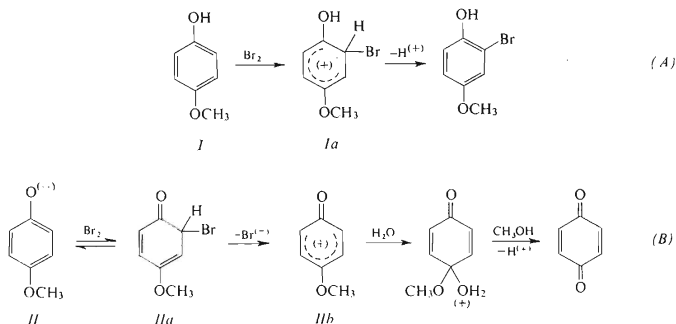
phenol by 4−5 orders of magnitude[4], it can be presumed that both the undissociated substrate and anion react with bromine molecule in the case of 4-methoxyphenol. On the addition of the electrophilic part of bromine molecule to the anion II, a neutral intermediate IIa is formed (Eq. (B)). The same intermediate is formed on addition of the bromonium cation to the undissociated phenol and splitting off of the proton from oxygen. However, the intermediate IIa is not split in the same way as the intermediate Ia (*i.e.* splitting of the proton and aromatization), but it splits off bromide anion to give the "pentadienyl-type" carbonium ion IIb. The cation IIb is attacked by a water molecule at the carbon atom carrying the methoxy group and decomposes into 1,4-benzoquinone, methanol and proton (Eq. (B)). Analogously the reaction of 4-ethoxyphenol with bromine in water gives 1,4-benzoquinone and ethanol. However, 4-methylphenol undergoes an electrophilic substitution with bromine in water, 2-bromo-4-methylphenol being formed. Thus the intermediate of the type IIa is stabilized by splitting off the proton. The attack of the carbon atom (carrying the methyl group) by a water molecule is impossible due to the CH_3^- being a very bad leaving group. From the analysis of the competition brominations of 4-methyl- and 4-methoxyphenols it follows that bromine reacts with the former more rapidly than with the latter in acid and neutral aqueous media, which stands in accord with the estimate of velocities according to σ_m^+ constants:

pH	4·12	5·96	7·99	10·11
k_A/k_C	1·44 ± 0·18	1·38 ± 0·09	1·85 ± 0·19	0·48 ± 0·04

A reverse order was found[1] for coupling reactions of these phenols with various benzenediazonium ions at pH $4-7$. The experiments carried out so far allow a mere statement of this interesting observation. In alkaline aqueous medium, on the contrary, 4-methoxyphenol reacts with bromine about 2 times faster than 4-methylphenol, which is in accord with the results of coupling reactions. The change of the reactivity order of 4-methyl- and 4-methoxyphenols takes place in the pH region in which the concentration of hypobromite steeply increases (pK of hypobromous acid[21] is 8.69). It is thus not excluded that the change of reactivity order is connected with the change of structure of brominating agent due to the change of medium.

We found that, during bromination in tetrachloromethane, 4-methoxyphenol reacted 2.21 times faster than 4-methylphenol. If we use the reaction constant of iodination of the 4-substituted phenols in aqueous medium[22] ($\varrho = -3.83$) and the respective substituent constants[23] σ_m^+ 0.047 and -0.066 for methyl and methoxy groups respectively, we can estimate the reactivity order of bromination of the both substrates to be reverse, *i.e.* 4-methylphenol should react almost about 3 times faster than 4-methoxyphenol.

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