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A Simple Adsorption Chromatographic Method for the Investigation of Phenolic Structures *

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A simple adsorption chromatographic method is described which permits a rapid investigation of phenolic structures with the aim of determining the type of phenol and the position of substituents.

Several methods have been utilized for the separation of phenolic mixtures and in the investigation of phenolic structures, *e.g.* paper chromatography [5], gas chromatography [6], electrophoresis [7] and thin layer chromatography [8,9]. Recently an adsorption chromatographic study of steric hindrance in *ortho*-substituted alkyl phenols was made by Carlton and Bradbury [10]. It was shown that the adsorption of this type of phenol on silica gel was considerably influenced by the size and position of the alkyl groups. Since there is a lack of simple methods for the determination of the position of alkyl groups and other groups in phenols, it was decided to investigate the general usefulness of adsorption chromatography on silica gel for this purpose. A novel technique for the detection of the position of the phenol on the column was also developed.

EXPERIMENTAL

Materials. Most of the phenols utilized in this investigation were of commercial origin. Their purity was ascertained by melting point or boiling point determinations and they were, if necessary, recrystallized or redistilled. Silica gel, 100–200 mesh, was used without any pretreatment. The elution was made using "benzene crystallisable". Phenol solutions were made up by dissolving 0.01 g of the phenol in 1 ml of benzene. The permanganate solution used for the detection of the position of the phenols was prepared by dissolving 0.01 mole of potassium permanganate in 1 000 ml of 0.5 % sulphuric acid.

Procedure (*cf.* Fig. 1). A plug of cotton wool was inserted at the end of a glass tube, 6 mm outside diameter and 200 mm long. A dropping tube drawn out to a capillary was placed in the middle of the chromatographic tube and silica gel was then packed to a height of 150 mm.

* Paper No. 5 in a series on analytical investigations of phenols and phenol derivatives. For previous papers, *cf.* Refs. [1-4].

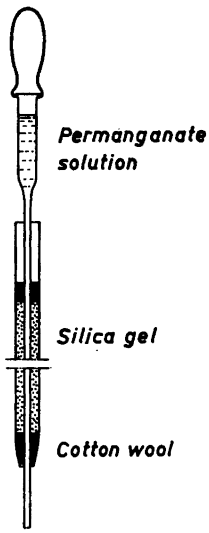

Fig. 1. Equipment used for the determination of R_F-values of phenols.

The dropping tube was filled with permanganate solution. One drop of the benzene solution of the phenol (containing about 100 μg of the phenol) was placed on the top of the column. Elution with benzene was started and allowed to proceed until the solvent reached the bottom of the column. A plug of cotton wool was put on the top of the column in order to hold the silica gel in place during the subsequent withdrawal of the dropping tube. The dropping tube was slowly drawn out and, at the same time, a stream of permanganate solution was evenly ejected into the silica gel layer. At the position of the phenol, the red colour of the permanganate was changed to a nuance between redish-yellow and brown. In some instances the colour disappeared completely. The distance from the middle of the phenolic zone to the beginning of the silica gel layer was measured and the R_F-values were calculated.

The method used for the detection of the position of the phenols was preferred to an extrusion of the column of adsorbent since it was more easy to handle, especially by inexperienced personnel.

RESULTS AND DISCUSSION

The results of the investigation are summarized in Table 1.

Alkylphenols (Nos. 1—18). The influence of *ortho*-situated alkyl groups on the R_F-values of alkylphenols is in accordance with the results obtained by Carlton and Bradbury [10]. The dominating effect seems to be a steric one and the influence of alkyl groups elsewhere than in the *ortho* position is almost negligible (*cf.* however, carvacrol below). As a consequence of different particle size and quality of the silica gel used, the R_F-values obtained here are different from those reported by Carlton and Bradbury [10]. Monohydric alkylphenols without substituents in the *ortho* position have R_F-values between 0.14 and 0.19. One methyl group in the *ortho* position raises the R_F-values to about 0.25 and, with two methyl groups in the *ortho* position, an increase to about 0.40 is obtained. The R_F-values also increase with an increase in the size of the group as shown by the series, *o*-cresol (0.26) — thymol (0.34) — 2,4-di*tert.*-butyl-*m*-cresol (0.70). Two *tert.*butyl groups in the *ortho* position completely

Table 1. R_F-values of various phenols.

No.	Compound	R_F	No.	Compound	R_F
1.	Phenol	0.17	37.	Picric acid	0.20
2.	*m*-Cresol	0.17	38.	*p*-Hydroxydiphenylether	0.17
3.	*p*-Cresol	0.16	39.	*o*-Hydroxydiphenylether	0.35
4.	*p-tert.*-Butylphenol	0.17	40.	Resorcinolmonomethylether	0.12
5.	3,4-Xylenol	0.17	41.	Hydroquinonemonomethylether	0.08
6.	3,5-Xylenol	0.19	42.	Guaiacol	0.30
7.	*o*-Cresol	0.26	43.	Eugenol	0.30
8.	2,3-Xylenol	0.25	44.	Isoeugenol	0.30
9.	2,4-Xylenol	0.26	45.	2,4-Dihydroxyanisol	0.07
10.	2,5-Xylenol	0.27	46.	*m*-Hydroxybenzaldehyde	0.05
11.	2,3,5-Trimethylphenol	0.25	47.	*p*-Hydroxybenzaldehyde	0.04
12.	Carvacrol	0.30	48.	*o*-Hydroxybenzaldehyde	0.30
13.	Thymol	0.34	49.	2,4-Dihydroxybenzaldehyde	0.07
14.	2,4-Di*tert.*-butyl-*m*-cresol	0.70	50.	3,4-Dihydroxybenzaldehyde	0.01
15.	2,6-Xylenol	0.43	51.	*p*-Hydroxyacetophenone	0.03
16.	2,4,6-Trimethylphenol	0.39	52.	*p*-Hydroxypropiophenone	0.02
17.	2,6-Di*tert.*-butylphenol	1.00	53.	*o*-Hydroxyacetophenone	0.22
18.	2,2-Bis(*p*-hydroxyphenyl)-propane	0.07	54.	2,4-Dihydroxyacetophenone	0.02
			55.	*m*-Hydroxybenzoic acid	0.04
19.	*o*-Allylphenol	0.41	56.	*p*-Hydroxybenzoic acid	0.02
20.	*p*-Hydroxydiphenyl	0.19	57.	Salicylic acid	0.06
21.	*o*-Hydroxydiphenyl	0.39	58.	3,4-Dihydroxybenzoic acid	0.02
22.	*o,o'*-Dihydroxydiphenyl	0.11	59.	Gallic acid	0.01
23.	α-Naphthol	0.25	60.	*m*-Hydroxymethylphenol	0.01
24.	β-Naphthol	0.20	61.	*p*-Hydroxymethylphenol	0.02
25.	*m*-Chlorophenol	0.28	62.	*o*-Hydroxymethylphenol	0.04
26.	*p*-Chlorophenol	0.25	63.	2,6-Dimethyl-4-hydroxymethyl-phenol	0.01
27.	*p*-Chloro-*m*-cresol	0.27			
28.	*o*-Chlorophenol	0.42	64.	2,5-Dimethyl-4-hydroxymethyl-phenol	0.05
29.	2-Chloro-5-methylphenol	0.42			
30.	2,4-Dichlorophenol	0.45	65.	Resorcinol	0.03
31.	2,4,5-Trichlorophenol	0.46	66.	Hydroquinone	0.02
32.	*o*-Bromophenol	0.46	67.	Pyrocatechol	0.06
33.	2,4,6-Tribromophenol	> 0.70	68.	Phloroglucinol	0.02
34.	*m*-Nitrophenol	0.04	69.	Pyrogallol	0.04
35.	*p*-Nitrophenol	0.06	70.	*p*-Aminophenol	0.02
36.	*o*-Nitrophenol	0.40	71.	*o*-Aminophenol	0.02

inhibit the adsorption of the phenol on silica gel (*cf.* No. 17). There seems to be a slight steric influence from larger alkyl groups in the *meta* position as evidenced by the high R_F-value obtained for carvacrol (No. 12) in comparison with that obtained for 2,5-xylenol (No. 10). It is of interest to note that, for 2,2-bis-[*p*-hydroxyphenyl]-propane (No. 18), the presence of two hydroxyl groups is indicated by the low R_F-value.

Alkenylphenols, diphenylols and naphthols (Nos. 19—24). The position of the hydroxyl group in the diphenylols is clearly reflected by the R_F-values. The unexpectedly large R_F-value for *o*-allylphenol might be due to internal hydrogen bonding to the allyl group [11]. Similarly, the R_F-value of *o*-hydroxydiphenyl might be influenced by internal hydrogen bonding to the phenyl

group [12,13]. In the naphthols, the proximity of the fused benzene ring makes the R_F-value of α-naphthol slightly higher than that of β-naphthol.

Halophenols (Nos. 25—33). Introduction of a chlorine atom in the *meta* or *para* position relative to the phenolic hydroxyl group increases the R_F-values. This fact throws some light on the way in which the bonding of the halophenols to the surface of the adsorbent takes place. The adsorption of the phenol might occur in several ways. There may be formed a hydrogen bond between the hydrogen atom of the phenolic hydroxyl group and an oxygen atom of the silica gel (Ar—O—H ← O—Si). A hydrogen bond could also be developed the other way, *i.e.* between a hydrogen atom of a hydroxyl group bonded to silicon and the oxygen atom of the phenolic hydroxyl group (Ar—O→ H—O—Si). Other bonding possibilities could arise from the coordination of oxygen or the aromatic ring to silicon. Solvent effects may also influence the adsorption process *.

Because halogen atoms increase the acidity of phenols, the R_F-values should decrease, on account of increased hydrogen bonding, upon substitution of halogen atoms for hydrogen in the phenolic ring if the first bonding alternative dominated. Since an increase is observed, the conclusion seems to be justified that hydrogen bonding from the hydrogen atom of the phenolic hydroxyl group to the adsorbent is not predominant in this case. An interaction between the halogen atom and the adsorbent, obviously, does not need to be considered. The steric effect of *ortho* substitution is considerable, the R_F-values being raised from 0.25—0.28 for chlorophenols with unoccupied *ortho* positions to 0.42—0.46 for chlorophenols with a chlorine atom in one of the *ortho* positions and the other unoccupied.

Nitrophenols (Nos. 34—37). While an increase in the R_F-values followed from a substitution of chlorine atoms for hydrogen *meta* and *para* to the phenolic hydroxyl group, the reverse was observed for nitro groups. Thus, *m*- and *p*-nitrophenol have lower R_F-values than phenol. This fact might, at least in part, be connected with an interaction between the nitro group and the adsorbent. That picric acid has a lower R_F-value than *o*-nitrophenol is also in accordance with this view.

Phenols with various oxygen-containing functional groups and aminophenols (Nos. 38—71) **. A number of phenols with various oxygen-containing functional groups as well as several hydroxyl groups have also been studied. The following groups were considered: Methoxy, phenoxy, formyl, keto, carboxyl and hydroxymethyl. In addition, some aminophenols were investigated.

All these groups confer on the phenol additional possibilities of bonding to the adsorbent. Accordingly, the R_F-values generally are low except in certain instances when the adsorption through the phenolic hydroxyl group is decreased by internal hydrogen bonding to and/or steric hindrance by a

* Attempts to develop formulae for calculating R_F-values for various phenols eluted from silica gel have been made but have not been quite successful [14,15].

** See also Nos. 18 and 22.

functional group in the *ortho* position. This is exemplified by guaiacol, eugenol and isoeugenol (Nos. 42—44), which have a methoxy group in the *ortho* position to the phenolic hydroxyl group and further by *o*-hydroxybenzaldehyde and *o*-hydroxyacetophenone (Nos. 48 and 53). In these cases, the *ortho* position of the functional group is indicated by the high R_F-values. In other instances, however, *ortho* substitution causes only a minor increase in the R_F-values. Thus, a hydroxyl, carboxyl, hydroxymethyl or amino group in the *ortho* position is difficult to trace by means of the R_F-value. In the hydroxydiphenylethers, the presence of the ether oxygen atom hardly influences the R_F-values as indicated by a comparison of the values obtained for *o*- and *p*-hydroxydiphenylether (Nos. 38 and 39) and *o*- and *p*-hydroxydiphenyl (Nos. 20 and 21).

Analytical use. The analytical usefulness of the present adsorption chromatographic method is evident from the preceding discussion. Especially, when combined with other physical and chemical investigation methods, it may give valuable information concerning the structures of phenols.

It is seen that, for alkylphenols, halophenols and certain types of phenols with oxygen-containing functional groups, the R_F-values give a clear indication of the presence of substituent groups in the *ortho* position relative to the phenolic hydroxyl group. Previously, a method for the determination of the number of free *ortho* and *para* positions in phenols has been developed by the present author [3]. This method, however, does not permit any decision as to whether a vacant position is placed *ortho* or *para* to the phenolic hydroxyl group. An additional adsorption chromatographic test, as described here, would in many cases give the required information. For 2,4,6-trialkylphenols, it was found that the justmentioned method, which was based on a bromide-bromate titration, gave erroneous results because of the tendency of these phenols to consume bromine despite the absence of vacant *ortho* and *para* positions. The present adsorption chromatographic method could not help to solve this problem since it is generally not possible to decide from the R_F-values whether an alkyl group is situated in the *meta* or *para* position. One might, for example, expect 2,4,6- and 2,3,6-trimethylphenol to have approximately the same R_F-values. There are, however, chemical methods by which the presence of a vacant *para* position may be proved *.

The presence of several phenolic hydroxyl groups in a molecule gives rise to a low R_F-value. This fact may be utilized for tracing the occurrence of phenolic hydroxyl groups in the *meta* position for which the available chemical tests are less reliable than for phenolic hydroxyl groups in the *ortho* and *para* positions. Similarly, the presence of several hydroxyl groups in phenols like 2,2-bis-[*p*-hydroxyphenyl]-propane (No. 18) is not easily proved by chemical tests but is indicated by the low R_F-value.

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