293. *Studies of the* ortho-*Effect. Part II. The Dissociation Constants of Some* o-*Substituted Acids.*

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The data here recorded extend our knowledge of the strengths of substituted aromatic acids. Special reference is made to the *o*-acids; in the benzoic series most of these are considerably stronger than their isomerides but this does not apply to the phenylacetic and cinnamic acids, as far as we have determined. Notable enhancement of acid strength occurs in other structures which admit of steric influences.

The greater bulk of phenyl as compared with methyl may be largely responsible for the striking increase in strength in passing from *o*-methoxy- to *o*-phenoxy-benzoic acid.

The somewhat low constant for *o*-nitrophenylacetic acid is attributed to a " hydrogen bond " between nitroxyl and methylene.

VALUES of the thermodynamic dissociation constants of several *o*-substituted benzoic acids in water at 25° have already been recorded and these are now supplemented by others listed below. *m*- and *p*-Phenoxybenzoic acids are included, since these have not previously been measured. Table I consists of the mean mobility data and the values of both classical and thermodynamic constants, together with the determinations ($10^5 K_{class.}$) which have already appeared in the literature.

TABLE I.

Acid.	Λ_0 (Na salt).	Λ_0 (acid).	$10^5 K_{class.}$.	$10^5 K_{therm.}$.	Earlier values.
o-Toluic	81·2; 81·9	381·2	12·7₅	12·3₅	12·0[1] ; 12·5[2] 13·0[3] ; 13·5[4]
o-Phenylbenzoic	73·6	373·2	35·5	34·7	—
o-Methoxybenzoic	80·3; 80·6	380·0	8·29	8·06	8·2[1]
o-Phenoxybenzoic	73·4	373·0	30·1	29·7	—
m-Phenoxybenzoic	73·7	373·3	11·3	11·2	—
p-Phenoxybenzoic	74·9	374·5	3·03	3·00	—
o-Nitrobenzoic	78·9; 78·9	378·5	660	671	616[1] ; 650[3] 620[5]
o-Nitrophenylacetic	79·0; 79·0	378·6	10·1₅	9·90	—
o-Chlorocinnamic	78·2	377·8	5·88	5·83	—
p-Chlorocinnamic	78·5	378·1	3·89	3·86	3·9[6]

[1] Ostwald, *Z. physikal. Chem.*, 1889, **3**, 415. [2] Euler, *ibid.*, 1896, **21**, 265. [3] Schaller, *ibid.*, 1898, **25**, 517. [4] White and Jones, *Amer. Chem. J.*, 1910, **44**, 184. [5] Kendall, J., 1912, **101**, 1295. [6] Betti and Lucchi, *Atti R. Accad. Lincei*, 1935, **22**, 367.

The older constants for *o*-toluic and *o*-methoxy- and *o*-nitro-benzoic acids approximate to our values, but that recently accorded to *o*-chlorocinnamic acid by Betti and Lucchi is much lower than ours, and scarcely different from that of the unsubstituted acid. It is possible that the sparing solubility of this acid in water added to the difficulties of these workers. There also exists complete lack of agreement between our data (already published) for *o*-chloro- and *o*-bromo-phenylacetic acids and those of Betti and Manzoni (*Atti R. Accad. Lincei*, 1935, **22**, 284), who record classical constants of 13·5 and 19·2 respectively, whereas we found 8·82 and 9·09.

We have already pointed out (J., 1936, 645) that at higher dilutions the classical constants calculated for *o*-iodobenzoic acid are slightly lower than the corresponding thermodynamic constants, and the reason has also been indicated. A similar and much more marked deviation exists in the results published here for the stronger *o*-nitrobenzoic acid at all the concentrations employed (see Table III).

Examination of the Λ_0 data for isomeric acids in the benzoic series shows that the anion mobility tends to be greatest when the substituent occupies the *o*-position; this is the case, however, only where the smaller groups are concerned.

Table II records the relative strengths of substituted benzoic and phenylacetic acids based on the data ($K_{therm.}$) published here and those already recorded by Dippy and Williams

(J., 1934, 161, 1888; 1935, 343) and Dippy and Lewis (J., 1936, 644); in each series the parent unsubstituted acid is taken as unity.

TABLE II.

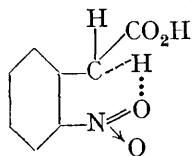|	Benzoic series.			Phenylacetic series.		
	o-.	m-.	p-.	o-.	m-.	p-.
Me	1·97	0·867	0·676	—	—	0·875
HO *	15·9	1·26	0·440	—	—	—
MeO	1·29	1·30	0·538	—	—	0·893
PhO	4·74	1·79	0·478	—	—	—
F	8·63	2·18	1·15	—	—	1·16
Cl	18·2	2·36	1·68	1·76	1·48	1·32
Br	22·3	2·46	1·71	1·81	—	1·33
I	21·9	2·25	—	1·88	1·42	1·36
NO₂	107	5·19	6·00	2·03	2·21	2·89

* These figures are derived from the measurements ($K_{therm.}$) of Branch and Yabroff (*J. Amer. Chem. Soc.*, 1934, **56**, 2568).

Almost all o-substituted benzoic acids are markedly stronger than the m- and p-isomerides, and a variety of causes may be responsible for this. The increase in strength in passing from o-methoxy- to o-phenoxy-benzoic acid can reasonably be attributed to the great difference in bulk of the substituents; the polar effects of these groups should not be very dissimilar (note also that the strengths of o-phenoxy- and o-phenyl-benzoic acids are alike). Elsewhere, methoxyl and phenoxyl behave in comparable manner; in the p-position they reduce the strength of benzoic acid whilst in the m-position they enhance it. The well-known combination of inductive (− I) and electromeric effects (+ T) in alkoxyl accounts for this (cf. J., 1935, 346). It is interesting, however, that in the p-position phenoxyl reduces K more effectively than does methoxyl, whereas in the m-position it leads to a comparatively greater strength. This last observation doubtless arises from the inherent electron-attractive character of phenyl (cf. Dippy and Lewis, this vol., p. 1008) as opposed to the electron-repulsive nature of methyl. On the other hand, in the p-phenoxyl group the ambipolar tautomeric character of phenyl, now free to exhibit itself, apparently gives rise to a greater accession of electrons towards the nucleus than does the inductive effect of methyl.

The order of strengths of anisidines and phenetidines, *viz.*, o- and m- < H < p- (Hall and Sprinkle, *J. Amer. Chem. Soc.*, 1932, **54**, 3469), is wholly consistent with the observations on alkoxybenzoic acids.

It is noticeable that in the phenylacetic acids o-substituents fail to produce abnormally large strengths (see Table II); actually, in the halogeno-compounds, for instance, there is a very *gradual* fall o- > m- > p- (cf. chlorocinnamic acids). It is remarkable how very similar the relative effects of the halogens are in each position in both series, and also that there is a much greater relative diminution in the strengths of m-acids than of p-acids in passing from the benzoic to the phenylacetic series.

In the nitro-acids the order is p- > m- > o-; it is surprising that o-nitrophenylacetic acid is not comparable with the p-acid in being rather stronger than the m-acid, since electromeric disturbances should operate from the o- and p-positions in such a way as to facilitate ionisation. The reason, however, may be that nitroxyl in the o-acid is capable of chelating with hydrogen of the methylene contained in the side-chain (see inset; cf. Sidgwick and Callow, J., 1924, **125**, 538, regarding o-nitrotoluene). This chelation is probably not extensive, but considerable enough to reduce acid strength to give the order, o- < m-.

It has already been pointed out (Flürscheim, *Chem. and Ind.*, 1925, **44**, 249; cf. Hey, J., 1928, 2321; Dippy and Lewis, this vol., p. 1012) that the increase in strength in going from the *trans*- to the *cis*-forms in such acids as crotonic and cinnamic may be correlated with the abnormality noted in the o-substituted benzoic acids, on the grounds of proximity of groups. The fact that α-naphthoic acid ($10^5 K = 20·4$) is stronger than the β-acid ($10^5 K = 6·78$) (Bethmann, *Z. physikal. Chem.*, 1890, **5**, 399) can be considered to have a similar bearing. It is noteworthy that German, Jeffery, and Vogel (J., 1935, 1624) found

the primary dissociation constant of *cyclo*propane-1 : 1-dicarboxylic acid to be very much greater ($10^4K = 150\cdot0$) than those of the homologous acids containing four-, five-, and six-membered rings ($10^4K = 7\cdot47$, $5\cdot89$, and $3\cdot54$ respectively); it was indicated that the distances (r) separating the carboxyl groups in the last three acids were comparable, and much greater than r in the stronger acid. This observation may be regarded simply as another case of abnormality in acid strength due to close proximity of groups.

There is no ponderable *ortho*-effect in phenols, and in the following data such an effect is totally absent,

Substituent.		*o*-.	*m*-.	*p*-.	(H = *ca.* $1\cdot0 \times 10^{-10}$.)
CH$_3$	($10^{11}K$)	6·3	9·8	6·7	(Boyd, J., 1915, **107**, 1540).
NO$_2$	(10^8K)	6·8	1·0	6·5	(Holleman and Herwig, *Rec. trav. chim.*, 1902, **21**, 444).

It is also remarked in Part I that the introduction of *any* *o*-substituent into aniline *depresses* the strength abnormally; the following instances serve to illustrate this clearly :

Substituent.		*o*-.	*m*-.	*p*-.	(H = *ca.* 5×10^{-10}.)
CH$_3$	($10^{10}K$)	0·73	2·9	11·3	(Farmer and Warth, J., 1904, **85**, 1726; Hall and Sprinkle, *loc. cit.*).
NO$_2$	($10^{12}K$)	0·015	4·2	1·1	(Löwenherz, *Z. physikal. Chem.*, 1898, **25**, 405).

On rudimentary grounds it is to be expected that both *o*- and *p*-toluidine will be stronger than *m*-toluidine, and also that *o*-nitroaniline will be only slightly weaker than *m*-nitro-aniline and comparable to the *p*-isomeride

A lower K ($\times 10^{-11}$) for α-naphthylamine (9·9) than for β-naphthylamine (20) (Farmer and Warth, *loc. cit.*) is in harmony with the strengths of *o*-substituted anilines. A steric influence may also be traced in aliphatic amines; Harned and Owen (*J. Amer. Chem. Soc.*, 1930, **52**, 5079) show that progressive methylation of ammonia does not lead to a steady increase in basic strength, as would be anticipated from the operation of the simple inductive effect of alkyl (10^5K : NH$_3$, 1·79; NH$_2$Me, 43·8; NHMe$_2$, 52·0; NMe$_3$, 5·45). Bredig (*Z. physikal. Chem.*, 1894, **13**, 298) and, more recently, Hall and Sprinkle (*loc. cit.*) have observed, with higher alkyl groups, a similar diminution in strength in passing from secondary to tertiary bases.

EXPERIMENTAL.

Details of the conductivity measurements have been described elsewhere (Dippy and Williams; Dippy and Lewis, *locc. cit.*). The water, as usual, had a conductivity of 0·9—1·0 gemmho, and the stock solutions of acids were made up to 250 ml. except in the cases of the less soluble *o*-phenylbenzoic (500 ml.), and *o*-, *m*-, and *p*-phenoxybenzoic, and *o*- and *p*-chloro-cinnamic acids (1 l.).

Materials.—*o*-Methoxybenzoic acid was obtained from the corresponding benzaldehyde by oxidation with alkaline permanganate. *o*-Toluic acid was supplied by British Drug Houses, Limited, and *o*-nitrobenzoic and *o*-nitrophenylacetic acids by Schering–Kahlbaum. The specimens of *o*-phenyl- and *o*-, *m*-, and *p*-phenoxy-benzoic acids were kindly provided by Dr. G. Lock, and *o*- and *p*-chlorocinnamic acids by Professor F. Böck. In each case preliminary purification was effected with a suitable solvent until the m. p. could be improved no further; successive recrystallisations from conductivity water then followed. The m. p.'s of the pure dry acids are recorded below, together with the highest m. p. in the literature. Satisfactory equivalents were obtained throughout.

Acid.	M. p. (corr.).	M. p. (literature).	
o-Toluic	107·5°	107—108°	(Ciamician and Silber, *Ber.*, 1912, **45**, 41).
o-Phenylbenzoic	114	113—114	(Weger and Döring, *Ber.*, 1903, **36**, 880).
o-Methoxybenzoic	101·5	100—101	(Claisen, *Annalen*, 1919, **418**, 87).
o-Phenoxybenzoic	113	113	(Graebe, *Ber.*, 1888, **21**, 503).
m-Phenoxybenzoic	146·5	145	(Griess, *ibid.*, p. 980).
p-Phenoxybenzoic	161·5	159·5	(Griess, *loc. cit.*).
o-Nitrobenzoic	148	148	(Holleman, *Rec. trav. chim.*, 1898, **17**, 248; Flaschner and Rankin, *Monatsh.*, 1910, **31**, 38).
o-Nitrophenylacetic	141	141	(Salkowski, *Ber.*, 1884, **17**, 507).
o-Chlorocinnamic	209·5	211	(Lasch, *Monatsh.*, 1913, **34**, 1654).
p-Chlorocinnamic	249	240—242	(Gabriel and Hertzberg, *Ber.*, 1883, **16**, 2036).

Both chlorocinnamic acids were *trans*-modifications.

The measurements made on the ten acids are summarised in Table III. In each instance details of one complete run are given.

TABLE III.

Cell const.	10^3C.	Λ.	$10^5K_{class.}$	$10^5K_{therm.}$	Cell const.	10^3C.	Λ.	$10^5K_{class.}$	10^5K_{therm}
				o-Toluic acid.					
0·1363	3·086	70·62	(13·00)	12·5$_5$	0·07319	0·9917	114·3	12·7$_5$	12·4$_5$
	1·477	96·27	12·6	12·2$_5$		0·5202	147·6	12·7$_5$	12·5
	1·282	102·4	12·6$_5$	12·3$_5$					

14 Determinations : limits of $10^5K_{therm.}$, 12·2—12·5$_5$.

				o-Phenylbenzoic acid.					
0·07906	0·4453	215·4	35·1	34·5	0·07906	0·1070	299·3	35·4	34·6
	0·2652	246·3	(33·9$_5$)	(33·5)		0·07789	313·7	34·5	34·4
	0·1474	283·5	35·9$_5$	35·2					

4 Determinations : limits of $10^5K_{therm.}$, 34·4—35·2.

				o-Methoxybenzoic acid.					
0·1360	4·501	48·26	8·31	8·00	0·07285	0·9099	98·31	8·22	8·03
	2·107	67·95	8·20	(7·96)		0·7498	106·9	8·26	8·07
	1·880	71·69	8·24	8·01		0·7487	107·2	8·23	8·05

12 Determinations : limits of $10^5K_{therm.}$, 8·00—8·12.

				o-Phenoxybenzoic acid.					
0·07906	0·5358	194·5	30·4$_5$	29·6$_5$	0·05421	0·1491	273·3	29·9$_5$	29·8
	0·4468	205·3	30·1	29·4$_5$		0·07698	307·5	29·8	29·7
	0·2063	254·7	30·3$_5$	29·9$_5$					

5 Determinations : limits of $10^5K_{therm.}$, 29·4$_5$—29·9$_5$.

				m-Phenoxybenzoic acid.					
0·07906	0·1911	196·6	11·2	11·1	0·05421	0·1501	213·7	11·5	11·4
	0·1907	196·9	11·2$_5$	11·1		0·1349	219·5	11·3	11·2$_5$
	0·1858	199·3	11·3$_5$	11·2$_5$					

10 Determinations : limits of $10^5K_{therm.}$, 11·1—11·4.

				p-Phenoxybenzoic acid.					
0·07906	0·1552	132·2	2·99$_5$	2·96	0·05421	0·09736	159·6	3·08	3·05
	0·1206	146·3	3·02	2·99		0·08079	170·0	3·05	3·03
						0·06637	180·7	2·98$_5$	2·97

12 Determinations : limits of $10^5K_{therm.}$, 2·94—3·05.

				o-Nitrobenzoic acid.					
0·1361	2·119	301·4	660	665	0·1361	1·623	314·4	661	670
	1·849	308·4	661	668		1·462	319·2	663	679
	1·776	310·0	658	667		1·129	329·6	663	(682)

12 Determinations : limits of $10^5K_{therm.}$, 665—679.

				o-Nitrophenylacetic acid.					
0·1361	4·230	54·23	10·1$_5$	9·77	0·07285	1·128	98·28	10·2$_5$	10·0
	2·050	75·39	10·1$_5$	9·87		0·7387	117·1	10·2$_5$	10·0$_5$
	1·661	83·20	10·3	10·0		0·5988	127·7	10·2$_5$	10·0$_5$

12 Determinations : limits of $10^5K_{therm.}$, 9·71—10·0$_5$.

				o-Chlorocinnamic acid.					
0·07291	0·1113	193·0	5·93	5·87	0·07291	0·08828	209·4	6·09	(6·04)
	0·09767	203·2	6·11	(6·06)	0·05142	0·08034	213·6	5·92	5·87
	0·09342	204·4	5·96	5·91		0·07145	221·6	5·95	5·90

13 Determinations : limits of $10^5K_{therm.}$, 5·69—5·91.

				p-Chlorocinnamic acid.					
0·07291	0·07068	193·9	3·82	3·79	0·07291	0·06295	203·2	3·92$_5$	3·90
	0·06630	199·1	3·88$_5$	3·85$_5$	0·05142	0·05631	207·9	3·78$_5$	3·76

17 Determinations : limits of $10^5K_{therm.}$, 3·76—3·94.