639. *The Separation of Polar and Steric Effects. Part V.[1] Kinetics of the Reactions of Substituted Benzoic Acids and Related Carboxylic Acids with Diazodiphenylmethane in Ethanol. Reaction Mechanism in Relation to Product Composition; Arrhenius Parameters and the Influence of* ortho-*Substituents.*

By K. Bowden, A. Buckley, N. B. Chapman, and J. Shorter.

Diazodiphenylmethane and carboxylic acids react in alcoholic solutions to form diphenylmethyl esters and ethers. We have measured the ratio, R, of the amount of diazodiphenylmethane consumed in the esterification to the total amount consumed (esterification plus etherification), for substituted benzoic acids and related acids reacting in various alcohols at several temperatures. For a given acid and solvent, R is virtually independent of temperature, and for substituted benzoic acids in ethanol is about 60%. However, R is increased by the introduction of electron-attracting substituents into the solvent ethanol. *meta-* and *para-*Substituents in the benzoic acid have little effect, but R is increased by *ortho-*substituents and tends towards a value also shown by some acids in which the carboxyl group is not conjugated with an aromatic ring. The invariance of R with temperature suggests that ester and ether formation are not completely independent reactions but proceed by way of a common intermediate, the difference arising only in the breakdown of the intermediate to give the products. The values of R are discussed in terms of such a mechanism.

Rate coefficients at several temperatures for the reactions in ethanol of benzoic acid, of $o\text{-}X\cdot C_6H_4\cdot CO_2H$ (X = Me, Et, Pr^i, Bu^t, F, Cl, Br, or I), and of *p*-nitrobenzoic acid with diazodiphenylmethane have been measured, and the Arrhenius parameters have been calculated. A slight influence of structure on the pre-exponential factor is observed and is discussed in terms of polar and steric effects. We have also measured rate coefficients for the reaction with diazodiphenylmethane in ethanol at 30·0° of a number of acids, in particular additional *ortho-*substituted benzoic acids. The secondary steric effect of *peri-*hydrogen atoms and of *ortho-*alkyl groups is examined in detail.

In Part I of this series [2] we described a study of the kinetics of the reactions of *ortho-*substituted benzoic acids with diazodiphenylmethane in ethanol. The esterification of carboxylic acids with diazodiphenylmethane has been much studied in recent years,[2-14] by using spectrophotometric techniques to follow the consumption of diazodiphenylmethane.

In solution in an alcohol, diazodiphenylmethane reacts with carboxylic acids to form diphenylmethyl esters:

$$RCO_2H + Ph_2C\colon N_2 \longrightarrow RCO_2\cdot CHPh_2 + N_2$$
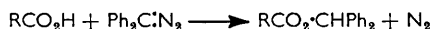
There is also a concurrent reaction between the alcohol and diazodiphenylmethane, catalysed by the acid, to give diphenylmethyl ethers:

$$R'OH + Ph_2C\colon N_2 \longrightarrow R'O\cdot CHPh_2 + N_2$$
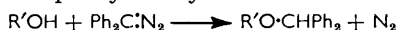
[1] Part IV, Bowden, Chapman, and Shorter, preceding Paper.
[2] Chapman, Shorter, and Utley, *J.*, 1962, 1824.
[3] Roberts and Watanabe, *J. Amer. Chem. Soc.*, 1950, **72**, 4869.
[4] Roberts, Watanabe, and McMahon, *J. Amer. Chem. Soc.*, 1951, **73**, 760.
[5] Roberts, Watanabe, and McMahon, *J. Amer. Chem. Soc.*, 1951, **73**, 2521.
[6] Roberts and Regan, *J. Amer. Chem. Soc.*, 1952, **74**, 3695.
[7] Taft and Smith, *J. Amer. Chem. Soc.*, 1954, **76**, 305.
[8] Roberts and Regan, *J. Amer. Chem. Soc.*, 1954, **76**, 939.
[9] Hancock, Gilby, and Westmoreland, *J. Amer. Chem. Soc.*, 1957, **79**, 1917.
[10] Smith and Hunt, *J. Amer. Chem. Soc.*, 1959, **81**, 590.
[11] Little and Eisenthal, *J. Amer. Chem. Soc.*, 1961, **83**, 4936.
[12] Buckley, Chapman, and Shorter, *J.*, 1963, 178.
[13] Bowden, Chapman, and Shorter, *J.*, 1963, 5239.
[14] Chapman, Shorter, and Toyne, *J.*, 1964, 1077.

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The ratio, R (conveniently expressed as a percentage), of the amount of diazodiphenyl-methane consumed in the reaction with the carboxylic acid to the total amount consumed has been measured [2,4,6,10,12,14] for ethanolic solutions, and with a few exceptions is observed to be about 60%. Most authors have accordingly not corrected the second-order rate co-efficient (which we denote by k_2^a) to give the true rate coefficient (k) for the esterification reaction. In the first Paper of this series,[2] however, some small effect of structure on R was noted, and corrected rate coefficients were therefore evaluated, cf. also ref. 12.

The temperature-dependence of rate coefficient and of R has been previously studied only for the reactions involving cyclohexanecarboxylic acids.[10] For these acids, Smith and Hunt[10] found that R was virtually independent of temperature. As an extension of our previous work on the reactions of substituted benzoic acids with diazodiphenylmethane in ethanol,[2] it was important to determine the temperature-dependence of rate coefficient and of R, which we now report. We have also examined the dependence of R on the structure of the acid in various alcohols as solvents. These studies have shed considerable light on the reaction mechanism. The effect of *ortho*-substituents[2] in benzoic acid on the rate of the reaction with diazodiphenylmethane in ethanol has also been further investigated.

DISCUSSION

Values of R, and the Reaction Mechanism.—Roberts, Watanabe, and McMahon[4] investi-gated the mechanisms of the two reactions involving benzoic acid and diazodiphenyl-methane in ethanol. They concluded that the benzhydryl ester was formed from benzoic acid and diazodiphenylmethane in a single-stage process, for which transition states may be formulated as shown below. The formation of the ether was considered " to proceed by a rate-determining formation of the benzhydryl cation (or possibly the corresponding diazonium ion) through general acid-catalysis of the variety previously demonstrated for picric acid,[3] with undissociated benzoic acid as the catalytic agent."[4]
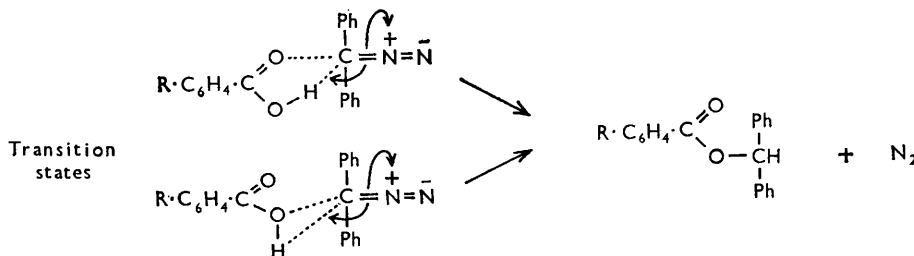
The main evidence for the cationic intermediate in the etherification was the effect of thiocyanate ion on benzoic acid consumption, which was correlated with the effect of this ion on the production of hydrochloric acid in the S_N1 ethanolysis of benzhydryl chloride. It should be noted, however, that 0.1M-sodium thiocyanate had a considerable effect on the ethanolysis but a negligible effect on the diazodiphenylmethane reaction, for which only a small effect was observed even with 0.5M-sodium thiocyanate. The possible inter-vention of a cationic intermediate in the esterification reaction was considered and dismissed.

Later, however, the same authors[5] suggested that esterification possibly proceeded by way of an initial slow transfer of a proton from the carboxylic acid to the diazodiphenyl-methane, with the production of an ion-pair intermediate in a solvent " cage." Presumably
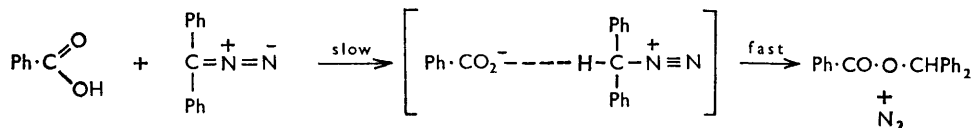
the transition state in the slow stage is attained by partial heterolysis of the oxygen–hydrogen bond of the carboxyl group, with synchronous partial co-ordination of hydrogen to the central carbon of diazodiphenylmethane and partial reorganisation of the electrons of the $>C=N^+=N^-$ group towards the configuration shown. Insofar as later workers [2,9] were concerned with details of the mechanism of the reaction of carboxylic acids with diazodiphenylmethane in ethanol, they generally accepted the suggestions in the earlier Paper of Roberts, Watanabe, and McMahon.[4] Hancock, Gilby, and Westmoreland,[9] in a study of the reactions of benzoic acid and substituted diazodiphenylmethanes in toluene, interpreted their results in terms of the mechanism proposed by Roberts *et al.*[4] for the esterification reaction in ethanol. They argued in favour of the three-centre transition state on the grounds that " the more positive of the two oxygens (*i.e.*, the hydroxyl oxygen) is more likely to attack the nucleophilic diazocarbon."

The results in Table 1, which shed light on the reaction mechanism, show that R is effectively independent of temperature for various substituted benzoic acids in several alcohols. In particular, for benzoic acid in ethanol, R is decreased by only 0·6% for a

TABLE 1.

Values of R (%) for diazodiphenylmethane reacting with substituted benzoic acids in alcohols at 0·0, 30·0, and 50·0°.

Subst. in benzoic acid	Temp. (°c)	In EtOH	In MeO·CH$_2$·CH$_2$·OH	In Bu^{t}OH	In X·C$_6$H$_4$·CH$_2$·OH		
					X = 4-OMe	X = H	X = 3-NO$_2$
None	0·0	59·5	—	—	—	—	—
	30·0	59·2	70·1	45·5	—	62·6	72·2
	50·0	58·9	—	45·3	46·3	62·4	—
o-Cl	30·0	61·7	71·8	53·9	—	77·0	89·9
	50·0	61·6	—	53·8	57·5	76·8	—
p-Cl	30·0	59·6	69·7	47·7	—	64·0	75·5•
	50·0	—	—	47·5	47·5	63·8	—
o-Me	30·0	61·4	72·3				
	50·0	61·2	—				
p-NO$_2$	30·0	57·6	—				
	50·0	57·5	—				

Values of R are reproducible to $\pm 0.2\%$ (units) or better.

temperature rise of 50°, whereas k_2^a increases by a factor of about 50 for the same rise in temperature. This virtual invariance of R with temperature means that if, as suggested,[4] the esterification and etherification reactions are essentially independent, their activation energies must be almost the same. The slight decrease in R with rise in temperature, which is observed, would correspond to a difference in activation energy of about 100 cal. mole^{-1}. It is unlikely that reactions proceeding by such different mechanisms would have such similar activation energies. We therefore suggest that the ester and ether formation proceed by way of a common intermediate, the distinction between ester formation and ether formation arising only in the breakdown of the intermediate to the products. Previously,[2] we have accepted the mechanism proposed by Roberts *et al.*[4] for esterification.

We now favour a mechanism similar to that suggested by Roberts, Watanabe, and McMahon in their later Paper,[5] involving a rate-determining proton transfer from the acid to the diazodiphenylmethane. Since benzoic acid is heavily solvated in alcoholic solution (otherwise it would be extensively dimerised as in hydrocarbon solvents [15]), we suggest that one solvent molecule is specifically and essentially associated with the ion-pair intermediate postulated by Roberts *et al.*; this solvated intermediate may be represented by formula (I).* The transition state for its formation is presumably similar to that described on p. 3381, except that the specific solvation we postulate may be only partly completed.

* In (I) and (II) and previous formulæ, dotted lines represent partial covalencies, and broken lines electrostatic interactions.

[15] Allen and Caldin, *Quart. Rev.*, 1953, **7**, 255.

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In (I) the configuration of the four covalent bonds about the central carbon atom of diazodiphenylmethane is tetrahedral. The alcoholic oxygen atom and one of the carboxyl oxygen atoms are considered as electrostatically bound to the central carbon atom. Breakdown to the products occurs by alternative processes (1) and (2), which are product- but not rate-determining, as indicated. (1) As the nitrogen molecule departs, the bond between the central carbon atom and the carboxyl oxygen develops and the ester is produced; the alcohol molecule reverts to the ordinary role of a solvent species. (2) As the nitrogen molecule departs, the bond between the central carbon atom and the alcoholic oxygen atom develops; the protonic part of the alcoholic hydroxyl group is transferred to the carboxyl oxygen atom, regenerating the carboxylic acid, and the ether is formed.

The transition states for processes (1) and (2) [(IIa) and (IIb), respectively] may be envisaged as structurally analogous to the transition state for S_N2 substitution of an alkyl halide. The bonds linking the central carbon atom of diazodiphenylmethane to the two
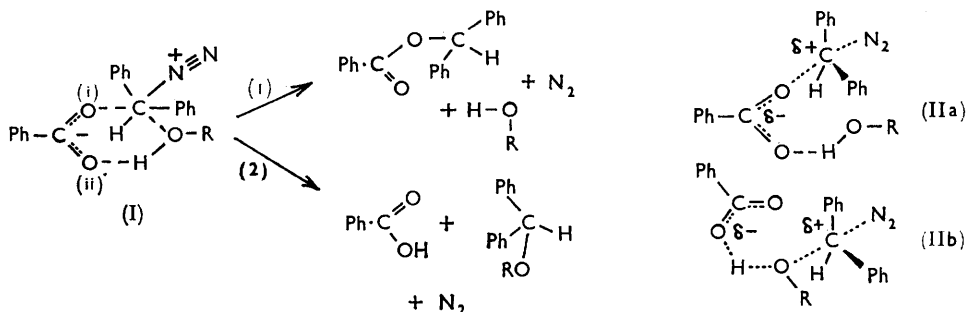
phenyl groups and the hydrogen atom are regarded as co-planar, with an attenuated bond between the central carbon atom and the departing nitrogen molecule at right angles to the plane. One of the carboxylic oxygen atoms (in IIa) or the alcoholic oxygen atom (in IIb) is weakly bound to the central carbon atom on the side away from the nitrogen molecule.*

The dependence of R on the structure of the alcohol. Table 1 shows that the mode of breakdown of the intermediate depends significantly on the structure of the alcohol. With substituted benzyl alcohols the electron-releasing *p*-methoxy-group favours breakdown to the ether, whilst the electron-withdrawing *m*-nitro-group favours ester formation. It is reasonable that electron-release to the alcoholic oxygen should favour the establishment of the bond to the central carbon atom, and electron withdrawal inhibit this. The higher values of R for benzyl alcohol compared with ethanol are explained by the electron-attracting properties of phenyl compared with methyl. The lower values for t-butyl alcohol may similarly be explained by the electron-releasing properties of the t-butyl group compared with ethyl, although the occurrence of a steric effect, reducing R for t-butyl alcohol, is conceivable. The high value of R for 2-methoxyethanol is due to the electron-attracting properties of methoxyl when attached to a saturated chain. The value of R of about 74% for reactions of arylaliphatic acids with diazodiphenylmethane in 2-n-butoxyethanol, recorded by Bowden, Chapman, and Shorter [13] (cf. 65·1 for phenylacetic acid in ethanol, see Table 4), accords well with this.

The dependence of R on the structure of the acid. The values of R are not nearly so sensitive to changes in the structure of the carboxylic acid; thus, R for *p*-nitrobenzoic acid in ethanol is only slightly smaller than for benzoic acid itself, whilst R for *p*-methoxybenzoic acid is virtually the same as for benzoic acid (Table 2). It is only when *ortho*-substituents

* In a personal communication, Dr. S. I. Miller (cf. Abstracts of Papers, 145th Meeting of the American Chemical Society, September 1963, p. 44T) has suggested to us that the solvated ion-pair intermediate (I) may first collapse with loss of nitrogen to form a solvated ion-pair whose formula may be written as $PhCO_2^- - - - - ^+CHPh_2,ROH$ (III), with the implication that the ROH plays the same role as in (I). (III) is then supposed to break down by a path analogous to either (1) or (2).

TABLE 2.

Values of R (%) for diazodiphenylmethane reacting with $X \cdot C_6H_4 \cdot CO_2H$ in
ethanol or in 2-methoxyethanol at $30 \cdot 0°$.

X	H	*m*-Cl	*m*-NO$_2$	*m*-Me	*p*-Cl	*p*-NO$_2$	*p*-OMe	*o*-F
Ethanol	59·2	60·0	60·0	61·1	59·6	57·6	60·0	61·0
2-Methoxyethanol ...	70·1	69·9	69·9	69·9	69·7	—	—	70·9

X	*o*-Cl	*o*-Br	*o*-I	*o*-Me	*o*-Et	*o*-Pr^i	*o*-Bu^t	2,6-Cl$_2$
Ethanol	61·7	61·7	61·7	61·4	64·2	65·2	65·8	63·8
2-Methoxyethanol ...	71·8	71·9	71·9	72·3	72·3	72·4	73·1	—

Values of R are reproducible to $\pm 0 \cdot 2\%$ (units) or better.

are introduced into the benzoic acid that significant effects on R appear. Such effects are not very pronounced when ethanol or 2-methoxyethanol is the solvent, but Table 2 shows that *ortho*-substitution increases R slightly (see also Table 2 in Part I [2]). Table 1 shows that the effects are more pronounced in t-butyl alcohol and in the benzyl alcohols. It is unlikely that this is due to a primary steric effect involving the *ortho*-substituent and the diazodiphenylmethane molecule, which would probably reduce R rather than increase it. Certain acids in which the carboxyl group is not conjugated with an aromatic ring also have a value of R higher than for benzoic acid (see Table 3; acids 1, 8, and 9 show R values of 60·7, 66·9, and 65·1, respectively). We suggest that the effect of *ortho*-substituents in benzoic acid is due to a secondary steric effect which reduces the degree of conjugation of the carboxyl group with the ring by twisting the carboxyl group out of the plane of the ring. This effect was invoked [2] to account for the increase in reactivity towards diazodiphenylmethane produced by bulky *ortho*-alkyl substituents. The R values (Table 2) tend to increase in the order Me < Et < Pr^i < Bu^t, *i.e.*, in the order of increase in bulk. Further, for those fused-ring systems which are, in effect, *ortho*-substituted benzoic acids and which show a secondary steric effect on reactivity (see below), the value of R is higher than for related fused-ring systems where no such steric effect occurs (*e.g.*, Table 3; acids 6 and 5).

For the reaction of benzoic acids with diazodiphenylmethane in ethanol the secondary steric effect of *ortho*-halogen was considered to make only a small contribution to the high reactivity of the compounds.[2] However, there is a small, but definite effect of *ortho*-halogens in the acid on R (Table 2). Whilst the effect of *o*-Cl on R is small with ethanol and 2-methoxyethanol as solvents, it is quite pronounced with t-butyl alcohol and the benzyl alcohols (Table 1). It appears that attachment of bulky groups to the α-carbon atom of the alcoholic solvent noticeably increases the secondary steric effect of *o*-Cl in benzoic acid.

In a carboxylic acid in which the carboxyl group is conjugated with an aromatic ring the oxygen atom of the carbonyl group carries a slightly greater negative charge than in an unconjugated acid. We suggest that the difference between the conjugated and unconjugated systems is carried over in some measure to the transition state of the diazodiphenylmethane reaction. The increase in nucleophilicity of the oxygen atom (ii) in the conjugated system [see (I)] should enhance ether formation by facilitating the transfer of the proton from the alcohol. Table 3 shows, by comparison of acid 1 with acids 3, 5, and 13, that extension of the conjugated ring system (enhancing conjugation of the carboxyl group with the ring) further reduces R. It can also be seen from Table 3 that introduction of a further methylene group, or an ethereal oxygen atom, into the side-chain of phenylacetic acid (acids 10 and 11 compared with 9), and the introduction of a conjugated side-chain double bond (12), reduce R.

Arrhenius Parameters.—Rate coefficients (k_2^a) for various temperatures and Arrhenius parameters for the reactions of substituted benzoic acids with diazodiphenylmethane in ethanol are shown in Tables 4 and 5, respectively. [In accordance with the reaction mechanism involving (I), we shall no longer evaluate k from k_2^a and R; k_2^a is now understood to relate to the common rate-determining step.] The log A values for benzoic acid

TABLE 3.

Values of rate coefficient (l. mole^{-1} min.$^{-1}$) and of R (%) for the reactions of
diazodiphenylmethane with various acids in ethanol at 30·0°.

No.	Acid	$k_2{}^a$	R	No.	Acid	$k_2{}^a$	R
1	Benzoic	0·983	60·7	9	Phenylacetic	1·08	65·1
2	1-Naphthoic	1·53	63·5	10	β-Phenylpropionic	0·735	62·0
3	2-Naphthoic	1·12	58·6	11	Phenoxyacetic	6·60	61·4
4	1-Anthroic	1·42	63·7	12	Cinnamic	0·972	59·7
5	2-Anthroic	1·14	59·0	13	Biphenyl-4-carboxylic	1·00	58·3
6	9-Anthroic	8·49	65·9	14	*o*-Aminobenzoic	0·423	60·0
7	9-Phenanthroic	1·87	64·0	15	*o*-Hydroxybenzoic	7·55	60·0
8	Acetic	0·517 *	66·9 *	16	*o*-Methoxybenzoic	1·23	61·6

Values of $k_2{}^a$ are reproducible to $\pm 1\%$ or better.

* Roberts and Regan, *J. Amer. Chem. Soc.*, 1952, **74**, 3695, give $k_2{}^a = 0.56$ and $R = 87\%$.

TABLE 4.

Values of rate coefficient for the reactions of diazodiphenylmethane with
substituted benzoic acids in ethanol at several temperatures.

No.	Subst. in benzoic acid	$k_2{}^a$ (l. mole^{-1} min.$^{-1}$)				
		10°	20°	30°	40°	50°
1	H	—	0·405	0·992	2·31	5·14
2	*o*-Me	—	0·351	0·894	2·08	4·74
3	*o*-Et	—	0·400	1·04$_5$	2·42	(6·08 at 51·8°)
4	*o*-Pr^i	—	0·603	1·48$_5$	3·29	(7·59 at 50·1°)
5	*o*-Bu^t	0·463	1·13	2·66	6·02	—
6	*p*-NO$_2$	0·368 (2·9°)	0·777	2·12	5·04	—
7	*o*-F	—	0·411	1·07	2·59	5·89
8	*o*-Cl	0·392 (3·2°)	0·781	2·01	4·96	—
9	*o*-Br	0·468 (2·8°)	0·959	2·49	5·82	—
10	*o*-I	0·407 (1·4°)	0·985	2·53	6·23	—

Values of $k_2{}^a$ are reproducible to $\pm 1\%$ or better.

Chapman, Shorter, and Utley (*J.*, 1962, 1824) give the following values for 30°: 1, 1·08; 2, 0·971;
3, 1·13; 4, 1·60; 5, 2·81; 7, 2·71; 8, 5·20; 9, 6·39; 10, 6·66. These values are somewhat higher
than those in the above Table, because of a trace of water in the ethanol (see Buckley, Chapman,
and Shorter, *J.*, 1963, 178).

TABLE 5.

Arrhenius parameters for the reactions of diazodiphenylmethane with substituted
benzoic acids in ethanol.

Substituent	H	*o*-Me	*o*-Et	*o*-Pr^i	*o*-Bu^t	*p*-NO$_2$	*o*-F	*o*-Cl	*o*-Br	*o*-I
E (kcal. mole^{-1})	15·9$_5$	16·3	16·2	15·8	14·9$_5$	16·1	15·6	15·8	15·5	15·7
log A (min. units) ...	11·49	11·70	11·68	11·54	11·19	12·32	11·67	12·08	11·92	12·12

Values of E are accurate to ± 0.2 kcal. mole^{-1} and of log A to ± 0.15 unit.

and *o*-methyl- and *o*-fluoro-benzoic acid are the same within the limits of experimental
error. On the other hand, the values for the other *o*-halogeno-acids and for *p*-nitrobenzoic
acid are significantly greater. Further, there are indications that log A falls slightly with
increase in the size of the *ortho*-alkyl group.

The formation of the intermediate involves the creation of an ion-pair, and thus the
transition state will be more heavily solvated than the initial state. We suggest that the
powerful electron-attracting polar effects of the *ortho*-halogens (except fluorine) and of the
p-nitro-group increase the solvation of the initial state so that a smaller increase in solvation
in the passage to the transition state is required, and hence log A is higher. It does not
seem possible to account for the influence of *ortho*-alkyl groups on log A in terms of
solvation. Whilst the overall influence of these groups on rate coefficients depends on the
acceleration produced by the secondary steric effect,[2] through lowering E (Table 5), it is
possible that there also is a small primary steric effect producing " hindrance to motions "

in the transition state,[1] and leading to the observed slight fall in log A with increase in size of the alkyl group.

The observed variations in E are all slight. For *ortho*-halogens these differences barely exceed the uncertainty in their measurement, the average value being just perceptibly less than for the reaction of benzoic acid. There is a downward trend in E for these reactions as the series *o*-Me, *o*-Et, *o*-Pr^i, *o*-Bu^t is traversed, but only with *o*-Bu^t is the difference from the unsubstituted case significantly beyond the uncertainties of measurement. The activation energy for the reaction of *p*-nitrobenzoic acid is a little higher than for the reactions of the *o*-halogeno-acids; this may be connected with a diminished role of increase of solvation in forming the transition state.

The Effect of Structure on Reactivity, with Particular Reference to the Effect of ortho-*Substitution.*—Rate coefficients at 30·0° for a number of acids not previously studied are shown in Table 3. 2-Naphthoic acid is slightly more reactive than benzoic acid owing to the electron-attracting power of the second ring. The further extension of the fused-ring system in 2-anthroic acid does not appreciably increase the reactivity towards diazodiphenylmethane. The introduction of a 4-phenyl group into benzoic acid also has little effect on the rate. The reactions of 1-naphthoic and 1-anthroic acid show considerably higher rate coefficients than those of their 2-isomers; this we attribute to a secondary steric effect of the *peri*-hydrogen atom. 1-Anthroic acid is somewhat less reactive than 1-naphthoic acid; there seems to be no obvious explanation of this. In 9-phenanthroic acid the steric and polar effects should be a combination of those shown by 1- and 2-naphthoic acids. Now, $\Delta\log k_2^a$ for 9-phenanthroic acid is 0·28 (relative to benzoic acid); the value calculated, on an additive basis, from 1- and 2-naphthoic acids is 0·25. 9-Anthroic acid shows the large secondary steric effect of the two *peri*-hydrogen atoms; this is discussed below.

The rate coefficients for the reactions of acetic, phenylacetic, and β-phenylpropionic acid show the electron-attracting inductive effect of the phenyl group combined with the damping effect of an intervening methylene group. The introduction of a side-chain double bond (cinnamic acid) enhances the transmission of the electron-attracting effect of the phenyl group. The replacement of the β-methylene group of β-phenylpropionic acid by oxygen (phenoxyacetic acid) markedly increases electron-withdrawal from the reaction centre.

The high reactivity of salicylic acid may be attributed to facilitation of the loss of the proton to the diazodiphenylmethane caused by hydrogen bonding between the *ortho*-hydroxyl group and the carbonyl oxygen atom. (Norris and Strain [16] observed a similar effect for the reaction of salicylic acid with diazodi-*p*-tolylmethane in toluene, and Little and Eisenthal [11] for that of α-hydroxybenzylferrocenecarboxylic acid). *o*-Methoxybenzoic acid, in which no such hydrogen bonding is possible, is much less reactive; the secondary steric effect of *ortho*-methoxyl is the dominant factor, although this is presumably opposed by the mesomeric effect. The low reactivity of *o*-aminobenzoic acid is due to the powerful mesomeric electron-release of the amino-group, which completely outweighs any effect of hydrogen bonding.

The secondary steric effect. The high reactivity of 9-anthroic acid ($k_2^a = 8·49$), of *o*-t-butylbenzoic acid ($k_2^a = 2·66$), and of 2,6-dimethylbenzoic acid ($k_2^a = 3·38$ *) may be analysed to show the effectiveness of the relevant *ortho*-substitution in suppressing the conjugation of the carboxyl group with the ring. The reactivity of benzoic acid towards diazodiphenylmethane, in the absence of such conjugation, can be estimated as follows. The $\Delta\log k_2^a$ values for phenylacetic and β-phenylpropionic acid relative to acetic acid are 0·320 and 0·152, respectively, showing that the additional methylene group in β-phenylpropionic acid damps the effect of the phenyl group by a factor of 0·48 (a factor of about 0·4 for such damping is often shown [13]). By applying this factor to the methylene group of

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* Roberts and Regan [8] give 3·64; values of k_2^a recorded by Roberts and his co-workers are generally about 7% higher than our present values, so 3·38 seems a fair value for comparison with our results.

[16] Norris and Strain, *J. Amer. Chem. Soc.*, 1935, **57**, 187.

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[1964] *The Separation of Polar and Steric Effects. Part V.* 3387

phenylacetic acid a value for log k_2^a for " unconjugated " benzoic acid may be calculated as $0.033 + 0.320/0.48 = 0.70$. [Another estimate may be based on the resonance energy (E_R) associated with the conjugation of the carboxyl group and the ring, which is about 1 kcal. mole^{-1}.[17] Complete inhibition of conjugation should lead to a Δlog k_2^a value of $E_R/2.303\ RT = 0.72$, *i.e.*, log k_2^a for " unconjugated " benzoic acid should be $-0.01 + 0.72 = 0.71$, cf. 0.70 above, but such good agreement may be fortuitous.]

An estimate of the Δlog k_2^a value due to the polar effect of *ortho*-methyl may be based on the relation between log k_2^a for *o*-alkylbenzoic acids and Taft steric parameters (E_s) for β-methyl-substituted ethyl groups by extrapolation to $E_s = 0$ (see Chapman, Shorter, and Utley,[2] Fig. 2 and discussion on p. 1828). The value is -0.07. Assuming that the polar effects of two *o*-methyl-groups are additive, log k_2^a for " unconjugated " 2,6-dimethylbenzoic acid should be $0.70 - 2 \times 0.07 = 0.56$; the observed value for 2,6-dimethylbenzoic acid (see above) is 0.53, indicating the complete absence of conjugation of the carboxyl group with the ring in this compound. If the polar effect of *o*-Bu^t is similarly taken as -0.07 (in the *para*-position Me and Bu^t are of comparable effect in this reaction[2]), log k_2^a for " unconjugated " *o*-t-butylbenzoic acid should be $0.70 - 0.07 = 0.63$; the observed value of 0.43 indicates that conjugation is not completely inhibited, whereas a study of models leads to the view that conjugation is almost completely inhibited; cf. Part I.[2]

The polar effect of fusing additional rings in the 2,3- and 5,6-positions of benzoic acid, to form 9-anthroic acid, should be approximately twice the effect of fusing a ring in the 3,4-position of 1-naphthoic acid to give 9-phenanthroic acid. [The pK_a values of 1- and 2-naphthylacetic acids at 25° in water (4.24 and 4.26, respectively;[18] cf. phenylacetic acid, pK_a 4.31) suggest that the polar effects of 2,3- and 3,4-ring fusion are similar.] On this basis, log k_2^a for " unconjugated " 9-anthroic acid should be $0.70 + 2 \times 0.09 = 0.88$ (cf. observed value of 0.93), indicating complete inhibition of conjugation between the carboxyl group and the ring.

EXPERIMENTAL

Materials.—The acids were commercial samples or were prepared by standard methods. They were recrystallised, usually from glacial acetic acid or aqueous ethanol, and then either from benzene or light petroleum (b. p. 60—80°). They had melting points identical with, or very close to, those recorded in the literature. Except for *p*-nitro- and *p*-methoxy-benzoic acid, each acid was esterified with diazomethane in ether, the ether was allowed to evaporate, and the residue was analysed by gas chromatography. The stationary phase was either 10% of Apiezon L or 10% of polypropylene sebacate on Celite 100—120 mesh, and the column temperature was 150°. No traces of impurities were found. The equivalent weight of each acid, determined by titration, was well within 1% of the calculated value. Diazodiphenylmethane was prepared by the method of Schroeder and Katz.[19] Solutions were stored in a refrigerator.

Solvents.—Pure ethanol, b. p. 78.3°, n_D^{25} 1.3591 (lit.,[20] 78.3°, 1.35941) was prepared by Smith's method.[21] 2-Methoxyethanol was dried by keeping it over freshly ignited potassium carbonate for some days, followed by treatment with a molecular sieve (type 4A). It was then distilled, and had b. p. 124—125°, n_D^{25} 1.4025 (lit.,[20] 124.40, 1.4017). Benzyl alcohol, purified similarly, had b. p. 205—207°, n_D^{20} 1.5398 (lit.,[20] 205.5°, 1.54033). t-Butyl alcohol, first dried over potassium carbonate, then refluxed over and distilled from sodium, had m. p. 25—26°, b. p. 82—82.5° (lit.,[20] 25.5°, 82.4°). 4-Methoxybenzyl alcohol, prepared by Meerwein and Schmidt's method,[22] had m. p. 25° (lit.,[23] 24—25°), and 3-nitrobenzyl alcohol, prepared by Becker's method,[24] m. p.

[17] Wheland, " Theory of Resonance," Wiley, New York, 1st edn., 1944, p. 69.
[18] Kortüm, Vogel, and Andrussow, " Dissociation Constants of Organic Acids in Aqueous Solution," Butterworths, London, 1961.
[19] Schroeder and Katz, *J. Org. Chem.*, 1954, **19**, 718.
[20] Weissberger, " Techniques of Organic Chemistry," vol. VII, Interscience, New York, 2nd edn. 1955.
[21] Vogel, " Practical Organic Chemistry," Longmans, London, 3rd edn., 1956, p. 168.
[22] Meerwein and Schmidt, *Annalen*, 1925, **444**, 236.
[23] Cannizzaro and Körner, *Ber.*, 1872, **5**, 436.
[24] Becker, *Ber.*, 1882, **15**, 2090.

27° (lit.,[25] 27°). Except for the last two compounds, gas chromatography was used to show the absence of impurities. For all the alcohols, Karl Fischer titration [26] (conducted in ethanol for the last two alcohols) showed a water content always $< 0.02\%$ by weight, sometimes $< 0.01\%$. The solvents were stored and manipulated with very careful exclusion of atmospheric moisture.

Measurements.—Values of R and k_2^a were determined as described previously.[12]

[25] Staedel, *Ber.*, 1894, **27**, 2112.
[26] Seaman, McComas, and Allen, *Analyt. Chem.*, 1949, **21**, 510.