300. *The S_N Mechanism in Aromatic Compounds. Part IV.**

By Joseph Miller and Vincent A. Williams.

ortho-Effects are shown to exhibit considerable variation in both magnitude and character. The lack of connection between geometrical and *ortho*-effects is clearly shown, and evidence is given for a field effect.

Steric effects associated with *ortho*-substituents in aromatic compounds have been known for many years, and numerous references are quoted by Hughes (*Quart. Reviews*, 1948, **2**, 167). In the field of reactions being studied in this series, the papers of Spitzer and Wheland (*J. Amer. Chem. Soc.*, 1940, **62**, 2995) and of Berliner, Quinn, and Edgerton (*ibid.*, 1950, **72**, 5305) may be given as examples.

Differential effects between *ortho-* and *para*-positions may normally be neglected only in comparison with the larger differences usual between effects at these positions, and at the *meta*-positions. A substituent in the *ortho*-position may have superimposed on its normal polar behaviour a steric factor which usually reduces its effect as compared with the same substituent at the *para*-position (cf. de la Mare, *J.*, 1949, 2871). This applies even where a hydrogen atom is being replaced. With the more common replacement here of halogens or larger groups the effect is enhanced.

The normally less potent *I* effects act more strongly from the nearby *ortho*-positions, but the *T* (including both *M* and *E*) effects, where available, will be reduced. This is due

---

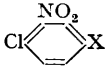
* Part III, *J.*, 1952, 3552.

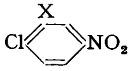
both to steric inhibition of conjugation of the group with the ring, and to the lesser delocalisation of the p or π electrons as compared with the same substituent at the *para*-position.

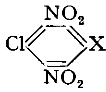
In the transition state of S_N2 reactions, the additional group bonded at the reactive centre normally enhances any steric hindrance (Dostrovsky, Hughes, and Ingold, *J.*, 1946, 173); however, in the aromatic series only four groups are bonded in the transition state, and this is also associated with a change to a quinonoid type of structure, and thus there may be little or no enhancement, and in fact, where there is already considerable steric hindrance in the initial state, the formation of the transition state may cause a steric acceleration (cf. Ingold, *Nature*, 1951, **167**, 987; Beckwith, Miller, and Leahy, Part III *). Finally, the existence of a direct-charge field effect, absent in the *para*-position, may accelerate or retard a reaction according to the sign of the charge and electrical character of the reagent.

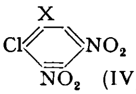
The work now described is intended to confirm these general differences between *ortho*- and *para*-substituents, to show that *ortho*-effects are mainly polar and not geometrical in origin, and in particular to show that *ortho*-effects may be accelerative as well as hindering.

The activating or deactivating power of substituents has been defined and measured in the form of substituent rate factors (Miller, *J.*, 1952, 3550). These correspond to the partial rate factors of aromatic electrophilic substitution (Ingold *et al.*, *J.*, 1927, 2918; 1931, 1959). The substituent rate factors, and the *para*/*ortho* ratios of these have been obtained by measurements in the mononitro-series (I and II) and dinitro-series (III and IV), X being the variable substituent.


(I)


(II)


(III)


(IV)

In this general paper the substituents investigated are the same as in Part II (*loc. cit.*). Some measurements for *para*-substituents are repeated from that paper but most of the results are new. The rates of attack of sodium methoxide in dry methanol on 20 compounds are given in Table 1, which also includes the substituent rate factors at 50°, and activation energies (E) and frequency factors (as $\log_{10} B$).

The *para*/*ortho*-ratios of the substituent rate factors (a convenient name for which is "steric index") vary from 1 with zero *ortho*-effect to convenient numbers showing the magnitude and direction of the *ortho*-effects. Values less than 1 show accelerative, and above 1 hindering, influences. Similarly the ratios of the indices in the mononitro- and dinitro-series show the change in the effects.

Discussion of Results.—It is instructive to compare the actual *ortho*-effects with the simple geometrical hindrance. The latter is most simply given by the overlaps between the *ortho*-substituents and chlorine which would be present if all the substituents were in the plane of the ring: the overlaps with hydrogen are less important. The physical data used to obtain the overlaps are derived either from Archer's measurements (*Proc. Roy. Soc.*, 1947, *A*, **188**, 51) or from Pauling ("Nature of the Chemical Bond," 2nd Edn.). The radius of the amino-group was estimated as 1·82 Å, and the C=O distance, 1·24 Å, of the carbomethoxy-group is an arbitrary choice between values quoted for aldehydes and for acids.

Experimental and geometrical *ortho*-effects are compared in Table 2. The geometrical hindrance is in the order $Me > NO_2 > CO_2^- = CO_2Me > NH_2 > Cl$, all substituents exhibiting considerable interference. The order of ortho effects is: (*a*) in the mononitro-series $CO_2^- > CO_2Me > NO_2 > Cl$, (*b*) in the dinitro-series $CO_2^- > CO_2Me > NO_2 > NH_2^* > Cl^* > Me^*$. The direction of the effect is accelerative.

The extreme cases CH_3 and CO_2^- give a very convincing proof that geometrical hindrance is unimportant. The CO_2^- has less overlap than the methyl group. However, the steric index in the dinitro-series is 170·5 for the CO_2^- as against only 1·29 for the methyl group. In the mononitro-series it is 21·2 against an assumed value between 1 and 1·29.

Admitting a specific effect consequent on the ionic charge of the CO_2^- and substituting the carbomethoxy-group, one obtains an equally convincing comparison.

The $-I$, $-T$ groups by markedly denuding the point of attack of electrons, and by stabilising the *cyclo*pentadiene-type structure of the transition state, facilitate the approach of the OMe group and lower the activation energy (E). This is shown by both the nitro- and the carbomethoxy-group. The *ortho*-effects when potent are associated with a much smaller fall in E, the difference being ascribed to repulsion by the oxygen atoms of these groups.

TABLE 1.

Compound *	10^5k_2 (temp. in parentheses)				10^5k_2 at 50°	Substituent	Substituent rate factor (H = 1)	E, kcal.	$\log_{10} B$
(i)	8·42 (71·0)	23·5 (81·6)	137 (100·8)	—	0·902	—	—	23·7	10·98
(ii)	3·62 (75·3)	6·82 (81·6)	37·45 (100·8)	—	0·260	—	—	23·5	10·30
(iii)	200 (0)	1060 (15·0)	2960 (25·0)	— —	28,750 —	p-NO_2 o-NO_2	$1·11 \times 10^5$ $3·19 \times 10^4$	17·43 —	11·26 —
(iv)	90·6 (26·35)	138 (30·2)	226 (35·0)	—	1,030	o-NO_2	$3·96 \times 10^3$	19·77	11·37
(v)	55·75 (30·2)	99·9 (34·8)	258 (45·3)	937 (59·9)	395	p-CO_2Me	$1·52 \times 10^3$	18·6	10·17
(vi)	99·75 (45·35)	322 (59·9)	1010 (75·3)	1560 (81·6)	147	o-CO_2Me	$1·63 \times 10^2$	17·04	8·69
(vii)	3610 (0)	6400 (5·2)	9170 (8·75)	—	355,300	p-CO_2Me	$3·45 \times 10^2$	16·1	11·43
(viii)	630 (−4·8)	1115 (0)	1955 (4·9)	—	154,300	o-CO_2Me	5·37	17·3	11·89
(ix)	4·85 (59·9)	20·45 (75·3)	36·4 (81·6)	165 (100·6)	1·96	p-CO_2^-	7·54	21·5	9·70
(x)	16·95 (81·6)	34·9 (87·8)	139 (100·8)	—	0·321	o-CO_2^-	$3·56 \times 10^{-1}$	28·6	13·87
(xi)	57·0 (0)	686 (26·1)	970 (30·2)	—	4,580	p-CO_2^-	4·45	15·17	8·91
(xii)	144 (35·15)	308 (41·85)	610 (48·05)	—	751	o-CO_2^-	$2·61 \times 10^{-2}$	22·02	12·77
(xiii)	18·6 (30·2)	79·2 (45·4)	343 (60·0	—	131	p-CH_3	$1·27 \times 10^{-1}$	19·20	10·08
(xiv)	114 (18·65)	260 (26·1)	402 (30·2)	650 (34·9)	2,820	o-CH_3	$9·81 \times 10^{-2}$	19·16	11·41
(xv)	23·8 (68·4)	30·4 (71·7)	86·0 (81·8)	418 (100·8)	3·61	p-Cl	$1·39 \times 10^1$	22·50	10·76
(xvi)	74·2 (69·9)	125 (75·6)	144 (77·2)	347 (87·1)	10·35	o-Cl	$1·15 \times 10^1$	21·90	10·80
(xvii)	51·8 (0)	546 (21·55)	762 (25·0)	—	7,360	p-Cl	7·15	17·37	10·61
(xviii)	743·5 (0)	1415 (4·55)	1590 (5·35)	2215 (9·05)	328,000	o-Cl	$1·14 \times 10^1$	21·36	14·97
(xix)	15·8 (81·8)	61·7 (100·1)	151 (112·6)	—	0·869	p-NH_2	$8·44 \times 10^{-4}$	20·40	8·73
(xx)	45·15 (41·25)	599 (69·9)	1100 (77·2)	1475 (81·6)	105·5	o-NH_2	$3·67 \times 10^{-3}$	19·58	10·26

(i) *p*-Chloronitrobenzene. (ii) *o*-Chloronitrobenzene. (iii) 1-Chloro-2 : 4-dinitrobenzene. (iv) 1-Chloro-2 : 6-dinitrobenzene. (v) Methyl 4-chloro-3-nitrobenzoate. (vi) Methyl 2-chloro-5-nitrobenzoate. (vii) Methyl 4-chloro-3 : 5-dinitrobenzoate. (viii) Methyl 2-chloro-3 : 5-dinitrobenzoate. (ix) 4-Chloro-3-nitrobenzoic acid. (x) 2-Chloro-5-nitrobenzoic acid. (xi) 4-Chloro-3 : 5-dinitrobenzoic acid. (xii) 2-Chloro-3 : 5-dinitrobenzoic acid. (xiii) 4-Chloro-3 : 5-dinitrotoluene. (xiv) 2-Chloro-3 : 5-dinitrotoluene. (xv) 2 : 5-Dichloronitrobenzene. (xvi) 3 : 4-Dichloronitrobenzene. (xvii) 1 : 4-Dichloro-2 : 6-dinitrobenzene. (xviii) 1 : 2-Dichloro-4 : 6-dinitrobenzene. (xix) 4-Chloro-3 : 5-dinitroaniline. (xx) 2-Chloro-3 : 5-dinitroaniline.

The CO_2^- group is of special interest. Although classified as a weakly activating $-I$, $-T$ group, it has available in the *ortho*-position only, a direct-field effect, opposite in sign and causing deactivation. The geometrical hindrance by this group is similar to that of the previous groups, but the repulsive effects are much stronger owing to the unit negative charge spread over two oxygen atoms. Very large steric indices are to be expected and are found experimentally. The effect is so marked that while *p*-CO_2^- is activating, *o*-CO_2^- is deactivating, particularly in the dinitro-series. The nature of the repulsive *ortho*-effect is clearly shown by the very high values of E. A more loosely bound transition state leads to high frequency factors also. In contrast, the *para*-compounds have quite low Arrhenius parameters.

TABLE 2.

Substituent	Steric index : * (*a*) mononitro-series	(*b*) dinitro-series	Ratio of steric indices, b/a	Overlaps (Å) between *o*-substituent and Cl
NO_2	3·48 †	28·0 ‡	8·05	0·75
CO_2Me	9·33	64·2	6·88	0·66
CO_2^-	21·2	170·5	8·04	0·66
CH_3	—	1·29	—	0·80
Cl	1·21	0·627	0·518	0·52
NH_2	—	0·230	—	0·61

* See p. 1476.

† Ratio of rate constants at 50° of *p*- and *o*-chloronitrobenzene.

‡ Ratio of rate constants at 50° of 1-chloro-2 : 4- and -2 : 6-dinitrobenzene.

The $+I(+M)$ methyl group is weakly deactivating. Its size is similar to that of the previous groups. The almost negligible *ortho*-effect is due to its lack of polar character.

The chloro- and amino-groups have opposing $-I$ and $+M$ effects. The former is activating and acts more strongly from the *ortho*-position : the latter is deactivating and acts more strongly from the *para*-position. The geometrical effects are also the smallest of the series. For both of these groups, therefore, *ortho*-acceleration may be considered probable, and further, this should be most marked for the amino-group since the *para*-deactivating $+M$ effect is so strong. Experimentally, *ortho*-acceleration is found for both groups and is stronger for the amino-group.

The activation by chloro and the deactivation by amino-groups due to the differing ratios of the I and M effects are, as expected, mainly associated with changes in E. However, the *o*-chloro-substituent in the dinitro-series has values of the Arrhenius parameters resembling those for the CO_2^- group. This is presumably associated with the negative field of the chlorine atom.

The following general conclusions may be drawn : (i) *ortho*-Effects are bigger in polar than non-polar compounds; (ii) they decrease in the order $-I$, $-T > -I$, $+M > +I(+M)$ groups; (iii) they tend to be accelerative for $-I$, $+M$ groups : this is associated with *para*-deactivation; (iv) they are generally bigger in the dinitro-series; *para*-effects vary much less, and are associated with a change in the extent of conjugation of the substituent group and the ring; (v) field effects are important; whereas (vi) geometrical effects are not.

EXPERIMENTAL

Kinetic investigations were carried out as in previous papers in this series (with one exception), end-points being obtained either electrometrically or with indicators. In the case of 4-chloro-3 : 5-dinitroaniline the runs were followed by electrometric estimation of chloride ion, since a side-reaction could not be satisfactorily allowed for by other means.

Preparations.—Those not recorded here are to be found in previous papers of the series (*locc. cit.*). M. p.s are corrected.

2-Chloro-5-nitrobenzoic acid, made from *o*-chlorobenzoic acid (Rupe, *Ber.*, 1897, **30**, 1099), had m. p. 165° (lit. 165°). Its methyl ester, made in 42% yield *via* the acid chloride, had m. p. 73° (lit. 73°). 2-Chloro-3 : 5-dinitrobenzoic acid, prepared from *o*-chlorobenzoic acid

(Ullmann, *Annalen*, 1909, **366**, 82), had m. p. 198° (lit. 199°), and its methyl ester (*idem, ibid.*) had m. p. 90° (lit. 88°). 2-Chloro-3 : 5-dinitrotoluene was made from *o*-cresol by dinitration (Gibson, *J.*, 1925, **127**, 45) followed by replacement of OH by Cl (Ullmann and Sane, *Ber.*, 1911, **44**, 3735); it had m. p. 63° (lit. 63—64°; 65°). 3 : 4-Dichloronitrobenzene, prepared from *o*-dichlorobenzene according to Hodgson and Kershaw (*J.*, 1929, 2922), had b. p. 254—256° (lit. 255—256°); n_D^{25} 1·5908.

1 : 2-Dichloro-4 : 6-dinitrobenzene was prepared by dinitration of *o*-chlorophenol followed by replacement of OH by Cl as above: m. p. 57° (lit. 56°).

2-Chloro-3 : 5-dinitroaniline, from the corresponding carboxylic acid (Blanksma and Verberg, *Rec. Trav. chim.*, 1934, **53**, 994), had m. p. 168° (lit. 168°).

4-Chloro-3-nitrobenzoic acid was prepared from *p*-chlorobenzoic acid as outlined by King and Murch (*J.*, 1925, **127**, 2646); the actual nitration was carried out at 65°, then for a few minutes at 90° until all material was in solution; The acid (90%) had m. p. 183° (lit. 182·5°). The methyl ester, prepared in 84% yield by standard procedures, had m. p. 83° (lit. 83°). Commercial 2 : 5-dichloro-1-nitrobenzene was purified to m. p. 54—55° (lit. 54·5°; 56°).

The authors are grateful for assistance from the research grant to Australian universities.

University of Western Australia,
Nedlands, Western Australia.

[*Received, July* 28*th*, 1952.]