

CCCVII.—*The Influence of the Sulphur Atom on the Reactivity of Adjacent Atoms or Groups. Part IV. Direct Polar Effects.*

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IN Part I (J., 1927, 477) it was shown that under conditions in which a γ -hydroxy-sulphide, $R \cdot S \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot OH$, was not attacked by hydrobromic acid a δ -hydroxy-sulphide, $R' \cdot S \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot OH$, readily yielded the cyclic sulphonium bromide $\left[R' \cdot S \begin{array}{l} \text{CH}_2 \cdot \text{CH}_2 \\ \text{CH}_2 \cdot \text{CH}_2 \end{array} \right] Br$.

It thus appeared that the hydroxyl group situated in the δ -position relative to a sulphur atom was much more reactive with hydrobromic acid than one in the γ -position. This is particularly interesting because there can be little doubt that the influence of the sulphur atom on the δ -hydroxyl group is transmitted directly through space rather than along the intervening chain of atoms.

The evidence then provided was, however, qualitative and indirect. For a valid comparison of reactivities the reactions compared must be analogous, and doubt was possible on this point

since neither the δ -hydroxy-sulphide in question nor the bromo-sulphide into which it was assumed to have been converted was actually isolated. The following possibilities have been considered : (a) that the hydroxy-sulphide might have been converted directly into the cyclic sulphonium hydroxide before reacting with hydrobromic acid (compare Part I, p. 478, footnote); and (b) that the hydroxy-sulphide might have been converted directly into the sulphonium bromide without the intermediate formation of the open-chain bromosulphide.

The synthesis of phenyl δ -hydroxybutyl and ϵ -hydroxyamyl sulphides (Bennett and Heathcoat, J., 1929, 268) made it possible to remove these uncertainties and obtain confirmation of the earlier result. These sulphides were subjected together with phenyl γ -hydroxypropyl sulphide to the action of fuming hydrobromic acid under identical conditions. In equal times the extent of reaction was for the γ -hydroxy-sulphide 1.0%, for the δ -hydroxy-sulphide 90%, and for the ϵ -hydroxy-sulphide 1.3%.

There can be little doubt that the original assumptions as to the course of the reactions involved were correct. The properties of phenyl δ -hydroxybutyl sulphide at once dispose of the supposition (a), for the substance has no tendency to ring closure at 100°. In order to eliminate the possibility (b) it seemed desirable to isolate the halogenated sulphide itself, or some derivative of it obtained without ring closure, and to test whether the yield in this reaction would be higher than that from the related γ -hydroxy-sulphide. This was effected by allowing hydrogen chloride to act on the γ - and δ -hydroxy-sulphides under similar conditions, the product from the latter being isolated as 1:4-diphenylthiolbutane ($\cdot\text{CH}_2\cdot\text{CH}_2\cdot\text{SPh}$)₂. The experiment proved that in the reaction with hydrogen chloride the δ -hydroxy-sulphide was converted first into the halogenated sulphide and reacted much faster than the γ -hydroxy-sulphide. It seems reasonable to assume that the reactions with hydrobromic acid are analogous.

In attributing the enhanced reactivity of the δ -hydroxyl group to a direct polar effect of the sulphur atom on the $\text{CH}_2\cdot\text{OH}$ group it is not necessary to regard the molecule of phenyl δ -hydroxybutyl sulphide as having a permanently coiled configuration with C₃ and S adjacent in space. The augmented reactivity can only arise when $\text{CH}_2\cdot\text{OH}$ and S approach within a certain distance of each other. The relative probabilities of such an approach occurring in the δ - and ϵ -hydroxy-sulphides should be similar to those revealed by the relative speeds of self-addition of the corresponding δ - and ϵ -chloro-sulphides to yield cyclic sulphonium salts (Part III, J., 1929, 2567), and it is consequently significant that the ratio of

the reactivities of the hydroxyl groups in the δ - and ϵ -positions is of the same order as the ratio of speeds of self-addition found for the δ - and ϵ -chloro-sulphides.

The increase of reactivity of the hydroxyl group in the δ - as compared with that in the γ - or ϵ -position is large: but from the point of view just indicated it is clear that the actual increase of reactivity at the moment when the atoms S and C₈ are adjacent in space must be of a still higher order.

It has been pointed out recently (Lapworth and Manske, J., 1928, 2536) that the effect of the external electrostatic field of a group (direct polar effect) can not be disentangled with certainty from polar influences transmitted through a single interposed atom, and some uncertainty of the same kind is unavoidable in discussing direct polar effects in aromatic substitution where the intervening atoms form a conjugated system (compare Ingold, *Rec. trav. chim.*, 1929, 48, 807; Lapworth and Robinson, *Mem. Manchester Phil. Soc.*, 1928, 72, 43). But there is a variety of evidence that internally propagated influences are negligible after the third atom of a saturated carbon chain and the elucidation of the various effects which determine the second dissociation constants of dibasic acids has been worked out on this basis in a very convincing manner (Gane and Ingold, J., 1928, 1594, 2267; 1929, 1691). Direct and internally propagated polar effects may therefore be indistinguishable in the α - and β -hydroxy-sulphides, but the effect observed in the δ -hydroxy-sulphide must be a direct one free from other complications.

Direct Polar Effect of the Methyl Group.—The increased strength of ortho- as compared with meta- and para-substituted benzoic acids may, as suggested by Lapworth and Manske (*loc. cit.*, p. 2539), be taken as evidence of a direct polar effect of the substituent on the carboxyl group. The direct effect thus exerted by a nitro-group or a chlorine atom is of the same sign as that of the general polar effect of these groups substituted in the meta- or para-position in benzoic acid or in aliphatic acids. But the methyl group appears to be anomalous in that the effect it produces is of the opposite sign from its general polar effect. Thus *o*-toluic acid (K , 11.7×10^{-5}) is stronger than benzoic acid (6.2×10^{-5}) while *m*-toluic acid (5.0×10^{-5}) is weaker, and similar effects are traceable in all the polymethylbenzoic acids. Furthermore, Auwers and Wissebach have shown (*Ber.*, 1923, 56, 715) that of the crotonic acids it is the stronger, *isocrotonic*, in which the methyl group is near the carboxyl group in space.

Regarding the methyl group as a small dipole exerting an electron-repulsion towards the remainder of the molecule and along the line

of its attachment to it, the force along this same line in the opposite direction outside the group must be of the opposite sign, namely, an electron-attraction. Similarly for any axially symmetrical atom or group there should be a field outside it of opposite sign from its general polar effect. The apparent anomaly in the effects of the methyl group is evidence of a characteristic variation of the field close to it in space, but this is consistent with the accepted structure of the group. A consideration of the charges present and their distribution (assuming that the shared electrons, even though moving in orbits, may be regarded as situated on the average between the carbon atom and the hydrogen nuclei) shows that the methyl group should differ from such a substituent as the chlorine atom in having an outer field of a more diffuse character persisting over a wider angular range. As a consequence of this the opposed direct polar effect of the methyl group of *o*-toluic acid reaches the carboxyl group, but not so that of the chlorine atom in *o*-chlorobenzoic acid.

Further support for these conceptions is obtained from an examination of the strengths of the halogenobenzoic acids. The general polar effect of fluorine is greater, as shown by the strengths of the substituted acetic acids, than that of chlorine, yet the extra strength shown by the ortho-substituted benzoic acid as compared with the meta- or para-isomeride is not greater but much less for fluorine than for chlorine or other halogen as substituent (dissociation constants: *m*-F 13.4; *o*-F 31.5; *m*-Cl 15.5; *o*-Cl 130×10^{-5}). This again was to be expected, for fluorine has a smaller atomic diameter than chlorine (Bragg, *Phil. Mag.*, 1926, 2, 258), so that in *o*-fluorobenzoic acid the carboxyl group is nearer to the reversed outer field of the substituent than in the chloro-acid.

The direct polar effect of the methyl group can be traced in certain other instances. Its influence on the strength of the normal aliphatic acids cannot be large, as the methyl and carboxyl groups are free to move and will be only intermittently near each other, but some increase in strength is nevertheless to be expected if the approach of these groups is sterically easy. This is in fact the case, for *n*-butyric acid (K , 1.5×10^{-5}) is stronger than propionic or *n*-heptoic acid (each having K , 1.3×10^{-5}). Moreover, when the chance of approach of the terminal groups is increased by a branching of the chain, the effect is increased, as in *isovaleric* acid (K , 1.7×10^{-5}) and *diethylacetic* acid (K , 2.0×10^{-5}), although the general polar effect in these cases would be expected to have an opposite tendency.

The converse influence upon the strengths of bases is also evident from the fact that *o*-toluidine is weaker, although *m*- and *p*-toluidines

are stronger, than aniline. It is probable that the low value of the true dissociation constant of trimethylamine (0.72×10^{-7}) as compared with that of dimethylamine (14.2×10^{-7}) (Moore and Winmill, J., 1912, 101, 1672) arises from the same kind of effect.

Lastly it may be pointed out that the field in the neighbourhood of methyl groups may be a factor contributing to the well-known valency-deflexion effects studied by Thorpe and Ingold. According to their theory it is the larger volumes occupied by the methyl groups in a *gem*-dimethyl group as compared with hydrogen atoms which causes the valency-deflexion. The suggestion now made is that the two methyl groups will by means of their outer fields exert a repulsive force on each other and on the adjacent methylene groups in the particular orientation which these must adopt in ring-closure. It will be seen on consideration that the volume effect is itself determined by electrical forces, but these must be between the carbon atoms chemically bound together, whereas the repulsion now suggested will arise chiefly between hydrogen atoms adjacent in space.

EXPERIMENTAL.

Conversion of Phenyl δ -Chlorobutyl Sulphide into 1:4-Diphenylthiolbutane.—The chloro-sulphide was heated with a boiling alcoholic solution of sodium thiophenoxide for $\frac{1}{4}$ hour, the solution acidified, and the alcohol and any excess of thiophenol removed in a current of steam. The oil solidified on cooling and was crystallised from ethyl alcohol. 1:4-Diphenylthiolbutane was thus obtained in good yield as silvery plates, m. p. 85° , insoluble in water but readily soluble in most organic solvents (Found: S, 23.4. $C_{16}H_{18}S_2$ requires S, 23.4%).

Action of Hydrogen Chloride on Phenyl γ -Hydroxypropyl and δ -Hydroxybutyl Sulphides.—A weighed quantity of each substance was heated in a small tube in a bath at 50° while dry hydrogen chloride was passed in for 5 minutes. The product from the γ -hydroxy-sulphide was taken up in ether, and the solution well washed. A determination of combined chlorine by Robertson's method on the residue from the evaporation of the ether showed that the hydroxy-sulphide had suffered reaction to the extent of 3.7%. The product from the δ -hydroxy-sulphide was added to an alcoholic solution of sodium thiophenoxide in excess and the mixture was boiled and then distilled in steam. The oil left in the flask solidified on cooling and was diphenylthiolbutane in a practically pure condition, m. p. 84° , not depressed by admixture of a pure specimen. The yield (33.2%) of this substance must represent that portion of the chloro-sulphide produced that had not already undergone ring-closure.

Action of Hydrobromic Acid on γ -, δ -, and ϵ -Hydroxy-sulphides.— A weighed sample of each sulphide was mixed with an excess of fuming hydrobromic acid maintained at laboratory temperature by water-cooling and the mixture was agitated for 5 minutes by means of a current of hydrogen bromide. In the case of the γ - and ϵ -hydroxy-sulphides the mixture was then diluted, the oil removed in ether, and the extract washed, dried, and evaporated. The combined bromine was then determined by Robertson's method. The percentage conversion into bromo-sulphide was found by duplicate experiments :

Phenyl γ -hydroxypropyl sulphide	1.16%, 0.92%.
Phenyl ϵ -hydroxyamyl sulphide.....	1.16%, 1.36%.

The reaction with phenyl δ -hydroxybutyl sulphide differed from the others in that the substance dissolved immediately in the aqueous hydrobromic acid. The solution at the end of the reaction-time was extracted with ether to remove any unaltered hydroxy-sulphide, and an excess of potassium bromoaurate added. The precipitate of *phenyltetramethylenesulphonium bromoaurate*, $[\text{Ph}\cdot\text{SC}_4\text{H}_8]\text{AuBr}_4$, was collected and washed twice with water and twice with alcohol, in which it was sparingly soluble (yield, 90.0%) (Found : Au, 28.7. $\text{C}_{10}\text{H}_{13}\text{Br}_4\text{SAu}$ requires Au, 28.9%). It formed a dark red, crystalline powder, m. p. 120° (decomp.).

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