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GEOMETRICAL SUBSTITUENT PARAMETERS FOR BENZENE DERIVATIVES: INDUCTIVE AND RESONANCE EFFECTS[1]

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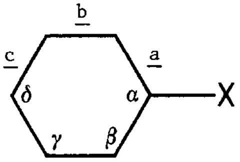
A full set of geometrical parameters describing the effect of 21 substituents on the internal angles of the benzene ring has been derived by linear regression from many structural results. The parameters are shown to reflect the inductive and resonance effects of the substituents.



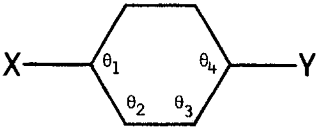
The geometry of the carbon hexagon in the monosubstituted derivatives of benzene is known to be sensitive to the electronic properties of the substituent.[2-4] The deformations caused by substitution are generally more marked in the part of the ring nearest to the substituent (*a* bonds, α and β angles). The α angle may differ considerably from 120° (the range of the values observed is 114-125°) and appears to be predominantly controlled by the σ-effects of the substituent. A table of α values for various functional groups was presented in 1976;[3] it was derived by averaging a large number of experimental values of bond angles from *para*-disubstituted benzene derivatives, on the understanding that they were not substantially affected by the presence of the *para* substituent.

Since that time, significant progress has been made in the knowledge of the structural effects of substitution. Firstly it has been recognized[4] that angular distortions may occur in the part of the ring opposite to the substituent (angles γ and δ). Although small, these distortions are relevant for the investigation of substituent effects, since they reflect the perturbations caused by the substituent in the π-electron system of the ring. By the use of factor analysis[5] we have shown[6] that there are just *two independent effects* that a substituent may exert on the angles of the benzene ring and these may be interpreted as due to the σ and π electronic effects of the substituent, respectively. Secondly, the amount and quality of the information available on the geometry of mono and *para*-disubstituted benzene derivatives have increased considerably. This has prompted us to derive a full set of angular parameters for the most important functional groups, based on a novel approach to the problem.

We have tentatively assumed that the substituent effects on the internal angles of the ring in para-substituted benzene derivatives act independently and can be superimposed, thus:

$$\theta_1 = 120° + \Delta\alpha_x + \Delta\delta_y \; ; \qquad \theta_2 = 120° + \Delta\beta_x + \Delta\gamma_y \; ;$$

$$\theta_3 = 120° + \Delta\beta_y + \Delta\gamma_x \; ; \qquad \theta_4 = 120° + \Delta\alpha_y + \Delta\delta_x \; .$$



where $\Delta\alpha_x$, $\Delta\beta_x$, $\Delta\gamma_x$ and $\Delta\delta_x$ are the distortions from 120° caused by X in a monosubstituted derivative. We have used idealized C_{2v} symmetry for the substituent effects and have averaged appropriate ring angles.[7] Using literature results for 71 different mono and para-disubstituted derivatives[8] we have determined by linear regression the values of $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$ and $\Delta\delta$ for 21 common functional groups (Table 1). The multiple correlation coefficients were 0.97 for both regressions, showing our assumption of superimposable effects to account for most of the variance. Through-conjugation (i.e. cooperative interaction between a π-donor, D, and a π-acceptor, A, para to each other) cannot be included in the linear model. Close inspection of the residuals suggests that it gives rise to measurable decreases in θ_1 and θ_4, and can be described by some function of $|\Delta\delta_D - \Delta\delta_A|$. Unfortunately the accuracy of the present data is not good enough for a quantitative analysis.

The four angular parameters given in Table 1 are not linearly independent. The constraint $\Delta\alpha + 2\Delta\beta + 2\Delta\gamma + \Delta\delta = 0$ holds exactly for any planar hexagon, and the second linear relationship expected from the factor analysis holds very well. For example the generally accepted relationship $\Delta\beta \simeq -\Delta\alpha/2$ is now $\Delta\beta = -0.54\Delta\alpha - 0.30$ (R = 0.986). The α values derived from Table 1 compare well with those given previously.[3] The slightly lower values of some of the old angles arise from neglecting the variation of δ.

The angular parameters of Table 1, although derived exclusively from mono and para-disubstituted benzene derivatives, appear to be of much wider applicability. We have found that they may be successfully used to predict molecular geometries of other, even highly substituted, benzene derivatives.

The marked sensitivity of α to σ-effects and its reasonably good correlation with Taft's inductive parameter, σ_I, have already been described,[3] and are confirmed by the present results (Fig. 1). The sensitivity of γ and δ to the π-effects of the substituent has been recently recognized.[4] Since Δγ has the lowest correlation coefficient with Δα it is the best single angular parameter for describing independent π-effects.[9] And indeed Δγ correlates fairly well with σ_R° (Fig. 2).

The angular parameters of Table 1 provide a measure of σ- and π-effects in monosubstituted benzene derivatives.[10] Their use for investigating substituent effects in the benzene series is a valuable addition to traditional reactivity parameters. They (i) are a measure of the effect of the substituent on the carbon skeleton of the ring in the ground state, (ii) are not dependent upon the choice of suitable reaction series, (iii) are not disturbed by solvent effects, insofar as the ring geometry appears to be independent of its environment, and (iv) can be related to the conformation of the substituent, since rotation about the C-X bond may affect the extent of conjugation and hence the ring geometry.[4]

TABLE 1

Angular substituent parameters (°) for benzene derivatives.[a,b,c] Only two out of the four parameters are independent (see text).

Substituent	$\Delta\alpha$	$\Delta\beta$	$\Delta\gamma$	$\Delta\delta$
NMe$_2$	-2.4 (3)	0.6 (2)	1.4 (2)	-1.7 (3)
Ph	-2.3 (2)	1.0 (1)	0.6 (1)	-0.9 (2)
Me	-1.9 (2)	1.0 (1)	0.4 (1)	-0.8 (2)
CH=CHR	-1.8 (2)	0.8 (1)	0.3 (1)	-0.4 (2)
NH$_2$	-1.2 (2)	0.2 (1)	1.0 (1)	-1.3 (2)
CH=NR	-1.2 (3)	0.4 (2)	0.4 (2)	-0.5 (3)
N=CHR	-1.0 (3)	0.2 (2)	0.5 (2)	-0.5 (3)
COMe	-1.0 (2)	0.4 (1)	0.2 (1)	-0.3 (2)
COOR	-0.6 (2)	0.2 (1)	0.3 (1)	-0.3 (2)
N=NR	-0.1 (2)	-0.3 (1)	0.5 (1)	-0.4 (2)
NHCOMe	-0.1 (3)	-0.3 (2)	0.7 (2)	-0.6 (3)
COOH	0.1 (2)	-0.2 (1)	0.1 (1)	0.2 (2)
OH	0.2 (2)	-0.4 (1)	0.6 (1)	-0.6 (2)
OMe	0.2 (2)	-0.6 (1)	1.1 (1)	-1.1 (2)
CN	1.1 (2)	-0.8 (1)	0.3 (1)	-0.1 (2)
SO$_3^-$	1.2 (2)	-1.1 (1)	0.5 (1)	0.0 (2)
SO$_2$Me	1.6 (2)	-1.3 (1)	0.2 (1)	0.6 (2)
NH$_3^+$	1.8 (2)	-1.2 (1)	0.4 (1)	-0.1 (2)
Cl	1.9 (2)	-1.4 (1)	0.6 (1)	-0.2 (2)
NO$_2$	2.9 (2)	-1.9 (1)	0.3 (1)	0.4 (2)
F	3.4 (2)	-2.0 (1)	0.5 (1)	-0.4 (2)

(a) Full details of the data used and their analysis will be given elsewhere. (b) For planar polyatomic substituents these values refer to a conformation where the dihedral angle between the ring and the substituent is never greater than 42°, and usually much less. (c) Estimated standard deviations are given in parentheses as units in the last digit.

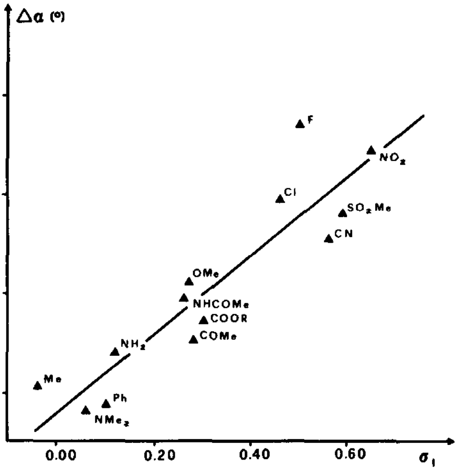


Fig. 1 - Plot of the substituent parameter $\Delta\alpha$ vs σ_I (values from ref. 11).

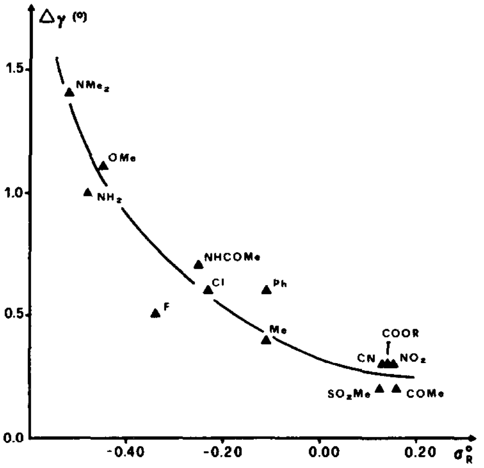


Fig. 2 - Plot of the substituent parameter $\Delta\gamma$ vs σ_R° (values from ref. 11).

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References and Notes

1. Presented in part at the XI International Congress of Crystallography, Warsaw, Poland (1978).
2. A. Domenicano, A. Vaciago and C.A. Coulson, Acta Cryst., B31, 221 and 1630 (1975).
3. A. Domenicano, P. Mazzeo and A. Vaciago, Tetrahedron Lett., 1029 (1976).
4. A. Domenicano and A. Vaciago, Acta Cryst., B35, in the press (1979).
5. P. Murray-Rust and S. Motherwell, Acta Cryst., B34, 2518 (1978); P. Murray-Rust and R. Bland, Acta Cryst., B34, 2527 (1978).
6. A. Domenicano, P. Murray-Rust and A. Vaciago, Acta Cryst., to be submitted.
7. Further lowering of the ring symmetry to C_s definitely occurs with certain asymmetric substituents, e.g. OMe (F. Di Rienzo, A. Domenicano, G. Portalone and A. Vaciago, 2nd Yugoslav-Italian Crystallographic Conference, Dubrovnik, Yugoslavia (1976). Abstracts, p. A102).
8. In all 334 observational equations were used to determine 84 parameters. The source of the data was mainly X-ray crystallography, but in some cases neutron diffraction, electron diffraction and microwave spectroscopy results have also been used.
9. We hope to determine linear combinations of angular parameters which are better independent measures of σ- and π-effects.
10. The rather small range of $\Delta\gamma$ limits somewhat its quantitative use. The determination of new, accurate molecular geometries will undoubtedly improve the number and precision of these parameters.
11. S. Ehrenson, R.T.C. Brownlee and R.W. Taft, Progr. Phys. Org. Chem., 10, 1 (1973).

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