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# ORIGIN OF ANOMALOUS SUBSTITUENT EFFECT ON IMIDOYL PROTON CHEMICAL SHIFT IN 4-SUBSTITUTED N-BENZYLIDENEANILINES.

## EVIDENCE FOR THE CONTRIBUTION OF THROUGH-SPACE FIELD EFFECT

Naoki Inamoto,* Shozo Masuda, Katsumi Tokumaru, Kazuo Tori[†] and Masayuki Yoshida
Department of Chemistry, Faculty of Science, The University of Tokyo, Hongo, Tokyo, 113 Japan,
and [†] Shionogi Research Laboratory, Shionogi & Co., Ltd., Fukushima-ku, Osaka, 553 Japan

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Introduction of a substituent into an aromatic compound produces chemical shift changes in the ring and side-chain protons. Although these $^1H$ chemical shifts have hitherto been correlated with Hammett-$\sigma$ constants only by negative values,[1] we have found for the first time that the $\rho$ value for the imidoyl proton $H_\alpha$ of 4-substituted N-benzylideneanilines (series II) has an opposite positive sign.[2,3] It is worthwhile to examine whether this anomaly in sign can be explained in the light of some of simple theories of predicting "substituent chemical shifts (SCS)" values. We here discuss the contribution of through-space field effects[4] to the anomaly on the basis of the calculation of approximate $H_\alpha$-SCS values for N-benzylideneanilines (series I and II), and demonstrate that the experimental result with series II provides clear evidence for the presence of the contribution of the field effects to the transmission of substituent effects.[5]

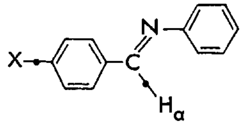
In a simple theory,[6] the $^1H$ chemical shift can be approximated by the localized diamagnetic shielding $\delta^{dia}_{HH}$. Then a shift difference between a substituted and an unsubstituted compound (a relative SCS value) is given by a change in diamagnetic shielding $\Delta\delta^{dia}_{HH}$, which can be calculated using the reported equation:[6] $\Delta\delta^{dia}_{HH} = 21.34\ \Delta P_{1s1s}$, where $P_{1s1s}$ is the value for the diagonal element of the density matrix corresponding to the 1s atomic orbital centered at a hydrogen atom. The magnitudes of $\Delta P_{1s1s}$ for $H_\alpha$ in series I and II were calculated by the CNDO/2 method.[7] The relationship between the calculated $\Delta\delta^{dia}_{HH}$ and Hammett-$\sigma$ constants exhibited negative $\rho$ values for both series, the results being inconsistent with the observations (see the TABLE).[2,3]

In an improved calculation,[8] the relative SCS can be expressed as $\Delta\delta_{C\text{-}H} = 16.0\ \Delta q_H + 8.39\ \Delta q_C$, TABLE. Electron Densities and Chemical Shifts of the Imidoyl Proton, $H_\alpha$

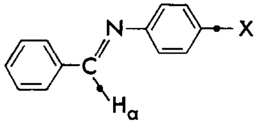
| Series | X | $q_{H_\alpha}$ [a] | $q_{C_{tot}}$ [a] | $\Delta\delta^{dia}_{HH}$ | $\Delta\delta_{C\text{-}H}$ | $\Delta\delta_Q$ | $\mu_{XC_6H_4\text{-}}$ (D) [b] | $\Delta\delta_E$ | $\Delta\delta_{H_\alpha}$ (obs) [c] |
|---|---|---|---|---|---|---|---|---|---|
| I | H | 1.0185 | 3.8999 | | | | -0.30 | | |
| | $NO_2$ | 1.0127 | 3.9113 | -0.124 | +0.003 | -0.114 | 3.73 | -0.079 | $-0.11_0$ |
| | Cl | 1.0159 | 3.9042 | -0.056 | -0.006 | -0.043 | 1.27 | -0.034 | $+0.02_0$ |
| | $CH_3$ | 1.0194 | 3.8973 | +0.019 | -0.007 | +0.026 | -0.64 | +0.005 | $+0.03_0$ |
| | $OCH_3$ | 1.0204 | 3.8937 | +0.041 | -0.022 | +0.062 | -1.57 | +0.021 | $+0.07_0$ |
| | $N(CH_3)_2$ | 1.0219[d] | 3.8905[d] | +0.073 | -0.025 | +0.094 | -1.88 | +0.026 | $+0.12_0$ |
| | ρ | | | -0.130 | +0.018 | -0.137 | | -0.070 | $-0.138_6$ |
| | r[e] | | | 0.976 | 0.831 | 0.978 | | 0.945 | 0.960 |
| II | $NO_2$ | 1.0158 | 3.8849 | -0.058 | -0.169 | +0.150 | 3.73 | $+0.016_4$ | $+0.02_0$ |
| | Cl | 1.0173 | 3.8941 | -0.026 | -0.068 | +0.058 | 1.27 | $+0.006_3$ | $+0.00_5$ |
| | $CH_3$ | 1.0191 | 3.9035 | +0.013 | +0.040 | -0.036 | -0.64 | $-0.001_5$ | $-0.01_0$ |
| | $OCH_3$ | 1.0193 | 3.9055 | +0.017 | +0.060 | -0.056 | -1.57 | $-0.005_2$ | $-0.03_0$ |
| | ρ | | | -0.074 | -0.222 | +0.199 | | $+0.020_2$ | $+0.040_6$ |
| | r[e] | | | 0.787 | 0.996 | 0.996 | | 0.994 | 0.910 |

[a] Calculated by the CNDO/2 method[7] using the reported geometry.[13] [b] Values for dipole moments employed.[10a, 12] [c] A positive value represents an upfield shift in ppm: for the measurements of $\delta_{H_\alpha}$ at 100 MHz in cyclohexane, see the preceding paper.[3] [d] Calculated as an $NHCH_3$ group.
[e] Correlation coefficients.

where $\Delta q_H$ and $\Delta q_C$ are the relative changes in electron density on the hydrogen and the bonded carbon atoms, respectively. The ρ values obtained from the calculated $\Delta\delta_{C\text{-}H}$ have opposite signs to those observed (see the TABLE), and this way for calculating relative SCS values does not account for the observed result.



Series I

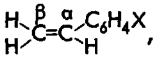


Series II

An alternative approach to predicting relative SCS values was carried out using an empirically established correlation between shielding and changes in total charge density ($Q_{tot}$) on the attached carbon atom; $\Delta\delta_Q = 10\,\Delta Q_{tot}$.[9] The $\Delta\delta_Q$ and ρ values calculated are listed in the TABLE. The sign alternation in the ρ values agrees with the observation, but the ρ value calculated for series II is extremely larger than that observed.

According to Buckingham, the chemical shift due to the electric field caused by a polar group at a particular proton in a molecule is given by $\delta_E = -AE_{C\text{-}H} - 10^{-18}\,E^2$, where A is an empirical constant and $E_{C\text{-}H}$ is the component of electric field E directed along the C-H bond.[10] The first term is dominant at most field strengths. The contribution of the second term to $^1H$ shielding is minor, and can be neglected for a remote substituent.[4a] For calculating $E_{C\text{-}H}$, Zürcher's method was employed.[11] The electric field $E_{C\text{-}H}$ at the proton in question is given by $E_{C\text{-}H} = \mu_X(3 \cos \phi_1 \cos \phi_R - \cos \phi_{\mu_X})/R^3$, where $\mu_X$ is the substituent dipole moment in a point-dipole approximation, R is the distance between the centre of the C-H bond[10b] and that of the C-X bond, $\phi_1$ is the angle between R and $\mu_X$, $\phi_R$ is that between R and the C-H bond, and $\phi_{\mu_X}$ is that between vector $\mu_X$ and the C-H bond. For calculating $\delta_E$, A was taken as $3.11 \times 10^{-12}$ e.s.u.;[4a] the values for the dipole moments of substituents ($\mu_{XC_6H_4-}$) here employed[10a,12] are listed in the TABLE; angles $\phi_1$, $\phi_R$, and $\phi_{\mu_X}$ were estimated from the geometry reported for N-benzylideneanilines;[13] the bond angle of $C\text{-}\overset{\|}{C}\text{-}H_\alpha$ was taken as 120° for series II.[14b]

Since recent studies of substituted styrenes[4a] and naphthalenes[6] have evidenced that a relative shift due to the magnetic anisotropy effect of a substituent is small upon a proton except that situated near the substituent, we can exclude the anisotropic effects on $H_\alpha$ from the present calculations. In addition, the ring-current effect due to a substituent upon $H_\alpha$ was also neglected on the basis of recent results with the substituted styrenes.[4a]

The relative $\delta_E$ values $\Delta\delta_E$ thus calculated for $H_\alpha$ (see the TABLE) show that the electric field model gives the best overall agreement with the SCS values observed. Furthermore, each sign and magnitude of the ρ values calculated are satisfactorily consistent with those observed. The present result agrees, in a qualitative sense, with that previously obtained for $H_{\beta(cis)}$ in 4-substituted styrenes  $H_2C\overset{\beta}{=}\overset{\alpha}{C}(H)C_6H_4X$,[4a] $H_{\beta(cis)}$ corresponding to $H_\alpha$ in series II.

Through-bond effects are known to be mainly transmitted through a π-electron system.[4b,15] Thus, it is strongly suggested that the through-space field effect which affords the reverse sign in $\rho_{H_\alpha}$ in series II, is disclosed up as a result of a decrease in the contribution of the through-bond transmission effect owing to the less conjugation of the benzene ring caused by a marked torsion of the N-Ph bond, i.e., 55.2° for N-benzylideneaniline.[13] In contrast, the conformation of substituted trans-stilbenes is planar or nearly planar;[14a] therefore, for $H_\beta$ corresponding to $H_\alpha$ in series II ($C_6H_5\underline{CH}{=}CHC_6H_4X$), the predominance of the through-bond effect may be expected. This view is illustrated by the finding that the $H_\beta$-SCS values observed linearly correlated with Hammett-σ by a large negative $\rho_{H_\beta}$ value of -0.171.[16]

Consequently, it is concluded that the through-space field effect is also responsible for $^1H$-SCS in addition to the through-bond transmission of a substituent effect, the magnitude of which depends upon the molecular conformation, and that the anomalous substituent effect on the $H_\alpha$ chemical shift in series II results predominantly from a marked decrease in the through-bond transmission effect.

## REFERENCES

(1) M. T. Tribble and J. G. Traynham, "Advances in Linear Free Energy Relationships," ed. N. B. Chapman and J. Shorter, Plenum Press, London, p. 165-172 (1972).

(2) N. Inamoto, K. Kushida, S. Masuda, H. Ohta, S. Satoh, Y. Tamura, K. Tokumaru, K. Tori and M. Yoshida, *Tetrahedron Lett*. 3617 (1974).

(3) N. Inamoto, S. Masuda, K. Tokumaru, M. Yoshida, Y. Tamura and K. Tori, the preceding paper.

(4) (a) G. K. Hamer and W. F. Reynolds, *Can. J. Chem.* **46**, 3813 (1968); (b) Idem, *Chem. Commun.* 1218 (1971).

(5) (a) G. K. Hamer, I. R. Peat and W. F. Reynolds, *Can. J. Chem.* **51**, 897, 915 (1973); (b) R. W. Taft and C. A. Grob, *J. Amer. Chem. Soc.* **96**, 1236 (1974); (c) T. W. Cole, Jr., C. J. Mayers and L. M. Stock, *ibid.* **96**, 4555 (1974).

(6) J. W. Emsley, J. C. Lindon, S. R. Salman and D. T. Clark, *J. C. S. Perkin II* 611 (1973).

(7) J. A. Pople and D. L. Beveridge, "Approximate Molecular Orbital Theory," McGraw-Hill, New York (1970).

(8) O. Kajimoto and T. Fueno, *Chem. Lett.* 103 (1972).

(9) T. B. Cobb and J. D. Memory, *J. Chem. Phys.* **50**, 4262 (1969).

(10) (a) A. D. Buckingham, *Can. J. Chem.* **38**, 300 (1960); (b) J. I. Musher, *J. Chem. Phys.* **37**, 34 (1962).

(11) R. F. Zürcher, *Progr. NMR Spectrosc.* **2**, 205 (1967).

(12) C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Chapter 3, p. 94-108, Cornell University Press, New York (1953); S. Nagakura and H. Baba, *J. Amer. Chem. Soc.*, **74**, 5693 (1952).

(13) J. Bernstein, *J.C.S. Perkin II* 946 (1972); J. Bernstein and G. M. J. Schmidt, *Ibid.* 951 (1972).

(14) (a) H. B. Bürgi and J. D. Dunitz, *Chem. Commun.* 472 (1969); (b) Idem, *Helv. Chim. Acta* **54**, 1255 (1971).

(15) J. Fukunaga and R. W. Taft, *J. Amer. Chem. Soc.* **97**, 1612 (1975).

(16) H. Güsten and M. Salzwedel, *Tetrahedron* **23**, 173 (1967).