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Substituent electrophilicities in the NMR spectra of barbituric derivatives

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Comparison of the ^{1}H and ^{13}C NMR spectra of a series of substituted 5-benzylidene-*N,N'*-dimethylbarbituric acids (1) revealed chemical-shift variations of different centers that correlated with the theoretical electrophilicities or with the substituent electrophilic constant σ_{ω}, in an example of the usefulness of these DFT-based indices. Copyright © 2012 John Wiley & Sons, Ltd.

Keywords: electrophilicity index; electrophilicity substituent constants; substituted 5-benzylidene-*N,N'*-dimethylbarbituric acids

Introduction

Theoretical parameters derived from the density functional and the hard-soft acid base theory have been increasingly employed in the prediction and interpretation of a variety of chemical processes. Among them, the concept of electrophilicity, originally defined in a quantitative way by Parr *et al.*[1] has proved a valuable tool for bridging a gap between theory and empirical data.[2–7] Reports of correlations of theoretical electrophilicities with rates and reactivities, and applications to the analysis of spectroscopic data are found in the literature.[8–10]

In the present communication, we investigated the existence of correlations of these DFT-based indices with NMR data from a system, in which substituent electrophilicities are expected to play an important role.

Substituted 5-benzylidene-1,3-dimethylbarbituric acids (**1**) (Scheme 1) constitute an interesting family of compounds, in which various features of their NMR spectra should depend on the electrophilicity of the X substituent. As an example, we had previously reported on the equivalence of the N-methyl singlets in their ^{1}H-NMR spectra, which depended on the nature of substituent X.[11]

This long-range effect, observed previously for two derivatives with substituents of widely different electrophilicities (*p*-NO_2 and *p*-NMe_2),[7] should vary systematically with the electrophilicity of X. Other features that also seemed to vary with the nature of X were the ^{13}C chemical-shifts of the carbonyl groups at C-4 and C-6, and the ^{13}C chemical-shift of C-5.

To investigate these variations in a systematic way, we prepared a series of substituted *N,N'*-dimethylbarbituric derivatives **1** and compared their ^{1}H and ^{13}C NMR spectra, in search of correlations between the spectral data and global or group electrophilicities, obtained from theoretical calculations.

Substituent electrophilicities were calculated theoretically by means of their electrophilic constants σ_{ω}, recently derived by us from the Hammett-like Eqn (1), based on the global electrophilicities ω_{B-X} of substituted benzoic acids. By analogy with the classical Hammett approach, Eqn (1) allowed the definition of electrophilic substituent constants σ_{ω} for the X substituents, by arbitrarily making $\rho_{\omega} = 1$.[7]

$$\log \omega_{B\text{-}X}/\omega_{B-H} = \rho_{\omega} \cdot \sigma_{\omega} \quad (1)$$

Following Hammett's approach, we postulated that constants σ_{ω} should provide an adequate measure of the electrophilic contribution of these substituents to other systems besides benzoic acids.[7] In the present communication, we decided to extend their use to the analysis of the NMR data of substituted derivatives **1**, showing that this approach also applies to data from spectroscopic measurements. The present report thus adds to the variety of chemical processes for which theoretical electrophilic constants σ_{ω} adequately describe the electronic contribution of substituents. It also probes the limitations of this theoretical parameter. Like Hammett's original σ constant, despite its applications to a potentially unlimited number of processes, it may fail to describe contributions where through-conjugation is present.

Experimental

Preparation and spectral characterization of compounds 1

Melting points were recorded with an Electrothermal apparatus and were not corrected. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker Avance DRX-300 spectrometer, operating at 300.13 (^{1}H) and 75.47 (^{13}C) MHz and employing 5-mm tubes, with average concentrations of 30 mg.ml^{-1}. CDCl3 was used as solvent, with tetramethylsilane as internal reference. Typical running conditions employed a spectral width of 4496.27 Hz for ^{1}H and 19607.25 Hz for ^{13}C, with 32768 (^{1}H and ^{13}C) data points.

Compounds **1** were prepared by a standard Knoevenagel condensation of equimolar amounts of *N,N'*-dimethylbarbituric acid (Aldrich) and the corresponding substituted benzaldehyde.[7] After refluxing the reagents in acetic acid for 2 h, product **1** crystallized out of the cooled solution, being washed with ether and recrystallized with ethanol.

In this way, the following 5-benzylidene-*N,N'*-dimethylbarbituric derivatives were prepared: 5-(4-nitrobenzylidene)-*N,N'*-dimethylbarbituric acid (**1a**), m.p. 192–194 °C, lit.[7], 193–195 °C; 5-(3-nitrobenzylidene)-*N,N'*-dimethylbarbituric acid (**1b**), m.p. 150–152 °C;

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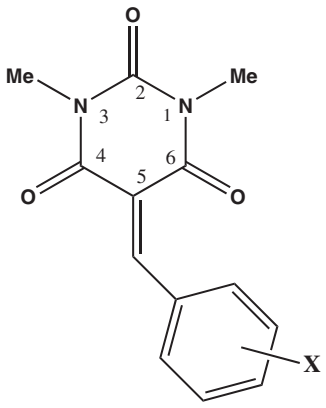

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Scheme 1. Structure of substituted 5-benzylidene-*N,N*′-dimethylbarbituric derivatives **1**, with the numbering of the barbituric ring atoms.

5-(4-bromobenzylidene)-*N,N*′-dimethylbarbituric acid (**1c**), m.p. 172–175 °C; 5-benzylidene-*N,N*′-dimethylbarbituric acid (**1 d**), m.p. 156 °C, lit.[7], 157–159 °C; 5-(3-methoxybenzylidene)-*N,N*′-dimethylbarbituric acid (**1e**), m.p. 135-136 °C; 5-(4-methylthiobenzylidene)-*N,N*′-dimethylbarbituric acid (**1f**), m.p. 156–159 °C; 5-(4-methoxybenzylidene)-*N,N*′-dimethylbarbituric acid (**1 g**), m.p. 144–145 °C, lit.[7], 143–145 °C; 5-(4-dimethylaminobenzylidene)-*N,N*′-dimethylbarbituric acid (**1 h**), m.p. 223–225 °C, lit.[7], m.p. 224–226 °C. ^{1}H and ^{13}C NMR data, in $CDCl_3$, of all derivatives are given in Table 1.

Theoretical calculations

All theoretical calculations employed the Gaussian03 package.[12] Optimizations were performed with the hybrid B3LYP/6-31 G(d) method. The chemical potential μ and hardness η of each molecule were calculated from Eqns (3) and (4), where E_{HOMO} and E_{LUMO} are the HOMO and LUMO energies, respectively, employing Koopmann's approximation.[2]

$$\mu = (E_{HOMO} + E_{LUMO})/2 \quad (2)$$

$$\eta = E_{LUMO} - E_{HOMO} \quad (3)$$

The global electrophilicity of each molecule was calculated with the aid of Eqn (4)[1]

$$\omega = \mu^2/2\eta \quad (4)$$

Results and Discussion

The ^{1}H and ^{13}C NMR spectra of compounds **1a–1 h** are given in Table 1.

In all proton spectra, the *N*-CH_3 signals appeared as two conspicuous singlets in the range $\delta = 3.30–3.50$ ppm. The ^{13}C carbonyl signals of all barbituric derivatives appeared in the range $\delta = 151–152$ (C-2) and $\delta = 159–165$ ppm (C-4 and C-6). Assignments were based on the proximity of the benzylidene group to the center under consideration. The benzylidene group

Table 1. ^{1}H- and ^{13}C-NMR spectra of compounds **1a–1 h** in $CDCl_3$

Cpd (X)	^{1}H-NMR/δ	^{13}C-NMR/δ
1a (4-NO_2)	3.36 (s, 3 H, 3-NCH_3); 3.45 (s, 3 H, 1-NCH_3); 7.95 (d, 2 H, J = 8.5 Hz, ArH *meta* to NO_2); 8.29 (d, 2 H, J = 8.5 Hz, ArH *ortho* to NO_2); 8.58 (s, 1 H, C = CH)	28.67(3-NCH_3); 29.34 (1-NCH_3); 120.87(C-5); 123.26 (2ArCH); 132.30(2ArCH); 139.21 (ArC); 149.05 (ArC-NO_2); 150.99 (NCON); 155.45(CH-olef); 159.84 (C-4); 161.54 (C-6)
1b (3-NO_2)	3.37 (s, 3H, 3-NCH_3); 3.44 (s, 3H, 1-NCH_3); 7.64 (t, 1H, J = 8.0 Hz, ArH *meta* to NO_2); 8.17 (m, 1H, ArH *ortho* to NO_2); 8.34 (m, 1H, ArH *para* to NO_2); 8.56 (s, 1H, CH = C); 8.83 (m, 1H, ArH *ortho* to NO_2)	28.71(3-NCH_3); 29.34 (1-NCH_3); 120.27 (C-5); 126.33 (ArCH); 126.90 (ArCH); 129.26 (ArCH); 134.34(ArC); 137.81(ArCH); 147.98 (ArC-NO_2); 151.03 (NCON); 155.47(CH-olef); 160.02 (C-4); 161.70 (C-6)
1c (4-Br)	3.36 (s, 3H, 3-NCH_3); 3.41 (s, 3H, 1-NCH_3); 7.59 (d, 2H, J = 10 Hz, ArH *ortho* to Br); 7.93 (d, 2H, J = 10 Hz, ArH *meta* to Br); 8.47 (s, 1H, CH = C)	28.58 (3-NCH_3); 29.24 (1-NCH_3); 118.04 (C-5); 128.12 (ArC); 131.52 (ArC); 131.70 (2ArCH); 134.91 (2ArCH); 151.21 (NCON); 157.62 (CH olef); 160.42 (C-4); 162.36 (C-6).
1 d (H)	3.35 (s, 3 H, 3-NCH_3); 3.39 (s, 3 H, 1-NCH_3); 7.44 (t, 1H, J = 7.5 Hz, ArH); 7.50 (q, 2H, J = 7.5 Hz, ArH); 8.03 (d, 2H, J = 7.5 Hz); 8.54 (s, 1H, C = CH)	28.56 (3-NCH_3); 29.22 (1-NCH_3); 117.66 (C-5); 128.36 (2ArCH); 132.79(ArC); 133.04 (ArCH); 133.54 (2ArCH); 151.38(NCON); 159.44(CH-olef); 160.46 (C-4); 162.61 (C-6)
1e (3-OMe)	3.37 (s, 3H, 3-NCH_3); 3.42 (s, 3H, 1-NCH_3); 3.86 (s, 3H, OCH_3); 7.08 (m, 1H, ArH *ortho* to OCH_3); 7.37 (t, 1H, J = 7.9 Hz, ArH *meta* to OCH_3); 7.57 (m, 1H, ArH *para* to OCH_3); 7.56 (m, 1H, ArH *ortho* to OCH_3); 8.17 (s, 1H, CH = C)	28.61(3-NCH_3); 29.25 (1-NCH_3); 55.56 (OCH_3); 117.76 (ArCH) and (C-5); 119.53 (ArCH); 126.73 (ArCH); 129.31 (ArCH); 133.92 (ArC); 151.37 (NCON); 159.29 (ArC-OCH3) and (CH-olef); 160.43 (C-4); 162.66 (C-6)
1f (4-SMe)	2.54 (s, 3H, SCH_3); 3.38 (s, 3H, 3-NCH_3); 3.41 (s, 3H, 1-NCH_3); 7.27 (d, 2H, J = 8.7 Hz, ArH *ortho* to SCH_3); 8.15 (d, 2H, J = 8.5 Hz, ArH *meta* to SCH_3); 8.49 (s, 1H, CH = C)	14.71 (SCH_3); 28.55(3-NCH_3); 29.22 (1-NCH_3); 115.85 (C-5); 124.61 (2ArCH); 128.83(C-Ar); 135.08 (2 ArCH); 147.78 (ArC-S); 151.44 (NCON); 158.67 (CH-olef); 160.88 (C-4); 162.98 (C-6).
1 g (4-OMe)	3.39 (s, 3 H, 3-NCH_3); 3.41 (s, 3H, 1-NCH_3); 3.91 (s, 3H, OCH_3), 6.98 (d, 2H, J = 8 Hz, ArH *ortho* to OMe); 8.32 (d, 2H, J = 8 Hz, ArH *meta* to OMe); 8.52 (s, 1H, C = CH)	28.50(3-NCH_3); 29.18 (1-NCH_3); 55.75 (OCH_3); 114.10 (2 ArCH); 114.42(C-5); 125.26(ArC); 138.08 (2ArCH); 151.55 (NCON); 159.02(CH-olef); 161.11 (C-4); 163.26 (C-6); 164.43 (ArC-OCH_3)
1 h (4-NMe_2)	3.13 (s, 6H, $N(CH_3)_2$); 3.37 (s, 3H, 3-NCH_3); 3.38 (s, 3H, 1-NCH_3); 6.68 (d, 2H, J = 8 Hz, ArH *ortho* to NMe_2); 8.39 (d, 2H, J = 8 Hz, ArH *meta* to NMe_2); 8.41 (s, 1H, C = CH)	28.33(3-NCH_3); 29.00 (1-NCH_3); 40.18 ($N(CH_3)_2$); 109.76(C-5); 111.14 (2ArCH); 121.18(C-Ar); 139.64 (2ArCH); 151.94(NCON); 154.52 (ArC-NMe_2); 158.87(CH-olef); 161.74 (C-4); 164.13 (C-6)

tended to deshield the centers closer to it, and its field effect also was dependent on its distance from the center, decreasing with this distance. Thus, the effect of the benzylidene substituent on the carbonyl signals decreased in the order C-2 < C-4 < C-6. In the same way, its effect on the N-CH_3 singlets was larger for the more deshielded 1-NCH_3 than for the 3-NCH_3.

Table 2 lists the chemical-shift differences, in Hz, between the *N*-methyl singlets ($\Delta\delta_{N\text{-}Me}$) in the ^{1}H NMR spectra and between the C-4 and C-6 carbonyl signals ($\Delta\delta_{C=O}$) in the ^{13}C NMR spectra of compounds **1a–1 h**. It also includes the ^{13}C chemical-shifts of the C-5 atom in these derivatives. As can be seen, these data vary with the substituent X. The table also includes the global electrophilicities of these compounds (ω), calculated with the aid of Eqn 4. A final set of theoretical values included in the table is the electrophilicity constant σ_ω for each substituent, derived from the Hammett-like Eqn (1), applied to substituted benzoic acids.[7]

The dependence of $\Delta\delta_{N\text{-}Me}$ and of $\Delta\delta_{C=O}$ on X may be understood with the aid of structures I and II that contribute to the resonance hybrid of **1** (Scheme 2).

Structure I depicts the delocalization of the electrons of the X substituent over the benzylidene fragment and the carbonyl groups at C-4 and C-6 of the barbituric ring. Structure II depicts the delocalization of the nitrogen electrons at N-1 and N-3 over the neighboring carbonyl groups at C-2, C-4 and C-6. Electron-donors, or nucleophilic substituents, should favor structure I, whereas electron-acceptors, or electrophilic substituents, should favor structure II. In the former, electron delocalization takes place on two independent moieties of the molecule, as shown in Scheme 2-I so that the upper part of the barbituric ring is 'switched off' from the lower part and the benzylidene group. In structure II, the benzylidene group no longer interacts with the barbituric ring, and the latter system is 'switched off' from the benzylidene group. Thus, the electrophilicity of the X substituent determines the degree of 'coupling' between the benzylidene and the barbituric fragments.

These considerations are reflected in some trends of the ^{1}H NMR spectra of derivatives **1**, highlighted in Table 2. As a consequence of the 'uncoupling' of the two moieties by nucleophilic substituents in structure I, the *N*-methyl protons become increasingly equivalent with the increased nucleophilicity of X, as part of a symmetric $H_3CN\text{-}CO\text{-}NCH_3$ fragment. This symmetry is reduced in structure II because of delocalization with the C-4 and C-6 carbonyl groups, which are not equivalent.

A similar argument applies to the variation of the $\Delta\delta_{C=O}$ values in the ^{13}C NMR spectra of **1**. Nucleophilic substituents favor a less symmetric moiety involving the C-4 and C-6 carbonyl groups in structure I and, accordingly, greater $\Delta\delta_{C=O}$ values. When the benzylidene group is 'switched off' from the barbituric ring, by the effect of electrophilic substituents in structure II, the carbonyl groups at C-4 and C-6 become more equivalent because of the greater symmetry of the barbituric moiety.

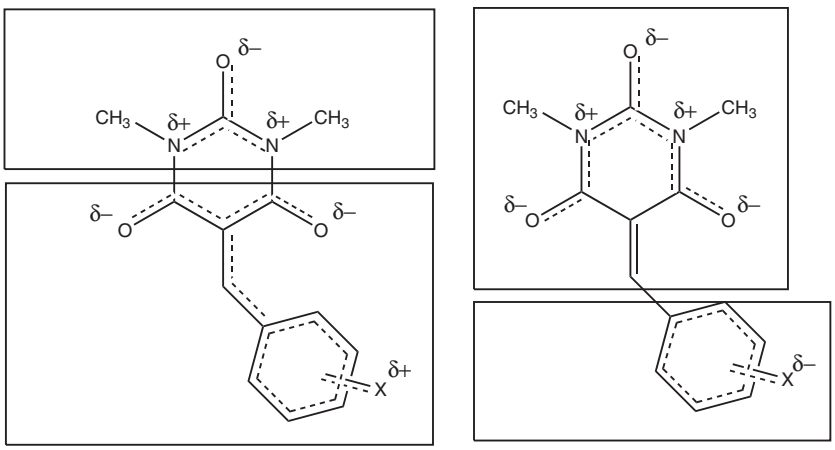
The above interpretations may be summarized by invoking the interaction between N-1/N-3 and C-4/C-6. The former, as part of a symmetric fragment, tend to be equivalent, if no perturbation by the rest of the molecule takes place. The latter, being closer to the benzylidene group, tend to be unequivalent, if 'switched off' from the symmetric $H_3CN\text{-}CO\text{-}NCH_3$ fragment. Both situations correspond to structure I. When the two groups interact, as in structure II, N-1/N-3 become less equivalent, by the influence of C-4/C-6, and C-4/C-6 become more equivalent, by the influence of N-1/N-3.

The hypothesis that the chemical-shift difference $\Delta\delta_{N\text{-}Me}$ should depend on the molecular electrophilicity was tested by plotting $\Delta\delta_{N\text{-}Me}$ against the global electrophilicity ω of molecules **1a–1 h** (Fig. 1).

Table 2. Chemical-shift differences between the N-Me singlets ($\Delta\delta_{N\text{-}Me}$) and between the C-4 and C-6 carbonyl signals ($\Delta\delta_{C=O}$) of substituted derivatives **1**

X	$\Delta\delta_{N\text{-}Me}$/Hz	$\Delta\delta_{C=O}$/Hz	$\delta_{C\text{-}5}$/ppm	ω[a]/kcal.mol^{-1}	σ_ω^b
p-NO_2 (a)	36	128	120.87	84.90	0.29
m-NO_2 (b)	28	126	120.27	74.23	0.25
p-Br (c)	20	146	118.04	66.6	0.07
H (d)	16	161	117.66	61.62	0.00
m-OMe (e)	20	167	117.76	60.31	- 0.07
p-SMe (f)	12	157	115.85	60.47	0.08
p-OMe (g)	8	161	114.42	55.68	- 0.11
p-NMe_2 (h)	4	179	109.76	49.30	- 0.28

[a]Global electrophilicities of compounds **1a–1 h** [b] Values of substituent electrophilicity constants taken from reference [7].



Scheme 2. Structures that contribute to the resonance hybrid of **1**, with an indication of how the X substituent affects conjugation and electron-delocalization between different fragments of the molecule.

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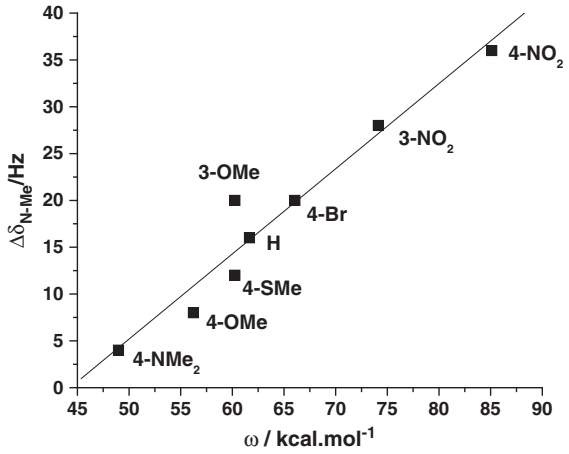


Figure 1. Variation of the chemical-shift differences $\Delta\delta_{N\text{-}Me}$ with the electrophilicity ω of compounds **1**. Correlation coefficient $R = 0.97$.

The chemical-shift difference between the N-Me singlets of **1** thus correlates with the global electrophilicity of the molecule ω by means of Eqn (5).

$$\Delta\delta_{N-Me} = -40.7 + 0.91\omega \ (\mathrm{N} = 8, \mathrm{R} = 0.97, \mathrm{SD} = 2.7) \quad (5)$$

As expected from the above analysis, the difference $\Delta\delta_{\mathrm{N\text{-}Me}}$ increases with the molecular electrophilicity, which increasingly favors contribution by the canonical structure II to the resonance hybrid.

The postulated validity of the electrophilic substituent constants σ_ω to a system different from substituted benzoic acids was tested next. According to this theoretical Hammett-like approach, a linear relationship of the form of (1) should exist between the global electrophilicities ω_X of substituted derivatives **1** and the previously determined set of electrophilic constants σ_ω. This is expressed by Eqn (6),

$$\log \omega_X/\omega_H = \rho\cdot\sigma_w \quad (6)$$

where the subscripts refer to the X substituent of **1** and ρ is a proportionality constant, which measures how the substituent electrophilicities affect the global molecular electrophilicity of the barbituric derivatives. Figure 2 is a plot of log ω_X against σ_ω.

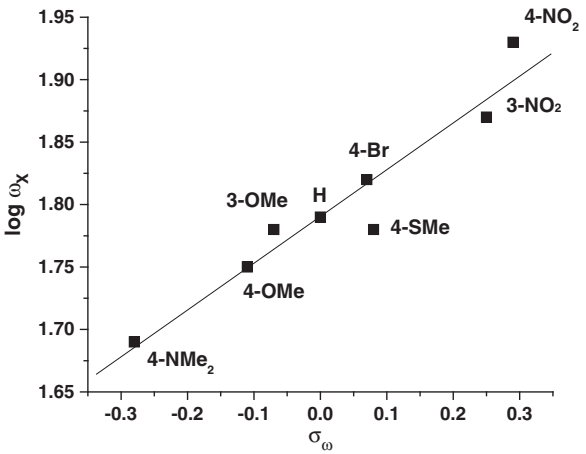


Figure 2. Linear relationship between the logarithm of the electrophilicity ω_X of compounds **1** and the electrophilic substituent constants σ_ω. Correlation coefficient $R = 0.96$.

The observed linear relationship ($R = 0.96$) yielded a value of $\rho = 0.37$, indicating that the substituent contribution to the global electrophilicity of compounds **1** is less significant than its contribution to the electrophilicity of substituted benzoic acids.

The general applicability of the electrophilic substituent constants σ_ω is verified in a plot of the ^{13}C chemical-shift differences $\Delta\delta_{C=O}$ of Table 2 against σ_ω (Fig. 3).

The shift difference $\Delta\delta_{C=O}$ varied with the substituent constant σ_ω according to relationship (7),

$$\Delta\delta_{C=O} = 155.8 - 95.9\,\sigma_\omega \ (\mathrm{N} = 8, \mathrm{R} = 0.96, \mathrm{SD} = 5.9) \quad (7)$$

thus showing that this theoretical parameter correlates reasonably well with the experimental spectral variations. In agreement with the above discussion based on the canonical structures of Scheme 2, $\Delta\delta_{C=O}$ decreases with an increased value of the electrophilic constant σ_{ω}, which reflects an increased contribution of canonical structure II to the resonance hybrid.

The above examples thus add to the list of data from chemical processes, which present good correlations with global or substituent electrophilicities, calculated from purely theoretical considerations. The Hammett-like approach defined by Eqn (1)[7] also is validated by the spectral trends exhibited by system **1**.

The general applicability of the theoretical σ_ω constants, confirmed by the particular plots of Figs 2 and 3, should not be a surprise, in view of the good correlations observed between σ_ω and Hammett's σ constants.[7] This observation also anticipates poorer performances of the theoretical σ_ω constant, when applied to experimental data that correlate poorly with Hammett's σ values. Kinetic data related with compounds **1** provide examples of this. Rate and equilibrium constants for the addition of amines to substituted 5-benzylidene barbituric acids have been measured in different solvents.[13,14] The obtained kinetic constants were found to correlate with σ^+ constants, showing that the reactivity of the electrophilic double-bond of compounds **1** depended more strongly on the nucleophilicity of the X substituent than might be expected from their σ values. This is a result of the well-known exalted through-resonance between *para*-substituents X and a conjugated double bond (Scheme 3) and should be observed in a comparison of the chemical shifts of the olefinic carbon atoms of substituted derivatives **1**.

Figure 4 is a plot of the C-5 chemical shifts of derivatives **1** listed in Table 2, against the electrophilic substituent constants σ_ω.

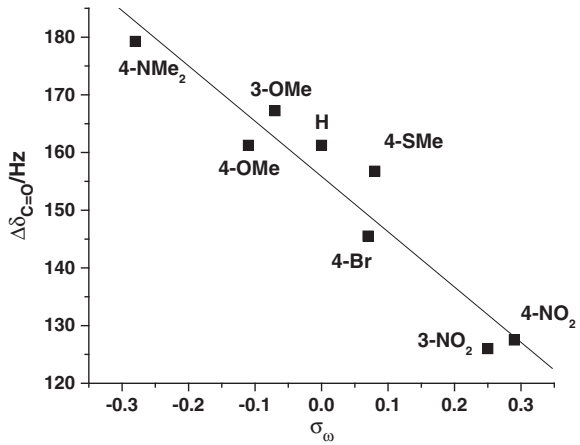
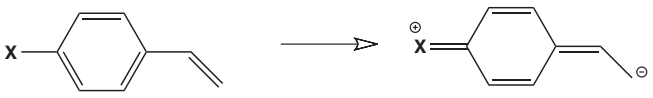


Figure 3. Variation of the ^{13}C chemical shift differences $\Delta\delta_{C=O}$ with the electrophilic substituent constants σ_ω of compounds **1**. Correlation coefficient $R = 0.96$.



Scheme 3. Canonical structures involved in through-conjugation between a strong donor substituent X and a double bond in benzylidene systems.

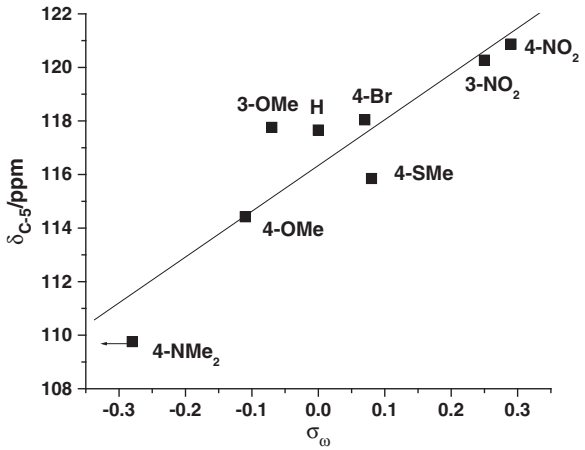


Figure 4. Variation of the chemical shifts of C-5 in the ^{13}C-NMR spectra of substituted **1** with the corresponding electrophilic substituent constants σ_ω ($R = 0.90$).

Nucleophilic substituents ($\sigma_\omega < 0$) tend to shield C-5, decreasing $\delta_{C\text{-}5}$. The plot confirms this trend, although the linear correlation is poorer ($R = 0.90$) than the ones obtained in Figs 2 and 3. As happens with the classical Hammett's σ values, which underestimate electron donation when through-conjugation operates, the plot shows that the electrophilic σ_ω value for the strongly nucleophilic *N*Me$_2$ group (−0.28) also underestimates the substituent contribution to the C-5 shielding.

Conclusions

An analysis of the ^{1}H and ^{13}C NMR spectra of a series of substituted 5-benzylidene-1,3-dimethylbarbituric acids **1** revealed long-range effects of the X substituent on the chemical-shift differences between the *N*-methyl protons ($\Delta\delta_{N\text{-}Me}$) and between the 4-C and the 6-C carbonyl signals ($\Delta\delta_{C=O}$) of the barbituric ring. These spectral differences correlated well with the global electrophilicities of compounds **1a–1 h** and also with the substituent electrophilic constants σ_ω, derived previously[7] from a Hammett-like equation for substituted benzoic acids. The theoretical substituent constants σ_ω also yielded a reasonable, although poorer correlation with the chemical-shifts of the C-5 atom in these derivatives. As observed for the classical Hammett's σ values, their poorer performance in this case may be ascribed to the enhanced electron-donation by through-conjugation in these systems, especially important for strongly nucleophilic substituents.

The good correlations between theoretical electrophilicities and experimental NMR data described in this paper are not novel. They add to examples from other systems described previously.[8–10] However, by relating electrophilicities derived from different systems, the present results emphasize a more general view. The existence of good correlations between theory and experiment points to the existence of a Hammett-like equation based on theoretical electrophilicities.[7] The parallel with the classical approach by Hammett was illustrated here: substituent electrophilic constants σ_ω derived from one set of compounds and their global electrophilicities may be employed in the analysis of completely different systems or processes. The fate of these theoretical substituent constants also is predictably similar to the fate of Hammett's σ values. Like Hammett's empirical constants, theoretical σ_ω values are likely to correlate with experimental data of an unlimited number of processes. However, their limitations also parallel those of Hammett's σ constants. They should describe less effectively enhanced electronic contributions of substituents by through-conjugation, reproducing failures that led in the past to corrections and the adoption of other empirical sets of constants, like the σ^+ and σ^- values.

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References

[1] R. G. Parr, L. Szentpály, S. Liu. *J. Am. Chem. Soc.* **1999**, *121*, 1922.
[2] P. K. Chattaraj, U. Sarkar, D. R. Roy. *Chem. Rev.* **2006**, *106*, 2065.
[3] K. Gupta, S. Giri, P. K. Chattaraj. *New J. Chem.* **2008**, *32*, 1945.
[4] E. Chamorro, M. Duque-Noreña, P. Pérez. *J. Mol. Struct. (THEOCHEM)* **2009**, *901*, 145.
[5] P. R. Campodónico, A. Aizman, R. Contreras. *Chem. Phys. Lett.* **2009**, *471*, 168.
[6] D. Wondrousch, A. Böhme, D. Thaens, N. Ost, G. Schüürmann. *J. Phys. Chem. Lett.* **2010**, *1*, 1605.
[7] M. C. Rezende, D. Millán. *J. Brazil. Chem. Soc.* **2011**, *22*, 2078.
[8] P. Pérez. *J. Org. Chem.* **2004**, *69*, 5048.
[9] R. Contreras, J. Andrés, L. R. Domingo, R. Castillo, P. Pérez. *Tetrahedron* **2005**, *61*, 417.
[10] M. Elango, R. Parthasarapathi, G. Karthik Narayanan, A. M. Sabeelullah, U. Sarkar, N. S. Venkatasubaramaniyan, V. Subramanian, P. K. Chattaraj. *J. Chem. Sci.* **2005**, *117*, 61.
[11] M. C. Rezende, F. Jara, M. Domínguez. *J. Chem. Educ.* **2006**, *83*, 937.
[12] M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, J. A. Montgomery Jr., T. Vreven, K. N. Kudin, J. C. Burant, J. M. Millam, S. S. Iyengar, J. Tomasi, V. Barone, B. Mennucci, M. Cossi, G. Scalmani, N. Rega, G. A. Petersson, H. Nakatsuji, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, M. Klene, X. Li, J. E. Knox, H. P. Hratchian, J. B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, P. Y. Ayala, K. Morokuma, G. A. Voth, P. Salvador, J. J. Dannenberg, V. G. Zakrzewski, S. Dapprich, A. D. Daniels, M. C. Strain, O. Farkas, D. K. Malick, A. D. Rabuck, K. Raghavachari, J. B. Foresman, J. V. Ortiz, Q. Cui, A. G. Baboul, S. Clifford, J. Cioslowski, B. B. Stefanov, G. Liu, A. Liashenko, P. Piskorz, I. Komaromi, R. L. Martin, D. J. Fox, T. Keith, M. A. Al-Laham, C. Y. Peng, A. Nanayakkara, M. Challacombe, P. M. W. Gill, B. Johnson, W. Chen, M. W. Wong, C. Gonzalez, J. A. Pople, *Gaussian 03, Revision C.02*, Gaussian, Inc., Wallingford CT, **2004**.
[13] B. Schreiber, H. Martinek, P. Wolschann, P. Schuster. *J. Am. Chem. Soc.* **1979**, *101*, 4708.
[14] C. F. Bernasconi, M. Panda. *J. Org. Chem.* **1987**, *52*, 3042.