Prediction of ortho substituent effect in alkaline hydrolysis of phenyl esters of substituted benzoic acids in aqueous acetonitrile

Vilve Nummert1, Mare Piirsalu2, Ilmar A. Koppel3*

Institute of Chemistry,
Tartu University,
50411 Tartu, Estonia

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Abstract: The second-order rate constants k for the alkaline hydrolysis of phenyl esters of meta-, para- and ortho-substituted benzoic acids, X-C6H5CO2C6H5, in aqueous 50.9% acetonitrile have been measured spectrophotometrically at 25°C. The log k values for meta and para derivatives correlated well with the Hammett σm,p substituent constants. The log k values for ortho-substituted phenyl benzoates showed good correlations with the Charton equation, containing the inductive, σI, resonance, σ°R, and steric, EsB, and Charton υ substituent constants. For ortho derivatives the predicted (log k)calc values were calculated with equation (log kortho)calc = (log kHAN)exp + 0.059 + 2.19σI + 0.304σ°R + 2.79EsB - 0.0164ΔE - 0.0854ΔEσI, where ΔE is the solvent electrophilicity, ΔE = EAN - EH2O = -5.84 for aqueous 50.9% acetonitrile. The predicted (log k)calc values for phenyl ortho-, meta- and para-substituted benzoates in aqueous 50.9% acetonitrile at 25°C precisely coincided with the experimental log k values determined in the present work.

The substituent effects from the benzoyl moiety and aryl moiety were compared by correlating the log k values for the alkaline hydrolysis of phenyl esters of substituted benzoic acids, X-C6H5CO2C6H5, in various media with the corresponding log k values for substituted phenyl benzoates, C6H5CO2C6H4-X.

Keywords: Ortho effect • Phenyl esters of benzoic acids • Correlation equations • Solvent effect • Substituent effects

1. Introduction

Earlier we investigated the dependence of the ortho, meta, and para substituent effects on the solvent electrophilicity (ΔE), polarity (ΔY) and polarizability (ΔP) parameters in the alkaline hydrolysis of substituted phenyl benzoates [1,2] containing substituents in acyl and aryl moiety, C6H5CO2C6H4-X, X-C6H5CO2C6H4 as well as in phenyl tosylates [3] CH3C6H4SO2OC6H4-X, and alkyl benzoates [4], C6H5CO2-R, including log k values for various aqueous media (water, aqueous 80% DMSO, 2.25 M Bu4NBr, 1.0 M Bu4NBr, 0.5 M Bu4NBr, 5.3 M NaClO4, and 4.8 M NaCl).

The variation of the ortho inductive, ortho resonance, meta and para polar substituent effects with solvent were found to be mainly dependent on the solvent electrophilicity parameter [5-11], ΔE, characterizing the hydrogen-bond donating power of the solvent. The meta and para polar, ortho inductive and resonance substituent effects were found to vary with the solvent electrophilicity, ΔE, nearly to the same extent in the alkaline hydrolysis of substituted phenyl benzoates containing substituents at the phenyl and benzoyl moiety [1,2], as in the alkaline hydrolysis of substituted phenyl tosylates, CH3C6H4SO2OC6H4-X [3].

In the alkaline hydrolysis of phenyl esters of substituted benzoic acids, X-C6H5CO2C6H5, at 25°C the dependence of the meta, para polar, ortho inductive and resonance substituent effects on the solvent electrophilicity, ΔE, calculated using log k values for various solvents (water, aqueous 50% DMSO, 2.25 M Bu4NBr, 1.0 M Bu4NBr, 0.5 M Bu4NBr, 5.3 M NaClO4) was found to be expressed as follows [2]:

Δlog kmp = log kP - log kno = (0.010 ± 0.023) + (1.77 ± 0.04)σ + (0.0683 ± 0.0055)ΔEσ (1)

R = 0.995, s = 0.087, s0 = 0.108, nmp = 55/55

* E-mail: ilmar.koppel@ut.ee
\[ \Delta \log k_{\text{exp}} = \log k^o - \log k^i = (0.059 \pm 0.055) + \\
+ (2.19 \pm 0.07)\sigma_i + (0.304 \pm 0.089)\sigma^p + \\
+ (2.79 \pm 0.09)E^o - (0.0164 \pm 0.0064)\Delta E\sigma_i - \\
- (0.0854 \pm 0.0114)\Delta E\sigma^p \\
R = 0.986, s = 0.114, s_o = 0.167, n/\bar{n}_o = 63/63 \]

In Eqs. 1 and 2 \( \Delta E \) is the solvent electrophilicity parameter, \( \Delta E = E_0 - E_{\text{iso}} \) [5-11], characterizing the hydrogen-bond donating power of the solvent, \( E_{\text{iso}} \), is the steric substituent constant of ortho substituents.

In the alkaline hydrolysis of substituted phenyl benzoates [1,2] and tosylates [3] the variation of the ortho inductive term with the solvent electrophilicity, \( \sigma^p \), was found to be approximately 2-3 fold smaller than that for para and meta substituents, while the ortho resonance term appeared to vary with the solvent electrophilicity nearly similarly to that for para substituents. The steric term of ortho substituents in the alkaline hydrolysis of substituted phenyl benzoates was approximately independent of solvent parameters [1,2].

In our previous work [12] we compared the predicted rate constants, \( k_{\text{calc}} \), with the experimental rate constants, \( k_{\text{exp}} \), in the alkaline hydrolysis of ortho-, para- and meta-substituted phenyl benzoates containing substituents in aryl moiety, \( \text{C}_6\text{H}_4\text{CO}_2\text{C}_6\text{H}_4\text{X}, \) in aqueous 50.9% (v/v) acetonitrile at 25°C. The predicted rates, \( k_{\text{calc}} \), in the alkaline hydrolysis of substituted phenyl benzoates, \( \text{C}_6\text{H}_4\text{CO}_2\text{C}_6\text{H}_4\text{X}, \) in aqueous 50.9% (v/v) CH\(_3\)CN (AN) at 25°C were calculated as sum (Eq. 3) that consisted of the experimental log \( k_{\text{exp}} \) value for un-substituted derivative \( (X = H) \) in aqueous 50.9% (v/v) CH\(_3\)CN (AN) at 25°C and the substituent effect component \((\Delta \log k^o)_{\text{calc}}\) calculated for the corresponding ortho, meta and para substituted derivatives with Eqs. 4 and 5 describing the variation of the substituent effect with the solvent electrophilicity parameter at 25°C using for aqueous 50.9% CH\(_3\)CN the solvent electrophilicity parameter, \( \Delta E = -5.84: \)

\[
(\log k^o)_{\text{calc}} = (\log k^o)_{\text{exp}} + (\Delta \log k^o)_{\text{calc}} \tag{3}
\]

\[
(\Delta \log k^o)_{\text{calc}} = \log k^o - \log k^i = (0.024 \pm 0.023) + \\
+ (1.136 \pm 0.042)\sigma - (0.0741 \pm 0.0054)\Delta E\sigma^o \\
R = 0.988, s = 0.088, s_o = 0.162, n/\bar{n}_o = 44/44 \tag{4}
\]

\[
(\Delta \log k^o)_{\text{calc}} = \log k^o - \log k^i = (0.017 \pm 0.070) + \\
+ (1.569 \pm 0.089)\sigma_i + (0.934 \pm 0.117)\sigma^p + \\
+ (1.076 \pm 0.125)\Delta E^o - (0.0299 \pm 0.0082)\Delta E\sigma_i - \\
- (0.0691 \pm 0.0132)\Delta E\sigma^p \\
R = 0.976, s = 0.122, s_o = 0.217, n/\bar{n}_o = 39/39 \tag{5}
\]

It was interesting to check up whether also in substituted phenyl benzoates containing ortho, meta and para substituents in the benzoyl moiety, X-C\(_6\)H\(_5\)CO\(_2\)C\(_6\)H\(_4\)X, the experimental rate constants, \( k \), for the alkaline hydrolysis in aqueous 50.9% CH\(_3\)CN at 25°C coincide with the predicted rate constants, \( k_{\text{calc}} \), when the solvent dependent substituent effect was calculated with equations 1 and 2 characterizing the variation of the substituent effect with the solvent electrophilicity parameter \( \Delta E \) at 25°C. It was also interesting to compare how the ortho inductive effect and para and meta polar effect vary in going from pure water to aqueous 50.9% CH\(_3\)CN in acyl-substituted phenyl benzoates, X-C\(_6\)H\(_5\)CO\(_2\)C\(_6\)H\(_4\), and in substituted phenyl benzoates, C\(_6\)H\(_5\)CO\(_2\)C\(_6\)H\(_4\)X, containing substituents in the aryl part.

For that aim in the present work the additional rates for the alkaline hydrolysis of ortho-, para- and meta-substituted phenyl benzoates, X-C\(_6\)H\(_5\)CO\(_2\)C\(_6\)H\(_4\), containing substituents in benzoyl part \( (X = H, 4-\text{NO}_2, 3-\text{NO}_2, 3-\text{Cl}, 4-\text{Cl}, 4-\text{F}, 4-\text{CH}_3, 4-\text{OCH}_3, 2-\text{NO}_2, 2-\text{CN}, 2-\text{F}, 2-\text{Cl}, 2-\text{I}, 2-\text{Br}, 2-\text{CF}_3, 2-\text{OCH}_3, 2-\text{CH}_3) \) were measured in aqueous 50.9% (v/v) acetonitrile at 25°C. For the alkaline hydrolysis of ortho-substituted phenyl benzoates containing substituents in benzoyl moiety, the kinetic data in aqueous acetonitrile solutions are not available in the literature. For para- and meta-substituted phenyl benzoates the rates of the alkaline hydrolysis has been previously determined in aqueous 10% [13], 31% [14], 33% [15] and 50% CH\(_3\)CN [16]. Earlier the rates of the alkaline hydrolysis of para-substituted phenyl benzoates in aqueous 50% (v/v) CH\(_3\)CN have been determined in 0.02 M phosphate buffer at 25°C [16].

To compare the influence of substituent effects from the benzoyl moiety with that from aryl moiety the log \( k \) values for the alkaline hydrolysis of phenyl esters of substituted benzoic acids, X-C\(_6\)H\(_5\)CO\(_2\)C\(_6\)H\(_4\), in various media were correlated with the corresponding log \( k \) values for substituted phenyl benzoates, C\(_6\)H\(_5\)CO\(_2\)C\(_6\)H\(_4\)X.

2. Experimental procedure

The preparation procedure and characteristics of phenyl esters of substituted benzoic acids, X-C\(_6\)H\(_5\)CO\(_2\)C\(_6\)H\(_4\), the technique of kinetic measurements and the purification of reagents are described earlier [17,18]. More detailed description of synthesis of phenyl esters of substituted benzoic acids was given in [17] and references cited therein. For kinetic measurements in aqueous 50.9% (v/v) acetonitrile, 0.10 M NaOH solutions were used. Kinetics was measured spectrophotometrically as described earlier [18]. The measurements were repeated and the arithmetic means of the corresponding second-order rate constants (dm\(^3\)mol\(^{-1}\)s\(^{-1}\)) were calculated. The second-