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HYDROGEN BONDING. 31. CONSTRUCTION OF A SCALE OF SOLUTE EFFECTIVE OR SUMMATION HYDROGEN-BOND BASICITY

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The β_2^H scale of solute hydrogen-bond basicity, formulated from 1:1 hydrogen-bond complexation constants in tetrachloromethane, has been used to set up a scale of effective or summation hydrogen-bond basicity, appropriate for the situation in which a solute is surrounded by solvent molecules. The method is based on the equation,

$$\log SP = c + rR_2 + s\pi_2^H + a\Sigma\alpha_2^H + b\Sigma\beta_2 + vVx$$

where *SP* is, in this work, a set of solute water–solvent partition coefficients in a given system. The explanatory variables are solute parameters as follows: R_2 is an excess molar refraction, π_2^H is the solute dipolarity/polarizability, $\Sigma\alpha_2^H$ and $\Sigma\beta_2$ are the effective solute hydrogen-bond acidity and basicity and Vx is McGowan's characteristic volume. Various equations are established using β_2^H in the equation, and then amended β_2^H values are back-calculated and new $\Sigma\beta_2^H$ values obtained. It is found that for most solutes, the effective basicity $\Sigma\beta_2^H$ is invariant over the systems used to within an experimental error of around 0·03 units. About 350 $\Sigma\beta_2^H$ values obtained from two or more experimental log *P* values are listed, together with values for homologous series and a number of singly determined values. For some specific solutes, such as sulphoxides, alkylanilines and alkylpyridines, $\Sigma\beta_2$ is not constant, and an additional solute basicity denoted as $\Sigma\beta_2^0$ is needed in order to deal with partitions from water to solvents that are partially miscible with water, such as isobutanol and octanol. Values of $\Sigma\beta_2^0$, and where possible $\Sigma\beta_2^H$ also, are listed for 80 additional solutes.

INTRODUCTION

Some years ago, Maria, Gal and co-workers[1] carried out an analysis of various kinds of basicity-dependent properties (*BDPs*). They showed that any two given *BDPs* will be linear, i.e. will show family-independent characteristics, if the two reference acids used to define the *BDPs* give rise to similar electrostatic-to-covalent ratios in the two sets of *BDPs*. The relative electrostatic-to-covalent ratio is given by an angle, θ, defined as $\tan^{-1}(S_2/S_1)$, where S_2 and S_1 are the coefficients of the base properties F_2 and F_1 in the multiple linear regression equation (1). The F_2 and F_1 parameters that characterize given bases were obtained by principal components analysis, and are listed in Table 1.

$$BDP = BDP_0 + S_1F_1 + S_2F_2 \quad (1)$$

In the event, different *BDPs* gave rise to different θ values, so that no general scale of basicity can exist. Even for a restricted type of basicity, that of solute hydrogen-bond basicity,[2] different θ values were shown

Table 1. The Maria–Gal F_1 and F_2 values

Compound	F_1	F_2
Nitrobenzene	-0.89	0.01
Acetonitrile	-0.57	-0.04
Diethyl carbonate	-0.52	-0.02
Ethyl acetate	-0.44	-0.02
Propanone	-0.37	-0.02
Cyclohexanone	-0.34	0.01
Diethyl ether	-0.29	-0.11
Trimethylphosphate	-0.08	0.24
Tetrahydrofuran	-0.21	-0.04
2,6-Dimethylpyridine	0.47	-0.10
2,4,6-Trimethylpyridine	0.53	-0.07
Dimethylsulfoxide	0.15	0.20
Tetramethylurea	0.20	0.11
N,N-Dimethylaniline	0.11	-0.40
Dimethylformamide	0.05	0.12
Dimethylacetamide	0.18	0.15
N-Methylpyrrolidinone	0.15	0.16
HMPT	0.48	0.38
Pyridine	0.42	-0.08
4-Methylpyridine	0.49	-0.05
Triethylamine	0.85	-0.26

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to arise from different reference acids, so that no completely general scale of solute hydrogen-bond basicity can exist.[2] Some values of θ obtained[2] by the Maria–Gal procedure are given in Table 2. It seemed that within a range of θ of around 64–73°, however, it should be possible to establish a 'reasonably general' scale of solute hydrogen-bond basicity based on 1 : 1 complexation constants in tetrachloromethane, equation (2):

$$A—H + B \rightleftharpoons A—H\cdots B \qquad (2)$$

Such a scale was later established by Abraham *et al.*[3] who showed that log$K$ values for bases against 34 reference acids in tetrachloromethane could be assembled as a set of 34 linear equations (3), where L_A and D_A characterize the particular acid and $\log K_B^H$ characterizes the various bases:

$$\log K = L_A \log K_B^H + D_A \qquad (3)$$

Then $\log K_B^H$ defines a solute hydrogen-bond basicity scale over a range of reference acids giving rise to θ values between 64 and 73°. This range of θ could be extended up to at least 86°, provided that bases such as ethers, aliphatic amines and pyridines were excluded. A very significant finding was that all the equations (3) intersected at a 'magic point' where $\log K_B^H = -1 \cdot 1$, so that a natural origin or zero point could be established. For convenience, the zero point was shifted to zero, rather than $-1 \cdot 1$, and the scale compressed somewhat, by the definition[3] of a solute hydrogen-bond basicity scale,

$$\beta_2^H = (\log K_B^H + 1 \cdot 1)/4 \cdot 636 \qquad (4)$$

This β_2^H scale, derived from 1 : 1 complexation constants, is the most general solute hydrogen-bond basicity scale in current use, especially now that it has been extended through the recent work of Laurence and co-workers[4–6] A separate issue, however, is the establishment of a β_2 scale that would reflect the hydrogen-bond basicity of a solute when surrounded by a large excess of solvent molecules, rather than the basicity of a solute towards a single hydrogen-bond acid. Such an 'effective' or 'overall' hydrogen-bond basicity scale is required for use as a solute descriptor in linear solvation energy relationships (LSERs) and in quantitative structure activity relationships (QSARs). Since the β_2^H solute scale is the most general one in use, it seemed useful to start with the simple β_2^H scale as a basis.

Two equations that can be used[7] as LSERs and QSARs are equations (5) and (6), where SP is some solute property for a series of solutes in a given system. The solute descriptors are R_2 an excess molar refraction,[8] π_2^H the solute dipolarity/polarizability,[9] $\Sigma\alpha_2^H$ the effective solute hydrogen-bond acidity,[7] $\Sigma\beta_2^H$ the effective solute hydrogen-bond basicity,[8] $\log L^{16}$, where L^{16} is the gas–hexadecane partition coefficient,[10] and Vx the solute characteristic volume of Abraham and McGowan.[11] Equation (5) is the more useful for the correlation of gas-condensed phase processes and equation (6) for processes within condensed phases.

$$\log SP = c + rR_2 + s\pi_2^H + a\Sigma\alpha_2^H + b\Sigma\beta_2^H + l\log L^{16} \qquad (5)$$

$$\log SP = c + rR_2 + s\pi_2^H + a\Sigma\alpha_2^H + b\Sigma\beta_2^H + Vx \qquad (6)$$

The R_2 descriptor is obtained from refractive index measurements, or can readily be estimated, π_2^H and $\log L^{16}$ have been determined for over 1000 solutes and Vx can simply be calculated from molecular structure. The units of Vx in this paper are (cm^3 mol^{-1})/100. For the very large number of solutes that have zero hydrogen-bond acidity, the only unknown descriptor is $\Sigma\beta_2^H$, and if we restrict discussion (at present) to solutes for which $\Sigma\alpha_2^H$ is zero, or to simple monoacidic solutes for which we can use α_2^H as an estimate for $\Sigma\alpha_2^H$, then equations (5) and (6) can be used to obtain $\Sigma\beta_2^H$ values. The procedure is to set up equations for various processes using β_2^H as a trial descriptor. Back-calculation will yield $\Sigma\beta_2^H$ values that either agree with the original trial values or can be used as new estimates. Further equations can be set up, and the process repeated until

Table 2. Values of θ for some reference acids in tetrachloromethane[a]

Reference Acid	θ/°
Diphenylamine	86
Trichloromethane	78
5-Fluoroindole	77
Methanol	73
Maleimide	70
4-Fluorophenol	70
Water	69
Phenol	67
Ethanol	67
Butan-1-ol	65

[a] From ref.2.

a self-consistent set of equations and $\Sigma\beta_2^H$ values is obtained. In the event, it turns out that for a wide variety of monofunctional solutes, either $\Sigma\beta_2^H$ is identical with β_2^H, or differs only marginally from β_2^H. Some general values are given in Table 3, and several hundred $\Sigma\beta_2^H$ values derived from β_2^H can be used to construct equations (5) and (6) from which further $\Sigma\beta_2^H$ values can be obtained.

A process to which equation (5) can be applied is that of gas–liquid chromatography (GLC). Although commercial GLC stationary phases are non-acidic (and therefore lead to regression equations that do not include the $b\beta_2^H$ term at all), a few acidic phases are available. However, little use was made of GLC data on such phases, except as a check on the relationship between $\Sigma\beta_2^H$ and β_2^H for simple solutes (cf. Table 3). The main equations used in this work are, with one exception, derived from water–solvent partition coefficients. These can be fitted to equations of type (6), where SP is P, the water–solvent partition coefficient for a series of solutes in a given system. Such equations offer considerable advantages over, e.g., equation (5) as applied to GLC data. First, $\log P$ values are available for a wide variety of solutes in various solvent systems.

Table 3. Comparison of $\Sigma\beta_2^H$ and β_2^H for some monofunctional bases

Solute base	$\Sigma\beta_2^H$	β_2^H
Rare gas	0.00	0.00
Alkane	0.00	0.00
Alk-1-ene	0.07	0.07
Di-n-alkyl ether	0.45	0.45
n-Alkanal	0.45	0.40
Alkan-2-one	0.51	0.48
n-Alkyl formate	0.38	0.38
n-Alkyl acetate	0.45	0.45
n-Alkyl propanoate	0.45	0.45
Alkan-1-ol	0.48	0.45
Di-n-alkylamine	0.69	0.70
Di-n-alkyl sulphide	0.32	0.29
Benzene	0.14	0.14
n-Alkylbenzene	0.15	0.15
Naphthalene	0.20	0.21
Anthracene	0.26	0.25
Fluorobenzene	0.10	0.10
Chlorobenzene	0.07	0.09
Bromobenzene	0.09	0.09
Benzaldehyde	0.39	0.42
Acetophenone	0.48	0.51
Thiophene	0.15	0.16
Dibenzothiophene	0.18	0.18

Second, since Vx can be calculated from molecular structure, equation (6) contains one less descriptor that requires experimental determination. Third, there is little restriction as to solute type. Finally, the regression equations constructed are good enough to back-calculate $\Sigma\beta_2^H$ with reasonable accuracy. The only exception, above, to the log$P$ equations, is an equation in gas–water partition coefficients, this process being selected because, unlike all other gas-solvent partition coefficients, regression equation (6) is applicable.

RESULTS AND DISCUSSION

Most of the log$P$ values used in this work were from the Pomona MedChem project,[12] or from the compilations of Taylor and co-workers[13,14] and of Testa and co-workers.[15–17] The log$P$ values for water–hexadecane partitions were from Abraham *et al.*,[10] as were also water–olive oil values, the latter at 310 rather than at 298 K. In a number of cases, water–solvent partition coefficients for rare gases and the lower alkanes were calculated from the corresponding gas–water and gas–solvent partitions. This is an important source of water–solvent partition coefficients, for mutually immiscible systems, in that the range of solutes studied is considerably increased. Gas–water partition coefficients were from a variety of compilations.[18–21]

Details of the regression equations obtained using β_2^H or modified β_2^H values as $\Sigma\beta_2^H$ are given in Table 4. Although these equations include a reasonable number of solutes, they are not to be regarded as definitive equations for the correlation and prediction of log$P$ values, but only as defining equations for the calculation of further $\Sigma\beta_2^H$ values. A more detailed analysis of the equations summarized in Table 4 will be given elsewhere; suffice it to say that the various coefficients all make general chemical sense. Note that to aid comparison, the final set of coefficients is for transfer from water to the gas phase. Also given in Table 4 are n, the number of solutes, ρ, the correlation coefficient, and sd, the overall standard deviation in log$P$. The last term is useful not only as a measure of goodness-of-fit, but also as an aid to estimation of the probable error in any back-calculated $\Sigma\beta_2^H$ value. This error will be given by sd divided by the coefficient of the descriptor, i.e. sd/b. Inspection of Table 4 shows that for most regressions, the value of sd/b is around 0·03 units, and this can be taken as a generally expected error in any calculated $\Sigma\beta_2^H$ value. As an example of a fuller analysis than those given in Table 4, details for the water–benzene

Table 4. Details of regression equations for water–solvent partition coefficients, based on equation (6)

Solvent	No	c	r	s	a	b	v	n	ρ	sd
Isobutanol	1	0.249	0.480	-0.639	-0.050	-2.284	2.758	35	0.9903	0.119
Octanol	2	0.081	0.585	-1.090	0.033	-3.401	3.810	584	0.9965	0.133
n-Butyl acetate	3	-0.468	0.712	-0.397	0.010	-3.743	3.865	47	0.9892	0.152
Diethyl ether	4	0.462	0.571	-1.035	-0.024	-5.508	4.346	84	0.9897	0.195
PGDP	5	0.287	0.338	-0.638	-0.908	-5.038	4.093	56	0.9909	0.175
Nitrobenzene	6	-0.181	0.576	0.003	-2.356	-4.420	4.263	84	0.9913	0.172
Chlorobenzene	7	0.046	0.259	-0.466	-3.047	-4.819	4.660	93	0.9973	0.115
Benzene	8	0.017	0.490	-0.604	-3.013	-4.628	4.587	112	0.9953	0.119
Toluene	9	0.015	0.594	-0.781	-2.918	-4.571	4.533	87	0.9957	0.114
Olive Oil	10	-0.086	0.575	-0.861	-1.447	-4.945	4.295	111	0.9972	0.129
Chloroform	11	0.125	0.118	-0.372	-3.390	-3.467	4.521	112	0.9972	0.112
Tetrachloromethane	12	0.223	0.564	-1.151	-3.510	-4.536	4.501	111	0.9980	0.102
Cyclohexane	13	0.124	0.844	-1.800	-3.727	-4.923	4.692	152	0.9955	0.155
Alkane	14	0.281	0.647	-1.687	-3.520	-4.848	4.326	173	0.9982	0.120
Hexadecane	15	0.103	0.686	-1.624	-3.566	-4.880	4.444	366	0.9983	0.123
Gas phase	16	1.003	-0.630	-2.496	-3.901	-4.843	0.852	353	0.9967	0.160

system are given below, with the standard deviation in the coefficients, and also the Fisher F-statistic listed:

$$\log P = (0{\cdot}017 \pm 0{\cdot}036) + (0{\cdot}490 \pm 0{\cdot}047)R_2 - (0{\cdot}604 \pm 0{\cdot}055)\pi_2^H - (3{\cdot}013 \pm 0{\cdot}048) \times \Sigma\alpha_2^H - (4{\cdot}628 \pm 0{\cdot}074)\Sigma\beta_2^H + (4{\cdot}587 \pm 0{\cdot}074)Vx$$

$n = 112$; $\rho = 0{\cdot}9953$; $sd = 0{\cdot}119$; $F = 2239$

The correlation matrix for the 112 solutes in this regression is

	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$
π_2^H	0·822			
$\Sigma\alpha_2^H$	0·463	0·498		
$\Sigma\beta_2^H$	0·005	0·181	−0.035	
Vx	0·521	0·627	0·223	0·539

where the only significant cross-correlation is that between R_2 and π_2^H ($\rho = 0{\cdot}822$, $\rho^2 = 0{\cdot}676$). Details for the other regressions in Table 4 are similar to those given above for the water–benzene system.

It is the difficulty of obtaining sufficiently low sd/b values that, so far, has prevented any large-scale use of regression equations based on GLC data. Thus, for gas–liquid partition coefficients on the acidic phase bis(3-allyl-4-hydroxyphenyl)sulphone,

$$\log L(394\text{ K}) = -0{\cdot}57 - 0{\cdot}51R_2 + 1{\cdot}32\pi_2^H + 1.27\Sigma\alpha_2^H + 1{\cdot}46\Sigma\beta_2^H + 0{\cdot}418\log L^{16} \quad (7)$$

$n = 58$; $\rho = 0{\cdot}9940$; $sd = 0{\cdot}069$

$$\log L(449\text{ K}) = -0{\cdot}75 + 0{\cdot}17R_2 + 1{\cdot}16\pi_2^H + 0{\cdot}81\Sigma\alpha_2^H + 1{\cdot}29\Sigma\beta_2^H + 0{\cdot}332\log L^{16} \quad (8)$$

$n = 54$; $\rho = 0{\cdot}9738$; $sd = 0{\cdot}134$

Even the better equation (7) leads to an sd/b ratio of 0·047, significantly larger than the general value of 0·03 found for the water–solvent partitions.

Solutes with a constant $\Sigma\beta_2^H$ value

Before any detailed examination of $\Sigma\beta_2^H$ values, it is important to establish whether or not the calculated $\Sigma\beta_2^H$ values are, indeed, constant over the systems listed in Table 4. This is especially relevant since Leahy *et al.*[23] found that for the water–solvent systems, with octanol, chloroform, alkane and propylene glycol dipelargonate (PGDP), there are a number of specific solutes for which β_2 seems to vary with system. Although the LSER equation used by Leahy *et al.*[23] was not the same as equation (6), this is such an important finding that it must be rigorously checked.

In the event, it is found that for a very large variety

Table 5. Examples of the calculation of $\Sigma\beta_2^H$ for various solutes

System	Et_2O	MeCOMe	Et_2NH	EtOH	$MeCO_2H$	C_6H_6	PhCHO	$PhCONH_2$	PhNHCOMe	PhOH	$PhCO_2H$	$PhSO_2Me$
Isobutanol			0.707	0.577	0.496							
Octanol	0.505	0.519	0.647	0.526	0.437	0.137	0.392	0.627	0.641	0.321	0.360	0.745
n-Butyl acetate					0.421					0.313	0.366	
Diethyl ether	0.436	0.440	0.685	0.490	0.406		0.354	0.710	0.685	0.311	0.380	
PGDP						0.145	0.383	0.707	0.673	0.287	0.414	0.727
Nitrobenzene		0.485		0.487		0.166				0.289		
Benzene		0.458	0.698	0.477	0.464	0.127	0.371	0.711		0.272	0.458	
Toluene			0.706	0.500	0.414					0.293	0.413	
Chloroform	0.424	0.507	0.696	0.464	0.423	0.118	0.486	0.676	0.666	0.283	0.443	0.819
Tetrachloromethane		0.485	0.687	0.472	0.447			0.714		0.331	0.429	
Cyclohexane	0.503	0.486	0.686	0.446	0.434	0.120	0.403	0.593	0.611	0.285	0.436	0.739
Alkane		0.488	0.675	0.508	0.474	0.124	0.385	0.659	0.700	0.304	0.392	0.764
Hexadecane	0.432	0.506	0.702	0.500	0.469	0.139	0.373			0.323		0.775
Gas phase	0.443	0.463	0.721	0.498	0.442	0.117	0.348		0.690	0.298	0.384	
Average:	0.457	0.484	0.692	0.495	0.444	0.133	0.388	0.675	0.667	0.301	0.407	0.762
sd:	0.037	0.024	0.019	0.033	0.027	0.016	0.040	0.045	0.031	0.018	0.033	0.033

of solutes $\Sigma\beta_2^H$ is constant over the systems studied; some examples are given in Table 5. To within an error of around 0·03 units, the $\Sigma\beta_2^H$ values for solutes ranging from diethyl ether to acetanilide and methyl phenyl sulphone are independent of the solvent system. For the more volatile compounds that can be examined by GLC, this is true also for a variety of gas–stationary phase processes. It is therefore technically possible to use the β_2^H scale as a basis for the construction of a fairly general $\Sigma\beta_2^H$ scale for the effective hydrogen-bond basicity of solutes. It is important to note, however, that even if $\Sigma\beta_2^H$ is constant for a set of solutes in various solvent systems, this does not imply that the absolute basicity of the solutes remains the same. All that can be said is that the relative basicity of the solutes in the series remains constant.

A selection of $\Sigma\beta_2^H$ values is given in Table 6, together with the number of systems used to obtain the average $\Sigma\beta_2^H$ value, and the *sd* in the average value. For the 353 solutes for which $\Sigma\beta_2^H$ is the average of two or more determinations, *sd* averages as exactly 0·03 units, again confirming our analysis based on *sb*/*b* ratios. For many homologous series $\Sigma\beta_2^H$ is constant, and rather than set out the individual values, the series $\Sigma\beta_2^H$ value is given in Table 7. The only homologous series for which results are rather scattered is that of the alk-1-ynes, and details of the calculation of $\Sigma\beta_2^H$ are given separately in Table 8. Further results would be an advantage here, especially to check the very disparate values for ethyne itself. In addition, results for the alkyl formates are consistently different as between solvent system 2 and systems 15 and 16, and values for some polyaromatic hydrocarbons are very low in the water–gas system. Further results are needed here also.

There has been only one previous calculation of $\Sigma\beta$ values on these lines. Leahy *et al.*[23] used the LSER equation (9) to back-calculate $\Sigma\beta$ values from results in four water–solvent systems, viz. 2, 5, 11 and 14. Because the other descriptors in equation (9) differ from those in equation (6), there is no reason why the $\Sigma\beta$ parameter of Leahy *et al.* should correlate with the $\Sigma\beta_2^H$ parameter in equation (6).

$$\log P = c + s\mu^2 + a\Sigma\alpha + b\Sigma\beta + n\beta + vV_I \qquad (9)$$

where μ is the solute dipole moment, $\Sigma\alpha$ is the solute hydrogen-bond acidity, $\Sigma\beta$ is the solute hydrogen-bond basicity, $n\beta$ is a correction term where n is number of lone pairs in the solute after the first and V_I is the solute intrinsic volume. For 31 common solutes where $n\beta < 2$, there is a reasonable connection between $\Sigma\beta_2^H$ and $\Sigma\beta$, equation (10). As might be expected, for solutes with a large correction term, $n\beta > 2$, then $\Sigma\beta$ is always smaller than calculated from $\Sigma\beta_2^H$.

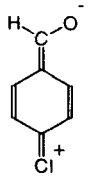
$$\Sigma\beta_2^H = 0{\cdot}090 + 0{\cdot}230\Sigma\beta$$
$$n = 31; \quad \rho = 0{\cdot}968; \quad sd = 0{\cdot}056 \qquad (10)$$

The $\Sigma\beta_2^H$ values for the aliphatic compounds in Table 6 give rise to no great surprises, and as can be seen from Table 7 lead to fairly constant values along homologous series. Chain branching in the alkylamines, the dialkylamines, the alkanoic acids and probably also the dialkyl sulphides results in an increase in $\Sigma\beta_2^H$, but the effect is not large. Steric effects that might result in a decrease in $\Sigma\beta_2^H$ seem either to be largely absent or masked by other effects. Thus, along the series diethyl ether, di-*n*-propyl ether and di-*n*-butyl ether, $\Sigma\beta_2^H$ is constant, and only with diisopropyl ether is there a reduction in $\Sigma\beta_2^H$ from 0·45 to 0·41 units.

The aromatic compounds are more interesting. For monofunctional compounds with deactivating groups, $\Sigma\beta_2^H$ is about the same as β_2^H (see Table 3) or, in the case of nitrobenzene and benzonitrile, slightly lower. However, for compounds with activating groups, $\Sigma\beta_2^H$ is larger than β_2^H, no doubt because the benzene ring also acts as a hydrogen-bond site when the solute is surrounded by an excess of solvent molecules. Some examples are given in Table 9. Leahy *et al.*[23] noted a similar effect in their LSER analysis of log$P$ values, although their analysis suggest a greater 'ring' effect than is indicated by the values in Table 9.

It would be very useful to devise a set of rules for the prediction of $\Sigma\beta_2^H$ for difunctional and polyfunctional aromatic compounds, but the situation seems too complicated. Some progress can be made by isolating groups of substituents. Thus, the simple addition of a methyl substituent has virtually no effect on $\Sigma\beta_2^H$, and within the experimental error of 0·03 units, all 2-, 3- and 4-methyl derivatives have the same $\Sigma\beta_2^H$ value as the parent compound. However, this is not necessarily so for dimethyl or polymethyl derivatives (see values for the phenols in Table 6).

For disubstituted compounds in general, it is not possible to obtain $\Sigma\beta_2^H$ by simple summation of 'substituent' values, because the aromatic ring itself can act as a substituent in some cases. With two deactivating substituents, this is not the case, but even here, as with halo derivatives of benzaldehyde, acetophenone, benzonitrile and nitrobenzene, simple summation is not appropriate. In such cases, the halides can deactivate the basic substituent group through an inductive effect, but can also activate the group via a push–pull mechanism (Scheme 1). In the event, 4-halo derivatives



Scheme 1

Table 6. Values of $\Sigma\beta_2^H$ for solutes of non-varying relative basicity

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	$\Sigma\beta_2^H$ avg	$\Sigma\beta_2^H$ sd	$\Sigma\beta_2^H$ taken
Adamantane	0.667	0.66	0.00	1	0.020		0.02
1,3-Butadiene	0.320	0.23	0.00	4	0.085	0.025	0.10
2-Methylbuta-1,3-diene	0.313	0.23	0.00	3	0.097	0.021	0.10
2,3-Dimethylbuta-1,3-diene	0.352	0.23	0.00	2	0.152	0.022	0.14
Cyclohexa-1,3-diene	0.515	0.30	0.00	1	0.137		0.14
Cyclohexa-1,4-diene	0.501	0.35	0.00	1	0.169		0.17
Cycloocta-1,5-diene	0.603	0.36	0.00	1	0.246		0.20
Cyclohepta-1,3,5-triene	0.764	0.46	0.00	3	0.192	0.002	0.20
Tetrafluoromethane	-0.280	-0.20	0.00	3	0.004	0.065	0.00
Dichloromethane	0.387	0.57	0.10	4	0.065	0.022	0.05
Trichloromethane	0.425	0.49	0.15	5	0.040	0.012	0.02
Tetrachloromethane	0.458	0.38	0.00	4	0.037	0.043	0.00
1,1-Dichloroethane	0.322	0.49	0.10	3	0.080	0.025	0.10
1,2-Dichloroethane	0.416	0.64	0.10	4	0.129	0.028	0.11
1,1,1,-Trichloroethane	0.369	0.41	0.00	3	0.090	0.020	0.09
1,1,2-Trichloroethane	0.499	0.68	0.13	3	0.129	0.054	0.13
1,1,2,2-Tetrachloroethane	0.595	0.76	0.16	3	0.143	0.024	0.12
1,1,1,2-Tetrachloroethane	0.542	0.63	0.10	3	0.086	0.032	0.08
Pentachloroethane	0.648	0.66	0.17	3	0.047	0.048	0.06
Hexachloroethane	0.680	0.22	0.00	1	0.107		0.06
1-Chloropropane	0.216	0.40	0.00	4	0.106	0.030	0.10
2-Chloropropane	0.177	0.35	0.00	3	0.142	0.023	0.12
1,2-Dichloropropane	0.371	0.60	0.10	3	0.127	0.040	0.11
1,3-Dichloropropane	0.408	0.74	0.00	3	0.174	0.028	0.17
1-Chlorobutane	0.210	0.40	0.00	3	0.096	0.047	0.10
1-Chloro-2-methylpropane	0.191	0.37	0.00	1	0.125		0.12
2-Chlorobutane	0.189	0.35	0.00	3	0.122	0.026	0.12
2-Chloro-2-methylpropane	0.142	0.25	0.00	4	0.071	0.057	0.12
1,4-Dichlorobutane	0.413	0.95	0.00	2	0.167	0.001	0.17
1,1-Dichloroethene	0.362	0.34	0.00	3	0.030	0.020	0.05
cis-1,2-Dichloroethene	0.436	0.61	0.11	3	0.021	0.008	0.05
trans-1,2-Dichloroethene	0.425	0.41	0.09	3	0.056	0.039	0.05
Trichloroethene	0.524	0.40	0.08	4	0.036	0.036	0.03
Tetrachloroethene	0.639	0.28	0.00	3	-0.016	0.053	0.00
1-Chloroprop-2-ene	0.327	0.56	0.00	2	0.080	0.013	0.05
Bromomethane	0.399	0.43	0.00	3	0.107	0.026	0.10
Dibromomethane	0.714	0.67	0.10	2	0.082	0.013	0.10
Tribromomethane	0.974	0.68	0.15	3	0.063	0.006	0.06
Bromoethane	0.366	0.40	0.00	4	0.137	0.020	0.12
1,2-Dibromoethane	0.747	0.76	0.10	3	0.158	0.060	0.17
1-Bromopropane	0.366	0.40	0.00	3	0.139	0.020	0.12
2-Bromopropane	0.332	0.35	0.00	3	0.164	0.021	0.14
1-Bromobutane	0.360	0.40	0.00	3	0.129	0.033	0.12
1-Bromo-2-methylpropane	0.337	0.37	0.00	3	0.133	0.030	0.12
2-Bromo-2-methylpropane	0.305	0.25	0.00	4	0.105	0.063	0.12
Bromocyclohexane	0.615	0.54	0.00	1	0.157		0.16
Diiodomethane	1.453	0.69	0.05	1	0.231		0.23
Iodoethane	0.640	0.40	0.00	6	0.134	0.019	0.15
1-Iodopropane	0.634	0.40	0.00	3	0.134	0.009	0.15
Halothane	0.102	0.38	0.15	3	0.047	0.025	0.05
Teflurane	-0.070	0.21	0.20	3	0.022	0.041	0.02
Dimethylether	0.000	0.27	0.00	2	0.385	0.037	0.41
Diethyl ether	0.041	0.25	0.00	6	0.457	0.037	0.45
Di-n-propylether	0.008	0.25	0.00	3	0.445	0.031	0.45

Table 6. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	$\Sigma\beta_2^H$ avg	$\Sigma\beta_2^H$ sd	$\Sigma\beta_2^H$ taken
Di-isopropylether	0.000	0.19	0.00	2	0.406	0.054	0.41
Di-n-butylether	0.000	0.25	0.00	3	0.436	0.012	0.45
Methoxyflurane	0.109	0.67	0.07	4	0.136	0.018	0.14
Isoflurane	-0.240	0.50	0.10	3	0.095	0.060	0.10
Enflurane	-0.230	0.40	0.12	2	0.127	0.015	0.13
Fluroxene	0.183	0.30	0.00	4	0.272	0.056	0.27
Tetrahydrofuran	0.289	0.52	0.00	3	0.481	0.053	0.48
2-Methyltetrahydrofuran	0.241	0.48	0.00	2	0.533	0.042	0.53
2,5-Dimethyltetrahydrofuran	0.204	0.38	0.00	3	0.578	0.010	0.58
Tetrahydropyran	0.275	0.47	0.00	3	0.538	0.039	0.55
1,4-Dioxane	0.329	0.75	0.00	4	0.649	0.036	0.64
Formaldehyde	0.220	0.70	0.00	2	0.305	0.033	0.33
Acetaldehyde	0.208	0.67	0.00	2	0.454	0.024	0.45
Propionaldehyde	0.196	0.65	0.00	2	0.469	0.008	0.45
Butyraldehyde	0.187	0.65	0.00	2	0.459	0.012	0.45
Isobutyraldehyde	0.144	0.62	0.00	2	0.440	0.021	0.45
Pentanal	0.163	0.65	0.00	2	0.452	0.003	0.45
Crotonal	0.387	0.80	0.00	2	0.500	0.003	0.50
trans-Hex-2-en-1-al	0.404	0.80	0.00	1	0.438		0.45
trans-Oct-2-en-1-al	0.441	0.80	0.00	1	0.451		0.45
Propanone	0.179	0.70	0.04	10	0.484	0.024	0.49
Butanone	0.166	0.70	0.00	9	0.508	0.011	0.51
Pentan-2-one	0.143	0.68	0.00	8	0.506	0.013	0.51
Hexan-2-one	0.136	0.68	0.00	8	0.504	0.008	0.51
Hexan-3-one	0.136	0.66	0.00	1	0.474		0.51
Heptan-2-one	0.123	0.68	0.00	8	0.494	0.008	0.51
Cyclopentanone	0.373	0.86	0.00	4	0.512	0.030	0.52
Cyclohexanone	0.403	0.86	0.00	3	0.562	0.040	0.56
Hex-5-ene-2-one	0.280	0.75	0.00	1	0.574		0.57
γ-Butyrolactone	0.366	1.74	0.00	1	0.451		0.45
Methyl formate	0.192	0.68	0.00	3	0.392	0.053	0.38
Ethyl formate	0.146	0.66	0.00	3	0.388	0.049	0.38
n-Propyl formate	0.132	0.63	0.00	3	0.399	0.037	0.38
Isopropyl formate	0.091	0.60	0.00	3	0.400	0.105	0.40
Isobutyl formate	0.095	0.60	0.00	3	0.425	0.063	0.40
Isopentyl formate	0.092	0.60	0.00	2	0.398	0.012	0.40
Methyl acetate	0.142	0.64	0.00	11	0.441	0.033	0.45
Ethyl acetate	0.106	0.62	0.00	12	0.452	0.023	0.45
n-Propyl acetate	0.092	0.60	0.00	9	0.455	0.024	0.45
Isopropyl acetate	0.055	0.57	0.00	3	0.510	0.043	0.47
n-Butyl acetate	0.071	0.60	0.00	9	0.450	0.018	0.45
n-Pentyl acetate	0.067	0.60	0.00	9	0.456	0.020	0.45
Methyl propanoate	0.128	0.60	0.00	8	0.433	0.019	0.45
Ethyl propanoate	0.087	0.58	0.00	3	0.475	0.017	0.45
Methyl butanoate	0.106	0.60	0.00	3	0.470	0.003	0.45
Ethyl butanoate	0.068	0.58	0.00	3	0.477	0.021	0.45
Methyl pentanoate	0.108	0.60	0.00	8	0.442	0.014	0.45
Ethyl pentanoate	0.049	0.58	0.00	3	0.487	0.006	0.45
Methyl hexanoate	0.080	0.60	0.00	8	0.461	0.024	0.45
Ethyl hexanoate	0.043	0.58	0.00	2	0.476	0.006	0.45
Acetonitrile	0.237	0.90	0.07	6	0.319	0.028	0.32
Proprionitrile	0.162	0.90	0.02	3	0.365	0.027	0.36
1-Cyanopropane	0.188	0.90	0.00	3	0.384	0.010	0.36

continued

Table 6. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	$\Sigma\beta_2^H$ avg	$\Sigma\beta_2^H$ sd	$\Sigma\beta_2^H$ taken
1-Cyanobutane	0.177	0.90	0.00	3	0.385	0.014	0.36
Ammonia	0.139	0.35	0.14	6	0.623	0.034	0.62
Methylamine	0.250	0.35	0.16	6	0.572	0.040	0.58
Ethylamine	0.236	0.35	0.16	11	0.622	0.036	0.61
n-Propylamine	0.225	0.35	0.16	11	0.606	0.037	0.61
Isopropylamine	0.181	0.32	0.16	1	0.582		0.61
n-Butylamine	0.224	0.35	0.16	11	0.613	0.043	0.61
Isobutylamine	0.198	0.32	0.16	2	0.626	0.031	0.63
s-Butylamine	0.170	0.32	0.16	2	0.632	0.049	0.63
t-Butylamine	0.121	0.29	0.16	2	0.705	0.010	0.71
n-Pentylamine	0.211	0.35	0.16	3	0.598	0.060	0.61
n-Hexylamine	0.197	0.35	0.16	4	0.609	0.063	0.61
n-Heptylamine	0.197	0.35	0.16	3	0.597	0.065	0.61
n-Octylamine	0.187	0.35	0.16	4	0.625	0.066	0.61
Cyclohexylamine	0.326	0.56	0.16	4	0.581	0.044	0.58
Allylamine	0.350	0.49	0.16	1	0.578		0.58
Dimethylamine	0.189	0.30	0.08	9	0.656	0.033	0.66
Diethylamine	0.154	0.30	0.08	11	0.692	0.020	0.69
Di-n-propylamine	0.124	0.30	0.08	7	0.692	0.039	0.69
Di-isopropylamine	0.053	0.24	0.08	4	0.727	0.048	0.73
Di-n-butylamine	0.107	0.30	0.08	3	0.661	0.048	0.69
Di-isobutylamine	0.046	0.24	0.08	2	0.689	0.017	0.69
Trimethylamine	0.140	0.20	0.00	12	0.671	0.033	0.67
Triethylamine	0.101	0.15	0.00	11	0.789	0.032	0.79
N-Me-N'-Pr-cyanoguanidine	0.600	0.60	0.43	3	1.169	0.023	1.17
Nitromethane	0.313	0.95	0.06	8	0.305	0.033	0.31
Nitroethane	0.270	0.95	0.02	4	0.328	0.020	0.33
1-Nitropropane	0.242	0.95	0.00	7	0.307	0.017	0.31
2-Nitropropane	0.216	0.92	0.00	3	0.348	0.051	0.33
1-Nitrobutane	0.227	0.95	0.00	4	0.288	0.014	0.29
2-Methyl-2-nitropropane	0.200	0.92	0.00	1	0.376		0.35
1-Nitropentane	0.212	0.95	0.00	4	0.288	0.036	0.29
Formamide	0.468	1.30	0.62	4	0.597	0.064	0.60
Acetamide	0.460	1.30	0.54	5	0.683	0.046	0.68
Propanamide	0.440	1.30	0.55	3	0.688	0.043	0.68
Butanamide	0.420	1.30	0.56	4	0.680	0.040	0.68
Isobutanamide	0.400	1.27	0.57	1	0.657		0.66
N-Methylformamide	0.405	1.30	0.40	1	0.542		0.55
N-Methylacetamide	0.400	1.30	0.40	1	0.722		0.72
N-Butylacetamide	0.360	1.30	0.40	2	0.740	0.037	0.74
N,N-Dimethylformamide	0.367	1.31	0.00	4	0.737	0.035	0.74
N,N-Dimethylacetamide	0.363	1.33	0.00	1	0.781		0.78
N,N-Diethylacetamide	0.296	1.30	0.00	3	0.862	0.080	0.78
N,N-Dimethylpropionamide	0.340	1.30	0.00	2	0.804	0.075	0.78
Formic acid	0.300	0.60	0.75	8	0.379	0.036	0.38
Acetic acid	0.265	0.65	0.61	12	0.444	0.027	0.44
Propanoic acid	0.233	0.65	0.60	12	0.445	0.013	0.45
Butanoic acid	0.210	0.62	0.60	12	0.452	0.016	0.45
2-Methylpropanoic acid	0.200	0.57	0.60	2	0.469	0.013	0.49
Pentanoic acid	0.205	0.60	0.60	12	0.455	0.017	0.45
2-Methylbutanoic acid	0.188	0.57	0.60	1	0.504		0.49
3-Methylbutanoic acid	0.178	0.57	0.60	5	0.491	0.026	0.49
Hexanoic acid	0.174	0.60	0.60	10	0.449	0.037	0.45
2-Methylpentanoic acid	0.178	0.57	0.60	1	0.497		0.49

Table 6. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	avg	sd	taken
2-Ethylbutanoic acid	0.180	0.57	0.60	1	0.532		0.49
Heptanoic acid	0.149	0.60	0.60	6	0.487	0.029	0.45
Octanoic acid	0.150	0.60	0.60	1	0.431		0.45
2-Ethylhexanoic acid	0.180	0.57	0.60	1	0.565		0.50
2-Propylpentanoic acid	0.180	0.57	0.60	1	0.533		0.50
Decanoic acid	0.124	0.60	0.60	2	0.445	0.013	0.45
Tetradecanoic acid	0.060	0.60	0.60	1	0.465		0.45
Hexadecanoic acid	0.035	0.60	0.60	1	0.461		0.45
Octadecanoic acid	0.015	0.60	0.60	1	0.461		0.45
Eicosanoic acid	0.005	0.60	0.60	1	0.463		0.45
Chloroacetic acid	0.373	1.08	0.74	7	0.364	0.028	0.36
Dichloroacetic acid	0.481	1.20	0.90	6	0.266	0.045	0.27
Trichloroacetic acid	0.589	1.33	0.95	6	0.276	0.029	0.28
Methanol	0.278	0.44	0.43	9	0.435	0.038	0.47
Ethanol	0.246	0.42	0.37	12	0.495	0.033	0.48
Propan-1-ol	0.236	0.42	0.37	11	0.542	0.144	0.48
Propan-2-ol	0.212	0.36	0.33	8	0.557	0.018	0.56
Butan-1-ol	0.224	0.42	0.37	11	0.499	0.019	0.48
2-Methylpropan-1-ol	0.217	0.39	0.37	10	0.498	0.023	0.48
Butan-2-ol	0.217	0.36	0.33	9	0.554	0.021	0.56
2-Methylpropan-2-ol	0.180	0.30	0.30	9	0.637	0.034	0.60
Pentan-1-ol	0.219	0.42	0.37	11	0.490	0.027	0.48
Pentan-2-ol	0.195	0.36	0.33	8	0.558	0.015	0.56
2-Methylbutan-1-ol	0.219	0.39	0.37	4	0.515	0.038	0.48
3-Methylbutan-1-ol	0.192	0.39	0.37	4	0.518	0.036	0.48
2-Methylbutan-2-ol	0.194	0.30	0.30	6	0.633	0.024	0.60
2,2-Dimethylpropan-1-ol	0.220	0.36	0.37	2	0.531	0.013	0.53
Hexan-1-ol	0.210	0.42	0.37	11	0.479	0.020	0.48
Hexan-2-ol	0.187	0.36	0.33	4	0.562	0.022	0.56
Heptan-1-ol	0.211	0.42	0.37	11	0.480	0.035	0.48
Heptan-2-ol	0.188	0.36	0.33	2	0.573	0.028	0.56
Octan-1-ol	0.199	0.42	0.37	6	0.480	0.040	0.48
Cyclopentanol	0.427	0.54	0.32	3	0.557	0.034	0.56
Cyclohexanol	0.460	0.54	0.32	3	0.573	0.030	0.57
Cycloheptanol	0.513	0.54	0.32	3	0.577	0.038	0.58
Cyclooctanol	0.578	0.54	0.32	1	0.575		0.58
Adamantan-1-ol	0.850	1.20	0.32	1	0.564		0.56
Allyl alcohol	0.342	0.46	0.38	6	0.483	0.012	0.48
Trifluoroethanol	0.015	0.60	0.57	4	0.247	0.048	0.25
HFIP	-0.240	0.55	0.77	4	0.113	0.063	0.10
2-Methoxyethanol	0.269	0.50	0.30	2	0.838	0.037	0.84
2-Ethoxyethanol	0.237	0.50	0.30	7	0.826	0.041	0.83
Methanethiol	0.400	0.35	0.00	2	0.251	0.004	0.24
Ethanethiol	0.392	0.35	0.00	3	0.236	0.023	0.24
n-Propanethiol	0.385	0.35	0.00	3	0.226	0.032	0.24
n-Butanethiol	0.382	0.35	0.00	3	0.247	0.025	0.24
Diethylsulphide	0.373	0.38	0.00	3	0.314	0.025	0.32
Di-n-propylsulphide	0.358	0.38	0.00	3	0.333	0.029	0.32
Di-isopropylsulphide	0.328	0.32	0.00	2	0.397	0.023	0.37
Methylethylsulphide	0.390	0.38	0.00	2	0.279	0.021	0.28
Dimethyl disulphide	0.695	0.46	0.00	2	0.289	0.008	0.28
Diethyl disulphide	0.670	0.51	0.00	3	0.271	0.030	0.28
Dimethylsulphone	0.590	1.70	0.00	1	0.747		0.76
Sulphur hexafluoride	-0.600	-0.20	0.00	3	0.004	0.006	0.00

continued

Table 6. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	$\Sigma\beta_2^H$ avg	$\Sigma\beta_2^H$ sd	$\Sigma\beta_2^H$ taken
Trimethylphosphate	0.113	1.10	0.00	6	1.001	0.018	1.00
Triethylphosphate	0.000	1.00	0.00	5	1.060	0.052	1.06
Tri-n-propylphosphate	-0.050	1.00	0.00	5	1.151	0.027	1.15
Tri-n-butylphosphate	-0.100	0.90	0.00	4	1.208	0.043	1.21
HMPT	0.368	0.85	0.00	2	1.594	0.224	1.60
Benzene	0.610	0.52	0.00	9	0.133	0.016	0.14
Toluene	0.601	0.52	0.00	8	0.144	0.016	0.14
Phenylethyne	0.679	0.58	0.12	1	0.232		0.24
Styrene	0.849	0.65	0.00	4	0.167	0.037	0.16
α-Methylstyrene	0.851	0.64	0.00	3	0.191	0.039	0.19
Biphenyl	1.360	0.99	0.00	4	0.214	0.041	0.22
4-Methylbiphenyl	1.380	0.98	0.00	1	0.226		0.23
Naphthalene	1.340	0.92	0.00	6	0.187	0.050	0.20
1-Methylnaphthalene	1.344	0.90	0.00	3	0.175	0.030	0.20
1,3-Dimethylnaphthalene	1.387	0.92	0.00	3	0.193	0.023	0.20
1,4-Dimethylnaphthalene	1.400	0.91	0.00	3	0.231	0.032	0.20
2,3-Dimethylnaphthalene	1.431	0.95	0.00	3	0.219	0.037	0.20
2,6-Dimethylnaphthalene	1.329	0.91	0.00	3	0.227	0.024	0.20
1-Ethylnaphthalene	1.371	0.88	0.00	3	0.222	0.034	0.20
2-Ethylnaphthalene	1.331	0.87	0.00	1	0.210		0.20
Indane	0.829	0.62	0.00	3	0.169	0.027	0.17
Acenaphthene	1.604	1.05	0.00	3	0.184	0.034	0.20
Fluorene	1.588	1.06	0.00	3	0.223	0.023	0.20
1-Methylfluorene	1.588	1.06	0.00	1	0.194		0.20
Azulene	1.340	1.17	0.00	1	0.158		0.16
Anthracene	2.290	1.34	0.00	4	0.262	0.086	0.26
9-Methylanthracene	2.290	1.30	0.00	1	0.296		0.26
9,10-Dimethylanthracene	2.290	1.30	0.00	1	0.272		0.26
Phenanthrene	2.055	1.29	0.00	3	0.214	0.068	0.26
1-Methylphenanthrene	2.055	1.25	0.00	1	0.270		0.26
2-Methylphenanthrene	2.055	1.25	0.00	1	0.223		0.26
3-Methylphenanthrene	2.055	1.25	0.00	1	0.264		0.26
Fluoranthene	2.377	1.53	0.00	1	0.197		0.20
Benz[a]fluorene	2.622	1.59	0.00	1	0.229		0.20
Benz[b]fluorene	2.622	1.57	0.00	1	0.209		0.20
Pyrene	2.808	1.72	0.00	1	0.298		0.29
Benz[a]anthracene	2.992	1.70	0.00	1	0.334		0.33
Naphthacene	2.847	1.70	0.00	1	0.319		0.33
Chrysene	3.027	1.73	0.00	1	0.347		0.33
Perylene	3.256	1.76	0.00	1	0.496		0.40
Dibenz[ac]anthracene	4.000	1.93	0.00	1	0.432		0.44
Benz[a]pyrene	3.625	1.98	0.00	1	0.445		0.44
Benz[ghi]perylene	4.073	1.90	0.00	1	0.496		0.46
Fluorobenzene	0.477	0.57	0.00	4	0.097	0.026	0.10
Trifluoromethylbenzene	0.225	0.48	0.00	4	0.109	0.049	0.10
Chlorobenzene	0.718	0.65	0.00	7	0.075	0.022	0.07
1,2-Dichlorobenzene	0.872	0.78	0.00	4	0.042	0.038	0.04
1,3-Dichlorobenzene	0.847	0.73	0.00	4	0.017	0.032	0.02
1,4-Dichlorobenzene	0.825	0.75	0.00	4	0.018	0.027	0.02
1,2,3-Trichlorobenzene	1.030	0.86	0.00	4	0.020	0.056	0.00
1,2,4-Trichlorobenzene	0.980	0.81	0.00	4	-0.009	0.033	0.00
1,3,5-Trichlorobenzene	0.980	0.73	0.00	4	-0.018	0.031	0.00
1,2,3,4-Tetrachlorobenzene	1.180	0.92	0.00	3	-0.018	0.057	0.00
1,2,3,5-Tetrachlorobenzene	1.160	0.85	0.00	3	0.053	0.031	0.00
1,2,4,5-Tetrachlorobenzene	1.160	0.86	0.00	4	-0.007	0.041	0.00

Table 6. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	$\Sigma\beta_2^H$ avg	$\Sigma\beta_2^H$ sd	$\Sigma\beta_2^H$ taken
Pentachlorobenzene	1.330	0.96	0.00	2	-0.029	0.083	0.00
Hexachlorobenzene	1.490	0.99	0.00	2	0.007	0.022	0.00
2-Chlorotoluene	0.762	0.65	0.00	3	0.090	0.044	0.07
3-Chlorotoluene	0.736	0.67	0.00	1	0.070		0.07
4-Chlorotoluene	0.705	0.67	0.00	1	0.050		0.07
Benzyl chloride	0.821	0.82	0.00	1	0.326		0.33
Bromobenzene	0.882	0.73	0.00	6	0.088	0.015	0.09
1,2-Dibromobenzene	1.190	0.96	0.00	1	0.047		0.04
1,3-Dibromobenzene	1.170	0.88	0.00	1	0.036		0.04
1,4-Dibromobenzene	1.150	0.86	0.00	2	0.048	0.030	0.04
2-Bromotoluene	0.923	0.72	0.00	1	0.079		0.09
3-Bromotoluene	0.896	0.75	0.00	1	0.065		0.09
4-Bromotoluene	0.879	0.74	0.00	3	0.089	0.020	0.09
Benzyl bromide	1.014	0.98	0.00	1	0.186		0.20
Iodobenzene	1.188	0.82	0.00	6	0.122	0.039	0.12
Anisole	0.708	0.75	0.00	8	0.286	0.017	0.29
Ethylphenyl ether	0.681	0.70	0.00	5	0.319	0.032	0.32
n-Propylphenyl ether	0.676	0.70	0.00	1	0.323		0.32
2-Methylanisole	0.725	0.74	0.00	1	0.291		0.30
3-Methylanisole	0.709	0.78	0.00	1	0.300		0.30
4-Methylanisole	0.699	0.77	0.00	1	0.300		0.30
2,6-Dimethylanisole	0.674	0.78	0.00	1	0.345		0.34
4-Chloroanisole	0.838	0.86	0.00	1	0.240		0.24
Diphenyl ether	1.216	1.08	0.00	1	0.201		0.20
1,3-Dimethoxybenzene	0.816	1.01	0.00	1	0.445		0.45
1,4-Dimethoxybenzene	0.806	1.00	0.00	1	0.500		0.50
Benzaldehyde	0.820	1.00	0.00	9	0.388	0.041	0.39
2-Methylbenzaldehyde	0.870	0.96	0.00	2	0.402	0.015	0.40
3-Methylbenzaldehyde	0.840	0.97	0.00	1	0.415		0.42
4-Methylbenzaldehyde	0.862	1.00	0.00	3	0.422	0.016	0.42
4-Chlorobenzaldehyde	0.930	1.08	0.00	3	0.358	0.016	0.36
Acetophenone	0.818	1.01	0.00	9	0.484	0.020	0.48
3-Methylacetophenone	0.806	1.00	0.00	1	0.490		0.49
4-Methylacetophenone	0.842	1.00	0.00	3	0.513	0.015	0.51
4-Fluoroacetophenone	0.690	1.02	0.00	2	0.469	0.004	0.47
3-Chloroacetophenone	0.924	1.07	0.00	2	0.396	0.022	0.40
4-Chloroacetophenone	0.955	1.09	0.00	2	0.439	0.005	0.44
Ethylphenylketone	0.804	0.95	0.00	2	0.509	0.004	0.51
Benzophenone	1.447	1.50	0.00	2	0.495	0.038	0.50
Methyl benzoate	0.733	0.85	0.00	8	0.460	0.037	0.46
Ethyl benzoate	0.689	0.85	0.00	3	0.437	0.019	0.46
n-Propyl benzoate	0.675	0.80	0.00	1	0.473		0.46
Isopropyl benzoate	0.660	0.76	0.00	2	0.464	0.019	0.48
n-Butyl benzoate	0.668	0.80	0.00	1	0.474		0.46
Methyl 2-methylbenzoate	0.772	0.87	0.00	1	0.432		0.43
Phenyl acetate	0.661	1.13	0.00	2	0.532	0.020	0.54
2-Methylphenyl acetate	0.680	1.04	0.00	1	0.626		0.62
3-Methylphenyl acetate	0.660	1.13	0.00	1	0.569		0.57
4-Methylphenyl acetate	0.660	1.01	0.00	1	0.561		0.56
Benzyl acetate	0.798	1.06	0.00	1	0.648		0.65
Methyl phenylacetate	0.703	1.13	0.00	1	0.582		0.58
Ethyl phenylacetate	0.660	1.01	0.00	2	0.572	0.002	0.57
Dimethylphthalate	0.780	1.41	0.00	1	0.858		0.88

continued

Table 6. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	avg	sd	taken
Diethylphthalate	0.729	1.40	0.00	1	0.898		0.88
Benzonitrile	0.742	1.11	0.00	5	0.334	0.023	0.33
2-Methylbenzonitrile	0.780	1.06	0.00	1	0.308		0.31
3-Fluorobenzonitrile	0.642	1.09	0.00	2	0.348	0.012	0.35
Phenylacetonitrile	0.751	1.15	0.00	2	0.450	0.025	0.45
2-Nitroaniline	1.180	1.37	0.30	10	0.361	0.021	0.36
3-Nitroaniline	1.200	1.71	0.40	8	0.349	0.023	0.35
4-Nitroaniline	1.220	1.91	0.42	8	0.380	0.023	0.38
1-Aminonaphthalene	1.670	1.26	0.20	7	0.556	0.023	0.57
2-Aminonaphthalene	1.670	1.28	0.22	7	0.535	0.023	0.55
9-Aminophenanthrene	2.400	1.74	0.26	1	0.586		0.59
Benzylamine	0.829	0.88	0.10	8	0.717	0.044	0.72
N,N-Dimethylbenzylamine	0.668	0.80	0.00	2	0.688	0.004	0.69
Nitrobenzene	0.871	1.11	0.00	8	0.278	0.013	0.28
2-Nitrotoluene	0.866	1.11	0.00	3	0.265	0.033	0.27
3-Nitrotoluene	0.874	1.10	0.00	2	0.251	0.030	0.25
4-Nitrotoluene	0.870	1.11	0.00	1	0.283		0.28
1-Chloro-4-nitrobenzene	0.980	1.17	0.00	1	0.253		0.25
1-Iodo-4-nitrobenzene	1.450	1.35	0.00	1	0.269		0.27
Benzamide	0.990	1.50	0.49	8	0.675	0.045	0.67
3-Methylbenzamide	0.990	1.50	0.49	1	0.626		0.63
N-Methylbenzamide	0.950	1.44	0.35	4	0.727	0.047	0.73
N,N-Dimethylbenzamide	0.950	1.40	0.00	3	0.976	0.016	0.98
N,N-Diethylbenzamide	0.950	1.40	0.00	1	1.100		1.10
Formanilide	0.970	1.40	0.50	1	0.504		0.50
4-Methylformanilide	0.970	1.40	0.50	1	0.525		0.52
Acetanilide	0.870	1.40	0.50	7	0.667	0.031	0.67
2-Methylacetanilide	0.870	1.40	0.50	1	0.696		0.70
3-Methylacetanilide	0.870	1.40	0.50	1	0.646		0.66
4-Methylacetanilide	0.870	1.40	0.50	2	0.670	0.042	0.67
Benzoic acid	0.730	0.90	0.59	11	0.407	0.033	0.40
2-Methylbenzoic acid	0.730	0.90	0.60	1	0.344		0.34
3-Methylbenzoic acid	0.730	0.90	0.59	1	0.371		0.38
4-Methylbenzoic acid	0.730	0.90	0.60	2	0.377	0.003	0.38
4-Ethylbenzoic acid	0.730	0.90	0.59	1	0.364		0.37
3-Chlorobenzoic acid	0.840	0.95	0.65	2	0.298	0.052	0.30
4-Chlorobenzoic acid	0.840	0.97	0.63	3	0.267	0.046	0.27
3-Nitrobenzoic acid	0.990	1.41	0.70	3	0.438	0.011	0.44
4-Nitrobenzoic acid	0.990	1.43	0.68	3	0.437	0.010	0.44
Phenol	0.805	0.89	0.60	13	0.301	0.018	0.30
o-Cresol	0.840	0.86	0.52	11	0.304	0.020	0.30
m-Cresol	0.822	0.88	0.57	10	0.342	0.026	0.34
p-Cresol	0.820	0.87	0.57	11	0.309	0.027	0.31
2,3-Dimethylphenol	0.850	0.81	0.53	5	0.362	0.009	0.36
2,4-Dimethylphenol	0.843	0.80	0.53	9	0.394	0.022	0.39
2,5-Dimethylphenol	0.840	0.79	0.54	9	0.369	0.019	0.37
2,6-Dimethylphenol	0.860	0.79	0.39	9	0.390	0.029	0.39
3,4-Dimethylphenol	0.830	0.86	0.56	8	0.386	0.018	0.39
3,5-Dimethylphenol	0.820	0.84	0.57	9	0.360	0.016	0.36
2,3,5-Trimethylphenol	0.860	0.84	0.52	1	0.417		0.42
2,3,6-Trimethylphenol	0.870	0.81	0.37	1	0.473		0.47
2,4,5-Trimethylphenol	0.850	0.79	0.52	1	0.439		0.44
2,4,6-Trimethylphenol	0.860	0.78	0.37	2	0.439	0.066	0.44
3,4,5-Trimethylphenol	0.830	0.88	0.55	1	0.443		0.44

Table 6. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	avg	sd	taken
2-Ethylphenol	0.831	0.84	0.52	4	0.369	0.039	0.37
3-Ethylphenol	0.810	0.91	0.55	3	0.372	0.025	0.37
4-Ethylphenol	0.800	0.90	0.55	9	0.357	0.023	0.36
2-n-Propylphenol	0.822	0.86	0.52	2	0.367	0.009	0.37
3-n-Propylphenol	0.789	0.90	0.55	1	0.388		0.37
4-n-Propylphenol	0.793	0.88	0.55	3	0.351	0.004	0.37
2-Isopropylphenol	0.842	0.89	0.52	2	0.381	0.005	0.38
4-Isopropylphenol	0.791	0.89	0.55	2	0.386	0.025	0.38
4-n-Butylphenol	0.796	0.88	0.55	3	0.392	0.077	0.37
2-s-Butylphenol	0.819	0.91	0.52	1	0.414		0.41
2-t-Butylphenol	0.823	0.92	0.52	1	0.400		0.40
4-t-Butylphenol	0.810	0.89	0.56	2	0.419	0.015	0.41
2-Isopropyl-5-methylphenol	0.822	0.79	0.52	1	0.443		0.44
4-t-Pentylphenol	0.810	0.89	0.56	1	0.412		0.41
2-Phenylphenol	1.550	1.40	0.56	1	0.488		0.49
3-Phenylphenol	1.560	1.41	0.59	1	0.446		0.45
4-Phenylphenol	1.560	1.41	0.59	2	0.452	0.004	0.45
2-Fluorophenol	0.660	0.69	0.61	9	0.259	0.024	0.26
3-Fluorophenol	0.667	0.98	0.68	4	0.165	0.010	0.17
4-Fluorophenol	0.670	0.97	0.63	8	0.230	0.026	0.23
2-Chlorophenol	0.853	0.88	0.32	9	0.311	0.040	0.31
3-Chlorophenol	0.909	1.06	0.69	10	0.148	0.015	0.15
4-Chlorophenol	0.915	1.08	0.67	13	0.198	0.049	0.20
4-Chloro-2-methylphenol	0.890	0.91	0.63	1	0.234		0.22
4-Chloro-3-methylphenol	0.920	1.02	0.65	3	0.191	0.071	0.22
2-Bromophenol	1.037	0.90	0.35	8	0.308	0.044	0.31
3-Bromophenol	1.060	1.15	0.70	2	0.155	0.028	0.16
4-Bromophenol	1.080	1.17	0.67	11	0.197	0.033	0.20
2-Iodophenol	1.360	1.00	0.40	9	0.349	0.031	0.35
3-Iodophenol	1.370	1.20	0.70	1	0.176		0.18
4-Iodophenol	1.380	1.22	0.68	9	0.198	0.028	0.20
3,4-Dichlorophenol	1.020	1.20	0.74	1	-0.014		0.00
3,5-Dichlorophenol	1.020	1.17	0.77	1	-0.089		0.00
2-Methoxyphenol	0.837	0.91	0.22	10	0.517	0.028	0.52
3-Methoxyphenol	0.879	1.17	0.59	10	0.385	0.051	0.39
4-Methoxyphenol	0.900	1.17	0.57	10	0.474	0.072	0.48
2-Hydroxybenzaldehyde	0.962	1.15	0.11	9	0.312	0.024	0.31
3-Hydroxybenzaldehyde	0.990	1.38	0.74	5	0.400	0.016	0.40
4-Hydroxybenzaldehyde	1.010	1.40	0.77	6	0.441	0.033	0.44
2-Cyanophenol	0.920	1.33	0.74	1	0.334		0.33
3-Cyanophenol	0.930	1.55	0.77	3	0.281	0.034	0.28
4-Cyanophenol	0.940	1.63	0.79	4	0.292	0.030	0.29
2-Aminophenol	1.110	1.10	0.60	7	0.662	0.025	0.66
3-Aminophenol	1.130	1.15	0.65	5	0.798	0.011	0.79
4-Aminophenol	1.150	1.20	0.65	4	0.826	0.011	0.83
2-Nitrophenol	1.015	1.05	0.05	14	0.367	0.043	0.37
3-Nitrophenol	1.050	1.57	0.79	13	0.230	0.019	0.23
4-Nitrophenol	1.070	1.72	0.82	14	0.260	0.035	0.26
Catechol	0.970	1.07	0.85	6	0.515	0.034	0.52
Resorcinol	0.980	1.00	1.10	6	0.577	0.050	0.58
Hydroquinone	1.000	1.00	1.16	7	0.605	0.060	0.60
Methyl p-hydroxybenzoate	0.900	1.37	0.69	7	0.434	0.031	0.45
Ethyl p-hydroxybenzoate	0.860	1.35	0.69	1	0.442		0.45

continued

Table 6. (*Continued*)

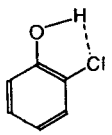
Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	avg	sd	taken
n-Butyl p-hydroxybenzoate	0.860	1.35	0.69	2	0.469	0.049	0.45
1-Naphthol	1.520	1.05	0.61	8	0.368	0.031	0.37
2-Naphthol	1.520	1.08	0.61	9	0.399	0.034	0.40
Benzyl alcohol	0.803	0.87	0.33	7	0.557	0.033	0.56
3-Methylbenzyl alcohol	0.815	0.90	0.33	1	0.593		0.59
4-Methylbenzyl alcohol	0.810	0.89	0.33	1	0.605		0.60
1-Phenylethanol	0.784	0.83	0.30	1	0.662		0.66
2-Phenylethanol	0.811	0.91	0.30	7	0.642	0.026	0.64
3-Phenylpropanol	0.821	0.90	0.30	3	0.670	0.012	0.67
Thiophenol	1.000	0.80	0.09	3	0.160	0.026	0.16
Methylphenylsulphone	1.080	1.85	0.00	6	0.762	0.033	0.76
Diphenylsulphone	1.570	2.15	0.00	1	0.697		0.70
Benzenesulphonamide	1.130	1.55	0.55	5	0.795	0.062	0.80
N-Methylbenzenesulphonamide	1.100	1.50	0.30	3	0.824	0.051	0.82
N,N-Dimethylbenzenesulphonamide	1.100	1.50	0.00	3	0.861	0.086	0.86
3-Methylbenzenesulphonamide	1.100	1.55	0.55	2	0.850	0.008	0.85
4-Methylbenzenesulphonamide	1.100	1.55	0.55	2	0.872	0.002	0.87
3-Isopropylbenzenesulphonamide	1.090	1.55	0.55	2	0.918	0.008	0.92
4-Isopropylbenzenesulphonamide	1.090	1.55	0.55	2	0.906	0.004	0.91
Furan	0.369	0.53	0.00	2	0.133	0.011	0.13
2-Methylfuran	0.372	0.50	0.00	1	0.143		0.14
Benzofuran	0.888	0.83	0.00	2	0.145	0.006	0.15
Benzodioxan	0.874	1.07	0.00	1	0.374		0.35
Paraldehyde	0.136	0.68	0.00	4	0.678	0.076	0.68
2-Fluoropyridine	0.489	0.89	0.00	1	0.358		0.36
3-Fluoropyridine	0.504	0.74	0.00	1	0.426		0.43
2,6-Difluoropyridine	0.375	0.94	0.00	2	0.241	0.008	0.24
2-Chloropyridine	0.738	1.03	0.00	5	0.367	0.013	0.37
3-Chloropyridine	0.732	0.83	0.00	4	0.402	0.020	0.40
4-Chloropyridine	0.740	0.85	0.00	1	0.399		0.40
3-Bromopyridine	0.905	0.90	0.00	1	0.376		0.38
4-Bromopyridine	0.900	0.93	0.00	1	0.383		0.38
2-Methoxypyridine	0.641	0.76	0.00	1	0.473		0.47
4-Methoxypyridine	0.680	0.93	0.00	1	0.534		0.53
2-Cyanopyridine	0.734	1.44	0.00	1	0.512		0.51
3-Cyanopyridine	0.750	1.26	0.00	3	0.623	0.008	0.62
4-Cyanopyridine	0.750	1.21	0.00	3	0.585	0.018	0.59
Piperidine	0.422	0.46	0.10	5	0.686	0.063	0.69
N-Methylpiperidine	0.318	0.39	0.00	3	0.693	0.059	0.69
N-Ethylpiperidine	0.300	0.32	0.00	1	0.634		0.63
Pyrrole	0.613	0.73	0.41	2	0.291	0.047	0.29
N-Methylpyrrole	0.559	0.79	0.00	2	0.311	0.012	0.31
N-Acetylpyrrolidine	0.550	1.63	0.00	2	0.922	0.039	0.92
Acridine	2.356	1.32	0.00	2	0.584	0.001	0.58
Pyrazine	0.629	0.95	0.00	2	0.621	0.002	0.62
2-Methylpyrazine	0.629	0.90	0.00	2	0.641	0.011	0.64
2,5-Dimethylpyrazine	0.626	0.90	0.00	1	0.688		0.69
2-Ethylpyrazine	0.629	0.90	0.00	1	0.648		0.65
Quinoxaline	1.300	1.20	0.00	2	0.586	0.024	0.59
Pyrimidine	0.606	1.00	0.00	2	0.646	0.002	0.65
Quinazoline	0.930	1.15	0.00	2	0.649	0.001	0.65
Pyridazine	0.670	0.85	0.00	2	0.810	0.025	0.81
Cinnoline	1.280	1.00	0.00	2	0.775	0.001	0.78
Oxazole	0.418	0.70	0.00	2	0.416	0.031	0.42

Table 6. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$ no	avg	sd	taken
Benzoxazole	0.900	1.00	0.00	2	0.375	0.017	0.38
Isoxazole	0.395	0.70	0.00	2	0.383	0.028	0.38
1,2-Benzisoxazole	0.877	1.00	0.00	2	0.329	0.026	0.33
2,1-Benzisoxazole	0.971	1.10	0.00	2	0.362	0.004	0.36
Morpholine	0.434	0.79	0.06	2	0.908	0.001	0.91
N-Methylmorpholine	0.333	0.74	0.00	2	0.900	0.011	0.90
Thiophene	0.687	0.56	0.00	5	0.144	0.005	0.15
2-Methylthiophene	0.688	0.56	0.00	4	0.165	0.009	0.16
Benzo[b]thiophene	1.323	0.88	0.00	2	0.200	0.023	0.20
Thiazole	0.800	0.80	0.00	2	0.450	0.001	0.45
Benzothiazole	1.330	1.10	0.00	2	0.402	0.010	0.40

of the above four benzenes have $\Sigma\beta_2^H$ almost the same as for the parent compound.

With 3-halo and 4-halo derivatives of activating groups such as anisole and phenol, the effect shown in Scheme 1 seems smaller, and the overall effect is rather deactivating. Of course, 2-halophenols are a special case, and there is no doubt that the intramolecular hydrogen bond (Scheme 2) plays some part.



Scheme 2

Such an intramolecular bond will lower the overall acidity but will *increase* the effective hydrogen-bond basicity of the oxygen atom. A 2-nitro group is even more effective in reducing $\Sigma\alpha_2^H$ (see Table 10 where $\Sigma\alpha_2^H$ and $\Sigma\beta_2^H$ values for *o*-, *m*- and *p*-substituted phenols are given). A rough measure of the effect of hydrogen-bonding is $\delta\Sigma\alpha_2^H$ and $\delta\Sigma\beta_2^H$, the differences between values for the *o*- and *p*-substituents. This assumes that electronic effects cancel out, as between the *o*- and *p*-positions. Judging from other compounds, this is not an unreasonable assumption, for example $\Sigma\beta_2^H$ is 0·36 and 0·38 for *o*- and *p*-nitroaniline, respectively.

The *o*- and *p*-differences show that the 2-fluoro and the 2-cyano substituents behave normally, and that the other 2-halo substituents and the 2-methoxy substituent form intramolecular hydrogen bonds. However, the 2-nitro substituent affects $\delta\Sigma\alpha_2^H$ even more, and reduces the effective acidity nearly to zero. Thus the intramolecular hydrogen bonding aids transfer from water to a hydrocarbon phase through the loss of acidity, but actually reduces transfer from water through the gain in hydrogen-bond basicity. In addition, the internally hydrogen-bonded species is less dipolar than the open-chain species, and this will aid transfer of the former. These affects are analysed for the typical case of transfer of chlorophenols and nitrophenols from water to cyclohexane (Table 11).

For the restricted case of 3- and 4-substituents, where the substituent itself is not a basic group, some progress can be made through correlations of $\Sigma\beta_2^H$ against the substituent constants σ_I and σ_R (compare previous correlations with β_2^H itself).[3] Of course, the 3- or 4-substituent will affect two basic sites: that of the first substituent, and the benzene ring itself. There are more data on substituted phenols than for any other system, and for the (non-basic) substituents alkyl, halide, and CF_3:

$$\Sigma\beta_2^H(m\text{-phenols}) = 0{\cdot}311 - 0{\cdot}482\sigma_I - 0{\cdot}275\sigma_R \quad (11)$$
$$n = 9; \quad \rho = 0{\cdot}9924; \quad sd = 0{\cdot}016; \quad F = 194{\cdot}0$$

$$\Sigma\beta_2^H(m\text{-phenols}) = 0{\cdot}327 - 0{\cdot}486\sigma_M \quad (12)$$
$$n = 9; \quad \rho = 0{\cdot}9859; \quad sd = 0{\cdot}020; \quad F = 242{\cdot}1$$

$$\Sigma\beta_2^H(p\text{-phenols}) = 0{\cdot}308 - 0{\cdot}421\sigma_I - 0{\cdot}335\sigma_R \quad (13)$$
$$n = 11; \quad \rho = 0{\cdot}9719; \quad sd = 0{\cdot}026; \quad F = 68{\cdot}1$$

$$\Sigma\beta_2^H(p\text{-phenols}) = 0{\cdot}294 - 0{\cdot}408\sigma_P \quad (14)$$
$$n = 11; \quad \rho = 0{\cdot}9639; \quad sd = 0{\cdot}028; \quad F = 118{\cdot}0$$

In these equations, all values of σ_I, σ_R, σ_M and σ_P are those given by Charton.[24] Equations (13) and (14) are rather poor, but if 4-methylphenol is left out, the fit is

greatly improved;

$$\Sigma\beta_2^H(p\text{-phenols}) = 0{\cdot}318 - 0{\cdot}449\sigma_I - 0{\cdot}351\sigma_R \quad (15)$$

$n = 10$; $\rho = 0{\cdot}9921$; $sd = 0{\cdot}015$; $F = 217{\cdot}6$

$$\Sigma\beta_2^H(p\text{-phenols}) = 0{\cdot}301 - 0{\cdot}432\sigma_p \quad (16)$$

$n = 10$; $\rho = 0{\cdot}9817$; $sd = 0{\cdot}021$; $F = 213{\cdot}0$

Equations (11), (12), (15) and (16) reproduce the $\Sigma\beta_2^H$ values to around 0·02 units, which is about the expected experimental error. Since $\Sigma\beta_2^H$ is available for all the *m*- and *p*-substituted halophenols and for the *m*- and *p*- trifluromethylphenols, there is little left to predict. However, equation (11) yields values of 0·36 for $\Sigma\beta_2^H$ for both *m*-isopropylphenol and *m-tert*-butylphenol.

There are too few data points for other series to construct reliable equations in σ_I/σ_R or in σ_M or σ_p, but some extra $\Sigma\beta_2^H$ values could be estimated using such equations, especially since the variations in $\Sigma\beta_2^H$ are small. However, it has not yet been possible to establish rules for the estimation of $\Sigma\beta_2^H$ values for disubstituted benzenes with two basic groups from values for the monosubstituted benzenes. Work is in progress on this problem.

Table 7. Values of $\Sigma\beta_2^H$ for homologous series

Alkane	0.00	Dimethylamine	0.66
Alk-1-ene	0.07	Di-n-alkylamine	0.69
Cycloalkene	0.10	Nitromethane	0.31
		Nitroethane	0.33
1-Fluoroalkane	0.10	1-Nitropropane	0.31
Chloromethane	0.08	1-Nitroalkane	0.29
1-Chloroalkane	0.10	Formamide	0.60
Bromomethane	0.10	n-Alkylamide	0.68
1-Bromoalkane	0.12	Dimethylformamide	0.74
Iodomethane	0.13	Di-n-alkylformamide	0.76
1-Iodoalkane	0.15	Formic acid	0.38
Dimethyl ether	0.41	Acetic acid	0.44
Di-n-alkyl ether	0.45	n-Alkanoic acid	0.45
1,2-Alkylene oxide	0.45	Water	0.35
Formaldehyde	0.33	Methanol	0.47
n-Alkanal	0.45	n-Alkanol	0.48
Propanone	0.49	s-Alkanol	0.56
Alkanone	0.51	t-Alkanol	0.60
n-Alkyl formate	0.38	Alkane thiol	0.24
n-Alkyl n-alkanoate	0.45	Dimethyl sulfide	0.29
n-Alkyl acrylate	0.42	Di-n-alkyl sulfide	0.32
n-Alkyl methacrylate	0.45	Di-n-alkyl disulfide	0.28
Acetonitrile	0.32	Di-n-alkyl sulfone	0.77
Cyanoalkane	0.36	Benzene	0.14
Methylamine	0.58	Toluene	0.14
n-Alkylamine	0.61	n-Alkyl benzene	0.15
		n-Alkyl benzoate	0.46
		n-Alkyl 4-hydroxybenzoate	0.45

Table 8. calculation of $\Sigma\beta_2^H$ for alkynes

Alkyne	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$			
				2[a]	15[a]	16[a]	Taken
Ethyne	0.190	0.25	0.21	0.21	-	-0.06	0.15
Prop-1-yne	0.183	0.25	0.13	0.20	0.13	0.10	0.15
But-1-yne	0.178	0.23	0.12	0.21	0.13	0.10	0.15
Pent-1-yne	0.172	0.23	0.12	0.21	0.12	0.09	0.12
Hex-1-yne	0.166	0.23	0.12	0.15	0.11	0.08	0.10
Hept-1-yne	0.160	0.23	0.12	0.13[b]	0.09	0.06	0.10
Oct-1-yne	0.155	0.23	0.12	0.11[b]	0.09	0.07	0.10
But-2-yne	0.261	0.30	0.00	0.20	-	-	0.15

[a]System in Table 4. [b]Using extrapolated values of logP (water-octanol) of 3.32 and 3.92 respectively.

Table 9. Comparison of $\Sigma\beta_2^H$ and β_2^H for activated aromatics

	$\Sigma\beta_2^H$	β_2^H
Anisole	0.29	0.26
Ethylphenyl ether	0.32	0.27
Phenol	0.30	0.22
o-Cresol	0.30	-
m-Cresol	0.34	0.24
p-Cresol	0.31	0.24
4-Fluorophenol	0.23	0.21
Benzyl alcohol	0.56	0.42
2-Phenylethanol	0.64	0.45

Solutes with a non-constant $\Sigma\beta_2$ value

As mentioned above, Leahy *et al.*[23] noted the possibility that the solute β value might vary with solvent system. In particular, they identified S=O and P=O bases that in terms of the LSER equation (9) had a variable β value. However, not all such bases behaved in this way: $PhSO_2Me$ and $PhSO_2NH_2$ had a constant β value, but PhSOMe and Ph_3PO had variable β values.

In the present analysis, solutes with a non-constant $\Sigma\beta_2$ value have also been identified. Of the particular solutes mentioned by Leahy *et al*,[23] $PhSO_2Me$ and $PhSO_2NH_2$ have again a constant $\Sigma\beta_2$ value (see Table 6), but sulphoxides, both aliphatic and aromatic, have variable $\Sigma\beta_2$ values. Not enough sound data was available to examine Ph_3PO in detail, but phosphate esters certainly have a constant $\Sigma\beta_2^H$ value (Table 6).

Two very important classes of bases, not discussed by Leahy *et al*,[23] were also found to have non-constant $\Sigma\beta_2$ values. These are the alkylanilines and alkylpyridines, although the nitroanilines and functionally substituted pyridines seem to behave normally (see Table 6). Examples of the calculated $\Sigma\beta_2$ values for some anilines, and pyridine itself, are given in Table 12, where the solvent systems are arranged in order of decreasing water content in the organic layer. Bearing in mind the expected error of 0·02–0·03 units in $\Sigma\beta_2$, the anilines definitely have larger $\Sigma\beta_2$ values in systems 2 and 3 than in systems 5–16, whereas pyridine has smaller $\Sigma\beta_2$ values in systems 1–3 than in systems 5–16.

Before investigating the origin of these effects, consideration must be given to the large set of log*P* values in systems 2, 11, 12, 14 and 15 for the 4-*n*-alkylpyridines up to *n*-nonylpyridine.[25] These log*P* values lead to very large differences between $\Sigma\beta_2$, calculated from set 2 (water–octanol) and from the other sets. However, the log*P* values refer to distributions between 1 mol dm^{-3} aqueous sodium chloride, and as Yeh and

Higuchi[25] pointed out, probably include some salting-out effect. They estimated that such an effect might contribute about 0·05 log units to log$P$ per methylene group. In Table 13 are given the original[25] log$P$ values and the corrected values for salting-out effects as suggested by Yeh and Higuchi.[25] Only the lower n-alkylpyridines are considered, because the corrections become very large for the longer chain compounds. In Table 14 are given calculated $\Sigma\beta_2$ values for the 4-methyl, 4-ethyl and 4-n-propyl compounds, using both the corrected Yeh and Higuchi log$P$ values and other literature values. There is reasonable agreement with, again, a marked division into two sets of $\Sigma\beta_2$ values.

The $\Sigma\beta_2$ values arising from sets 5–16 are denoted as $\Sigma\beta_2^H$, because these seem to be the 'normal' $\Sigma\beta_2$ values, in that they can be used in regression equations covering a wide range of processes, including GLC studies on acidic stationary phases. The $\Sigma\beta_2$ values from sets 1–4

Table 10. Effect of intramolecular hydrogen-bonding in phenols[a]

Substituent	$\Sigma\alpha_2^H$	$\Sigma\beta_2^H$	$\delta\Sigma\alpha_2^H$	$\delta\Sigma\beta_2^H$
None	0.60	0.30		
2-F	0.61	0.26	-0.02	0.03
3-F	0.68	0.17		
4-F	0.63	0.23		
2-Cl	0.32	0.31	-0.35	0.11
3-Cl	0.69	0.15		
4-Cl	0.67	0.20		
2-Br	0.35	0.31	-0.22	0.11
3-Br	0.70	0.16		
4-Br	0.67	0.20		
2-I	0.40	0.35	-0.28	0.15
3-I	0.70	0.18		
4-I	0.68	0.20		
2-OMe	0.22	0.52	-0.35	0.04
3-OMe	0.59	0.39		
4-OMe	0.57	0.48		
2-CN	0.74	0.33	0.05	0.04
3-CN	0.77	0.28		
4-CN	0.79	0.29		
2-NO_2	0.05	0.37	-0.77	0.11
3-NO_2	0.79	0.23		
4-NO_2	0.82	0.26		
2-OH	0.85	0.52	-0.31	-0.08
3-OH	1.10	0.58		
4-OH	1.16	0.60		

[a]$\delta\Sigma\alpha_2^H$ and $\delta\Sigma\beta_2^H$ are for the 2-substituent less the 4-substituent.

are denoted as $\Sigma\beta_2^O$, because the important water–octanol system, set 2, requires this basicity parameter. It should be noted that the equations summarized in Table 4 specifically exclude all compounds with a variable $\Sigma\beta_2$ value, and have been constructed only through $\Sigma\beta_2^H$ values. In Table 15 are summarized the $\Sigma\beta_2^H$ and $\Sigma\beta_2^O$ values obtained for solutes that exhibit variable $\Sigma\beta_2$ values.

These different $\Sigma\beta_2$ values do not arise through different Maria–Gal θ values. The F_1 and F_2 parameters in Table 1 can be applied to 18 solutes for which $\Sigma\beta_2^H$ and $\Sigma\beta_2^O$ values are available and lead to θ

Table 11. Effect of hydrogen-bonding on log*P*(water-cyclophexane)

Solute	c	rR	$s\pi_2^H$	$a\Sigma\alpha_2^H$	$b\Sigma\beta_2^H$	vV_x	— logP — calc	obs
2-Chlorophenol	0.12	0.72	-1.44	-1.99	-1.62	4.21	0.80	0.87
4-Chlorophenol	0.12	0.77	-1.94	-2.50	-1.03	4.21	-0.37	-0.35
2-Nitrophenol	0.12	0.87	-1.89	-0.19	-1.82	4.45	1.54	1.45
4-Nitrophenol	0.12	0.90	-3.10	-3.05	-1.27	4.45	-1.95	-2.05

Table 12. Examples of solutes with non-constant β_2 values

System	Aniline	p-Toluidine	N,N-Dimethyl-aniline	Pyridine
1				0.44
2	0.53	0.55	0.47	0.43
3	0.46	0.50		0.48
4	0.49			0.51
5	0.43		0.41	0.52
8	0.40	0.47		0.54
9	0.41	0.47		0.55
11	0.41	0.43	0.39	0.47
12	0.40	0.44	0.45	0.53
13	0.41	0.46	0.43	0.53
14	0.40	0.46	0.40	0.52
15		0.45	0.42	0.53
16		0.43	0.37	0.52
Average 1-3	0.50	0.52	0.47	0.45
Average 5-16	0.41±0.01	0.45±0.02	0.41±0.03	0.52±0.02

values of 73° and 74°, respectively, that is of the general order of β_2^H itself, 68°. The origin of this variable β_2 is thus not obvious. What can be deduced is that if $\Sigma\beta_2$ changes, so that the relative basicity is less in solvents such as octanol than it is in water, then the calculated $\Sigma\beta_2$ value from partition coefficients will appear to be too large. This is the situation with the anilines, where $\Sigma\beta_2^O > \Sigma\beta_2^H$. On the other hand, if the relative basicity is more in solvents such as octanol than it is in water, the calculated $\Sigma\beta_2$ value will appear to be too small. This is the case with pyridines, where $\Sigma\beta_2^O < \Sigma\beta_2^H$. One possibility is some type of preferential solvation that could involve the aromatic rings, in solvents where there is a high concentration of water at saturation. This might explain why the substituted compounds with deactivated aromatic rings either show this effect to a less extent, or even not at all. However, the different behaviour of anilines and pyridines must lead

Table 13. Corrected log*P* values used in the calculations[a] for 4-*n*-alkylpyridines

Set	4-Me	4-Et	4-n-Pr
11	1.77 (1.82)	2.35 (2.45)	2.93 (3.08)
12	0.79 (0.84)	1.40 (1.50)	2.00 (2.15)
14	0.16 (0.21)	0.73 (0.83)	

[a] Parenthesised values from ref 25, unparenthesised values corrected for salting-out as described in the text.

Table 14. Calculations of β_2 for pyridines

Set	4-Methyl	4-Ethyl	4-n-Propyl
2	0.425	0.460[a]	0.488
8	0.521		
9	0.584		
10	0.521		
11	0.523[b]	0.542[b]	0.558[b]
12	0.559[b]	0.570[b]	0.577[b]
13	0.568		
14	0.552[b]	0.555[b]	0.565
15	0.549	0.574	0.588
16	0.571	0.571	0.587
Average 8-16:	0.550	0.562	0.575
sd:	0.023	0.014	0.013

[a] Using an estimated value of 1.66 for logP. [b] Using the corrected logP values in Table 13.

Table 15. Values of $\Sigma\beta_2$ for solutes of variable relative basicity

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^O$	$\Sigma\beta_2^H$
Dimethylsulfoxide	0.522	1.74	0.00	0.75	0.88
Methylphenylsulfoxide	1.104	1.80	0.00	0.75	0.91
Diphenylsulfoxide	1.500	2.15	0.00	0.72	
Aniline	0.955	0.96	0.26	0.50	0.41
o-Toluidine	0.966	0.92	0.23	0.59	0.45
m-Toluidine	0.946	0.95	0.23	0.55	0.45
p-Toluidine	0.923	0.95	0.23	0.52	0.45
2-Ethylaniline	0.962	0.92	0.23	0.61	
4-Ethylaniline	0.942	0.91	0.23	0.55	
2,4-Dimethylaniline	0.950	0.95	0.20	0.62	
2,6-Dimethylaniline	0.972	0.89	0.20	0.59	0.46
N-Methylaniline	0.948	0.90	0.17	0.48	0.43
2-Methyl-N-methylaniline	0.959	0.98	0.17	0.47	
4-Methyl-N-methylaniline	0.916	0.98	0.17	0.47	
N-Ethylaniline	0.945	0.85	0.17	0.51	
N,N-Dimethylaniline	0.957	0.84	0.00	0.47	0.41
2-Methyl-N,N-dimethylaniline	1.090	0.65	0.00	0.55	
4-Methyl-N,N-dimethylaniline	0.940	0.83	0.00	0.48	
N,N-Diethylaniline	0.953	0.80	0.00	0.50	
4-Amino methyl benzoate	1.078	1.52	0.32	0.64	0.59
4-Amino ethyl benzoate	1.040	1.52	0.32	0.64	0.59
4-Amino propyl benzoate	1.030	1.50	0.32	0.64	0.59
4-Amino butyl benzoate	1.020	1.47	0.32	0.64	0.59
3-Amino acetophenone	1.230	1.35	0.30		0.60
4-Amino propiophenone	1.170	1.39	0.32	0.81	0.65
3-Aminobiphenyl	1.560	1.51	0.26	0.58	0.48
4-Aminobiphenyl	1.565	1.48	0.26	0.58	0.48
2-Fluoroaniline	0.744	0.88	0.28	0.44	
3-Fluoroaniline	0.749	1.08	0.30	0.37	
4-Fluoroaniline	0.760	1.09	0.28	0.41	
2-Chloroaniline	1.033	0.92	0.25	0.40	0.31
3-Chloroaniline	1.053	1.10	0.30	0.36	0.30
4-Chloroaniline	1.060	1.13	0.30	0.35	0.31
2-Bromoaniline	1.070	0.98	0.31	0.39	
3-Bromoaniline	1.128	1.19	0.31	0.34	
4-Bromoaniline	1.190	1.19	0.31	0.35	
2-Iodoaniline	1.290	1.00	0.31	0.45	
4-Iodoaniline	1.414	1.28	0.31	0.40	
3-Cyanoaniline	1.077	1.59	0.38	0.48	
2-Methoxyaniline	0.988	1.00	0.23	0.67	0.50
3-Methoxyaniline	1.027	1.10	0.25	0.72	0.59
4-Methoxyaniline	1.050	1.10	0.23	0.72	0.65
Pyridine	0.631	0.84	0.00	0.47	0.52
2-Methylpyridine	0.598	0.75	0.00	0.48	0.58
3-Methylpyridine	0.631	0.81	0.00	0.44	0.54
4-Methylpyridine	0.630	0.82	0.00	0.43	0.55
2,3-Dimethylpyridine	0.657	0.77	0.00	0.50	0.62
2,4-Dimethylpyridine	0.634	0.76	0.00	0.49	0.63
2,5-Dimethylpyridine	0.633	0.74	0.00	0.49	0.62
2,6-Dimethylpyridine	0.607	0.70	0.00	0.49	0.63
3,4-Dimethylpyridine	0.676	0.85	0.00	0.48	0.62
3,5-Dimethylpyridine	0.659	0.79	0.00	0.44	0.60
2,4,6-Trimethylpyridine	0.634	0.69	0.00	0.60	
2-Ethylpyridine	0.613	0.71	0.00	0.49	0.59
3-Ethylpyridine	0.640	0.79	0.00	0.47	0.57
4-Ethylpyridine	0.634	0.80	0.00	0.47	0.57
4-n-Propylpyridine	0.627	0.80	0.00	0.48	0.57
3-Formylpyridine	0.817	1.16	0.00	0.69	0.76

continued

Table 15. (*Continued*)

Solute	R_2	π_2^H	$\Sigma\alpha_2^H$	$\Sigma\beta_2^O$	$\Sigma\beta_2^H$
4-Formylpyridine	0.796	1.12	0.00	0.61	0.70
3-Acetylpyridine	0.795	1.17	0.00	0.76	0.90
4-Acetylpyridine	0.771	1.13	0.00	0.75	0.84
4-Aminopyridine	0.980	1.10	0.41	0.64	0.77
4-Dimethylaminopyridine	0.980	1.00	0.00	0.67	
Quinoline	1.268	0.97	0.00	0.51	0.54
2-Methylquinoline	1.287	0.88	0.00	0.53	
6-Methylquinoline	1.309	0.95	0.00	0.52	
7-Methylquinoline	1.305	0.95	0.00	0.54	
8-Methylquinoline	1.313	0.87	0.00	0.53	
Isoquinoline	1.211	1.00	0.00	0.47	0.54
Benzo[h]quinoline	1.878	1.22	0.00	0.50	
Indole	1.200	1.12	0.44	0.31	0.22
2-Methylindole	1.200	1.05	0.44	0.37	
3-Methylindole	1.200	1.06	0.44	0.35	
5-Methylindole	1.200	1.08	0.44	0.32	
N-Methylindole	1.206	0.92	0.00	0.36	0.31
Carbazole	1.787	1.42	0.47	0.26	
Imidazole	0.710	0.85	0.42	0.50	0.78
N-Methylimidazole	0.589	0.95	0.00	0.60	0.83
Benzimidazole	1.270	1.10	0.42	0.52	0.76
Pyrazole	0.620	1.00	0.54	0.34	0.45
N-Methylpyrazole	0.540	0.95	0.00	0.51	
Indazole	1.180	1.35	0.54	0.30	0.34
2-Aminothiazole	1.150	1.24	0.40	0.50	

to the conclusion that the anilines are preferentially solvated by the weakly acidic organic component in the organic layer, and the pyridines are preferentially solvated by the strongly acidic water component. In any event, the differences in $\Sigma\beta_2^H$ and $\Sigma\beta_2^O$ are not very large. Thus, for aniline itself, with values of 0·41 and 0·50, respectively, the difference in a calculated log$P$ value when the constant b is, say, −3·40 will be 0·31 log units, that is, just over two standard deviations in the water–octanol regression equation. However, it seems useful to be able to take this into account.

Only for the anilines is it possible to construct equations for substituent effects, as follows:

$$\Sigma\beta_2^O(m\text{-anilines}) = 0{\cdot}503 - 0{\cdot}459\sigma_I - 0{\cdot}244\sigma_R \quad (15)$$

$n = 5$; $\rho = 0{\cdot}9968$; $sd = 0{\cdot}011$; $F = 153{\cdot}7$

$$\Sigma\beta_2^O(m\text{-anilines}) = 0{\cdot}512 - 0{\cdot}455\sigma_M \quad (16)$$

$n = 5$; $\rho = 0{\cdot}9867$; $sd = 0{\cdot}018$; $F = 110{\cdot}2$

$$\Sigma\beta_2^O(p\text{-anilines}) = 0{\cdot}497 - 0{\cdot}404\sigma_I - 0{\cdot}247\sigma_R \quad (17)$$

$n = 7$; $\rho = 0{\cdot}9735$; $sd = 0{\cdot}023$; $F = 36{\cdot}2$

$$\Sigma\beta_2^O(p\text{-anilines}) = 0{\cdot}466 - 0{\cdot}440\sigma_p \quad (18)$$

$n = 7$; $\rho = 0{\cdot}9355$; $sd = 0{\cdot}032$; $F = 35{\cdot}1$

Equation (15) can be used to estimate $\Sigma\beta_2^O$ values for 3-ethylaniline (0·54) and 3-iodoaniline (0·36), so that $\Sigma\beta_2^O$ is known or estimated for all the eight *m*- and *p*-substituted haloanilines.

Although Leahy *et al.*[23] are the only previous workers to attempt to extract $\Sigma\beta_2$ values directly from LSER equations that relate to log$P$ values, El Tayar *et al.*[17] have developed an indirect method for obtaining $\Sigma\alpha_2$ and $\Sigma\beta_2$ values. They define polar interactive parameters through the equations

$$\log P_{oct} = av + b\Lambda_{oct} \quad (19)$$

$$\log P_{alk} = av + b\Lambda_{alk} \quad (20)$$

where v is the calculated solute van der Waals volume. Then, knowing logP_{oct}, logP_{alk} and v, the polar parameters Λ_{oct} and Λ_{alk} can be obtained. El Tayar *et al.*[17] then showed that Λ_{oct} and Λ_{alk} can be related to parameters such as π_2, $\Sigma\alpha_2$ and $\Sigma\beta_2$. It may turn out that quantities such as Λ_{oct} and Λ_{alk} are useful in the interpretation of effects of solutes in solution, but the indirect method is not very suitable for the determination of $\Sigma\alpha_2$ or $\Sigma\beta_2$ values through back-calculations.

Finally, it should be pointed out that the $\Sigma\beta_2$ values obtained in this work are suitable for use in regression equations (5) and (6). They should not be used in combination with any descriptors other than those in these equations.

CONCLUSION

An analysis of partition coefficients, as log$P$ values, of solutes between water and 16 phases (including the gas phase) has shown that for the majority of solutes it is possible to define a hydrogen-bond basicity descriptor, $\Sigma\beta_2^H$, the value of which remains constant over all the phases. For certain solutes, transfers between water and phases that are considerably aqueous (e.g. isobutanol, octanol and *n*-butyl acetate) require another basicity parameter denoted as $\Sigma\beta_2^O$. This finding is in agreement with previous work by Leahy *et al.*[23]

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APPENDIX

Calculation of descriptors

The general equations (5) and (6) are easy to handle for solutes with only one descriptor (usually $\Sigma\beta_2^H$) missing. However, if enough log$P$ values are available, for different solvent systems, it is possible to obtain reasonable estimates of two or more missing descriptors. Indeed, for complicated solutes, such as drug molecules, this is one of the few practical methods of determining descriptors. As an example of the determination of two descriptors, trimethyl phosphate can be cited. Both R_2 (0·113) and Vx (0·9707) are available, but neither π_2^H nor $\Sigma\beta_2^H$ is known. Fortunately, log$P$ values are available in seven systems, and both π_2^H and $\Sigma\beta_2^H$ can be obtained by trial and error. One method is to calculate and then average $\Sigma\beta_2^H$ for a range of π_2^H values, and then select the $\Sigma\beta_2^H$ average with the smallest standard deviation. With trimethyl phosphate, this was found at $\pi_2^H = 1{\cdot}10$ units, giving rise to the calculated $\Sigma\beta_2^H$ values listed in Table 16. Also given are the log$P$ values that can be regenerated using $\pi_2^H = 1{\cdot}10$ and $\Sigma\beta_2^H$ as 1·00, the average of the seven values. Of course, the observed and calculated log$P$ values must be in reasonable agreement, but this is a useful check on the calculated $\Sigma\beta_2^H$ value.

A more lengthy procedure is needed to calculate the three missing descriptors π_2^H, $\Sigma\alpha_2^H$ and $\Sigma\beta_2^H$, although a value of $\Sigma\alpha_2^H$ can often be deduced (as an initial value) from the 1 : 1 α_2^H values. In any case, both π_2^H and $\Sigma\alpha_2^H$ have to be varied until the average $\Sigma\beta_2^H$ value shows the lowest *sd* value. For 4-hydroxy methyl benzoate, or methyl paraben, $R_2 = 0{\cdot}900$ and $Vx = 1{\cdot}1320$; then with the 'best' values for π_2^H of 1·37 and $\Sigma\alpha_2^H$ of 0·69, an average $\Sigma\beta_2^H$ value of 0·434 may be calculated, as above. Comparison with other alkyl parabens leads to a general $\Sigma\beta_2^H$ of 0·45 units, and in Table 17 the calculated and observed log$P$ values are given. They show that the designated solute descriptors can reproduce the log$P$ values with an average deviation of 0·15

log units, i.e. not much more than the *sd* in the defining equations (Table 4). However, the calculations also show how outlying log*P* values can be identified and how log*P* values that are very difficult to measure can be estimated; as an example, the water–gas–phase partition coefficient is given in Table 17.

Table 16. The calculation of π_2^H and $\Sigma\beta_2^H$ for trimethyl phosphate

System	logP		$\Sigma\beta_2^{II}$(calc)[a]	logP(calc)[b]
Octanol	-0.78		1.007	-0.75
Benzene	-0.70		0.985	-0.77
Chloroform	0.76		0.969	0.65
Tetrachloromethane	-1.07		0.983	-1.15
Cyclohexane	-2.22		1.018	-2.13
Alkane	-2.22		1.014	-2.15
		avg:	0.996	
		sd:	0.020	

[a] With R_2 = 0.113 and Vx = 0.9707, and with the 'best' value of 1.10 for π_2^{II}. [b]Using π_2^{II} = 1.10 and $\Sigma\beta_2^{II}$ = 1.00 units.

Table 17. Calculated and observed log*P* values for 4-hydroxymethyl benzoate

System	logP(obs)	logP(calc)[a]
Octanol	1.96	1.92
n-Butyl acetate	2.40	2.33
Nitrobenzene	1.53	1.55
Benzene	0.79	0.66
Toluene	0.77	0.54
Olive oil	0.38	0.64
Chloroform	1.23	0.94
Tetrachloromethane	0.56	-0.21
Cyclohexane	-1.24 to 0.40	-1.06
Alkane	-0.93 to -0.13	-1.16
Gas phase	-	-6.89

[a] using R = 0.900, π_2^{II} = 1.37, $\Sigma\alpha_2^{II}$ = 0.69, $\Sigma\beta_2^{II}$ = 0.45 and Vx = 1.1320