HIGHLIGHTS

- Solute descriptors calculated from measured 2-methyl-6-nitroaniline solubilities

- Solute descriptors calculated from measured 5-nitro-8-hydroxyquinoline solubilities

- Solute descriptors calculated from measured terephthaldialdehyde solubilities

- Calculated solute descriptors are used to estimate solubilities in additional organic solvents

Abraham Model Linear Free Energy Relationships as a Means of Extending Solubility Studies to Include the Estimation of Solute Solubilities in Additional Organic Solvents

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Abstract

Abraham model solute descriptors are calculated for 5-nitro-8-hydroxyquinoline, 2-methyl-6-nitroaniline, and terephthaldialdehyde using experimental solubility data taken from papers published in *This Journal* in 2016. The calculated solute descriptors are then used to predict the solubility of the three fore-mentioned solutes in 29 different organic solvents of varying polarity and hydrogen-bonding character.

Key Words and Phrases: solubility; crystalline nonelectrolyte solutes; predictive methods; solute descriptors

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1. Introduction

In the last five years there has been a significant increase in the number of papers that report experimental solubility data, both in *This Journal* [1-6] and in other journals published by Elsevier [7-12]. The majority of these publications have pertained to the solubility of a crystalline nonelectrolyte solute in several neat organic solvents and/or in one or more binary solvent system(s). In the case of neat solvents the authors determined the solubility at several temperatures, and for binary solvent mixtures the solubility was often measured as both a function of temperature and binary solvent composition. The purpose of the studies was to provide measured solubility data that could be used in selecting a suitable solvent for solute purification through recrystallization or for solute solubilization for quantitative analysis, drug formulations and other practical applications. Most of the published papers provided mathematical representations describing how the solute solubility varied with temperature (e.g. modified Apelblat model [13], Buchowski-Ksiazczak λh model [14]) and binary solvent composition (e.g. Combined NIBS/Redlich-Kister model [15,16], Jouyban-Acree model [17,18]). While such publications do provide valuable experimental data regarding the solubility of the given solute molecule in the few organic solvents (or solvent mixtures) studied, there was very little discussion given regarding how the measured data could be used to predict the solubility of the solute in additional solvents or solvent systems outside of the solvents studied by the reporting authors.

Quantitative structure-property relationships (QSPRs) and linear free energy relationships (LFERs) provide a convenient means for authors to extend their experimental studies to include expressions capable of making solubility predictions in additional organic solvents. Of the QSPR and LFER methods, the Abraham solvation parameter model [19-22] is perhaps the most versatile of the published methods in that the model uses a single set of solute properties (called solute

descriptors) for all neat organic solvents and partitioning systems. Mathematical equations have

been derived for predicting the solubility of crystalline nonelectrolyte organic solutes in more than

100 different organic solvents:

$$\log (P \text{ or } C_{\text{S,organic}}/C_{\text{S,water}}) = c_p + e_p \cdot \mathbf{E} + s_p \cdot \mathbf{S} + a_p \cdot \mathbf{A} + b_p \cdot \mathbf{B} + v_p \cdot \mathbf{V} \qquad (1)$$

$$\log (K \text{ or } C_{\text{S,organic}}/C_{\text{S,gas}}) = c_k + e_k \cdot \mathbf{E} + s_k \cdot \mathbf{S} + a_k \cdot \mathbf{A} + b_k \cdot \mathbf{B} + l_k \cdot \mathbf{L} \qquad (2)$$

where $C_{\text{S,organic}}$ is the molar solubility of the solute in the organic solvent, $C_{\text{S,water}}$ is the molar

solubility of the solute in water, and $C_{\text{S,gas}}$ is a molar solute concentration in the gas phase. The

dependent variables in Eqns. 1 and 2 are the logarithms of solute molar solubility ratios, $\log (P$ or

$C_{\text{S,organic}}/C_{\text{S,water}})$ and $\log (K$ or $C_{\text{S,organic}}/C_{\text{S,gas}})$, logarithms of the solute water-to-partition

coefficients, $\log P$, and logarithms of the solute gas-to-water partition coefficients, $\log K$. The

independent variables on the right-hand side of Eqns. 1 and 2 are the solute descriptors, which are

identified by the uppercase alphabetical letters.   The solute descriptors are defined as: $\mathbf{E}$

corresponds to the solute excess molar refractivity in units of $(\text{cm}^3 \text{ mol}^{-1})/10$, $\mathbf{S}$ quantifies the

dipolarity/polarizability of the solute, $\mathbf{A}$ and $\mathbf{B}$ measure the overall or total hydrogen-bond acidity

and basicity, $\mathbf{V}$ refers to the McGowan volume in units of $(\text{cm}^3 \text{ mol}^{-1})/100$, and $\mathbf{L}$ is defined as the

logarithm of the gas-to-hexadecane partition coefficient at 298 K. Solute descriptors are calculable

from measured solubility and partition coefficient data by constructing a series of mathematical

equations in the form of Eqns. 1 and 2. Once the descriptor values have been calculated one can

use their numerical values to estimate the solubility and partition coefficients of the solute in more

than 100 different organic solvents and partitioning systems. The lowercase solvent and process

equation coefficients need in these calculations are available in several of our earlier publications

[20-22]. In Table 1 we have compiled a list of equation coefficients from our earlier publications

for the solvents that we are using in the solute descriptor calculations. The equation coefficients

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pertain to either "dry" or "wet" solvents depending upon whether the organic solvent has been in physical contact with water as would be the case in a direct water-to-organic solvent partitioning process. In the case of the direct partitioning process the organic phase is the water-saturated organic solvent and the aqueous phase is water saturated with the organic solvent. For several partitioning processes the mutual solubility of water and the organic solvent is very small, such as for cyclohexane and toluene, and the same set of equation coefficients is used for the "wet" and "dry" organic solvent.

We illustrate the calculation of solute descriptors for 5-nitro-8-hydroxyquinoline, 2-methyl-6-nitroaniline, and terephthaldialdehyde using experimental solubility data taken from papers published in *This Journal* in 2016. The examples provide us with the opportunity to illustrate the computation method whenever both experimental partition coefficient and solubility data are available, and the case whenever one has only experimental solubility data. The latter two examples will likely be more useful to authors as many of the published solubility studies pertain to solutes for which experimental partition coefficient data is lacking.

2. Solute Descriptor Calculation for 5-Nitro-8-hydroxyquinoline

The computational method for determining solute descriptors is first illustrated for 5-nitro-8-hydroxyquinoline, which is solute for which we recently calculated solute descriptors ($\mathbf{E}$ = 1.66, $\mathbf{S}$ = 1.86, $\mathbf{A}$ = 0.20, $\mathbf{B}$ = 0.53, $\mathbf{V}$ = 1.2772, and $\mathbf{L}$ = 7.490) based on experimental log P data [21]. The published mole fraction solubility data of Cong et al. [4] for 5-nitro-8-hydroxyquinoline dissolved in acetonitrile, ethyl acetate, methanol, ethanol, propan-1-ol, butan-1-ol, propan-2-ol, propanone, toluene and acetic acid at 298.15 K is used to update our existing solute descriptor values. Mole fraction solubilities, $x_{S,Organic}$, are converted to molar solubilities, $C_{S,Organic}$, by dividing $x_{S,Organic}$ by the ideal molar volume of the saturated solution:

$$C_{S,pyridine} \approx x_{S,organic}/V_{ideal\ soln} \tag{3}$$

$$V_{ideal\ soln} = x_{S,organic}\,V_{Solute} + (1 - x_{S,organic})\,V_{Solvent} \tag{4}$$

The molar volume of 5-nitro-8-hydroxyquinoline, $V_{solute}/(cm^3\ mol^{-1}) = 131.5$, was calculated by summing group volume values for the different functional groups contained in the molecule. The mole fraction solubility is sufficiently small that the solute's volume makes only a very small contribution to the molar volume of the saturated solution. The calculated molar solubilities and logarithms of the water-to-organic solvent partition coefficients [23] are tabulated in Table 2. In total there are 16 experimental values that can be used in determining the solute descriptors of 5-nitro-8-hydroxyquinoline.

There are six solute descriptors, however, two of the solute descriptors can be calculated based on molecular structure considerations. The McGowan characteristic volume, **V**, can be calculated from the molecular structure, atomic sizes and number of bonds as described elsewhere [24]. The **E** solute descriptor can be estimated by the PharmaAlgorithm software [25], which is based on molecular structure considerations using fragment group values [26,27], or calculated using a measured value (liquid solute) or an estimated value (solid solute) for the solute's refractive index. The refractive index of solid solutes can be estimated using the (free) ACD software [28]. The values of **V** and **E** that we calculate are **V** = 1.2772 and **E** = 1.820 [25]. This leaves us with three solute descriptors (**S**, **A** and **B**) to be calculated from the measured experimental partition coefficient and solubility data. In the present case, the aqueous molar solubility of 5-nitro-8-hydroxyquinoline is unknown, which leaves us with a fourth value to be calculated.

It is possible to double the number of equations by converting all the log (P or $C_{S,organic}/C_{S,water}$) values into log ($K$ or $C_{S,organic}/C_{S,gas}$) values through Eq. 5, where K_w is the gas-

to-water partition coefficient (unit-less if concentrations in the gas phase and the aqueous phase are both in mol L^{-1})

$$\log (P \text{ or } C_{\text{S,organic}}/C_{\text{S,water}}) = \log (K \text{ or } C_{\text{S,organic}}/C_{\text{S,gas}}) - \log K_{\text{w}} \qquad (5)$$

Then if sixteen $\log (P \text{ or } C_{\text{S,organic}}/C_{\text{S,water}})$ values are available, as is the case here, sixteen more equations in $\log (K \text{ or } C_{\text{S,organic}}/C_{\text{S,gas}})$ can be used, and two more equations in $\log K_{\text{w}}$ are also available

$$\log K_{\text{w}} = -0.994 + 0.577 \mathbf{E} + 2.549 \mathbf{S} + 3.813 \mathbf{A} + 4.841 \mathbf{B} - 0.869 \mathbf{V} \qquad (6)$$

$$\log K_{\text{w}} = -1.271 + 0.822 \mathbf{E} + 2.743 \mathbf{S} + 3.904 \mathbf{A} + 4.814 \mathbf{B} - 0.213 \mathbf{L} \qquad (7)$$

Log K_{w} will normally have to be found by trial-and-error, so that two extra descriptors ($\mathbf{L}$ and log K_{w}) have to be determined. The 34 equations that available are sufficient in number to calculate the four missing descriptors ($\mathbf{S}$, $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{L}$), the aqueous molar solubility of 5-nitro-8-hydroxyquinoline ($C_{\text{S,water}}$) and log K_{w}. The 34 equations were solved simultaneously using Microsoft Solver software to yield numerical values of: $\mathbf{E} = 1.820$; $\mathbf{S} = 1.697$; $\mathbf{A} = 0.133$; $\mathbf{B} = 0.631$; $\mathbf{V} = 1.2772$; $\mathbf{L} = 7.615$; log $C_{\text{S,water}} = -3.639$; and log $K_{\text{w}} = 6.829$ with the overall standard error being SE = 0.110 log units. This method has been applied extensively to the solubility of solids by Acree, Abraham and coworkers to chemically diverse organic solutes [29-33], including both the monomeric [31,32] and dimeric forms [33] of carboxylic acids. The updated solute descriptors are only slightly different than our earlier values, which were based on a much smaller data set containing only 7 experimental log P values. As an informational note, there is an experimental value of log $C_{\text{S,water}} = -3.863$ for the solubility of 5-nitro-8-hydroxyquinoline in a aqueous buffer solution (pH = 4.5) [34]. The solubility of 5-nitro-8-hydroxyquinoline in an aqueous buffer solution should be different than the molar solubility in water. One would expect a slightly lower solubility in a buffered solution due to the salting-out effect by the ions present.

3. Solute Descriptor Calculation for Terephthaldialdehyde

The next computational examples involves terephthaldialdehyde, which is a solute for which we have a very preliminary set of solute descriptors ($\mathbf{E}$ = 1.030; $\mathbf{S}$ = 1.294 ± 0.059; $\mathbf{A}$ = 0.000; $\mathbf{B}$ was not determined; $\mathbf{V}$ =1.0296; $\mathbf{L}$ = 5.500 ± 0.379) based on gas chromatographic retention measurements on two liquid stationary phase [35]. The recently published experimental data of Xu and coworkers [5] for terephthaldialdehyde dissolved in ethanol, propan-1-ol, butan-1-ol, propan-2-ol, 3-methylbutan-1-ol, propanone, butanone, acetonitrile and N,N-dimethylformamide provides the opportunity to update our existing solute descriptors using a much larger database. As before the published mole fraction solubilities are converted to molar solubilities using a value of $V_{solute}/(cm^3\ mol^{-1})$ = 117.5 for the molar volume of terephthaldialdehyde. The calculated molar solubilities are given in Table 3, along with a calculated log P value that was taken from Netzeva and Schultz [36]. The calculated log P value was based on the CLogP method. The values of $\mathbf{V}$ and $\mathbf{E}$ that we calculate are $\mathbf{V}$ = 1.0296 and $\mathbf{E}$ = 1.030 [25], and the value of the $\mathbf{A}$ solute descriptor is set equal to zero as terephthaldialdehyde cannot act as a hydrogen-bond donor as the molecule lacks an acidic hydrogen. This leaves us with just three solute descriptors ($\mathbf{S}$, $\mathbf{B}$ and $\mathbf{L}$), an aqueous molar solubility and log K_w value to calculate from a total of 22 log (P or $C_{S,organic}/C_{S,water}$) and log ($K$ or $C_{S,organic}/C_{S,gas}$) equations. The equations were solved simultaneously using Microsoft Solver software to yield numerical values of: $\mathbf{E}$ = 1.030; $\mathbf{S}$ = 1.235; $\mathbf{A}$ = 0.000; $\mathbf{B}$ = 0.566; $\mathbf{V}$ = 1.2772; $\mathbf{L}$ = 5.235; log $C_{S,water}$ = -1.852; and log K_w = 4.591 with the overall standard error being SE = 0.079 log units. The updated solute descriptors back-calculate the observed solubility data (see numerical entries in Table 3) and fall within the range encompassed by our preliminary numerical values.

4. Solute Descriptor Calculation for 2-Methyl-6-nitroaniline

The final computational example pertains to 2-methyl-6-nitroaniline, which is a solute for which solute descriptors are not available in an online, noncommercial database. The Helmholtz Center for Environmental Research - UFZ [37] provides an online Abraham model solute descriptor database that is searchable by compound name and Chemical Abstract Services Registry Number (CAS-RN). The database contains solute descriptors for several thousand organic compounds. Solute descriptors for 2-methyl-6-nitroaniline can be calculated, however, from the recently published solubility measurements of Cong and coworkers [1]. The authors determined the mole fraction solubility of 2-methyl-6-nitroaniline in ten organic solvents (cyclohexane, toluene, methanol, ethanol, propan-1-ol, propan-2-ol, 1,4-dioxane, ethyl acetate, propanone and acetonitrile). Mole fraction solubilities are converted to molarity-based solubilities using Eqns. 3 and 4, and value of $V_{solute}/(cm^3 \ mol^{-1}) = 124.0$ for the molar volume of 2-methyl-6-nitroaniline. The calculated molar solubilities are listed in Table 4 along with a calculated log $P = 2.29$ [28] for the water-to-octanol partition coefficient. The measured partition coefficient and molar solubility data provides us with 11 log (P or $C_{S,organic}/C_{S,water}$) and 11 log ($K$ or $C_{S,organic}/C_{S,gas}$) equations, plus the two log K_w equations , to use in the solute descriptor computations. The values of $\mathbf{V}$ and $\mathbf{E}$ that we calculate are $\mathbf{V} = 1.1313$ and $\mathbf{E} = 1.190$ [25]. The equations were solved simultaneously using Microsoft Solver software to yield numerical values of: $\mathbf{E} = 1.190$; $\mathbf{S} = 1.530$; $\mathbf{A} = 0.207$; $\mathbf{B} = 0.342$; $\mathbf{V} = 1.1313$; $\mathbf{L} = 6.135$; log $C_{S,water} = -2.830$; and log $K_w = 5.060$ with the overall standard error being SE = 0.058 log units. The low standard error suggests that the calculated solute descriptors can be used to predict the solubility of 2-methyl-6-nitroaniline in additional organic solvents for which we have determined equation coefficients. To date we have derived Abraham

model predictive equations for more than 100 different organic solvents. The predictive nature of the Abraham model will be illustrated shortly.

5. Solubility Predictions in Additional Organic Solvents

The majority of solubility papers that have been published in *This Journal* have reported solubility at several temperatures, and used as either the modified Apelblat equation [13] or Buchowski-Ksiazczak λh model [14] as the mathematical representation for how the mole fraction solubility varies with temperature. Such mathematical descriptions are useful in designing separation processes if needs to know the solubility of the solute in one of the studied organic solvents at a particular temperature. What is often needed in design applications, however, is knowledge of the solubility of solutes in many different organic solvents so that one can make an appropriate solvent selection for liquid-liquid extractions or recrytallizations. Neither the modified Apelblat equation nor Buchowski-Ksiazczak λh model provides this type of solubility information. The Abraham solvation parameter model, on the other hand, allows one to estimate the solubility of the solute in additional organic solvents once the solute descriptors have been calculated. In Table 5 we have tabulated the predicted log $C_{S,organic}$ values for 5-nitro-8-hydroxyquinoline, terephthaldialdehyde, and 2-methyl-6-nitroaniline in 29 different organic solvents. The predictions were achieved by simply substituting the equation coefficients from Table 1 and the calculated solute descriptors into Eqns. 1 and 2. The calculated logarithms of the molar solubility ratios, log ($C_{S,organic}/C_{S,water}$) and log ($C_{S,organic}/C_{S,gas}$), are converted to log $C_{S,organic}$ values using the numerical values of log $C_{S,water}$ and log K_w from the respective solute descriptor computations. Solubility and partition coefficient predictions can be made for the more than 100 solute transfer processes for which we have determined equation coefficients. A more complete listing of equation coefficients for chemical systems [20-22] and for biological systems [38-40] can be found

elsewhere. For solubility calculations one will need to use the coefficients designated for "Dry" or "Wet/Dry" organic solvents.

6. Concluding Remarks

One of the stated objectives of many of the solubility studies published in *This Journal* in the last five years has been to determine solubility data that is needed in the solvent selection for liquid-liquid and for recrystallizations. Experimental data is reported for only a few of the common organic solvents that are used in commercial separation processes. The Abraham solvation parameter model is shown to provide a convenient means of furthering these objectives. Researchers have at hand a simple method for predicting solubilities in solvents that were not studied in the experimental determinations.

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Table 1. Equation coefficients for Abraham Model Log (P or $C_{S,organic}/C_{S,water}$) and Log ($K$ or $C_{S,organic}/C_{S,gas}$) Correlations

Solvent	Type	c	e	s	a	b	l	v
Water-to-Organic Solvent, Eqn. 1								
Octan-1-ol	Wet	0.088	0.562	-1.054	0.034	-3.460	0.000	3.814
Dichloromethane	Wet/Dry	0.319	0.102	-0.187	-3.058	-4.090	0.000	4.324
Trichloromethane	Wet/Dry	0.191	0.105	-0.403	-3.112	-3.514	0.000	4.395
Tetrachloromethane	Wet/Dry	0.199	0.523	-1.159	-3.560	-4.594	0.000	4.618
1,2-Dichloroethane	Wet/Dry	0.183	0.294	-0.134	-2.801	-4.291	0.000	4.180
Cyclohexane	Wet/Dry	0.159	0.784	-1.678	-3.740	-4.929	0.000	4.577
Benzene	Wet/Dry	0.142	0.464	-0.588	-3.099	-4.625	0.000	4.491
Toluene	Wet/Dry	0.125	0.431	-0.644	-3.002	-4.748	0.000	4.524
Chlorobenzene	Wet/Dry	0.065	0.381	-0.521	-3.183	-4.700	0.000	4.614
Methanol	Dry	0.276	0.334	-0.714	0.243	-3.320	0.000	3.549
Ethanol	Dry	0.222	0.471	-1.035	0.326	-3.596	0.000	3.857
Propan-1-ol	Dry	0.139	0.405	-1.029	0.247	-3.767	0.000	3.986
Butan-1-ol	Dry	0.165	0.401	-1.011	0.056	-3.958	0.000	4.044
Pentan-1-ol	Dry	0.150	0.536	-1.229	0.141	-3.864	0.000	4.077
Octan-1-ol	Dry	-0.034	0.489	-1.044	-0.024	-4.235	0.000	4.218
Propan-2-ol	Dry	0.099	0.344	-1.049	0.406	-3.827	0.000	4.033
2-Methylpropan-1-ol	Dry	0.188	0.354	-1.127	0.016	-3.568	0.000	3.986
Butan-2-ol	Dry	0.127	0.253	-0.976	0.158	-3.882	0.000	4.114
2-Methylpropan-2-ol	Dry	0.211	0.171	-0.947	0.331	-4.085	0.000	4.109
3-Methylbutan-1-ol	Dry	0.073	0.360	-1.273	0.090	-3.770	0.000	4.273
Tetrahydrofuran	Dry	0.223	0.363	-0.384	-0.238	-4.932	0.000	4.450
1,4-Dioxane	Dry	0.123	0.347	-0.033	-0.582	-4.810	0.000	4.110
Methyl acetate	Dry	0.351	0.223	-0.150	-1.035	-4.527	0.000	3.972
Ethyl acetate	Dry	0.328	0.369	-0.446	-0.700	-4.904	0.000	4.150

Propanone	Dry	0.313	0.312	-0.121	-0.608	-4.753	0.000	3.942
Butanone	Dry	0.246	0.256	-0.080	-0.767	-4.855	0.000	4.148
Cyclohexanone	Dry	0.038	0.225	0.058	-0.976	-4.842	0.000	4.315
Carbon disulfide	Wet/Dry	0.047	0.686	-0.943	-3.603	-5.818	0.000	4.921
Dimethylformamide	Dry	-0.305	-0.058	0.343	0.358	-4.865	0.000	4.486
Acetonitrile	Dry	0.413	0.077	0.326	-1.566	-4.391	0.000	3.364
Acetic acid	Dry	0.175	0.174	-0.454	-1.073	-2.789	0.000	3.725
Gas-to-Organic Solvent, Eqn. 2								
Octan-1-ol	Wet	-0.198	0.002	0.709	3.519	1.429	0.858	0.000
Dichloromethane	Wet/Dry	0.192	-0.572	1.492	0.460	0.847	0.965	0.000
Trichloromethane	Wet/Dry	0.157	-0.560	1.259	0.374	1.333	0.976	0.000
Tetrachloromethane	Wet/Dry	0.217	-0.435	0.554	0.000	0.000	1.069	0.000
1,2-Dichloroethane	Wet/Dry	0.017	-0.337	1.600	0.774	0.637	0.921	0.000
Cyclohexane	Wet/Dry	0.163	-0.110	0.000	0.000	0.000	1.013	0.000
Benzene	Wet/Dry	0.107	-0.313	1.053	0.457	0.169	1.020	0.000
Toluene	Wet/Dry	0.085	-0.400	1.063	0.501	0.154	1.011	0.000
Chlorobenzene	Wet/Dry	0.064	-0.399	1.151	0.313	0.171	1.032	0.000
Methanol	Dry	-0.039	-0.338	1.317	3.826	1.396	0.773	0.000
Ethanol	Dry	0.017	-0.232	0.867	3.894	1.192	0.846	0.000
Propan-1-ol	Dry	-0.042	-0.246	0.749	3.888	1.076	0.874	0.000
Butan-1-ol	Dry	-0.004	-0.285	0.768	3.705	0.879	0.890	0.000
Pentan-1-ol	Dry	-0.002	-0.161	0.535	3.778	0.960	0.900	0.000
Octan-1-ol	Dry	-0.147	-0.214	0.561	3.507	0.749	0.943	0.000
Propan-2-ol	Dry	-0.048	-0.324	0.713	4.036	1.055	0.884	0.000
2-Methylpropan-1-ol	Dry	-0.003	-0.357	0.699	3.595	1.247	0.881	0.000
Butan-2-ol	Dry	-0.034	-0.387	0.719	3.736	1.088	0.905	0.000
2-Methylpropan-2-ol	Dry	0.053	-0.443	0.699	4.026	0.882	0.907	0.000
3-Methylbutan-1-ol	Dry	-0.052	-0.430	0.628	3.661	0.932	0.937	0.000

2-Pentanol	Dry	-0.031	-0.325	0.496	3.792	1.024	0.934	0.000
Tetrahydrofuran	Dry	0.193	-0.391	1.244	3.256	0.000	0.994	0.000
1,4-Dioxane	Dry	-0.034	-0.389	1.724	2.989	0.000	0.922	0.000
Methyl acetate	Dry	0.134	-0.477	1.749	2.678	0.000	0.876	0.000
Ethyl acetate	Dry	0.182	-0.352	1.316	2.891	0.000	0.916	0.000
Propanone	Dry	0.127	-0.387	1.733	3.060	0.000	0.866	0.000
Butanone	Dry	0.112	-0.474	1.671	2.878	0.000	0.916	0.000
Cyclohexanone	Dry	-0.086	-0.441	1.725	2.786	0.000	0.957	0.000
Carbon disulfide	Wet/Dry	0.101	0.251	0.177	0.027	0.095	1.068	0.000
N,N-Dimethylformamide	Dry	-0.391	-0.869	2.107	3.774	0.000	1.011	0.000
Acetonitrile	Dry	-0.007	-0.595	2.461	2.085	0.418	0.738	0.000
Acetic acid	Dry	-0.070	-0.366	1.300	2.736	2.117	0.796	0.000
NIST retention index	Dry	0.070	0.012	0.076	0.000	0.000	0.200	0.000

Table 2. Comparison Between Experimental Logarithm of Water-to-Organic Solvent Partition Coefficients, Log P, and Logarithm of the Molar Solubilities, Log $C_{S,organic}$, and Calculated Values Using the Updated Solute Descriptors for 5-Nitro-8-nitroquinoline

Solvent	Experimental Values		Back-Calculated Values		
	Log P	Log $C_{s,organic}$	log P	Log $C_{s,organic}$; Eqn. 1	Log $C_{s,organic}$; Eqn. 2
Octan-1-ol	1.98		2.016		
Chloroform	2.64		2.683		
Tetrachloromethane	1.85		1.713		
1,2-Dichloroethane	2.70		2.752		
Benzene	2.53		2.397		
Carbon disulfide	1.89		1.834		
Methanol		-1.656		-1.495	-1.613
Ethanol		-1.698		-1.615	-1.691
Propan-1-ol		-1.801		-1.761	-1.837
Butan-1-ol		-1.859		-1.783	-1.864
Propan-2-ol		-1.859		-1.903	-1.963
Toluene		-1.382		-1.437	-1.444
Propanone		-1.018		-1.006	-1.103
Acetonitrile		-1.359		-1.212	-1.221
Ethyl acetate		-1.173		-1.281	-1.334
Acetic acid		-1.145		-1.061	-1.238
NIST retention index	1.841[a]				

[a] Value is the retention index divided by 1000.

Table 3. Comparison Between Experimental Logarithm of Water-to-Organic Solvent Partition Coefficients, Log P, and Logarithm of the Molar Solubilities, Log $C_{S,organic}$, and Calculated Values Using the Updated Solute Descriptors for Terephthaldialdehyde

	Experimental Values		Back-Calculated Values		
Solvent	Log P	Log $C_{s,organic}$	log P	Log $C_{s,organic}$; Eqn. 1	Log $C_{s,organic}$; Eqn. 2
Octan-1-ol	1.360		1.333		
Ethanol		-0.474		-0.488	-0.491
Propan-1-ol		-0.549		-0.596	-0.629
Butan-1-ol		-0.626		-0.600	-0.636
Propan-2-o1		-0.878		-0.709	-0.719
3-Methylbutan-1-ol		-0.623		-0.715	-0.730
Propanone		0.012		0.000	-0.042
Butanone		-0.036		0.080	0.039
Acetonitrile		0.011		0.020	0.076
N,N-Dimethylformamide		0.208		0.070	0.165

Table 4. Comparison Between Experimental Logarithm of Water-to-Organic Solvent Partition Coefficients, Log P, and Logarithm of the Molar Solubilities, Log $C_{S,organic}$, and Calculated Values Using the Updated Solute Descriptors for 2-Methyl-6-nitroaniline

Solvent	Experimental Values		Back-Calculated Values		
	Log P	Log $C_{s,organic}$	log P	Log $C_{s,organic}$; Eqn. 1	Log $C_{s,organic}$; Eqn. 2
Octan-1-ol	2.290		2.283		
Methanol		-0.388		-0.319	-0.304
Ethanol		-0.413		-0.430	-0.419
Propan-1-ol		-0.488		-0.511	-0.544
Propan-2-o1		-0.585		-0.589	-0.614
Cyclohexane		-1.652		-1.586	-1.643
Propanone		0.383		0.379	0.376
Toluene		-0.269		-0.303	-0.294
Acetonitrile		0.245		0.156	0.265
1,4-Dioxane		0.418		0.542	0.528
Ethyl acetate		0.212		0.129	0.106

Table 5. Prediction of the Logarithm of the Molar Solubilities of 5-Nitro-8-hydroxyquinoline, Terephthaldialdehyde, and 2-Methyl-6-nitroaniline in Various Organic Solvents at 298 K based on the Abraham Solvation Parameter Model

Solvent	5-Nitro-8-hydroxyquinoline		Terephthaldialdehyde		2-Methyl-6-nitroaniline	
	Log $C_{S,organic}$; Eqn. 1	Log $C_{S,organic}$; Eqn. 2	Log $C_{S,organic}$; Eqn. 1	Log $C_{S,organic}$; Eqn. 2	Log $C_{S,organic}$; Eqn. 1	Log $C_{S,organic}$; Eqn. 2
Dichloromethane	-0.914	-0.841	0.477	0.533	0.187	0.211
Trichloromethane	-0.956	-0.871	0.485	0.556	-0.003	0.049
Tetrachloromethane	-1.926	-1.962	-0.392	-0.394	-0.864	-0.784
1,2-Dichloroethane	-0.887	-0.831	0.342	0.384	0.182	0.204
Cyclohexane	-2.659	-2.791	-1.036	-1.090	-1.586	-1.643
Benzene	-1.242	-1.209	0.047	0.077	-0.176	-0.133
Toluene	-1.437	-1.444	-0.109	-0.078	-0.303	-0.294
Chlorobenzene	-1.258	-1.168	0.051	0.130	-0.153	-0.084
Methanol	-1.495	-1.613	-0.340	-0.367	-0.319	-0.304
Ethanol	-1.615	-1.691	-0.488	-0.491	-0.430	-0.419
Propan-1-ol	-1.761	-1.837	-0.596	-0.629	-0.511	-0.544
Butan-1-ol	-1.783	-1.864	-0.600	-0.636	-0.501	-0.531
Pentan-1-ol	-1.81	-1.895	-0.658	-0.699	-0.602	-0.634
Octan-1-ol	-1.841	-1.934	-0.727	-0.757	-0.561	-0.666
Propan-2-ol	-1.903	-1.963	-0.709	-0.719	-0.589	-0.614
2-Methylpropan-1-ol	-1.876	-1.962	-0.607	-0.633	-0.653	-0.673
Butan-2-ol	-1.881	-1.913	-0.632	-0.634	-0.536	-0.587
2-Methylpropan-2-ol	-2.008	-2.038	-0.717	-0.736	-0.544	-0.596
3-Methylbutan-1-ol	-1.979	-2.028	-0.715	-0.730	-0.713	-0.668
Tetrahydrofuran	-0.865	-0.874	0.060	0.087	0.537	0.514
1,4-Dioxane	-0.801	-0.866	0.095	0.077	0.542	0.528
Methyl acetate	-1.055	-1.207	0.069	-0.055	0.290	0.283
Ethyl acetate	-1.281	-1.334	-0.199	-0.204	0.129	0.106
Propanone	-1.006	-1.103	0.000	-0.042	0.379	0.376
Butanone	-0.928	-1.025	0.080	0.039	0.474	0.431

Cyclohexanone	-0.765	-0.771	0.190	0.156	0.590	0.588
Carbon disulfide	-1.805	-1.413	-0.491	-0.220	-0.576	-0.629
N,N-Dimethylformamide	-0.758	-0.665	0.070	0.165	0.808	0.894
Acetonitrile	-1.212	-1.221	0.020	0.076	0.156	0.265