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Isao Kojima[a]; Stanley S. Davis[a]
[a] DEPARTMENT OF PHARMACY, UNIVERSITY OF NOTTINGHAM, NOTTINGHAM, UNITED KINGDOM

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Prediction of the Distribution Constant of Some Solutes Containing Hydrophilic Functional Groups from Data on the Solubility of Water in Organic Solvents

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ISAO KOJIMA* and STANLEY S. DAVIS†

DEPARTMENT OF PHARMACY
UNIVERSITY OF NOTTINGHAM
UNIVERSITY PARK, NOTTINGHAM NG7 2RD, UNITED KINGDOM

Abstract

The distribution behavior of solutes containing a hydrophilic group, between aqueous and different organic phases, has been examined from the standpoint of the influence of the organic solvent. The distribution constant (K_d) has been well correlated with the solubility of water in the organic phase (S_{H_2O}) by an equation of the form

$$\log K_d = a \log S_{H_2O} + b$$

where the constant a approximates to unity for a solute with a single polar functional group. The dimerization behavior of solutes in different organic phases and the relationship between the solubility of water in a solvent and interfacial tension between water and that solvent have also been examined.

INTRODUCTION

Information on the distribution of solutes between aqueous and organic phases finds application in a number of diverse areas, ranging from the practical aspects of solvent extraction (*1*) to analysis (*2*), medicinal chemistry (*3*), and studies on solute–solvent interactions (*4*). In the past, various attempts have been made to correlate the distribution constants obtained for a given solute with the properties of the solvent used as the

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*On leave from the Laboratory of Analytical Chemistry, Nagoya Institute of Technology, Showa-ku, Nagoya 466, Japan.

†To whom correspondence should be addressed.

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organic phase in distribution studies (e.g., dielectric constant (*5–7*), dipole moment (*8*), solubility parameter (regular solution theory) (*9*), solvent polarizability values (E_T value (*8, 10*), *DE* values (*11, 12*), surface and interfacial tensions (*13–17*), and the solubility of water in the organic solvent (*18, 19*)). Of these various solvent properties, the solubility parameter and E_T value have often been most successfully correlated with distribution constants of selected solutes (*20*). However, such correlations have not been universally applicable.

Recent reviews on the determination and application of distribution constants have suggested that the solubility of water in the organic phase could have an important bearing on the magnitude of derived values (*18, 20, 21*), and in the present paper we describe some linear free energy relationships that correlate the distribution constant of selected solutes having hydrophilic functional group(s) and the solubility of water in the relevant organic solvent. These correlations also take into account relationships between the solubility of water in organic solvents and interfacial tension values as well as the association and hydration of organic solutes in water-saturated organic solvents.

Data on the distribution of solutes between water and a range of organic solvents with differing polarity have been taken from literature sources or obtained by experiment.

EXPERIMENTAL

Distribution constants for selected phenols were obtained for various phenolic compounds and different organic solvents using the shake flask technique. Full details of the materials and methods have been given previously (*22, 23*).

RESULTS AND DISCUSSION

Relation between the Solubility of Water in the Organic Phase and the Distribution Constant

The objective of this work was to examine any possible correlation between distribution constant data and the nature of the organic phase as expressed in terms of the solubility of the water in the solvent, and to examine the role of solute hydration in the organic phase. The quantity of water that will dissolve in an organic liquid is highly dependent on the chemical nature of that liquid and its ability to participate in specific interactions such as hydrogen bonding (*21*). In the same way, physical properties, such as the interfacial tension between a water and an organic liquid, are determined by the relative cohesive properties of the two phases. Thus, it is to be expected that an organic liquid such as hexane, where only simple dispersion force interactions can take place, will interact little with water, and therefore demonstrate a low solubility of water in the solvent and a high interfacial tension. At the other extreme, a liquid such as 1-octanol will be able to form hydrogen bonds with dissolved water and thus demonstrate a much higher water content and lower interfacial tension. Some solvents used in distribution studies are given in Table 1 together with various physical quantities, including water solubility and interfacial tension.

In a distribution experiment, both aqueous and organic phases are mutually saturated. The content of water in the organic phase provides an indication of the ability of the solvent to interact with hydrophilic groups in a distributed solute (i.e., solvation) as well as the availability of dissolved water to hydrate the distributed solute. Indeed, for some solvents these two processes will be in competition (*24*). The solute properties of water and its effect on the distribution of polar molecules between mutually saturated aqueous and organic phases has been well covered by Christian and Affsprung and others (*24–26*). The small quantities of dissolved water in such solvents as benzene and CCl_4 significantly influence the association equilibria of polar solutes dissolved in these media. In addition, the (formal) solubility of water in such solvents can increase as the concentration of the polar solute increases.

The relative contributions of solvation and hydration in water-saturated organic solvents have been considered by Christian (*24*) who found that one method of correlating the effect of solvation on hydration equilibria appears to be to arrange the solvents in the order of their ability to dissolve water. Almost without exception the hydration formation constants were smaller in those solvents which dissolved greater amounts of water at a given water activity. This tendency was understandable, inasmuch as the solubility of water is a direct measure of the free energy of interaction between water and the solvent. The stronger the interaction, the more effective a solvent will be in competing with the polar solute–water association reaction.

The role of water in the organic phase in determining the magnitude of the distribution constant has also been mentioned recently by various authors (*27–32*) who have stressed the importance of possible specific hydration effects in the organic phase. Recently van de Waterbeemd and Testa (*28*) discussed the group contribution (fragmental constant)

TABLE 1
Physicochemical Properties of Organic Solvents

Solvent	Molar volume (V_{org})	Surface tension (γ_s)	Interfacial tension between water and solvent (γ_i)	Molar solubility of water in solvent ($\log S_{H_2O}$)	Mole fraction solubility of water in solvent ($\log S^x_{H_2O}$)	Dielectric constant (ε)	Solubility parameter (δ)	Polarizability value (E_T)
Cyclohexane	108	25.5	50.2	−2.55	−3.51	2.03	8.2	31.2
2,2,4-Trimethylpentane	165	18.4	49.3	−2.68	−3.46	1.94	6.85	—
n-Heptane	144	20.3	50.2	−2.48	−3.31	—	7.5	—
n-Hexane	131	18.4	49.7	−2.49	−3.37	1.89	7.3	30.9
Carbon tetrachloride	97	27.0	43.7	−2.09	−3.10	2.24	8.6	32.5
Isopropylbenzene	140	27.7	38.7	−1.86	−2.71	2.38	8.9	—
Toluene	106	27.9	35.7	−1.66	−2.63	2.38	8.9	33.9
Chlorobenzene	102	33.7	37.9	−1.55	−2.54	5.71	9.5	37.5
Benzene	89	28.2	34.0	−1.46	−2.51	2.28	9.15	34.5
Dibromoethane	86	24.2	36.5	−1.06	−2.13	—	10.4	—

Dichloroethane	80	38.4	34.1	−0.90	−2.01	10.7	9.8	41.9
Methylene chloride	64	26.5	28.0	−0.84	−2.03	9.08	9.7	41.1
Nitrobenzene	102	43.9	25.5	−0.78	−1.77	34.8	11.1	42.0
Chloroform	81	27.2	31.6	−1.13	−2.22	4.81	9.2	39.1
Isopropyl ether	141	17.1	17.9	−0.65	−1.50	3.88	7.0	34.0
Ethyl ether	104	17.0	10.5	−0.26	−1.24	4.34	7.4	34.6
Octane-1-ol	158	27.5	8.8	0.24	−0.56	10.3	10.3	—
2-Ethyl-hexane-1-ol	156	—	—	0.02	−0.79	—	9.5	—
Cyclohexanone	104	—	—	0.49	−0.49	18.3	9.9	40.8
Perfluorohexane	205	11.9	56.6	−3.01	−3.70	—	5.6	—
Methyl isobutyl ketone	126	—	10.8	−0.11	−1.01	—	—	—
Butyl ether	169	22.9	25.2	−1.10	−1.87	—	7.8	—
Ethyl acetate	99	23.9	6.8	0.11	−0.89	6.02	9.1	38.1
Butane-1-ol	91	24.2	1.8	0.75	−0.29	17.51	11.4	50.2
o-Dichlorobenzene	113	—	—	−1.62	−2.57	9.93	10.0	38.1
Carbon disulfide	61.5	31.4	48.1	−2.15	−3.37	2.64	10.0	32.6

approach to predicting distribution constants in terms of the hydration and solvation of solutes. They suggest that in solvents such as octanol and dibutyl ether, the contribution from hydration effects will predominate and that derived distributed constant values are a global quantity that comprises a size term (solute volume) and a lipophilicity term related to such hydration effects:

$$f_i = 0.0534V_i + \lambda_i \tag{1}$$

where f_i is the fragmental constant, such that

$$\log K_d = \Sigma f_i \tag{2}$$

V_i is the van der Waals volume and λ_i is a lipophilicity term (hydration effects).

Briggs (*32*) considered the distribution constant in terms of volume and hydration terms, basing his arguments on the differences in internal pressures of the two liquid phases and the assumption that the water content of an organic liquid can be taken as a measure of its hydrogen bonding ability. Following an original approach by Lambert (*33*), based on a cohesive energy density (solubility parameter) approach, Briggs (*32*) obtained the expression

$$\log\ K_d = aP\Delta u \tag{3}$$

where P is the parachor (volume term) and Δu is the difference in internal pressure of the two phases. On the assumption that hydrogen bonding effects will dominate and that the content of water in the two phases is a measure of such interactions, he then wrote

$$\log K_d = a'P\Delta w \tag{4}$$

where Δw is the difference in water concentration in the aqueous and organic phases.

From the foregoing discussions we expect that for a polar solute, the distribution constant is related to the ability of the organic phase to dissolve water and the relative contributions from hydration and solvation effects. In line with others (*34, 35*), we have considered the matter in terms of extrathermodynamic linear free energy models of the form

$$\log K_d^x = a \log S_{H_2O}^x + b \tag{5}$$

$$\log K_d = a' \log S_{H_2O} + b' \tag{6}$$

for mole and molar fraction concentration scales. K_d^x, the mole fraction distribution constant, is calculated from the molar distribution constant K_d by

$$K_d^x = K_d V_{org} V_{H_2O}^{-1} \tag{7}$$

where V_{org} and V_{H_2O} are the molar volumes of the organic and aqueous phases, respectively.

$S_{H_2O}^x$ can be calculated from

$$S_{H_2O}^x = S_{H_2O}\left(\frac{1000 - S_{H_2O}V_{H_2O}}{V_{org}} + S_{H_2O}\right)^{-1} \tag{8}$$

where S_{H_2O} is the molar solubility of water in the organic solvent and V_{org} and V_{H_2O} are the molar volume of the organic solvent and water, respectively. For inert solvents, S_{H_2O} is negligibly small compared with the molar concentration of the organic solvent used, and Eq. (8) can be simplified to

$$S_{H_2O}^x = S_{H_2O} V_{org} 1000^{-1} \tag{9}$$

Thus, a plot of log K_d^x (or log K_d) versus log $S_{H_2O}^x$ (or log S_{H_2O}) should be linear with a slope of a. Some examples covering a range of solvents with different water solubilities are shown in Fig. 1. The values of a and b and the correlation coefficients from linear regression analysis obtained for different solutes are listed in Table 2. It can be seen that for those solutes containing one polar group, the gradient of the log K_d^x versus log $S_{H_2O}^x$ plot approaches unity while for the solute with two polar functional groups (*p*-hydroxyacetophenone), the slope is somewhat larger.

Of the many organic solvents normally used in solvent extraction, cyclohexane has the lowest solubility of water. Therefore, by selecting cyclohexane as a reference solvent for the distribution of a given solute, Eq. (6) can be rewritten as

$$\log K_{d,\text{org}} - \log K_{d,\text{cyclohexane}} = \log S_{H_2O,\text{org}} - \log S_{H_2O,\text{cyclohexane}} \tag{10}$$

and in simpler form as

$$\Delta\log K_d = \Delta\log S_{H_2O} \tag{11}$$

A plot of Δlog K_d against Δlog S_{H_2O} should give a straight line with unit slope and zero intercept irrespective of the solutes distributed. As is shown

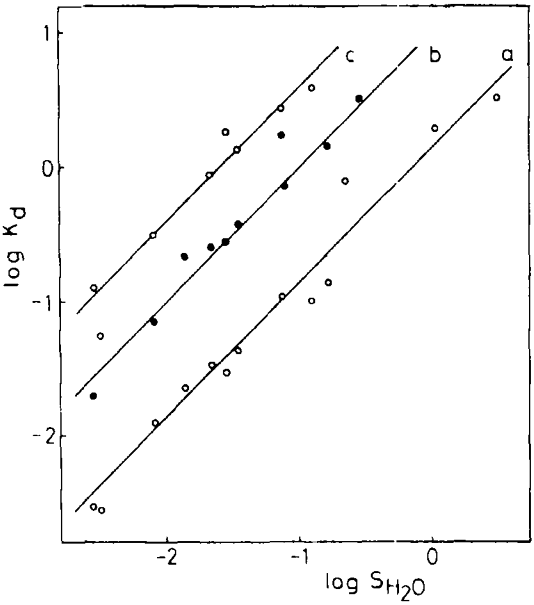

FIG. 1. Relationships between distribution constant and solubility of water in organic solvents: (a) propionic acid, (b) dibutylphosphoric acid, (c) benzoic acid.

TABLE 2

Relation between Distribution Constants of Some Solutes and Solubility of Water in Organic Solvents

$$\log K_d^x = a \log S_{H_2O}^x + b$$

Solute	a	b	n	Correlation coefficient r	Source of data
Propionic acid	1.052	1.980	13	0.984	Ref. 45
Benzoic acid	1.094	3.590	8	0.962	Refs. 40, 17
Dibutylphosphoric acid	1.103	3.055	10	0.976	Ref. 46
Phenol	0.984	2.926	7	0.990	Ref. 22 and this work
p-Chlorophenol	0.940	3.830	5	0.989	Ref. 22
p-Hydroxyacetophenone	1.340	3.578	5	0.997	Ref. 22
1-Nitropropane	0.920	3.990	6	0.982	Ref. 18

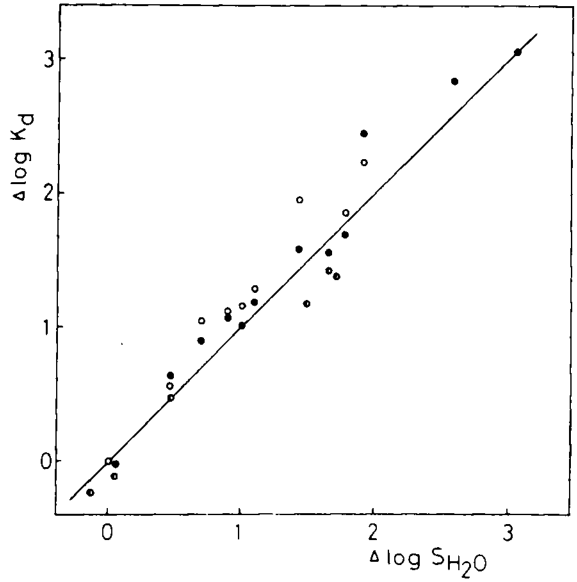

FIG. 2. Relationship between distribution constant and solubility of water in organic solvents.

$$\Delta\log K_d = \log K_{d,\mathrm{org}} - \log K_{d,\mathrm{cyclohexane}}$$

$$\Delta\log S_{H_2O} = \log S_{H_2O,\mathrm{org}} - \log S_{H_2O,\mathrm{cyclohexane}}$$

Propionic acid (●), benzoic acid (◐), dibutylphosphoric acid (○).

TABLE 3

Relation between Distribution Constants of Some Solutes and Solubility of Water in Organic Solvents

$$\Delta\log K_d = a\Delta\log S_{H_2O} + b$$

Solute	*a*	*b*	*n*	*r*
Propionic acid	1.041	0.055	13	0.983
Benzoic acid	1.065	−0.144	8	0.970
Dibutylphosphoric acid	1.121	0.098	10	0.978
Phenol	0.883	−0.102	7	0.990
p-Chlorophenol	0.841	0.006	5	0.991

in Fig. 2 and in Table 3, this plot gave a straight line with approximately unit slope and zero intercept for phenols, propionic, benzoic, and dibutylphosphoric acids. From Eq. (10) we can calculate the distribution constant of a given solute for different organic solvents. Distribution constants obtained experimentally and calculated from Eq. (10) are listed in Table 4. As evident from Table 4, the experimental and calculated values shown for phenol, propionic, benzoic, and dibutylphosphoric acids are in good agreement. Therefore, we can predict the distribution constant of a given solute having a hydrophilic functional group for different kinds of organic solvents, provided log S_{H_2O} is known or can be predicted.

A linear free energy (Collander (*36*)) equation of the form

$$\log K_{d,s_1} = a \log K_{d,s_2} + b \tag{12}$$

that relates distribution values obtained with one solvent (s_1) to those obtained with another (s_2), is well known in distribution studies (*21, 37*). When Solvent 2 is cyclohexane and a is unity, Eqs. (12) and (10) are the same.

The term b in Eq. (12) can be correlated to the difference in the solubility of water in Solvents 1 and 2. Similar conclusions have been reached by Briggs (*32*) and Testa and Seiler (*31*). The latter proposed an equation of the form

$$\log K_{d,s_1} = \log K_{d,\text{octanol}} + m\omega \tag{13}$$

where $m\omega$ is a term that takes into account differences in the states of hydration of solutes in the solvent s_1 and octanol. A similar equation has been proposed by Shmidt et al. (*11, 12*):

$$\Delta \log K_d = \log K_d - \log K_{d,\text{benzene}} = aDE \tag{14}$$

where K_d is the distribution constant obtained with solvents and $K_{d,\text{benzene}}$ the distribution constant obtained with benzene as a reference solvent. DE is a universal constant dependent on the solvent, and a is the constant dependent only on the extraction system.

Relation between Interfacial Tension and Solubility of Water in Organic Phases

The ability of a solvent to dissolve water is related to the physical properties of the solvent and its ability to interact specifically through

TABLE 4
Prediction of Distribution Constants of Some Solutes

Solvent	Logarithmic distribution constant (log K_d)							
	HDBP[a]		Propionic acid		Benzoic acid		Phenol	
	Obs	Calc	Obs	Calc	Obs	Calc	Obs	Calc
Cyclohexane	−1.71	−1.71	−2.54	−2.54	−0.89	−0.89	−0.77	−0.77
Carbon tetrachloride	−1.15	−1.25	−1.90	−2.08	−0.50	−0.43	−0.30	−0.31
Isopropylbenzene	−0.66	−1.02	−1.64	−1.85	—	—	—	—
Toluene	−0.59	−0.82	−1.47	−1.65	−0.06	0.00	—	—
Chlorobenzene	−0.55	−0.71	−1.53	−1.54	0.27	0.11	—	—
Benzene	−0.42	−0.62	−1.36	−1.45	0.14	0.20	—	—
Chloroform	0.24	−0.29	−0.96	−1.12	0.44	0.53	—	—
Nitrobenzene	0.14	0.06	−0.86	−0.77	—	—	—	—
Isopropyl ether	0.52	0.19	−0.09	−0.14	—	—	—	—
Dichloroethane	—	—	−0.99	−0.89	0.59	0.76	0.65	0.88
2-Ethylhexanol	—	—	0.30	0.03	—	—	—	—
n-Hexane	—	—	−2.56	−2.48	−1.26	−0.83	−0.89	−0.71
2,2,4-Trimethylpentane	—	—	—	—	—	—	−1.01	−0.90
Methylene chloride	—	—	—	—	—	—	0.60	0.94
Dibromoethane	—	—	—	—	—	—	0.40	0.72
Cyclohexanone	—	—	0.52	0.50	—	—	—	—
Butyl ether	−0.14	−0.26	—	—	—	—	—	—

[a] HDBP = dibutyl phosphoric acid.

hydrogen bonds. Thus it is to be expected that a solvent that has a high water content at saturation will also demonstrate a relatively low interfacial tension between water and the same solvent.

Donahue and Bartell (*38*) reported that a rectilinear relationship exists between the interfacial tension (γ_i) and the mutual solubility of organic solvents and water,

$$\log (S^x_{H_2O} + S^x_{org})$$

where $S^x_{H_2O}$ and S^x_{org} are the mole fraction solubilities of water in organic solvents and organic solvent in water, respectively, while Timmons and Zisman (*39*) used $\log S^x_{H_2O}$ instead of mutual solubility. We find that Eq. (15) holds for many kinds of solvent; for example, alcohols, ketones, ethers, esters, hydrocarbons, and halogenated hydrocarbons:

$$\log S^x_{H_2O} = a\gamma_i + b \tag{15}$$

where a and b are constants.

Using preferred solubility data presented in recent literature (*21, 40–44*) (Table 1), we have obtained a rectilinear relationship (Fig. 3) of the form

$$\log S^x_{H_2O} = -0.0611\gamma_i - 0.301 \tag{16}$$

and $n = 22$, correlation coefficient (r) = 0.984.

A similar relation holds for $\log S_{H_2O}$ and γ_i and is given by

$$\log S_{H_2O} = -0.0629\gamma_i + 0.702 (n = 22, r = 0.975) \tag{17}$$

Effect of Interfacial Tension on Distribution Constant

Very few attempts have been made to correlate the distribution constants for a given solute with the interfacial tension of the relevant organic solvents (*13–17*). In earlier work (*16, 17*) it was found that the logarithmic ratio of the concentration of the distributing species in both phases is linearly related to the interfacial tension. Korenman (*16*) reported a series of straight parallel lines for the plot of $\log K_d$ against γ_i for some phenols down to a γ_i value of about 10 mN/m. From these results he considered that γ_i has the same effect on the distribution of all of the phenols. More recently Rubio et al. (*17*) found a linear relationship between the distribution constant, $\log K_d$, of monomeric carboxylic acid and interfacial tension for γ_i values in the range 24–52 mN/m. Using our own data and

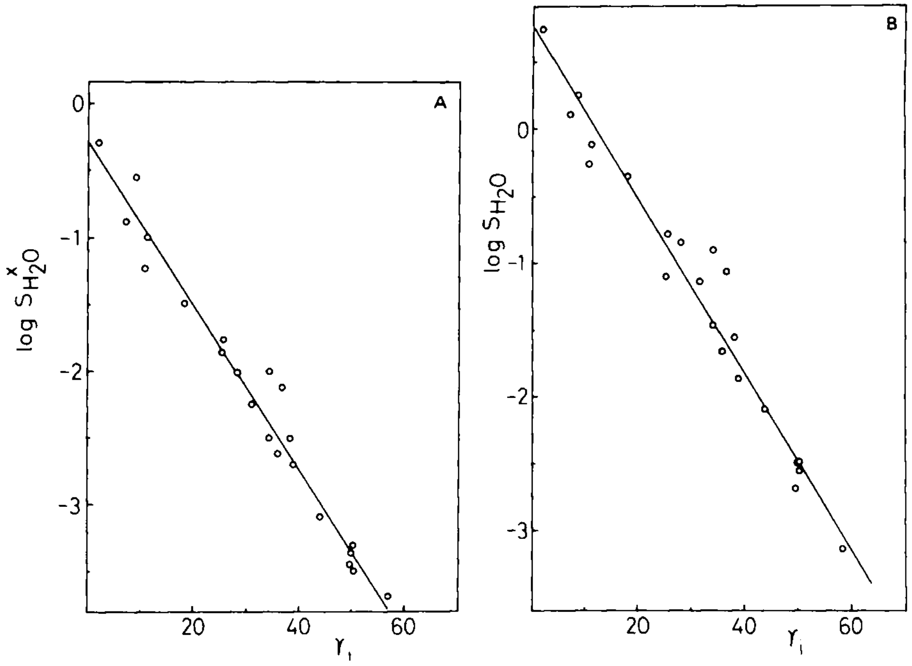

FIG. 3. Relationship between solubility of water in organic solvents and the interfacial tension (mN/m) between water and that solvent.

those available from published papers, we have plotted the distribution constants of selected solutes containing hydrophilic groups (carboxylic acids (*40, 42, 45*), dibutylphosphoric acid (*46*), phenols (*22*), 8-quinolinol (*47*), and acetylacetone (*48*)) against γ_i. For the carboxylic acids, dibutylphosphoric acid, and phenols, good linear relationships are obtained (Fig. 4). For 8-quinolinol and acetylacetone, a poor but linear correlation was observed. From the linear relationships we can write

$$\log K_d^x = a\gamma_i + b \tag{18}$$

$$\log K_d = a'\gamma_i + b' \tag{19}$$

where a and a' are solute-independent constants and b and b' are solute-dependent constants. The values of a and b obtained from Eq. (18) for different solutes are given in Table 5.

Other intercorrelations between solubility of water data and solvent properties can be found. For example, the E_T value, which is the molar transition energy for the solvatochromic band in the spectrum of pyridi-

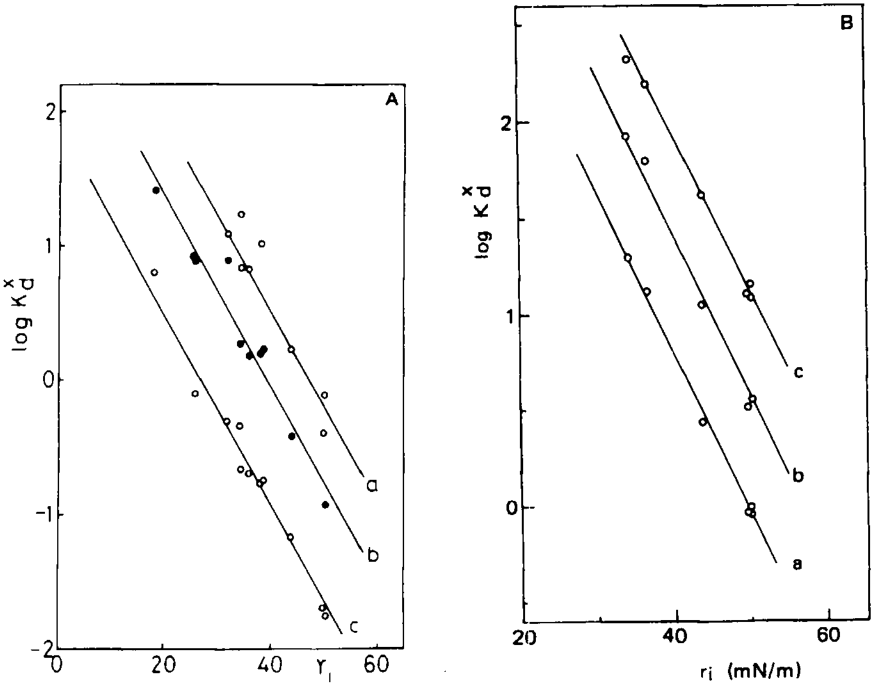

FIG. 4. Relationships between distribution constant of solutes and interfacial tension between water and various organic phases. A: (a) benzoic acid, (b) dibutylphosphoric acid, (c) propionic acid. B: (a) phenol, (b) *p*-chlorophenol, (c) *p*-ethylphenol.

TABLE 5

Relation between Distribution Constants of Some Solutes and Interfacial Tension

$\log K_d^X = a\gamma_i + b$

Solute	*a*	*b*	*n*	*r*
Propionic acid	−0.0742	2.010	13	0.986
Benzoic acid	−0.0782	3.690	8	0.950
Dibutylphosphoric acid	−0.0710	2.781	10	0.972
Phenol	−0.0817	4.644	7	0.998
p-Chlorophenol	−0.0928	5.163	5	0.995
p-Methoxyphenol[a]	−0.1091	5.181	5	0.998

[a] From Ref. 22.

nium *N*-phenolbetaine in a variety of solvents (*10, 49*), is well correlated with the solubility of water in the same solvents:

$$\log S^{x}_{H_2O} = 0.143E_T - 6.754 \tag{20}$$

($n = 10, r = 0.957$).

The extraction constant in ion pair extraction has been found to be fairly well correlated with E_T (and *DE*) values (*6, 12*), and the contribution of co-extracted water and organic solvents to the extractability of symmetric alkylammonium salts has been mentioned by Iwamoto et al. (*30*). Thus it is to be expected that a good linear relationship should hold between the extraction constant of ion associated species and the solubility of water in the organic solvent. As an example, we present a good linear relationship for the extraction constants of tetrabutylammonium picrate (*50*) (Fig. 5).

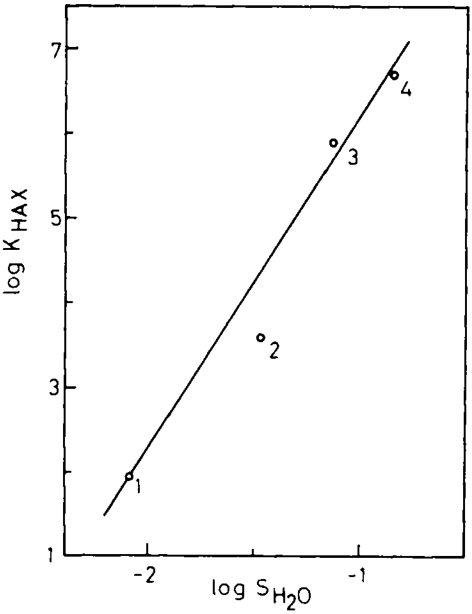

FIG. 5. Relationship between extraction constant of tetrabutylammonium picrate and solubility of water.

$$HA^+ + X^- \underset{}{\overset{K_{HAX}}{\rightleftarrows}} HAX_{org}; \quad K_{HAX} = \frac{[HAX]_{org}}{[HA][X]}$$

Solvents: (1) CCl_4, (2) C_6H_6, (3) $CHCl_3$, (4) CH_2Cl_2.

Effect of Water Solubility on the Dimerization Constant of Solute in an Organic Phase

It is well known that the distribution constant K_d of a monomeric solute and the dimerization constant K_2 of solute in an organic phase can be expressed as (*24*)

$$K_d^2 K_2 = \text{constant} \tag{21}$$

From Eqs. (19) and (21) a linear relationship is to be expected between the dimerization constant of a solute and the interfacial tension of the organic solvents. Rubio et al. (*17*) obtained a linear relationship by plotting the dimerization constant of propionic acid, log K_2, against γ_i. From the available data we have plotted the log K_2 of some carboxylic acids and dibutylphosphoric acid against γ_i. As shown in Fig. 6, this plot gave a straight line with a positive slope, in contrast to the log K_d^x versus γ_i plot. This relationship is expressed as

$$\log K_2 = 0.125\gamma_i - 2.260$$

($r = 0.982$) for propionic acid, and

$$\log K_2 = 0.145\gamma_i - 0.142$$

($r = 0.984$) for dibutylphosphoric acid.

Similarly, Eq. (22) is derived from Eqs. (6) and (21):

$$\log K_2 = -2 \log S_{H_2O} + \text{constant} \tag{22}$$

As shown in Fig. 7 for propionic and dibutylphosphoric acids, the plot of log K_2 against log S_{H_2O} gave a straight line with a slope of about -2, as expected from Eq. (22). As in the case of the distribution constant by selecting cyclohexane as a reference solvent, Eq. (22) is rewritten as

$$\log K_{2,\text{org}} - \log K_{2,\text{cyclohexane}} = \log S_{H_2O,\text{org}} - \log S_{H_2O,\text{cyclohexane}} \tag{23}$$

A plot of ($\log K_{2,\text{org}} - \log K_{2,\text{cyclohexane}}$) against ($\log S_{H_2O,\text{org}} - \log S_{H_2O,\text{cyclohexane}}$) gave a straight line with a slope of -2 for propionic and dibutylphosphoric acids (Fig. 8). However, as is evident from Fig. 8, the intercept does not go through zero. The reason for this can be attributed to the uncertainty of the K_2 value, since the K_2 value is indirectly obtained by calculation from the values of $K_2 K_d^2$ and K_d. From Eq. (23) we can predict

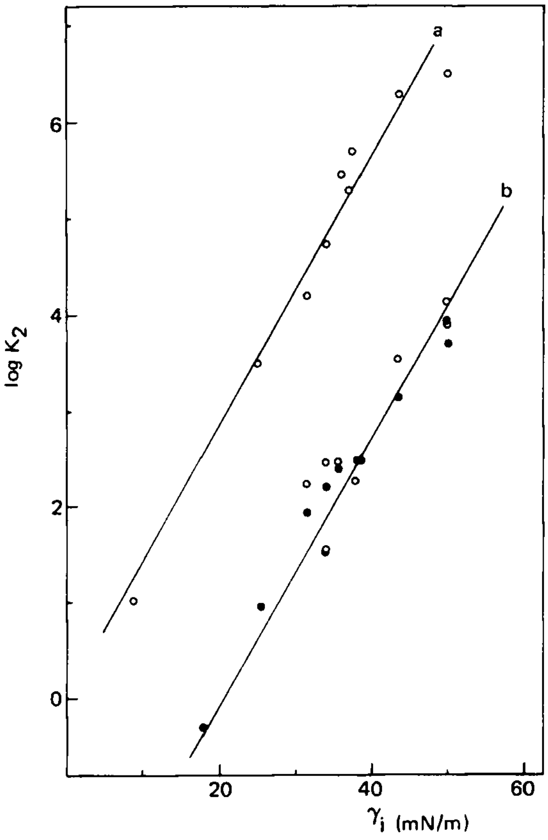

FIG. 6. Relationship between dimerization constant and interfacial tension: (a) dibutylphosphoric acid; (b) benzoic acid (○), propionic acid (●)

the dimerization constant of a given solute in different organic solvents in a manner similar to the prediction of the distribution constant.

Effect of Interfacial Tension and Solubility of Water on the Thermodynamics of Solute Transfer

The thermodynamics of distribution of a solute between an aqueous environment and different organic phases can be written as

$$\Delta G = -RT \ln K_d^x = \Delta H - T\Delta S \qquad (24)$$

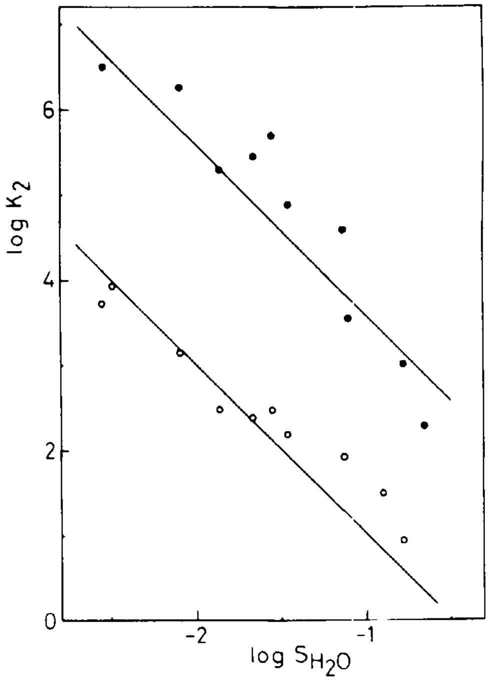

FIG. 7. Relationship between dimerization constant and solubility of water in organic solvents: proprionic acid (○), dibutylphosphoric acid (●).

where ΔG, ΔH, and ΔS are the partial molar free energy, enthalpy, and entropy change on distribution of the solute. As shown above, the term ΔG, i.e., log K_d^x, is well correlated with the terms γ_i and log $S_{H_2O}^x$ for solutes having a hydrophilic functional group. As a consequence of the linear enthalpy and entropy compensation effects (*15*), it is expected that ΔH will also be well correlated to γ_i and log $S_{H_2O}^x$. Figure 9 shows the plots of ΔH against log $S_{H_2O}^x$. ΔH is fairly well correlated to both terms.

In conclusion, the distribution and dimerization constants for a given solute containing a hydrophilic functional group can be easily estimated for different kinds of organic solvents from knowledge of the solubility of water in organic solvent, or the interfacial tension between water and the solvent provided one datum point for distribution and dimerization constants of the solute for one organic solvent are available. For solutes which have not a hydrophilic functional group and are not solvated nor hydrated in the organic phase, the derived relationships cannot be used to estimate distribution and dimerization constants.

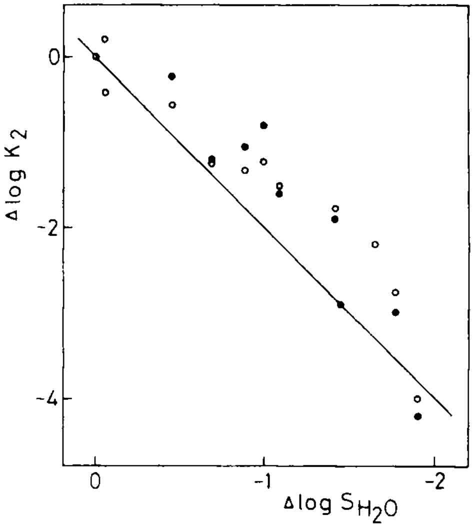

FIG. 8. Relationship between dimerization constant and solubility of water in organic solvents.

$$\Delta \log K_2 = \log K_{2,\mathrm{org}} - \log K_{2,\mathrm{cyclohexane}}$$

$$\Delta \log S_{H_2O} = \log S_{H_2O,\mathrm{org}} - \log S_{H_2O,\mathrm{cyclohexane}}$$

Dibutylphosphoric acid (●), propionic acid (○).

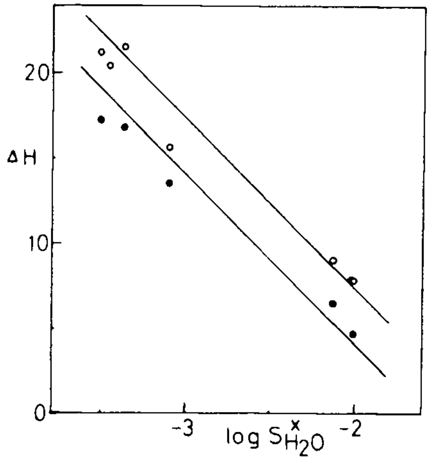

FIG. 9. Relationship between the enthalpy of distribution of phenols from 0.15 mol/dm^3 NaCl solution to organic solvents and solubility of water in these solvents. Phenol (○), *p*-chlorophenol (●).

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