

## Contribution of Substituents to the Distribution Coefficient of *N*-Benzoyl-*N*-phenylhydroxylamine Derivatives

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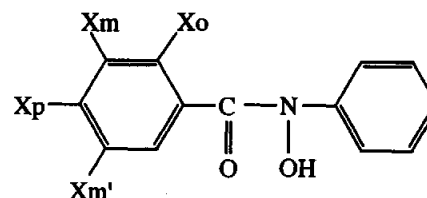
The distribution coefficient ( $K_D$ ) for twenty kinds of *N*-benzoyl-*N*-phenylhydroxylamine (BPHA) derivatives between chloroform or benzene and the aqueous phase was determined. A linear correlation was obtained between  $\log K_D$  and the number of carbon atoms containing substituent groups for a series of alkyloxy derivatives. However, the data for those having a series of alkyloxy groups, and others having a straight or branched alkyl chain, fall on two independent lines in plots of  $\log K_D$  vs. the van der Waals volume of the BPHA derivatives. From these results, the empirical contribution values ( $\pi_X$ ), defined as  $\pi_X = \log K_D(X) - \log K_D(H)$  ( $K_D(H)$  is the distribution coefficient of a parent compound and  $K_D(X)$  that of a derivative), of the functional group to the distribution coefficient ( $\log K_D$ ), were as follows: 0.54 in a chloroform/water system and 0.49 in a benzene/water system for the methyl and methylene groups, 0.30 in a chloroform/water system and 0.27 in a benzene/water system for the methoxy group, and  $-0.23$  in a chloroform/water system and  $-0.12$  in a benzene/water system for the nitro group, respectively. The utility of the contribution values ( $\pi_X$ ) for the methyl, methylene, methoxy and nitro groups was verified for estimating the distribution coefficient ( $K_D$ ) of the BPHA derivatives.

**Keywords** *N*-Benzoyl-*N*-phenylhydroxylamine derivatives, solvent extraction, distribution coefficient

Solvent extraction is one of the most effective separation methods, and is widely used in basic analytical chemistry, such as in the separation and concentration of metal ions. A number of chelating agents are used as the extracting agents of many metal ions. In chelating extraction systems, the extraction constant of metal ions is a function of the distribution coefficient of the chelating agent ( $K_D$ ), the distribution coefficient of the metal chelate ( $K_{DC}$ ), the acid-dissociation constant of the chelating agent ( $K_a$ ), and the stability constant of the metal chelate ( $\beta_n$ ). Therefore, the distribution coefficient of the chelating agent between the organic and aqueous phases is one of the important equilibrium constants in metal-extraction systems. For estimating the distribution coefficient of many organic compounds, the contribution value ( $\pi_X$ ) was defined by Hanch *et al.*<sup>1</sup> as follows:  $\pi_X = \log K_D(X) - \log K_D(H)$ , where  $K_D(H)$  is the distribution coefficient of a parent compound and  $K_D(X)$  is the value for a derivative. If the electronic nature in the parent compound is not influenced by introducing a substitution (X), the  $\pi_X$  value can be regarded as being the intrinsic value for any substance. As made clear in the definition for  $\pi_X$ ,  $\log K_D(X)$  can be calculated by using  $\pi_X$  and  $\log K_D(H)$ ;  $\log K_D(X)$  is generally represented as the sum of  $\log K_D(H)$  of a parent compound and the  $\pi_{X_i}$  values of substituents constituting compound as  $\log K_D(X) = \log K_D(H) + \sum \pi_{X_i}$ . The empirical contribution ( $\pi_X$ ) of substituents (X) to the extractability have been successfully used to estimate the liquid-liquid distribution coefficient of non-ionic neutral molecules<sup>2</sup>

and the ion-association constant of quaternary ammonium ions with various anions.<sup>3-6</sup>

In the present work, the distribution coefficient between chloroform or benzene and water for twenty kinds of *N*-benzoyl-*N*-phenylhydroxylamine (BPHA) derivatives (which are extensively used as extracting agents of various metal ions) was determined in order to obtain fundamental knowledge (empirical group contribution values) for estimating the liquid-liquid distribution coefficient of the BPHA derivatives.



Structure 1 *N*-(*ortho*, *meta* and *para*)-Substituted-benzoyl-*N*-phenylhydroxylamine.

### Experimental

#### Reagents and apparatus

The BPHA derivatives were synthesized by the reaction of phenylhydroxylamine with appropriate acid chlorides, as previously reported.<sup>7</sup> Crude products

were purified by recrystallizing from ethanol and water, and were dissolved in chloroform or benzene just prior to use. The following solutions were used to obtain the desired pH values: 0.1 mol dm<sup>-3</sup> solutions of sodium acetate, acetic acid, dipotassium hydrogenphosphate, sodium carbonate, ammonium acetate, sodium hydroxide and hydrochloric acid. Chloroform was washed three times with distilled water, and benzene was saturated with distilled water before use. All other reagents used were of analytical grade. A Hitachi Model U-3210 spectrophotometer was used for determining the distribution ratio of the BPHA derivatives between chloroform or benzene and water. A Horiba F-13 pH meter, calibrated daily at 4.01 and 6.86 using buffer solutions provided by Toa Denpa Co. Ltd., was used for all of the measurements. A liquid chromatograph was used which comprised a Hitachi Model L-6000 pump, a Hitachi Model L-4200 detector and a Hitachi Model D-2500 Chromato-Integrator. An ERC-ODS 1282 column (6.0×300 mm, Erma Optical Works) was employed. A 75 v/v% ethanol-water mixture containing 0.01 mol dm<sup>-3</sup> acetic acid was used as the eluent.

#### Acid-dissociation constant

*p*-Isopropyl, *p*-isobutyl, *p*-*n*-butyl and *p*-*tert*-butyl derivatives are slightly soluble in water. Therefore, the absorbances at 265 nm for *p*-isopropyl, *p*-isobutyl and *p*-*n*-butyl derivatives, and 310 nm for *p*-*tert*-butyl derivative at various pH values were measured in aqueous solution to obtain the p*K*<sub>a</sub> values, respectively. However, since *p*-phenyl derivative is scarcely soluble in water, the absorbance at 330 nm for the *p*-phenyl derivative was measured in 40–50% (v/v) ethanol-water mixtures, respectively. Potassium chloride was added to adjust the ionic strength to 0.1, and a 0.1 mol dm<sup>-3</sup> buffer solution was used for obtaining the desired pH.

#### Distribution of the reagents

The distribution ratios for *m*-methyl, *m*-trifluoromethyl, *m*-cyano, *m*-nitro, *m,m'*-dinitro, *o,p*-dinitro, *m*-methoxy and *o*-methoxy derivatives between benzene and water were measured as follows: a 10 cm<sup>3</sup> portion of 10<sup>-2</sup> mol dm<sup>-3</sup> benzene solution of the reagent was vigorously shaken in a 50-cm<sup>3</sup> vial fitted with a polyethylene liner and a plastic cap for 1 h with 10 cm<sup>3</sup> of an aqueous solution of pH 4.5–9.5 containing 0.1 mol dm<sup>-3</sup> potassium chloride at 23±1°C. After phase separation, the concentration of the reagent in the aqueous phase was measured based on its absorbance at 240 nm after dilution with a 0.1 mol dm<sup>-3</sup> sodium hydroxide solution to complete the anionic species of the reagent. The pH at equilibrium was measured after phase separation.

## Results and Discussion

#### Acid dissociation constant of the BPHA derivatives

The acid dissociation constant of the BPHA deriva-

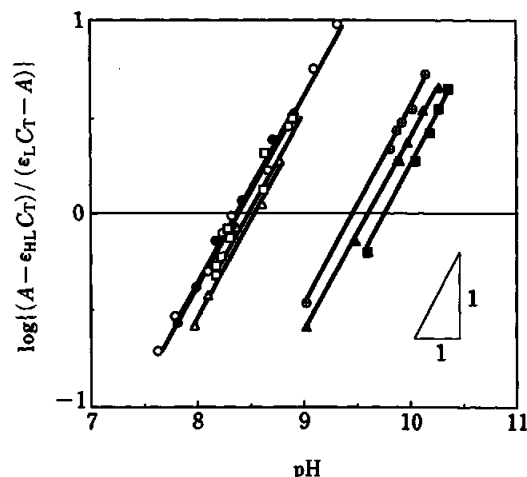


Fig. 1 Plots for determining the dissociation constants of the BPHA derivatives.  $I=0.1$  (KCl). *p*-(CH<sub>3</sub>)<sub>2</sub>CH (○); *p*-(CH<sub>3</sub>)<sub>2</sub>CHCH<sub>2</sub> (●); *p*-CH<sub>3</sub>(CH<sub>2</sub>)<sub>3</sub> (△); *p*-(CH<sub>3</sub>)<sub>3</sub>C (□); *p*-C<sub>6</sub>H<sub>5</sub> in 40% ethanol (⊕); *p*-C<sub>6</sub>H<sub>5</sub> in 45% ethanol (▲); *p*-C<sub>6</sub>H<sub>5</sub> in 50% ethanol (■).

tives is defined by  $K_a = [H^+][L^-]/[HL]$ , where [HL] and [L<sup>-</sup>] are the concentrations of the neutral and anionic species of the BPHA derivatives, respectively. This equation can be rewritten as follows:  $pK_a = pH - \log\{[L^-]/[HL]\} = pH - \log\{(A - \epsilon_{HL} C_T)/(\epsilon_L C_T - A)\}$ . Here,  $\epsilon_{HL}$  and  $\epsilon_L$  are the molar absorptivities of the neutral and anionic forms of the BPHA derivatives, respectively.  $A$  is the measured absorbance, and  $C_T$  is the total reagent concentration. A plot of  $\log\{(A - \epsilon_{HL} C_T)/(\epsilon_L C_T - A)\}$  vs. the obtained pH gave a fairly straight line with a slope of 1 and an intercept equal to p*K*<sub>a</sub>, as shown in Fig. 1. The obtained p*K*<sub>a</sub> values were 8.38 for *p*-isopropyl, 8.36 for *p*-isobutyl, 8.49 for *p*-*n*-butyl and 8.43 for *p*-*tert*-butyl derivatives, respectively. Kawase *et al.*<sup>8</sup> determined the acid dissociation constant of 2-(2-benzoxazolylazo)-1-naphthol in various aqueous dioxane concentrations, and then determined the p*K*<sub>a</sub> value in aqueous solution by extrapolating to a dioxane concentration of zero. Since the *p*-phenyl derivative of BPHA is also scarcely soluble in water, the p*K*<sub>a</sub> values were determined at various aqueous ethanol concentrations. The p*K*<sub>a</sub> values obtained for the *p*-phenyl derivative were 9.46, 9.61 and 9.75 in 40, 45 and 50% ethanol, respectively. Thus, the p*K*<sub>a</sub> value of the *p*-phenyl derivative in an aqueous solution was determined to be 8.30 by extrapolation to an ethanol concentration of zero.

#### Distribution coefficient of the BPHA derivatives

The distribution ratio ( $D$ ) of the BPHA derivatives (HL) between the aqueous and organic phases can be written as

$$D = [HL]_o / ([HL] + [L^-]) = K_D / (1 + K_a [H^+]^{-1}), \quad (1)$$

where  $K_D$  is a distribution coefficient defined by  $K_D =$

$[HL]_o/[HL]$ , and subscript o denotes the species in the organic phases. Plots of the  $\log D$  values between benzene and water for *m*-methyl, *m*-trifluoromethyl, *m*-cyano, *m*-nitro, *m,m'*-dinitro, *o,p*-dinitro, *m*-methoxy

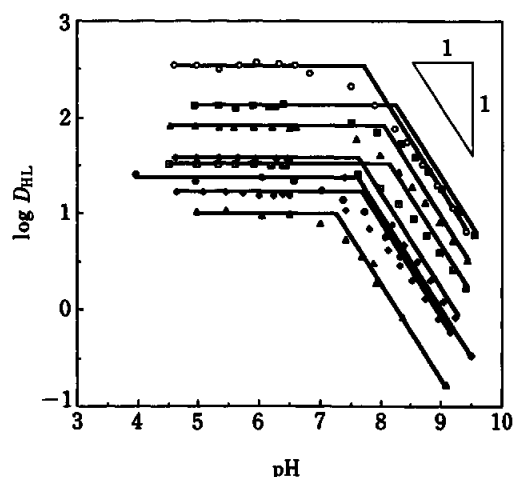


Fig. 2 Distribution ratio of BPHA derivatives between benzene and water.  $[HL]_{\text{Total}}=10^{-3}$  mol dm $^{-3}$  for *m,m'*-dinitro and *o,p*-dinitro derivatives, and  $10^{-2}$  mol dm $^{-3}$  for others, respectively.  $I=0.1$  (KCl). *m*-CF $_3$  (○); *m*-CH $_3$  (■); *m*-CH $_3$ O (△); *m*-NO $_2$  (◆); *o*-CH $_3$ O (□); *m,m'*-diNO $_2$  (●); *m*-CN (◇); *o,p*-diNO $_2$  (▲).

and *o*-methoxy derivatives against the pH in the aqueous phase are shown in Fig. 2. The distribution ratio ( $\log D$ ) of the compounds between benzene and water is nearly equal to constant value ( $\log K_D$ ) in a higher hydrogen-ion concentration range, while  $\log D$  is expressed as  $\log K_D+pK_a-pH$  for a lower hydrogen-ion concentration range. Thus, plots of  $\log D$  vs. pH are straight lines with a slope of  $-1$  according to the theoretical line in a lower hydrogen-ion concentration range. Since the distribution coefficients for *p*-isopropyl, *p*-isobutyl, *p*-*n*-butyl, *p*-*tert*-butyl and *p*-phenyl derivatives were very large, the distribution ratios were measured at a high pH region of 10.5–13.0; the distribution coefficient ( $K_D$ ) for these derivatives was then calculated from Eq. (1) with the aid of the acid-dissociation constant ( $K_a$ ). The distribution coefficients of BPHA and its derivatives (not described above) have already been reported elsewhere.<sup>7,9-13</sup> The  $\log K_D$  values for the BPHA derivatives are summarized in Table 1. The extractability of the BPHA derivatives with chloroform is superior to those with benzene (Table 1). As expected, the bulkier and more organophilic is the introduced substituent, the larger are the  $\log K_D$  values.

#### Statistical study of the distribution coefficient

The relationship between  $\log K_D$  in the chloroform/water system and that in the benzene/water system is shown in Fig. 3. Collander<sup>14</sup> showed that a good linear relationship existed between the distribution coefficients

Table 1 Distribution coefficient for the BPHA derivatives

No.	Compound	Chloroform/water system		Benzene/water system		$\log k'$	Ref.
		$\log K_D$	$\Delta \log K_D(R)^a$	$\log K_D$	$\Delta \log K_D(R)^a$		
1	BPHA	2.33		1.66		-0.73	9, 10
BPHA derivatives							
2	<i>m</i> -CH $_3$	2.86	0.53	2.12	0.46	-0.60	11, this work
3	<i>m</i> -CF $_3$	2.93	0.60	2.54	0.88	—	11, this work
4	<i>m</i> -CN	1.99	-0.34	1.21	-0.45	—	11, this work
5	<i>m</i> -NO $_2$	2.17	-0.16	1.58	-0.08	—	11, this work
6	<i>m,m'</i> -diNO $_2$	1.75	-0.58	1.37	-0.29	—	12, this work
7	<i>o,p</i> -diNO $_2$	1.31	-1.02	1.01	-0.65	—	12, this work
8	<i>o</i> -CH $_3$ O	2.42	0.09	1.51	-0.15	-0.89	13, this work
9	<i>m</i> -CH $_3$ O	2.60	0.27	1.90	0.24	-0.79	13, this work
10	<i>p</i> -CH $_3$ O	2.66	0.33	1.96	0.30	-0.80	7, 13
11	<i>p</i> -CH $_2$ CH $_2$ O	3.28	0.95	2.48	0.82	-0.63	7
12	<i>p</i> -CH $_2$ (CH $_2$ ) $_3$ O	4.3	1.97	3.41	1.75	-0.28	7
13	<i>p</i> -CH $_2$ (CH $_2$ ) $_4$ O	—	—	3.97	2.31	-0.13	7
14	<i>p</i> -CH $_2$ (CH $_2$ ) $_5$ O	—	—	4.41	2.75	0.02	7
15	<i>p</i> -CH $_2$ (CH $_2$ ) $_6$ O	—	—	4.89	3.23	0.18	7
16	<i>p</i> -CH $_2$ (CH $_2$ ) $_7$ O	—	—	>5	—	0.32	7
17	<i>p</i> -(CH $_2$ ) $_2$ CH	4.13 <sup>b</sup>	1.80	3.23 <sup>b</sup>	1.57	-0.34	this work
18	<i>p</i> -CH $_2$ (CH $_2$ ) $_3$	4.49 <sup>b</sup>	2.16	3.65 <sup>b</sup>	1.99	-0.16	this work
19	<i>p</i> -(CH $_2$ ) $_2$ CHCH $_2$	4.69 <sup>b</sup>	2.36	3.72 <sup>b</sup>	2.06	-0.18	this work
20	<i>p</i> -(CH $_2$ ) $_3$ C	4.29 <sup>b</sup>	1.96	3.56 <sup>b</sup>	1.90	-0.25	this work
21	<i>p</i> -C $_6$ H $_5$	4.37 <sup>b</sup>	2.04	3.62 <sup>b</sup>	1.96	-0.35	this work

a.  $\Delta \log K_D(R)=\log K_D(R\text{-BPHA})-\log K_D(\text{BPHA})$ , where R is the substituent. b.  $I=0.2$ (KCl).  $[HL]_{\text{Total}}=10^{-3}$  mol dm $^{-3}$ . In Eq. (1),  $pK_a=8.38$  for *p*-isopropyl derivative, 8.36 for *p*-isobutyl, 8.49 for *p*-*n*-butyl, 8.43 for *p*-*tert*-butyl and 8.30 for *p*-phenyl were used for the calculation of  $\log K_D$ . Experimental errors are within  $\pm 0.09$ .

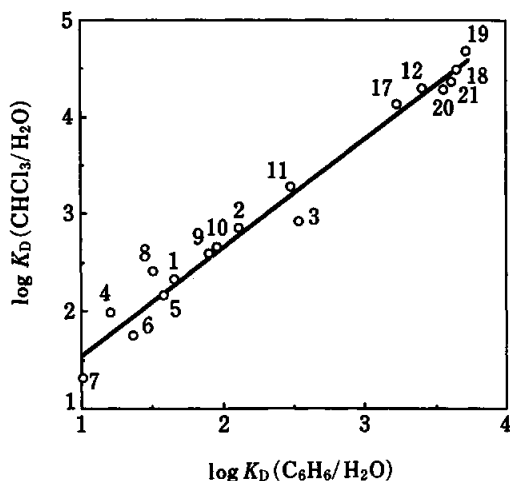


Fig. 3 Relationship between  $\log K_D(\text{C}_6\text{H}_6/\text{H}_2\text{O})$  and  $\log K_D(\text{CHCl}_3/\text{H}_2\text{O})$ . The numbers are the same as those in Table 1.

in one system ( $K_{D1}$ ) and those in the second system ( $K_{D2}$ ). There is also a comparatively good linear correlation between  $\log K_D$  in both systems, as expressed by the following equation (described by Collander):

$$\log K_D(\text{CHCl}_3/\text{H}_2\text{O}) = 1.13 \log K_D(\text{C}_6\text{H}_6/\text{H}_2\text{O}) + 0.40, \\ (r = 0.9872).$$

Later, Leo and Hansch<sup>15</sup> clarified that the correlation expressed by the above equation was not always applicable to the distribution coefficients in two different solvent systems having different natures concerning the relative hydrogen-bond donating and accepting abilities between the solvent and the solute. For example, in the case of the benzene/water and octanol/water systems, at least two equations are needed to relate a wide variety of solute molecules. Thus, the linear correlation in Fig. 3 may indicate that the solvent-solute interaction in both systems is either negligible or approximately equivalent.

An apparently good linear relationship exists between  $\log K_D$  and the number of carbon atoms ( $N_C$ ) of the constituting substituent groups for a series of alkyloxy derivatives, as shown in following equations:<sup>7,13</sup>

$$\log K_D(\text{CHCl}_3/\text{H}_2\text{O}) = 0.54N_C + 2.15 \quad (r = 0.9987)$$

and

$$\log K_D(\text{C}_6\text{H}_6/\text{H}_2\text{O}) = 0.49N_C + 1.49 \quad (r = 0.9997).$$

However, in the relationship between the volume of the reagents calculated by Bondi's method<sup>16</sup>, that is, van der Waals volume of the reagents, and  $\log K_D$  in both systems, the plots for those having an alkyloxy group and for the others having a straight and branched alkyl group as a substituent fall on two independent lines, respective-

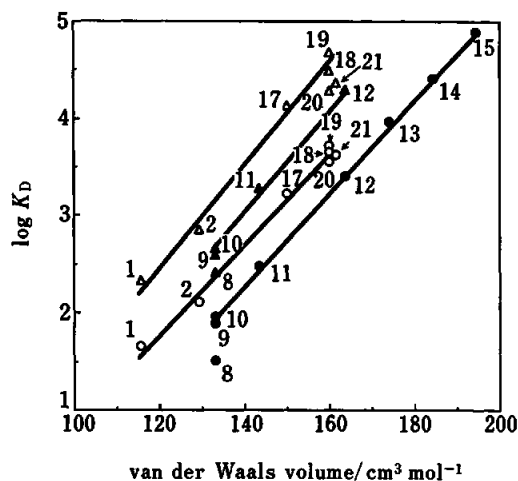


Fig. 4 Relationship between  $\log K_D$  and the van der Waals volume of the BPHA derivatives. A circle and a triangle indicates a plot of  $\log K_D$  in benzene/water and chloroform/water systems, respectively. White and black painted indicate a plots of alkyl or phenyl derivatives and alkyloxy derivatives, respectively. Numbers are the same as those in Table 1.

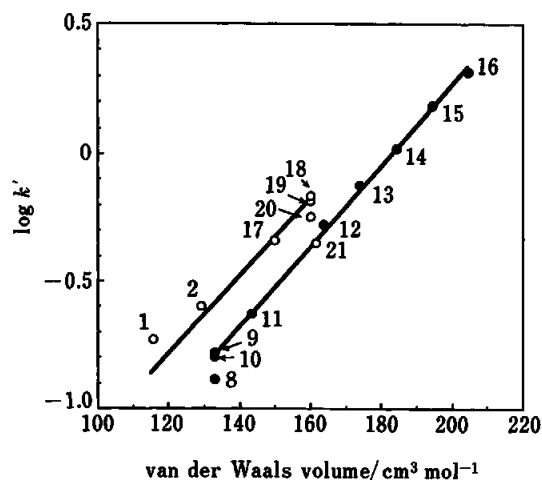


Fig. 5 Relationship between the capacity factor ( $\log k'$ ) and the van der Waals volume of the BPHA derivatives: Alkyloxy derivatives (●); alkyl and phenyl derivatives (○). Numbers are the same as those in Table 1.

ly, as shown in Fig. 4. From these results, it was found that the distribution coefficient for the BPHA derivatives increase with increasing the van der Waals volumes of these reagents and with increasing the number of carbon atoms constituting the substituent groups for the alkyloxy derivatives.

Further, the HPLC chromatographic behavior of these reagents was examined. The capacity factor ( $k'$ ) for each BPHA derivative was calculated from these data using  $k' = (V_R - V_m) / V_m$ , where  $V_m$  and  $V_R$  are the void and observed retention volumes, respectively. The  $\log k'$

Table 2 Group contribution values ( $\pi_X$ ) to the distribution coefficients

Group (X)	$\pi_X$		Equation for calculation
	Chloroform/ water system	Benzene/ water system	
CH <sub>3</sub> ( <i>m</i> )	0.53	0.46	(2)
CH <sub>2</sub> ( <i>p</i> )	0.54	0.49	(3)
CH <sub>2</sub> ( <i>p</i> )	0.56	0.49	(4)
CH <sub>2</sub> ( <i>p</i> )	0.54	0.51	(5)
Average value for $\pi_{\text{CH}_3, \text{CH}_2}$	0.54	0.49	
CH <sub>3</sub> O( <i>m</i> )	0.27	0.24	(6)
CH <sub>3</sub> O( <i>p</i> )	0.33	0.30	(6)
Average value for $\pi_{\text{CH}_3\text{O}}$	0.30	0.27	
NO <sub>2</sub> ( <i>m</i> )	-0.16	-0.08	(7)
NO <sub>2</sub> ( <i>m, m'</i> )	-0.29	-0.15	(8)
Average value for $\pi_{\text{NO}_2}$	-0.23	-0.12	

values are given in Table 1. The relationship between the logarithm of the capacity factors ( $k'$ ) of these BPHA derivatives and the van der Waals volume are shown in Fig. 5. Plots for those having an alkyloxy group, and for others having a straight or branched alkyl group as a substituent, also fall on two independent lines, respectively, as well as in the case of the plots of  $\log K_D$  vs. van der Waals volume. As can be seen from Figs. 4 and 5, a similar behavior for liquid-liquid and liquid-solid distributions was observed. These results obviously indicate that the distribution of the reagents is dependent on the molecular size, and that alkyl substituents are preferable to alkyloxy substituents for distribution into the organic phase.

#### Empirical group contribution values for estimating the distribution coefficient

The contribution of the functional group to the distribution coefficient, the so-called group (X) contribution value ( $\pi_X$  value), was calculated using equations (2) – (8), as described by Leo *et al.*<sup>2</sup>, when  $\Delta \log K_D(\text{R})$  is the difference in  $\log K_D$  between the parent compound and its derivatives. The obtained results along with the average values of  $\pi_X$  (X=CH<sub>3</sub>, CH<sub>2</sub>, CH<sub>3</sub>O and NO<sub>2</sub>) are given in Table 2.

$$\pi_{\text{CH}_3} = \Delta \log K_D(m\text{-CH}_3) \quad (2)$$

$$\pi_{\text{CH}_2} = \Delta \log K_D\{p\text{-CH}_3(\text{CH}_2)_n\text{O}\} - \Delta \log K_D\{p\text{-CH}_3(\text{CH}_2)_{n-1}\text{O}\} \quad (3)$$

$$\pi_{\text{CH}_2} = \Delta \log K_D\{p\text{-(CH}_3)_2\text{CHCH}_2\} - \Delta \log K_D\{p\text{-(CH}_3)_2\text{CH}\} \quad (4)$$

$$\pi_{\text{CH}_2} = 1/3[\Delta \log K_D\{p\text{-CH}_3(\text{CH}_2)_3\} - \Delta \log K_D(m\text{-CH}_3)] \quad (5)$$

$$\pi_{\text{CH}_3\text{O}} = \Delta \log K_D(m\text{- and } p\text{-CH}_3\text{O}) \quad (6)$$

$$\pi_{\text{NO}_2} = \Delta \log K_D(m\text{-NO}_2) \quad (7)$$

$$\pi_{\text{NO}_2} = 1/2 \Delta \log K_D(m, m'\text{-diNO}_2) \quad (8)$$

In Table 2, the contribution value for the nitro group has a negative value because of the hydrophilic character of the nitro group. Motomizu *et al.*<sup>5</sup> reported that the ion-association extraction constant ( $\log K_{\text{ex}}$ ) for the Zephiramine ion (benzyltrimethyltetradecylammonium ion) with benzoate and benzenesulfonate with the methoxy and nitro groups at the para position was 0.53 larger than the value for those with the methoxy and nitro groups at the *ortho* position. Fujita *et al.*<sup>17</sup> also reported that the distribution coefficients between 1-octanol and water for phenoxyacetic acid with the methoxy and nitro groups at the 3- and 4-positions were larger than the values for those with the methoxy and nitro groups at the 2-position. In our investigation, the distribution coefficient for the *ortho* position of the methoxy and nitro groups substituted compounds is apparently smaller than those for the other positions of these groups substituted compounds, although the reason for this is not clear. Therefore,  $\pi_X$  obtained from the *ortho* position of the methoxy and nitro groups substituted compounds was not included in these averages. The group-contribution values for the cyano, trifluoromethyl and phenyl groups were not determined, since the distribution coefficients for these BPHA derivatives were measured for only one kind of derivative, respectively. Freiser and Fresco<sup>18</sup> reported that the contribution of the methyl group to the distribution coefficients of 2-methyl- and 4-methyl-8-quinolinol was 0.58 and 0.63, respectively, in a chloroform/water system. Schill<sup>19</sup> and Gustavii<sup>20</sup> also found that the contribution of the methylene group to the extraction constant of an ion-pair with alkylammonium cations was 0.44 to 0.63 in dichloromethane or chloroform/water systems. Further, it has been reported that the contribution of the methoxy and nitro groups to the distribution coefficient are -0.26 – 0.11 for  $\pi_{\text{CH}_3\text{O}}$ <sup>5,21,22</sup> and -0.28 – 1.05 for  $\pi_{\text{NO}_2}$ <sup>5,21</sup> in octanol or chloroform/water systems. The  $\pi_X$  values obtained in the present work are generally in agreement with the reported values.

It was also found that the  $\pi_X$  values for the methyl, methylene, and methoxy groups in the chloroform/water and benzene/water systems are almost equal. However, the  $\pi_X$  value for the nitro group in both systems is somewhat different, although the reason is not clear.

#### Estimation of the distribution coefficient for the BPHA derivatives

By using the empirical parameters (average values for  $\pi_X$ , respectively) given in Table 2, the distribution coefficients for the BPHA derivatives were estimated and

Table 3 Comparison of the distribution coefficients obtained experimentally and by calculation

Compound	log $K_D(\text{CHCl}_3/\text{H}_2\text{O})$		log $K_D(\text{C}_6\text{H}_6/\text{H}_2\text{O})$	
	Found	Calcd.	Found	Calcd.
BPHA	2.33		1.66	
BPHA derivatives				
<i>m</i> -CH <sub>3</sub>	2.86	2.87	2.12	2.15
<i>m</i> -NO <sub>2</sub>	2.17	2.10	1.58	1.54
<i>m,m'</i> -NO <sub>2</sub>	1.75	1.87	1.37	1.42
<i>p</i> -CH <sub>3</sub> O	2.66	2.63	1.96	1.93
<i>m</i> -CH <sub>3</sub> O	2.60	2.63	1.90	1.93
<i>p</i> -CH <sub>3</sub> CH <sub>2</sub> O	3.28	3.17	2.48	2.42
<i>p</i> -CH <sub>3</sub> (CH <sub>2</sub> ) <sub>3</sub> O	4.3	4.25	3.41	3.40
<i>p</i> -CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> O	—	—	3.97	3.89
<i>p</i> -CH <sub>3</sub> (CH <sub>2</sub> ) <sub>5</sub> O	—	—	4.41	4.38
<i>p</i> -CH <sub>3</sub> (CH <sub>2</sub> ) <sub>6</sub> O	—	—	4.89	4.87
<i>p</i> -(CH <sub>3</sub> ) <sub>2</sub> CH	4.13	3.95	3.23	3.13
<i>p</i> -(CH <sub>3</sub> ) <sub>2</sub> CHCH <sub>2</sub>	4.69	4.49	3.72	3.62
<i>p</i> -CH <sub>3</sub> (CH <sub>2</sub> ) <sub>3</sub>	4.49	4.49	3.65	3.62

compared with those obtained experimentally (Table 3). For example, the distribution coefficients for a series of alkyloxy derivatives {CH<sub>3</sub>(CH<sub>2</sub>)<sub>n</sub>O-BPHA} could be calculated according to the following equation;

$$\log K_D\{\text{CH}_3(\text{CH}_2)_n\text{O-BPHA}\} \\ = \log K_D(\text{BPHA}) + \pi_{\text{CH}_3\text{O}} + n\pi_{\text{CH}_2}$$

The calculated distribution coefficients were in good agreement with those obtained experimentally with a relative standard deviation of within 5%.

It was found that the empirical contribution values obtained in the present work are very useful for estimating the unknown distribution coefficient for BPHA derivatives.

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