[CONTRIBUTION FROM THE FURMAN CHEMICAL LABORATORY, VANDERBILT UNIVERSITY]

PARTITION RATIOS OF ORGANIC ACIDS FOR IDENTIFICATION PURPOSES

D. E. PEARSON AND MAX LEVINE[1]

Received April 3, 1952

The data of Dermer and Dermer (1), as given in Shriner and Fuson (2) concerning the distribution of organic acids between ether and water, have been useful as a means of identifying water-soluble acids. The purpose of this paper is to extend the distribution studies to solvents other than ether in order to provide two or three partition ratios[2] rather than one with very little additional manipulation. Furthermore, by choice of the proper solvent, large values of the partition ratio which are difficult to determine accurately may be reduced. After considerable exploratory work,[3] methyl isobutyl ketone and methylisobutylcarbinol were selected as the most satisfactory solvents.

EXPERIMENTAL

Methyl isobutyl ketone and *methylisobutylcarbinol* (Shell Chemical Corporation) were washed with sodium bicarbonate solution, dried, and distilled through a small column (b.p. 115–116° and 131–132°, respectively). The solvents were then saturated with water. Though Dermer and Dermer (1) do not saturate their ether, it is believed that it would have been desirable to do so in order to minimize volume changes. The acid solute was at least of Distillation Products Inc. White Label grade or was purified to an equivalent state. The neutral equivalents of stock solutions of the acid solutes were determined to check gross (but not slight) contaminations. The partition ratios were determined at two concentrations in most cases. The acid (1.00 g. or 0.50 g.) was dissolved and diluted with water to 100.0 ml., and the normality of an aliquot was determined with a Beckman *p*H meter, Model H-2. The aqueous acid solution (25.0 ml.) was then shaken intermittently with water-saturated solvent (25.0 ml.) for at least three hours. At the end of this time, or on standing overnight, an aliquot of 5.0 to 10.0 ml. of the aqueous phase was retitrated. K was then determined as the quotient of the concentration in water (by direct titration) and the concentration in the organic solvent (by difference). All partition ratios were run in duplicate, and the average recorded in the Tables. No attempt was made to control the temperature of equilibration (25 ± 2°) since the solutions were dilute and the phases almost completely immiscible[4] (3, 5). The results are given in Tables I and II.

The question was raised that the efficiency of extraction of methylisobutylcarbinol may be due to partial esterification of the acid solute, particularly in the case of formic acid, during the equilibration period. The following experiment answered that question: formic acid (0.1125 *N*) was equilibrated overnight with an equal volume of methylisobutylcarbinol,

---

[1] This paper is based upon part of the thesis of Max Levine submitted to the Graduate School, Vanderbilt University, in partial fulfillment of the requirements for the Ph.D. degree (1951).

[2] K, the partition ratio as defined by Craig (3), is equal to the concentration of the acid solute in water divided by the concentration in the organic solvent. Large values of K refer to high water solubility—small values to high organic solvent solubility.

[3] The authors are indebted to Miss Mary Catlett and Mr. T. D. Taylor for performing most of the exploratory experimentation.

[4] Water solubility in methyl isobutyl ketone 1.9%; in methylisobutylcarbinol 1.7%; solubility of ketone in water 2.8%; of carbinol in water 5.8% (4).

and an aliquot of the aqueous phase then titrated (K = 1.745). The remaining aqueous phase was then removed from the carbinol and re-equilibrated overnight with a fresh sample of methylisobutylcarbinol. An aliquot of the aqueous phase was titrated (K = 1.705). The conclusion was that a slight amount of esterification had taken place but not enough to affect seriously the results.

TABLE I
PARTITION RATIOS OF SOME ORGANIC ACIDS
(K = concentration in water/concentration in organic solvent)

ACID	METHYL ISOBUTYL KETONE		METHYL ISOBUTYLCARBINOL	
	0.5 g Acid/100 ml. H_2O	1.0 g. Acid/100 ml. H_2O	0.5 g. Acid/100 ml. H_2O	1.0 g Acid/100 ml. H_2O
p-Toluenesulfonic	81	95	14	10.7
d-Camphor-10-sulfonic		92	30	28
Glycine[a]	85	48	70	62
2,5-Dichlorobenzenesulfonic		48	6.0	3.3
Citric	45	44	12	14.6
d-Tartaric	41	40	28	14
Sulfanilic		39	27	25
Benzenesulfonic		38.5		13.7
N-Acetylglycine		31.3		7.6
dl-Malic	24	21	10	9.3
Sulfosalicylic	22	19	13	12.2
Diglycolic	18.7	10	4.3	4.2
Oxalic	13.8	9.5	7.9	5.5
Tricarballylic	10.6	7.5	1.9	2.0
Lactic	7.2	7.0[b]	2.7	2.3
Malonic	6.5	6.1	2.7	2.7
Succinic	4.9	5.4[b]	1.7	1.7
Maleic	4.8	4.6		2.1
Potassium hydrogen phthalate	4.4	4.2		3.0
Methoxyacetic	3.9	4.0		2.0
Glutaric	2.8	2.3		0.7
Formic		2.3	1.68	1.70
Aconitic	2.3	2.1		
Acetic	2.1	2.0	1.1	1.1
Itaconic	1.88	1.8		
Cyanoacetic	1.46	1.3		
Adipic	1.3	1.2[b]		0.33
Trifluoroacetic	1.15	0.77		
Fumaric[c]	0.71	0.65[b]		0.25
Propionic		0.61		0.32
Phthalic[c]	0.45	0.42		0.25
Acrylic	0.42	0.41		
Trichloroacetic	0.52	0.35		
Picric	0.31	0.19		0.69
Sorbic[c]		0.08		
Resorcylic	0.028	0.029		

[a] Gravimetric determination; not as accurate as titration data. [b] Reference 7: succinic 5.4; adipic 1.2; fumaric 0.83; lactic acid, K unreliable because of ester formation. [c] Concentration less than 1.0 g./100 ml. due to insolubility of acid.

DISCUSSION

The data have been put to practical test in the characterization laboratory. The partition ratios of unknown acids have been determined by the Dermer and Dermer procedure (1, 2) and then a second aliquot used to determine the partition ratios in the water-methyl isobutyl ketone system (or water-carbinol system if K is very large). The supplementary procedure was particularly useful with acids which are quite water-soluble ($K > 1.0$). In fact, it was impractical to use the supplementary procedure for less water-soluble acids since K did not change sufficiently to be characteristic. In some ways, the ketone-water system is superior to the ether-water system: K is smaller and is less dependent on the concentration of the acid solute, thus permitting some variable initial concentration of the acid solute.

TABLE II

EFFECT OF CHAIN LENGTH ON PARTITION RATIOS OF FORMIC AND ACETIC ACID IN WATER-ALCOHOL SYSTEMS

(K = concentration in water/concentration in solvent)

ALCOHOL	FORMIC ACID (0.1125 *N*) K	ACETIC ACID (0.1015 *N*) K	G. OF H_2O TO SATURATE 100 G. OF ALCOHOL[a]
1-Pentanol	1.75[d]	1.12[e]	10.7[b]
1-Hexanol	2.22	1.36	6.75[c]
1-Heptanol	2.85	1.65	—
1-Octanol	3.43	1.93	6.4
1-Decanol	4.50	2.70	2.7

[a] Determined by titration. End-point considered to be at that increment of water which did not dissolve in two hours. Temperature = 26 ± 1°. [b] Reference 4: 6.8% at 20°; Seidell, *Solubilities of Organic Compounds*, 3rd Ed., Van Nostrand Co., N. Y., 1941: 9.4% at 20°. [c] Reference 4: 7.2% at 20°. [d] Reference 11: K = 1.8. [e] Reference 11: K = 1.07.

These data also permit speculation on the general behavior of organic acids when distributed between water and an organic solvent — a problem which is of considerable importance at the present time (6). The generalizations are more specific than those of Craig (3), Marvel and Richards (7), Treybal (8), or Golumbic (9) but are more restricted in scope than those deduced from the extensive work of Collander (10). The interplay of forces which control partition is complex but apparently resolvable in part.

Concerning the effect of the solvent. The abscissa of Fig. 1 is some function of the extracting efficiency of various solvents. The efficiency of extraction for any solvent is presumably the resultant of its hydrogen-bonding ability, its dipole attraction (both forces operating in competition with those of water), and van der Waals attractive forces — the latter usually opposing the polar influences. Solvents other than those given in Fig. 1 will be situated on the abscissa approximately in the order given by Marvel and Richards (7). If the polar forces of any solvent are greater than those of a standard solvent, the solvent will be situated to the right of the standard solvent in Fig. 1. If van der Waals forces are greater, the solvent will be situated to the left. In fact, assuming that the polar forces are the same in a series of primary alcohols, it is noted from Fig. 2 that the partition ratio of any acid is almost a linear function of the increase in van der Waals forces as denoted by an increase in chain length of the alcohol. In other words, it is clear that extraction efficiency for any water-soluble acid can be increased by choice of a solvent of low molecular weight.

Of equal or greater importance is the choice of a solvent with the proper functional group which can participate in hydrogen bonding with the acid solute. It is apparent from Fig. 1 that alcohols are outstandingly efficient extractors of organic acids from water solution. Alcohols are capable of being both acceptor and donor molecules in hydrogen bonding, and it is quite likely that both these properties account for the resultant efficiency. This point is further investigated in the following paper.

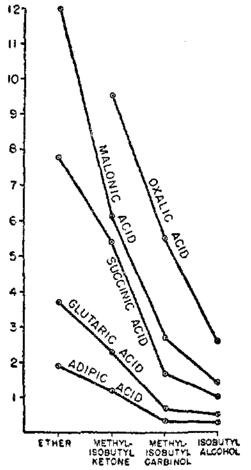

FIG. 1. PARTITION RATIO (K) *vs.* EFFICIENCY OF EXTRACTION OF SOME ORGANIC SOLVENTS

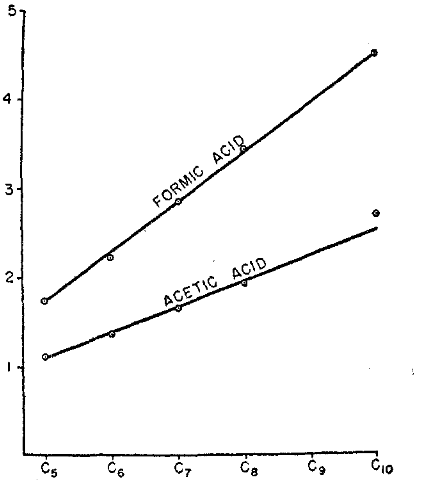

FIG. 2. PARTITION RATIO (K) *vs.* CHAIN LENGTH OF PRIMARY ALIPHATIC ALCOHOLS. Note: the bottom line shows some tendency to curve upwards.

Concerning the effect of the acid solute. The ordinate of Figs. 1 and 2 is the partition ratio which can be visualized as a measure of water solubility in competition with organic solvent solubility. It is noted in Fig. 1 that the partition ratios of a series of acids in one solvent converge when a second more efficient solvent is used. In other words, large K values are reduced considerably, but small K values are reduced only slightly. This is a consequence of the forces in action. Acid solutes with large K values are small in molecular weight, polyfunctional or ionic and thus susceptible to polar influences of the solvent. Acid solutes with small K values have a non-polar group equivalent to at least two methylene groups. The non-polar group, operating through van der Waals attractive forces between like molecules and solvent molecules, reduces proportionately the overall effect of polar influences. Thus, K is small and remains about the same no matter what solvent is used. Further support of this observation is given in Fig. 2. The slopes of the lines are in the order: formic acid > acetic acid; if propionic acid or butyric acid had been tested, the slope would approach zero.

Secondly, it is noteworthy that the partition ratios of acid solutes are less dependent on the concentration of the acid solute in those solvents which are farther to the right in Fig. 1. In other words, the aggregates in the aqueous and organic solvent phases become of similar size (3).

Lastly, in the majority of cases, the partition ratios of acid solutes hold their relative positions in shifting from one solvent to another (Fig. 1, Table I). This is discouraging from the point of view of separation and no doubt the reason that buffering has been more successful in separation. However, if an acid solute differs considerably from the average carboxylic acid in its donor-acceptor properties, the relative positions may be altered by choice of a proper solvent. For example, sulfonic acids are extremely insoluble in all solvents tested except alcohols. The most plausible explanation is that the sulfonate anion, the predominant species in the aqueous phase, would have little tendency to complex with any other structure than that of a hydrogen donor such as an alcohol. Weizmann, *et al.* (12) propose a similar explanation in the study of other solutes.

SUMMARY

The partition ratios of thirty-six, water-soluble organic acids have been determined in the systems, water-methyl isobutyl ketone and water-methylisobutylcarbinol. The data are useful for the identification of unknown acids by the method of Dermer and Dermer (1, 2) and are helpful in the discussion of factors which control partition.

NASHVILLE 4, TENN.

REFERENCES

(1) DERMER AND DERMER, *J. Am. Chem. Soc.*, **65**, 1653 (1943).
(2) SHRINER AND FUSON, *Identification of Organic Compounds*, 3rd ed., John Wiley and Sons, New York, N. Y., 1948, p. 147.
(3) CRAIG AND CRAIG in WEISSBERGER, *Technique of Organic Chemistry*, Interscience Publishers, New York, N. Y., 1950, Vol. III, p. 171.
(4) DURRANS, *Solvents*, Chapman and Hall, London, 1950.
(5) PAGEL AND SCHWAB, *Anal. Chem.*, **22**, 1207 (1950).
(6) CRAIG, *Anal. Chem.*, **24**, 66 (1952).
(7) MARVEL AND RICHARDS, *Anal. Chem.*, **21**, 1480 (1949).
(8) TREYBAL, *Liquid Extraction*, McGraw-Hill Co., New York, N. Y., 1951, p. 79.
(9) GOLUMBIC, *Anal. Chem.*, **23**, 1210 (1951).
(10) COLLANDER, *Acta Chem. Scand.*, **3**, 717 (1949); *Acta Chem. Scand.*, **4**, 1085 (1950); *Acta Physiol. Scand.*, **13**, 363 (1947).
(11) ARCHIBALD, *J. Am. Chem. Soc.*, **54**, 3178 (1932).
(12) WEIZMANN, *et al.*, *J. Soc. Chem. Ind. (London)*, **67**, 203 (1948).