state of 1-butene (molecular weight 56.0616) are: $R = 0.08206$, $A_0 = 16.6979$, $a = 0.11988$, $B_0 = 0.24046$, $b = 0.10690$, $c = 300 \times 10^4$ in units of normal atmospheres, liters per mole,

and °K. (T, °K. $= t° + 273.13$).

The polymerization of 1-butene is slow at 200° but becomes quite rapid by 250°.

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Partition Studies. V. Partition Coefficients and Ionization Constants of Methyl-substituted Pyridines and Quinolines[1]

BY CALVIN GOLUMBIC AND MILTON ORCHIN

Previous papers in this series[2] dealt with the partition coefficients of phenols and application of this information to the isolation of certain phenolic constituents of coal-hydrogenation oil. In the present work, the partition properties of some alkyl-substituted pyridines and quinolines have been investigated. In addition, practical separations of mixtures of these compounds that can be achieved by countercurrent distribution are illustrated. The compounds chosen for study may be considered as prototypes of the basic constituents of coal-hydrogenation oil.

Relation between Partition Coefficient and Ionization Constant.—Analogous to a previously derived equation relating the partition coefficient and ionization constant of an organic acid,[2a,3,4] the equilibria involved in the distribution of an organic base between an organic solvent and an immiscible acid buffer phase may be described by the equation

$$\log k' = pH + \log k - pKa \qquad (1)$$

where k' is the observed partition coefficient, k is the partition coefficient of the un-ionized base, and pKa is the acidic ionization constant. The equation is limited to those circumstances in which $pH << pKa$ and in which no association occurs in the organic phase.

According to this equation, $\log k'$ is directly proportional to pH, and a plot of these variables should give a straight line with a slope of 1. To test the validity of this relation, partition coefficients were measured for the distribution of pyridine, picolines, 2,6-lutidine and 3-aminoquinoline between chloroform and citrate–phosphate buffer and for the distribution of quinoline, isoquinoline, and methyl-substituted quinolines between cyclohexane and citrate–phosphate buffer. The initial concentration of base was 0.5 mg. per ml. At this concentration, association effects are either absent or negligible (see experimental part). Plots of the logarithms of the observed partition

coefficients vs. pH are presented in Figs. 1 and 2. The partition coefficients are expressed as (concentration in organic phase)/(concentration in aqueous phase). Straight lines are obtained for each monoacid base, and the slopes (m) are all very close to 1 (Table I, column 2). It is interesting to note that the slope of the aminoquinoline curve becomes greater than 1 in the strongly acid range. This is the result to be expected, because 3-aminoquinoline is known to form a di-acid salt in highly acid solutions.[5] Hence, the observed slope should increase from 1 to a limiting value of 2 when the pH has become $<< pK_2$.

A further test of equation (1) was made by employing it for calculation of approximate ionization constants (pKa) of each base studied. In order to do this, the k values had to be measured first. This was accomplished by determining the partition coefficient of each base when distributed between the organic phase and water. Corrections for the "salting-out effect" of the buffer were negligible except in the case of 2,6-dimethylquinoline. When concentrated buffers are employed in distribution, the "salting-out" effect is appreciable.[2a] The experimental k values are listed in Table I, column 3. As was expected, the

TABLE I

PARTITION COEFFICIENTS AND IONIZATION CONSTANTS OF PYRIDINES AND QUINOLINES

Compound	m	k $(H_2O)^a$	pKa	pKa literature
Pyridine	0.95	27	5.5	5.35,[b] 5.38,[c] 5.48[d]
2-Picoline	.98	62	6.1	6.02,[b] 6.65,[c] 6.51[d]
3-Picoline	.97	77	5.8	6.04[d]
4-Picoline	.95	75	6.1	6.04[d]
2,6-Lutidine	.98	198	6.9	..
Quinoline	1.00	18	5.0	4.80,[c] 4.94[f]
Isoquinoline	1.00	13	5.4	..
2-Methylquinoline	1.00	44	5.8	5.42[e]
4-Methylquinoline	1.04	34	5.6	5.20[e]
6-Methylquinoline	1.01	52	5.2	4.92[e]
8-Methylquinoline	1.05	164	5.0	4.60[c]
2,6-Dimethylquinoline	1.02	104	6.1	..
3-Aminoquinoline	0.96–1.15	19	4.9	4.95[e]

^{a} Measured at 25°. ^{b} Barron, *J. Biol. Chem.*, **12**, 313 (1937). ^{c} Goldschmidt and Salcher, *Z. physik. Chem.*, **29**, 114 (1899). ^{d} Constam and White, *Am. Chem. J.*, **29**, 46 (1903). ^{e} Felsing and Biggs, THIS JOURNAL, **55**, 3624 (1933). ^{f} Albert and Goldacre, *Nature*, **153**, 407 (1944).

(1) Article not copyrighted.

(2) (a) Golumbic, Orchin and Weller, THIS JOURNAL, **71**, 2624 (1949); (b) Golumbic, *ibid.*, **71**, 2627 (1949); (c) Orchin and Golumbic, *ibid.*, **71**, 4151 (1949); Golumbic, Woolfolk, Friedel and Orchin, *ibid.*, **72**, 1939 (1950).

(3) Yabroff, *Ind. Eng. Chem.*, **32**, 257 (1940).

(4) Irving, Cooke, Woodger and Williams, *J. Chem. Soc.*, 1847 (1949).

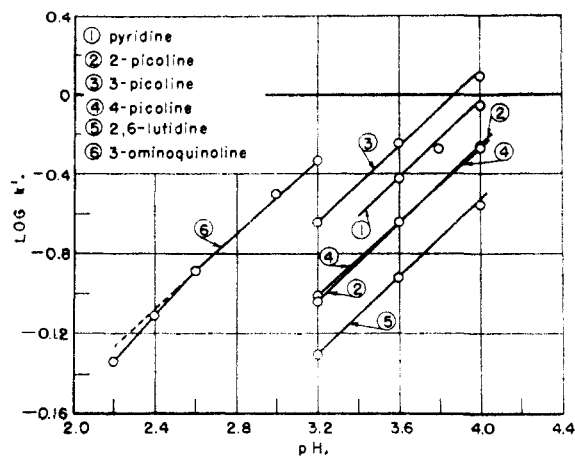(5) Mills and Watson, *ibid.*, **97**, 741 (1910).

Fig. 1.—Effect of pH on partition coefficients of pyridines and of 3-aminoquinoline.
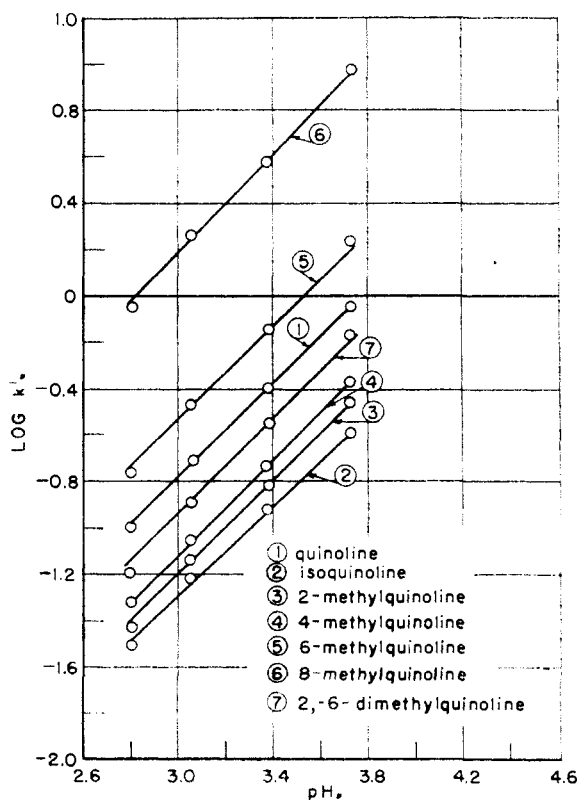

Fig. 2.—Effect of pH on distribution constants of quinolines.

position of the methyl groups in each group of isomers had little effect on the k values except in one instance. The high k value of 8-methylquinoline is probably due to a steric effect, *i.e.*, the methyl group in the 8-position interferes with hydrogen bonding between water molecules and the nitrogen atom and thereby decreases the solubility of the 8-methylquinoline in the aqueous phase. The intramolecular action of hydroxyl and amino groups

in the 8-position with the nuclear nitrogen atom is, of course, well-known.

The calculated pKa values are in fair agreement with values reported in the literature (compare columns 4 and 5, Table I). It is apparent from these data that certain generalizations on the base strengths of pyridines described by Brown and Barbaras[6] can be extended to the quinoline series. The introduction of a methyl group into the quinoline nucleus increases base strength. The effect is most pronounced with 2- and 4-methyl substituents, probably because the hyperconjugative effect of the methyl group in these positions (resonance forms, I and II) would be base strengthening. Methyl groups in the 6 and 8 position, which might lead to the resonance contributions of forms III and IV, do not increase the availability of the electrons on the nitrogen atom and are not base strengthening.
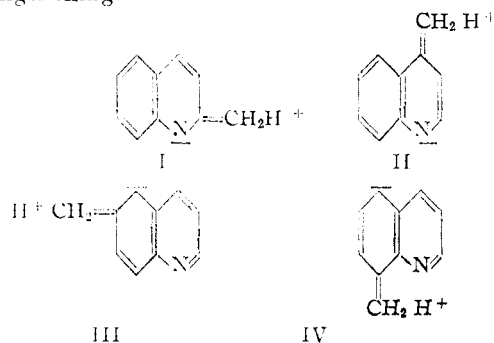
That the resonance forms III and IV are important is in accord with the fact that electrophilic reagents attack 6- and 8-methylquinoline at the 5-position.[7]

Separation of Isomeric Pyridines and Quinolines.—The data of Table II, in which the partition coefficients, k', of individual bases are compared with their boiling points, show that some separations that would be difficult by fractional distillation should be possible by a multiple

TABLE II

COMPARISON OF PARTITION COEFFICIENTS AND BOILING POINTS OF PYRIDINES AND QUINOLINES

| Compound | Partition coefficient at 25°, k' | | Boiling point, °C. |
	(at pH 4.00)	(at pH 3.72)	
Pyridine	0.87	..	115.5
2-Picoline	0.55	..	129.4
3-Picoline	1.24	..	144.0
4-Picoline	0.52	..	144.6
2,6-Lutidine	0.28	..	143.8
Quinoline	.	0.89	237.3
Isoquinoline	..	.24	243.3
2-Methylquinoline	..	.34	247.6
4-Methylquinoline	..	.42	264.2
6-Methylquinoline	..	1.76	258.6
8-Methylquinoline	..	9.64	247.8

(6) Brown and Barbaras, THIS JOURNAL, **69**, 1137 (1947).

(7) Noelting and Trautmann, *Ber.*, **23**, 3655 (1890); Herzfeld, *ibid.*, **17**, 905 (1884); Lellmann and Ziemssen, *ibid.*, **24**, 2117 (1891).

extraction procedure such as the countercurrent distribution technique of Craig.[8] This prediction was verified by actual countercurrent distribution experiments. Mixtures of 3- and 4-picoline and of 2- and 8-methylquinoline were readily separated by 53-plate distributions in the systems, chloroform vs. citrate–phosphate buffer of pH 4.0 and cyclohexane vs. citrate–phosphate buffer of pH 3.40, respectively.

Experimental

Materials.—The picolines and 2,6-lutidine were furnished by Dr. J. J. McGovern, Koppers Company Fellowship, Mellon Institute, and were reported to have a purity of 97–99%. The pyridine was a reagent-grade sample which was dried over barium oxide before use. Quinoline and isoquinoline were commercial samples which were purified by fractional distillation in a Podbielniak column operating at about 25 theoretical plates. The methylquinolines were Eastman Kodak Co. highest-purity grade. They were subjected to 1–2 plate fractionation, and the constant-boiling fraction was used for partition measurements. 3 - Aminoquinoline and 2,6 - dimethylquinoline were Eastman Kodak Co. chemicals and were recrystallized to constant melting point.

The solvents employed for the organic phase were spectrographic-grade cyclohexane and reagent-grade chloroform. The latter was distilled through a Vigreux column before use.

The buffers were McIlvaine standard phosphate–citrate mixture.[9]

Determination of Partition Coefficient.—A standard solution of the organic base (0.5 mg. per ml.) in the purified solvent was equilibrated at 25° with an equal volume of the buffer. The partition ratio was determined by the relation $k' = C/(C_0 - C)$, where C_0 and C are the concentrations of base in the organic solvent before and after equilibration. The measurements of concentration were made by ultraviolet spectroscopy employing the Cary recording spectrophotometer. For values of $k' > 20$, the procedure had to be slightly altered to obtain significant differences in optical density. The ratio of the volumes of organic to buffer phases was decreased, and the organic phase was repeatedly equilibrated with fresh buffer. The

partition coefficient, k', was then calculated by applying the relation

$$(k'r/k'r + 1)^n = C_1/C_0 \qquad (2)$$

where C_0 is the initial quantity of phenol in the organic phase, C_1 its amount after n extractions with buffer, and r the ratio of volumes of organic and buffer phases.

Effect of Concentration in Partition Coefficient.—The results presented in Table III show that the partition coefficients of pyridine and quinoline are essentially constant over the concentration range involved in this work. Since the experimental and theoretical curves for the countercurrent distribution of picolines and methylquinolines were nearly superimposable, constancy of partition ratios for these compounds is also shown.

TABLE III

EFFECT OF CONCENTRATION ON PARTITION COEFFICIENT OF PYRIDINE AND QUINOLINE

Compound	Initial concn., mg. per ml.	pH of buffer phase	Partition coefficient at 25°
Pyridine	1.0	4.00	0.88
	0.5	..	.82
	.1	..	.87
	.05	..	.67
Quinoline	1.0	3.72	.99
	0.5	..	.89
	.1	..	.84
	.05	..	.85
	.01	..	.77

Acknowledgment.—The authors are indebted to George Goldbach for technical assistance.

Summary

The distribution of pyridine, quinoline, and certain methyl-substituted derivatives has been studied in immiscible systems composed of cyclohexane or chloroform and water or citrate–phosphate buffer. Partition coefficients and approximate ionization constants were determined. This information provided a basis for the separation of isomeric heterocyclic bases by countercurrent distribution.

(8) Craig, *J. Biol. Chem.*, **155**, 519 (1944).

(9) Clark, "The Determination of Hydrogen Ions," The Williams and Wilkins Co., Baltimore, Md., 1927, p. 116.

Organophosphorus Compounds. Alkyldichlorophosphines[1]

BY ROBERT B. FOX

In undertaking a study of the simpler molecules of trivalent organophosphorus acids, it was necessary to prepare a homologous series of the intermediate alkyldichlorophosphines.

Although extensive investigations have been carried out on the synthesis of phenyldichlorophosphine and its homologs, the methods used in the aromatic series are not readily applicable to the preparation of the aliphatic series of dichlorophosphines. Hitherto, the only methods available for the synthesis of alkyldichlorophosphines

have been through a metathetical reaction between phosphorus trichloride and a dialkylmercury[2,3] or tetraalkyllead[4] derivative. Not only are these organometallic compounds highly toxic and therefore somewhat difficult to work with, but the mercury derivatives require reaction under pressure and yield dichlorophosphines contaminated with alkylmercuric chlorides. Tetraethyllead has been reported to give excellent yields of ethyldichlorophosphine.[4] However, the prepara-

(1) The opinions contained herein are the private ones of the writer and are not to be construed as official or reflecting the view of the Navy Department or the naval service at large.

(2) (a) Michaelis, *Ber.*, **13**, 2174 (1880); (b) Guichard, *ibid.*, **32**, 1572 (1899).

(3) Drake and Marvel, *J. Org. Chem.*, **2**, 389 (1937).

(4) Kharasch, Jensen and Weinhouse, *ibid.*, **14**, 429 (1949).