

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

(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.

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

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

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
Quinoline	.05	..	.67
	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.

BRUCETON, PENNSYLVANIA RECEIVED FEBRUARY 23, 1950

[CONTRIBUTION FROM THE NAVAL RESEARCH LABORATORY]

Organophosphorus Compounds. Alkyldichlorophosphines¹

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 tetraalkyllead⁴ 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) Gnichard, *ibid.*, **32**, 1572 (1899).

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

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

TABLE I
 ALKYLDICHLOROPHOSPHINES

Compound	Formula	Yield, %	Normal b. p., °C.	d_{25}^{25}	n_D^{20}	Analyses, %			
						Phosphorus Calcd.	Phosphorus Found	Chlorine Calcd.	Chlorine Found
Ethyl	$C_2H_5PCl_2$	26	112	1.2485 ^{a,p}	1.4930	23.6	^c	54.1	54.3
<i>n</i> -Propyl	$C_3H_7PCl_2$	44	134.5	1.1664 ^d	1.4842	21.4	^c	48.8	48.7
<i>n</i> -Butyl	$C_4H_9PCl_2$	47	160	1.1341	1.4838	19.4	19.2	44.5	43.7
<i>n</i> -Amyl	$C_5H_{11}PCl_2$	40	184	1.0997	1.4815	17.9	17.9	40.9	40.6
<i>n</i> -Hexyl	$C_6H_{13}PCl_2$	41 ^e	208	1.0653	1.4800	16.5	16.0	37.9	37.6
<i>n</i> -Heptyl	$C_7H_{15}PCl_2$	42	228.5	1.0636	1.4788	15.4	15.1	35.3	35.5
<i>n</i> -Octyl	$C_8H_{17}PCl_2$	33	247	1.0433	1.4778	14.4	14.4	33.0	32.0

^a d_{25}^{25} . ^b Guichard² gives d_{19}^{19} 1.2952. ^c Analysis for phosphorus by usual methods gave inconsistent results. ^d Guichard² gives d_{19}^{19} 1.1771. ^e Based on one run.

tion of other tetraalkyllead derivatives not readily available does not make this method a convenient laboratory procedure. The more reactive organometallic derivatives, such as Grignard reagents and lithium alkyls, yield the trialkylphosphine with phosphorus trichloride; no mono- or di-substituted products have been reported.

In view of the recent work on the synthesis of ketones from acid chlorides by means of organocadmium derivatives,⁵ it was thought that these compounds might lead to a stepwise substitution of the chlorine atoms in phosphorus trichloride without the attendant disadvantages of the mercury and lead methods. This expectation has been borne out with the preparation of seven *n*-alkyldichlorophosphines.

Essentially, the reaction consists of three steps: preparation of the appropriate Grignard reagent, conversion to the corresponding organo-cadmium compound, and reaction of the cadmium derivative with phosphorus trichloride. The first two

steps are achieved by conventional means.⁶ Although the addition of phosphorus trichloride to the organocadmium derivative yields a mixture of mono-, di- and tri-substituted products, reverse addition—*i. e.*, the addition of the cadmium compound to an excess of phosphorus trichloride, gave little evidence of reaction with more than one halogen atom; after removal of the alkyldichlorophosphine, only a very small residue of higher boiling material remained. While no systematic study to determine the optimum conditions for the reaction was carried out, it was found that the best yields of the dichlorophosphines were obtained by the addition of the dialkylcadmium to the phosphorus trichloride at a rate consistent with the maintenance of reaction temperature in the vicinity of -20° . After the addition, the reactions were essentially complete on refluxing the mixtures for two to three hours.

Experimental

Materials and Apparatus.—In all phases of the synthesis, diethyl ether, dried over sodium, was used as a solvent. The cadmium chloride was a powdered anhydrous C. P. grade, dried an additional hour at 110° , and stored in a desiccator over calcium chloride. The alkyl bromides were redistilled commercial products. A C. P. grade of phosphorus trichloride was used without further purification.

All cadmium reactions were carried out under an atmosphere of nitrogen in an all-glass apparatus consisting of a three-necked round-bottom flask fitted with a Hershberg stirrer, reflux condenser through which nitrogen was admitted, and a dropping funnel. The dialkylcadmium reaction mixture was added to the phosphorus trichloride through a delivery tube which replaced the dropping funnel by means of nitrogen pressure; the delivery tube led to a second three-necked flask fitted in the same manner as the first but with a drying tube at the opening of the reflux condenser. Filtration of the final precipitate was carried out with sintered glass filters of fine porosity. All distillations were performed under nitrogen in conventional equipment.

General Procedure.—The preparations of the dialkylcadmium reagents were generally carried out according to the methods of Cason⁵ except that the reaction mixture was usually stirred or refluxed for one to two hours depending upon the compound, and a Gilman test was not used before adding the mixture to the phosphorus trichloride. Since the procedure subsequent to the preparation of the dialkylcadmium was the same for all the dichlorophosphines, the synthesis of *n*-butyldichlorophosphine will serve as an illustration. This method has been used successfully in runs up to 1.0 mole.

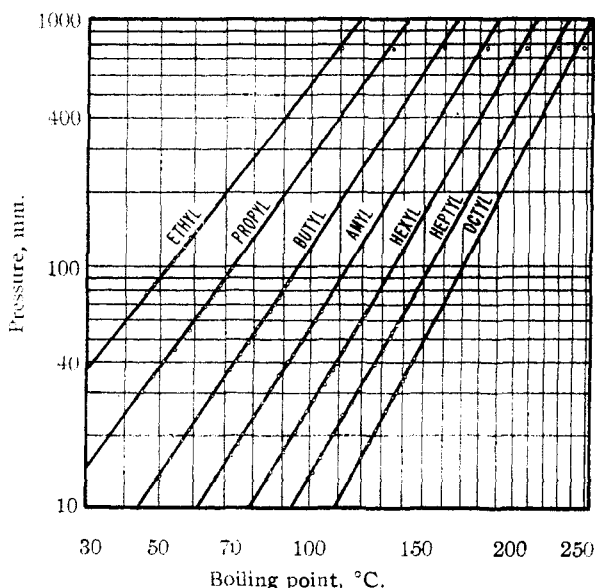


Fig. 1.—Boiling points of *n*-alkyldichlorophosphines at various pressures.

(5) Cason, *Chem. Revs.*, **40**, 15 (1947).

(6) Cason, *This Journal*, **68**, 2079 (1946), and preceding papers.

Di-*n*-butylcadmium was prepared by the rapid addition of 50.4 g. (0.275 mole) of cadmium chloride to the cooled solution of *n*-butylmagnesium bromide formed from 12.15 g. (0.5 mole) of magnesium and 75.4 g. (0.55 mole) *n*-butyl bromide in 550 ml. of diethyl ether. Following the addition, the mixture was stirred in an ice-bath for two hours. The di-*n*-butylcadmium reaction mixture, including the precipitate, was then added to a stirred solution of 85.9 g. (0.625 mole) of phosphorus trichloride in 100 ml. of ether over a period of twenty-five minutes. The phosphorus trichloride reaction mixture was maintained at -20° by means of a Dry Ice and acetone bath. After the addition, 100 ml. of ether was flushed through the cadmium reaction vessel into the main reaction mixture from which the delivery tube was then withdrawn. The cooling bath was removed and the stirred reaction mixture allowed to warm to room temperature (0.5 hour) subsequent to refluxing for 2.5 hours.

The reaction was worked up by allowing the mixture to stand overnight at room temperature followed by decantation of the main portion of the ethereal solution. The residual precipitate was diluted with 100 ml. of ether, filtered by gravity and washed with ether. (Care must be taken in the disposal of this precipitate, since hydrolysis of traces of residual dichlorophosphine in the precipitate yields some alkylphosphine. Careful addition to a large volume of water in an efficient fume hood is necessary.) Ether was removed from the combined decantate, filtrate, and washings by distillation at atmospheric pressure, and the residue was distilled under reduced pressure to yield the crude dichlorophosphine. Fractionation of the crude through an 18-inch glass-helices packed column gave 37.4 g. (47% based on magnesium) of *n*-butyldichlorophosphine, b. p. $58-60^{\circ}$ at 22 mm.

Properties of Alkyldichlorophosphines.—The alkyldichlorophosphines are water-white liquids with obnoxious odors. On standing, particularly in contact with atmospheric moisture, they deposit a yellow amorphous solid which was not identified. Both the odor and the tendency to deposit a solid decrease as the length of the carbon chain increases. A sample of *n*-amyldichlorophosphine in a sealed bottle was kept at room temperature for seven months without appreciable change in purity. *n*-Amyldichlorophosphine and its lower homologs can be distilled at atmospheric pressure without decomposition of the still-pot residue.

Physical Measurements.—Boiling points at various pressures were determined by distilling a fractionated sample of constant boiling range through an 18-inch glass helices-packed column and observing the vapor temperature in the still head; a high reflux ratio was maintained at all times. A closed-tube mercury manometer was used for pressure observations. Boiling points at atmospheric pressure were made by sand-bath distillation of a constant-boiling sample in a Claisen flask with all-glass joints. These data are shown on the Cox Chart (Fig. 1) and indicate that the vapor pressure curve of $\log p$ vs. $1/T$ is not quite a straight line function. Refractive indices were measured on an Abbe-type refractometer, and densities were determined in a Weld pycnometer of approximately 10 ml. capacity.

Summary

The synthesis of a series of alkyldichlorophosphines by reaction of dialkylcadmium compounds with phosphorus trichloride has been developed.

WASHINGTON, D. C.

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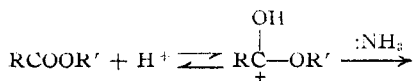
[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE POLYTECHNIC INSTITUTE OF BROOKLYN]

The Aminolysis of Esters. A Preliminary Study

BY RICHARD BALTZLY, IRVING M. BERGER¹ AND ARNOLD A. ROTHSTEIN¹

Although the ammonolysis of esters has received considerable attention, relatively little has been published on the kinetics of the kindred reaction of aminolysis. Glasoe, Kleinberg and Audrieth² examined the reaction of ethyl phenylacetate in *n*-butylamine (serving as solvent and reactant). Grunfeld³ determined reaction rates of some long-chain aliphatic amines with esters in ethanol and petroleum ether as solvents.

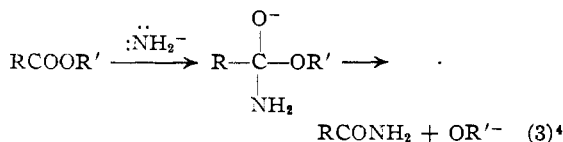
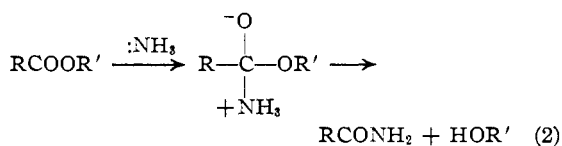
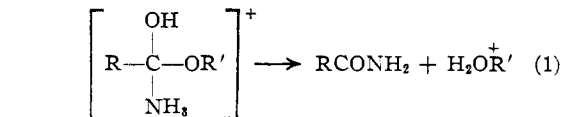
While an additional variable, the structure of the amine, is involved in the reaction with amines, there is no reason to suppose that the mechanism differs essentially from ammonolysis. *A priori* the reaction might be uncatalyzed or subject to acid or basic catalysis according to Equations 1-3



(1) From theses presented by I. M. Berger and A. A. Rothstein to the School of Graduate Study of the Polytechnic Institute of Brooklyn in partial fulfillment of the requirements for the degree of Master of Science, May, 1948, and May, 1949.

(2) Glasoe, Kleinberg and Audrieth, *THIS JOURNAL*, **61**, 2387 (1939).

(3) Grunfeld, *Ann. chim. phys.*, [10], **20**, 351 (1933).



Simultaneous operation of the mechanisms of Equations 1 and 3 would not be expected but either mechanism could be concurrent with that

(4) A variant of this mechanism, suggested by Gordon, Miller and Day (*THIS JOURNAL*, **71**, 1245 (1949)) involves attack by a hydrogen-bonded complex. For catalysis by methylate anion in methanol this would be written as $\text{RNH}-\text{H}\cdots\text{OCH}_3$. Since an amide anion in methanol would also be subject to hydrogen bonding and should be written as $\text{RNH}^-\cdots\text{H}-\text{OCH}_3$, it is our opinion that the distinction is academic.