mole taken from hydrocarbon oxidation data, and, furthermore, that ethylene and acetylene have activation energies markedly below those of the straight chain hydrocarbons. Using the new activation energies and experimental flame temperatures (which are thought by the authors to be preferable to adiabatic temperatures), the burning velocities of ethylene and acetylene relative to propane, as predicted by the Semenov equation, have been re-evaluated, as shown in Table I.

TABLE I

MAXIMUM BURNING VELOCITIES OF HYDROCARBON FLAMES

Hydrocarbon	Vol. fuel, %	Activation energy,[3] kcal./mole	Exp. flame temp., °K.	Burning velocity cm./sec. Exptl.	Burning velocity cm./sec. Sem. eqn.
Propane	4.5	26.1	2158[a]	39.0[d]	39.0
Ethylene	7.4	23.6	2238[a]	68.3[d]	71.0
Acetylene	10.4	20.4	2480[b]	141.0[c]	152.5

[a] G. W. Jones, B. Lewis, J. B. Friauf and G. St. J. Perrott, THIS JOURNAL, **53**, 869 (1931). [b] H. Behrens and F. Rossler, *Z. Naturforsch.*, **5a**, 311 (1950). [c] O. Levine and M. Gerstein, *Natl. Advisory Comm. Aeronaut.*, RM E51JO5, 1951. [d] M. Gerstein, O. Levine and E. L. Wong, THIS JOURNAL, **73**, 418 (1951).

These new results give insight into the character of the variation of the specific reaction rate constant in the Semenov equation for ethylene and acetylene as compared to other hydrocarbons. The simplified Semenov equation[1] contains the specific reaction rate constant in the form, $k = Ke^{-E/RT}$. In the above correlation, the steric factor, K, by necessity is assumed independent of hydrocarbon, thus implying that variation in the specific reaction rate constant at a given temperature is simply due to a variation in the energy of activation. The fact that the above correlation is successful would seem to indicate that the steric factor of acetylene and ethylene for the combustion reaction is not greatly different from that of other hydrocarbons. It also emphasizes the important role which activation energy plays in determining the fundamental burning velocity of a hydrocarbon. Perhaps the major significance of the results, however, is that the activation energies of hydrocarbons determined from lean limit and ignition energy data bring the flame speed predictions into line with experimental results, suggesting that the same mechanism may be important in the different combustion phenomena.

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The Absence of Quaternary Salt Formation between Phosphoryl Chloride and Pyridine[1]

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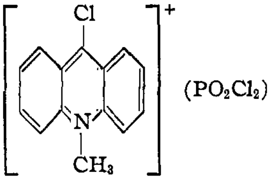
The Grignard reagent, RMgX, can be used to place alkyl or aryl groups on the phosphorus atom in $POCl_3$; when the reaction is conducted according to the normal procedure (addition of $POCl_3$ to the Grignard reagent in ether), all three chlorine atoms are replaced to produce phosphine oxides, R_3PO. It was shown[2] that one Cl atom can be blocked by the preliminary synthesis of an amido compound, $R_2N{-}POCl_2$, which can be isolated and put through the Grignard reaction, thus placing two R groups on the phosphorus atom.

One Cl atom can also be blocked in Grignard reactions if the $POCl_3$ is first added to N-methylacridone to form a 1:1 complex salt.[3] This compound was isolated[3,4] and the authors presented evidence to show that salt formation (Formula I) occurs through interaction of $POCl_3$ and the carbonyl group of the acridone. Kosolapoff[5] later found that R_2POCl compounds are produced predominantly, in Grignard reactions of $POCl_3$ in ether solution, if pyridine is first added to the $POCl_3$ in equimolar amounts. He ascribed this effective blocking of one Cl atom to quaternary salt formation between pyridine and $POCl_3$ and reported the reaction as

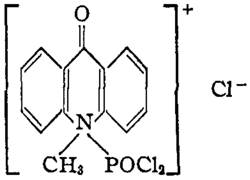
$$POCl_3 + C_5H_5N \longrightarrow C_5H_5N(POCl_2)Cl \xrightarrow[(HOH)]{2RMgX} R_2PO_2H$$

Kosolapoff felt that the reactions described by Gleu and Schubert involved a similar quaternary nitrogen salt (Formula II) and that phosphonic acids, $RPO(OH)_2$, could be synthesized by this method if other complexes of pyridine and $POCl_3$ could be formed. He was unable to block two Cl atoms by doubling the ratio of pyridine to $POCl_3$ and suggested that the larger complexes might be stable only at low temperatures.[5] The existence of the 2:1 compound at normal temperatures had been reported previously[6] and later disputed with good evidence.[7]

The present work was initiated to determine the temperatures at which the postulated complex compounds of $POCl_3$ and pyridine exist, and thus to define conditions for the preparation of phosphinic and phosphonic acids in good yields by means of the Grignard reaction.



Formula I



Formula II

Materials.—The $POCl_3$ used was distilled at 106.5–106.9° from a sample of Mallinckrodt Analytical Reagent material. The freezing point of the distillate was 1.02°; literature values are: b.p. 106.4–106.7°, f.p. 1.17°.[8]

The pyridine was obtained from the Eastman Kodak Co. and distilled over barium oxide prior to use; b.p. 114–115.5°, f.p. −42.3°, $n^{25}D$ 1.5061; literature values are: b.p. 115.5°[9]; f.p. −42.0°[10]; $n^{25.2}D$ 1.5070.[11]

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(1) Abstracted from an M.S. thesis submitted by B. M. Zeffert to the Graduate School, University of Maryland.

(2) G. M. Kosolapoff, THIS JOURNAL, **71**, 369 (1949).

(3) K. Gleu and A. Schubert, *Ber.*, **73**, 805 (1940).

(4) K. Gleu, S. Nitzsche and A. Schubert, *ibid.*, **72**, 1093 (1939).

(5) G. M. Kosolapoff, THIS JOURNAL, **72**, 5508 (1950).

(6) D. R. Boyd and D. E. Ladhams, *J. Chem. Soc.*, 215 (1928).

(7) W. Gerrard, *ibid.*, 106 (1945).

(8) D. M. Lichty, THIS JOURNAL, **34**, 1440 (1912).

(9) J. Timmermans, "Physico-Chemical Constants of Pure Compounds," Elsevier Publ. Corp., New York, N. Y., 1950.

(10) G. S. Parks, S. S. Todd and W. A. Moore, THIS JOURNAL, **58**, 398 (1936).

(11) "International Critical Tables," p. 80, Vol. VII.

Apparatus and Procedures.—The thermistor-cryostat used for the freezing point determinations has been described in a previous publication from this Laboratory.[12] The equipment was modified by substituting a line-operated power supply for the dry cells previously used for the Wheatstone bridge. This source was suitably regulated, rectified and tapped to provide the small d.c. voltages required.

The appearance of solid phases above the binary freezing points and certain anomalous arrests obtained on thermal analysis of the time–temperature curves in preliminary runs were found to be caused by moisture contamination of the solutions. The solids thus produced have been described as $2C_5H_5N–POCl_2(OH)$ and $C_5H_5N–HCl$.[7] Rigorous precautions were then taken to prevent absorption of water into the system. Dry pyridine was obtained by distillation over barium oxide, and subsequent storage over this drying agent. Crystallization from the melt was used to purify $POCl_3$, but the manipulations required in transfers allowed deterioration, and efficient use of drying agents in storage was precluded by the irreversible reaction of $POCl_3$ with water. The highest freezing point we obtained for $POCl_3$ was with a recrystallized sample distilled directly into the cryostat, and it was not until solutions were prepared by distilling recrystallized $POCl_3$ into the solution-mixing bottles that cloudiness of mixtures was entirely prevented. All other transfers (of pyridine to mixing bottles, and of solutions to cryostat) were conducted in a controlled atmosphere box at zero-humidity meter reading. Solutions prepared in this manner did not precipitate solid on mixing, nor exhibit any evidence of phase changes above the binary freezing points.

Results

The temperature–composition relationship for pyridine and $POCl_3$, which is given in Table I, shows no compound formation in the binary system. Second arrests were observed at −55.6 to −55.7°.

TABLE I

PYRIDINE–PHOSPHORYL CHLORIDE SYSTEM

Composition, mole % pyridine	Freezing point, °C.
100	−42.3
93.2	−46.0
87.5	−49.4
77.5	−55.3
76.9 eutectic (extrapd.)	−55.6
74.1	−52.5
63.7	−40.6
54.0	−31.4
42.9	−23.1
30.5	−15.0
20.4	− 9.3
4.78	− 1.26
0	1.02

The Clausius–Clapeyron equation in the form

$$\ln N = -L_f \Delta T / R T_0 T_1$$

where N is the mole fraction of solvent, L_f its heat of fusion, R the gas constant, and T_0 and T_1 the freezing points of pure solvent and of solution, respectively, serves as a criterion for estimation of the deviations of solutions from ideal behavior. The L_f of $POCl_3$ calculated thereby, using observed freezing points of dry solutions, was essentially constant to about 50 mole %, and was only 4% lower at the eutectic than at 95 mole % $POCl_3$. The calculated 3.18 kcal./mole is the same as the literature value obtained from freezing point data with other solutes.[13]

Similarly, the L_f for pyridine was calculated from freezing points on the other side of the eutectic. The obtained value of 1.96 kcal./mole was constant within experimental error from 7 mole % $POCl_3$ to the eutectic point. The best literature value is 1.97 kcal./mole, obtained by direct measurement.[10]

Further evidence of the ideal behavior of this system was obtained by comparison with a concentrated solution of benzene in $POCl_3$. The latter system has been shown to deviate only slightly from ideal behavior at low $POCl_3$ content.[14] A 37.7 mole % benzene solution froze at −19.7°, which is the same temperature obtained for an equally concentrated pyridine solution in the same solvent.

Phosphoryl Chloride–α-Picoline System.—When it became apparent, during the preliminary work, that no compounds were formed in the pyridine–$POCl_3$ system, it was attempted to produce quaternary salts between $POCl_3$ and a more alkaline pyridine base. α-Picoline (K_b 3.2 × 10^{-8}) is approximately ten times more basic than pyridine (K_b 3.0 × 10^{-9})[15] and a fresh sample of practical grade Eastman Kodak α-picoline (b.p. 126–130°) was available. The sample contained small percentages of other pyridine bases. Eight mixtures with $POCl_3$ were prepared and measured, points being obtained between zero and 80 mole % α-picoline which were very close to values obtained with pyridine Mixtures of greater than 80 mole % α-picoline did not crystallize, even with seeding, at temperatures several degrees below the expected freezing points, and the complete temperature–composition diagram was not obtained. Sufficient data were obtained, however, to indicate the absence of compound formation at molar ratios of less than 3:1 of α-picoline to $POCl_3$, and to reveal the closeness to ideal behavior of the system.

Discussion

The phase diagram of the pyridine–$POCl_3$ system shows that no addition compounds are formed at atmospheric pressure and no binary complexes of these components are to be expected in the presence of additional components. The freezing point depressions show there is negligible association even in the liquid phase. The postulation that pyridine improves the yields of phosphinic acids in Grignard reactions of $POCl_3$ by complexing with the latter compound[5] must therefore be ruled out. The fact remains, however, that pyridine is effective in this reaction; this effectiveness must therefore be due to change in the reaction medium. In a publication[16] which appeared during the course of the present work, it was stated that the relative proportion of Grignard reagent, the reaction temperature and basicity of solvent are factors affecting the yields in Grignard reactions. When the ratio of RMgX to reactant to be substituted is small, or the temperature is lowered, or solvents of high basicity are used, the reaction rates are reduced. Thus, it

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[12] B. M. Zeffert and Saul Hormats, *Anal. Chem.*, **21**, 1420 (1949).

[13] G. Oddo and A. Mannessier, *Gazz. chim. ital.*, **41**, II, 212 (1911).

[14] A. R. Morgan and S. T. Bowden, *Trans. Faraday Soc.*, **36**, 394 (1940).

[15] E. J. Constam and J. White, *Am. Chem. J.*, **29**, 1 (1903).

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appears reasonable that the mechanism whereby pyridine prevents complete substitution of $POCl_3$ to R_3PO involves an effective reduction in Grignard reagent concentration, probably by association with RMgX. The suggestion that phosphonic acids may be produced in better yield by using larger proportions of pyridine at lower temperatures[5] may be valid, but not because of blocking Cl atoms in $POCl_3$. Work has been started in this Laboratory to study quantitatively the effect of bases on Grignard reactions involving $POCl_3$ and related compounds.

The work with pyridine and α-picoline indicates that $POCl_3$ probably does not form quaternary salts with any pyridine bases. Actually, compounds have been isolated between $POCl_3$ and acids such as SO_3[17] and $SnCl_4$.[18] In light of the results obtained with pyridine bases, formula I, may be considered a more likely structure than formula II. An incidental result of the present work is that doubt is cast on the postulated reaction mechanism in a recent paper,[19] which requires quaternary compound formation between $POCl_3$ and a pyrazine derivative.

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COMMUNICATIONS TO THE EDITOR

THE NATURE OF THE XANTHINE OXIDASE FACTOR

Sir:

A factor(s) in liver residue and soy flour which increases the level of liver and intestinal xanthine oxidase when fed to weanling rats has been described by Westerfeld and Richert.[1,2,3,4] An excellent assay for this factor utilizing rat intestine also has been described by these authors.[5] However, the nature and mode of action of this substance(s) is unknown.

During the course of fractionation studies on liver residue it was found that the xanthine oxidase factor(s) could be partially liberated by autoclaving in water. The activity of the extracts so obtained was found to be dialyzable and stable to severe acid or alkaline treatment.

When liver residue or extracts from liver residue were ashed, the activity, surprisingly enough, was found to be unaltered. The inorganic material so obtained, when assayed spectrographically,[6] was found to contain many elements among which were Al, Sb, Ba, B, Cr, Co, Pb, Mo, Ni, Ag, Sn, Ti, V and Zn. The more "common" elements such as K, P, Na, Cu, Fe, Si, Mg and Mn were also present. In addition, the activity of liver residue or its ash could be replaced by including a supplement of Hoagland's A-Z solution[7] in the diet of rats. Further investigation with single salt supplements revealed that the ingestion of molybdate ion is responsible for the increased xanthine oxidase levels.

The addition of as little as 1 mg. of sodium molybdate/kg. diet or the injection of 10γ subcutaneously gave values for xanthine oxidase equal to that obtained when 10% liver residue was fed. Table I shows some typical data. Preliminary studies indicate that no other element is able to replace molybdenum and the highly specific nature of this effect is therefore apparent.

TABLE I

EFFECT OF LIVER RESIDUE, LIVER RESIDUE FRACTIONS AND MOLYBDATE ION ON RAT INTESTINAL XANTHINE OXIDASE VALUES

Supplement added to basal diet/kg.	Average X. O. value, c.mm.O_2 uptake/ unit time/unit wgt. of intestine
None	4.4
10% liver residue (LR)	25.6
Liver residue extract (LRE) ≈16% LR	32.0
Ash of LR ≈ 10% LR	28.2
Ash of LRE ≈ 20% LR	26.9
Dialyzed LRE ≈ 20% LR	5.1
Sodium molybdate, 1 mg.	23.5

To our knowledge, this represents the first report suggesting an *in vivo* role for molybdate in an animal enzyme system. The possible importance of this finding on the role of molybdenum in animal nutrition is of course obvious. Studies are now in progress to elucidate the precise role of molybdenum on the activity of xanthine oxidase.

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RECEIVED JANUARY 21, 1953

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[5] D. A. Richert and W. W. Westerfeld, *ibid.*, **192**, 49 (1951).

[6] We are indebted to Mr. W. L. Dutton and his staff of the Stamford Research Laboratories, American Cyanamid Co., for the spectrographic analysis.

[7] D. R. Hoagland and W. C. Snyder, *Proc. Amer. Soc. Hort. Sci.*, **30**, 288 (1933).