connection, data reported in the previous paper of this series[2] indicate that the equations derived in this report may be applied to analogous reactions of thiols with α,β-unsaturated systems by inclusion of a nucleophilicity factor N, which corrects for the greater reactivity of mercaptide ions as compared to amino groups.

A future publication will be concerned with relative inductive effects of electron-withdrawing functional groups.

Experimental Section

Source of Materials.—The amino acids and peptides were the best commercial grades available. Acrylamide, acrylonitrile, and methyl vinyl ketone were obtained from Matheson[23]; methyl acrylate and methyl methacrylate from Rohm and Haas; bis-(β-chloroethyl) vinyl phosphonate from Stauffer; 4-vinylpyridine from Riley; crotononitrile from Aldrich; *trans*-crotononitrile, *trans*-methyl crotonate, and methyl vinyl sulfone from K and K Laboratories. The compounds were usually distilled before use although similar rate constants were generally obtained even when distillation was not done.

Separation of Crotononitrile into *cis* and *trans* Isomers.—Crotononitrile was separated into *cis* and *trans* isomers *via* gas chromatography on a preparative scale by means of an Autoprep A-7000 on a 10-ft, 0.25-in. column packed with 10% dinonyl phthalate on Celite. Crotononitrile separates into two major peaks.[24] After 100-μl portions were injected, the two peaks were monitored on a recorder and collected separately with cooling.

Preparation of *trans*-Crotononamide.—To 2 g (30 mmoles) of redistilled *trans*-crotononitrile was added 1.6 ml of concentrated H_2SO_4 dropwise with stirring and cooling. After stirring the reaction mixture for 2 days, it solidified to a transparent mass. The product was taken up in 25 ml of water and neutralized with 4 *N* NaOH. The aqueous solution was extracted with four 75-ml portions of ether. Most of the ether was evaporated off on an aspirator, and fluffy white needles crystallized from the remainder: yield 1 g (15 mmoles, 50%); mp 159°, lit.[25] mp 159–160°.

Kinetic Measurements.—A tightly stoppered flask of amino compound in a pH 8.75 borate buffer containing the vinyl compound was placed in a 30° constant-temperature bath together with blank solutions as previously described.[7] When feasible, the vinyl derivative was used in excess to obtain pseudo-first-order kinetics. The concentration of the amino component was 0.01 *M* and that of the vinyl compound ranged from 0.08 to 0.17 in most runs depending on its solubility. Several rate determinations were carried out with more dilute concentrations of both reactants for the fastest reacting vinyl compounds, methyl vinyl ketone and methyl vinyl sulfone, to obtain a convenient reaction time. Rates were carried out for at least four half-lives with all vinyl compounds except methyl crotonate and methyl methacrylate. With the former, rates were run to about 50% reaction and with the latter, to about 20%, to minimize the possibility of hydrolysis of these esters under the reaction conditions. The pseudo-first-order linear plots for these vinyl compounds were extrapolated to complete reaction. The pH of the medium was measured before and after reaction. Where any noticeable change was observed, an intermediate pH value was used to calculate the anion rate constants. The accuracy of the rate determinations is estimated to be ±5%; that of the pH of the medium during reaction, ±0.05 pH units; and that of the pK_2 values of amino groups, ±0.03 pK_2 units. The progress of reaction was followed as previously described.[7]

Acknowledgment.—We wish to acknowledge the assistance of Miss Judith A. Romersberger and Mr. Gary V. Kaiser with the rate determinations.

(23) The mention of firm names or trade products does not imply that they are recommended by the Department of Agriculture over other firms or similar products not mentioned.

(24) (a) G. S. Reddy, J. H. Goldstein, and L. Mandell, *J. Am. Chem. Soc.*, **83**, 1300 (1961); (b) D. E. McGreer, *J. Org. Chem.*, **25**, 852 (1960).

(25) P. Bruylants and A. Castille, *Bull. Classe Sci., Acad. Roy Belg.*, (5) **13**, 767 (1927); *Chem. Zentr.*, 1644 (1928).

The Preparation and Unusual Reactions of Dimethyldodecylphosphinimine

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N-Trimethylsilyldimethyldodecylphosphinimine (III) was prepared and treated with acidic methanol at −35° in an attempt to obtain dimethyldodecylphosphinimine (IV). Although IV was most likely formed, it reacted further to give bis(dimethyldodecylphosphoranylidene)ammonium methoxide (V) and/or dimethyldodecylphosphine oxide depending on the concentration of the reactants in the medium. It was demonstrated that V is also unstable to methanol and that there are two competing pathways by which the phosphine oxide can ultimately be formed from the methanolysis of IV (and hence III). Dimethyldodecylphosphinimine (IV) can be prepared in good yield from the reaction of aminodimethyldodecylphosphonium chloride and *n*-butyllithium. A lithium chloride complex of IV is initially formed which can be destroyed by distillation to give free IV and then reformed by addition of lithium chloride.

Since the work of Staudinger in 1921,[1] very few reports have appeared in the literature concerning the chemistry of phosphinimines in which all of the substituents on phosphorus are aliphatic. Recently, however, the preparation of N-trimethylsilyltrialkylphosphinimines and their subsequent acid-catalyzed methanolysis to the corresponding unsubstituted trialkylphosphinimines was reported by Birkofer.[2] Using this method he prepared the triethyl, tripropyl, and tributyl compounds (IIa–c, respectively) in yields of 85–90%, and these are the only reported examples of unsubstituted trialkylphosphinimines. As part of an investigation of the chemistry of alkyldimethylphosphinimines, we attempted to apply Birkofer's procedure to N-trimethylsilyldimethyldodecylphosphinimine (III)

$$R_3P{=}NSiMe_3 \xrightarrow[-20^\circ]{MeOH\text{–}H_2SO_4} R_3P{=}NH + MeOSiMe_3$$

Ia, R = Et; b, R = *n*-Pr; c, R = *n*-Bu — IIa, R = Et; b, R = *n*-Pr; c, R = *n*-Bu

$$C_{12}H_{25}P(Me_2){=}NSiMe_3 \qquad C_{12}H_{25}P(Me_2){=}NH$$

III IV

in order to prepare dimethyldodecylphosphinimine (IV). Although the desired product apparently was formed, it could not be isolated, and this paper deals with the interesting subsequent reactions that prevented

(1) H. Staudinger and E. Hauser, *Helv. Chem. Acta*, **4**, 861 (1921); *Chem. Abstr.*, **16**, 1074 (1922).

(2) (a) L. Birkofer and S. M. Kim, *Ber.*, **97**, 2100 (1964); (b) this type of reaction has also been used to prepare triphenylphosphinimine, $(C_6H_5)_3P{=}NH$ [L. Birkofer, A. Ritter, and S. M. Kim, *ibid.*, **96**, 3099 (1963)].

its isolation, along with its ultimate preparation by a totally different route.

Results and Discussion

I. N-Trimethylsilyldimethyldodecylphosphinimine (III). Preparation and Hydrolysis.—The phosphinimine III was readily prepared in 77% yield from dimethyldodecylphosphine and trimethylsilyl azide using the general procedure of Birkofer,[2a] and the assigned

$$C_{12}H_{25}P(Me_2) + Me_3SiN_3 \longrightarrow III + N_2$$

structure was firmly established by infrared, P^{31} nmr, and proton nmr spectroscopy (see Experimental Section).

Compound III hydrolyzed rapidly when exposed to the moisture in air and hence had to be handled in an inert atmosphere. The products isolated from hydrolysis were dimethyldodecylphosphine oxide, ammonia, and hexamethyldisiloxane. However, the initial products of hydrolysis, by analogy to Birkofer's work, were probably the unsubstituted phosphinimine IV and trimethylsilanol. The latter compound no doubt led to the disiloxane by its rapid self-condensation,[3] while IV, which is also very hydrolytically unstable, reacted further to give the other isolated products, ammonia and the phosphine oxide.

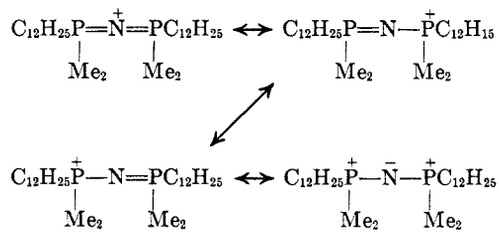
Methanolysis.—Initially the conversion of III to IV was attempted using a large excess of methanol containing a trace of sulfuric acid at room temperature. Reaction was complete within 5 min, but the only phosphorus-containing product obtained was dimethyldodecylphosphine oxide. Hence, all succeeding reactions were carried out at −35° over a 1–2-hr period using a procedure which is basically that of Birkofer[2a] (see Experimental Section). Most of the solvent was then evaporated (0.5 mm) at or below room temperature, but it was shown by gas chromatographic and infrared analyses that substantial amounts of methanol could not be removed from the reaction products, even after long periods of evacuation. Nevertheless, using this procedure, N-trimethylsilyltributylphosphinimine (Ic) was converted to the corresponding unsubstituted compound IIc in 66% yield, thus showing the correctness of Birkofer's report and also that IIc is fairly stable to significant quantities of methanol.

The methanolysis of the dimethyldodecyl compound III was not so straightforward. Although the expected $MeOSiMe_3$ was formed, in none of the many experiments run was the phosphinimine IV isolated. Instead, either the phosphine oxide, a compound identified as $[C_{12}H_{25}P(Me_2)=N=PC_{12}H_{25}(Me_2)]^+\bar{O}Me$ [V, a bis(phosphoranylidene)ammonium salt], or a mixture of the two was obtained. Ammonia was also detected among the reaction products, as was dimethyl ether when the phosphine oxide was formed.

$$III \xrightarrow[-35°]{MeOH\text{–}H_2SO_4} [C_{12}H_{25}P(Me_2)=N=PC_{12}H_{25}(Me_2)]^+\bar{O}Me \text{ and/or } C_{12}H_{25}P(Me_2)=O$$

V

Bis(dimethyldodecylphosphoranylidene)ammonium methoxide (V) was identified by infrared and nmr analyses and its chemical reactions. The infrared spectrum exhibited a broad strong band centered at 9.33 μ due to methoxide ion[4] and strong absorption at 8.1 μ. The latter absorption apparently is characteristic of this kind of salt since $[(C_6H_5)_3P=N=P(C_6H_5)_3]^+Cl^-$, first prepared by Appel,[5] also exhibits an intense band in this region. The P^{31} nmr spectrum of V showed a single, broad, unresolved peak at −32 ppm. The proton nmr spectrum displayed a singlet at τ 6.63 due to the three protons of the methoxide ion, a doublet (J_{PCH} = 12 cps) centered at τ 8.12 due to the protons of the two methyls on phosphorus, and the resonances expected for the two α-methylene protons, the twenty other methylene protons, and the terminal methyl protons of the dodecyl group at τ 8.00 (m), 8.75 (s), and 9.13 (t), respectively. The fact that the $P(CH_3)_2$ doublet is far downfield from that of III (τ 8.71), IV (τ 8.74), or $C_{12}H_{25}P(Me_2)=O$ (τ 8.52) is indicative of the partial positive charge on the phosphorus atoms of V. Also, the facts that only one $P(CH_3)_2$ doublet was observed and that a single peak was present in the P^{31} nmr spectrum must mean that the positive charge is distributed equally over both phosphorus atoms.



Further evidence supporting structure V was provided by the discovery that the products of hydrolysis (or methanolysis) of the compound are dimethyldodecylphosphine oxide and ammonia. Unfortunately, this instability prevented a sample from being purified satisfactorily for microanalysis.

Turning once more to the methanolysis of III, the relative ratio of the phosphine oxide to V formed from the reaction always varied when the reaction time and molar ratios of reactants were changed. Qualitatively it appeared that long reaction times and large mole ratios of methanol to starting material increased the yield of the phosphine oxide and that the amount of acid had little effect.

The most logical explanation of this behavior is that the desired phosphinimine IV was initially formed in the methanolysis but reacted further with methanol to give either the phosphine oxide or V, depending on the concentration of methanol.

Support for this idea was obtained when it was found that, under the conditions of methanolysis, a 0.42 M solution of IV[6] in acidic methanol reacted to give only dimethyldodecylphosphine oxide, but, when the concentration was 4.2 M, a mixture of the phosphine

(3) C. Eaborn, "Organosilicon Compounds," Butterworth and Co. (Publishers) Ltd. London, 1960, p 247.

(4) F. H. Seubold, Jr., *J. Org. Chem.*, **21**, 156 (1956).

(5) R. Appel and G. Büchler, *Z. Naturforsch.*, **17B**, 422 (1962).

(6) The unsubstituted phosphinimine IV used in this and succeeding experiments was prepared by the method described in the next section.

oxide and V was formed. Although V is converted by methanol to the phosphine oxide, it was shown that the reaction is much too slow to account for the amount of the latter product in either of the reactions.

A more quantitative demonstration of the importance of the methanol concentration was afforded by the determination, using P^{31} nmr, of the relative ratios of IV, V, and the phosphine oxide present when IV was treated in benzene solution with varying concentrations of methanol. The data are presented in Table I.

TABLE I[a-c]
SUMMARY OF DATA FOR REACTIONS OF IV AND V WITH METHANOL

Run	Time, hr	Phosphorus reactant	Concn of phosphorus reactant	Concn of MeOH	% IV	% V	% $R_3P{=}O$
1	70	IV	1.65	0.82	92	8	0
2	70	IV	1.54	0.77	93	7	0
3	70	IV	1.46	1.46	75	25	0
4	70	IV	1.84	3.68	10	84	0
5	18	IV	1.11	11.1	0	61	39
6	18	V	0.57	11.8	0	78	22

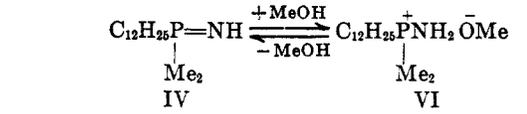
[a] Reactions were carried out in dry benzene at room temperature. [b] Runs 1–4 were carried out simultaneously as were runs 5 and 6. [c] Concentrations are expressed in moles per liter.

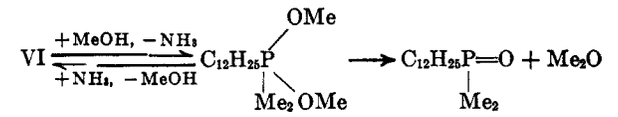
Comparison of runs 1 (or 2), 3, and 4 shows that the ratio of V/unreacted IV increased as the concentration of methanol was increased relative to that of IV. In none of these experiments was the phosphine oxide detected. The good agreement in the percentages of IV and V when the ratio of [MeOH]/[IV] was kept nearly constant (runs 1 and 2) should be noted.

However, when the [MeOH]/[IV] ratio was markedly increased (run 5), the starting material IV was completely destroyed over a shorter reaction time than was used in the first four runs, and some dimethyldodecylphosphine oxide started to appear at the expense of V. It has been previously mentioned that V is converted by methanol to the phosphine oxide, so it was necessary to consider the possibility that this pathway was the source of all the phosphine oxide formed in run 5. If such were the case, it can be shown (remembering that 2 moles of IV are required to produce 1 mole of V) that the *maximum* concentrations in which V and methanol could have been present in run 5 (that is, assuming that IV was initially and completely converted to V) were 0.56 and 10.7 moles/l., respectively. Therefore a run (6) was carried out in which the concentrations of V (0.57 *M*) and methanol (11.8 *M*) were slightly higher than the maximum respective concentrations in run 5. After the same length of time, only about one-half as much of the phosphine oxide was produced (22%) as in run 5 (39%).

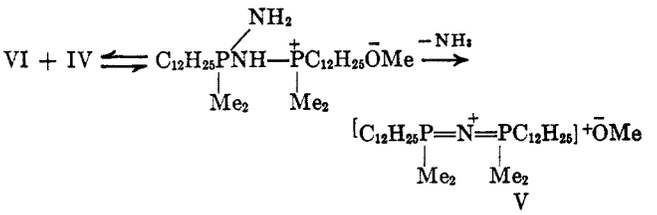
On the basis of this evidence and the previously mentioned fact that the phosphine oxide can be prepared in good yields from treatment of IV with acidic methanol under conditions wherein V is almost completely stable, it can be concluded that there must be two separate and distinct ways by which the phosphine oxide can arise from IV. The same conclusion holds for the phosphine oxide formed from the methanolysis of III if, as seems most likely, IV is formed as an intermediate.[7] Reasonable possibilities for the two ways are presented below along with an explanation of the data based on these mechanisms.

The unsubstituted phosphinimine IV in the presence of methanol is no doubt in equilibrium with the aminophosphonium methoxide VI. If VI is formed in the presence of relatively high concentrations of methanol, it could be converted directly to the phosphine oxide. However, if the concentration of unreacted IV in the





medium is quite high, VI could react with it instead of with methanol to subsequently yield V. The



inclusion of the equilibria and the pentacovalent phosphorus intermediates in the equations above is arbitrary since the intimate details of the mechanism are unknown.

The fact that only V was formed from the reaction of IV at methanol concentrations wherein there was more methanol in the medium than unreacted IV (run 4) means that the aminophosphonium methoxide VI is attacked faster and/or more efficiently by IV than by methanol. This is another demonstration of the high degree of nucleophilicity of the nitrogen of unsubstituted phosphinimines that seems to be common to such compounds. For example, nucleophilic attack on halogens[8,9] or $ClSO_2NH_2$[8] by the nitrogen of $(C_6H_5)_3P{=}NH$ occurs quite readily.

It is tempting to speculate that the reason that tributylphosphinimine IIc is stable toward acidic methanol at −35° (as shown by its isolation from the methanolysis of Ic), while IV is not, is mainly a steric one. However, the actual cause is probably a combination of steric, inductive, and solvation factors, and it is impossible to assess their relative importance on the basis of the present work.

II. Dimethyldodecylphosphinimine (IV).—The method chosen for preparation of the unsubstituted phosphinimine IV was deprotonation of aminodimethyldodecylphosphonium chloride (VII) using *n*-butyllithium. Compound VII was readily prepared from the reaction of dimethyldodecylphosphine with gaseous

(7) The "previously mentioned fact" demands this latter conclusion if the assumption is valid. However, a referee has pointed out that the data in Table I, which were obtained in neutral media, do not necessarily support the conclusion for the methanolysis of III since this was done in an acidic medium. While this is true in a strict sense, the objection probably is not serious since the same products, V and the phosphine oxide, are formed from methanolysis of IV whether acid catalyzed or not.

(8) R. Appel and A. Hauss, *Z. Anorg. Allgem. Chem.*, **311**, 290 (1961).

(9) R. Appel and G. Büchler, *ibid.*, **320**, 3 (1963).

chloramine,[10] but care had to be taken in handling it owing to its slow hydrolysis by the moisture in air to the corresponding phosphine oxide and ammonium chloride.

$$C_{12}H_{25}P(Me_2) + NH_2Cl \longrightarrow C_{12}H_{25}\overset{+}{P}(Me_2)NH_2Cl^-$$

VII

When VII was treated in benzene solution with 1 equiv of *n*-butyllithium, a vigorous exothermic reaction occurred. Evaporation of the solvent yielded a gum which could not be purified but which was identified as the lithium chloride complex (VIII) of dimethyldodecylphosphinimine on the basis of the evidence presented below.

Its infrared spectrum displayed strong NH stretching absorption while its P^{31} nmr spectrum showed a single unresolved peak with a chemical shift of −36 ppm. The proton nmr spectrum exhibited a doublet (J_{PCH} = 12 cps) at τ 8.35 corresponding in area to six protons and attributable to the two methyl groups on phosphorus. The only other resonances in the spectrum were due to the single NH proton and the 25 protons of the dodecyl group, thus showing that all of the *n*-butyllithium had been destroyed.

Distillation of the gum yielded a colorless liquid which slowly crystallized to give a white solid. This proved to be the uncomplexed phosphinimine IV. The free phosphinimine, in contrast to its complex, showed only weak NH stretching absorption in the infrared. Its P^{31} nmr chemical shift was −18 ppm (broad multiplet) and the H^1 nmr doublet due to the phosphorus methyl groups (J_{PCH} = 12 cps) appeared at τ 8.74. It should be noted that these nmr resonances (that is, the P^{31} singlet and the H^1 doublet) are upfield from their respective counterparts in the spectrum of the undistilled material. They therefore indicate a greater amount of positive charge on the phosphorus atom of undistilled material and hence support the idea that this substance is the complex VIII.

The most compelling evidence for the complex formation was provided by the observation that the infrared spectrum (strong NH stretching) and nmr spectra [P^{31} chemical shift = −37 ppm, $P(CH_3)_2$ doublet at τ 8.27] of the material formed when lithium chloride was stirred with a benzene solution of the distilled solid were nearly identical with those of the undistilled gum. That is, addition of LiCl to IV reformed the complex.

Inorganic salt complexes of the phosphinimines $(C_6H_5)_3P{=}NH$,[11] $(C_6H_5)_3P{=}NC_6H_5$,[12] and $Me_3P{=}NSiMe_3$[13] have been reported, but the metallic ligands in all of these complexes were of the Lewis acid type. Hence it was surprising that lithium chloride, which has essentially no Lewis acid character, also formed a complex with a phosphinimine. This behavior must be a reflection of the high degree of dipolar character in the PN bond of trialkylphosphinimines.

Both the free and complexed phosphinimines were rapidly hydrolyzed to dimethyldodecylphosphine oxide and ammonia, and both could be reconverted to the aminophosphonium chloride VII by treatment with NH_4Cl. As would be predicted, the complex VIII reacted more slowly with the ammonium chloride than did IV.

$$VII \xrightarrow{n\text{-BuLi}} C_{12}H_{25}P(Me_2){=}NH{\cdot}LiCl \underset{LiCl}{\overset{\text{distil}}{\rightleftharpoons}} C_{12}H_{25}P(Me_2){=}NH$$

VIII IV

$$C_{12}H_{25}P(Me_2){=}O + NH_3 \quad (H_2O;\ NH_4Cl) \quad VII$$

Several other bases were employed in an attempt to cleanly deprotonate VII and thus prepare IV. These include KNH_2 in liquid ammonia,[14] tetramethylguanidine,[15] and solid sodium hydride, but in each case a mixture of IV and substantial amounts of phosphine oxide was formed despite attempts to rigorously exclude moisture. Thus *n*-butyllithium may prove to be valuable for the preparation of phosphinimines such as IV which are extremely sensitive to even trace amounts of hydroxylic materials.

Experimental Section[16]

N-Trimethylsilyldimethyldodecylphosphinimine (III).—To 2.76 g (24.0 mmoles) of Me_3SiN_3[17] dissolved in 6 ml of benzene under argon was added 5.30 g (23.1 mmoles) of dimethyldodecylphosphine, and the resulting solution was boiled under reflux for 26 hr. Gas chromatographic analysis using a 6-ft 20% Apiezon-L on Fluoropak column at 240° showed that the phosphine had reacted completely to give only the phosphinimine. The solvent was evaporated (0.5 mm) to give a light yellow liquid which was distilled at 0.01 mm. A colorless liquid (5.50 g, 72%) was collected over the temperature range 95–100° and was shown to be 98% pure by gc analysis. The infrared spectrum showed bands at 7.68, 8.02, 8.24, 10.74, 11.74, and 12.02 μ. The nmr spectrum showed a sharp singlet at τ 9.96 attributable to the nine protons of the Me_3Si group and a doublet centered at τ 8.71 arising from the six protons of the PMe_2 moiety. The remainder of the spectrum was comprised of the usual peaks due to the dodecyl group protons. The P^{31} nmr spectrum showed a single unresolved absorption at −6 ppm; by way of comparison, the P^{31} chemical shift of Ic was −9 ppm. The microanalytical sample was purified by gas chromatography.

Anal. Calcd for $C_{17}H_{40}NPSi$: C, 64.29; H, 12.70; N, 4.41. Found: C, 64.1; H, 13.0; N, 4.37.

Compound III was stored and handled under an argon atmosphere since it hydrolyzed very rapidly when exposed to moist air. The hydrolysis products were identified as (1) dimethyldodecylphosphine oxide by infrared analysis, mp 84–86° (lit.[18] 84–85°), and mmp 83–86°, (2) ammonia by its characteristic odor and litmus test, and (3) hexamethyldisiloxane by gas chromatographic analysis using a 6-ft Ucon Polar column at room temperature.

(10) H. H. Sisler, A. Sarkis, H. S. Ahuja, R. J. Drago, and N. L. Smith, *J. Am. Chem. Soc.*, **81**, 2982 (1959).

(11) R. Appel and R. Schaaff, *Z. Naturforsch.*, **16B**, 405 (1961).

(12) W. Seidel, *Angew. Chem. Intern. Ed. Engl.*, **4**, 785 (1965).

(13) H. Schmidbaur and W. Wolfsberger, *Angew. Chem.*, **78**, 306 (1966).

(14) R. Appel and A. Haus, *ibid.*, **71**, 626 (1959).

(15) B. Grushkin, French Patent 1,345,811 (1963); *Chem. Abstr.*, **60**, 12055 (1964).

(16) Infrared spectra were recorded with a Perkin-Elmer Model 137 Infracord. The proton nmr spectra were obtained using a Varian spectrometer Model A-60 or Model HA-100 and were measured in deuteriochloroform solutions using tetramethylsilane as an internal standard. Phosphorus nmr spectra were recorded on a Varian HR-60 spectrometer and are reported in ppm relative to 85% H_3PO_4 as an external standard. Analyses were carried out by the Analytical Section of Procter and Gamble's Miami Valley Laboratories and by Spang Microanalytical Laboratories. *n*-Butyllithium was purchased from Foote Mineral Co. and was titrated immediately before use. All solvents were distilled and dried over molecular sieves.

(17) The trimethylsilyl azide used in this experiment was prepared according to the method of L. Birkofer, A. Ritter, and P. Richter, *Ber.*, **96**, 2750 (1963).

(18) R. G. Laughlin, *J. Org. Chem.*, **30**, 1322 (1965).

Methanolysis of III.—Several experiments were carried out using the following procedure. A weighed portion of III was added under argon to a 25-ml round-bottomed flask equipped with a pressure-equalizing dropping funnel containing a mixture of methanol (usually from 30 to 300 equiv) and a trace (usually about 10 μl) of concentrated sulfuric acid. The phosphinimine III was cooled to $-35°$, and the contents of the dropping funnel were slowly added. The coolant was removed just long enough (about 1 min) to allow the frozen phosphinimine to dissolve and then was replaced. The resulting solution was stirred for about 2 hr and evaporated to dryness (0.5 mm) at or below room temperature. Gas chromatographic and infrared analyses of the residue always revealed the presence of a substantial amount of methanol, while infrared and P^{31} nmr analyses usually showed that both dimethyldodecylphosphine oxide and the V were formed. The ratio of the latter two products was quite variable, and sometimes only one or the other was formed. The experiments described below concerning the methanolysis of the trialkylphosphinimine IV, which is most likely initially formed in the methanolysis of III, show why this is the case.

The dimethyldodecylphosphine oxide formed in these reactions was identified by its infrared spectrum, melting point, and mixture melting point. Compound V was identified by infrared and nmr analyses and by its chemical reactions. Due to its hygroscopic nature and hydrolytic instability, a satisfactory microanalysis was not obtained. Its infrared spectrum showed bands at 7.76, 8.11, 9.32, 10.38, 10.54, and 10.88 μ.

A small portion of V was dissolved in methanol and the solution was allowed to stand for 2 days at room temperature in a sealed flask. At the end of this time, ammonia was detected by its odor and litmus test. Evaporation of the methanol gave a white solid shown to be pure dimethyldodecylphosphine oxide by infrared analysis.

Methanolysis of IV.—Compound IV (500 mg) was cooled to $-35°$ under argon, and a solution of 1 μl of concentrated H_2SO_4 in 5.0 ml of methanol that had previously been cooled to $-35°$ was added. The initial concentration of IV in methanol was therefore 0.42 *M*. The solution was stirred for 1.5 hr in the cold and then evaporated (0.5 mm) at or below room temperature to yield a white residue shown to be only dimethyldodecylphosphine oxide by infrared analysis.

In an experiment similar to the one just described, 725 mg of IV was treated under argon with 0.7 ml of methanol containing 0.5 μl of concentrated H_2SO_4. The solution (4.2 *M* in IV) was stirred for 3 hr at $-35°$ and then evaporated (0.5 mm) at or below room temperature. The resulting white solid was shown by infrared analysis to be a mixture of the phosphine oxide and V in roughly equal amounts.

The experiments recorded in Table I were carried out in the following manner. In 2.0 ml of benzene contained in a pyrolysis tube under argon was dissolved a weighed amount of IV (or, in the case of run 6, V). An amount of methanol calculated to be 0.5 (runs 1 and 2), 1 (run 3), 2 (run 4), or 10 equiv (run 5) relative to IV was then added using a microliter syringe. In run 6, a sufficient amount of methanol was added so that its molarity would be higher than it could have been in run 5 if all of IV were converted to V (see discussion) The first four runs were carried out simultaneously over a 70-hr period while the last two runs (5 and 6) were conducted in parallel over an 18-hr period. After the tubes had stood the desired length of time at room temperature, the contents were analyzed by P^{31} nmr spectroscopy. The peaks in the spectra at -22 ppm[19] were assigned to IV, and those at -32 and -47 ppm were assigned to V and dimethyldodecylphosphine oxide, respectively. The percentages given in Table I were calculated from the relative areas under the peaks and are considered accurate to $\pm 5\%$. However, it should be noted that the agreement between runs 1 and 2 in which nearly equal ratios of [IV]/[MeOH] were used is considerably better than 5%.

In some runs the solutions were evaporated to dryness after the P^{31} nmr spectra had been determined, and the resulting residues were subjected to infrared analysis. In all of the cases examined, the infrared spectra were completely consistent with the nmr interpretations.

Aminodimethyldodecylphosphonium Chloride (VII).—A 500-ml three-necked round-bottom flask was fitted with a rubber septum, a gas inlet tube, and a water condenser with a gas outlet adapter connected to a mineral oil bubbler. A magnetic stirring bar was added and the flask was alternately evacuated and filled several times with argon. Then 15.4 g (67.2 mmoles) of dimethyldodecylphosphine and 200 ml of benzene were added using a syringe injected through the septum, and chloramine[20] (1.5 equiv) was bubbled through the stirred solution causing an exothermic reaction to occur and a white solid to precipitate. (Excess NH_2Cl was used since it had previously been shown that some of this gas passed through the solution unchanged; however, gas chromatographic analysis of the benzene solution after 1.5 equiv had been passed through showed that the phosphine was completely destroyed.) After chloramine addition was complete, the mixture was stirred for 2 hr under argon at room temperature and then filtered. When the collected solid was extracted three times with dichloromethane and the extracts were combined, dried ($MgSO_4$), and evaporated at 0.5 mm, 18.89 g (100%) of a white solid was obtained. The solid was recrystallized several times from a dichloromethane–benzene mixture to give white plates which melted to a viscous liquid at 74.5–76.5°. However, the liquid did not become fluid until the temperature was raised to about 140°. The infrared spectrum showed bands at 3.08, 3.18, 6.46, 7.66, 9.20, 9.67, 9.99, 10.20, and 13.88 μ.

Anal. Calcd for $C_{14}H_{33}ClNP$: C, 59.65; H, 11.80; N, 4.91; P, 10.90. Found: C, 59.69; H, 11.75; N, 4.98; P, 11.02.

All manipulations with the compound were carried out under argon to avoid its slow hydrolysis to dimethyldodecylphosphine oxide and ammonium chloride. These products were identified on the basis of their infrared spectra after a portion of VII had been allowed to stand in aqueous solution for a few hours.

Lithium Chloride Complex of Dimethyldodecylphosphinimine (VIII).—To a stirred solution of 4.10 g (14.6 mmoles) of VII in 100 ml of benzene under argon at room temperature was added 9.34 ml (14.6 mmoles) of 1.56 *N* *n*-butyllithium. An exothermic reaction took place along with some gas evolution. The solution was stirred overnight and then evaporated to dryness at 0.5 mm to give a white gum. This gum, which could neither be crystallized nor satisfactorily purified for microanalysis, was identified as VIII on the basis of its infrared and nmr spectra and its chemical reactions. The infrared spectrum showed bands at 3.01, 7.65, 7.73, 9.65 (very strong and broad), 10.48, and 11.59 μ.

Addition of water to VIII caused it to dissolve with formation of ammonia. When the water was evaporated after 1 hr, a white solid residue was obtained which was identified as dimethyldodecylophosphine oxide by infrared analysis, melting point, and mixture melting point.

A 321-mg (0.90 mmole) portion of VIII was dissolved in 10 ml of benzene. NH_4Cl (481 mg, 10 equiv) was added and the mixture was stirred under argon for 3 days. The excess ammonium chloride was removed by filtration and the filtrate was evaporated to dryness to give a white solid. One recrystallization from a dichloromethane–hexane mixture gave white crystals identified as VII by infrared analysis.

Dimethyldodecylphosphinimine (IV).—In an experiment similar to the one described above, the aminophosphonium chloride VII was treated in benzene solution with 1 equiv of *n*-butyllithium. Evaporation of the solvent yielded a gum with an infrared spectrum identical with that of VIII. This material was distilled (at 0.01 mm using a pot temperature of 180°) from a 50-ml round-bottomed flask to a second flask connected to the first by a 1.5-in. length of 12-mm Pyrex tubing bent at a 90° angle. The distillation was carried out as rapidly as possible to avoid thermal decomposition of the product, and a colorless liquid (74%) which slowly crystallized was collected. This solid was identified as IV on the basis of spectral data and its chemical reaction. Very small amounts (<2%) of phosphine oxide, probably arising from oxygen-containing impurities in the *n*-BuLi, invariably codistilled with IV. No way was found to remove this impurity; thus a satisfactory microanalysis could not be obtained. The infrared spectrum of IV exhibited absorptions at 2.97, 7.75, 7.83, 8.53, 9.15, 9.54, 10.60, 11.07, 11.95, 13.73, and 13.87 μ.

Ammonia was liberated when water was added to IV or when it was exposed to moist air. The presence of dimethyldodecylphosphine oxide after hydrolysis was confirmed by infrared analysis and melting point.

(19) As the chemical shift of IV in pure benzene is -18 ppm, it appears that IV is involved in hydrogen bonding with the added methanol, thus causing the downfield shift. In support of this idea, at the relatively high methanol concentration used in run 4, the chemical shift of IV was actually -25 ppm.

(20) Chloramine was prepared by the gas phase reaction of ammonia and chlorine using a generator similar to the one described by R. Mattair and H. H. Sisler, *J. Am. Chem. Soc.*, **73**, 1619 (1951).

A portion of IV was dissolved in benzene under argon and stirred for 16 hr with 10 equiv of NH_4Cl. The mixture was filtered and the filtrate was evaporated to dryness at 0.5 mm to yield VII as shown by infrared analysis.

To a solution of 226 mg (0.92 mmole) of IV in 5 ml of benzene under argon was added 39 mg (0.92 mmole) of lithium chloride that had been previously dried over P_2O_5 in a vacuum. The reaction mixture was vigorously stirred for 2 hr at room temperature and then evaporated to dryness at 0.5 mm. The infrared and nmr spectra of the resulting white gummy solid were nearly identical with those of VIII.

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Friedländer Syntheses with *o*-Aminoaryl Ketones. I. Acid-Catalyzed Condensations of *o*-Aminobenzophenone with Ketones[1]

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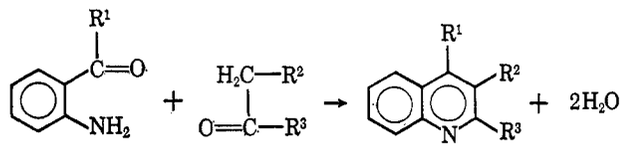
A study of the Friedländer reaction under conditions involving acid catalysis has shown that good yields of 4-phenylquinolines can be obtained in condensations of *o*-aminobenzophenone with ketones containing the grouping $-CH_2CO-$, many of which either fail to react or give unsatisfactory results when attempts are made to condense them with this *o*-aminoaryl ketone under classical Friedländer reaction conditions. Examples are given of reactions with a variety of aliphatic, aliphatic-aromatic, and alicyclic ketones, and the results of experiments carried out under different conditions are compared. Orientation in the condensation of *o*-aminobenzophenone with methyl ethyl ketone was found to be dependent on the type of catalyst used, acid catalysis leading predominantly to the formation of 2,3-dimethyl-4-phenylquinoline and base catalysis giving mostly 2-ethyl-4-phenylquinoline. Benzyl methyl ketone reacted exclusively at the α-methylene group in the presence of either acid or base, giving 2,4-diphenyl-3-methylquinoline as the only isolable product under both sets of conditions, although the yield was much higher in the acid-catalyzed reaction.

One of the most generally useful methods for preparing 2- and 3-substituted quinolines is the Friedländer synthesis,[2] in which *o*-aminobenzaldehyde (**1**, R^1 = H) is condensed with an aldehyde, ketone, or polyfunctional carbonyl compound having the grouping $-CH_2CO-$. Attempts to extend this method to the



1 **2** **3**

synthesis of 4-alkyl- and 4-arylquinolines from *o*-aminoaryl ketones (**1**, R^1 = alkyl or aryl), however, appear to have met with very limited success. Thus it has been reported that while *o*-aminobenzophenone behaves normally in Friedländer-type condensations with acetone[3] and acetophenone,[4] it fails to undergo analogous reactions with acetaldehyde,[3] cyclohexanone,[4] deoxybenzoin,[4] and β-keto esters.[5] These results have led some investigators to hypothesize that this aminoaryl ketone may be capable of undergoing Friedländer-type condensations only with ketones of the type $RCOCH_3$.[4]

To test the validity of this conclusion and provide further information on the scope and limitations of the Friedländer synthesis, we have undertaken a systematic investigation of the reactions of *o*-aminoaryl ketones with various classes of carbonyl compounds under both classical and nonclassical conditions. The present paper describes the results obtained in a study of the condensation of *o*-aminobenzophenone with a number of representative monofunctional ketones of type **2**, selected to illustrate the influence of various alkyl and aryl substituents on the reactivity of the $-CH_2CO-$ group.

Friedländer reactions are usually carried out either by refluxing an aqueous or alcoholic solution of the reactants in the presence of a base or by heating a mixture of the reactants at temperatures ranging from 150 to 220° in the absence of solvent and catalyst. Since preliminary experiments in this laboratory indicated that *o*-aminobenzophenone does indeed fail to condense with some simple ketones under these classical reaction conditions or, at best, gives poor yields of difficultly isolable products, other means of bringing about the desired condensation were investigated. It soon became evident that acids are particularly effective catalysts for this type of reaction[7] and that, under appropriate conditions, good yields of 4-phenylquinolines can be obtained in acid-catalyzed condensations of *o*-aminobenzophenone with ketones of type **2**, including cyclohexanone, deoxybenzoin, and

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(2) For a comprehensive review of the Friedländer synthesis, see R. C. Elderfield, "Heterocyclic Compounds," Vol. 4, R. C. Elderfield, Ed., John Wiley and Sons, Inc., New York, N. Y., 1950, pp 45–47, 209.

(3) R. Geigy and W. Koenigs, *Ber.*, **18**, 2400 (1885).

(4) W. Borsche and F. Sinn, *Ann.*, **538**, 283 (1939).

(5) Although quinoline derivatives are obtained in condensations of *o*-aminoaryl ketones with acetoacetic and benzoylacetic esters under appropriate conditions,[4,6] the products are 3-acylcarbostyrils (**3**, R^2 = $COCH_3$ or COC_6H_5, R^3 = OH) rather than the expected 3-quinolinecarboxylic esters (**3**, R^2 = $COOC_2H_5$, R^3 = CH_3 or C_6H_5). For a discussion of the unusual behavior of β-keto esters in these condensations, see E. A. Fehnel, J. A. Deyrup, and M. B. Davidson, *J. Org. Chem.*, **28**, 1996 (1958).

(6) R. Camps, *Ber.*, **32**, 3228 (1899).

(7) The only previously recorded examples of the use of acid catalysis in the Friedländer synthesis are to be found in the condensation of *o*-aminobenzaldehyde with 2-indanone in dilute hydrochloric acid [G. R. Clemo and D. G. I. Felton, *J. Chem. Soc.*, 1658 (1952)] and of *o*-aminoacetophenone (as the *hydrochloride*) with a number of cyclic ketones [G. Kempter, *et al.*, *Chem. Ber.*, **97**, 16 (1964); G. Kempter and S. Hirschberg, *ibid.*, **98**, 419 (1965)]. The work of Kempter and co-workers came to our attention only after most of the work described in the present paper had been completed.