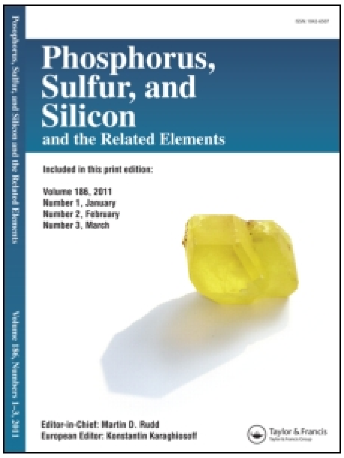


Phosphorus, Sulfur, and Silicon and the Related Elements
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713618290

MONOALKYLPHOSPHINAMIDES: SYNTHESIS AND RELATIVE STABILITY

Patricia C. Thorstenson[a]; Herbert S. Aaron[b]
[a] Chemistry Department, University of the District of Columbia, Washington, D.C. [b] Research Division, Chemical Research and Development Center, Aberdeen Proving Ground, MD

To cite this Article Thorstenson, Patricia C. and Aaron, Herbert S.(1985) 'MONOALKYLPHOSPHINAMIDES: SYNTHESIS AND RELATIVE STABILITY', Phosphorus, Sulfur, and Silicon and the Related Elements, 22: 2, 145 — 151

To link to this Article: DOI: 10.1080/03086648508073441

URL: http://dx.doi.org/10.1080/03086648508073441

Phosphorus and Sulfur, 1985, Vol. 22, pp. 145–151
0308-664X/85/2202-0145/$15.00/0

MONOALKYLPHOSPHINAMIDES: SYNTHESIS AND RELATIVE STABILITY[1]

PATRICIA C. THORSTENSON*

Chemistry Department, University of the District of Columbia, Washington, D.C., 20008

HERBERT S. AARON

Research Division, Chemical Research and Development Center, Aberdeen Proving Ground, MD 21010

(Received August 6, 1984; in final form November 3, 1984)

P-Monoalkylphosphinamides [$RPH(O)NR'_2$] have been conveniently prepared by the reaction of the corresponding phosphonous diamides [$RP(NR'_2)_2$] with an equivalent of water at ambient temperature. The reaction was in general conducted with an added 10% trimethylamine hydrochloride, which served as an effective catalyst for the hydrolysis. The thermal stability of the phosphinamide products increased in the order $MePH(O)NMe_2 < MePH(O)NEt_2 < EtPH(O)NEt_2$, with only the latter being stable to vacuum distillation. Thus, the isolated products have all been characterized by their ^{31}P and ^{1}H NMR spectra. The further hydrolysis of *N,N*-diethylmethylphosphinamide (**2b**) has been studied and found to be significantly slower than the initial hydrolysis of its precursor, *N,N,N′,N′*-tetraethylmethylphosphonous diamide (**1b**).

INTRODUCTION

While many examples of amide derivatives of P-disubstituted phosphinic acids are known and their properties have been widely described, very little is known about the amide derivatives of P-monosubstituted phosphinic acids (**2**). Indeed, only four examples of such phosphinamides have been reported. Thus, Dewar[2] has described an unusual heteroaromatic phosphinamide (from hydrolysis of the corresponding chloride), while Andreev[3] has reported the *N,N,P*-triethylphosphinamide (**2c**) along with its P-cyclohexyl and P-phenyl analogs. These were obtained by hydrolysis of the corresponding phosphonous diamides in dioxane at elevated (90°C) temperatures, but none was reported and characterized as distilled products. There are several reports in the literature predating Andreev's work, which describe attempts to prepare phosphinamides by hydrolytic methods; all were unsuccessful.[4] In most cases, only the anhydrides or polymeric products were obtained. These attempts were also conducted at elevated temperatures.

---

*Author to whom all correspondence should be addressed.

RESULTS AND DISCUSSION

We now report the results of our investigations into the ambient temperature hydrolysis of phosphonous diamides **1a–c**, whereby are generated P-monoalkylphosphinamides **2a–c** (equation 1). To our knowledge, neither **2a** nor **2b** has beeen described elsewhere. Although these amides were obtained in varying degrees

$$RP(NR'_2)_2 + H_2O \xrightarrow{R.T.} R-\overset{\overset{O}{\parallel}}{\underset{\underset{H}{|}}{P}}-NR'_2 + R'_2NH \qquad (1)$$

1 **2**

a: R = R' = Me

b: R = Me, R' = Et

c: R = R' = Et

of purity, their structures are unambiguously defined by the parameters of their ^{31}P and ^{1}H NMR spectra (Tables I and II). The ^{31}P chemical shifts are consistent with a tetracoordinate phosphoryl phosphorus center bearing both alkyl and nitrogen substituent groups.[5] The large coupling constants observed in the ^{1}H undecoupled ^{31}P spectra (ca. 500 Hz) show the presence of hydrogen bonded directly to phosphorus. Additionally, the observed multiplicities of these P—H signals in the ^{1}H NMR spectra confirm the presence of the CH_3—P—H fragment in **2a** and **2b** as well as the CH_2—P—H unit in **2c**. IR analysis of amide **2c** showed both the P—H (2325 cm^{-1}) and P=O (1235 cm^{-1}) moieties, in agreement with reported values.[3]

The catalytic effect of diethylamine hydrochloride (present as an impurity) upon the hydrolysis of the P-phenylphosphonous diamide has been noted.[3] We have also found the hydrolysis to be dependent upon the presence of an amine hydrochloride, since pure **1b** was essentially inert to hydrolysis. However, we have found that by the addition of ca. 10 mol% trimethylamine hydrochloride, the reaction can be conveniently carried out at ambient temperature. We have found further that this addition caused **1b** to be hydrolyzed approximately six times as rapidly as it was when contaminated by a comparable amount of residual diethylamine hydrochloride. The greater catalytic efficiency of trimethylamine hydrochloride appears to be related to its greater acidity.

TABLE I

^{31}P NMR data for $RPH(O)NR'_2$

Compound	δ^{a}	$^{1}J_{PH}{}^{b}$	Purity[c]
2a	30.0	498	77
2b	24.8	504	94
2c	35.3	483	88

[a] Phosphorus chemical shifts are in ppm relative to 85% H_3PO_4 external standard.

[b] Coupling constants are in Hertz.

[c] Mol% in crude reaction mixture, except for **2c**, which is the value obtained after molecular distillation.

TABLE II

^1H NMR data for $RPH(O)NR'_2$

	Chemical shifts[a] and coupling constants		
Comp.	R	PH	R′
2a	CH_3: 1.38, dd J_{PH} = 14.5 Hz J_{HH} = 3 Hz	6.9,[b] dq J_{PH} = 498 Hz J_{HH} = 3 Hz	CH_3: 2.56, d J_{PH} = 12 Hz
2b	CH_3: 1.44, dd J_{PH} = 14 Hz J_{HH} = 3 Hz	6.9,[b] dq J_{PH} = 504 Hz J_{HH} = 3 Hz	CH_3: 1.05, t J_{HH} = 7 Hz CH_2: 3.04, dq J_{PH} = 12 Hz J_{HH} = 7 Hz
2c	CH_3: 1.10, t J_{HH} = 7 Hz CH_2: 1.67, m	6.79, dt J_{PH} = 492 Hz J_{HH} = 2.5 Hz	CH_3: 1.10, t J_{HH} = 7 Hz CH_2: 3.09, dq J_{PH} = 11.5 Hz J_{HH} = 7 Hz

[a] Chemical shifts are in ppm from TMS without solvent, except for **2a**, which is in dioxane.

[b] Calculated value using downfield half (ca. 11 ppm) of double quartet and P—H coupling constant from ^{31}P NMR.

As noted above, the three phosphinamides were produced in varying states of purity. Analysis of the crude products by ^{31}P NMR indicated that the two most commonly encountered phosphorus impurities were unreacted diamide and the amine salt of the corresponding phosphinic acid. Our subsequent attempts to purify the phosphinamides were not uniformly successful. The major factor seemed to be the stability of the phosphinamide itself.

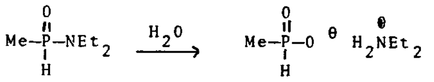
The trimethylphosphinamide (**2a**) was the least stable of the three. Within a few hours, it was observed (^{31}P NMR) to begin a slow decomposition to a complex mixture with concomitant evolution of dimethylamine. Attempted vacuum distillation (0.5 mm) gave no distillate, only a very viscous pot residue in which none of **2a** could be detected by ^1H NMR analysis. Two subsequent attempts to prepare **2a** gave variable results (see Experimental). In both instances we were unable to isolate pure **2a** from the reaction mixture. Thus, no further investigations were undertaken in this system.

In addition to the greater degree of purity in which **2b** could be generated, it also was found to be considerably more stable. No decomposition or loss of diethylamine from sealed samples was detected (^1H NMR) over the course of several days at room temperature. Stored under dry nitrogen at −30°C, the amide was stable for several months. Like **2a**, **2b** could not be further purified by vacuum distillation, but it was not completely destroyed in the attempt (see Experimental). The fact that this phosphinamide could routinely be prepared and isolated in yields up to 90% and ^{31}P purity of 90–95 mol% has led to its being utilized in a number of further investigations.

Triethylphosphinamide **2c** was the most stable of the three. It alone could be successfully purified by vacuum distillation. It too is the subject of ongoing investigations.

The generation of phosphinamides **2a–c** and the isolation of relatively pure samples of **2b** and **2c** stand in contrast to an earlier report[6] on the hydrolysis of a phosphonous diamide, wherein it was suggested that the failure to obtain a phosphinamide resulted from the latter being even more readily hydrolyzed than its diamide precursor. Obviously such was not the case in the systems we have examined.

Furthermore, we have investigated the hydrolytic susceptibility of *N,N*-diethylmethylphosphinamide and have found that even with a large excess of water the reaction (equation 2) was relatively slow.



$$\mathrm{Me{-}\underset{\underset{H}{|}}{\overset{\overset{O}{\|}}{P}}{-}NEt_2} \xrightarrow{H_2O} \mathrm{Me{-}\underset{\underset{H}{|}}{\overset{\overset{O}{\|}}{P}}{-}O^{\ominus}\;H_2\overset{\oplus}{N}Et_2} \qquad (2)$$

2b **3**

Here, very little hydrolysis was observed over the course of several hours. Even after one day a substantial amount of unreacted amide remained (Table III). In this respect, the relative reactivity of amides **1b** and **2b** is comparable to that of the analogous phosphorus esters, where the conversion of diethyl methylphosphonite to ethyl methylphosphinate was shown to be considerably faster than the subsequent hydrolysis of the monoester to methylphosphinic acid.[7] Initial results from a preliminary study indicated that phosphinamide **2c** exhibited a similar resistance to further hydrolysis. Under comparable conditions, approximately 10% of the amide was converted to ethylphosphinic acid after 2.5 hours.

In conclusion, the ease with which reasonably pure P-monoalkylphosphinamides can now be prepared opens the way for further investigations into the chemical potential of this little-studied class of organophosphorus compounds. Such studies are now in progress and preliminary results are the subject of a forthcoming report.

TABLE III

Hydrolysis data for phosphinamide **2b**

	% composition[a]	
Time (hr.)	**2b**[b]	**3**[c]
0	90	10
0.25	89	11
0.50	88	12
1.0	88	12
1.5	87	13
5.7	82	18
22	39	61
46	0	100

[a] Determined from integration of downfield (ca. 11 ppm) half of respective P—H signals, $\Delta\delta$ ca. 13 Hz, in ^{1}H NMR spectrum.

[b] Signal appeared as double multiplet (J_{PH} = 520 Hz) in ^{1}H-undecoupled ^{31}P NMR spectrum.

[c] Signal appeared as double quartet (J_{PH} = 480 Hz) in ^{1}H-undecoupled ^{31}P NMR spectrum.

EXPERIMENTAL

All experiments were conducted in an atmosphere of dry nitrogen. The ^{31}P NMR spectra were recorded with either Varian FT-80A or XL-200 Fourier-transform spectrometer. The ^1H NMR spectra were recorded on a Varian EM360 spectrometer. IR data were obtained from a Nicolet MX-1 spectrophotometer.

Phosphonous Diamides (**1a–c**). The diamides were prepared from the corresponding dichlorides using the procedure described by Maier.[8] *N,N,N′,N′,P*-Pentamethylphosphonous diamide (**1a**) was obtained in 72% yield: b.p. 70–71°C (40 mm); lit.[8] 62–63°C (45 mm). Analysis by ^{31}P NMR showed 98.7 mol% purity, δ 87.6; lit.[8] δ 86.4. Proton chemical shifts and coupling constants agreed with reported[9] values. *N,N,N′,N′*-tetraethylmethylphosphonous diamide (**1b**) was obtained in 63% yield: b.p. 53°C (1 mm); lit.[8] 78°C (5 mm). Though found to be 99 mol% pure by ^{31}P NMR, δ 80.1 (lit.[8] δ 80.4), ^1H NMR revealed the presence of 8 mol% diethylamine hydrochloride impurity. Upon redistillation at 34°C (0.25 mm) it was obtained > 99 mol% pure by both ^{31}P and ^1H NMR: (neat/TMS) $NCH_2C\underline{H}_3$, δ 1.02 (t, $J_{HH} = 7$ Hz); PCH_3, δ 1.20 (d, $J_{PH} = 8.5$ Hz); NCH_2, δ 3.02 (dq, $J_{HH} = 7$ Hz, $J_{PH} = 9$ Hz). Analysis by atomic absorption showed residual chloride ion content in **1b** to be 0.0018 weight%. *N,N,N′,N′,P*-Pentaethylphosphonous diamide (**1c**) was obtained in 69% yield: b.p. 60–61.5°C (0.75 mm); lit.[10] 72–73°C (2 mm). Analysis by ^{31}P NMR gave 97.3 mol% purity, δ 93.1; lit.[3] δ 92. Analysis by ^1H NMR revealed less than 0.5 mol% residual diethylamine hydrochloride. ^1H NMR (neat/TMS) $NCH_2C\underline{H}_3$ coincident with $PCH_2C\underline{H}_3$, δ 0.98 (t, $J_{HH} = 7$ Hz); PCH_2, δ 1.5, m; NCH_2, δ 2.98 (dq, $J_{HH} = 7$ Hz, $J_{PH} = 9$ Hz).

Preparation of N,N,P-Trimethylphosphinamide (**2a**). A mixture of **1a** (1.35 g, 10.1 mmol) and water (0.17 g, 9.5 mmol) was stirred magnetically at ambient temperature until the mixture was homogeneous (ca. 25 min). The mixture was sampled for analysis by ^{31}P NMR, which gave the following mol% composition: unreacted **1a**, 6% (δ 87.8); phosphinamide **2a**, 77% (δ 30.0); dimethylammonium methylphosphinate, 16% (δ 14.9). Analysis by ^1H NMR using the CH_3—P integrals gave 10%, 76% and 14%, respectively. Attempted vacuum distillation of the mixture (0.5 mm, external temperature slowly raised to 80°C) afforded no distillate. The very viscous pot residue was dissolved in dioxane and examined by ^1H NMR. No signals corresponding to **2a** were detected. In a second hydrolysis experiment (3-fold scale-up), modest evolution of heat was noted. Subsequently the entire mixture solidified during transfer for vacuum distillation. Analysis by ^{31}P NMR (dioxane) gave 23%, 30%, and 45% respectively, of the three components found previously. The remainder of the phosphorus content was distributed among seven unidentified substances. When the hydrolysis was repeated with modest (15°C) external cooling and dropwise addition of the water over 2 hours, some crystalline material formed within the reaction vessel. ^{31}P NMR analysis of the liquid phase gave **1a**, 14%; **2a**, 52%, acid salt, 10%; and seven minor components totaling 7%. Also present was a new component (17%), which was not identified but presumed to be some kind of anhydride (P—O—P) species as its ^1H decoupled ^{31}P signal (δ 52) appeared as a doublet. The evolution of dimethylamine continued for several hours as additional crystalline material formed. ^{31}P NMR analysis indicated that **2a** had decreased to 29%, while the acid salt and "anhydride" components had increased to 18% and 43%, respectively.

Preparation of N,N-Diethylmethylphosphinamide (**2b**). A mixture of **1b** (4.360 g, 22.9 mmol), water (0.412 g, 22.9 mmol) and trimethylamine hydrochloride (0.253 g, 2.60 mmol) was stirred magnetically at 15°C until it became homogeneous (ca. 2 hours). Shortly thereafter fine white needle-like crystals (later shown to be diethylamine hydrochloride) formed. The mixture was filtered through scintered glass and freed of hydrolysis byproduct diethylamine under reduced pressure (0.5 mm, 30 min) to give 2.757 g of a clear, mobile liquid. ^1H NMR analysis showed it to be a 90 : 10 mixture of phosphinamide **2b** and the acid salt **3**, respectively, which corresponds to an 84% yield of **2b**. In another comparable experiment, the crude product was analyzed by ^{31}P NMR, which gave the following mol% composition: unreacted **1b**, 4.6% (δ 79.9); phosphinamide **2b**, 93.5% (δ 24.8) and acid salt **3**, 1.9% (δ 13.0). Vacuum distillation (0.15 mm, oil bath heated slowly to 38°C) of a 1.86 g portion of this material gave 0.22 g of distillate. Though ^{31}P NMR analysis indicated 91 mol% **2b**, ^1H NMR analysis revealed that the distillate contained only 63 mol% **2b** and 31 mol% diethylamine. A portion of the very viscous pot residue was taken up in dioxane and analyzed by ^{31}P NMR, which showed the presence of eleven different phosphorus-containing species (δ's 18.3–58.4). The major component (37 mol%) was acid salt **3**; none of the chemical shifts of the remaining components corresponded to that of **2b**. Comparable results were obtained upon molecular distillation (22°C, 30 μ).

Preparation of N,N,P-Triethylphosphinamide (**2c**). In a similar manner, the mixture of **1c** (8.85 g, 43.4 mmol), water (0.75 g, 42 mmol) and trimethylamine hydrochloride (0.38 g, 4.0 mmol) gave the crude product as a clear, mobile liquid (5.92 g, 91% recovery based on **1c**). Analysis by ^{31}P NMR showed **2c**, 76 mol% (δ 35.4; lit.[3] δ 36); unreacted **1c**, 3 mol% (δ 93.3); and more than a dozen unidentified minor (1–2 mol% each) components. After molecular distillation (22°C, 30 μ) ^{31}P NMR showed **2c**, 88 mol%, and six unidentified minor (1–2% each) components. IR bands (liq. film) ν P—H, 2325 cm^{-1}; ν P=O, 1238 cm^{-1}.

Amine hydrochloride catalysis of the hydrolysis of phosphonous diamide **1b**. The following experiments were all conducted in flame-dried, nitrogen-flushed NMR tubes which were capped, sealed with parafilm and given vigorous intermittent agitation to mix their contents. The progress of the reaction was monitored visually for the attainment of homogeneity and by ^{1}H NMR for the downfield (ca. 11 ppm) half of the double quartet P—H signal from the phosphinamide product, **2b**. The extent of hydrolysis was determined from the integrated intensities of the CH_3—P signals from reactant **1b** and product **2b** on the assumption that these were the only phosphorus-containing species.

(a) *Pure diamide.* A mixture of **1b** (0.461 g, 2.43 mmol, free of residual diethylamine hydrochloride) and water (0.047 g, 2.6 mmol) remained heterogenous after being heated to 45°C for 90 min. No P—H signal could be detected even with a fifty-fold increase in the ^{1}H NMR spectrum amplitude. After being heated an additional 40 min and standing overnight at ambient temperature, the sample was still not homogeneous. Examination by ^{1}H NMR confirmed that no detectable hydrolysis had taken place.

(b) *Pure diamide with added trimethylamine hydrochloride.* The NMR sample from part (a) was opened for the addition of trimethylamine hydrochloride (0.030 g, 0.31 mmol, 11 mol%). Within 15 min at 45°C the mixture had become homogeneous. ^{1}H NMR analysis showed the hydrolysis of **1b** to be 95% complete. Analysis by ^{31}P NMR gave the following mol% composition: unreacted **1b**, 1%; phosphinamide **2b**, 90%; acid salt **3**, 8%.

(c) *Diamide contaminated by 8 mol% residual diethylamine hydrochloride.* The addition of water (0.036 g, 2.0 mmol) to a 0.368 g portion of impure **1b** [0.351 g, (1.84 mmol) **1b**; 0.017 g (0.16 mmol) diethylamine hydrochloride] gave a heterogeneous mixture which persisted despite frequent agitation over a one hour period. After standing overnight at ambient temperature the still heterogeneous mixture was examined by ^{1}H NMR, which showed that very little hydrolysis had occurred (P—H signal just visible with 30-fold increase in spectrum amplitude). Thus the mixture was heated to 45°C for one hour, whereupon it became homogeneous. ^{1}H NMR analysis indicated 83% conversion to **2b**. Heating for an additional 30 min. followed by ^{31}P NMR analysis gave the following mol% composition: unreacted **1b**, 7%; phosphinamide **2b**, 88%; acid salt **3**, 4%.

Hydrolysis of N,N-Diethylmethylphosphinamide **2b**. Amide **2b** (0.218 g, 1.6 mmol) was combined with water (0.411 g, 22.8 mmol) in an NMR sample tube. The ^{1}H spectrum of the homogeneous mixture was immediately recorded (t_0); additional spectra were obtained periodically. The time-dependent changes in relative composition (**2b** : **3**) were calculated from the integrated intensities of the downfield (ca. 11 ppm) half of the respective P—H doublets. Both signals ($\Delta\delta$ = 13 Hz) appeared as quartets as a result of additional coupling between the P—H and P—CH_3 hydrogen nuclei [**2b**, $^3J_{HH}$ = 3 Hz; **3**, $^3J_{HH}$ = 2 Hz (lit.[11] $^3J_{HH}$ = 2 Hz)]. In another series of experiments the composition was also determined from the integrated intensities of the respective CH_3—P signals and found to agree ($\pm$3%) with the values obtained as described above. Additionally a sample whose composition at one point was found to be 75 : 25 (**2b** : **3**) gave the value 72 : 28 by ^{31}P NMR shortly thereafter.

ACKNOWLEDGMENTS

Financial support for this work, which was performed at Chemical Research and Development Center (CRDC) under the sponsorship of the Intergovernmental Personnel Act, was provided jointly by the University of D.C. and the U.S. Department of the Army. This assistance is gratefully acknowledged. We also thank L. L. Szafraniec and W. T. Beaudry, Physical Organic Chemistry Section, Research Division, CRDC for the ^{31}P NMR spectra. The additional financial support provided to P.C.T. by the National Institutes of Health Research Grant No. RR-08005 is also gratefully acknowledged.

REFERENCES AND NOTES

1. Portions of this work were presented at the 186th National Meeting of the American Chemical Society, Washington, D.C., August, 1983.

2. M. J. S. Dewar and V. P. Kubba, *J. Amer. Chem. Soc.*, **82**, 5685 (1960).
3. N. Andreev, O. Grishna and V. Smirnov, *Zhur. Obshch. Khim.*, **49**, 332 (1979).
4. E. E. Nifant'ev, *Russ. Chem. Reviews*, **47**, 835 (1978).
5. V. Mark, C. H. Dungan, M. M. Crutchfield and J. R. van Wazer, *Topics in Phosphorus Chemistry*, **5**, 227 (1967).
6. M. J. Gallagher and I. D. Jenkins, *J. Chem. Soc. C*, **1966**, 2176.
7. K. E. Daugherty, W. A. Eychaner and J. I. Stevens, *Appl. Spectroscopy*, **22**, 95 (1968).
8. L. Maier, *Helv. Chim. Acta*, **46**, 2667 (1963).
9. H. Vahrenkamp and H. Noth, *J. Organometal. Chem.*, **12**, 281 (1968).
10. R. N. Sterlin, R. D. Yatsenko, L. N. Pinkina and I. L. Knunyants, *Izv. Akad. Nauk SSSR, Odt. Khim. Nauk.*, **1960**, 1991.
11. D. Fiat, M. Halman, L. Kugel and J. Reuben, *J. Chem. Soc.*, **1962**, 3837.