change for a single compound suggests intramolecular carboxyl group catalysis to be enhanced by a decrease in the dielectric constant of the media (*i.e.*, decrease in k_{ga} due to weakening of the acidity of the general acid catalyst is somewhat compensated for by an increase). This suggests that the proton transfer between the carboxyl group of Glu-35 and the substrate in the ES complex of lysozyme may be facilitated by the non-polar nature[26] of the environment of the enzyme surface in this region. An ion-pair formation between a carboxyl anion and a proton would be anticipated to be enhanced by a decrease in the dielectric of the media.

Acknowledgment. This work was supported by a grant from the National Institutes of Health.

(26) J. B. Howard and A. N. Slayer, *J. Biol. Chem.*, **244**, 1399 (1969).

Preparation and Synthetic Applications of (Dimethylamino)phenyloxosulfonium Methylide[1]

Carl R. Johnson,* Manfred Haake, and Calvin W. Schroeck

Contribution from the Department of Chemistry, Wayne State University, Detroit, Michigan 48202. *Received May 4, 1970*

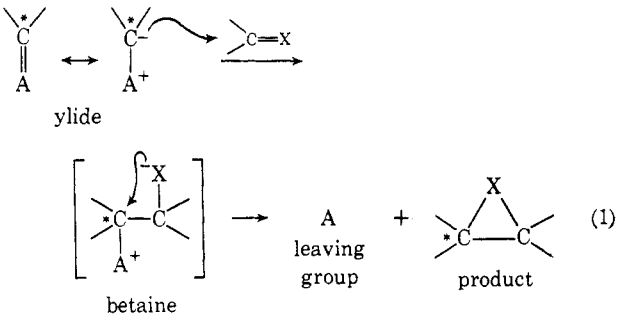
Abstract: The preparations of *N,S*-dimethyl *S*-phenyl sulfoximine and its N-methylated salt—(dimethylamino)-methylphenyloxosulfonium fluoroborate—are described. These materials represent classes of compounds not previously reported. Treatment of the above salt with sodium hydride in a variety of solvents generated the title ylide. The ylide has been shown to react with aldehydes and ketones to produce oxiranes, with electrophilic olefins to yield cyclopropanes, with benzalaniline to produce 1,2-diphenylaziridine, and with benzoyl chloride and phenyl isocyanate to produce carbonyl-stabilized ylides. In the nucleophilic methylene transfer reactions the by-product is *N,N*-dimethylbenzenesulfinamide.

Sulfonium ylides have been extensively utilized as reagents for organic syntheses.[2] The most typical applications of sulfonium ylides involve stepwise methylene insertions across the double bond of a carbonyl or electrophilic olefin to yield an oxirane or cyclopropane, respectively.

Of the sulfonium ylides that have been examined to date, perhaps the most useful is dimethyloxosulfonium methylide (**1**).[3] This ylide is quite reactive, yet moderately stable. Furthermore, the precursor, trimethyloxosulfonium iodide, is easily available by the S methylation of dimethyl sulfoxide. Unfortunately, S alkylation of sulfoxides is not a general reaction and, with trivial exceptions, it is not possible to obtain other salts in the trialkyloxosulfonium series. This limits ylides in the series to the methylide.

We have now achieved the preparation of a new type of oxosulfonium salt—(dialkylamino)oxosulfonium salts.[4] Such salts are derived from sulfoximines and can be prepared with extensive structural variation. The stability and reactivity of the ylides derived by deprotonation of these new salts closely parallel those of dimethyloxosulfonium methylide. In this paper we report the preparation and reactions of the model compound in this series—(dimethylamino)methylphenyloxosulfonium fluoroborate (**3**). This study has provided the foundation for future work which we believe will significantly increase the scope of synthetic applications of sulfonium ylides.[5]

In the design of a new ylide reagent for the stepwise addition of methylene across an electrophilic double bond the following factors need be considered: (1) the nucleophilicity of the carbanionic center, (2) the ability of the onium group to stabilize the anionic site, and, subsequently (3) to act as a leaving group. A generalized ylide reaction is shown in eq 1.



Very stable ylides (such as those containing additional electronegative substituents on the carbanionic carbon) may lack sufficient nucleophilicity for successful addition to an electrophilic double bond. With very unstable ylides, α elimination to carbenoid species may be a problem.

Dimethyloxosulfonium methylide (**1**) is an ylide reagent with a convenient balance between reactivity and stability. With this ylide the leaving group is dimethyl sulfoxide. This investigation originated with the idea that ylides of similar characteristics might be available

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(1) Part XXVI in the series "Chemistry of Sulfoxides and Related Compounds." We gratefully acknowledge support by the National Science Foundation (GP 8648).

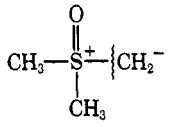
(2) For a review of sulfonium ylide chemistry see A. W. Johnson, "Ylide Chemistry," Academic Press, New York, N. Y., 1966.

(3) E. J. Corey and M. Chaykovsky, *J. Amer. Chem. Soc.*, **87**, 1353 (1965).

(4) For preliminary reports of this work see C. R. Johnson, E. R. Janiga, and M. Haake, *ibid.*, **90**, 3090 (1968).

(5) For example, asymmetric syntheses employing optically active ylides in this series; C. R. Johnson and C. S. Schroeck, *ibid.*, **90**, 6852 (1968).

by deprotonation of *N,N*-dialkyl salts of sulfoximines. In this series we anticipated that the ylides **2** would have reactivity and stability similar to **1**, and the sulfinamide moiety should function as well as dimethyl sulfoxide as a leaving group.



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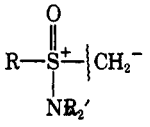

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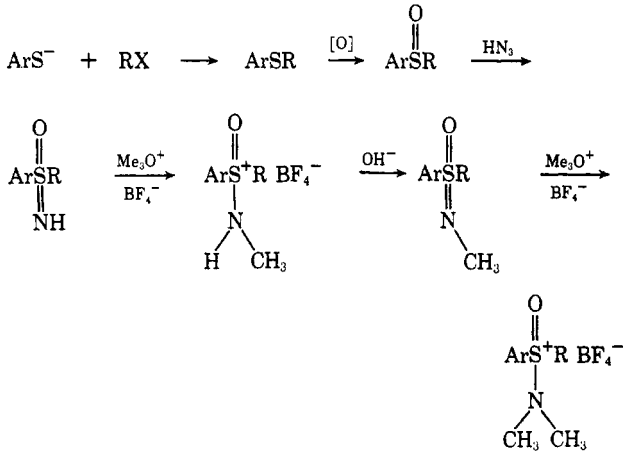
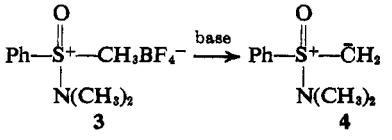
Results and Discussion

A general method for the preparation of appropriate (dialkylamine)oxosulfonium salts is outlined in Scheme I. The starting point of this scheme, the alkylation of an arenethiolate, is a high yield reaction which allows the synthesis of aryl–alkyl sulfides with widely diverse alkyl groups. Whereas oxidation of a sulfide to a sulfoxide offers no particular problems, the subsequent conversion of a sulfoxide to a sulfoximine is not always a facile reaction. In the case of methyl phenyl sulfoxide the conversion occurs in high yield with hydrazoic acid.[6] Alkylation of free sulfoximines to (dimethylamino)oxosulfonium fluoroborates can be accomplished in high yield employing trimethyloxonium fluoroborate.[7] We have isolated and characterized mono-*N*-alkyl sulfoximines, but for the preparature of ylide precursor **3**, this is not necessary or desirable. As in the case of simple amines, attempted monoalkylation often resulted in mixtures, whereas exhaustive alkylation procedures yielded pure products.

Scheme I



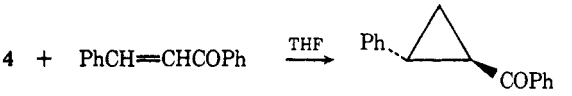
Beginning with methyl phenyl sulfide the sulfoxide can be prepared in 91% yield by periodate oxidation,[8] the sulfoxide was converted to methyl phenyl sulfoximine in 92% yield and the sulfoximine dimethylated to (dimethylamino)methylphenyloxosulfonium fluoroborate in 80% yield. This corresponds to an overall conversion from sulfide to salt **3** of 68%.



3 **4**

Treatment of a solution of **3** in dimethyl sulfoxide (DMSO) or a slurry of **3** in tetrahydrofuran (THF) with sodium hydride resulted in the rapid and quantitative evolution of 1 equiv of hydrogen and the formation of a slightly yellow solution of the ylide **4**. Addition of water to a solution of ylide **4** resulted in the formation of a strongly basic solution from which the original salt could be regenerated by neutralization with fluoroboric acid.

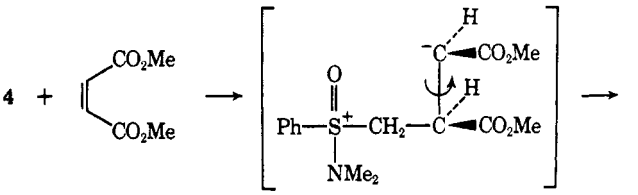
Reaction of ylide **4** in THF with benzalacetophenone resulted in essentially a quantitative yield of *trans*-1-benzoyl-2-phenylcyclopropane (**5**). The ylide **4** has



5

long term stability. A sample of the ylide was generated in DMSO-d_6; after 1 hr the nmr spectrum was obtained and exchange of the methylene hydrogens of the ylide for deuterium was found to be complete. The stoppered tube was allowed to stand for 2 months at room temperature; the nmr spectrum was found to be unchanged. Addition of 1 equiv of benzalacetophenone to the ylide in the nmr tube resulted in the production of **5** containing two deuteriums on C-3.

The apparent pathway of addition of ylide **4** to electrophilic olefins is illustrated for the case of dimethyl



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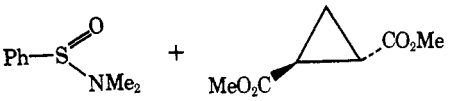


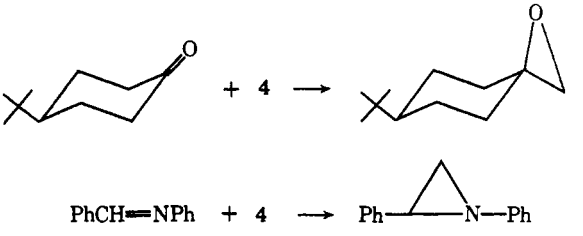
7 **8**

maleate. The formation of the trans-adduct **8** indicates that the betaine **6** has sufficient lifetime to allow rotation about a single bond. Control experiments showed that the ylide isomerized (in part) the excess dimethyl maleate to dimethyl fumarate, suggesting that the initial addition is reversible.

In all of these reactions the by-product, *N,N*-dimethylbenzenesulfinamide (**7**), could be removed by passing a benzene solution of the reaction products through a short column of silica gel.

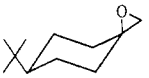
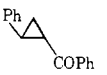
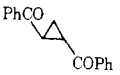
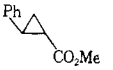
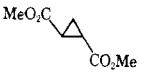
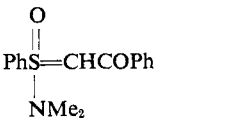
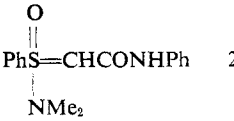
Other examples of reactions of ylide **4** with electrophilic olefins are summarized in Table I.

Reaction of ylide **4** with aldehydes and ketones provided oxiranes whereas reaction with benzalaniline gave the corresponding aziridine.



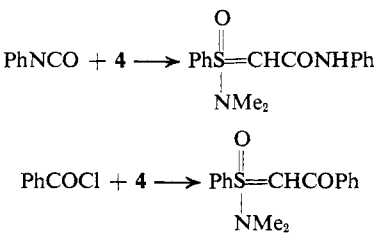
(6) H. R. Bentley and J. K. Whitehead, *J. Chem. Soc.*, 2081 (1950).
(7) H. Meerwein, *Org. Syn.*, **46**, 120 (1966).
(8) C. R. Johnson and J. E. Keiser, *ibid.*, **46**, 78 (1967).

Table I. Reactions of Ylide **4**

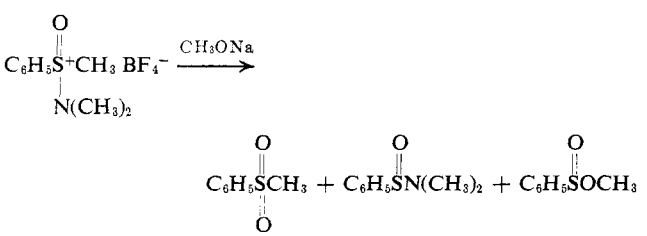
Substrate	Product	Reaction condn: Time, hr	Temp °C	Solvent	Mol % excess ylide	Microanal, % Calcd C	Calcd H	Found C	Found H	Yield, %	Remarks
p-Chlorobenzaldehyde		5	25	THF	9	62.15	4.56	62.36	4.60	60	Liquid
4-*tert*-Butylcyclohexanone		20	25	DMSO	50					84[a]	
trans-Benzalacetophenone		4	25	THF	7	86.44	6.35	86.43	6.26	100	Mp 45–48°[b]
trans-1,4-Diphenyl-2-butene-1,4-dione		2	25	THF	7	81.58	5.64	81.57	5.73	80	Mp 100–102°[c]
trans-Methyl cinnamate		72	25	DMSO	50					72[a]	Ir 1730 cm^{-1}
Dimethyl fumarate (or dimethyl maleate)		1	25	DMSO	5	53.16	6.37	53.36	6.50	75	Ir 1730 cm^{-1}
Benzalaniline		20	25	THF	9					23[a]	
Benzoyl chloride		2	5	THF	100	66.87	5.96	66.64	6.14	85	Ir 1550 cm^{-1}[d]
Phenyl isocyanate		20	25	THF	5	63.55	6.00	63.60	6.28	55	Mp 189–190° Ir 1630 cm^{-1}[d]

[a] Spectral properties are identical with those of an authentic sample. [b] Lit.[3] 45.5–50°. [c] Mp 103–104° (J. B. Conant and R. E. Lutz, *J. Amer. Chem. Soc.*, **49**, 1083 (1927)). [d] *Cf.* ref 9.

Stable ylides were formed by reaction of ylide **4** with phenyl isocyanate[9] and benzoyl chloride.



The reaction of (dimethylamine)methylphenyloxosulfonium fluoroborate with sodium methoxide in refluxing methanol is illustrated below.



It should be pointed out that simple *N*-alkyl sulfoximines, (dialkylamino)oxosulfonium salts, and derived ylides represent classes of compounds not recorded in the earlier literature.

(9) Similar reactions have been achieved with dimethyloxosulfonium methylide and phenyl isocyanate [H. Mitzger and H. Konig, *Z. Naturforsch.*, **18L**, 987 (1963)] or benzoyl chloride (ref 3).

Experimental Section

***S*-Methyl *S*-Phenyl Sulfoximine.**[10] In a 2-l. three-necked flask equipped with a condenser, mechanical stirrer, and an addition funnel, a mixture of 70 g (0.50 mol) of methyl phenyl sulfoxide, 36 g (0.55 mol) of sodium azide,[8] and 500 ml of chloroform was cooled in an ice bath. To this slurry, 125 ml of concentrated sulfuric acid was added over 15 min. The mixture was then carefully warmed up to 45°. This reaction temperature was maintained using a water bath until the evolution of nitrogen began to subside. The mixture was heated further in a mantle at 45° for 12 hr. After cooling 1 l. of ice water was added. After all of the salts were dissolved, the chloroform layer was separated and the aqueous layer was re-extracted with 300 ml of chloroform. The aqueous layer was made slightly alkaline with a 20% sodium hydroxide solution and extracted twice with 500 ml of chloroform. After drying over magnesium sulfate, evaporation of the solvent yielded 71.0 g (92%) of the sulfoximine as a pale yellow oil: ir (neat) 3250 (N–H), 1220 (O=S=N, asym), 1090 (O=S=N, sym),[11] 1010, 990 cm^{-1}; nmr ($CDCl_3$) δ 8.0–7.3 (two m, 5 C_6H_5), 3.45 (s, 1, N–H), 2.9 (s, 3, CH_3).

***N*-(Phenylcarbamyl) *S*-Methyl *S*-Phenyl Sulfoximine.** Equimolar amounts of methyl phenyl sulfoximine and phenyl isocyanate were mixed in a test tube with ether. An exothermic reaction took place immediately. An oil separated which crystalized upon standing. The crude product was collected, washed with ether, and recrystallized from ethanol, mp 129–130°.

Anal. Calcd for $C_{14}H_{14}N_2O_2S$: C, 61.29; H, 5.14. Found: C, 61.43; H, 5.37.

(Methylamino)methylphenyloxosulfonium Fluoroborate. In a 100-ml three-necked flask equipped with a stirrer and condenser, 4.5 g (0.03 mol) of trimethyloxonium fluoroborate was suspended in 30 ml of methylene chloride. To this mixture, a solution of 4.7

(10) R. Fusco and F. Tericoni, *Chim. Ind. (Milan)*, **47**, 61 (1965); *Chem. Abstr.*, **62**, 10357*h* (1965).

(11) A. J. Bannister, L. F. Moore, and J. S. Padley, *Spectrochim. Acta, Part A*, **23**, 2705 (1967).

g (0.03 mol) of methyl phenyl sulfoximine in 20 ml of methylene chloride was added at once with vigorous stirring. After a few minutes, the mixture began to reflux and became clear. The mixture was allowed to stir for 1 hr at room temperature. During this time, the oxosulfonium salt began to precipitate. The solvent was evaporated and the residue was washed with dry ether. After drying with nitrogen, recrystallization from isopropyl alcohol yielded a white hygroscopic salt, 6.5 g (85%), mp 65–67°. The ir was consistent for that structure; (Nujol) 1245, 1100–1000 cm^{-1} (BF_4^-).

N,S-**Dimethyl** *S*-**Phenyl Sulfoximine.** This *N*-alkyl sulfoximine was obtained by neutralization of the fluoroborate described above. In a 250-ml erlenmeyer flask, 6.0 g (0.0225 mol) of (methylamino)-methylphenyloxosulfonium fluoroborate was dissolved in 50 ml of water. This solution was made slightly alkaline with 20% sodium hydroxide and extracted twice with 50 ml of chloroform. After drying over magnesium sulfate, evaporation yielded a nearly colorless liquid, 3.1 g (82%). The ir showed a weak N–H indicating the presence of a small amount of the starting methyl phenyl sulfoximine. This was removed by treatment with phenyl isothiocyanate in ether for 2 days; filtration of the crystals and vacuum distillation of the concentrated liquor yielded the pure *N*-methyl sulfoximine, bp 115–118°, 0.4 mm, ir (neat) 1240 and 1145 cm^{-1} (presumably O=S=N, asym and sym); nmr ($CDCl_3$) δ 7.8–7.5 (m, 5, phenyl), 2.9 (s, 3, S–CH_3), 2.4 (s, 3, N–CH_3). A small sample was converted to the picrate, mp 189–191°.

Anal. Calcd for $C_{14}H_{14}N_4O_8S$: C, 42.21; H, 3.54. Found: C, 42.04; H, 3.83.

(Dimethylamino)methylphenyloxosulfonium Fluoroborate (3). This salt was obtained by two methods: (a) alkylation of the *N*-methyl sulfoximine or (b) dialkylation of the free (N–H) sulfoximine. For preparative purposes the latter method is preferable.

(a) To a suspension of 1.5 g (0.01 mol) of trimethyloxonium fluoroborate in 15 ml of methylene chloride was added a solution of *N,S*-dimethyl-*S*-phenyl sulfoximine in 10 ml of methylene chloride with stirring. After 15 min, the mixture became clear. It was allowed to stir for 1 hr at room temperature. The salt was then precipitated with ether and filtered. Two recrystallizations from isopropyl alcohol yielded 1.9 g (70%) of a white solid, mp 118–119°; ir (Nujol) 1100–1000 cm^{-1} (BF_4^-); nmr ($CDCl_3$) δ 8.2 (m, 5, phenyl), 3.95 (s, 3, *S*-methyl), 3.1 (s, 6, *N,N*-dimethyl).

Anal. Calcd for $C_9H_{14}BF_4NOS$: C, 39.88; H, 5.21; N, 5.17. Found: C, 39.89; H, 5.46; N, 5.30.

(b) In a 250-ml flask fitted with a drying tube, 5.0 g (0.0323 mol) of methyl phenyl sulfoximine was dissolved in 60 ml of methylene chloride. To this solution was added 4.8 g (0.0323 mol) of trimethyloxonium fluoroborate at once with vigorous magnetic stirring. This was done in a room-temperature water bath; the reaction is mildly exothermic. After 15 min, 17 g (0.16 mol) of anhydrous sodium carbonate was added and the mixture was allowed to stir vigorously for 3 hr. Then another equivalent (4.8 g) of trimethyloxonium fluoroborate was added and the mixture was allowed to stir for 3 additional hr. Finally, another 0.5 equiv (2.4 g) of the trimethyloxonium fluoroborate was added and the mixture was stirred for 1 hr. The mixture was then filtered and the inorganic salts were washed by boiling with ethanol and filtering. After evaporation of the methylene chloride solution, that material was combined with the ethanol solution and it was reduced to 125 ml. Upon cooling, the sulfoximine salt crystallized and was filtered off. At this point, the small amount of inorganic salts which had dissolved in the boiling ethanol was removed by dissolving the material in methylene chloride, filtering, and evaporating the solution. Recrystallization from 100 ml of ethanol yielded 7.0 g (80%) of the sulfoximine salt, mp 118–120°. The ir was identical with that of the salt obtained by procedure (a).

(Dimethylamino)phenyloxosulfonium Methylide (4). A. Preparation in DMSO. In a 50-ml three-necked flask equipped with a stirrer, reflux condenser, and gas-inlet tube fitted with a serum stopper was placed 0.05 g (0.002 mol) of sodium hydride (as a 59.4% dispersion in mineral oil). The hydride dispersion was washed several times with dry petroleum ether in order to remove the mineral oil. The hydride was finally dried with a stream of nitrogen. To this, 0.542 g (0.002 mol) of (dimethylamino)methylphenyloxosulfonium fluoroborate in 3 ml of DMSO (distilled from calcium hydride) was added *via* syringe with good stirring. Immediately a vigorous evolution of hydrogen could be observed and the mixture became warm. After a few minutes, the theoretical amount of hydrogen was collected and a clear yellow solution was obtained.

B. Preparation in THF. The same procedure was used as above except that the fluoroborate was added as a solid due to its low solubility in THF. The THF (distilled from sodium dispersion) was then injected into the reaction flask. The evolution of hydrogen was much slower, requiring about 30 min for the theoretical amount to be collected.

C. General Method. The ylide may be prepared and treated in DMSO, THF, *N,N*-dimethylformamide, or *tert*-butyl alcohol. It is more reactive in DMSO and DMF than it is in THF. The ylide was usually prepared more simply by a variation of the above procedures. A one-necked flask with a side arm was fitted with a condenser and a serum stopper and positioned in a cool water bath. A nitrogen cover was provided through a needle inlet in the stopper. An equivalent amount of sodium hydride–mineral oil dispersion was added all at once to a magnetically stirring solution or slurry of the salt in the solvent. The mineral oil was easily removed in chromatography of the product by first eluting with pentane.

Reactions of Ylide 4. The details of some exemplary reactions of ylide **4** are given below. Other reactions are summarized in Table I.

trans-**1-Benzoyl-2-phenylcyclopropane.** Ylide **4** was prepared from 1.85 g (0.0068 mol) of **3** and 0.165 g (0.0068 mol) of sodium hydride in 10 ml of THF by method C. To the stirring ylide solution was added, *via* syringe, a solution of 1.32 g (0.0064 mol) of benzalacetophenone in 5 ml of THF. The mixture was allowed to stir at 25° for 4 hr under nitrogen. After evaporation of the solvent, petroleum ether was added and the mixture was extracted several times with water. The solution was dried over magnesium sulfate and evaporated. Chromatography on a short column of silica gel with benzene yielded 1.4 g (*ca.* 100%) of an oil which solidified upon cooling. After recrystallization from petroleum ether, it was identified as *trans*-1-benzoyl-2-phenylcyclopropane: mp 45–48°; ir (Nujol) 1670 cm^{-1} (C=O); nmr (CCl_4) δ 8.0–7.0 (m, 10, phenyls), 3.0–2.45 (m, 2, COCH and CH), 2.0–1.2 (two m, 2, CH_2).

p-**Chlorostyrene Oxide.** Ylide **4** was prepared from 0.81 g (0.0030 mol) of **3** and 0.072 g (0.0030 mol) of sodium hydride in 3.5 ml of DMSO. To this solution was added 0.35 g (0.0025 mol) of *p*-chlorobenzladehyde in 1 ml of DMSO. The mixture was allowed to stir for 12 hr at room temperature. Then 25 ml of water was added and the mixture was extracted twice with ether. The combined ether solutions were then washed twice with 25 ml of saturated sodium chloride solution. The solution was dried over magnesium sulfate and evaporated. Chromatography on a short column of silica gel with benzene yielded 0.286 g (74%) of *p*-chlorostyrene oxide: nmr (CCl_4) δ 7.3–7.1 (m, 4, aryl), 3.65 (q, 1, CHO), 2.95–2.55 (two q, 2, CH_2).

Further elution of the silica gel with chloroform yielded the by-product *N,N*-dimethylbenzenesulfinamide[12] (54%). It was identified by comparison with an authentic sample prepared by reaction of benzenesulfinyl chloride with dimethylamine: ir (neat) 1090, 1060, and 925 cm^{-1}; nmr ($CDCl_3$) δ 7.5 (s, 5, phenyl), 2.25 (s, 6, *N,N*-dimethyl).

(Dimethylamino)phenyloxosulfonium Benzoylmethylide. The ylide **4** was prepared from 1.36 g (0.0050 mol) of **3** and 0.120 g (0.0050 mol) of sodium hydride by method C in 10 ml of THF. The mixture was cooled to 5° and 0.35 g (0.0025 mol) of benzoyl chloride in 2 ml of THF was added *via* syringe. After 2 hr at 5°, the mixture was maintained at 25° for 20 hr. Then 100 ml of ether was added and the salts were filtered. Evaporation of this pale yellow solution and column chromatography on alumina with chloroform yielded a colorless, viscous liquid: 0.613 g (85%); ir 1550 cm^{-1}; nmr ($CDCl_3$) δ 2.83 (s, 6, $N(CH_3)_2$), 4.80 (s, 1, CH).

(Dimethylamino)phenyloxosulfonium (*N*-Phenylcarbamoyl)methylide. The ylide **4** was prepared from 1.022 g (0.0038 mol) of **3** and 0.091 g (0.0038 mol) of sodium hydride in 10 ml of THF. The mixture was cooled to 5° and 0.43 g (0.0036 mol) of phenyl isocyanate in 2 ml of THF was added *via* syringe. After a few minutes, a white solid started to precipitate. The mixture was stirred at room temperature for 20 hr. The solvent was then evaporated and the residue was dissolved in methylene chloride. Filtration of the insoluble sodium fluoroborate and evaporation gave a yellow solid (1.0 g, 90%). Recrystallization twice from isopropyl alcohol yielded white needles: 0.55 g (50%), mp 189–190° dec; ir ($CHCl_3$) 3400 (N–H), 1630 cm^{-1} (C=O).

Reaction of 3 with Sodium Methoxide. Salt **3** (1.14 g, 4.2 mmol) and sodium methoxide (0.23 g, 4.2 mmol) were dissolved in 10 ml of absolute methanol. The mixture was refluxed under a nitrogen

(12) J. von Braun and W. Kaiser, *Ber. Deut. Chem. Ges. B*, **56**, 549 (1923).

atmosphere for 20 hr. The solvent was removed and the residue was stirred with diethyl ether. The ether phase was separated from the crystalline material (sodium fluoroborate, 0.44 g). By crystallization and chromatographic techniques the ether fraction was found to contain methyl phenyl sulfone (0.22 g), methyl benzenesulfinate[13] (0.21 g), and *N,N*-dimethylbenzenesulfinamide[12] (0.11 g).

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Chemical Evolution. IV. An Evaluation of Cyanovinyl Phosphate as a Prebiotic Phosphorylating Agent[1]

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Abstract: The structure of the phosphate adduct of HC≡CCN is *cis*-β-cyanovinyl phosphate (CVP) (I). The cis configuration was assigned on the basis of an especially characteristic nmr spectrum with signals at δ 4.73 (q, J = ~5, 1.3 Hz) and 7.33 (q, J = 7.8, 6.2 Hz) for H-2 and H-3, respectively. Pyrophosphate is obtained when aqueous solutions of CVP and orthophosphate are heated. Pseudo-first-order kinetics were observed for the addition of orthophosphate and hydroxide to 10^{-4} M HC≡CCN. The bimolecular rate constants (l. mol^{-1} min^{-1}), $\Delta H^{\pm}$ (kcal), and $\Delta S^{\pm}$ (eu) were found to be, respectively: HPO_4^{2-}, 2.5×10^{-1}, +22.0, −4.0; $H_2PO_4^-$, 7.5×10^{-2}, +24.6, +1.8; OH^-, 8.8×10, +19.0, −0.6. The first-order rate constant for the hydrolysis of CVP at 60° is 10^{-4} min^{-1} ($\Delta H^{\pm}$ = 28 kcal, $\Delta S^{\pm}$ = −0.6 eu). The rate of hydrolysis is pH independent between pH 7 and 11 and increases only fourfold going from pH 7 to 1.3. There is a small positive salt effect and a small solvent isotope effect (k_{H_2O}/k_{D_2O} = 1.3) on the solvolysis rate. These data and other results established that the rate-determining step in the solvolysis is P–O cleavage with the formation of the anions of metaphosphate and cyanoacetaldehyde. It was calculated that cyanovinyl phosphate may have accumulated in the oceans of the primitive earth with orthophosphate concentrations as low as 10^{-6} M. However, the concentration of orthophosphate on the primitive earth would have to exceed 10^{-3} M before appreciable quantities of pyrophosphate would be formed from CVP.

The origin of life is believed to have been the end result of the interaction of light, electrical discharges, and other forms of energy with the earth's primitive atmosphere. It is postulated that reactive organic molecules were produced which condensed in the primitive ocean to yield the biological molecules from which the first living system originated. One such reactive organic molecule may have been cyanoacetylene. It is produced when an electrical discharge is passed through a mixture of methane and nitrogen.[3] In aqueous solution, cyanoacetylene reacts with inorganic compounds to yield cytosine, uracil, aspartic acid, asparagine, and 6-aminonicotinamide.[3-5] The genesis of such a wide array of biological molecules from one source prompted our further investigation of the chemistry of cyanoacetylene.

The Structure of β-Cyanovinyl Phosphate

A phosphate adduct of cyanoacetylene, β-cyanovinyl phosphate (CVP) (I), is produced when cyanoacetylene is dissolved in orthophosphate buffers.[6] This adduct was characterized by an absorption maximum at 225 nm. Initially we were reluctant to assign structure I to the adduct since enol phosphates are known to be unstable in aqueous solution.[7] However, this structure is the only one consistent with the analytical data, the ultraviolet (uv) maximum at 225 nm,[8] and the infrared (ir) absorption bands at 2240 (C≡N) and 1660 cm^{-1} (C=C).

$$HC{\equiv}CCN + HPO_4^{2-} \longrightarrow {}^{2-}O_3POCH{=}CHCN$$

The nuclear magnetic resonance (nmr) spectrum of CVP in D_2O exhibits a quartet at δ 4.73 (J = ~5,[9] 1.3 Hz) and 7.33 (J = 7.8, 6.2 Hz). The signal at δ 7.33 collapses to a doublet (J = 7.7 Hz) when the center of the quartet at 4.73 is irradiated. From these data and the nmr spectra of related compounds[10] we assigned the δ 4.73 resonance to H-2 with a 1.3-Hz coupling to phosphorus. The H-3 proton is at δ 7.33 with a 6.2-Hz coupling to H-2 and a 7.7-Hz coupling to phosphorus.

This cis geometry was assigned to the double bond on the basis of the magnitude of the H-2,H-3 coupling constant. The cis-coupling constants of vinyl phosphates are 4.1–5.8 Hz and the trans-coupling constants are 11.1–13.2 Hz.[10] The observation of the *cis*-olefin is in agreement with the general rule that nucleophilic

(1) For the previous paper in this series see J. P. Ferris and J. E. Kuder, *J. Amer. Chem. Soc.*, **92**, 2527 (1970). Supported by Grant No. GP 8254 from the National Science Foundation.

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