78-2; **15**, 1706-31-6; **16**, 10137-17-4; semicarbazone of **16**, 10137-18-5; 4-acetamido-3-acetoxy-6-methoxy-4-methyl-5-phenyl-2-piperidone, 10137-19-6.

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P–N Heterocycles. Their Synthesis and Use in the Catalytic Conversion of Isocyanates into Carbodiimides

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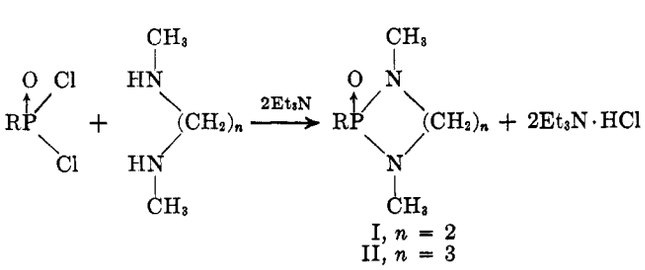
Several novel 1,3-dimethyl-1,3,2-diazaphospholidine 2-oxides and 1,3-dimethylhexahydro-1,3,2-diazaphosphorine 2-oxides were synthesized, and their catalytic activity in the conversion of isocyanates into carbodiimides has been demonstrated.

Although the oxides and sulfides of many organic compounds which contain elements from groups V and VIb of the periodic table are effective catalysts in the conversion of isocyanates to carbodiimides,[1] for the element phosphorus only the cyclic, five-membered phosphine oxides, compounds available form a laborious synthesis,[2] are known to be successful.[3]

The two-step mechanism proposed for these phospholene oxide catalyzed reactions involves the initial formation of a phosphinimide intermediate which reacts with a second molecule of the isocyanate to both afford the carbodiimide and regenerate the catalyst.[3] Since phosphinimides are known to react rapidly with isocyanates,[4] the first step is probably rate determining and would, therefore, be facilitated by a reduction in the polarity of the phosphorous–oxygen bond. In diazaphospholidines, where two nitrogen atoms are juxtaposed to the phosphorous, such a reduction would be anticipated.

Several 1,3-dimethyl-1,3,2-diazaphospholidine 2-oxides (I) and 1,3-dimethylhexahydro-1,3,2-diazaphosphorine 2-oxides (II) were prepared from the reaction of the corresponding N,N′-dimethylalkylenediamines with phosphonic dichlorides in the presence of triethylamine (see Tables I and II).



I, n = 2
II, n = 3

Confirmation of structure was made from elementary analyses and from H^1 nmr spectroscopy. The protons in both the NCH_3 and NCH_2 groupings were coupled with the phosphorus and generally gave rise to well-defined doublets. A correlation of the coupling constants and the chemical shifts is presented in Table III. The protons in the NCH_2 groupings were equivalent, except in the R = CH_2CH_3 (Table III, no. 3) and R = C_6H_5 (Table III, no. 6) derivatives. In the former case two protons, of both NCH_2 groups were equivalent with the remaining two protons giving rise to singulets of equal intensity; in the latter the diamagnetic anisotropy of the benzene ring influenced the chemical shift of both neighboring protons. A similar affect was observed in the diazaphosphorine derivative (Table III, no. 9).

The carbodiimides were prepared by refluxing the isocyanate with 0.5% by weight of the catalyst for 20–30 min, followed by distillation *in vacuo*.

The catalytic activity of several P–N heterocycles in the conversion of *o*-tolyl isocyanate to di-*o*-tolylcarbodiimide is shown in Table IV. Complete conversion was indicated by both the disappearance of the NCO absorption in the infrared at 4.4 μ and by an increase in refluxing temperature.

All of the P–N heterocycles listed in Tables I and II showed some catalytic activity, the diazaphospholidines being much more effective than the hexahydrodiazaphosphorines.[5] The substituents in the α position markedly influenced catalytic activity: ethyl > phenyl > chloromethyl > ethoxy > dimethylamino, the ethyl being the most effective.

The steric sensitivity of the reaction was made apparent by the range of time necessary for complete conversion of non-, 2-, and 2,6-substituted aryl isocyanates (see Table V). Aliphatic isocyanates were less reactive than the aromatic. Octadecyl isocyanate was converted in 2 hr at 200–252°, and phenyl isocyanate in 8 min at 160–230°. *t*-Octyl isocyanate failed to react (see Table V).

The heterocyclic compound (IV) in which the steric hindrance caused by the 1,3-dimethyl groupings in I and II would be absent, was prepared from diethyl minomalonate dihydrochloride (III).

(1) (a) J. J. Monagle, *J. Org. Chem.*, **27**, 3851 (1962); (b) L. Maier, *Helv. Chem. Acta*, **47**, 120 (1964).

(2) W. B. McCormack, *Org. Syn.*, **43**, 73 (1963).

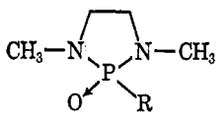
(3) (a) T. W. Campbell and J. J. Monagle, *J. Am. Chem. Soc.*, **84**, 1493 (1962); (b) T. W. Campbell, J. J. Monagle, and V. S. Foldi, *ibid.*, **84**, 3673 (1962); (c) T. W. Campbell and K. C. Smeltz, *J. Org. Chem.*, **28**, 2069 (1963); (d) K. Issleib, K. Krech, and K. Gruber, *Chem. Ber.*, **96**, 2186 (1963).

(4) H. Staudinger and E. Hauser, *Helv. Chim. Acta*, **4**, 861 (1921).

(5) Eberhard and Westheimer[6] reported that the rates of hydrolysis of five-membered cyclic esters of phosphonic acid were extraordinarily larger than those of the six-membered cyclic esters.

(6) A. Eberhard and F. H. Westheimer, *J. Am. Chem. Soc.*, **87**, 253 (1965).

TABLE I
1,3-DIMETHYL-1,3,2-DIAZAPHOSPHOLIDINE 2-OXIDES (I)

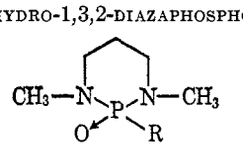


I

No.	R	Bp (mm), °C	Yield, %	Formula	Anal., % Calcd C	Calcd H	Calcd N	Calcd P	Found C	Found H	Found N	Found P
1	CH_2Cl	75–77[a]	~100[b]	$C_5H_{12}ClN_2OP$			15.34	16.97			15.37	16.54
2	CCl_3	88[a]	~100[b]	$C_5H_{10}Cl_3N_2OP$			11.13	12.31			11.19	12.30
3	C_2H_5	90–92 (0.8)	70.5	$C_6H_{15}N_2OP$	44.42	9.32	17.20	19.10	44.27	8.74	17.09	19.24
4	OC_2H_5	82–84 (0.3)	59.5	$C_6H_{15}N_2O_2P$			15.78	17.39			15.40	17.52
5	$N(CH_3)_2$	80 (0.2)	76	$C_6H_{16}N_3OP$			23.71				23.99	
6	C_6H_5	130 (0.7)	70	$C_{10}H_{15}N_2OP$	57.13	7.18	13.32	14.73	57.14	7.03	13.13	14.74

[a] Melting points of recrystallized material. [b] The crude yield was nearly quantitative with extensive losses occurring in crystallization from ligroine.

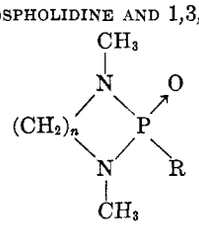
TABLE II
1,3-DIMETHYLHEXAHYDRO-1,3,2-DIAZAPHOSPHORINE 2-OXIDES (II)



II

No.	R	Bp (mm), °C	Yield, %	Formula	Anal., % Calcd C	Calcd H	Calcd N	Calcd P	Found C	Found H	Found N	Found P
7	C_2H_5	98 (0.3)	63.5	$C_7H_{17}N_2OP$	47.71	9.72	15.98	17.57	47.60	9.64	15.83	17.39
8	$N(CH_3)_2$	90–91 (0.1)	75.0	$C_7H_{18}N_3OP$			22.00				21.72	
9	C_6H_5	140–143 (0.3)	71.5	$C_{11}H_{17}N_2OP$			12.40				12.50	

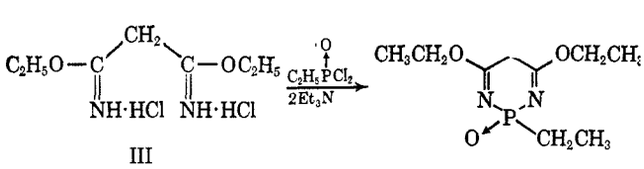
TABLE III
H^1 NMR CORRELATIONS[a] FOR 1,3,2-DIAZAPHOSPHOLIDINE AND 1,3,2-DIAZAPHOSPHORINE 2-OXIDE DERIVATIVES



$n = 1, 2$

No.	NCH_3 δ, ppm	NCH_3 J_{PH}, cps	NCH_3 M[b]	NCH_2 δ, ppm	NCH_2 J_{PH}, cps	NCH_2 M[b]	R	δ, ppm	J_{PH}, cps	M[b]
1	2.68	9.5	d	3.24	8.0	d	CH_2Cl	3.71	9.0	d
2[c]	2.88	8.5	d	3.35	7.5	d	CCl_3	...	...	...
3	2.60	9.5	d	3.12	9.0	d, s	CH_2CH_3	1.68	15.5	pq
								0.99	18.5	pt
4	2.57	10.0	d	3.08	10.0	d	OCH_2CH_3	3.88	10.0	pq
								1.18	7.0[d]	t
5	2.55	9.5	d	3.13	9.0	d	$N(CH_3)_2$	2.48	9.5	d
6[c]	2.52	10.0	d	3.28	...	m	C_6H_5	7.55	...	m
7	2.60	9.5	d	3.1	...	m	CH_2CH_3	...[e]	...[e]	m
8	2.62	9.5	d	~3.0	...	m	$N(CH_3)_2$	2.42	10.5	d
9	2.45	10.0	d	3.2	...	m	C_6H_5	7.5	...	m

[a] Varian A-60, 25% (w/w) in CCl_4, δ relative to TMS. [b] M = multiplicity, s = singulet, d = doublet, t = triplet, pt = pair of triplets, pq = pair of quartets, and m = multiplet. [c] 10% (w/w) solution in $CDCl_3$. [d] $J_{CH_3CH_2}$. [e] Complex pattern, specific assignments not possible.



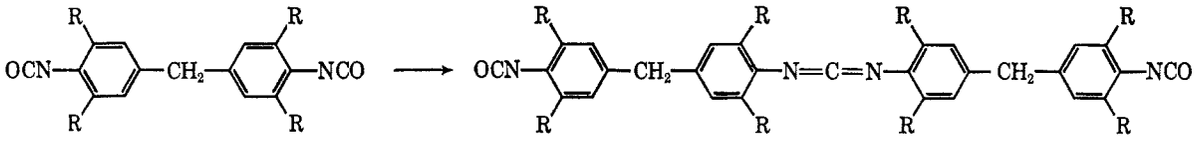
III

IV

Structural confirmation of IV was made from elementary analysis and H^1 nmr spectroscopy. The CH_2O protons gave rise to a quartet at 3.5, the CH_2 protons in the ring, to a singulet at 2.2, and the CH_3 protons of the ethoxy group to a triplet at 0.4 ppm, *i.e.*, in the region of the multiplet associated with the ethyl group attached to phosphorus. The proton ratio was the expected 4:2:11, respectively, for the methylene groups adjacent to oxygen, the ring methylene group, and the remaining protons at 0.4 ppm.

The heating of *o*-tolyl isocyanate with 1% by weight of IV at 180° failed to affect conversion to the carbodiimide, although initial catalysis was evident by ap-

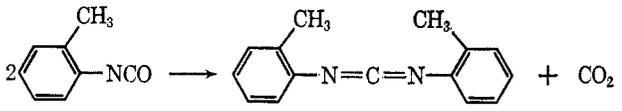
SCHEME I

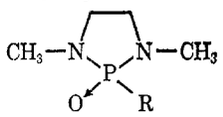
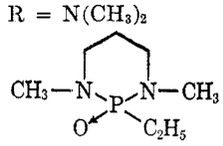


V, R = CH_2CH_3 VI

TABLE IV

CATALYTIC CONVERSION OF *o*-TOLYL ISOCYANATE TO DI-*o*-TOLYLCARBODIIMIDE



Catalyst[a]	Time for complete convn, min
	
R = C_2H_5	20
R = C_6H_5	68
R = CH_2Cl	167
R = OC_2H_5	789
R = $N(CH_3)_2$	1740
	1770

[a] The concentration of catalyst was 0.5% by weight and the reaction temperature was 180–250°.

TABLE V

CATALYTIC CONVERSION OF ISOCYANATES TO CARBODIIMIDES[a]

$$2RNCO \longrightarrow RN{=}C{=}NR + CO_2$$

R	Time for complete convn, min	Reacn temp, °C
Phenyl	8	160–230
o-Tolyl	20	180–250
2,6-Diethylphenyl	330	200–243
Octadecyl	217	200–252
t-Octyl	...[b]	170

[a] Catalyst employed was 2-ethyl-1,3-dimethyl-1,3,2-diazaphospholidine 2-oxide, 0.5% by weight. [b] No reaction after refluxing for 8 hr.

pearance of carbodiimide absorption in the infrared at the start of the heating period. Apparently, reaction of IV with the isocyanate *via* a cycloaddition sequence occurs, leading to ring opening and loss of catalytic activity.

Diisocyanates were also convertable to isocyanato-terminated carbodiimides. 3,3′,5,5′-Tetraethyldiphenylmethane 4,4′-diisocyanate (V), for example, afforded the dimeric species (VI) (see Scheme I).

Experimental Section

1,3-Dimethyl-1,3,2-diazaphospholine[7] or Hexahydro-1,3,2-diazaphosphorine 2-Oxides. General Procedure.—The preparation of 2-ethyl-1,3-dimethyl-1,3,2-diazaphospholidine 2-oxide well demonstrates the general procedure followed in the synthesis of those compounds listed in Tables I and II. To 3000 ml of dry benzene was added 202 g (2 moles) of triethylamine and 88 g (1 mole) of N,N′-dimethylethylenediamine, followed by the dropwise addition of 147 g (1 mole) of ethylphosphonic dichloride with stirring over a 40-min period. A gradual rise in reaction temperature to 58° and precipitation of triethylamine hydrochloride were observed. After stirring for 90 min, the reaction mixture was filtered to remove 260 g (94.5%) of the triethylamine hydrochloride, and the mother liquor was distilled to afford 114.1 g (70.5%) of 2-ethyl-1,3-dimethyl-1,3,2-diazaphospholidine 2-oxide, bp 90–92° (0.8 mm).

Di-*o*-tolylcarbodiimide.—To 26.6 g (0.2 mole) of *o*-tolyl isocyanate was added 0.125 g of 2-ethyl-1,3-dimethyl-1,3,2-diazaphospholidine 2-oxide. The reaction mixture was heated to reflux and then distilled *in vacuo* to afford 18.6 g (84%) of di-*o*-tolylcarbodiimide, bp 128–130° (0.3 mm).

Similarly obtained were 81.7% of diphenylcarbodiimide, bp 118° (0.7 mm); 93.3% of di-*m*-chlorophenylcarbodiimide, bp 174–176° (1.4 mm), mp 43–46°; 83.6% of di-2,6-diethylphenylcarbodiimide, bp 189° (0.5 mm); 77.5% of dicyclohexylcarbodiimide, bp 96–98° (0.3 mm); and 100% of dioctadecylcarbodiimide, mp 50–53°.

2-Ethyl-4,6-diethoxy-1,3,2-diazaposphorine (IV).—To 22.4 g (0.097 mole) of diethyl iminomalonate dihydrochloride (III)[9] in 300 ml of chloroform was added dropwise with stirring 40.4 g (0.4 mole) of triethylamine, followed by 14.7 g (0.1 mole) of ethylphosphonic dichloride. A rise in reaction temperature to 65° was observed. The chloroform was evaporated and a 250-ml portion of benzene was added to cause precipitation of the triethylamine hydrochloride which was then removed by filtration in 100% of theory (55 g). Evaporation of the benzene gave 15.3 g (66%) of crude product which could not be further purified by distillation *in vacuo*. The material was crystallized from ethyl acetate to afford pale yellow crystals of 2-ethyl-4,6-diethoxy-1,3,2-diazaphosphorine (IV), mp 147–148°.

Anal. Calcd for $C_9H_{17}N_2O_3P$: C, 46.54; H, 7.37; N, 12.06; P, 13.34. Found: C, 46.43; H, 7.54; N, 12.16; P, 12.89.

Di[2,6-diethyl-4-(3,5-diethyl-4-isocyanatobenzyl)phenyl]carbodiimide (VI).—A mixture of 72.4 g (0.2 mole) of 3,3′,5,5′-tetraethyldiphenylmethane 4,4′-diisocyanate (V) and 0.724 g of 2-ethyl-1,3-dimethyl-1,3,2-diazaphospholidine 2-oxide was heated at 230° under nitrogen for 60 min and an aliquot portion of the mixture was removed for analysis. Infrared analysis showed a 44% disappearance of the isocyanate. The reaction mixture was cooled and a 10-g sample was crystallized from 100 ml of dry acetone to afford 2.54 g of VI, mp 88–90°.

Anal. Calcd for $C_{45}H_{52}N_4O_2$: N, 8.32. Found: N, 8.67.

Registry No.—1, 7778-03-2; 2, 7778-04-3; 3, 7778-05-4; 4, 10026-27-4; 5, 7778-06-5; 6, 6226-05-7; 7, 7778-08-7; 8, 7778-09-8; 9, 7784-90-9; IV, 7778-10-1; di-*o*-tolylcarbodiimide, 1215-57-2; diphenylcarbodiimide, 622-16-2; di-*m*-chlorophenylcarbodiimide, 7778-12-3; di-2,6-diethylphenylcarbodiimide, 2162-75-6; dicyclohexylcarbodiimide, 538-75-0; dioctadecylcarbodiimide, 10028-39-4; VI, 10022-18-1.

Acknowledgment.—Appreciation is extended to Mr. J. Almaza for his assistance in the experimental portions of this work.

(7) The preparation of 2-phenyl-1,3-dimethyl-1,3,2-diazaphospholidine 2-oxide by a similar procedure[8] was reported after our work had been completed.

(8) C. H. Yoder and J. J. Zuckerman, *J. Am. Chem. Soc.*, **88**, 2170 (1966).

(9) S. M. McElvain and J. P. Schroeder, *ibid.*, **71**, 40 (1949).