Studies in Cyclophosphazenes. Part 11.[1] Geminal Amination of (Alkylamino)pentachlorocyclotriphosphazenes *via* a Conjugate-base Mechanism

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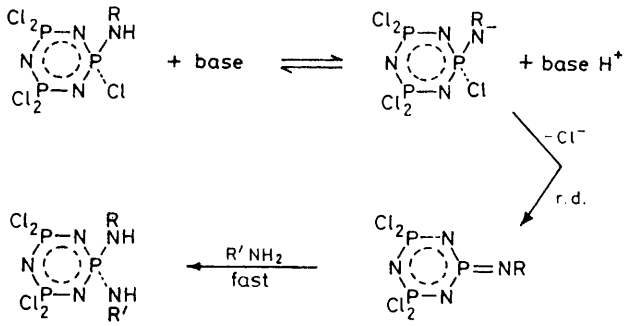
Geminal amination of aminocyclotriphosphazenes is believed to proceed *via* a conjugate-base mechanism, but no study of this mechanism has been reported. Therefore in an endeavour to test this the effect of base concentration on the ratio of geminal to non-geminal products in the general reaction $N_3P_3Cl_5(NRR') + NHR''R''' \xrightarrow{base} N_3P_3Cl_4(NRR')(NR''R''') + base{\cdot}HCl$ (R,R',R'',R''' = H or alkyl) has been investigated. The influence of the substituent groups, the amine, the solvent, and the base and its concentration have been studied. Geminal isomer formation was found to be enhanced by increased base concentration, but only if the phosphazene had a primary amine substituent. These findings conform with the proposed proton abstraction mechanism but conflict with another postulated mechanism.

THE stereoselectivity of amination reactions of halogenocyclotriphosphazenes has been studied extensively,[2,3] but the geminal reactions that give products such as *gem*-$N_3P_3Cl_4(NH_2)_2$ [4] and *gem*-$N_3P_3Cl_4(NHBu^t)_2$ [5] have been relatively neglected. These reactions are thought to proceed by a mechanism that involves deprotonated species as shown in the Scheme.



SCHEME
r.d. = Rate determining

This type of mechanism has also been postulated in other reactions,[6-8] and has been invoked as a rationalization of several reported effects.[3,9-13] The isolation of stabilized three-co-ordinate meta-iminophosphate type compounds has, moreover, added plausibility to these proposals.[14] However, an alternative mechanism involving the formation of a hydrogen-bonded intermediate has been advanced to explain the prevalent formation of geminal products in many reactions of primary amines.[13]

We undertook the present work as a preliminary to a full kinetic study because no investigation of the mechanism of the formation of geminal products in these reactions has been reported. Inspection of the Scheme, indicates that by this mechanism the reaction that leads to geminal products is base-catalyzed, whilst at least in tetrahydrofuran (thf) the competing non-geminal reactions are known to be uninfluenced by base,[15] so it can be predicted that the ratio of geminal to non-geminal products will be a function of base concentration. Therefore, we investigated the effect of base concentration on the ratios of geminal to non-geminal isomers formed in the reactions of (alkylamino)pentachlorocyclotriphosphazenes with amines in a molar ratio of 1 : 1 to produce bis(alkylamino)tetrachlorocyclotriphosphazenes. Here we report these results, a brief version of some of which have appeared before.[16]

EXPERIMENTAL

Materials.—The $N_3P_3Cl_6$ and (methylamino)- and (dimethylamino)-pentachlorocyclotriphosphazenes used were prepared by published procedures.[1,17]

Concentrated solutions of *purum* anhydrous methylamine and dimethylamine (Fluka) in the appropriate solvents were prepared by direct dissolution of the gases. The other amines (n-propylamine, n-butylamine, triethylamine, and pyridine), also all *purum* products from Fluka, were used without further purification. Reagent grade thf and benzene were dried over sodium and distilled.

Instrumentation.—The Packard 873 gas chromatograph (g.c.) and the Autolab System IV integrator have been described in detail.[18] Correction of the signal areas for the *gem*-, *trans*-, and *cis*-isomers of $N_3P_3Cl_4(NHMe)_2$ using a calibration solution of these three isomers at known concentrations resulted in ratios that only differed very slightly from the uncorrected values, and the overall trends in the results were only unappreciably changed. Therefore we dispensed with calibration in all other cases. The peaks in the gas chromatograms were identified by their known order of elution for the mono, *gem*-bis, *trans*-bis, and *cis*-bis compounds.[19]

Determination of Isomer Ratios.—Each experiment consisted of a series of 12 solutions which were made up in a constant volume as follows. The given volumes of the appropriate concentrated solutions (or solvent) were added to stoppered test-tubes in the order specified: (*i*) 2 cm^3 of a solution of the reacting amine at a given concentration; (*ii*) variable volumes, x (= 0,0.5,1,2,4,6,8,10,12,14,16,18 cm^3), of an equimolar solution of the base (triethylamine or pyridine); (*iii*) (18 − x) cm^3 of the appropriate solvent; and (*iv*) 2 cm^3 of an equimolar solution of the substrate, $N_3P_3Cl_5(NRR')$ (R = Me, R' = H or R = R' = Me). These mixed solutions were allowed to stand overnight and then a part of the supernatant solution was removed and analyzed by g.c. Most solutions were injected twice. When discrepancies were found, one or two more injections were

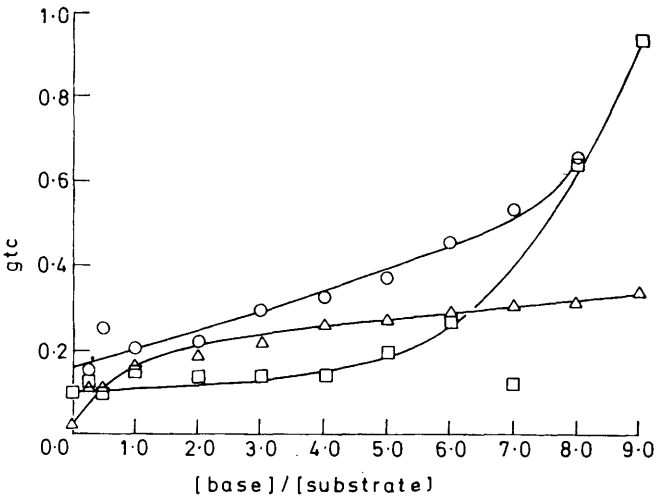
made. In the 'control' experiments (see Results and Discussion) only solutions 1 and 12 of each series were prepared.

Effect of Dilution.—Using the reactants and composition of the twelfth solution of experiment 7 (see Table), a series of solutions with increasing total dilution up to two-fold was prepared. The solutions were analyzed by g.c. in the usual way.

RESULTS AND DISCUSSION

Columns 1—7 of the Table give details of the experiments performed. The results of the g.c. analyses are presented in terms of a factor, gtc, defined by equation (1) where a_{gem}, a_{trans}, and a_{cis} are the integrated areas of the g.c. signals of the *gem*, *trans*, and *cis* isomers of the disubstituted products respectively. A graphical presentation of some typical examples of how gtc changes as a function of base concentration for experiments 1, 2, and 9 appears in the Figure. The results of the other experiments are not presented graphically but are summarized in the Table. In column 9, values of $(gtc)_1$ appear. These are the values of gtc measured in the first solution of every series; these solutions contained no base at all, except the reacting amine. Column 11 shows the values of $(gtc)_{12}$, which are those measured in the twelfth solution of each series: these are the ones that contain the maximum concentration of base. Finally values of the ratio $(gtc)_{12}/(gtc)_1$ appear in column 12. This ratio is a measure of the increase in geminal isomer produced by a nine-fold increase in base concentration, relative to the phosphazene substrate and amine present. It should be noted that in certain cases the values that appear in columns 9 and 12 refer not to $(gtc)_1$ but to $(gtc)_2$. The use of these latter values was unavoidable as in these cases $(gtc)_1$ was too small (*i.e.* $\leqslant 1\%$ of the total area integrated) to be integrated.

$$gtc = a_{gem}/(a_{trans} + a_{cis}) \qquad (1)$$



Typical graphs of gtc against molar ratio [base]/[substrate]; experiment no. 1 (○), no. 2 (□), no. 9 (△)

From the Table it will be seen that in experiments 1—9, in which the substrate was $N_3P_3Cl_5(NHMe)$, the following parameters were varied from one experiment to another: (1) the nature of the amine (primary or secondary), methylamine or dimethylamine; (2) the solvent, thf or benzene, and (3) the base, triethylamine or pyridine. Other amines were used in experiments 10 and 11, in which the substituent and the amine were the same, n-propylamine in the former experiment and n-butylamine in the latter one. The experiments differed from the rest in that the substrate was $N_3P_3Cl_6$ and in that the relative molar concentrations of the amines were double those otherwise employed. This caused formation of the disubstituted isomers whose ratios were measured in the usual way. The values that appear in column 12 show that in all cases there were appreciable increases in the relative amounts of the geminal isomers resulting from the nine-fold increases in base concentrations.

Using $N_3P_3Cl_5(NMe_2)$ as substrate a series of control experiments in which the parameters (1)—(3) were

Influence of added base on the geminal to non-geminal isomer ratio in the reactions $N_3P_3Cl_5(NRR') + NHR''R''' \xrightarrow{base} N_3P_3Cl_4(NRR')(NR''R''') + [NH_2R''R''']Cl$. Details of the experiments and of the g.c. analyses

	Substrate			Amine				Base					
								1st soln. of series			12th soln. of series		
Expt. no.	$N_3P_3Cl_5$-(NRR') R	R′	10^3 Conc./ mol dm^{-3}	NH″R‴ R″	R‴	10^3 Conc./ mol dm^{-3}	Solvent		10^3 Conc./ mol dm^{-3}	$(gtc)_1$	10 Conc./ mol dm^{-3}	$(gtc)_{12}$	$\frac{(gtc)_{12}}{(gtc)_1}$
1	Me	H	0.818	Me	H	0.909	thf	NEt_3	0.227 [a]	0.15 [b]	0.818	0.65	4.3 [c]
2	Me	H	0.451	Me	H	0.451	thf	NEt_3	0	0.10	0.406	0.93	9.3 [d]
3	Me	H	0.476	Me	H	0.476	thf	Pyridine	0.119	0.038	0.380	0.20	5.3 [c]
4	Me	H	0.449	Me	Me	0.449	thf	NEt_3	0	0.056	0.404	0.09	1.6
5 [e]	Me	H	0.250 [f]	Me	H	0.250 [f]	Benzene	NEt_3	0.056	0.12	0.386	0.29	2.4
6 [e]	Me	H	4.50 [g]	Me	H	5.00 [g]	Benzene	NEt_3	0	0.10	0.778	1.22	12.2
7	Me	H	0.521	Me	H	0.521	Benzene	NEt_3	0	0.14	0.469	0.76	5.4
8	Me	H	0.429	Me	H	0.429	Benzene	Pyridine	0	0.15	0.386	2.49	6.6
9	Me	H	0.535	Me	Me	0.535	Benzene	NEt_3	0	0.020	0.482	0.34	17.0
10	$N_3P_3Cl_6$ [h]		0.438	Pr^n	H	0.875	Benzene	NEt_3	0	0.032	0.394	0.97	30.3
11	$N_3P_3Cl_6$ [h]		0.438	Bu^n	H	0.875	Benzene	NEt_3	0	0.043	0.394	1.39	32.3

[a] Concentration for solution no. 2. [b] $(gtc)_2$. [c] $(gtc)_{12}/(gtc)_2$. [d] For comparison with experiments nos. 1 and 3, $(gtc)_{12}/(gtc)_2$ for this experiment is 7.3. [e] Total volume in these experiments not held constant. [f] This concentration refers to 1st solution. In solution no. 12 substrate and amine concentrations are 0.0571 mol dm^{-3}. [g] These concentrations refer to the substrate and amine in the 1st solution. The corresponding concentrations for solution no. 12 are 0.010 and 0.011 mol dm^{-3}. [h] See text.

varied was also carried out. No increase in the relative amount of geminal isomer, with increasing base concentration, was observed in any of these experiments. This observation is in agreement with the proposed mechanism as this substrate cannot undergo proton abstraction.

Another variable checked was the effect of the concentrations of the reactants and the base, at a constant ratio, on the amount of geminal isomer formed. The amount formed was found to be uninfluenced by dilution in the range of concentrations checked, as the values of $(gtc)_{12}$ were constant within the experimental error of the measurements.

Summarizing the above results, it is apparent that, irrespective of the attacking amine, the solvent, the base, the concentration, or the amino-substituent, *provided* it has an ionizable proton, geminal isomer formation, relative to non-geminal isomer formation, is enhanced by added base. This result is consistent with the mechanism proposed which leads to the rate law $d\textit{gem}/dt = k_1[\text{substrate}][\text{base}]$ for geminal isomer formation. In thf, non-geminal isomer formation has been shown to obey the rate law $d\textit{non-gem}/dt = k_2[\text{substrate}][\text{amine}]$.[15] Therefore the ratio of geminal to non-geminal isomers will be given by equation (2).

$$\frac{d\textit{gem}/dt}{d\textit{non-gem}/dt} = \frac{k_1[\text{substrate}][\text{base}]}{k_2[\text{substrate}][\text{amine}]} = k_3\frac{[\text{base}]}{[\text{amine}]} \quad (2)$$

The lack of linearity between gtc and base concentration as simply predicted by this expression can easily be explained in terms of the action of two factors. (*i*) The amine which also acts as a base and contributes to the numerator and (*ii*) the solvent; thf can cause non-linearity as it is itself basic and catalytically active, although this activity does not find expression in the rate law.[15] In benzene in which it is known that non-geminal isomer formation is base-catalyzed,[20] a more complex expression that calls for non-linearity presumably applies.

The results of this study, whilst clearly supporting the proposed mechanism, contradict the alternative one that has been put forward.[13] This latter mechanism does not necessitate deprotonation therefore predicting the catalytic effect to occur with secondary amine substituents too. Moreover, it requires that catalysis be observed with primary amines only. Our findings are in conflict with both these expectations.

Finally we wish to point out that the base-catalyzed preferential formation of geminal isomers should facilitate the development of improved preparative methods for their synthesis, but especially at high base concentrations polymer formation interferes with the efficiency of the geminal reactions and reduces useful yields.

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