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Novel Acid Catalysed 1,4-Addition-Type Ring-Opening Polymerisation of Cyclic Phosphorimidates

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Abstract

New phosphorus containing oligomeric compounds of general formula $(NR^1CH_2CHR^2OP(O)R)_n$, analogous to polypeptides, were isolated and characterised. These are stable intermediaries in the acid catalysed imide-amide rearrangement of cyclic phosphorimidates through a ring-opening polymerisation, revealing an intermolecular two step mechanism for this rearrangement.

Keywords: *Phosphine imines; polymerisation; phosphoramides; rearrangements.*

Organophosphorus compounds are widely known for their biological activity (mainly as insecticides and fungicides) and have increasingly been used in asymmetric organic chemistry as illustrated by numerous examples in the literature of the application of these kinds of compound in a wide range of chemical reactions [1-4]. Also, polymeric organophosphorus compounds have recently found use in material sciences as flame retardants [5-7]. Our interest in the development of new synthetic pathways for the preparation of chiral cyclic oxaza and diaza amidophosphates led us to study the Lewis acid catalysed imide-amide rearrangement of cyclic phosphorimidates. This paper presents preliminary results of the study of this rearrangement, namely the identification of new types of oligomeric organophosphorus compounds (**1** and **2**) formed by a novel 1,4-addition-type ring-opening polymerisation of cyclic phosphorimidates and, for the first time, evidence of the intermolecular nature of this rearrangement reaction. Ongoing studies indicate that this is a promising general method for the preparation of compounds of type **1** and **2** and the corresponding amidophosphates **3**. The oligomeric materials **1** and **2**, due to their structural analogy to polypeptides and biologically active

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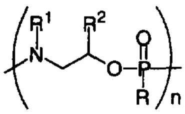

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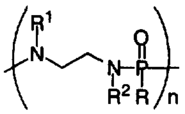

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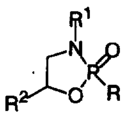

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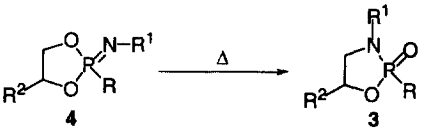
organophosphorus compounds, are likely to have important biological applications. We also believe that the method here reported will contribute to enlarge the library of compounds to be tested as polymer flame retardants.

It has been reported in the literature that phosphorimidates undergo 1,3-thermal rearrangement (above 150 °C) to amidophosphates involving conversion of an alkoxy oxygen to a phosphoryl oxygen and migration of an alkyl group from oxygen to nitrogen [8-10]. This rearrangement occurs with virtually all types of phosphorus substituents. Cyclic phosphorimidates **4** with several different substituents also show the same behaviour (scheme 1) [8-10]. For this family of compounds there is also a precedent in the literature for the acid catalysed imide-amide rearrangement (R = NMe_2, NEt_2, NBu_2; R^1 = Ph and R^2 = H) under milder conditions (60 °C with $BF_3 \cdot Et_2O$ as catalyst) [11].

The reaction was performed using the experimental acid catalysis conditions described in the literature [11] starting from the previously reported compounds (tab. 1, entries 1 and 2) and from compounds with different amine substituents on the phosphorus and on the imidic nitrogen atoms (tab. 1, entries 3, 4 and 5). The reaction was followed by ^{31}P-NMR. To a solution of phosphoramidite (1.1 M in benzene) was added the appropriate azide (phenylazide or benzylazide) and, after completion of the Staudinger reaction, 10 mol % of $BF_3 \cdot Et_2O$ was added, leading to the disappearance of the ^{31}P-NMR resonance signal of the phosphorimidate **4** with the concomitant appearance of another ^{31}P-NMR resonance. The latter was initially interpreted as due to the expected rearranged product **3**. Nevertheless the discrepancy between the chemical shift of this signal and that of authentic samples pointed to a different outcome of the reaction (tab. 1)[1].

Scheme 1



R = OMe, OEt, NMe_2, NEt_2, NBu_2

R^1 = Ph; R^2 = H, Me

Table 1

Reported (lit. [11]) and observed (found) ^{31}P chemical shift (ppm) of several phosphorimidates **4** versus their rearranged products (after Lewis acid) and the corresponding authentic samples **3** (as). Values in ppm downfield from external H_3PO_4.

entry	R	R^1	R^2	**4**		After Lewis acid		**3** (as)
				δ lit.[11]	δ found	δ lit.[11]	δ found	δ found
1	NEt_2	Ph	H	-	19.9	17.7	13.8	18.4
2[a]	NEt_2	Ph	Me	18.1	19.2	15.3	12.8	19.6
				17.6	18.8	-	13.2	19.3
3	NPr^i_2	Ph	H	-	18.0	-	13.1	19.3
4	NEt_2	Bn	H	-	26.0	-	18.4	19.3
5	NPr^i_2	Bn	H	-	25.3	-	17.0	27.0

a) Two diastereoisomers.

The ^{1}H-, ^{13}C- and ^{31}P-NMR spectra were clearly not in accord with the authentic samples and the use of Size Exclusion Chromatography (SEC/GPC, table 2) and MALDI-MS (Matrix-Assisted Laser Desorption Ionisation) were required in order to identify the products as being short chain polymers [12, 13].

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[1] The authentic samples were prepared by mixing the appropriate aminoalcohol with Et_2NPOCl_2 or $Pr^i_2NPOCl_2$ in dry THF in the presence of Et_3N and DMAP (catalytic) at room temperature.

Table 2

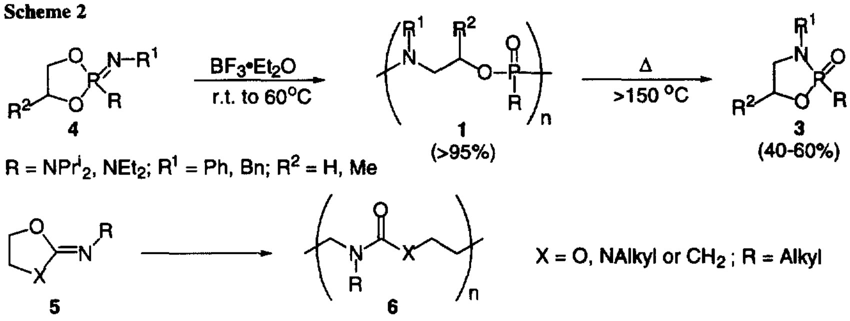
Averaged molecular weight in number ($\overline{Mn}$) and polydispersion index for several oligomers **1**, obtained by SEC.

R	R^1	R^2	$\overline{Mn}$	Polydispersion index^a	R	R^1	R^2	$\overline{Mn}$	Polydispersion index^a
NEt_2	Ph	H	1515	3.38	NEt_2	Ph	Me	3890	4.70
NPr^i_2	Ph	H	3996	3.92	NPr^i_2	Npht	H	2682	2.99
NPr^i_2	Bn	H	9727	5.30	NPr^i_2	Bn	Me	3024	2.99
NPr^i_2	pNO$_2$Bn	H	3395	2.70					

a) calibration curve with polystyrene as standard.

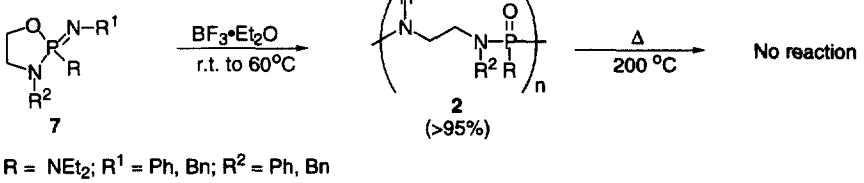
The MALDI spectra of different samples corroborated the SEC results, indicating the presence of oligomers with chain length between 5 and 10 monomers. Heating the oligomers to 150 - 200 °C (with or without solvent) afforded the rearranged monomers **3**, as was proven by comparing the spectral data of the compounds thus obtained with those of the authentic samples. These reactions therefore proceed by a two step transformation (scheme 2) where the intermediary **1** (oligomer) is a stable product which can be isolated[2].

Scheme 2



The structure proposed for the oligomeric species[3] is based on the analogy between the phosphorimidates and exo-imino cyclic compounds, such as ethylene iminocarbonates **5**, which afford polyurethanes **6** through a 1,4-addition-type ring-opening polymerisation (scheme 2) [14-17]. In this class of compounds the imino group has a strongly basic and nucleophilic character due to the alkoxy group, thus reacting easily with cationic catalysts to form reactive intermediate adducts which promote the ring-opening polymerisation. Since it is known that phosphorimidates react with BF_3 to form the same kind of adducts [18], it is reasonable to assume that they will also be activated for 1,4-addition-type ring-opening polymerisation, with the formation of the thermodynamically stable phosphoryl double bond as the reaction driving force. The use of oxaza compounds **7** (scheme 3) instead of the dioxo derivatives leads to the same kind of oligomeric structures **2**. Nevertheless, when heated at 200 °C

Scheme 3



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[2] In the literature [11] the purification of the reaction products was achieved through high vacuum distillation at temperatures around 150 °C, therefore affording directly the rearranged monomers without identification of the intermediary species.

[3] Comparison of the ^{1}H- and ^{13}C-NMR spectra of the oligomers **1** and the starting materials **4** clearly shows a new C-N bond.

for 30 min, these oligomers do not show any change, indicating that the full rearrangement is only possible when there is still one oxygen atom bonded to phosphorus in each repeating unit. The thermal stability of these compounds is an interesting property which will be further explored.

In conclusion, this paper presents a novel 1,4-addition-type ring-opening polymerisation of cyclic phosphorimidates which leads to the formation of stable oligomeric organophosphorus compounds. These compounds were identified as being the intermediaries of the imide-amide rearrangement of cyclic phosphorimidates and their identification revealed the intermolecular nature of the rearrangement reaction. We are now continuing work in this area in order to fully elucidate the reaction mechanism, evaluate the possibility of controlling the chain length and stereochemistry of the products and also to extend this methodology to the synthesis of interesting phosphoramides and polyphosphoramides of type **2**. The latter compounds, due to their thermal stability and similarity to known organophosphorus flame retardants, might prove extremely useful.

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