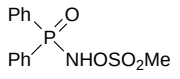
Base induced rearrangement of *N,O*-bis(diphenylphosphinoyl)hydroxylamine: ^{18}O-labelling evidence on how the phosphonamidic-phosphinic anhydride product is formed

Martin J. P. Harger*

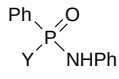
Department of Chemistry, The University, Leicester, UK LE1 7RH

The ^{18}O-labelled substrate $Ph_2P(O)NHOP(^{18}O)Ph_2$ rearranges with base (KOBu^t) to give $Ph(PhNH)P(O)O\text{-}P(^{18}O)Ph_2$ but not $Ph(PhNH)P(O)^{18}OP(O)Ph_2$, in accord with a concerted mechanism rather than one involving a metaphosphonimidate intermediate; $Ph(PhNH)P(^{18}O)\text{-}OP(O)Ph_2$ is also formed, but only because the substrate rapidly equilibrates with $Ph_2P(^{18}O)NHOP(O)Ph_2$ prior to rearrangement.

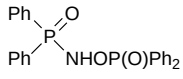
When suitably activated, *N*-phosphinoylhydroxylamines undergo base-induced reactions in which an aryl or alkyl group migrates from phosphorus to nitrogen.[1] Thus, for example, the *O*-sulfonyl compound **1** reacts readily with amines and alkoxides to give the phosphonamidic acid derivative **2** (Y = RNH or RO).[2] The *O*-phosphinoyl compound **3** is much less reactive but with *tert*-butoxide it does rearrange, giving the phosphonamidic-phosphinic mixed anhydride **4**.[3] The formation of **4** is important, adding weight to the circumstantial evidence than an analogous but short-lived phosphonamidic-sulfonic anhydride is formed initially in the rearrangement reactions of **1**.[4] Thus by studying the mechanism of the rearrangement of **3** to **4**, the more versatile and useful rearrangement reactions of **1** and related sulfonyl compounds may also be better understood.



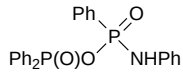
1



2

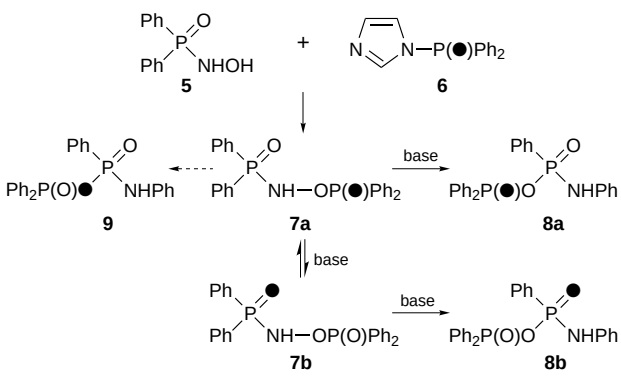


3



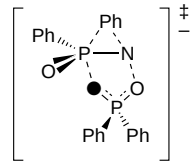
4

Isotopically enriched $Ph_2P(^{18}O)Cl$ was obtained from Ph_2PCl (in CH_2Cl_2) by hydrolysis with [^{18}O]water (1 equiv.) followed by treatment with chlorine (slight excess). Reaction with *N*-(trimethylsilyl)imidazole then afforded the phosphinylating agent **6** (Scheme 1) and this, on stirring with *N*-(diphenylphosphinoyl)hydroxylamine **5** in CH_2Cl_2 (4 h at room temp.), gave the ^{18}O-labelled substrate **7a**, mp 181–183 °C (from $CHCl_3$–diethyl ether). The mass spectrum of **7a** indicated 78% enrichment with one ^{18}O atom [*m/z* (FAB) 434 and 436 $(M + H)^+$] and the ^{31}P NMR spectrum [Fig. 1(*a*)] confirmed the location of the label: δ_P ($CDCl_3$; 162 MHz) 39.38 or 39.33 (both d, J_{PP} 19 Hz; ratio 22 : 78; ^{18}O-induced shift 0.048 ppm) and 29.68 (d, J_{PP} 19 Hz).

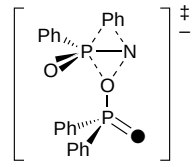


Scheme 1

The labelled substrate **7a** (0.07 mmol) was shaken with KOBu^t (0.10 mmol) in *tert*-butyl alcohol (containing 10% C_6D_6 for NMR lock) (0.5 ml) and the ^{31}P NMR spectrum of the reaction mixture was recorded. For the anhydride rearrangement product, ^{18}O-induced high-field peaks, of equal intensity, were seen in both the phosphinoyl and phosphonamidoyl resonances [Fig. 1(*b*); *t* = 40 min]: δ_P (reaction mixture; 162 MHz) 24.12 or 24.08 (both d, J_{PP} 35 Hz; ^{18}O-induced shift 0.044 ppm) and 7.74 or 7.70 (both d, J_{PP} 35 Hz; ^{18}O-induced shift 0.037 ppm.† This might suggest structure **9** (Scheme 1), with the label located in the bridging (P–O–P) position, and a reaction mechanism in which the conjugate base of the substrate rearranges concertedly *via* a transition state such as **10**. However, the intensities of the isotope-induced high-field peaks (*ca*. 40% of the total signal) are only about half of what they should be for **9**, given the ^{18}O-enrichment (78%) of the substrate. This points instead to an even distribution of the label between the two non-bridging (P=O) positions of the anhydride product, corresponding to an equal mixture of the structures **8a** and **8b**. Such a labelling pattern is difficult to reconcile with any reasonable rearrangement mechanism, but degradation of the product showed it to be true: reaction with methoxide gave some $Ph_2P(O)OMe$ by attack at one of the phosphorus atoms of the anhydride and some PhP(O)(NHPh)OMe by attack at the other, and these both had ^{18}O-enrichments (40 and 37% respectively by GC–MS) equal to about half that (78%) of the substrate.



10



11

The reaction of the labelled substrate **7a** was repeated but with quenching (CF_3CO_2H) after just 2 min, at *ca*. 10% completion. The ^{31}P NMR spectrum of the remaining substrate showed the ^{18}O label to be equally shared between the P=O groups of the *O*- and *N*-phosphinoyl moieties. Apparently, under the conditions of the rearrangement, the two phosphoryl (P=O) oxygen atoms in the substrate rapidly equilibrate, *i.e.* **7a** ⇌ **7b** (Scheme 1).‡ The product resulting from the rearrangement of **7b** can only be **8b**, with the label in the phosphonamidic non-bridging position, so from **7b** we can learn nothing about the mechanism of the rearrangement. Attention must therefore be focussed on the behaviour of **7a** (half the total ^{18}O after

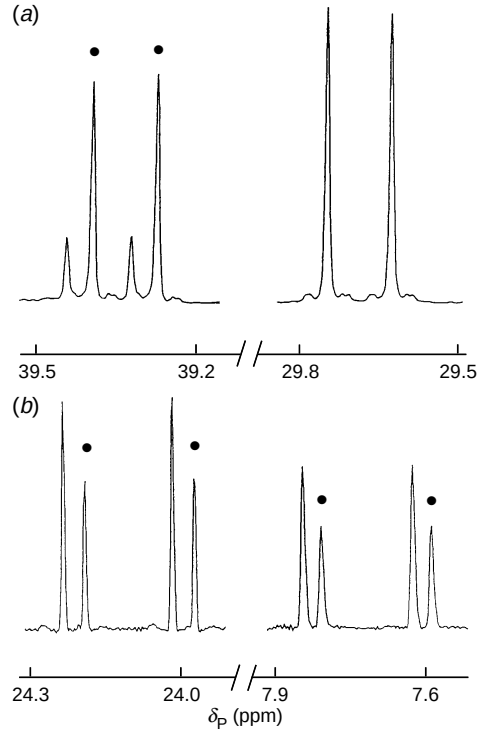
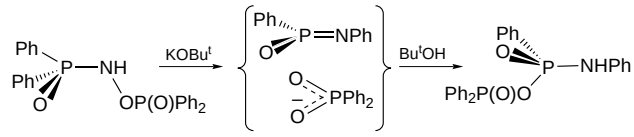


Fig. 1 ^{31}P NMR spectra (162 MHz; ^{1}H decoupled) of (*a*) ^{18}O-enriched substrate **7a** (in $CDCl_3$) and (*b*) rearrangement product **8a** + **8b** [in Bu^{t}OH–C_6D_6 containing KOBu^t]; isotope-shifted peaks (●) at high field

equilibration with **7b**). When **7a** rearranges it is a labelled phospinate group [OP(^{18}O)Ph_2] that is transferred from nitrogen to phosphorus, so formation of the new O–P bond might involve the labelled or the unlabelled oxygen atom. The latter seems actually to be the case. In the ^{31}P NMR spectrum of the rearrangement product [Fig. 1(*b*)] there are substantial high-field isotope-induced peaks for structure **8a** (δ_P 24.08; $\Delta\delta$ 0.044 ppm), derived from **7a**, and for **8b** (δ_P 7.70; $\Delta\delta$ 0.037 ppm), derived from **7b**, but not for **9**. In the case of **9** the isotope-induced shifts, due to P–^{18}O single bonds, would be relatively small.[5] Appropriate peaks (δ_P 24.09; $\Delta\delta$ 0.033 ppm) may just be detectable in the phosphinoyl resonance [Fig. 1(*b*)], but they are hardly significant.§ The conclusion must be that, in the rearrangement, the phosphinate group is transferred from nitrogen to phosphorus without any appreciable incorporation of the phosphoryl (P=O) oxygen atom into the new O–P bond. If the rearrangement of the conjugate base of the substrate is concerted, it must proceed *via* a transition state that resembles **11** rather than **10**.

In principle the rearrangement could be non-concerted, with a three-coordinate metaphosphonimidate intermediate, but in that case the phosphinate group would be set free and would become a fully-formed anion (Scheme 2). In the limit the two



Scheme 2

oxygen atoms in the anion would be equivalent and involved equally in the formation of the new O–P bond, *i.e.* **7a** would give equal amounts of **8a** and **9**. Initially, when first released from nitrogen, the oxygen atoms of the phosphinate anion might be non-equivalent, because of differences in solvation (by Bu^{t}OH) and/or association with the counterion (K^+), but it seems unlikely that they could remain distinct to the extent that only one of them plays any part in forming the new bond to phosphorus. We therefore feel bound to favour a concerted mechanism for the rearrangement, with a transition state resembling **11**, and also to reconsider our preference for a non-concerted mechanism in the case of sulfonyl compounds such as **1**.[6]

We thank Dr G. A. Griffith for recording NMR spectra and Professor P. M. Cullis for advice and encouragement.

Footnotes and References

† The mixed anhydride reacts very readily with traces of water in basic media. Moisture was excluded as far as possible but some formation of the hydrolysis products $Ph_2P(O)O^-$ (δ_P 17.53 or 17.49; ^{18}O-induced shift 0.036 ppm) and Ph(PhNH)P(O)O$^-$ (δ_P 7.05 or 7.02; ^{18}O-induced shift 0.035 ppm) could not be avoided.

‡ The unexpected equilibration of the phosphoryl oxygen atoms (or the phosphinoyl groups) is interesting but peripheral to the present investigation.

§ The magnitude of an ^{18}O-induced shift depends on the environment of the phosphorus atom, but the single bond (P–^{18}O) shift is generally in the range 0.3 to 0.7 times the double bond (P=^{18}O) shift (ref. 5). That being so, any appreciable amount of **9** would certainly be detectable in the presence of **8a** and **8b**. An attempt to confirm this experimentally, by treating $Ph_2P(O)^{18}O^-$ with Ph(PhNH)P(O)Cl in Bu^{t}OH, was complicated by side reactions but the phosphinoyl resonance of the mixed anhydride clearly showed a single bond shift 0.7 times the double bond shift.

1 M. J. P. Harger and A. Smith, *J. Chem. Soc., Perkin Trans. 1*, 1987, 683; M. J. P. Harger and P. A. Shimmin, *Tetrahedron*, 1992, **48**, 7539 and references cited therein.
2 M. J. P. Harger, *J. Chem. Soc., Perkin Trans. 1*, 1983, 2699.
3 M. J. P. Harger, *Tetrahedron Lett.*, 1990, **31**, 1451.
4 M. J. P. Harger and A. Smith, *J. Chem. Soc., Perkin Trans. 1*, 1990, 2507; M. J. P. Harger and R. Sreedharan-Menon, *J. Chem. Soc., Perkin Trans. 1*, 1994, 3261.
5 P. M. Cullis, in *Phosphorus-31 NMR Spectral Properties in Compound Characterisation and Structural Analysis*, ed. L. D. Quin and J. G. Verkade, VCH, Weinheim, New York and Cambridge, 1994, pp. 315–331.
6 M. J. P. Harger, *Chem. Commun.*, 1997, 403.

Received in Cambridge, UK, 28th April 1997; 7/2856C