Reaction of Stabilised Phosphorus Ylides with Nitrogen Dioxide

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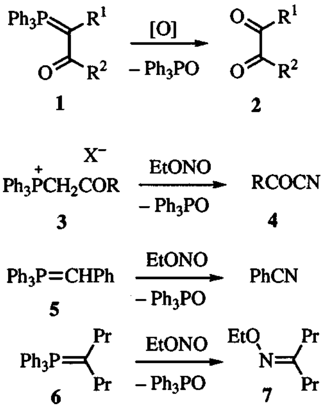
The reaction of the stabilised ylides **14–23** with an excess of NO_2 in CH_2Cl_2 at room temperature gives different results depending on the structure of the starting ylide. The monacyl ylides **14–16** give the corresponding α-oxo nitriles **4** together with $Ph_3PO \cdot HNO_3$ (**24**) which has been fully characterised for the first time. Under the same conditions, the ylide **18** gives 2,4-dinitrobenzonitrile (**26**), Ph_3PO, and benzoic acid. The other ylides examined all give **24** together with a variety of other products.

Reaction of β-oxoalkylidenetriphenylphosphoranes **1** with a variety of oxidising agents results in cleavage of the P=C bond to give Ph_3PO and the 1,2-diones **2**.[1] Reagents successfully used for this transformation include ozone,[2] peracetic acid,[3] benzoyl peroxide,[4] lead tetraacetate, iodobenzene diacetate and lead dioxide,[5] potassium permanganate,[6] sodium periodate,[7] triphenyl phosphite ozonide,[8] *N*-sulfonyloxaziridines,[9] singlet oxygen,[10] potassium peroxymonosulfate (Oxone®),[11] and dimethyldioxirane.[12] In an early study Zbiral and Fenz described a different mode of oxidation in which reaction of a range of β-oxoalkylphosphonium salts **3** with ethyl nitrite gave the corresponding α-oxonitriles **4**, Ph_3PO, and ethanol.[13] In this study the ylide **5** was also found to give benzonitrile while for **6** the oxime ether **7** was obtained. A recent detailed study by Bestmann and coworkers described the rather complex pattern of reactivity of phosphorus ylides with nitrogen dioxide.[14] The products obtained from **8** depended on the nature of R^1 and R^2 as shown. With a single non-stabilising substituent the nitrolic acid **9** was formed while a single stabilising substituent led to formation of the nitrile **10** together with the conjugate phosphonium salt **11**. With alkyl and ester substituents present the α-nitro-α-nitrosoester **12** was produced, while for R^1 = Ph nitration of the ring was observed to give **13**. In this paper we present the results of our parallel and complementary investigation of the reactivity of stabilised ylides with NO_2 which differ significantly from those of Bestmann.

Results and Discussion

In the previous study[14] all reactions were performed in THF, in which NO_2 exists as a blue molecular complex, and at temperatures of −78 to −30°C. In addition precisely two equivalents of NO_2 (one of N_2O_4) were generally used. For convenience we chose instead to use dichloromethane as the solvent at room temperature and to use 3 equiv. of NO_2. The reactivity of the ten ylides **14−23** was examined under these conditions.



The three examples **14−16** with a single stabilising group were found to give the corresponding α-oxonitriles **4** together with a compound containing both phosphorus and nitrogen. Elemental analysis showed this to have the composition $Ph_3PO \cdot HNO_3$ (**24**) which could be considered to some extent as hydroxytriphenylphosphonium nitrate. Rather surprisingly, this does not appear to have been fully characterised before, although its structure has been investigated by IR methods[15]. An authentic sample of **24** was prepared by direct reaction of Ph_3PO with nitric acid and this was indeed identical to the product from the oxidation reactions although the physical and spectroscopic data seemed to vary considerably between individual samples probably due to the presence of traces of free acid. For comparison the 2:1 adduct of Ph_3PO with nitric acid (**25**) was also prepared and characterised and it proved to have remarkably similar spectroscopic properties to **24** so that elemental analysis was in fact the most reliable method to distinguish between the two adducts.

The conversion of **14−16** into **4** and **24** by reaction with two equivalents of NO_2 forms a balanced equation as shown, although the likely mechanism, as described in detail by Bestmann,[14] is rather complex involving such species as HNO_2 and N_2O_3. The distinction between our results and the conversion of **8** into **10** is that, in that case, more ylide was used in proportion to the NO_2 so that the nitric acid formed reacted with a second equivalent of **8** to

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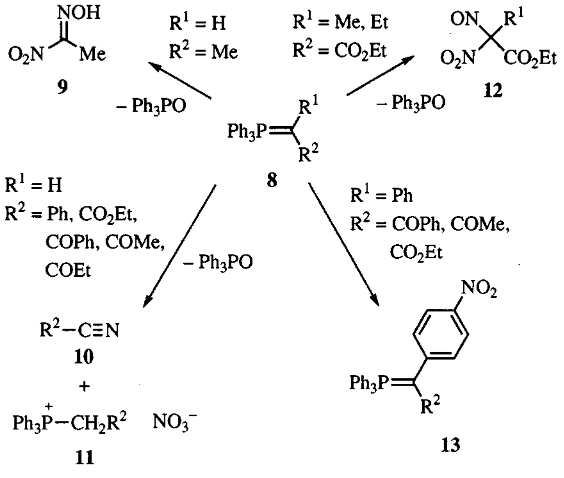
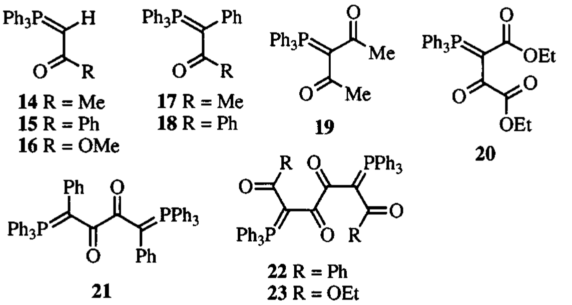
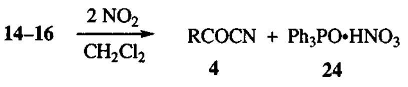






$$\mathbf{14{-}16} \xrightarrow[CH_2Cl_2]{2\ NO_2} \underset{\mathbf{4}}{RCOCN} + \underset{\mathbf{24}}{Ph_3PO\cdot HNO_3}$$

$[Ph_3P{=}O\cdots H\cdots O{=}PPh_3]^+\ NO_3^-$

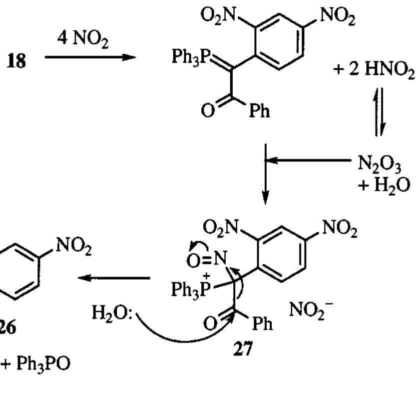
25

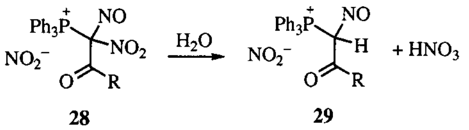
give the salt **11**. In our case where an excess of NO_2 is used and this is not possible, the nitric acid instead reacts with the Ph_3PO to afford **24**.

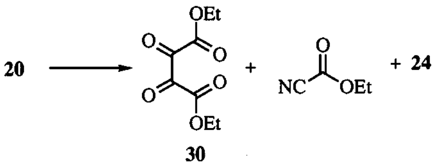
Both **17** and the dioxo ylide **19** gave rather disappointing results in that both did give **24** but the only other product identified was a low yield of benzoic acid in the case of **17**. The reaction of **18** with NO_2 took a different course: alone among the ylides in this study it gave almost entirely Ph_3PO as the phosphorus product with only a trace of **24**. The other products were 2,4-dinitrobenzonitrile (**26**) and benzoic acid. In analogy to to the mechanisms proposed by Bestmann[14] we suggest that this reaction proceeds by initial electrophilic nitration of the activated ring followed by nitrosation by N_2O_3 present in equilibrium from the nitrous acid produced in the first step. Direct hydrolysis of the salt **27** then gives benzoic acid and sets up the ylide function for Wittig-type elimination of Ph_3PO to give the nitrile. It should be noted that this sequence does not produce nitric acid whereas the corresponding process applied to **14−16** involves the intermediacy of the salts **28** which are hydrolysed to give **29** and nitric acid, thus explaining the formation of **24** in our study and **11** from **8**.

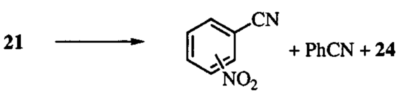
The remaining ylides **20−23** with more complex structures gave a variety of different products together with the salt **24** in each case. With the trioxo ylide **20** there was oxidative cleavage of the C=P bond to give the dioxo diester **30** but also some formation of ethyl cyanoformate, with **21** both benzonitrile and a nitrated benzonitrile were produced, while **22** gave benzoyl cyanide and benzoic acid and for **23** the other product was not identified.

In agreement with the previous study[14] we have found that the reaction of phosphorus ylides with NO_2 is rather complex and depends on the substituents present. By using an excess of NO_2 the monoacyl ylides **14−16** can be converted entirely into the nitriles **4** rather than a 1:1 mixture of **4** and **11** as occurs with less NO_2. The reaction of **18** shows that, with suitable substituents present, the ring nitration and nitrile formation processes can be combined. Further work is clearly required to explain the reactivity of the more complex ylide types **20−23**.









22 ⟶ PhCOCN + $PhCO_2H$ + **24**

Experimental Section

General: M. p.: Reichert hot-stage microscope, uncorrected. − IR: Perkin Elmer 1420. − NMR: Bruker AM300 (300 MHz for ^1H, 75 MHz for ^{13}C), Varian CFT 20 (32 MHz for ^{31}P). All spectra, $CDCl_3$ as solvent. Internal TMS as reference for ^1H and ^{13}C and external 85% H_3PO_4 as reference for ^{31}P. − GCMS: Hewlett-Packard 5890A/Finnigan Incos (70 eV).

Preparation of Starting Materials: The required ylides **14**−**16** are commercially available, while **17** and **18**,[16] **19**,[17] **20**,[18] and **21**−**23**[19] were prepared using the literature methods. A stock solution of NO_2 in dry CH_2Cl_2 was prepared by adding a weighed amount of the liquid gas from a cylinder. This brown solution was stored over Na_2CO_3 at room temp. and in the dark.

Reaction of Ylides with NO_2: A solution of NO_2 (6.0 mmol) in CH_2Cl_2 was added dropwise to a solution of the ylide (2 mmol) in dry CH_2Cl_2 (25 mL). The mixture was stirred at room temp. until all the starting material was consumed (monitored by ^{31}P NMR) and evaporated to give the products as follows:

From (Acetylmethylene)triphenylphosphorane (14): A yellow mixture of crystals and oil which were separated by trituration with dry diethyl ether and identified as $Ph_3PO \cdot HNO_3$ **24** (quantitative yield) m.p. 68−70°C. − ^1H NMR: $\delta = 17.72$ (br s, 1 H, OH), 8.01−7.26 (m, 15 H, Ph). − ^{13}C NMR: $\delta = 132.9$ (d, $J = 3$, 3× C-4 of Ph), 132.1 (d, $J = 11$, 6× C-2 of Ph), 129.5 (d, $J = 108$, 3× C-1 of Ph), 128.9 (d, $J = 13$, 6× C-3 of Ph). − ^{31}P NMR: $\delta = +34.6$. − $C_{18}H_{16}NO_4P$ (341.3): calcd. C 63.34, H 4.73, N 4.10; found C 63.83, H 4.75, N 4.26. − By-product pyruvonitrile (55 mg, 40%). − IR (CH_2Cl_2): $\tilde{\nu} = 2220$ cm^{-1} (CN), 1750 (CO). − ^1H NMR: $\delta = 2.28$ (s, 3 H).

From (Benzoylmethylene)triphenylphosphorane (15): Pale yellow crystals and a yellow oil which were separated by trituration with dry diethyl ether and identified respectively as **24** (quantitative yield) − data as above − and benzoyl cyanide (170 mg, 65%). − IR (CH_2Cl_2): $\tilde{\nu} = 2220$ cm^{-1} (CN), 1680 (CO). − ^1H NMR: $\delta = 8.17$−8.11 (2 H, m). − ^{13}C NMR: $\delta = 170.8$ (CO), 136.6, 130.0, 129.2, 128.1, 112.5 (CN). − MS (GCMS); *m/z* (%): 131 (49) $[M^+]$, 105 (100), 77 (81), 51 (60).

From (Methoxycarbonylmethylene)triphenylphosphorane (16): A yellow mixture of crystals and oil which were separated by trituration with dry diethyl ether and identified respectively as **24** (quantitative yield) − data as above − and methyl cyanoformate (94 mg, 55%). − IR (CH_2Cl_2): $\tilde{\nu} = 2220$ cm^{-1} (CN), 1750 (CO), 1630. − ^1H NMR: $\delta = 3.88$ (s, 3 H). − ^{13}C NMR: $\delta = 164.3$ (CO), 117.8 (CN), 54.6 (Me). − MS (GCMS); *m/z* (%): 86 (0.5) $[M + H^+]$, 84 (10), 59 (19), 54 (100), 45 (37), 41 (73), 31 (91), 29 (70), 15 (90).

From 1-Phenyl-1-triphenylphosphoranylidenepropan-2-one (17): Pale yellow crystals and a yellow oil which was shown to contain **24** − data as above − and benzoic acid (24 mg, 10%) and other unidentified material.

From 1,2-Diphenyl-2-(triphenylphosphoranylidene)ethanone (18): A mixture containing, as major products, Ph_3PO (306 mg, 55%). − ^{31}P NMR: $\delta = 29.2$, benzoic acid (94 mg, 40%). − ^1H NMR: $\delta = 12.2$ (s, 1 H), 8.15 (m, 2 H), 7.65 (m, 1 H), 7.48 (m, 2 H). − MS (GCMS); *m/z* (%): 122 (7)$[M^+]$, 105 (100), 77 (91), 51 (40), and 2,4-dinitrobenzonitrile (**26**) and, as a minor product (34 mg, 5%) **24** − data as above. Separation by chromatography (diethyl ether/petroleum ether, 1:1) gave 2,4-dinitrobenzonitrile (**26**) (135 mg, 35%) as yellow crystals, m.p. 103.5−105°C (ref.[20] 104°C). − ^1H NMR: $\delta = 9.18$ (d, $J = 2$ Hz, 1 H, 3-H), 8.70 (m, 1 H, 5-H), 8.23 (d, $J = 9$ Hz, 1 H, 6-H). − ^{13}C NMR: $\delta = 150.0$ (4ry), 149.3 (4ry), 137.1, 128.5, 120.9, 113.3, 113.2. − MS (GCMS); *m/z* (%): 193 (8) $[M^+]$, 147 (2), 100 (15), 75 (20), 50 (29), 30 (100).

From 3-Triphenylphosphoranylidenepentane-2,4-dione (19): A yellow mixture of crystals and oil in which only **24** could be identified.

From Diethyl 2-Oxo-3-triphenylphosphoranylidenebutanedioate (20): A yellow mixture which was separated by trituration with dry diethyl ether and identified as **24** (quantitative yield) − data as above, and a mixture of diethyl dioxobutanedioate (**30**) (81 mg, 20%) and ethyl cyanoformate (30 mg, 15%).

Diethyl Dioxobutanedioate: Colourless crystals. − ^1H NMR: $\delta =$ 4.31 (OCH_2), 1.30 (CH_2Me). − ^{13}C NMR: $\delta = 158.8$ (CO), 63.2 (OCH_2), 13.9 (CH_2Me). − MS (GCMS); *m/z* (%): 202 (1) $[M^+]$, 102 (2), 74 (4), 29 (100).

Ethyl cyanoformate: − IR (CH_2Cl_2): $\tilde{\nu} = 2400$ cm^{-1} (CN), 1735 (CO), 1620. − ^{13}C NMR: $\delta = 101.4$ (CN). − MS (GCMS); *m/z* (%): 98 (1) $[M^+ - 1]$, 97 (82), 81 (9), 55 (100).

From 1,4-Bis(triphenylphosphoranylidene)-1,4-diphenylbutane-2,3-dione (21): A yellow mixture of crystals and oil which was shown to contain **24** (quantitative yield) − data as above − and a mixture of benzonitrile (42 mg, 10%) and an isomer of nitrobenzonitrile (88 mg, 15%). − IR (CH_2Cl_2): $\tilde{\nu} = 2250$ cm^{-1} (CN). Benzonitrile: − MS (GCMS); *m/z* (%): 103 (100) $[M^+]$, 76 (44). − Nitrobenzonitrile: − MS (GCMS); *m/z* (%): 148 (27) $[M - H^+]$, 122 (4), 102 (100), 90 (25), 75 (42).

From 2,5-Bis(triphenylphosphoranylidene)-1,6-diphenylhexane-1,3,4,6-tetraone (22): A yellow mixture which contained **24** (quantitative yield) − data as above − and a mixture of benzoyl cyanide (79 mg, 15%) and benzoic acid (49 mg, 10%) − data as for products from **15** and **18**, respectively.

From Diethyl 2,5-Bis(triphenylphosphoranylidene)hexane-3,4-dione-1,6-dioate (23): A yellow mixture of crystals and oil which contained **24** (quantitative yield) − data as above− and an unidentified ethyl-containing material. − ^1H NMR: $\delta = 4.38$ (q, $J = 7$ Hz, 2 H), 1.39 (t, $J = 7$ Hz, 3 H).

Authentic Preparation of Adducts

1:1 Adduct of Ph_3PO with Nitric acid (24): Concentrated nitric acid (0.20 cm^3, 3.6 mmol) was added in one portion to a solution of triphenylphosphane oxide (0.5 g, 1.8 mmol) in CH_2Cl_2 and the mixture stirred vigorously for 10 min, then diluted with CH_2Cl_2 (20 cm^3). The mixture was dried and the solvent evaporated to give the title compound (0.55 g, 90%), m.p. 80−82°C. − IR (Nujol): $\tilde{\nu} = 3400$ cm^{-1}, 1625, 1420. − ^1H NMR: $\delta = 13.25$ (br s, 1 H, OH), 7.81−7.26 (m, 15 H, Ph). − ^{13}C NMR: $\delta = 133.2$ (d, $J = 3$ Hz, 3× C-4 of Ph), 132.2 (d, $J = 11$ Hz, 6× C-2 of Ph), 129.0 (d, $J = 13$ Hz, 6× C-3 of Ph), 128.9 (d, $J = 108$ Hz, 3× C-1 of Ph). − ^{31}P NMR: $\delta = +36.9$. − $C_{18}H_{16}NO_4P$ (341.3): calcd. C 63.34, H 4.73, N 4.10; found C 63.31, H 4.63, N, 4.08.

2:1 Adduct of Ph_3PO with Nitric Acid (25): Reaction as above using triphenylphosphane oxide (0.5 g, 1.8 mmol) and nitric acid (0.05 cm^3, 0.90 mmol) gave $[Ph_3PO]_2.HNO_3$ (0.47 g, 85%) as waxy yellow crystals, m.p. 68−70°C. − IR (Nujol): $\tilde{\nu} = 1620$ cm^{-1}, 1440. − ^1H NMR: $\delta = 13.34$ (br s, 1 H, OH), 7.82−7.27 (m, 30 H, Ph). − ^{13}C NMR: $\delta = 132.5$ (d, $J = 3$ Hz, 6× C-4 of Ph), 132.1 (d, $J = 10$ Hz, 12× C-2 of Ph), 130.8 (d, $J = 106$ Hz, 6× C-1 of Ph), 128.7 (d, $J = 12$ Hz, 12× C-3 of Ph). − ^{31}P NMR: $\delta = +32.1$. − $C_{36}H_{31}NO_5P_2$ (619.6): calcd. C 69.78, H 5.05, N 2.26; found C 68.36, H 4.72, N 2.43.

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[1] Review; A. W. Johnson, *Ylides and Imines of Phosphorus*, Wiley, Chichester, **1993**, p. 133.
[2] F. Ramirez, R. B. Mitra, N. B. Desai, *J. Am. Chem. Soc.* **1960**, *82*, 5763−5764.
[3] D. B. Denney, L. C. Smith, J. Song, C. J. Rossi, C. D. Hall, *J. Org. Chem.* **1963**, *28*, 778−780.
[4] D. B. Denney, T. M. Valega, *J. Org. Chem.* **1964**, *29*, 440−442.
[5] [5a] E. Zbiral, E. Werner, *Tetrahedron Lett.* **1966**, 2001−2004. − [5b] E. Zbiral, E. Werner, *Monatsh. Chem.* **1966**, *97*, 1797−1820.
[6] [6a] E. Zbiral, M. Rasberger, *Tetrahedron* **1968**, *24*, 2419−2423. − [6b] R. A. Aitken, J. I. G. Cadogan, I. Gosney, *Phosphorus, Sulfur, and Silicon*, **1995**, *101*, 281−286.
[7] H. J. Bestmann, R. Armsen, H. Wagner, *Chem. Ber.* **1969**, *102*, 2259−2269.
[8] H. J. Bestmann, K. Kumar, L. Kisielowski, *Chem. Ber.* **1983**, *116*, 2378−2382.
[9] F. A. Davis, B.-C. Chen, *J. Org. Chem.* **1990**, *55*, 360−363.
[10] H. H. Wasserman, V. M. Rotello, D. R. Williams, J. W. Benbow, *J. Org. Chem.* **1989**, *54*, 2785−2786.
[11] H. H. Wasserman, C. B. Vu, *Tetrahedron Lett.* **1990**, *31*, 5205−5208.
[12] H. H. Wasserman, C. M. Baldino, S. J. Coats, *J. Org. Chem.* **1995**, *60*, 8231−8235.
[13] E. Zbiral, L. Fenz, *Monatsh. Chem.* **1965**, *96*, 1983−1999.
[14] H. J. Bestmann, W. Kamberger, T. Röder, R. Zimmermann, *Liebigs Ann.*. **1996**, 845−851.
[15] [15a] D. Hadzi, *J. Chem. Soc.* **1962**, 5128−5138. − [15b] D. Hadzi, N. Kobilarov, *J. Chem. Soc. (A)* **1966**, 439−445.
[16] H. J. Bestmann, B. Arnason, *Chem. Ber.* **1962**, *95*, 1513−1527.
[17] P. A. Chopard, R. J. G. Searle, F. H. Devitt, *J. Org. Chem.* **1965**, *30*, 1015−1019.
[18] R. A. Aitken, H. Hérion, A. Janosi, N. Karodia, S. V. Raut, S. Seth, I. J. Shannon, F. C. Smith, *J. Chem. Soc., Perkin Trans. 1* **1994**, 2467−2472.
[19] R. A. Aitken, H. Hérion, C. E. R. Horsburgh, N. Karodia, S. Seth, *J. Chem. Soc., Perkin Trans. 1* **1996**, 485−489.
[20] P. Cohn, P. Friedländer, *Ber. Dtsch. Chem. Ges.* **1902**, *35*, 1265−1267.

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