Reactivity of 1,2-Dihydrophosphetes: Formation and Structural Characterization of a Formal [4 + 2] Cycloadduct

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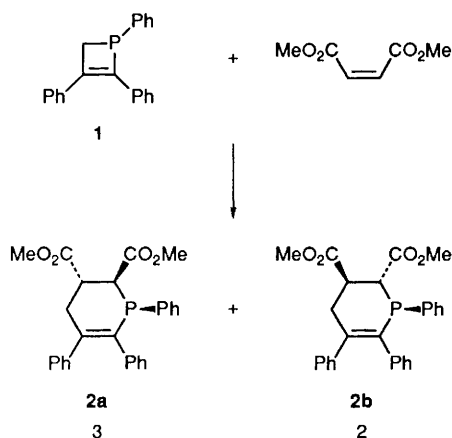
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Dihydrophosphetes (phosphacyclobutenes) react with Michael acceptors to form cycloadducts, apparently through the intermediacy of zwitterionic species.

Thermal and photochemical ring opening of heterocyclobutenes to heterobutadienes is well-known.[1]. Sila-[2] and aza-butadienes,[3] for example, have been prepared in this way. Cycloadditions of the heterobutadienes provide access to a number of interesting heterocyclic ring systems. In contrast to the considerable body of synthetic work with azabutadienes which has appeared,[4] synthetic applications of the corresponding phosphacyclobutenes or phosphabutadienes[5] have scarcely been examined.[5c] We report herein out preliminary observations regarding the reactions of phosphacyclobutenes with Michael acceptor dienophiles. In contrast to reactions of the aza analogues,[3] these reactions do not appear to proceed *via* concerted cycloadditions to ring-opened phosphabutadienes.

Dihydrophosphete[6] **1** reacts with dimethyl maleate (1 equiv. in C_6D_6 at 110 °C for 14 h) to produce a mixture of diastereoisomeric cycloadducts. Isomer **2b** (apparently resulting from the least hindered approach of the phosphorus atom to the alkene) appears to be the kinetic product, being favoured in the earlier stages of the reaction, while isomer **2a** appears to be the thermodynamic product. Silica chromatography (65% diethyl ether–35% pentane) gives the purified cycloadducts in 34% combined yield. Recrystallization by vapour diffusion from toluene–heptane affords colourless plates of the major isomer **2a**. ^{1}H NMR spectral analysis, including 2D COSY and NOESY studies and analysis of [31]P–[1]H coupling constants, suggested the stereochemistry depicted; this was subsequently confirmed by X-ray crystallographic analysis (Fig. 1).[†] The phosphacyclohexene ring

shows a puckering at C(6) due to the small C(6)–P(1)–C(2) bond angle. Both the C=C bond length (1.359 Å) and the phosphorus–sp³-carbon bond length (1.881 Å) are almost identical to those found in the parent compound **1** (1.336 Å and 1.886 Å, respectively). As in **1**, the *P*-phenyl ring is bent well out of the plane of the ring, minimizing its steric interactions with the ester groups.

Both isomers contain *trans* ester groups, suggesting a non-concerted pathway for the cycloaddition [equation (1)]. This is supported by the fact that formation of cycloadducts is faster in [²H₆]-acetone than in [²H₆]-benzene, suggesting charged (zwitterionic) intermediates are formed.‡ Formation of the same 3:2 mixture of diastereoisomers from dimethyl fumarate also supports this suggestion.‡ However, dimethyl maleate is isomerized to dimethyl fumarate under the reaction conditions, presumably through Michael addition of the dihydrophosphete to maleate, followed by C–C bond rotation and loss of the dihydrophosphete. Thus, mechanisms involving concerted cycloaddition to an intermediate phosphabutadiene should not be excluded. (Since electrocyclic ring opening to the phosphabutadiene, which does not involve formation of charged species, might be expected to be rate limiting, our observation of a solvent dependence of reaction rate may argue against such a mechanism.) Interestingly, reported reactions of phospholes and tungsten-coordinated

1

2a   **2b**

3   **2**

(1)

3   **4**
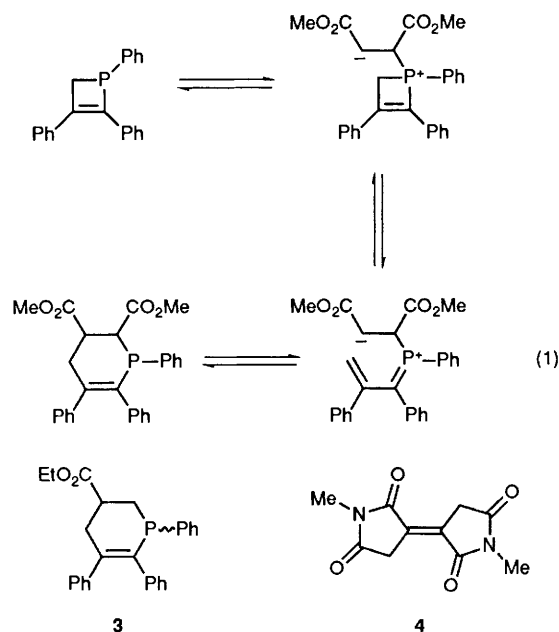
‡ The solvent polarity effect would appear to rule against single electron transfer mechanisms. However, such possibilities are not rigorously excluded. Ghosez[7] reports similar stereochemical results in reactions of fumarate and maleate with an azabutadiene, without discussion of whether loss of stereochemistry occurs before or during the presumed cycloaddition step.
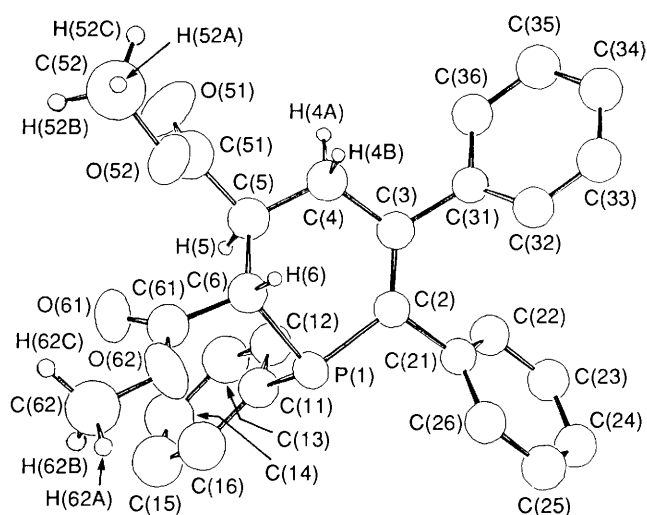
Fig. 1. Molecular structure of cycloaddition product 2a. Selected bond lengths (Å): P(1)–C(2), 1.829(5); C(2)–C(3), 1.359(7); C(3)–C(4), 1.513(7); C(4)–C(5), 1.520(7); C(5)–C(6), 1.525(8); C(6)–P(1), 1.881(6); P(1)–C(11), 1.826(4); C(2)–C(21), 1.508(6); C(3)–C(31), 1.511(6); C(5)–C(51), 1.525(9); C(6)–C(61), 1.495(8). Selected bond angles (°): C(6)–P(1)–C(2), 99.8(2); P(1)–C(2)–C(3), 124.0(4); C(2)–C(3)–C(4), 124.3(5); C(3)–C(4)–C(5), 116.3(5); C(4)–C(5)–C(6), 110.1(4); C(5)–C(6)–P(1), 110.4(4); P(1)–C(2)–C(21), 112.6(3); C(21)–C(2)–C(3), 123.3(4); C(2)–C(3)–C(31), 123.1(4); C(31)–C(3)–C(4), 112.5(4); C(4)–C(5)–C(51), 106.1(5); C(51)–C(5)–C(6), 118.2(5); C(5)–C(6)–C(61), 113.3(5); C(61)–C(6)–P(1), 109.5(4); C(6)–P(1)–C(11), 101.4(2); C(11)–P(1)–C(2), 103.2(2).

dihydrophosphetes with dienophiles do appear to be concerted cycloadditions.[5c,h,i]

Consistent with intermediate formation of a Michael adduct, ethyl acrylate reacts with dihydrophosphete 1 to give a single regioisomer 3, with the ester group β to the phosphorus. (Two diastereoisomers are formed, in a ca. 85:15 ratio. Assignment of relative stereochemistry has not yet proved possible.) The reaction is much slower (reaction time: 130 h at 110°C) with this poorer Michael acceptor than that with maleate, and the (unoptimized) yield is low (~15–20% isolated yield).

Benzaldehyde, reported to react at a reasonable rate with a tungsten-coordinated dihydrophosphete,[5c] is completely unreactive with 1; even after prolonged heating at temperatures as high as 150 °C, only slow decomposition of 1 is observed.§

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§ Heating the 1,2-dihydrophosphete alone at the same temperatures resulted in formation of the same decomposition products.

A small amount of the cycloadduct is formed with N-methylmaleimide.¶ However, the major product of this reaction is a maleimide dimer, shown by X-ray crystallographic analysis to have structure 4, (and small amounts of a trimer).[8,9]

We are continuing to examine the reactivity of 1 and related dihydrophosphetes with dienophiles and Michael acceptors, and have begun an examination of the effects of metal coordination on the reactivity of these systems.

References

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¶ The dimerization uses up 0.51 equiv. of the N-methyl maleimide. The yield of cycloaddition product based on the remaining amount of maleimide (0.49 equiv.) is 16%.