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ALLYLIC REARRANGEMENT OF
 α,β -UNSATURATED KETONE-DIETHYL PHOSPHOROCYANIDATE ADDUCTS

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α,β -Unsaturated ketones react with diethyl phosphorocyanidate in the presence of lithium cyanide to give α -diethylphosphonooxy nitriles which are transformed into conjugated allylic phosphates via a novel boron trifluoride etherate-catalyzed allylic rearrangement.

KEYWORDS — diethyl phosphorocyanidate; lithium cyanide; cyano-phosphate; α,β -unsaturated ketone; boron trifluoride etherate; allylic rearrangement

We recently reported that the *p*-benzoquinone-diethyl phosphorocyanidate [DEPC, $(\text{EtO})_2\text{P}(\text{O})\text{CN}$] adduct, a product of 1,2-addition to enone, was an effective intermediate for the synthesis of some 3-aryl-4-hydroxybenzonitriles.¹⁾ Selective 1,2-addition to enones has also been reported with cyanotrimethylsilane by Evans and co-workers.²⁾ Conjugate hydrocyanation of α,β -unsaturated carbonyl compounds as a powerful tool in organic synthesis has been extensively studied.^{3,4,5)} This paper describes a 1,2-addition of DEPC to α,β -unsaturated ketone (A) and a novel boron trifluoride (BF_3) etherate-catalyzed rearrangement of the resulting allylic phosphate B to the isomer C.

Bartlett and co-worker have demonstrated the bis(acetonitrile)palladium(II)-chloride-catalyzed rearrangement of allylic phosphate in the synthesis of 3-phosphoshikimic acid.⁶⁾ However, this rearrangement requires long reaction times up to 7 days at room temperature.

To a solution of DEPC (90 mmol, 14.67 g) and lithium cyanide (LiCN) (90 mmol, 2.97 g) in 45 ml of THF was added 2-cyclohexen-1-one (1a, 30 mmol, 2.88 g) at room temperature. The mixture was stirred for 5 min, then the THF was removed by evaporation. The residue was partitioned between water (20 ml) and benzene-ethyl acetate (70 ml). The organic layer was separated, washed (water, brine), dried (Na_2SO_4), and concentrated. The resulting 1,2-adduct 2a was stirred with BF_3 etherate (3 mmol, 426 mg) in 45 ml of benzene at room temperature for 2 h. After the addition of benzene (50 ml), the reaction mixture was washed (water, brine), dried (Na_2SO_4), and concentrated. Column chromatography of the residue afforded 6.30 g (81%) of 1-cyano-3-diethylphosphonooxy-1-cyclohexene (3a).⁷⁾ When a solution of 2a

in benzene was refluxed without BF_3 etherate, 3a was obtained in 48% yield, thus indicating the effectiveness of BF_3 etherate as a catalyst for the allylic rearrangement. In contrast to the behavior of 1a, 2-cyclopenten-1-one (1b) has been found to react with DEPC-LiCN at room temperature to yield the enol phosphate (4)⁸⁾ in 74% yield. But at -17°C the reaction afforded the 1,2-adduct 2b which was readily converted to 3b in 64% overall yield. Of the stereochemical interest, the 1,2-adduct 6 was derived from 4-*t*-butyl-2-cyclohexen-1-one (5)⁹⁾ under the condition described above and was then transformed to 7 as a sole product by treatment with BF_3 etherate in 51% yield. The structure of 7 whose diethylphosphonoxy group is in a quasi-equatorial orientation was assigned based on the ^1H -NMR analysis.¹⁰⁾

Furthermore, cholest-4-en-3-one (8) was treated with DEPC-LiCN in THF at -10°C followed by treatment of the resulting 1,2-adduct (9)¹¹⁾ with BF_3 etherate affording the heteroannular-diene nitrile (10)¹²⁾ in 90% yield. When a solution of 9 in benzene was refluxed for 2 h without a catalyst, conjugated allylic phosphate (11, 53%)¹³⁾ and allyl alcohol (12, 17%)¹³⁾ as well as diene nitrile (10, 17%) were obtained. Treatment of 11 with BF_3 etherate gave 10 in quantitative yield, thus indicating that 11 is a precursor of 10.¹⁴⁾ Reaction of 6-methylbicyclo[4.4.0]dec-1-en-3-one (13) with DEPC-LiCN gave the 1,2-adduct 14 [^1H -NMR (CDCl_3) δ : 1.17 (3H, s, CH_3), 5.60 (1H, s, $=\text{CH}$)] as a sole product which was converted to the diene nitrile 15 by treatment with BF_3 etherate in 94% yield. Refluxing a benzene solution of 14 for 2 h without catalyst gave a mixture of 15 (50%) and 16 (46%), and the latter gave 15 in quantitative yield when treated with BF_3 . Hydrolysis of 16 with dil. hydrochloric acid-EtOH gave the allyl alcohol (17) in 21% yield together with 15 in 42% yield. The stereochemistry of 14, 16 and 17 was inferred from comparisons of the ^1H - and ^{13}C -NMR spectra of the dihydro derivative (18) of 17 with those of *cis*- and *trans*-10-methyl-9-decalol.¹⁵⁾

In summary, we have described a novel BF_3 etherate-catalyzed allylic rearrangement of α, β -unsaturated ketone cyanophosphates to produce conjugated allylic phosphates, which are useful intermediates for the synthesis of α, β ; γ, δ -unsaturated heteroannular-diene nitriles or β -cyano- α, β -unsaturated ketones.

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- 7) $\text{IR}_{\text{liq}}^{\text{max}} \text{ cm}^{-1}$: 2190 (CN), 1260, 960-1020 [$\text{P}(\text{O})(\text{OEt})_2$]. ^1H -NMR (CDCl_3) δ : 4.95 (1H, m, CHOP), 6.65 (1H, bs, $=\text{CH}$).

- 8) Compound 4 was easily differentiated from 3b by hydrolysis of 4 with dil. hydrochloric acid-EtOH to yield 3-cyanocyclopentanone.
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- 10) The multiplet [H-C-P(O)(OEt)₂, δ 4.93 ppm] changed to the double triplet ($J=7$, 7, 2.5 Hz) by irradiation at a vinyl proton.
- 11) The ¹H-NMR spectrum of 9 showed a vinyl proton at δ 5.50 ppm as a singlet. Treatment of 9 with 20% NaOH in MeOH at 0°C afforded 8 in 50% yield.
- 12) The structure was confirmed by the fact that no Diels-Alder adduct with 4-phenyl-1,2,4-triazolin-3,5-dione was formed and by UV [λ_{max} cyclohexane nm (ϵ): 262 (27,930)] spectral analysis.
- 13) The stereochemistry has not been determined yet. The ¹H-NMR spectrum showed a vinyl proton at δ 6.65 ppm in 11 and 6.63 ppm in 12 as a singlet.
- 14) Direct formation of the diene-nitrile 10 from 9 is also possible.
- 15) Catalytic hydrogenation (5% Pd-C) of 17 gave the saturated nitrile (18) whose NMR spectra showed angular methyl protons and carbon signals [¹H-NMR (CCl₄), δ 0.89 ppm; ¹³C-NMR (CDCl₃), δ 21.8 ppm] which are more comparable to the data of cis-10-methyl-9-decalol [¹H-NMR (CCl₄), δ 0.93 ppm¹⁶]; ¹³C-nmr (CDCl₃), δ 22.4 ppm¹⁷] than those of trans-isomer [¹H-NMR (CCl₄), δ 1.02 ppm¹⁶]; ¹³C-nmr (CDCl₃), δ 20.4 ppm¹⁷]. The following mechanism explains the stereochemistry of 14 in which the diethylphosphonoxy group should be quasi-equatorial.

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