Molybdenum-Mediated Deconjugation of α,β-Unsaturated Fused-Cyclopentenone Phosphonates

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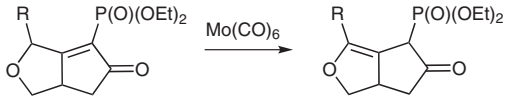
† Dedicated to the memory of Professor Srebnik

Abstract: The synthesis of diethyl (3-alkyl-5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonates from the corresponding 3-allyloxy-1-propynylphosphonates is described. The in situ reaction involves two steps: an intramolecular Pauson–Khand reaction followed by an unusual double bond deconjugation mediated by molybdenum hexacarbonyl in dimethyl sulfoxide.

Key words: double bond isomerization, molybdenum, phosphonate, Pauson–Khand reaction, deconjugation

Organophosphonate compounds possess important pharmacological activity.[1–3] Phosphonates and aminophosphonates have been found to possess chelating properties toward metals,[4] irreversible inhibition properties against serine proteases[5] and the ability to inhibit zinc-dependent enzymes of the metalloprotease family.[6–8] As part of ongoing research in our laboratory, we have reported different synthetic methods for the synthesis of novel, highly substituted vinyl phosphonate compounds from 1-alkynylphosphonates using zirconium(II) or titanium(II) reagents,[9–20] as well as the synthesis of fused-cyclopentenone phosphonates from 1-alkynylphosphonates via an intramolecular Pauson–Khand reaction[21] using molybdenum hexacarbonyl [$Mo(CO)_6$].[22]

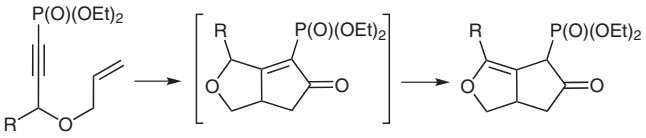
In the course of our research on fused-cyclopentenone phosphonate compounds,[21] we encountered double bond migration. This involved deconjugation from the cyclopentenone ring to the furan ring, a process that gave the double bond regioisomer of the classical Pauson–Khand reaction product (Scheme 1).



Scheme 1 Deconjugation to form β,γ-unsaturated phosphonates

A similar double bond migration in vinyl phosphonates to form allyl phosphonates is known in the literature for non-cyclic systems. According to Gerber et al.,[23] the phosphonate group has a very weak stabilizing effect on an adjacent double bond. Herein, in the isomerization reaction of α,β- to β,γ-unsaturated phosphonates, formation of the thermodynamically favored product will be determined by structural factors (such as allylic hydrogens, alkyl substituents, etc.) and not by the relative positions of the alkene bond and the phosphonate group.[23] For example, Kiddle et al. showed that vinyl phosphonates can isomerize into the corresponding allyl phosphonates by treatment with a catalytic quantity of potassium *tert*-butoxide in dimethyl sulfoxide. The basicity of the *tert*-butoxide anion in dimethyl sulfoxide plays a crucial role in the isomerization.[24] Modro et al. concluded that during the isomerization of a vinyl phosphonate into an allyl phosphonate under basic conditions, the α,β-unsaturated phosphonate was the kinetic product while the β,γ-unsaturated phosphonate was the thermodynamic product. In addition, Modro suggested that the isomerization of α,β- into β,γ-unsaturated phosphonates proceeds via an allylic carbanion intermediate.[25] The use of metal complexes under neutral conditions for double bond isomerization has also been explored.[26–31]

However, to the best of our knowledge, the deconjugation of an α,β-unsaturated enone in a fused-cyclopentenone phosphonate system into the corresponding β,γ-unsaturated ketone product has not been reported. In this paper, we explore and describe our initial results on the general one-pot synthesis of β,γ-unsaturated diethyl (3-substituted 5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonates (Scheme 2).



Scheme 2 One-pot synthesis of β,γ-unsaturated phosphonates

In the course of our research on fused-cyclopentenone phosphonates **2**,[21] we observed formation of the deconjugated double bond regioisomers **3**. Several sets of reaction conditions were examined (Table 1). We discovered that the highest yield of the desired product **3a** (R = Me) was obtained when compound **1a** (R = Me) was heated at 100 °C in toluene in the presence of two equivalents of molybdenum hexacarbonyl and 10 equivalents of dimeth-

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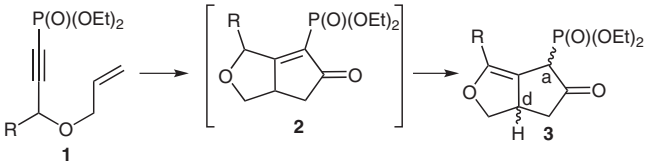
yl sulfoxide for one hour, and then incubated for three days at 70 °C after evaporation of toluene.[32] Under these conditions, complete conversion of enyne **1a** into fused cyclopentenone phosphonate **3a** and unidentified by-products was observed, and the desired product was isolated in 35% yield. It is noteworthy that the direct synthesis of **3** from intermediate **2** was also possible; however, its conversion in the presence of 1.2 equivalents of molybdenum hexacarbonyl in dimethyl sulfoxide at 70 °C was not complete even after 27 days. This may indicate that more active molybdenum–ligand [$Mo(L)_n$] species form during the conversion of **1** into **2**.

Next, the scope of the cyclization of diethyl 3-allyloxy-1-propynylphosphonates **1** into cyclopenta[*c*]furan-4-yl-phosphonates **3** was studied. The novel (3-substituted 5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonates **3a**–**h** were formed in excellent yields according to NMR spectroscopy, however, they were relatively unstable due to possible isomerization and hydrolysis, as can be expected for 3,4-dihydrofurans (Table 1). Nevertheless, the products could be isolated by silica gel column chromatography in low to moderate yields (14–35%).

The relative configurations of the products at the allylic hydrogens on carbons (a) and (d) (Table 1) was not conclusive and this aspect is still under investigation.

Table 1 Scope of the Method

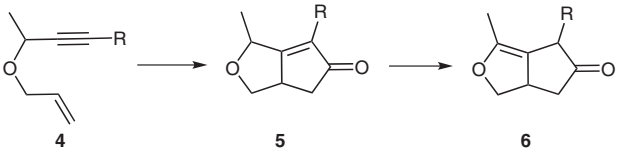


Entry	Product	R	Time (d)	Conv.[a]	Yield (%)[b]
1	**3a**	Me	3	>98	35
2	**3b**	*n*-Bu	5	>98	33
3	**3c**	*n*-C_5H_{11}	2	>98	32
4	**3d**	*n*-C_7H_{15}	2	95	28
5	**3e**	*n*-C_9H_{19}	3	95	25
6	**3f**	*n*-$C_{10}H_{21}$	2	>98	28
7	**3g**	*n*-$C_{11}H_{23}$	5	90	29
8	**3h**	Bn	5	>98	14

[a] Based on ^{31}P NMR spectroscopy.
[b] Yield of isolated product after silica gel column chromatography.

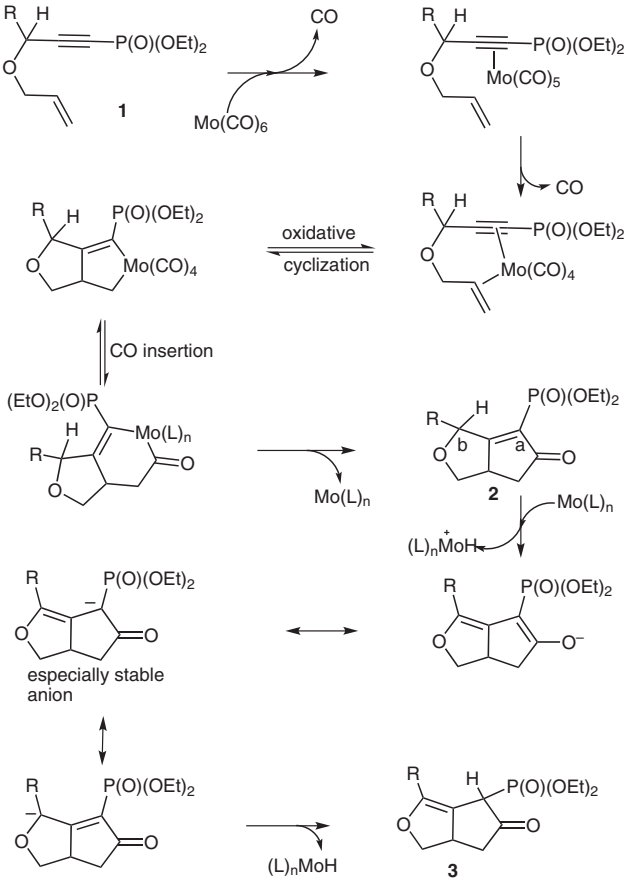
We also investigated the effect of different substituents on the triple bond of substrates **1** (Table 2). Thus compounds of type **1** bearing phenyl and carboxylic ester groups were synthesized. The reaction of the phenyl-containing enyne (Table 2, entry 1) led to the conjugated product **5a** after 27 hours at 100 °C. However, the double bond isomeric product **6a** was not observed, even after incubation for an additional nine days at 70 °C. In the case of the more electron-withdrawing carboxylate substituent (Table 2, entry 2), the Pauson–Khand product **5b** (obtained after three hours at 100 °C) isomerized into deconjugated product **6b** after three days at 70 °C (although unidentified by-products were also formed).

Table 2 Attempted Isomerization of the Double Bond with Groups Other Than Phosphonate



Entry	R	Product(s)[a]	Yield (%)[b]
1	Ph	**5a**	74
2	CO_2Et	**6b**	27
		5b	n.d.
		by-products	n.d.

[a] According to ^1H NMR spectroscopy.
[b] Isolated yield after silica gel column chromatography; n.d. = not determined.



Scheme 3 Proposed mechanism for the synthesis of **3** from **1** and $Mo(CO)_6$

Based on these findings, we propose a mechanism for the one-pot transformation which involves two stages (Scheme 3). The first stage, involving cyclization of the

enyne **1** into enone **2**, has been explained in our previous work on the molybdenum hexacarbonyl mediated intramolecular Pauson–Khand reaction of alkynylphosphonates.[21] Briefly, the first stage involves complexation between molybdenum hexacarbonyl and the alkyne and alkene sites of the starting enyne **1**, followed by oxidative cyclization and insertion of a carbonyl (CO) to yield the fused-cyclopentenone phosphonate **2**. The second stage comprises the double bond isomerization, from **2** into **3**, apparently involving formation of an anion.[28,29] The $Mo(L)_n$ complex (its exact nature under the reaction conditions is uncertain) is apparently sufficiently basic to abstract the acidic α-hydrogen creating an enolate. The formation of the anion is facilitated by the presence of the electron-withdrawing phosphonate or carboxylate group. It is thought that the most stable resonance structure is that in which the negative charge is at the allylic position, being adjacent to both the carbonyl and phosphonate groups. This stabilizes the charge through resonance and inductive effects, respectively. Finally, protonation of this intermediate leads to the observed product **3**.

To conclude, a novel synthesis of (3-substituted-5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonates **3a**–**h**, starting from diethyl 3-allyloxy-1-propynylphosphonates has been discussed. This one-pot reaction involves the creation of an intermediate Pauson–Khand reaction product, followed by isomerization of the double bond.

All reactions were carried out using anhydrous solvents. Toluene was distilled over sodium, DMSO was distilled over CaH and stored over 4 Å molecular sieves in a sealed flask. Et_2O was dried by standing over 0.4 nm molecular sieves for at least 24 h. IR spectra were recorded on a Smart iTR instrument, Nicolet iS10 (Thermo Scientific), the samples were placed directly on the diamond nicolet and data was collected in the 500–4000 cm^{-1} range; the spectra were evaluated with Omnic software. ^1H NMR (500 MHz) and ^{13}C NMR (125.7 MHz) spectra were recorded in $CDCl_3$ using a Varian Unity Inova 500-MHz spectrometer equipped with a 5 mm switchable probe. ^{31}P NMR (202.4 MHz) spectra were recorded in $CDCl_3$ using the same instrumentation and were compared to a reference solution of H_3PO_4 in D_2O. HRMS was carried out using an Orbi-trap XL (Thermo Finnigan) employing a nanospray attachment. Samples were nano-sprayed into the Orbi-trap MS system in MeCN (50%)–HCO_2H (1%) solution. The products were purified by column chromatography on 250–400 mesh silica gel. The syntheses of diethyl 3-allyloxy-1-propynylphosphonates **1** and diethyl (3-substituted-5-oxo-3,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonates **2**, and their characterization including NMR data and elemental analysis has been reported in our previous work.[21]

Diethyl (3-Methyl-5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonate (3a); Typical Procedure

To $Mo(CO)_6$ (2.639 g, 10 mmol) in anhyd toluene (20 mL) was added diethyl 3-(allyloxy)but-1-ynylphosphonate (**1a**) (1.23 g, 5 mmol) followed by anhyd DMSO (3.906 g, 50 mmol). The resulting mixture was heated at reflux temperature (100 °C) for 1 h and then the toluene was evaporated at 65 °C over 1 h on a rotary evaporator. Next, the reaction flask was stoppered with a rubber septum and the contents heated for 3 d at 70 °C. After cooling, EtOAc (50 mL) was added and the mixture filtered through silica gel eluting with EtOAc. The product was separated by silica gel column chromatography [PE (100%), Et_2O (100%), EtOAc–Et_2O gradient (1:20 to 1:1), final wash with EtOAc (100%)] to yield 0.4795 g (35%) of phosphonate **3a** as a colorless oil.

IR (neat): 2982, 2933, 1742, 1646, 1444, 1235, 1154, 1100, 1017, 970 cm^{-1}.

^1H NMR (500 MHz): 4.27 (t, J = 8.5 Hz, 1 H), 4.22–4.14 (m, 4 H), 3.79 (dd, J = 5.0 Hz, J = 8.0 Hz, 1 H), 3.21–3.15 (m, 1 H), 3.05 (d, J_{PH} = 27.0 Hz, 1 H), 2.99 (dd, J = 9.5 Hz, J = 18.5 Hz, 1 H), 2.69 (dd, J = 10.0 Hz, J = 19.0 Hz, 1 H), 2.30 (dd, J = 6.0 Hz, J = 19.0 Hz, 1 H), 1.55 (s, 3 H), 1.38 (t, J = 7.0 Hz, 3 H), 1.35 (t, J = 7.0 Hz, 3 H).

^{13}C NMR (125.7 MHz): δ = 211.3 (d, $^2J_{PC}$ = 5.0 Hz), 104.4, 104.3, 73.2, 62.8 (d, $^2J_{PC}$ = 6.4 Hz), 62.5 (d, $^2J_{PC}$ = 6.5 Hz), 51.3, 48.9 (d, $^1J_{PC}$ = 130.0 Hz), 44.0, 37.6, 25.4, 16.2 (d, $^3J_{PC}$ = 3.0 Hz).

^{31}P NMR (202.4 MHz): δ = 22.9.

HRMS (ESI, +): m/z $[M + H]^+$ calcd for $C_{12}H_{20}O_5P$: 275.10429; found: 275.10425.

Diethyl (3-Butyl-5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonate (3b)

Yield: 0.5214 g (33%); colorless oil.

IR (neat): 2957, 2872, 1744, 1649, 1468, 1231, 1156, 1096, 1016, 965 cm^{-1}.

^1H NMR (500 MHz): δ = 4.27 (t, J = 8.0 Hz, 1 H), 4.21–4.13 (m, 4 H), 3.79 (dd, J = 4.5 Hz, J = 8.0 Hz, 1 H), 3.20–3.14 (m, 1 H), 3.04 (d, J_{PH} = 24.0 Hz, 1 H), 2.70 (dd, J = 11.0 Hz, J = 19.0 Hz, 1 H), 2.30 (dd, J = 6.0 Hz, J = 19.0 Hz, 1 H), 1.77–1.74 (m, 2 H), 1.46–1.43 (m, 2 H), 1.39–1.34 (m, 8 H), 0.93 (t, J = 7.0 Hz, 3 H).

^{13}C NMR (125.7 MHz): δ = 211.3 (d, $^2J_{PC}$ = 6.0 Hz), 106.0, 105.9, 73.0, 62.9 (d, $^2J_{PC}$ = 6.0 Hz), 62.3 (d, $^2J_{PC}$ = 6.0 Hz), 49.3 (d, $^1J_{PC}$ = 130.0 Hz), 43.8, 38.7, 37.6, 25.5, 22.7, 16.1 (d, $^3J_{PC}$ = 5.0 Hz), 13.8.

^{31}P NMR (202.4 MHz): δ = 22.9.

HRMS (ESI, +): m/z $[M + H]^+$ calcd for $C_{15}H_{26}O_5P$: 317.15124; found: 317.15125.

Diethyl (5-Oxo-3-pentyl-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonate (3c)

Yield: 0.5288 g (32%); colorless oil.

IR (neat): 2931, 2872, 1745, 1650, 1444, 1232, 1153, 1095, 1020, 965 cm^{-1}.

^1H NMR (500 MHz): δ = 4.26 (t, J = 8.0 Hz, 1 H), 4.21–4.13 (m, 4 H), 3.79 (dd, J = 4.0 Hz, J = 8.0 Hz, 1 H), 3.22–3.14 (m, 1 H), 3.04 (d, J_{PH} = 24.0 Hz, 1 H), 2.69 (dd, J = 11.0 Hz, J = 19.0 Hz, 1 H), 2.30 (dd, J = 5.0 Hz, J = 19.0 Hz, 1 H), 1.76–1.73 (m, 2 H), 1.49–1.48 (m, 2 H), 1.38–1.30 (m, 10 H), 0.90 (t, J = 7.0 Hz, 3 H).

^{13}C NMR (125.7 MHz): δ = 211.2 (d, $^2J_{PC}$ = 4.0 Hz), 105.8, 105.7, 72.8, 62.8 (d, $^2J_{PC}$ = 6.0 Hz), 62.1 (d, $^2J_{PC}$ = 6.0 Hz), 49.1 (d, $^1J_{PC}$ = 130.0 Hz), 43.7, 38.7, 37.5, 31.7, 23.0, 22.2, 16.0 (d, $^3J_{PC}$ = 5.0 Hz), 13.7.

^{31}P NMR (202.4 MHz): δ = 23.0.

HRMS (ESI, +): m/z $[M + H]^+$ calcd for $C_{16}H_{28}O_5P$: 331.16689; found: 331.16687.

Diethyl (3-Heptyl-5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonate (3d)

Yield: 0.5014 g (28%); colorless oil.

IR (neat): 2926, 2855, 1745, 1650, 1457, 1234, 1158, 1095, 1018, 969 cm^{-1}.

^1H NMR (500 MHz): δ = 4.26 (t, J = 8.0 Hz, 1 H), 4.20–4.14 (m, 4 H), 3.79 (dd, J = 4.5 Hz, J = 8.0 Hz, 1 H), 3.22–3.14 (m, 1 H), 3.04

(d, J_{PH} = 25.0 Hz, 1 H), 2.69 (dd, J = 11.0 Hz, J = 18.0 Hz, 1 H), 2.30 (dd, J = 6.0 Hz, J = 19.0 Hz, 1 H), 1.76–1.73 (m, 2 H), 1.48–1.42 (m, 2 H), 1.37–1.27 (m, 14 H), 0.89 (t, J = 7.0 Hz, 3 H).

^{13}C NMR (125.7 MHz): δ = 211.2 (d, $^{2}J_{PC}$ = 4.0 Hz), 105.9, 105.8, 73.0, 62.8 (d, $^{2}J_{PC}$ = 6.0 Hz), 62.2 (d, $^{2}J_{PC}$ = 6.0 Hz), 49.2 (d, $^{1}J_{PC}$ = 130.0 Hz), 43.8, 38.9, 37.6, 31.5, 29.6, 29.0, 23.4, 22.4, 16.1 (d, $^{3}J_{PC}$ = 5.0 Hz), 13.9.

^{31}P NMR (202.4 MHz): δ = 22.9.

HRMS (ESI, +): m/z [M + H]$^+$ calcd for $C_{18}H_{32}O_5P$: 359.19819; found: 359.19818.

Diethyl (3-Nonyl-5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonate (3e)
Yield: 0.4826 g (25%); colorless oil.

IR (neat): 2923, 2853, 1745, 1649, 1466, 1232, 1161, 1095, 1016, 968 cm^{-1}.

^{1}H NMR (500 MHz): δ = 4.24 (t, J = 9.0 Hz, 1 H), 4.19–4.11 (m, 4 H), 3.77 (dd, J = 4.0 Hz, J = 8.0 Hz, 1 H), 3.20–3.11 (m, 1 H), 3.03 (d, J_{PH} = 25.0 Hz, 1 H), 2.67 (dd, J = 10.0 Hz, J = 19.0 Hz, 1 H), 2.28 (dd, J = 7.0 Hz, J = 19.0 Hz, 1 H), 1.74–1.71 (m, 2 H), 1.47–1.39 (m, 2 H), 1.38–1.19 (m, 18 H), 0.87 (t, J = 7.0 Hz, 3 H).

^{13}C NMR (125.7 MHz): δ = 211.0 (d, $^{2}J_{PC}$ = 4.0 Hz), 106.1, 106.0, 73.2, 62.9 (d, $^{2}J_{PC}$ = 6.0 Hz), 62.4 (d, $^{2}J_{PC}$ = 6.0 Hz), 49.4 (d, $^{1}J_{PC}$ = 129.0 Hz), 43.9, 39.2, 37.7, 31.8, 29.7, 29.4, 29.2, 23.5, 22.5, 16.2 (d, $^{3}J_{PC}$ = 5.0 Hz), 13.9.

^{31}P NMR (202.4 MHz): δ = 23.0.

HRMS (ESI, +): m/z [M + H]$^+$ calcd for $C_{20}H_{36}O_5P$: 387.22949; found: 387.22952.

Diethyl (3-Decyl-5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonate (3f)
Yield: 0.5601 g (28%); colorless oil.

IR (neat): 2923, 2853, 1746, 1647, 1457, 1257, 1160, 1097, 1017, 972 cm^{-1}.

^{1}H NMR (500 MHz): δ = 4.24 (t, J = 8.5 Hz, 1 H), 4.20–4.11 (m, 4 H), 3.77 (dd, J = 4.0 Hz, J = 8.0 Hz, 1 H), 3.20–3.11 (m, 1 H), 3.03 (d, J_{PH} = 25.0 Hz, 1 H), 2.68 (dd, J = 10.0 Hz, J = 18.0 Hz, 1 H), 2.29 (dd, J = 6.0 Hz, J = 19.0 Hz, 1 H), 1.75–1.71 (m, 2 H), 1.45–1.40 (m, 2 H), 1.37–1.22 (m, 20 H), 0.88 (t, J = 7.0 Hz, 3 H).

^{13}C NMR (125.7 MHz): δ = 211.1 (d, $^{2}J_{PC}$ = 5.0 Hz), 106.1, 106.0, 73.2, 62.9 (d, $^{2}J_{PC}$ = 6.0 Hz), 62.4 (d, $^{2}J_{PC}$ = 6.0 Hz), 49.4 (d, $^{1}J_{PC}$ = 130.0 Hz), 43.9, 39.2, 37.7, 31.8, 29.54, 29.51, 29.48, 29.40, 29.2, 23.5, 22.6, 16.2 (d, $^{3}J_{PC}$ = 3.0 Hz), 14.0.

^{31}P NMR (202.4 MHz): δ = 22.9.

HRMS (ESI, +): m/z [M + H]$^+$ calcd for $C_{21}H_{38}O_5P$: 401.24514; found: 401.24518.

Diethyl (5-Oxo-3-undecyl-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonate (3g)
Yield: 0.6011 g (29%); colorless oil.

IR (neat): 2922, 2852, 1746, 1649, 1466, 1232, 1160, 1096, 1018, 969 cm^{-1}.

^{1}H NMR (500 MHz): δ = 4.27 (t, J = 8.0 Hz, 1 H), 4.21–4.14 (m, 4 H), 3.79 (dd, J = 4.0 Hz, J = 8.0 Hz, 1 H), 3.22–3.13 (m, 1 H), 3.04 (d, J_{PH} = 24.0 Hz, 1 H), 2.70 (dd, J = 11.0 Hz, J = 19.0 Hz, 1 H), 2.30 (dd, J = 6.0 Hz, J = 19.0 Hz, 1 H), 1.76–1.73 (m, 2 H), 1.48–1.42 (m, 2 H), 1.38–1.23 (m, 22 H), 0.89 (t, J = 7.0 Hz, 3 H).

^{13}C NMR (125.7 MHz): δ = 211.3 (d, $^{2}J_{PC}$ = 4.0 Hz), 106.0, 105.9, 73.0, 62.9 (d, $^{2}J_{PC}$ = 6.0 Hz), 62.3 (d, $^{2}J_{PC}$ = 6.0 Hz), 49.3 (d, $^{1}J_{PC}$ = 129.0 Hz), 43.8, 39.0, 37.6, 31.7, 29.7, 29.5, 29.4, 29.1, 23.5, 22.5, 16.1 (d, $^{3}J_{PC}$ = 5.0 Hz), 13.9.

^{31}P NMR (202.4 MHz): δ = 22.9.

HRMS (ESI, +): m/z [M + H]$^+$ calcd for $C_{22}H_{40}O_5P$: 415.26079; found: 415.26077.

Diethyl (3-Benzyl-5-oxo-4,5,6,6a-tetrahydro-1*H*-cyclopenta[*c*]furan-4-yl)phosphonate (3h)
Yield: 0.2461 g (14%); colorless oil.

IR (neat): 2922, 2851, 1727, 1647, 1601, 1453, 1239, 1144, 1022, 965 cm^{-1}.

^{1}H NMR (500 MHz): δ = 7.33–7.24 (m, 5 H), 4.24 (t, J = 8.0 Hz, 1 H), 4.14–4.01 (m, 4 H), 3.61 (dd, J = 3.5 Hz, J = 9.0 Hz, 1 H), 3.30 (s, 2 H), 3.10–2.99 (m, 2 H), 2.64 (dd, J = 10.0 Hz, J_{PH} = 20.0 Hz, 1 H), 2.15 (dd, J = 6.0 Hz, J = 18.0 Hz, 1 H), 1.34 (t, J = 7.0 Hz, 3 H), 1.30 (t, J = 7.0 Hz, 3 H).

^{31}P NMR (202.4 MHz): δ = 22.9.

Supporting Information

Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synthesis.

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