Efficient Syntheses of (α-Fluoropropargyl)phosphonate Esters

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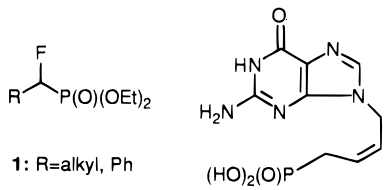
The utilization of a phosphonate group as a phosphate mimic in biological systems is a well-established strategy[1] that has been enhanced by fluorine substitution on the α-carbon of phosphonates.[2] Fluorine increases the effectiveness of phosphate mimetics due to the isosteric and isoelectronic character of the resulting fluoromethylenephosphonate derivative, *viz. a viz.* the parent phosphate. The importance of fluorine substitution in phosphonates has been underscored by numerous reported syntheses of α-fluoroalkanephosphonates **1**, the majority of which utilized the diethyl ester of (fluoromethylene)phosphonate-($^+$M$^-$CHF−P(O)(OEt)$_2$) as a fluorine-containing synthon.[3] Notable exceptions are the synthesis of α-fluoroalkanephosphonates via electrophilic fluorination,[4] and (diethylamidosulfur trifluoride (DAST) promoted replacement of (α-hydroxybenzyl)phosphonates.[5] Recently, the discovery of antiviral and antitumor activity in certain cyclic and acyclic unsaturated phosphonate derivatives such as **2**[6] has sparked interest in the synthesis of *β,γ*-unsaturated alkenephosphonates. It is plausible to speculate that α-fluorine substitution may render unsaturated phosphonate analogues with enhanced biological activity. However, in clear contrast to the many syntheses of **1**, there is no literature precedence for the preparation of *β,γ*-unsaturated α-fluoro phosphonate esters (e.g., **3** or **4**). The nucleophilic nature of $^-$CH(F)P(O)(OEt)$_2$ precludes its general use in coupling reactions with sp^2 or sp carbons. Clearly, there is a need for a new fluorinated molecular building block for the introduction of fluorine on the α-carbon of *β,γ*-unsaturated phosphonates. We postulated that α-fluoroalkynephosphonate **3** could fill this gap by serving not only as a convenient starting material for the preparation of more complex α-fluoro phosphonates but also as a fluorinated scaffold for the synthesis of fluorine-containing organic molecules. For example, the alkyne platform in **3** can be considered a masked alkene or ketone, and the phosphonate group on the α-carbon could help stabilize the generation of a carbanion from **3** for use in condensation, addition, or alkylation reactions.



In a preliminary communication,[7] we reported the first preparation of **3** (R^1 = Me, R^2 = H, R^3 = Et) via regiospecific fluorination of the corresponding α-hydroxy phosphonate **7**. By using a propargylic moiety, we avoided the rearrangement associated with fluorination of allylic alcohols using DAST.[5] In line with our objectives regarding the use of **3** as a fluorinated synthon, we showed that partial hydrogenation of the triple bond in **3** yielded the hitherto unknown fluoroalkenephosphonate **4**. We now report an improved preparation of α-fluoroalkynephosphonates that can accommodate various alkynes and phosphorus substrates. In addition, a new example that previews the synthetic potential of α-fluoroalkynephosphonates as an effective fluorine-containing synthon will be presented.

Results and Discussion

If α-fluoroalkynephosphonate **3** was to be considered a fluorinated synthon, then a short and high yield synthesis of it must be available. The two most important steps in the synthesis of **3** are the introduction of the phosphonate group and of the fluorine atom. Our initial approach to the introduction of the phosphonate group relied on a base-promoted 1,2 O to C phosphorus migration[8] of propargylic phosphate **6** to yield **7** (Scheme 1). Phosphate **6** could be easily obtained by phosphorylation of readily available alkynol **5** using an electrophilic phosphorus reagent such as diethyl chlorophosphate. We accomplished this task in one vessel without isolating the

† Henry Dreyfus Teacher−Scholar 1996.

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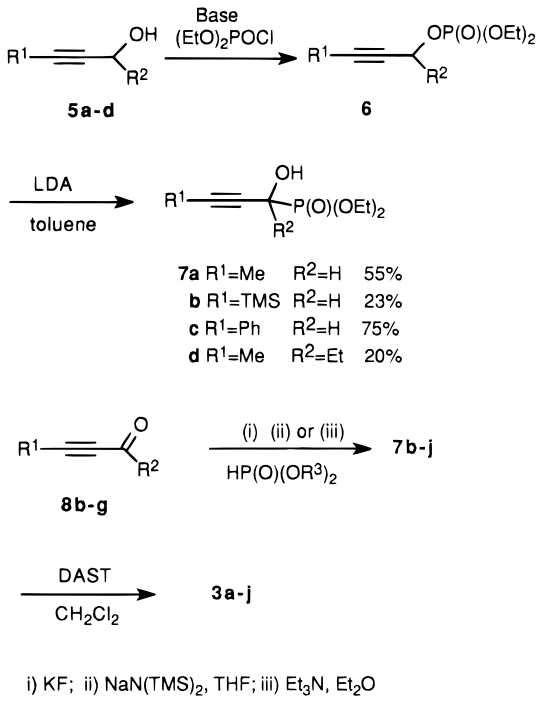
Scheme 1



intermediate **6**. Accordingly, the starting alkynol was phosphorylated using LDA in toluene at −50 °C; the resulting propargylphosphate, in the presence of excess LDA, rearranged to give the desired hydroxyalkynephosphonate **7** after mild acid workup. The efficiency of this rearrangement depended on the substrate used. Yields ranged from 20 to 75%. Secondary alkynol **5d** gave the lowest yield. Attempts to introduce other substituents on the phosphorus terminus were unsuccessful. For example, using diphenyl chlorophosphate, phosphate **6k** produced only phenol (81% yield) after being treated with excess LDA. A competitive O to aryl C migration of phosphorus, with precedence in the literature,[9] could help to explain this experimental result. Using bis(2,2,2-trichloroethyl) chlorophosphate and alkynol **5a**, the phosphate−phosphonate protocol led to an intractable mixture. We speculated that the increased electrophilicity of phosphorus, arising from the electron-withdrawing effect of the two trichloroethyl groups, might have promoted an initial nucleophilic attack by LDA on the phosphorus atom rather than the expected deprotonation on the α-carbon.

The moderate yields and competitive side reactions observed using the phosphate to phosphonate rearrangement led us to seek an alternate preparation of α-hydroxy phosphonate **7**. We decided to reverse the polarity of the phosphorus-containing reagent, and selected for this task a well-known base-catalyzed addition of nucleophilic phosphites to carbonyl substrates known as the Pudovik reaction.[10] With α,β-unsaturated carbonyl compounds and alkoxide bases, this reaction is known to give a mixture of products corresponding to 1,4 or 1,2 addition of phosphite.[11] In our case, we found exclusive 1,2 addition of phosphite to propargyl aldehydes and ketones **8 b**−**g** in the presence of neat $KF{\cdot}2H_2O$.[12] With aliphatic

Table 1. Preparation of α-Hydroxy Phosphonates 7a−j and α-Fluoro Phosphonates 3a−j

				% yield[a]	
entry	R^1	R^2	R^3	**7**	**3**
a	Me	H	Et	55[b]	85
b	TMS	H	Et	74	80
c	Ph	H	Et	73	94
d	Me	Et	Et	78	67[c]
e	Et	Me	Et	76	86[d]
f	Ph	Me	Et	73	91
g	n-C_5H_{11}	H	Et	83	94
h	Ph	H	Bu	83	89
i	Ph	H	$CH_2CH(Et)C_4H_9$	77	79
j	n-C_5H_{11}	H	$CH_2CH(Et)C_4H_9$	74	76

[a] Isolated yield. [b] Obtained via phosphate−phosphonate Methodology. [c] Based on ^{31}P NMR. [d] Based on ^{19}F NMR.

alkynyl ketones **8d,e**, the reaction did not go to completion, even after being stirred for several days; in these cases, replacement of $KF{\cdot}2H_2O$ with $NaN(TMS)_2$ in THF led to complete reactions in 1−3 h. When R^1 = TMS (**8b**), use of potassium fluoride led to desilylation. This problem was circumvented by substituting diethylamine in ether.[13] Overall, the phosphite addition was much more efficient than the phosphate−phosphonate protocol, with isolated yields ranging from 73 to 83% (Table 1). No traces of a 1,4 addition product could be detected. The reaction was very easy to carry out, and it could be scaled up to molar amounts. α-Hydroxy phosphonates were stable at room temperature but thermally labile, yielding, in some cases (e.g., **7c** and **7f**), peaks in the GC-MS spectra that corresponded to triethyl phosphate and the starting aldehyde. α-Hydroxy phosphonate **7** suffered gradual decomposition in silica or alumina chromatography, and in some cases (e.g., **7e,h**−**j**) the degradation was extensive. To our satisfaction, the phosphite addition route yielded crystallizable solids[14] or essentially pure oils that could be fluorinated directly.

With an efficient synthesis of α-hydroxy phosphonate **7** in hand, we investigated the optimum conditions needed for regiospecific fluorination and found that, at low temperatures, use of DAST in CH_2Cl_2 led to the exclusive formation of the desired α-fluoro phosphonate **3** in very good yields. Only in the case of α-fluoro phosphonates **3d,e** were moderate yields obtained. We attributed this outcome to the existence of two competing processes, the dehydration of tertiary alcohols, yielding a phosphonate enyne[15] (<10%), and possibly a S_N2' fluorination through a fluoroallene intermediate, as evidenced from ^{31}P and ^{19}F NMR.[16] Contrary to our experience with α-hydroxy phosphonate **7**, we found that fluoro phosphonates **3a**−**j** were thermally stable com-

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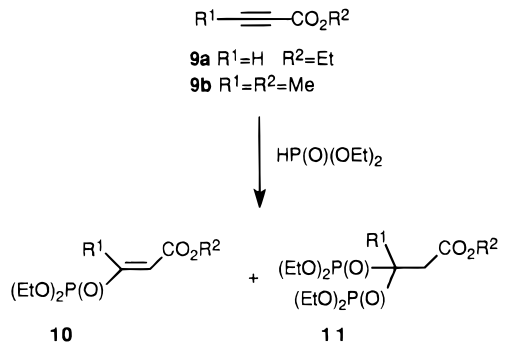
(15) 4-(Diethoxyphosphinyl)-2-hexyn-4-ene: 8% by ^{31}P NMR; ^1H NMR δ 6.99 (dq, J = 20.0, 6.7); ^{31}P NMR δ 16.0 (s); EIMS 216 (M^+, 39), 188 (18), 160 (54), 141 (20), 106 (12), 91 (24), 81 (45), 79 (60), 78 (100), 77 (91).
(16) It has been shown that allenes can be formed from alkynes in the presence of a nucleophile when there is a good leaving group on the carbon α to an alkyne (see: Taylor, D. R. *Chem. Rev.* **1967**, *67*, 317−59). In addition, bimolecular nucleophilic substitution reactions in α,β-unsaturated systems which possess significant steric hindrance at the reactive site undergo nucleophilic attack at C3 rather than C1. Comparison of the small ^{19}F and ^{31}P NMR coupling constants in the crude product mixture suggest the occurrence of γ-fluoro substitution: ^{31}P NMR δ 13.3 (d, J = 4); ^{19}F NMR δ −132 (d, J = 3); and ^{31}P NMR δ 13.5 (d, J = 3); ^{19}F NMR δ −138 (d, J = 3).

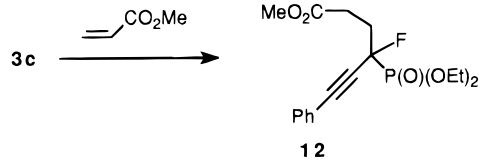
Scheme 2



pounds and moderately sensitive to silica gel chromatography.

We decided to apply the newly found reaction conditions to the synthesis of α-keto phosphonates, using for this purpose, an α,*β*-conjugated ester (**9**) and diethyl phosphite. If this approach succeeded, fluorination of the resulting α-keto phosphonate could yield the corresponding (α,α-difluoropropargyl)phosphonate in only two steps from propargyl esters. Disappointingly, we found that no reaction took place between propargylic esters **9a,b** and diethyl phosphite in the presence of $KF{\cdot}2H_2O$. Replacing the base with $NaN(TMS)_2$ in THF led to low yields of bisphosphinyl ester **11a** via two succesive 1,4 additions of diethyl phosphite anion to **9a** (Scheme 2). When we added a new carbon to the ester chain, as in methyl homolog **9b**, the same reaction produced mono- and bisphosphinyl esters **10b** and **11b** (3:1 ratio), respectively. In both cases, no traces of a 1,2 addition product were detected.

In order to explore the feasibility of using **3** as a synthon for the preparation of complex α-fluoro phosphonates, we conducted a Michael reaction utilizing **3c** and methyl acrylate. This reaction would extend the carbon chain on the α-position of **3**, introducing at the same time a carboxylic ester group on the resulting fluoro phosphonate **12**. A preliminary experiment using NaH



in benzene at room temperature did not yield the desired compound. Most of the starting material was recovered unchanged. When we carried out a similar reaction using $NaN(TMS)_2$ in THF at 0 °C, we isolated the desired fluoro phosphinyl ester **12** in 56% yield (96% pure by ^{31}P NMR). This result lent validity to our argument in support of the role of (α-fluoropropargyl)phosphonate **3** as a fluorine-containing synthon.

In conclusion, we have developed the first synthesis of (α-fluoropropargyl)phosphonate ester **3**, through the intermediacy of α-hydroxy phosphonate **7**, using a short and efficient protocol applicable to readily available propargyl aldehydes and ketones. An alternative preparation of α-hydroxy phosphonate **7**, involving an O to C phosphorus migration (e.g., **6** to **7**), proved to be less efficient. Finally, we have successfully explored the functionalization at the α-carbon in (α-fluoropropargyl)-phosphonates, via a Michael reaction. The investigation of this and other carbon−carbon bond forming reactions is in progress, and the results will be reported in due course.

Experimental Section

Materials and Methods. All moisture sensitive reactions were performed under a nitrogen atmosphere using dry, freshly distilled solvents, oven-dried glassware, and magnetic stirring. THF was distilled from Na/benzophenone. Toluene and methylene chloride (CH_2Cl_2) were distilled from calcium hydride. *N*,*N*-Diisopropylamine was distilled from sodium hydroxide. Diethyl phosphite was distilled prior to use. All other reagents were used as received. All reactions were monitored using one of the following techniques: TLC, GC, GC-MS, ^{31}P and/or ^{19}F NMR. Preparative TLC was performed using E. Merck silica gel 60 F_{254}. Analytical TLC was performed using Macherey-Nagel polygram sil G/UV_{254} precoated plates. Column chromatography utilized silica gel, 63−200 μm (Scientific Adsorbents, Inc.), neutral alumina, 32−63 μm (Scientific Adsorbents, Inc.), or acidic alumina, 150 mesh, 58 Å (Aldrich). Flash chromatography was performed using silica gel, Davisil, grade 633, 200−425 mesh, 60 Å. Dry column chromatography was performed using Florisil, 60−100 mesh (U.S. Silica Company). Solid phase extraction was performed using Extract-Clean columns (silica gel, 60 Å). Melting points are uncorrected. ^1H, ^{19}F, ^{31}P, and ^{13}C NMR spectra were recorded in $CDCl_3$ at 300, 282, 121, and 75 MHz, respectively. ^1H NMR spectra are referenced against internal tetramethylsilane, ^{19}F NMR spectra against external $CFCl_3$, ^{31}P NMR spectra against 85% H_3PO_4, and ^{13}C NMR spectra against internal tetramethylsilane at δ 0.0 ppm. ^{31}P and ^{19}F NMR spectra were broad-band decoupled from hydrogen nuclei. *J* values are given in hertz. Low-resolution EI mass spectra were recorded with an ionization voltage of 70 eV; peaks are reported as *m*/*e* (percent intensity relative to base peak). Elemental analyses were performed by Atlantic Microlab, Inc., Norcross, GA.

Synthesis of Hydroxy Phosphonate 7 from Alkynol 5. Method 1 (Two-Step Protocol). Representative Procedure for Diethyl (1-Hydroxy-2-butynephosphonate (7a). 2-Butyn-1-ol (2.4 mL, 32 mmol) was added to a well-stirred mixture of diethyl chlorophosphate (5.6 mL, 38 mmol), NaOH (50%, 200 mL), triethylbenzylammonium chloride (4.0 g), and CH_2Cl_2 (100 mL). After being stirred for 1 h, the mixture was diluted with water (1 L), the aqueous layer was back-extracted with CH_2Cl_2, and the combined organic layers were dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. Kugelrohr distillation gave **6a** (5.54 g, 84%) as a colorless oil: ^1H NMR (60 MHz) δ 1.37 (t, J = 7, 6H), 1.87 (t, J = 2, 3H), 4.57 (m, 4H), 4.65 (m, 2H); EIMS 206 (M^+, 2), 150 (43), 127 (8), 99 (100), 81 (25), 53 (47). Anal. Calcd for $C_8H_{15}O_4P$: C, 46.60; H, 7.33. Found: C, 46.44; H, 7.31. To a stirred solution of **6a** (6.41 g, 31.1 mmol) in toluene (75 mL) at −50 °C was added LDA [prepared in situ from *N*,*N*-diisopropylamine (6.9 mL) and *n*-BuLi (1.6 M, 29.2 mL)] in toluene (41 mL). The resulting mixture was stirred for 50 min, and the solution was quenched with acetic acid (1 M in Et_2O, 100 mL). The gelatinous mixture was washed with water, the aqueous layer was back-extracted with CH_2Cl_2, and the combined organic layers were concentrated. Dry column chromatography (Florisil, ethyl acetate−hexane gradient) produced **7a** (3.17 g, 49%) as an oil which solidified on standing: ^1H NMR δ 1.36 (td, J = 7.1, 1.8, 6H), 1.90 (dd, J = 5.7, 2.4, 3H), 4.12−4.40 (m, 4H), 4.64 (dq, J = 15.1, 2.2, 1H), 4.83 (br s, 1H); ^{31}P NMR δ 18.7 (s); EIMS 191 (M^+ − 15, 5), 177 (32), 149 (36), 138 (31), 111 (69), 82 (100), 69 (59), 41 (33). Anal. Calcd for $C_8H_{15}O_4P$: C, 46.60; H, 7.33. Found: C, 46.76; H, 7.37.

Method 2 (One-Flask Protocol). Representative Procedure for 7a. LDA was prepared in situ from *N*,*N*-diisopropylamine (9.0 mL, 64 mmol) and *n*-BuLi (1.6 M, 38 mL, 61 mmol) in toluene (53 mL) at −50 °C. An aliquot of this LDA solution (0.6 M, 33 mL, 20 mmol) was transferred via syringe and added dropwise to 2-butyn-1-ol (1.2 mL, 16 mmol) in toluene (20 mL) at −50 °C followed by diethyl chlorophosphate (2.5 mL, 18 mmol). The mixture was allowed to stir for 45 min at −50 °C after which the remainder of the LDA solution was added dropwise with stirring over a period of 30 min. After 1 h at −50

°C, acetic acid (1 M in diethyl ether, 50 mL) was added and the mixture was washed with water and concentrated to give an oil which was purified as above to furnish **7a** (1.83 g, 55%).

Diethyl 1-hydroxy-3-(trimethylsilyl)-2-propynephosphonate (7b) was prepared from **5b** (0.625 g, 4.9 mmol) according to method 2. Attempted purification of an aliquot (0.62 g) of the crude product by Kugelrohr distillation ended in partial decomposition of the **7b**. Purification of another aliquot (0.66 g) by flash chromatography (silica, hexane−ethyl acetate 1:2) provided an analytically pure sample of **7b** (0.15 g, 23%): ^{1}H NMR δ 0.15 (s, 9H) 1.36 (td, J = 7.0, 3.6, 6H), 4.09−4.30 (m, 4H), 4.64 (d, J = 16.9, 1H); ^{31}P NMR δ 17.6 (s); EIMS 235 (M^+ − 29, 83), 207 (22), 179 (48), 155 (35), 121 (87), 111 (100), 82 (65), 45 (57). Anal. Calcd for $C_{10}H_{21}O_4PSi$: C, 45.57; H, 7.67. Found: C, 45.69; H, 7.70.

Diethyl 1-hydroxy-3-phenyl-2-propynephosphonate (7c) was prepared from **5c** (2.11 g, 16.0 mmol) according to method 1. Preliminary purification using dry column chromatography (Florisil, ethyl acetate−hexane gradient) gave **7c** (2.37 g, 75%). Recrystallization from petroleum ether/CH_2Cl_2 gave **7c** as short, white needles: mp 71−72 °C; ^{1}H NMR δ 1.34−1.40 (m, 6H), 4.23−4.35(m, 4H), 4.88 (d, J = 16.3, 1H), 7.26−7.48 (m, 5H); ^{13}C NMR δ 16.5, 16.4, 59.4 (d, J = 169), 64.4, 64.5, 83.2, 88.0, 128.3, 128.8, 130.0, 131.8, 133.0; ^{31}P NMR δ 18.1; EIMS 269 (M^+, 28), 251(37), 239 (100), 211 (38), 183 (67), 159 (25), 138 (22). Anal. Calcd for $C_{13}H_{17}O_4P$: C, 58.20; H, 6.40. Found: C, 58.26; H, 6.44.

Diethyl 1-ethyl-1-hydroxy-2-butynephosphonate (7d) was prepared from **5d** (0.45 mL, 4.0 mmol) according to method 2 yielding an oil (0.189 g, 20%) which solidified upon standing: ^{1}H NMR δ 1.10 (t, J = 7.4, 3H), 1.37−1.32 (m, 6H), 1.81−1.86 (m, 2H), 1.88 (d, J = 5.3, 3H), 4.18−4.29 (m, 4H); ^{31}P NMR δ 21.4 (s); EIMS 177 (16), 149 (13), 138 (11), 121 (30), 111 (49), 97 (25), 82 (71), 67 (67), 43 (100). Anal. Calcd for $C_{10}H_{19}O_4P$: C, 51.28; H, 8.18. Found: C, 51.35; H, 8.20.

Attempted Synthesis of Diphenyl 1-Hydroxy-2-butynephosphonate (7k). To a stirred solution of 2-butyn-1-ol (0.75 mL, 10 mmol) in dry toluene (30 mL) at −50 °C was added slowly dropwise LDA (0.5 M, 24 mL, 12 mmol) [prepared in situ from *N*,*N*-diisopropylamine (2.5 mL, 18 mmol) and *n*-BuLi (8.6 mL, 1.75 M) in toluene (19 mL)]. After 30 min, diphenyl chlorophosphate (2.5 mL, 12 mmol) was added and the resulting mixture stirred for 2 h. The reaction was quenched by addition of CF_3COOH (2 M in Et_2O, 10 mL), forming two layers. The organic layer was separated and the aqueous layer extracted with Et_2O (3 × 25 mL). The combined organic phases were dried over $MgSO_4$, filtered, and concentrated to give an orange oil which was purified by dry column chromatography (Florisil, ethyl acetate−hexane gradient). This afforded **6k** (2.140 g, 71%) as a yellow oil: ^{1}H NMR δ 1.76 (t, J = 2.4, 3H), 4.79 (dq, J = 2.3, 10.8, 2H), 7.09−7.35 (m, 10H); ^{31}P NMR δ 11.1 (s). To a stirred solution of **6k** (0.313 g, 1 mmol) in dry toluene (10 mL) at −50 °C was added LDA (0.5 M, 4.4 mL, 2.2 mmol) in toluene. This mixture was allowed to stir for 45 min, after which CF_3COOH (2 M in Et_2O, 4 mL) was added. The organic layer was separated and the aqueous layer extracted with Et_2O (3 × 20 mL). The combined organic phases were pooled, dried over $MgSO_4$, filtered, and concentrated. The resulting residue (0.241 g) was redissolved in Et_2O (25 mL) and extracted with 10% NaOH (3 × 20 mL), leaving 0.042 g of an unidentified residue in the original ether layer. The combined aqueous phases were acidified with HCl (6 M) and extracted with Et_2O (3 × 20 mL). The combined ether layers were dried over $MgSO_4$, filtered, and concentrated to afford phenol (0.153 g, 81%).

Synthesis of Hydroxy Phosphonate 7 from Propargylic Aldehydes or Ketones 8. Diethyl 1-Hydroxy-3-(trimethylsilyl)-2-propynephosphonate (7b). To a stirred solution of diethylamine (0.074 g, 1.0 mmol) in anhydrous Et_2O (10 mL) at 25 °C was added diethyl phosphite (0.138 g, 1.0 mmol). After 5 min of stirring, **8b** (0.126 g, 1.0 mmol) was added and stirring continued for an additional 1.5 h at 25 °C. The reaction was quenched by the addition of water (20 mL) to the mixture. The aqueous layer was extracted with Et_2O (3 × 25 mL). The organic layers were pooled, washed with water (3 × 5 mL), dried over $MgSO_4$, filtered, and concentrated to give **7b** (0.195 g, 74%) as a dark oil (97% pure by ^{31}P NMR).

Method 1 ($KF·2H_2O$). Representative Procedure for Diethyl 1-Hydroxy-3-phenyl-2-propynephosphonate (7c). To a stirred mixture of diethyl phosphite (1.3 mL, 10 mmol) and potassium fluoride dihydrate (4.70 g, 50 mmol) at 25 °C was added **8c** (1.2 mL, 10 mmol). After 1 h, the mixture was partitioned between Et_2O (100 mL) and water (100 mL) and stirring continued for an additional 5 min. The aqueous layer was separated and the organic layer washed with water (3 × 50 mL) and concentrated. The resulting oil was solidified by introducing it into an ice bath for 2 h. Recrystallization from petroleum ether/CH_2Cl_2 gave **7c** (1.97 g, 73%).

Method 2 ($NaN(TMS)_2$). Representative Procedure for Diethyl 1-Ethyl-1-hydroxy-2-butynephosphonate (7d). To a stirred solution of diethyl phosphite (0.721 g, 5.2 mmol) in dry THF (5.0 mL) at −78 °C was added sodium bis(trimethylsilyl)-amide (1 M in THF, 5.2 mL, 5.2 mmol). After 30 min, this mixture was transferred slowly dropwise to a second flask containing a stirred solution of **8d** (0.507 g, 5.3 mmol) in THF (5.0 mL) at −78 °C. After 1 h, the reaction was slowly warmed to room temperature over 3 h before being quenched with water (3.0 mL). The organic layer was separated and the aqueous layer extracted with CH_2Cl_2 (3 × 25 mL). The combined organic layers were dried over $MgSO_4$, filtered, and concentrated to give **7d** (0.956 g, 78%) as a yellow oil (76% pure by ^{31}P NMR).

Diethyl 1-hydroxy-1-methyl-2-pentynephosphonate (7e) was prepared from **8e** (0.157 g, 1.6 mmol) according to method 2. After 3 h, the reaction was slowly warmed to room temperature before being quenched with water (1.0 mL). The organic layer was separated and the aqueous layer extracted with ethyl acetate (3 × 25 mL). The combined organic layers were dried over $MgSO_4$, filtered, and concentrated to give **7e** (0.290 g, 76%) as a yellow oil (95% pure by ^{31}P NMR). Attempts to purify **7e** by chromatography led to decomposition: ^{1}H NMR δ 1.15 (t, J = 7.2, 3H), 1.37 (t, J = 7.1, 6H), 1.64 (d, J = 15.0, 3H), 2.26 (dq, J = 7.5, 4.7, 2H), 4.26 (m, 4H); ^{31}P NMR δ 21.2 (s); EIMS 205 (9), 191 (50), 177 (8), 163 (28), 138 (21), 135 (79), 111 (99), 97 (47), 83 (49), 82 (100), 81 (76).

Diethyl 1-Hydroxy-1-methyl-3-phenyl-2-propynephosphonate (7f). Diethyl phosphite (1.2 mL, 9.3 mmol), potassium fluoride dihydrate (0.753 g, 8.0 mmol), and **8f** (0.992 g, 6.9 mmol) were stirred for 8 h according to method 1, yielding a clear yellow oil which solidified upon immersion in an ice bath for 2 h. The solid was recrystallized from petroleum ether/CH_2Cl_2 to give **7f** (1.418 g, 73%) as white needles: mp 80−81 °C; ^{1}H NMR δ 1.29−1.37 (m, 6H), 1.76 (d, J = 15.0, 3H), 4.18−4.30 (m, 4H), 4.45 (br s, 1H), 6.95−7.14 (m, 5H); ^{31}P NMR δ 20.6 (s); ^{13}C NMR δ 16.6, 16.7, 25.3, 64.2, 64.3, 66.0 (d, J = 173), 86.2, 88.1, 122.4, 122.5, 128.3, 128.7, 131.9, 131.9. Anal. Calcd for $C_{14}H_{19}O_4P$: C, 59.57; H, 6.78. Found: C, 59.49; H, 6.78.

Diethyl 1-Hydroxy-2-octynephosphonate (7g). Diethyl phosphite (6.4 mL, 50 mmol), **8g** (6.2 g, 50 mmol), and potassium fluoride dihydrate (23.5 g, 250 mmol) were stirred for 12 h according to method 1, yielding **7g** (10.8 g, 83%) as a yellow oil (98% pure by ^{31}P NMR). An aliquot was further purified by preparative TLC (silica, hexane−ethyl acetate 1:1). The band with R_f = 0.30 was scraped and eluted with CH_2Cl_2 to provide a sample of analytical purity: ^{1}H NMR δ 0.90 (t, J = 7.0, 3H), 1.33−1.39 (m, 10H), 1.46−1.53 (m, 2H), 2.23−2.26 (m, 2H), 4.21−4.28 (m, 4H), 4.67 (dt, J = 15.0, 2.1, 1H); ^{13}C NMR δ 13.7, 16.1, 16.2, 18.6, 21.9, 27.9, 30.7, 58.6 (d, J = 172), 74.6, 88.1; ^{31}P NMR δ 18.8 (s); EIMS 233 (M^+ − 29, 4), 205 (4), 177 (8), 138 (8), 111 (26), 82 (28), 29 (100). Anal. Calcd for $C_{12}H_{23}O_4P$: C, 54.96; H, 8.77. Found: C, 54.44; H, 8.72.

Dibutyl 1-Hydroxy-3-phenyl-2-propynephosphonate (7h). **8c** (0.60 mL, 5.0 mmol) was treated with dibutyl phosphite (1.0 mL, 5.0 mmol) and potassium fluoride dihydrate (2.350 g, 25 mmol) according to Method 1. This afforded **7h** (1.351 g, 83%) as a viscous yellow-orange oil (96% pure by ^{31}P NMR). Attempted purification by preparative TLC resulted in loss of hydroxy phosphonate. ^{1}H NMR δ 0.89 (td, J = 7.2, 1.3, 6H), 1.35−1.44 (m, 4H), 1.62−1.70 (m, 4H), 4.20−4.27 (m, 4H), 4.92 (d, J = 16.2, 1H), 7.27−7.46 (m, 5H); ^{31}P NMR δ 18.2 (s).

Bis(2-ethylhexyl) 1-Hydroxy-3-phenyl-2-propynephosphonate (7i). Bis(2-ethylhexyl) phosphite (1.7 mL, 5.0 mmol), potassium fluoride dihydrate (2.35 g, 25 mmol), and **8c** (0.60 mL, 5.0 mmol) were stirred for 1 h according to method 1. Workup as for **7h** above furnished **7i** (1.68 g, 77%) as a viscous orange oil (94% pure by ^{31}P NMR). Attempted purification by preparative TLC resulted in loss of hydroxy phosphonate. ^{1}H NMR δ 0.82−0.93 (m, 12H), 1.25−1.43 (m, 18H), 4.08 - 4.16

(m, 4H), 4.93 (d, J = 16.0, 1H), 7.28 - 7.59 (m, 5H); ^{13}C NMR δ 10.7, 10.8, 13.9, 22.8, 23.0, 23.1, 28.7, 28.7, 29.7, 29.7, 40.2, 59.3 (d, J = 170), 69.8, 70.2, 83.8, 87.5, 128.1, 128.3, 128.5, 128.6, 131.7, 131.7; ^{31}P NMR δ 18.1 (s).

Bis(2-ethylhexyl) 1-Hydroxy-2-octynephosphonate (7j). Potassium fluoride dihydrate (4.70 g, 50 mmol), bis(2-ethylhexyl) phosphite (3.3 mL, 10 mmol), and **8g** (1.42 mL, 10 mmol) were stirred according to method 1. After 5 h, CH_2Cl_2 (50 mL) was added and stirring continued for an additional 10 min. The mixture was then filtered and the solid residue washed with CH_2Cl_2. The filtrate was dried over $MgSO_4$, filtered, and concentrated to furnish **7j** (3.16 g, 74%) as a pale yellow oil (95% pure by ^{31}P NMR). Purification attempts by column chromatography (neutral alumina, hexane−ethyl acetate 4:1) and preparative TLC resulted in the loss of compound. ^{1}H NMR δ 0.84−0.95 (m, 15H), 1.21−1.42 (m, 24H), 2.20−2.32 (m, 2H), 4.08−4.16 (m, 4H), 4.65 (dt, J = 15.0, 2.14, 1H); ^{31}P NMR δ 18.5 (s); EIMS 113 (M^+ − 317, 9) 96 (18), 83 (100), 71 (23), 69 (9), 57 (41), 41 (23), 28 (27).

General Method for the Synthesis of Dialkyl 1-Fluoro-2-alkynephosphonates 3a−j. Representative Procedure for Diethyl 1-Fluoro-3-phenyl-2-propynephosphonate (3c). To a stirred solution of **7c** (2.80 g, 10.4 mmol) in dry CH_2Cl_2 (20 mL) at −78 °C was added DAST (1.6 mL, 12.5 mmol). After 1 h at −78 °C, the reaction mixture was decanted carefully into a saturated $NaHCO_3$ solution (50 mL). The aqueous layer was extracted with CH_2Cl_2 (3 × 50 mL). Combined organic phases were dried over $MgSO_4$, filtered, and concentrated to give **3c** (2.64 g, 94%) as an orange oil (92% pure by ^{31}P NMR). An analytically pure sample was obtained by column chromatography (acidic alumina, hexane−ethyl acetate 4:1): ^{1}H NMR δ 1.20−1.46 (m, 6H), 4.05−4.41 (m, 4H), 5.59 (dd, J = 47.2, 12.1, 1H), 7.20−7.51 (m, 5H); ^{13}C NMR δ 16.2, 16.3, 64.6, 64.7, 78.2 (dd, J = 176, 182), 79.2, 92.5, 121.1, 128.2, 129.5, 131.8; ^{31}P NMR δ 11.5 (d, J = 77); ^{19}F NMR δ −195 (d, J = 77); EIMS 270 (M^+, 5), 214 (5), 133 (85), 114 (100), 109 (54), 91 (27), 81 (81). Anal. Calcd for $C_{13}H_{16}FO_3P$: C, 57.77; H, 5.92. Found: C, 57.79; H, 5.97.

Diethyl 1-Fluoro-2-butynephosphonate (3a). DAST (2.9 mL, 22 mmol) was reacted with **7a** (3.82 g, 18 mmol) in CH_2Cl_2 (50 mL) at −50 °C for 1 h, yielding **3a** (3.25 g, 85%). Purification either by Kugelrohr distillation (99 °C, 1.0 Torr) or flash column chromatography (silica, hexane−ethyl acetate 1:1) yielded analytically pure material: ^{1}H NMR δ 1.28−1.49 (m, 6H), 1.83−2.02 (m, 3H), 4.20−4.33 (m, 4H), 5.31 (ddq, J = 47.4, 11.4, 2.2, 1H); ^{31}P NMR δ 12.2 (d, J = 78); ^{19}F NMR δ −196 (d, J = 77); EIMS 208 (M^+, 3), 152 (27), 129 (23), 101 (100), 81 (97), 52 (98). Anal. Calcd for $C_8H_{14}FO_3P$: C, 46.16; H, 6.78. Found: C, 46.37; H, 6.82.

Diethyl 1-Fluoro-3-(trimethylsilyl)-2-butynephosphonate (3b). A stirred solution of **7b** (0.132 g, 0.50 mmol) in CH_2Cl_2 (10 mL) at −78 °C was treated with DAST (0.20 mL, 1.3 mmol). After being stirred for 30 min at −78 °C, the mixture was diluted with Et_2O (10 mL), washed with saturated $NaHCO_3$ (3 × 10 mL), dried over $MgSO_4$, filtered, and concentrated to give **3b** (0.106 g, 80%) as a dark oil (76% pure by ^{31}P NMR). An analytically pure sample was obtained by column chromatography (acidic alumina, hexane−ethyl acetate 4:1): ^{1}H NMR δ 0.20 (s, 9H), 1.26−1.43 (m, 6H), 4.07−4.31 (m, 4H), 5.01 (dd, J = 47.2, 12.1, 1H); ^{31}P NMR δ 11.1 (d, J = 76); ^{19}F NMR δ −196 (d, J = 76); EIMS 251 (M^+ − 16, 8), 210 (20), 195 (46), 157 (100), 123 (58), 109 (62), 81 (75), 47 (79). Anal. Calcd for $C_{10}H_{20}FO_3PSi$: C, 45.11; H, 7.51. Found: C, 45.24; H, 7.47.

Diethyl 1-Ethyl-1-fluoro-2-butynephosphonate (3d). Treatment of **7d** (0.358 g, 1.5 mmol) with DAST (0.35 mL, 2.7 mmol) for 2.5 h according to the general method produced **3d** (0.198 g, 67% by ^{31}P NMR) as an amber oil. An analytically pure sample was obtained by solid phase extraction (hexane−ethyl acetate 7:3): ^{1}H NMR δ 1.15 (t, J = 7.3, 3H), 1.34−1.41 (m, 6H), 1.96 (dd, J = 7.0, 4.9, 3H), 2.04−2.21 (m, 2H), 4.21−4.34 (m, 4H); ^{31}P NMR δ 14.9 (d, J = 88); ^{19}F NMR δ −162 (d, J = 89); EIMS 236 (M^+, 2), 221 (2), 188 (3), 160 (6), 127 (10), 101 (38), 79 (100), 65 (38). Anal. Calcd for $C_{10}H_{18}FO_3P$: C, 50.85; H, 7.68. Found: C, 50.96; H, 7.75.

Diethyl 1-Fluoro-1-methyl-2-pentynephosphonate (3e). A solution of **7e** (0.447 g, 1.9 mmol) and DAST (0.40 mL, 3.0 mmol) in dry CH_2Cl_2 (10 mL) was allowed to react for 6 h, affording **3e** (0.236 g, 86% by ^{19}F NMR) as a clear yellow oil. An analytically pure sample was obtained by solid phase extraction (hexane−ethyl acetate 1:1): ^{1}H NMR δ 1.18 (t, J = 7.5, 3H), 1.36−1.42 (m, 6H), 1.82 (dd, J = 22.1, 14.3, 3H), 2.26−2.37 (m, 2H), 4.22−4.36 (m, 4H); ^{13}C NMR δ 12.5, 13.1, 16.3, 16.4, 24.1 (d, J = 25), 64.1, 64.5, 74.6, 86.6 (dd, J = 182, 178), 93.4; ^{31}P NMR δ 14.9 (d, J = 89); ^{19}F NMR δ −152 (d, J = 89); EIMS 180 (3), 159 (13), 149 (7), 129 (5), 111 (23), 101 (31), 79 (100), 77 (51). Anal. Calcd for $C_{10}H_{18}FO_3P$: C, 50.85; H, 7.68. Found: C, 50.56; H, 7.53.

Diethyl 1-Fluoro-1-methyl-3-phenyl-2-propynephosphonate (3f). Reaction of **7f** (0.468 g, 1.7 mmol) with DAST (0.40 mL, 3.0 mmol) in CH_2Cl_2 (10 mL) at −50 °C for 4 h according to the general method furnished **3f** (0.429g, 91%) as an amber oil (100% pure by ^{31}P NMR). An analytically pure sample was obtained by solid phase extraction (hexane−ethyl acetate 1:1): ^{1}H NMR δ 1.37−1.42 (m, 6H), 1.93 (dd, J = 22.0, 14.2, 3H), 4.25−4.39 (m, 4H), 7.30−7.49 (m, 5H); ^{13}C NMR δ 16.5, 16.6, 24.0 (d, J = 24), 64.4, 64.7, 83.8, 86.9 (dd, J = 180, 179), 90.4, 121.4, 128.5, 129.5, 132.0; ^{31}P NMR δ 14.4 (d, J = 88); ^{19}F NMR δ −153 (d, J = 88); EIMS 284 (M^+, 1), 255 (2), 227 (8), 147 (100), 128 (62), 109 (26), 81 (43). Anal. Calcd for $C_{14}H_{18}FO_3P$: C, 59.15; H, 6.38. Found: C, 59.24; H, 6.45.

Diethyl 1-Fluoro-2-ocytnephosphonate (3g). Treatment of **7g** (2.62 g, 10 mmol) with DAST (1.6 mL, 12 mmol) following the general method afforded, after 8 h of stirring, **3g** (2.48 g, 94%) as an oil (90% pure by ^{31}P NMR) Kugelrohr distillation (110 °C, 7 × 10^{-2} Torr) furnished an analytically pure sample: ^{1}H NMR δ 0.86−1.02 (t, J = 7.1, 3H), 1.25−1.49 (m, 10H), 1.49−1.55 (m, 2H), 2.25−2.43 (m, 2H), 4.21−4.46 (m, 4H), 5.32 (dd, J = 47.3, 11.4, 1H); ^{13}C NMR δ 13.8, 16.3, 16.4, 18.9, 22.0, 27.6, 30.8, 63.9, 64.4, 70.7, 78.04 (dd, J = 178, 180), 94.5; ^{31}P NMR δ 11.9 (d, J = 77); ^{19}F NMR δ −159 (d, J = 77); EIMS 208 (M^+ − 56, 20), 180 (8), 160 (15), 152 (22), 129 (28), 109 (87), 91 (52), 81 (100). Anal. Calcd for $C_{12}H_{22}FO_3P$: C, 54.54; H, 8.33. Found: C, 54.57; H, 8.36.

Dibutyl 1-Fluoro-3-phenyl-2-propynephosphonate (3h). A mixture of **7h** (0.474 g, 1.5 mmol) and DAST (0.25 mL, 1.8 mmol) in CH_2Cl_2 (10 mL) was allowed to stir at −78 °C for 1 h according to the general method, affording **3h** (0.434 g, 89%) as an orange oil (75% pure by ^{31}P NMR). An aliquot (0.102 g) was further purified by preparative TLC (hexane−ethyl acetate 1:1). The band with R_f = 0.65 was scraped and eluted with CH_2Cl_2 to afford an analytical sample (0.018 g): ^{1}H NMR δ 0.87−0.97 (m, 6H), 1.33−1.48 (m, 4H), 1.67−1.75 (m, 4H), 4.15−4.31 (m, 4H), 5.60 (dd, J = 47.2, 12.1, 1H), 7.30−7.52 (m, 5H); ^{13}C NMR δ 13.4, 18.5, 32.4, 68.0 (dd, J = 7, 21), 78.1 (dd, J = 177, 182), 79.5, 92.2, 121.0, 128.3, 129.9, 131.9; ^{31}P NMR δ 11.5 (d, J = 77); ^{19}F NMR δ −195 (d, J = 78); EIMS 326 (M^+, 3), 270 (9), 214 (100) 213 (20), 137 (21), 133 (94), 114 (79), 57 (60), 41 (54). Anal. Calcd for $C_{17}H_{24}FO_3P$: C, 62.57; H, 7.41. Found: C, 62.59; H, 7.38.

Bis(2-ethylhexyl) 1-Fluoro-3-phenyl-2-propynephosphonate (3i). A mixture of **7i** (2.00 g, 4.6 mmol), CH_2Cl_2 (10 mL), and DAST (0.80 mL, 6.0 mmol) was stirred for 1 h according to the general method. This procedure afforded **3i** (1.59 g, 79%) as an orange oil (90% pure by ^{31}P NMR). An aliquot (0.120 g) was further purified by preparative TLC (hexane−ethyl acetate 1:1). The band with R_f = 0.80 was scraped and eluted with CH_2Cl_2. The resulting green oil was eluted through a short column of silica (hexane−ethyl acetate 7:3) to provide an analytical sample (0.090 g): ^{1}H NMR δ 0.86−0.93 (m, 12 H), 1.29−1.43 (m, 18H), 4.13−4.19 (m, 4H), 5.60 (dd, J = 45.9, 11.8, 1H), 7.32−7.48 (m, 5H); ^{13}C NMR δ 10.7, 13.9, 22.8, 23.1, 28.7, 29.7, 40.2, 70.2 (dd, J = 7, 25), 78.0 (dd, J = 178, 182), 79.6 (dd, J = 5, 22), 92.2 (dd, J = 10, 12), 121.1, 128.4, 129.4, 131.8; ^{31}P NMR δ 11.5 (d, J = 77); ^{19}F NMR δ −195 (d, J = 78); EIMS 214 (M^+ − 224, 41), 195 (13), 133 (35), 114 (33), 57 (100), 49 (87). Anal. Calcd for $C_{25}H_{40}FO_3P$: C, 68.47; H, 9.19. Found: C, 68.58; H, 9.25.

Bis(2-ethylhexyl) 1-Fluoro-2-octynephosphonate (3j). To a stirred solution of DAST (0.60 mL, 4.5 mmol) in CH_2Cl_2 (20 mL) at −50 °C was added **7j** (1.94 g, 4.5 mmol) following the general method. The mixture was allowed to react for 1 h, affording **3j** (1.48 g, 76%) as an oil (84% pure by ^{31}P NMR). An analytically pure sample was obtained by column chromatography (acidic alumina, hexane−ethyl acetate 4:1): ^{1}H NMR δ 0.79−0.98 (m, 15H) 1.21−1.67 (m, 24H), 2.21−2.35 (m, 2H), 3.97−4.19 (m, 4H), 5.35 (ddt, J = 48.7, 12.7, 3.7, 1H); ^{31}P NMR

δ 12.0 (d, J = 77); ^{19}F NMR δ −194 (d, J = 77); EIMS 227 (M^+ − 205, 9), 209 (12), 152 (32), 107 (14), 79 (16), 57 (100), 34 (8), 41 (79). Anal. Calcd for $C_{24}H_{46}FO_3P$: C, 66.66; H, 10.64. Found: C, 66.80; H, 10.74.

Ethyl 3,3-Bis(diethoxyphosphinyl)propanoate (11a).[17] To a stirred solution of diethyl phosphite (0.80 mL, 6.0 mmol) in dry THF (12 mL) at −50 °C was added sodium bis(trimethylsilyl)amide (5.0 M, 5.0 mL, 5.0 mmol). This solution was allowed to stir for 15 min at −50 °C after which ethyl propiolate (0.50 mL, 5.0 mmol) was added. After 10 min the reaction mixture was decanted into approximately 40 mL of distilled water and extracted with Et_2O (3 × 25 mL). Organic layers were pooled and concentrated. The resulting oil was purified by dry column chromatography (Florisil, ethyl acetate−hexane gradient) to give **11a** (0.310 g, 33%) as a pale yellow oil: ^{1}H NMR δ 1.12−1.26 (m, 15H), 2.72 (td, J = 15.9, 6.3, 2H), 2.99 (tt, J = 24.0, 6.3, 1H), 4.01−4.14 (m, 10H); ^{13}C NMR δ 13.4, 15.5, 15.6, 29.9 (t, J = 5), 32.1 (t, J = 136), 60.5, 62.1, 62.3, 170 (t, J = 9); ^{31}P NMR δ 22.8 (s); EIMS 273 (M^+ − 101, 22), 237 (100), 189 (42), 165 (68), 135 (86), 109 (98), 91 (75), 81 (62), 65 (58). Anal. Calcd for $C_{13}H_{28}O_8P_2$: C, 41.71; H, 7.54. Found: C, 41.97; H, 7.60.

Methyl 3-(Diethoxyphosphinyl)-2-butenoate (10) and Methyl 3,3-Bis(diethoxyphosphinyl)butanoate (11b). To a stirred solution of diethyl phosphite (1.6 mL, 12 mmol) in dry THF (20 mL) at −55 °C was added sodium bis(trimethylsilyl)amide (1 M, 12.0 mL, 12 mmol). This was allowed to stir for 10 min, after which **9b** (1.0 mL, 10 mmol) was added. After 2 h the reaction mixture was decanted into water (65 mL). The resulting emulsion was extracted with diethyl ether (3 × 30 mL). The combined organic phases were dried over $MgSO_4$, filtered, and concentrated to give a mixture (2.14 g) of the mono- and diphosphorylated products **10** and **11b**, respectively. Column chromatography (neutral alumina, ethyl acetate−hexane gradient) provided pure **11b** (0.235 g, 11%) and a mixture (0.60 g, 28%) of (*E*) and (*Z*) monoaddition products in a 1:1 ratio. Further chromatography resulted in the isolation of pure (*E*)-**10** (0.004 g). (*E*)-Monoaddition product: ^{1}H NMR δ 1.32 (m, 6H), 2.27 (dd, J = 15, 1.6, 3H), 3.77 (s, 3H), 4.05−4.25 (m, 4H), 6.65 (dq, J = 24, 1.6, 1H); ^{31}P NMR δ 19.4 (s); EIMS 204 (M^+ − 32, 13), 177 (25), 176 (19), 149 (42), 148 (100), 121 (21), 121 (21), 120 (13), 99 (13), 81 (29), 67 (42), 68 (17), 59 (25).

11b: ^{1}H NMR δ 1.25−1.38 (m, 12H), 1.68 (t, J = 16, 3H), 2.81 (dd, J = 16, 13, 2H), 3.68 (s, 3H), 4.12−4.25 (m, 8H); ^{31}P NMR δ 25.6 (s); EIMS 237 (M^+ − 137, 100), 205 (39), 177 (35), 149 (83), 123 (35), 109 (46), 81 (83), 65 (89). Anal. Calcd for $C_{13}H_{28}O_8P_2$: C, 41.72; H, 7.54. Found: C, 41.44; H, 7.45.

Methyl 4-(Diethoxyphosphinyl)-4-fluoro-6-phenyl-5-hexynoate (12). To a stirred solution of sodium bis(trimethylsilyl)amide (1 M in THF, 1.0 mL, 1.0 mmol) in dry THF (10 mL) at 0 °C were added methyl acrylate (0.086 g, 1.0 mmol) and **3c** (0.270 g, 1.0 mmol) in rapid succession. After stirring for 2 h at 0 °C, the mixture was quenched with water (30 mL) and extracted with Et_2O (3 × 20 mL). Organic layers were pooled, washed with a saturated $NaHCO_3$ solution (3 × 20 mL), and concentrated to afford essentially pure **12** (0.199 g, 56%) as an orange oil (96% pure by ^{31}P NMR). An analytically pure sample was obtained by column chromatography (acidic alumina, hexane−ethyl acetate 4:1): ^{1}H NMR δ 1.35−1.45 (m, 6H), 2.55 (m, 2H), 2.75 (m, 2H), 3.71 (s, 3H), 4.25−4.43 (m, 4H), 7.30−7.55 (m, 5H); ^{13}C NMR δ 16.4, 16.5, 28.5, 31.5, 51.8, 64.4, 64.7, 81.6 (d, J = 25), 89.0 (t, J = 181), 92.0, 127.6, 128.5, 129.5, 131.9, 172.8; ^{31}P NMR δ 13.1 (d, J = 86); ^{19}F NMR δ −161 (d, J = 86); EIMS 308 (M^+ − 48, 9), 269 (17), 191 (26), 159 (100), 141 (22), 81 (17). Anal. Calcd for $C_{17}H_{22}FO_5P$: C, 57.30; H, 6.17. Found: C, 57.38; H, 6.30.

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(17) This compound first appeared in the literature as the product of the alkylation of metalated methylenediphosphonate esters; only its ^{31}P NMR was reported. See: Quimby, O. T.; Curry, J. D.; Allan, D.; Prentice, J. B.; Roy, C. H. *J. Organomet. Chem.* **1968**, *13*, 199−207.