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α-Phosphonovinyl Nonaflate: Their Synthesis and Cross-Coupling Reactions

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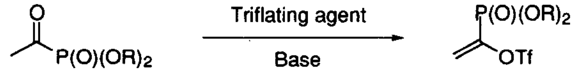
Abstract: A new class of vinylphosphonates, α-phosphonovinyl nonafluorobutanesulfonates (*i.e.* nonaflates) is readily prepared from the corresponding acylphosphonates and nonafluorobutanesulfonyl fluoride in the presence of DBU. The obtained nonaflates are converted to the phosphono-containing enynes and dienes *via* Pd catalyzed coupling reactions. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Phosphonic acids and derivatives; Sulfonic acid and derivatives; Enynes; Dienes.

Vinyl perfluoroalkanesulfonates, *e.g.* vinyl triflates, are widely utilized in organic synthesis[1] due to the high leaving-group ability of the perfluoroalkanesulfonyloxy group. They are effective precursors of vinyl cations[2] and alkyliden carbenes,[3] and are often used in transition-metal-catalyzed cross-coupling reactions.[1,4] Various functionalized vinyl perfluoroalkanesulfonates have been reported so far,[1] but, to the best of out knowledge, α-phosphono functionalized vinyl perfluoroalkanesulfonates are still unknown. The cross-coupling reaction of α-phosphonovinyl perfluoroalkanesulfonates would provide a new method to prepare functionalized vinylphosphonates, compounds which have been widely studied due to their synthetic[5] and biological usefulness.[6] As a continuation of our studies on vinylphosphonates,[7] we became interested in the preparation of this new class of vinylphosphonates, the α-phosphonovinyl perfluoroalkanesulfonates. Herein we describe the first synthesis of α-phosphonovinyl nonafluorobutanesulfonates (*i.e.* nonaflates) from acylphosphonates[8] and their application to cross-coupling reactions with acetylenes and vinylstannanes.

Vinyl triflates are usually prepared from carbonyl compounds either by trapping the corresponding enolate with a triflating agent or by reacting the carbonyl compounds with triflic anhydride in the presence of a base.[1] Thus, we applied these methods to the preparation of α-phosphono vinyl triflate **2** from acylphosphonate **1**, which is readily prepared from triethyl phosphite and acetyl chloride (eq. 1).



1 R=Et, ^{i}Pr **2** R=Et, ^{i}Pr (1)

Reactions using triflating agents (Tf$_2$O, *N*-phenyltriflimide, *N*-pyridyltriflimide) and bases (LDA, LiTMP, LiHMDS, ^{i}Pr$_2$NEt, Et$_3$N, 2,4,6-^{t}Bu-pyridine, NaH) afforded **2** in low yields (0–34%) accompanied by a significant amount of polar byproducts. The byproducts were considered to be formed by the reaction of the highly electrophilic triflating agents with the phosphoryl oxygen of **1** or **2**, base, or solvent instead of the carbonyl oxygen of **1**. In order to prevent the formation of these byproduct, the more moderate electrophile

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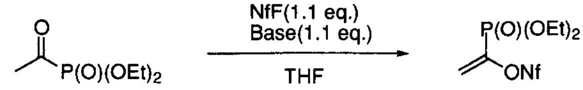
nonafluorobutylsulfonyl fluoride (NfF: nonaflyl fluoride)[9] was used. Acylphosphonate **1a** was treated with NfF in the presence of base in THF. The reaction proceeded cleanly without any formation of the polar byproducts and the highest yield was obtained when DBU was used as the base (eq. 2, Table 1).[10]



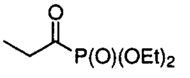
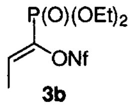
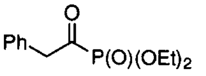
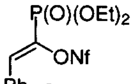
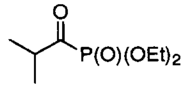
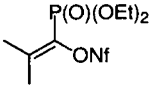
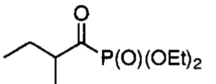
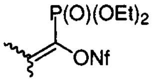
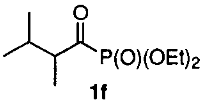
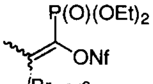
1a **3a** (2)

Table 1. Effect of a Base in the Reaction of Acylphosphonate **1a** with NfF in THF

Run	Base	Conditions	Yield of **3a**/%[a]
1	LDA	−78 °C~rt, 56 h	2
2[b]	LiHMDS	−78 °C~rt, 20 h	–
3[b,c]	LiHMDS	−78 °C, 4 h	33
4[b,c]	NaHMDS	−78 °C, 4 h	24
5	Et_3N	−78 °C~rt, 56 h	–
6	DBN	−78 °C, 4 h	63
7	DBU	−45 °C, 4 h	**83**

[a] Isolated yield based on **1a**. [b] **1a** : NfF : Base = 1.0 : 1.5 : 1.1. [c] THF : HMPA = 10 : 1.

Table 2. Preparation of α-Phosphonovinyl Nonaflate **3** from Several Acylphosphonates **1**[a]

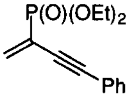
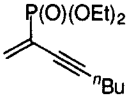
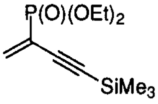
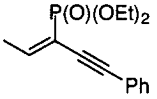
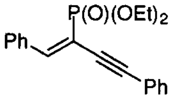
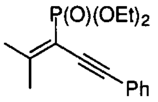
Run	Substrate	Product	Yield/%[b]
1	 **1b**	 **3b**	82
2	 **1c**[c]	 **3c**	41
3	 **1d**	 **3d**	80
4	 **1e**	 **3e**[d]	72
5	 **1f**	 **3f**[e]	73

[a] The reaction was carried out at −45 °C in THF. **1** : NfF : DBU = 1.0 : 1.1 : 1.1. [b] Isolated yield based on **1**. [c] Mixture of keto– and enol–form. [d] *E*:*Z*≈1:1. [e] *E*:*Z*=78:22.

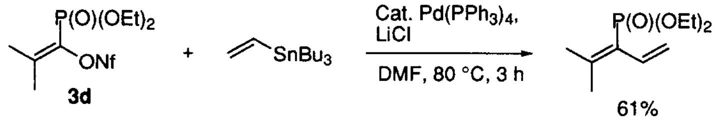
We examined the reaction of several acylphosphonates **1b–f** with NfF in the presence of DBU. As shown in Table 2, mono- and disubstituted α-phosphonovinyl nonaflates were obtained in moderate to good yields. The nonaflate **3c** was not obtained in good yield under these reaction conditions, probably because **1c** mainly existed as its enol–form. The acylphosphonates **1b**, **1c**, and **1f** gave predominantly (*E*)-products, which bear βsubstituents of diffent steric sizes. The olefin stereochemisty was assigned based on ${}^3J_{P\text{-}C}$ coupling constants in ${}^{13}C$ NMR spectra.[11]

Having accomplished the first synthesis of α-phosphonovinyl perfluoroalkanesulfonates **3**, we next focused on the application of **3** to the synthesis of phosphonoenynes and -dienes. The palladium-catalyzed cross-coupling reaction[12] of α-phosphonovinyl nonaflates with acetylenes furnished the corresponding phosphono-containing enynes, which are not readily accessible using other conventional methods (Table 2).[5,13] Among the solvents tested, toluene was the solvent of choice for optimum reaction rate and yield. Furthemore, treatment of **3d** with vinylstannane in the presence of Pd catalyst successfully led to the desired 2-phosphono-1,3-butadiene[14] (eq. 3).

Table 3. Palladium–Catalyzed Cross–Coupling Reaction of α-Phosphonovinyl Nonaflate **3** and Acetylenes[a]

Run	Substrate	Acetylene	Product	Yield/%[b]
1[c]	**3a**	≡—Ph		88
2[d]	**3a**	≡—^{n}Bu		81
3[d]	**3a**	≡—SiMe$_3$		93
4	**3b**	≡—Ph		quant
5	**3c**	≡—Ph		95
6	**3d**	≡—Ph		71

[a] The reaction was carried out in the presence of Pd(PPh$_3$)$_4$, CuI, and ^{i}Pr$_2$NEt under reflux in toluene. **3** : acetylene : Pd cat. : CuI : Base = 1.0 : 2.0 : 0.04 : 1.3 : 3.0.
[b] Isolated yield based on **3**. [c] The reaction was carried out at rt. [d] The reaction was carried out at 60 °C.



(3)

The results disclosed above demonstrate that α-phosphonovinyl nonaflates are easily prepared from triethyl phosphite and various acid chlorides, and provide a new and easy access to phosphonoenynes and phosphonodienes.

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References and Notes

1 Ritter, K. *Synthesis*, **1993**, 735; Stang, P. J.; Hanack, M.; Subramanian, L. R. *Synthesis* **1982**, 85.

2 Stang, P. J.; Rappoport, Z.; Hanack, M.; Subramanian, L. R. *Vinyl Cations*; Academic: New York, 1979.

3 Stang, P. J. *Chem. Rev.* **1978**, *78*, 383.

4 Stille, J. K. *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 508.

5 Minami T.; Motoyoshiya, J. *Synthesis* **1992**, 333.

6 Engel, R. *Chem. Rev.* **1977**, *77*, 349; Harnden, M. R.; Parkin, A.; Parratt, M. J.; Perkins, R. M. *J. Med. Chem.* **1993**, *36*, 1345; Breaker, R. R.; Gough, G. R.; Gilham, P. T. *Biochemistry* **1993**, *32*, 9125; Lazrek, H. B.; Rochdi, A.; Khaider, H.; Barascut, J.-L.; Imbach, J.-L.; Balzarini, J.; Witvrouw, M.; Pannecouque, C.; De Clercq, E. *Tetrahedron* **1998**, *54*, 3807.

7 Kouno, R.; Okauchi, T.; Nakamura, M.; Ichikawa, J.; Minami, T. *J. Org. Chem.* **1998**, *63*, 6239; Okauchi, T.; Fukamachi, T.; Nakamura, F.; Ichikawa, J.; Minami, T. *Bull. Soc. Chim. Belg.* **1997**, *106*, 525; Okauchi, T.; Kakiuchi, T.; Kitamura, N.; Utsunomiya, T.; Ichikawa, J.; Minami, T. *J. Org. Chem.* **1997**, *62*, 8419 and references cited therein.

8 Acylphosphonates **1a–d** were prepared from acid chloride and triethylphosphite following literature procedures: Berlin, K. D.; Hellwege, D. M.; Nagabhushanam, M. *J. Org. Chem.* **1965**, *30*, 1265; Takamizawa, A.; Sato, Y.; Sato, H. *Chem. Pharm. Bull.* **1967**, *15*, 1183; Tam, C. C.; Mattocks, K. L.; Tishler, M. *Proc. Natl. Acad. Sci. USA* **1981**, *78*, 3301.

9 Nonafluorobutanesulfonyl fluoride is commercially available.

10 Typical experimental procedure for preparation of α-phosphonovinyl nonaflates is as follows: to a solution of acylphosphonate **1a** (53 mg, 0.30 mmol) and nonafluorobutanesulfonyl fluoride (58 μl, 0.33 mmol) in THF (2 ml) was added DBU (49 μl, 0.33 mmol) at –45 °C. The mixture was stirred at –45 °C for 4 h, and pH 4 aqueous buffer was added to quench the reaction. After a usual work–up, the crude product was purified by TLC on silica gel to give α-phosphonovinyl nonaflate **3a** (113 mg, 83% yield). Selected data for **3a**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.25 (1H, dd, J = 6.1, 4.0 Hz), 6.05 (1H, dd, J = 27.2, 4.0 Hz), 4.3–4.1 (4H, m), 1.38 (6H, t, J = 6.4 Hz); ^{13}C NMR (126 MHz, $CDCl_3$) δ 146.7 (d, $J_{P\text{-}C}$ = 229 Hz), 122.2 (d, $J_{P\text{-}C}$ = 23 Hz), 121–106 (m), 63.9 (d, $J_{P\text{-}C}$ = 5 Hz), 16.1 (d, $J_{P\text{-}C}$ = 6 Hz); IR neat 1427, 1353, 1241, 1203,. 1145, 1022 cm^{-1}; HRMS (FAB) calcd for $C_{10}H_{13}F_9O_6PS$ ($M+H^+$) 463.0027, found 463.0021; Found: C, 26.15; H, 2.62%. Calcd for $C_{10}H_{12}F_9O_6PS$: C, 25.99; H, 2.62%.

11 Ahlbrecht, H.; Farnung, W. *Chem. Ber.* **1984**, *117*, 1; Ahlbrecht, H.; Farnung, W.; Simon, H. *Chem. Ber.*, **1984**, *117*, 2622.

12 Sonogashira, K.; Tohda, Y.; Hagihara, N. *Tetrahedron Lett.* **1975**, *50*, 4467; Scott, W. J.; Peña, M. R.; Swärd, K.; Stoessel, S.; Stille, J. K. *J. Org. Chem.* **1985**, *50*. 2302; Cacchi, S. *Synthesis* **1986**, 320.

13 Minami T.; Okuma, K. In *Comprehensive Organic Functional Group Transformations*; Katritzky, A. R.; Meth-Cohen, O.; Rees, C. W., Ed.; Pergamon: Oxford, 1995; Vol. 2, Chapter 2.16.

14 Al-Badri, H.; About-Jaudet, E.; Collingnon, N. *Synthesis* **1994**, 1072; Al-Badri, H.; About-Jaudet, E.; Collingnon, N. *J. Chem. Soc., Perkin Trans. 1* **1996** 931; Al-Badri, H.; About-Jaudet, E.; Collingnon, N. *Tetrahedron Lett.* **1996**, *37*, 2951.