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## Mild and efficient oxidation of phosphorus(III) compounds with Selectfluor

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#### ARTICLE INFO

### ABSTRACT

Article history: Received Received in revised form Accepted Available online A novel and efficient oxidation of phosphorus(III) compounds with Selectfluor is described. The reactions smoothly led to the formation of tertiary phosphine oxides, phosphinates and phosphonates in up to 99% yield under mild conditions in minutes.

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Keywords: Phosphines Phosphine oxides Oxidation Selectfluor

Organophosphorus compounds have been widely used in organic synthesis,<sup>1</sup> materials,<sup>2</sup> bioorganic and medical chemistry,<sup>3</sup> coordination chemistry and catalysis,<sup>4</sup> and flame retardants.<sup>5</sup> Phosphine oxides, phosphinates and phosphonates are popularly introduced into the synthesis of organophosphorus compounds,<sup>6</sup> which shows that the oxygen atom of P=O bonds serves as a protecting group for phosphorus because of the strong nucleophilicity of phosphorus(III) compounds. Trivalent phosphines, which are the most important class of ligands in metal-catalyzed reactions,<sup>7</sup> are usually synthesized by the reduction of phosphine oxides.<sup>8</sup> On the other hand, phosphine oxides are also applied as reagents in Wittig-Horner reactions,<sup>9</sup> as ligands<sup>10</sup> and Lewis bases.<sup>11</sup> A variety of methods are used for the oxidation of P(III) compounds: (1) the use of oxidants including chromium(VI) compounds,<sup>1</sup>  $H_2O_2$ ,<sup>1</sup> dimesityldioxirane,<sup>14</sup> oxone,<sup>15</sup> and HOF;<sup>16</sup> and (2) photocatalytic electron-transfer oxidations.<sup>17</sup> The efficient oxidation of P(III) compounds under milder conditions is still a demand to fulfill the modern synthesis.



Figure 1. Structures of NFSI and Selectfluor

Recently, electrophilic fluorinating reagents with the general structure  $R_2N-F$  or  $R_3N^+-F$  have been of particular interest to reactions.<sup>18</sup> fluorination For example, NFSI (Nfluorobenzenesulfonimide) or Selectfluor (1-chloromethyl-4fluoro-1,4-diazoniabicyclo[2.2.2]octane bis(tetrafluoroborate)) (Figure 1) provides a convenient entry to site-selective monofluorination.<sup>18,19</sup> On the other hand, electrophilic fluorinating reagents can also play an important role in a variety of reactions as oxidants.<sup>18,20</sup> In comparison with the previous oxidants,<sup>12-16</sup> NFSI and Selectfluor were milder, user-friendly, safer, and more stable. With the above background and our recent investigations on the synthesis of arylphosphonates and tertiary phosphine oxides,<sup>21</sup> we became interested in studying the oxidation of P(III) compounds with electrophilic fluorinating reagents. Herein, we report a novel and efficient oxidation of P(III) compounds with Selectfluor to afford P(V) compounds in high yields under mild conditions in minutes.

First we carried out the reaction of triphenylphosphine **1a** with NFSI (2 equiv) in CH<sub>3</sub>CN/H<sub>2</sub>O (v/v = 100/1) at room temperature (Table 1, entry 1), and triphenylphosphine oxide **2a** was obtained in 40% yield. To our delight, switching the oxidant from NFSI to Selectfluor led to the formation of **2a** in quantitative yield in 5 minutes, and no purification was needed (entry 2). To elucidate the oxygen source of **2a**, we carried out the reaction in anhydrous CD<sub>3</sub>CN under air, and only trace amounts of **2a** were detected (entry 3), which indicates that water served as the oxygen source. We then turned to screen other moist solvents (entries 4–9). The use of EtOH or acetone decreased the yield, while **2a** was obtained in quantitative yield in DMSO, DMF, or CH<sub>3</sub>CN/H<sub>2</sub>O (v/v = 1/1). When 1 equiv of

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Selectfluor was introduced, the oxidation reaction was still completed smoothly in 5 minutes (entry 10). When 0.5 equiv of Selectfluor was used, the desired product was obtained in 50% yield (entry 11), which suggests that Selectfluor cannot catalyze this oxidation reaction. Thus, we concluded that the optimized combination for the oxidation of P(III) compounds was to use 1 equiv of Selectfluor as the oxidant,  $CH_3CN/H_2O$  (v/v = 100/1) as the solvent, and the reaction was set at room temperature (entry 10).

#### Table 1

Optimzation of the reaction conditions<sup>a</sup>

	PL PL	oxidant		
	Ph Ph — Ph	solvent, rt	Ph-P-Ph	
	1a		2a	
Entry	Oxidant (equiv)	Solvent	Time	Yield <sup>b</sup> (2a)
1	NFSI (2)	CH <sub>3</sub> CN/H <sub>2</sub> O	30 min	40%
2	Selectfluor (2)	CH <sub>3</sub> CN/H <sub>2</sub> O	5 min	quant.
3°	Selectfluor (2)	CD <sub>3</sub> CN	30 min	trace
4	Selectfluor (2)	EtOH/H <sub>2</sub> O	5 min	15%
5	Selectfluor (2)	acetone/H2O	5 min	45%
6	Selectfluor (2)	DMSO/H <sub>2</sub> O	5 min	quant.
7	Selectfluor (2)	DMF/H <sub>2</sub> O	5 min	quant.
8	Selectfluor (2)	THF/H <sub>2</sub> O	5 min	quant.
9 <sup>d</sup>	Selectfluor (2)	CH <sub>3</sub> CN/H <sub>2</sub> O	5 min	quant.
10	Selectfluor (1)	CH <sub>3</sub> CN/H <sub>2</sub> O	5 min	quant.
11	Selectfluor (0.5)	CH <sub>3</sub> CN/H <sub>2</sub> O	12 h	50%

<sup>a</sup> The reaction of **1a** (0.2 mmol) and Selectfluor was carried out in 2 mL of organic solvent/H<sub>2</sub>O (v/v = 100/1) at room temperature.

<sup>b</sup> Yield based on **1a** was determined by <sup>1</sup>H NMR analysis of crude products using an internal standard.

 $^{\circ}$  The reaction of **1a** (0.05 mmol) and Selectfluor (0.1 mmol) was carried out in anhydrous CD<sub>3</sub>CN (0.5 mL) under air in a sealed NMR tube.

<sup>d</sup> CH<sub>3</sub>CN/H<sub>2</sub>O (v/v = 1/1) was used as the solvent.

To investigate the scope of the oxidation protocol, we applied the optimized reaction conditions to a variety of P(III) compounds 1 and the results are illustrated in Table 2. Triarylphosphines 1a-f were all tolerated for the oxidation reaction to smoothly give triarylphosphine oxides 2a-f in 91-99% isolated yields (entries 1-6). It is noteworthy that the oxidation of electron-poor tris(4-fluorophenyl)phosphine required 60 minutes (entry 6). For the oxidation of tris(2furanyl)phosphine, the desired product 2g was isolated in only 36% yield (entry 7). When one of phenyl groups on PPh<sub>3</sub> was replaced by an electron-poor pyridyl group, the reaction also afforded the desired product 2h in 88% yield in minutes (entry 8). For the oxidation of alkyldiphenylphosphines, the desired products 2i-k were obtained in high yields (entries 9–11). To our delight, ethyl diphenylphosphinite can also smoothly react with Selectfluor to afford ethyl diphenylphosphinate 21 in 84% yield in 10 min (entry 12). Similarly, the reaction of dppe, Bu<sub>2</sub>PPh or PCy<sub>3</sub> with Selectfluor gave diphosphine oxide 2m, phosphine oxide 2n or 20 in good yield, respectively (entries 13-15). It is

noteworthy that the oxidation of dimethyl phenylphosphonite afforded dimethyl phenylphosphonate in 54% yield (entry 16), while triethyl phosphite and tribenzyl phosphite did not gave the desired products (entries 17 and 18).

#### Table 2

Scope of the oxidation reactions of phosphorus(III) compounds with  $\mbox{Selectfluor}^a$ 



<sup>a</sup> All reactions were carried out with 1 (0.2 mmol) and Selectfluor (0.2 mmol) in 2 mL of CH<sub>3</sub>CN/H<sub>2</sub>O (v/v = 100/1) at room temperature.

<sup>b</sup> Isolated yield based on **1**.

 $^{\rm c}$  The reaction of dppe (0.2 mmol) and Selectfluor (0.4 mmol) was carried out in 4 mL of CH<sub>3</sub>CN/H<sub>2</sub>O (v/v = 100/1).

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Based on the experimental results, a plausible mechanism of the oxidation of P(III) compounds with Selectfluor is proposed as shown in Scheme 1. P(III) compound 1 interacts with Selectfluor to form the fluoro-phosphonium cation  $3^{22}$  which reacts with water to form the unstable intermediate 4. Subsequent HF elimination gives the desired oxidation product 2.



Scheme 1. Plausible mechanism of the oxidation of phosphorus(III) compounds with Selectfluor

In summary, we have developed an efficient oxidation protocol for phosphorus(III) compounds with Selectfluor, which provides a facile methodology for the synthesis of tertiary phosphine oxides, phosphinates and phosphonates under mild conditions in minutes. To the best of our knowledge, only the oxidation of PPh<sub>3</sub> with Selectfluor was simply mentioned in gold-catalyzed oxidative cross-coupling reactions by Zhang and co-workers.<sup>23</sup> This property of Selectfluor should lead to new and useful applications in organophosphorus chemistry. Further investigations on the transformations of phosphorus compounds with electrophilic fluorinating reagents are ongoing and will be reported in due course.

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#### Supplementary data

Supplementary data (these data include experimental details, analytical data, <sup>1</sup>H, <sup>13</sup>C and <sup>31</sup>P NMR spectra of compounds **2**) associated with this article can be found, in the online version, at http://...

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### **Highlights**

- 1. The oxidation of P(III) compounds with Selectfluor smoothly affords P(V) compounds in high yields.
- Acception The reactions give tertiary phosphine oxides, 2. phosphinates and phosphonates at room
- 3.