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Reactive, dicationic electrophiles: electrophilic activation involving the phosphonium group

Yun Zhang, Sharon L. Aguirre† and Douglas A. Klumpp*

Department of Chemistry, California State Polytechnic University, 3801 West Temple Avenue, Pomona, CA 91768, USA

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Abstract—In the following letter, we report our studies of dicationic electrophiles involving the phosphonium group and we present evidence that the cationic phosphonium group may dramatically enhance the reactivities of adjacent electrophilic centers. We describe superacid-catalyzed reactions involving phosphonium-substituted aldehydes, ketones, olefins, and alkynes, and their conversions to products of condensation and addition reactions. We also report the direct observation of a phosphonium–carboxonium dication in FSO_3H–SbF_5–SO_2ClF by low-temperature ^{13}C NMR spectroscopy.

More than 20 years ago, the Olah group reported that electrophilic nitrations and acylations are facilitated by superacids.[1] These seminal studies led to the proposal of superelectrophilic activation.[2] In the case of nitration, superelectrophilic activation involves protonation of the nitronium cation (NO_2^+) to give the protio-nitronium dication (HNO_2^{2+}). Superelectrophiles and analogous dications have since been proposed or studied in biological systems,[3] in metal complexes,[4] and in numerous superacid-catalyzed reactions.[5] Related studies have also been conducted using mass spectrometry techniques, and recently the protio-nitronium was observed in these gas-phase studies.[6]

Our group has reported several examples in which an ammonium group can be used to activate an adjacent electrophilic center.[7] These dicationic electrophiles are highly reactive and exhibit chemistry similar to the superelectrophiles. In this report, we show that the phosphonium group can also activate adjacent electrophilic groups, we describe a route to obtain arylated phosphonium salts, and we report the direct observations of a dicationic electrophilic species having a phosphonium group.

Carboxonium ions can be readily formed by protonation of aldehydes or ketones, but the resulting electrophiles are generally not reactive enough to attack benzene or deactivated arenes.[8] Despite being almost completely protonated in solutions of CF_3SO_3H (triflic acid, TfOH), neither *n*-octanal nor cyclohexanone reacts with benzene. In contrast, phosphonium-substituted aldehydes and ketones **1**–**4** condense with benzene in excellent yields from TfOH (Table 1).[9] Using either the phosphonium salt or the ylid, we propose that reaction with TfOH generates the dicationic electrophiles (**18** and **19** from **4**, Scheme 1). These dications are sufficiently electrophilic to react with benzene. Since carboxonium ions are generally unreactive towards benzene, these results suggest that the phosphonium group increases the electrophilic reactivity of the adjacent carboxonium ions. This activation may be the result of electrostatic effects and/or inductive effects.

Using low-temperature ^{13}C NMR spectroscopy, phosphonium–carboxonium dications may be observed directly. When compound **4** is added to a solution of FSO_3H–SbF_5 (1:1) with SO_2ClF diluent at −80°C, dication **18** appears as a cleanly formed species (Fig. 1). The methylene resonance is at 39 ppm and the carboxonium resonance is at 240 ppm. Although TfOH (H_o −14.1) is much less acidic than FSO_3H–SbF_5 (H_o −20),[10] the observation of dication **18** indicates that phosphonium–carboxonium dications can be produced in high concentrations in superacid.

Olefinic phosphonium salts (**5**–**8**) also react with benzene and TfOH to give the arylated products (**14**–**17**) in good yields (Table 1). In these reactions, there is no evidence of oligomerization between the dicationic intermediates and the unreacted olefinic phosphonium salts. The reactions of the olefinic systems are consistent with the rules of Markovnikov addition: the most stable carbocationic structure directs the position of aryla-

* Corresponding author. E-mail: daklumpp@csupomona.edu

† S. L. Aguirre is an American Chemical Society Scholar, 2001-2002.

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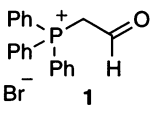
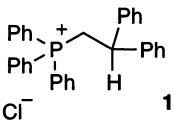
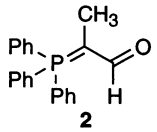
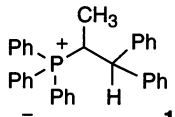
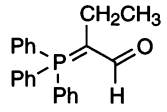
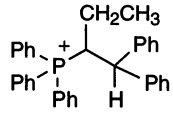
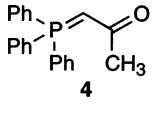
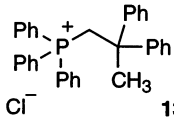
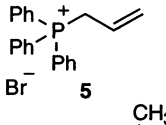
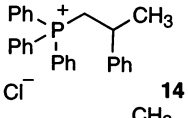
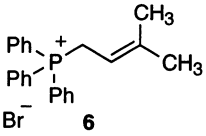
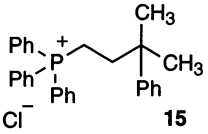
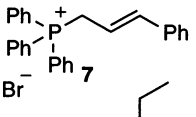
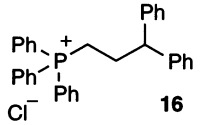
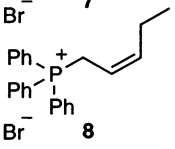
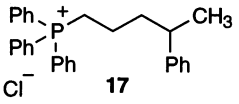
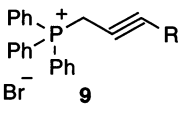
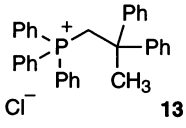
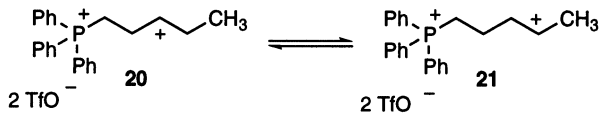
Table 1. Products and yields from the reactions of phosphonium salts (**1**–**9**) with CF_3SO_3H and C_6H_6

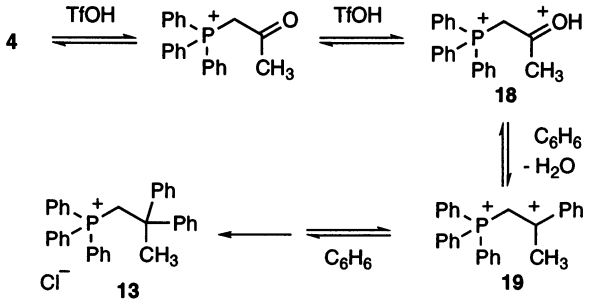
STARTING MATERIAL	PRODUCT	YIELD[a]
 **1**	 **10**	99%
 **2**	 **11**	95%
 **3**	 **12**	92%
 **4**	 **13**	88%
 **5**	 **14**	96%
 **6**	 **15**	92%
 **7**	 **16**	96%
 **8**	 **17**	99%
 **9**	 **13**	(R = H) 85% (R =TMS) 81%

[a]Isolated yields of the crude products.

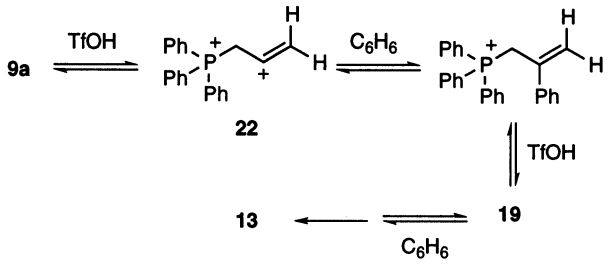
tion. Compounds **5** and **6** react through the more highly substituted carbocations while **7** reacts through the resonance stabilized carbocation. When compound **8** is reacted with C_6H_6 in TfOH, product **17**[11] is formed as the only major product. Compound **17** is apparently the result of the rapid equilibration of the dicationic intermediates and subsequent reaction with benzene. Thus, protonation of **8** initially gives the 1,4-dication (**20**), equilibration with the acid provides the 1,5-dication (**21**), and reaction with benzene yields **17**. This equilibration can be explained by electrostatic effects; the separation of the two charge centers lowers the energy of the intermediate.



The propargyl phosphonium salt (**9a**) and the trimethylsilylpropargyl phosphonium salt (**9b**) also react with C_6H_6 in TfOH to give the addition product



Scheme 1.



Scheme 2.

(**13**) in good yields (Table 1). We propose that these conversions go through the novel phosphonium–vinyl dication (**22**) and the phosphonium–carbenium dication (**19**, Scheme 2). In the case of **9b**, the conversion also includes a step involving the protolytic cleavage of the silyl group.

In summary, we have found that propargyl and olefinic phosphonium salts react in superacid to give addition products in high yields. Phosphonium-substituted aldehydes and ketones also react with benzene in superacid to give condensation products in good yields. We propose a series of dicationic electrophiles as intermediates for these reactions. In one case, the dicationic electrophile can be directly observed by low-temperature NMR spectroscopy. Our results also indicate that the phosphonium group can enhance the reactivity of adjacent electrophilic sites, such as carboxonium groups.

Acknowledgements

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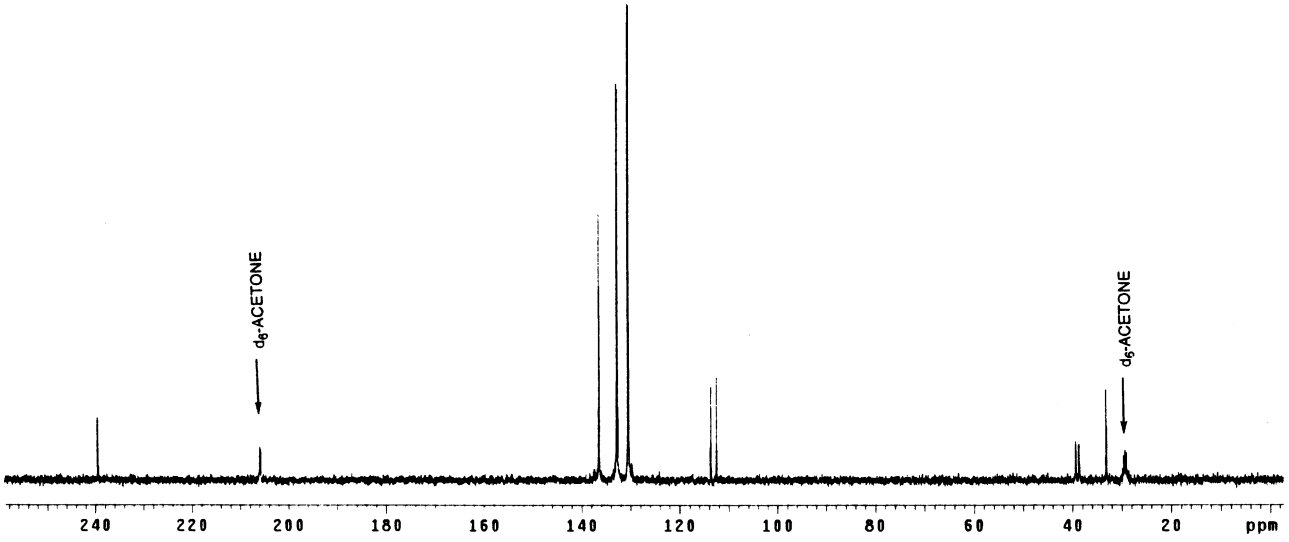

Figure 1. ^{13}C NMR spectrum of the dication **18** from the reaction of **4** with FSO_3H–SbF_5 in SO_2ClF at −60°C.

1964; Vol. 2, pp. 597–640; (b) March, J. In *Advanced Organic Chemistry*, 4th ed.; Wiley: New York, 1992; pp. 548–549; (c) An exception to this involves carboxonium ions adjacent to strong electron-withdrawing groups, such as -CF_3 and -CCl_3; see for example: Kray, W. D.; Rosser, R. W. *J. Org. Chem.* **1977**, *42*, 1186.

9. (a) For a review of TfOH chemistry, see: Stang, P. J.; White, M. R. *Aldrichim. Acta* **1983**, *16*, 15; (b) TfOH may be quantitatively recycled; for a procedure, see: Booth, B. L.; El-Fekky, T. A. *J. Chem. Soc., Perkin Trans. 1* **1979**, 2441.
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11. Analytical data of selected compounds.
Product **10**: ^{1}H NMR ($CDCl_3$): δ 4.18–4.25 (m, 3H), 6.96–7.10 (m, 6H), 7.20–7.28 (m, 4H), 7.48–7.66 (m, 15H); ^{13}C NMR ($CDCl_3$): δ 28.9 (d, $J_{C-P}=81.9$ Hz), 46.5 (d, $J_{C-P}=3.5$ Hz), 117.8 (d, $J_{C-P}=142.8$ Hz), 127.5, 127.6, 129.4, 130.6 (d, $J_{C-P}=20.9$ Hz), 133.7 (d, $J_{C-P}=16.7$ Hz), 135.3 (d, $J_{C-P}=5.0$ Hz), 142.3 (d, $J_{C-P}=13.3$ Hz); mp (MeOH:Et_2O): 137–138°C.
Product **13**: ^{1}H NMR ($CDCl_3$): δ 1.69 (s, 3H), 4.40 (d, $J=12.6$ Hz, 2H), 7.09–7.13 (m, 10H), 7.53–7.67 (m, 15H); ^{13}C NMR ($CDCl_3$): δ 29.7, 35.1 (d, $J_{C-P}=82.0$ Hz), 46.4 (d, $J_{C-P}=5.6$ Hz), 118.4 (d, $J_{C-P}=140.9$ Hz), 127.2, 127.3, 128.9, 130.4 (d, $J_{C-P}=20.9$ Hz), 133.8 (d, $J_{C-P}=16.6$ Hz), 134.9 (d, $J_{C-P}=4.8$ Hz), 146.1 (d, $J_{C-P}=13.8$ Hz); mp (MeOH:Et_2O): 175–177°C.
Product **17**: ^{1}H NMR ($CDCl_3$): δ 1.15 (d, $J=3.9$, 1.5 Hz, 3H), 1.43 (m, 2H), 1.78 (m, 1H), 2.20 (m, 1H), 2.74 (m, 1H), 3.16–3.42 (m, 2H), 7.04–7.29 (m, 5H), 7.48–7.76 (m, 15H); ^{13}C NMR ($CDCl_3$): δ 20.6 (d, $J_{C-P}=7.1$ Hz), 22.1 (d, $J_{C-P}=84.0$ Hz), 23.0, 37.8 (d, $J_{C-P}=25.6$ Hz), 39.1, 118.4 (d, $J_{C-P}=147.3$ Hz), 126.4, 127.3, 128.8, 130.7 (d, $J_{C-P}=20.8$ Hz), 133.6 (d, $J_{C-P}=16.1$ Hz), 135.3 (d, $J_{C-P}=4.8$ Hz), 146.2; clear oil.