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Regioselective Proton Abstraction and 1,3-Migration of a Phosphorus Group in 1,3-Dienes by Iron Coordination: A New Method for the Synthesis of α-Phosphono-α,*β*-unsaturated Ketones

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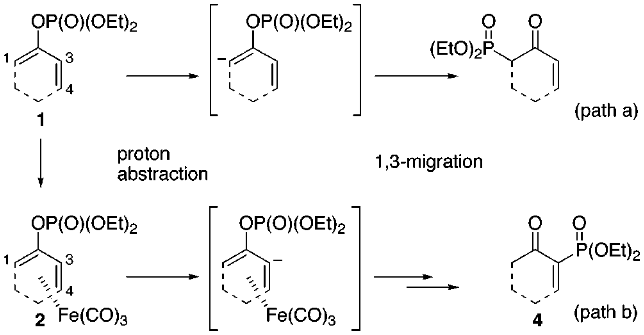
Vinylphosphonates containing various functional groups have been widely studied due to their synthetic usefulness.[1] We previously reported that vinylphosphonates having an electron-withdrawing group at the α-position underwent Lewis acid-catalyzed cyclizations, for example, intramolecular ene reactions,[2] [2 + 2] cycloadditions,[3] and Nazarov cyclizations.[4] Our interest in vinylphosphonate chemistry led us to explore the synthesis of cyclic vinylphosphonates bearing an electron-withdrawing group, that is, α-phosphono-α,*β*-unsaturated cyclic ketones. Although a few reports on the preparation of such kinds of cyclic vinylphosphonates have been found, the preparation procedures are considered to be too lengthy.[5] Thus, the need for a convenient and general method for the preparation of the cyclic vinylphosphonate is manifest.

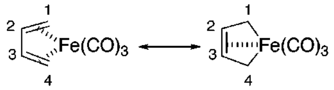
1,3-Migration of phosphorus from oxygen to carbon is convenient for preparing *β*-keto phosphonates (path **a** in Scheme 1), since dienyl phosphates are easily obtained and rearranged regioselectively to the C-1.[6] This reaction involves regioselective proton abstraction at the *C-1* of dienyl phosphate **1** and subsequent migration of phosphorus to give *β*-keto phosphonate. We envisioned that the migration might be used for the preparation of α-phosphono-α,*β*-unsaturated ketone if regioselective abstraction of the proton at the *C-3* in **1** could be performed.

Iron-1,3-diene complexes have a half-sandwich structure and are described by the following resonance forms (Scheme 2). Considering these forms, the complex would have dialkylmetal characters to some extent, and C-1 and C-4 carbons of the 1,3-diene part would have greater sp^3 character than C-2 and C-3 carbons.[7] It can, therefore, be presumed that when the complex **2** is treated with a strong base the proton abstraction would occur at C-3 and phosphorus would successively migrate to C-3 to give phosphonoenone **4** after demetalation (path **b** in Scheme 1). We now report the first example of the controlled regioselectivity of the proton abstraction from 1,3-diene by iron coordination[8] and a convenient method for the synthesis of α-phosphono-α,*β*-unsaturated cyclic ketones using iron−diene complexes.

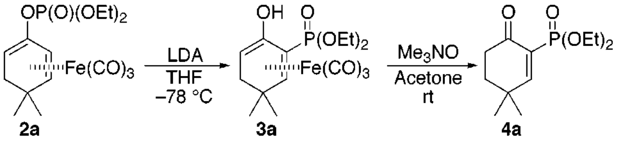
Scheme 1



Scheme 2



Iron complex **2a** was easily prepared from a dienyl phosphate and (η^4-benzylideneacetone)tricarbonyliron[9] in 43% yield. Treatment of **2a** with 2.2 equiv of LDA at −78 °C selectively furnished 1,3-phosphorus migration product **3a** in 78% yield (eq 1). This demonstrates that coordination of Fe(CO)$_3$ to the diene dramatically altered the regioselectivity of the proton abstraction. Removal of the iron moiety from **3a** was accomplished by the oxidation with Me_3NO,[10] giving the desired α-phosphono-α,*β*-unsaturated cyclic enone **4a** in 95% yield (eq 1).



(1)

Various iron−diene complexes **2b**−**l** having a phosphate group were prepared from dienyl phosphates **1b**−**l** and were subjected to treatment with LDA. As summarized in Table 1, the phosphorus migration to C-3 of cyclic and acyclic diene complexes proceeded smoothly to give the corresponding products **3** in good yields (except for **2d**, entry 4). Interestingly, iron−diphenyl dienyl phosphonate complex **2c** was converted to iron-coordinated α-phosphono-α,*β*-unsaturated ketone **3c** (entry 3). In contrast to this result, Wiemer reported that phosphorus migration to the aromatic ring was observed when diphenyl vinyl phosphate was treated with LDA.[11] Therefore, we conclude that acidity of a proton at C-3 of the iron−diene complex is higher than that of an aromatic proton at the ortho position of the oxygen. For acyclic complexes **2i**−**m**, it is of interest to mention that the elimination was suppressed by iron coordination and that the phosphorus migration to the C-3 occurred exclusively to give iron-coordinated α-phosphono-α,*β*-unsaturated ketones **3i**−**m**, since treatment of

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[1] For recent reviews, see: Minami, T.; Motoyoshiya, J. *Synthesis* **1992**, 333; Minami, T.; Okauchi, T.; Kouno, R. *Synthesis* **2001**, 349.

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[7] The right form in Scheme 2 is equivalent to the population of back-bonding to the LUMO of butadiene. Back-bonding is not so extensive in metal complexes with carbonyl ligands. However, C-3−C-4 and C-1−C-2 bonds in diene-iron complexes are elongated compared with free butadiene, and pyramidalization angles at C-1 and C-4 are greater than those of C-2 and C-3. These are interpreted that back-bonding in diene-iron complexes is strong enough to increase sp^3 character of C-1 and C-4 higher than that of C-2 and C−3. See, Deeming. A. J. Mononuclear Iron Compounds with $\eta2-\eta6$ Hydrocarbon Ligands. In *Comprehensive Organometallic Chemistry*; Wilkinson, G., Stone, F. G. A., Abel, E. W., Eds.; Pergamon: Oxford, 1982; Vol. 4, p 377.

[8] The anion generation from iron−cyclobutadiene complexes is known. However, this is a special case and distinct from normal diene−iron complexes: see, Bunz, U. H. F. *Organometallics* **1993**, *12*, 3594.

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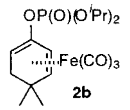
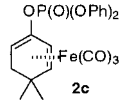
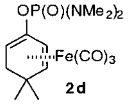
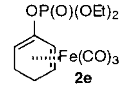
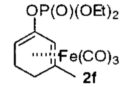
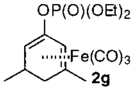
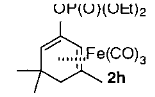
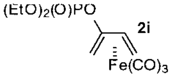
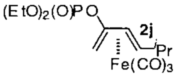
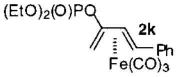
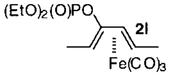
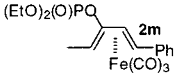
10.1021/ja016958r CCC: $20.00

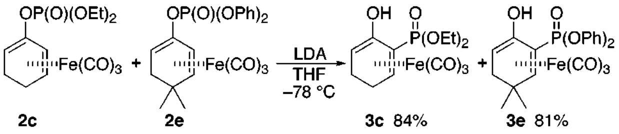
Table 1. 1,3-Phosphorus Migration of Iron Complexes **2**[a]

entry	iron complex, **2**	time (h)	product, **3**	yield (%)[b]
1	**2a**	1	**3a**	quant.
2	 **2b**	2	**3b**	64[c]
3	 **2c**	1	**3c**	87
4	 **2d**	2	–	–
5	 **2e**	1	**3e**	quant
6	 **2f**	0.5	**3f**	96
7	 **2g**	1	**3g**	89
8	 **2h**	1	**3h**	quant.
9	 **2i**	1.5	**3i**	quant.
10	 **2j**	1	**3j**	96
11	 **2k**	1	**3k**	92
12	 **2l**	1	**3l**	88
13	 **2m**	1	**3m**	93

[a] Iron complex **2**, LDA (2.2 equiv) were reacted in THF at −78 °C. [b] Isolated yield. [c] Reaction run at −63 °C.

iron-free acyclic dienyl phosphates with LDA produces enynes with an elimination of the diethyl phosphoric group.[12]

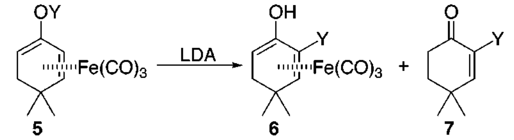
To determine whether this migration occurred inter- or intramolecularly, a crossover experiment was conducted (eq 2).



(2)

Treatment of an equimolar mixture of **2c** and **2e** with LDA only provided products **3c** and **3e**, indicating that the migration is an intramolecular process.

Table 2. 1,3-Migration of a Sulfonyl or Benzyl Group in Iron Complex **5**[a]

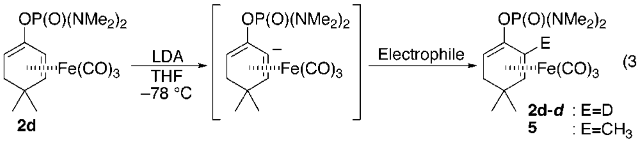


entry	**5**, Y	temp (°C)	time	yield of **6**(%)[b]
1	**5a**, $CF_3(CF_2)_3SO_2$	−78	5 min	80
2	**5b**, CF_3SO_2	−78	5 min	83
3	**5c**, PhCO	0	0.5 h	96[c]

[a] Iron complex **5**, LDA (1.1 equiv) were reacted in THF at −78 °C. [b] Isolated yield. [c]**7** was obtained.

A similar reaction of several iron−diene complexes bearing a sulfonyloxy or benxyloxy group was investigated. The results are shown in Table 2. The migration proceeded quite successfully to give the expected iron complexes **6** or the corresponding decomplexed enones **7**. When the complex with a migrating group having acidic protons, such as a methanesulfonyl or acetyl group, was employed, no migration product was obtained; instead, iron−dienol complex **5** (Y = H) was formed quite rapidly even at low temperature.

Next, we tried to trap the anion intermediate of the iron−diene complex by an electrophile intermolecularly.[13] Complex **2d** was selected as the starting substrate because its phosphonic amide group did not migrate (Table 1, entry 4). **2d** was treated with LDA under the same conditions as shown in Table 1, and then D_2O was added into the reaction mixture at −78 °C (eq 3). ^{1}H NMR integration of recovered **2d** (82%) showed 93% deuterium incorporation at C-3. An attempt to trap the generated anion by iodometane afforded the alkylated complex **8** in 76% yield. These are the first examples of generation of the anion from an iron−diene complex and of its reaction with an electrophile.



(3)

In conclusion, iron coordination to 1,3-diene with a phosphate group allows proton abstraction at C-3 and subsequent 1,3-migration or alkylation to occur. Removal of the iron moiety from the migration product gives α-phosphono-α,*β*-unsaturated ketones. This procedure provides a new approach to synthesize cyclic vinylphosphonates bearing an electron-withdrawing group. Furthermore, iron−diene complexes with a sulfonyl or an acyl goup are also successfully employed in this reaction. These results indicate that the acidity of protons at C-2 and C-3 of the iron−1,3-diene complex may be higher than that of the C-1 and C-4 protons.

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Supporting Information Available: Detailed experimental procedures including spectroscopic and analytical data (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

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