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Selective preparation of 1,3-butadienyl phosphines, 1-iodo- and 1,4-diiodo-butadienyl phosphine oxides via zirconocene-mediated cross-coupling of alkynylphosphines

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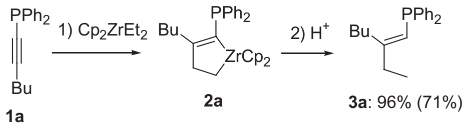
Abstract—Stereodefined butadienyl phosphines and related derivatives were readily prepared in high yields with perfect regioselectivity via the zirconocene-mediated pair-selective coupling of alkynylphosphines with ethylene or alkynylphosphines with normal alkynes. Interesting and synthetically useful iodination reactions were found when the in situ generated α-phosphinozirconacyclopentenes or α-phosphinozirconacyclopentadienes were treated with I_2.

Tertiary phosphines and their oxides are the most popular ligands in organometallic chemistry and in coordination chemistry.[1] The nature of these ligands has critical influences on the reactivity of catalysis.[1,2] Therefore, development of synthetically useful methods for a variety of tertiary phosphines and their oxides with a wide structural diversity continues to be a very attractive area. Among a number of known methods,[3,4] the zirconocene-mediated procedure has been demonstrated to be useful.[5] For example, preparation of phospholes from zirconacyclopentadienes and $PhPCl_2$,[6–8] and preparation of 1,4-diphosphino-1,3-butadienes from CuCl-mediated reaction of zirconacyclopentadienes with Ph_2PCl have been achieved.[9] As part of our continuing interest in the development of synthetic methodologies using the zirconocene-mediated selective coupling of unsaturated substrates,[10] we examined coupling reaction of alkynylphosphines,[7a,11] aiming at development of preparative methods for tertiary phosphines with one alkenyl substituent, especially butadienylphosphines and related compounds, which are potentially very important ligands and are not readily available via known methods.

We found that stereodefined butadienyl phosphines could be readily prepared in high yields with perfect regioselectivity from an alkynylphosphine and a different alkyne. Interesting and synthetically useful iodination reactions were found when the in situ generated α-phosphinozirconacyclopentenes or α-phosphinozirconacyclopentadienes were treated with I_2. In this paper, we report our preliminary results.

First, we investigated the pair-selective coupling of alkynylphosphine **1a** with zirconocene–ethylene complexes, which were generated in situ from Cp_2ZrEt_2.[12] The alkenyl(diphenyl)phosphine **3a** was formed in 96% GC yield (71% isolated yield) with perfect regio- and stereoselectivity (Scheme 1).

In order to synthesize alkenylphosphines with more functional groups, we treated the in situ generated intermediate **2a** with I_2. Interestingly, we found that **2a** reacted with I_2 in a different manner from the known iodination reaction of zirconacyclopentenes.[13] The



Scheme 1.

Keywords: Alkynylphosphine; Cross-coupling; 1-Iodo-1-phosphino-1,3-butadiene; 1,3-Butadienyl phosphine; Zirconacyclopentene; Zirconacyclopentadiene.

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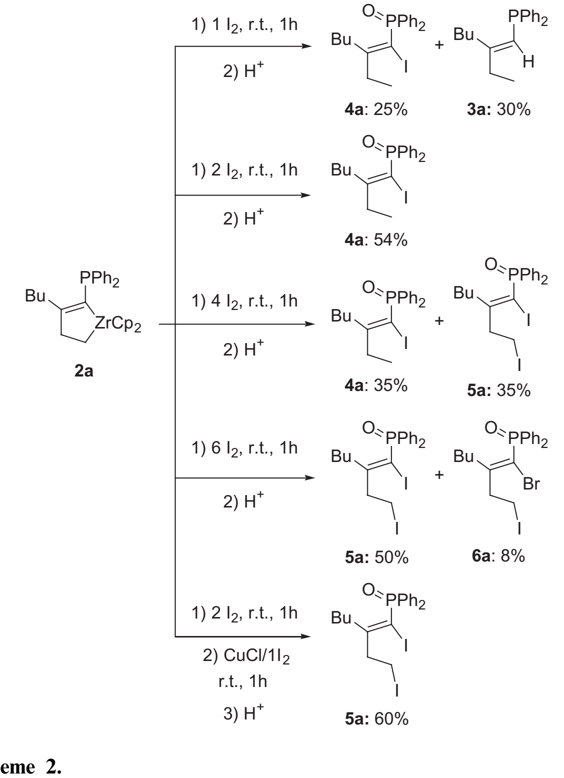
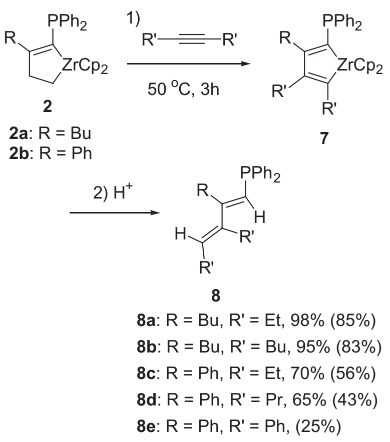
results are given in Scheme 2. When 1 equiv of I_2 was used, hydrolysis of the reaction mixture with aqueous 3 N HCl afforded a mixture of two products **4a** and **3a**. When 2 equiv of I_2 were used, the iodinated product **4a** was formed exclusively in 54% isolated yield. No formation of other iodinated products was observed. The P atom in the product was completely oxidized to be pentavalent alkenylphosphine oxides. If the amount of I_2 was increased to 4 equiv, the diiodination product **5a** appeared. When 6 equiv of I_2 were used, the monoiodination product **4a** disappeared. In addition to **5a**, mixed halogenated product **6a** was also formed. The Br atom in **6a** came from magnesium salt, which was in situ formed by the reaction of EtMgBr with Cp_2ZrCl_2 for the formation of Cp_2ZrEt_2.[12] The desired diiodo compound **5a** was formed as the only product in good isolated yield when **2a** was first treated with 2 equiv of I_2 and followed by further treatment with 1 equiv of CuCl, and 1 equiv of I_2.[14] These results indicate that (1) the Zr–C^{sp2} bond of zirconacyclopentene **2a** is much more easily iodinated than the Zr–C^{sp3} bond; (2) iodine oxidizes the P atom more easily.

Zirconocene-mediated cross-coupling of two different alkynes has been developed and applied to the synthesis of various useful compounds. In order to develop preparative methods for butadienylphosphines and related compounds, we treated the in situ generated α-phosphinozirconacyclopentenes **2** with a different alkyne. After the reaction mixture was stirred at 50 °C for 3 h, α-phosphinozirconacyclopentadienes **7** were formed in quantitative NMR yield. Hydrolysis of the reaction mixtures with aqueous 3 N HCl afforded all-*trans* 1,3-butadienyl diphenylphosphines **8** in good to excellent yields (Scheme 3). It is noteworthy that only the cross-coupling product **8** was formed in most cases. When diphenylacetylene was used as the second alkyne, in addition to the desired cross-coupling product **8e**, homocoupling product of diphenylacetylene was also obtained in 19% isolated yield. To ascertain the stereo- and regiochemistry of the product, the structure of **8e** was determined by single-crystal X-ray analysis (Fig. 1).

Like the case for iodination of the in situ generated α-phosphinozirconacyclopentene **2a**, treatment of α-phosphinozirconacyclopentadienes **7** with I_2 revealed an interesting result.[14] As demonstrated in Scheme 4, a mixture of two products, the hydrolyzed product **8a**, and the monoiodinated product **9a**, was formed when **7a** was treated with 1 equiv of I_2. When 2 equiv of I_2 were used, the 1-iodo-1,3-butadienyl phosphine oxide **9a** was formed as the only product in 65% isolated yield. If **7a** was first treated with 2 equiv of I_2, followed by addition of CuCl and I_2,[14] 1,4-diiodo-1,3-dienyl phosphine oxide **11a** was formed exclusively in 56% isolated yield. These results again demonstrated that (1) the Zr–C bond attached with the Ph_2P moiety reacted with I_2 more readily; (2) the P atom was oxidized more easily due to the existence of the *gem*-I;[15] (3) both monoiodo- and diiodo-1,3-dienyl phosphine oxides **9**, and **11** could be readily prepared in high yields with perfect selectivity.



Scheme 2.



Scheme 3.

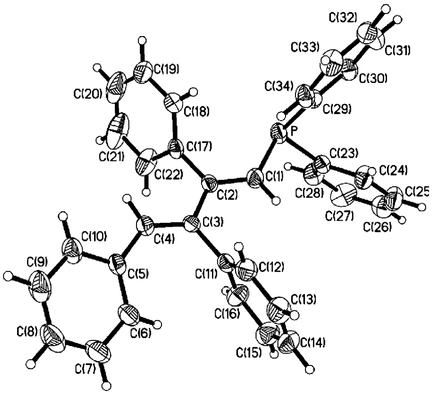
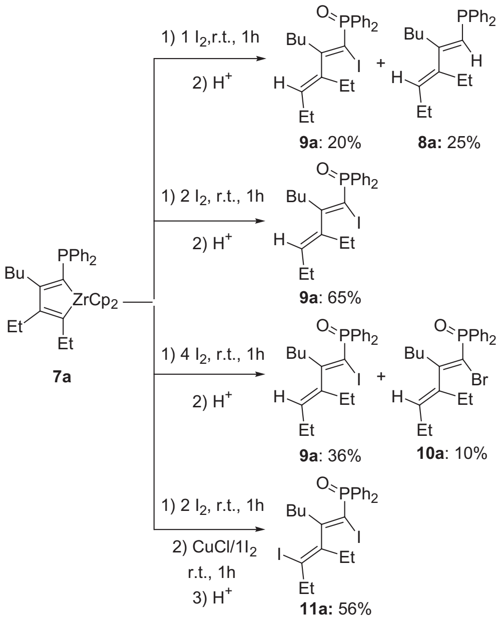


Figure 1. Single-crystal structure of **8e**.



Scheme 4.

In summary, we have demonstrated that Ph_2P-substituted zirconacycles have interesting reactivities toward iodination. Significantly, these reactions reported in this paper provide valuable synthetic methods for butadienyl phosphines and related compounds, including 1-phosphino-1,3-dienes, 1-iodo-1,3-dienyl phosphine oxides, and 1,4-diiodo-1,3-dienyl phosphine oxides. Further investigation into the scope, limitation, and application of the reactions is in progress.

Acknowledgements

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