Double Ortho-lithiation of (Diethylamino)diphenylphosphine Oxide and *tert*-Butyldiphenylphosphine Oxide

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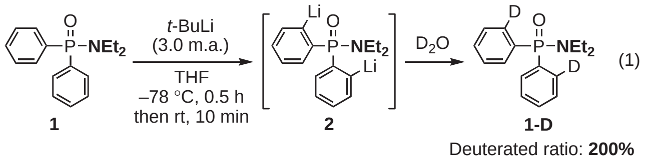
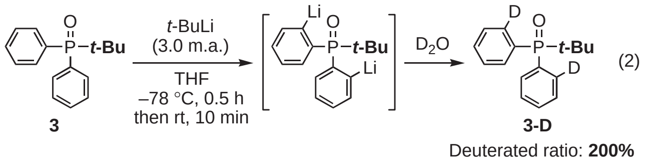
We have developed the double ortho-lithiation of a (diethylamino)diphenylphosphine oxide and *tert*-butyldiphenylphosphine oxide. The resulting doubly lithiated species can be converted to various ortho-difunctionalized products as well as phosphorus heterocycles, such as dibenzophospholes and 9-phospha-10-metalla-9,10-dihydroanthracene derivatives. The structure and photophysical properties of the prepared 9-phospha-10-sila-9,10-dihydroanthracene derivative were also studied.

The hydrogen–metal exchange reaction on the aromatic ring is a versatile method for the preparation of functionalized arenes from the viewpoint of synthetic efficiency.[1] The metalation is directed by a certain atom (F etc.) or functional group (OR, NR_2, amide, ester, etc.), called the directing group. A heavier element-containing group, such as the phosphoryl group[2] and aminosilyl group,[3] can also direct the reaction to produce a main group element-containing π-electron system which has drawn much attention because of its characteristic electronic properties derived from the orbital interaction between the element and the C=C π-conjugated framework.[4]

Most of many previous reports have dealt with single-metalation, by which one aromatic ring is metalated with the assistance of a directing group. In contrast, there are only a few examples of double metalation, by which two aromatic rings in a molecule are simultaneously metalated.[5,6] The resulting bis(metaloarene)s would be good precursors for the simultaneous functionalization of two aromatic rings as well as for the construction of a cyclic structure by the intramolecular oxidative coupling or reaction with difunctional electrophiles. In this paper, we present the double ortho-lithiation[7–9] of (diethylamino)diphenylphosphine oxide (**1**) and the transformation of the dilithio species to phosphole *P*-oxide and 9-phospha-10-metalla-9,10-dihydroanthracene derivatives.

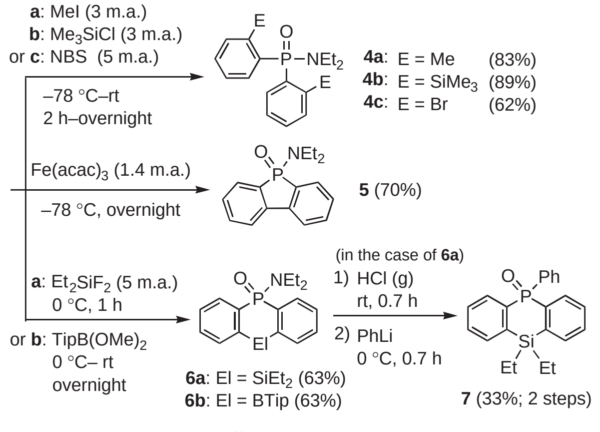




The optimized procedure of the double ortho-lithiation of **1** is shown in eq 1. Thus, (diethylamino)diphenylphosphine oxide (**1**) was treated with 3 molar amount (m.a.) of *tert*-butyllithium (pentane solution) in THF at −78 °C for 0.5 h and the reaction mixture was stirred at room temperature for 10 min. The yield of the lithiation was evaluated by the ^{1}H NMR analysis of the deuterated product **1-D** which resulted in the deuterated ratio of 200%,[10] indicating that the double ortho-lithiation quantitatively took place under these reaction conditions. The perfect double ortho-lithiaton of the *tert*-butyldiphenylphosphine oxide also took place under these reaction conditions (eq 2). This observation is in sharp contrast to the reaction of the triphenylphosphine oxide with *tert*-butyllithium, which affords a mixture of the mono ortho-lithiated triphenylphosphine oxide and partially ortho-lithiated *tert*-butyldiphenylphosphine oxide, generated by the in situ substitution of one phenyl group into a *tert*-butyl group.[2a] Hereinafter, we deal with the further transformation of the doubly lithiated species generated from **1** due to the versatility of the amino group which can be easily replaced by other groups.

Thus, the doubly lithiated species **2** was transformed into some doubly ortho-functionalized (diethylamino)diphenyl-phosphine oxides as summarized in Scheme 1.[11] The doubly lithiated species **2** was treated with an excess amount of methyl iodide, chlorotrimethylsilane, or *N*-bromosuccinimide to afford the corresponding doubly ortho-methylated-, silylated-, or brominated product **4a**–**4c** in good isolated yields. These new compounds were fully characterized by ^{1}H, ^{13}C, and ^{31}P NMRs and mass spectra as well as elemental analysis.

The intramolecular cyclization reactions of **2** were also conducted to prepare the phosphorus-containing dibenzo-heterocyclic compounds. Thus, the intramolecular oxidative coupling of **2** with tris(acetylacetonato)iron(III) at −78 °C afforded the dibenzophosphole derivative **5** in a 70% isolated yield. The forma-



Scheme 1.

tion of the dibenzophosphole framework was confirmed by NMR spectroscopy and single-crystal X-ray crystallography.[12] To the best of our knowledge, the present method constitutes a new class of dibenzophosphole syntheses based on the oxidative cyclization of di(*ortho*-lithiophenyl)phosphorus derivatives.[13,14]

The doubly ortho-lithiated species **2** was also converted into the 9-phospha-10-metalla-9,10-dihydroanthracene derivatives by the reaction with difunctional electrophiles under high dilution conditions (ca. 0.03 M). Thus, the reactions of **2** with diethyldifluorosilane (5 m.a.) and dimethyl 2,4,6-triisopropylphenylborate ($TipB(OMe)_2$; 2 m.a.) at 0 °C afforded the corresponding 9-phospha-10-metalla-9,10-dihydroanthracene derivatives **6a** (63%) and **6b** (63%), respectively.[15] The only by-product derived from **2** was the starting material **1**.

Product **6a** was further transformed into the *P*-phenyl-substituted compound **7** by the substitution reaction of the diethylamino group into a chlorine atom using dry HCl gas, followed by the reaction with phenyllithium. The structure of **7** was determined by X-ray crystallography. There are two crystallographically independent molecules, and one of them is shown in Figure 1a.[12] The P···Si distances (3.3521(8) and 3.4050(9) Å) are smaller than the sum of the van der Waals radii (P 1.90 Å and Si 2.00 Å), while other bond lengths and angles around the phosphorus and the silicon centers are within the normal range.

Figure 1b shows the electronic spectra of **7** measured in cyclohexane at room temperature. The absorption band of the π–π^* transition appears at 268–279 nm. The fluorescence spectrum (excitation at 260 nm) shows a maximum at 313 nm. These absorption and emission maxima are red-shifted by ca. 10 and 30 nm, respectively, as compared to those observed for the parent 9,10-dihydroanthracene.[16] The fluorescence excitation spectrum (emission at 300 nm) virtually coincides with the absorption band. Detailed studies on the photophysical properties of the 9-phospha-10-metallaanthracenes are now in progress and will be reported elsewhere.

In summary, we have developed the double ortho-lithiation of (diethylamino)diphenylphosphine oxide and *tert*-butyldiphenylphosphine oxide. The present method provides a concise route for ortho-difunctionalized diarylphosphine oxides as well as the phosphorus-containing heterocycles, such as the dibenzophosphole and 9-phospha-10-metalla-9,10-dihydroanthracene derivatives. The present work would provide a hint for the development of a general method for the main group element-directed double ortho-metalation.

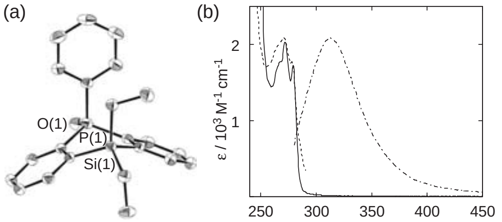


Figure 1. (a) ORTEP drawing of the 9-phospha-10-sila-9,10-dihydroanthracene derivative **7** with thermal ellipsoid plot (50% probability). P(1)···Si(1) distance: 3.3521(8) Å. (b) UV absorption (solid line), fluorescence (chain line), and fluorescence excitation (broken line) spectra of **7** in cyclohexane at room temperature.

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References and Notes

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9 There is one example of the double lithiation of dithienylphosphoryl compounds, but the double ortho-lithiation of simple diphenylphosphoryl compounds is unprecedented. See Ref. 6 (e).

10 In this manuscript, the "deuterated ratio = 200%" means that each on the ortho-protons of both benzene rings has been quantitatively deuterated.

11 A typical procedure. To a suspension of **1** (1.37 g, 5.0 mmol) in THF (10 mL) was added a 1.48 M pentane solution of *t*-BuLi (10 mL, 15.0 mmol) at −78 °C. The reaction mixture was stirred for 30 min at this temperature and then at 0 °C for 30 min. To monitor the degree of lithiation, an aliquot of the reaction mixture was taken and quenched with D_2O. The ^1H NMR measurement determined the deuterated ratio to be 200%. The resulting solution of the dilithiated species **2** was used for further reactions.

12 Crystallographic data reported in this manuscript have been deposited with Cambridge Crystallographic Data Centre as supplementary publication Nos. CCDC-607521 for **5** and CCDC-607522 for **7**. Copies of the data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge, CB2 1EZ, UK; fax: +44 1223 336033; or deposit@ccdc.cam.ac.uk).

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