Regioselective Metalation of a Tertiary Phosphine. Solution and Solid-State Structures of an Unusual Aminobenzyllithium Complex

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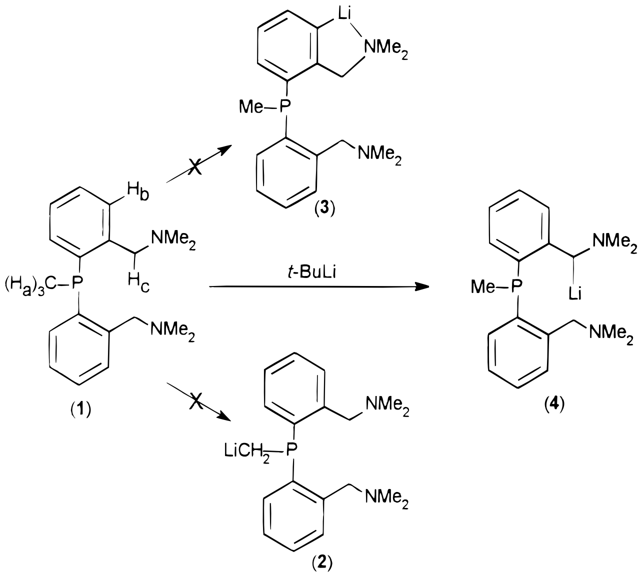
Summary: Metalation of the tertiary phosphine MeP-(C_6H_4-2-CH_2NMe_2)$_2$ with t-BuLi proceeds exclusively to give the novel dimeric benzyllithium complex [MeP(C_6H_4-2-CH_2NMe_2){C_6H_4-2-CH(Li)NMe_2}]$_2$; variable-temperature NMR studies show that this complex undergoes a novel dynamic process in solution.

The synthesis of phosphinomethanide complexes, Li-($R_2CPR'_2$), by the reaction of tertiary phosphines of the form (R_2CH)PR'_2 with strong bases such as *n*-BuLi/tmeda or *t*-BuLi has been well documented, and many examples of such complexes have been isolated and structurally characterized.[1] We recently reported that the acidity of the CH group adjacent to P in (Me_3Si)$_2$CHP(C_6H_4-2-CH_2NMe_2)$_2$ is kinetically enhanced through chelation assistance by the additional NMe_2 donor functionality on the periphery of the ligand.[2] We were interested to explore whether such enhanced reactivity would be exhibited by donor-functionalized tertiary phosphines which do not contain charge-stabilizing silicon substituents or whether the donor functionality would favor chelation-assisted orthometalation of the aryl ring in such cases.[3] We report the selective metalation of the tertiary phosphine MeP-(C_6H_4-2-CH_2NMe_2)$_2$ (**1**), the solid-state structure of the corresponding lithium complex, and its unusual dynamic behavior in solution.

The amino-functionalized tertiary phosphine **1** may potentially undergo deprotonation at any of the three positions H_a, H_b, or H_c (Scheme 1) to give a phosphorus-stabilized carbanion (**2**), an aryllithium (**3**) via chelation-assisted orthometalation of **1** (both of which reactions have ample precedent),[1−3] or a benzyllithium compound (**4**), respectively.[4] Unexpectedly, metalation of **1** with *t*-BuLi in light petroleum yields the benzyllithium derivative [MeP(C_6H_4-2-CH_2NMe_2){C_6H_4-2-CH(Li)-NMe_2}]$_2$ ([**4**]$_2$),[5] in which the carbanion center is immediately adjacent to N, as the sole product (a $^{31}P\{^1H\}$ NMR spectrum of the reaction solution confirms that neither of the alternative products is formed; the phosphinomethanide complex Li[CH_2P(C_6H_4-2-CH_2-NMe_2)$_2$] (**3**) may be synthesized by treatment of **1** with *n*-BuLi, $^{31}P\{^1H\}$ NMR $\delta = -16$ ppm).[6] To our knowl-

Scheme 1



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[4] Although **1** may also potentially undergo deprotonation at the site ortho to phosphorus, this is unlikely in such a crowded molecule and has far less precedent.

[5] A solution of *t*-BuLi (2.30 mL of a 1.7 M solution in pentane, 3.91 mmol) was added to a solution of **1** (1.25 g, 3.98 mmol) in light petroleum (bp 40−60 °C, 10 mL). The reaction mixture was stirred for 1 h, and the precipitate was isolated by filtration and washed with light petroleum (3 × 10 mL). The powder was recrystallized from cold (−20 °C) toluene as deep red, air-sensitive prisms of (*RRSS*,*SSRR*)-[**4**]$_2$·(C_7H_8). Yield of crystalline (*RRSS*,*SSRR*)-[**4**]$_2$·(C_7H_8): 0.73 g, 50.1% based on *t*-BuLi. Anal. Calcd for $C_{45}H_{60}Li_2N_4P_2$: C, 73.75; H, 8.25; N, 7.65. Found: C, 72.98; H, 8.83; N, 7.97. ^1H NMR (500 MHz, [D]$_8$-toluene, 25 °C): δ 1.01 (s, 6H, PCH_3), 2.15 (s, br, 24H, NMe_2), 2.31 (d, 2H, *J*(P,H) 3.4 Hz, CHLi), 2.43 (d, 2H, ^2J(H,H) 12.0 Hz, *J*(P,H) 1.8 Hz, CH_2N), 4.06 (d, 2H, ^2J(H,H) 12.0 Hz, CH_2N), 6.31−7.35 (m, 16H, ArH). ^{13}C NMR (125 MHz, [D]$_8$-toluene, 25 °C): δ 10.4 (d, *J*(P,C) 4.6 Hz, PCH_3), 46.8 (s, br, NMe_2), 65.9 (d, *J*(P,C) 12.2 Hz, CH_2N), 84.1 (s, br, CHLi), 110.3 (d, *J*(P,C) 3.5 Hz, Ar), 111.5 (d, *J*(P,C) 3.5 Hz, Ar), 113.8 (d, *J*(P,C) 11.6 Hz, Ar), 128.4, 129.2 (d, *J*(P,C) 1.5 Hz, Ar), 129.3, 130.1, 130.9 (Ar), 131.4 (d, *J*(P,C) 7.2 Hz, Ar), 131.5 (d, *J*(P,C) 1.8 Hz, Ar), 140.0 (d, *J*(P,C) 23.6 Hz, P−Ar), 151.0 (d, *J*(P,C) 18.6 Hz, P−Ar). $^{31}P\{^1H\}$ NMR (121 MHz, [D]$_8$-toluene, 25 °C): δ −47.6 (septet, *J*(P,Li) 31.6 Hz). ^7Li NMR (117 MHz, [D]$_8$-toluene, 25 °C): δ 0.85 (t, *J*(P,Li) 31.6 Hz).

[6] Clegg, W.; Izod, K.; O'Shaughnessy, P. Unpublished results.

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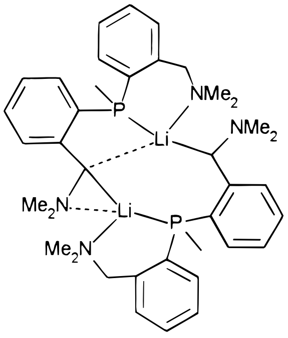

[**4**]$_2$

edge, this represents the first *direct* α-lithiation of a tertiary benzylamine; the regioselective generation of α-carbanions from protected primary and secondary amines via dipole-stabilized intermediates has been reported widely,[7] while recently developed strategies for the α-lithiation of *tertiary* benzylamines include multistep syntheses involving the formation of benzylstannane intermediates[8] and activation of the benzylic site by complexation of the tertiary amine with a Lewis acid.[9]

The molecular structure of [**4**]$_2$ consists of a rather complex asymmetric dimer (Figure 1).[10] The ligand is chiral at both phosphorus and methine carbon centers, and the compound crystallizes as pairs of *RRSS* (with reference to the two P and two C centers, respectively) and *SSRR* stereoisomers. Each lithium atom is primarily associated with a benzylic carbon (and adjacent atoms) from one ligand, with supplementary coordination by N and P groups from the other ligand. The two Li atoms in the dimer are in distinct coordination environments, with Li(1) in close contact with the α-carbon C(36), adjacent ipso- and ortho-carbons C(35) and C(34), N(4) of ligand *A*, and P(1) and N(1) of ligand *B*. The α-carbon C(36) of ligand *A* effectively bridges the two lithium centers. The Li(1)−C(36) distance of 2.222(5) Å is similar to the Li−C distance (2.230(7) Å) in the benzyl-bridged dimer [{$C_6H_5CHNMe_2$}Li(OEt_2)]$_2$;[8b] the Li(2)−C(36) distance (2.465(5) Å) is somewhat greater.

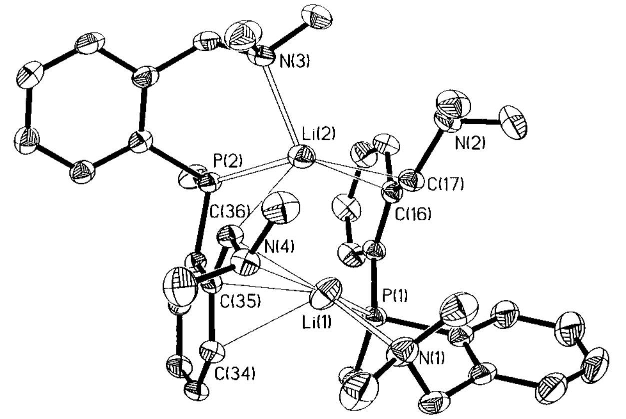

Figure 1. Molecular structure of [**4**]$_2$ without H atoms and with 50% probability thermal ellipsoids. Selected distances (Å): Li(1)−N(1) 2.118(5), Li(1)−P(1) 2.482(4), Li(1)−N(4) 2.029(5), Li(1)−C(36) 2.222(5), Li(1)−C(35) 2.595(5), Li(1)−C(34) 2.756(6), Li(2)−N(3) 2.234(5), Li(2)−P(2) 2.553(4), Li(2)−C(17) 2.302(5), Li(2)−C(16) 2.512(5), Li(2)−C(36) 2.465(5).

The coordination environment of Li(2) is quite different. Li(2) has close contacts with the α- and ipso-carbons C(16) and C(17) of ligand *B* and P(2) and N(3) of ligand *A*, supplemented by weak contact with the bridging α-carbon C(36) of ligand *A*. The observation of multihapto interactions between the benzylic ligands and lithium is consistent with previous reports that bidentate ligands and weak Lewis bases favor η^3-interactions in (dimethylamino)benzyllithium complexes.[8a]

The Li(1)−P(1) and Li(2)−P(2) distances of 2.482(4) and 2.553(4) Å, respectively, are somewhat shorter than other Li−P distances in which phosphorus acts as a neutral donor;[1c,11] the “cross-dimer” Li(1)···P(2) and Li(2)···P(1) distances (4.432 and 3.809 Å, respectively) are greater than the sum of their van der Waals radii (3.65 Å).[12]

Multielement NMR spectra show that the main features of the solid-state structure are maintained in [D]$_8$-toluene solution at 203 K, although some residual internal motion leads to effective C_2 symmetry for the dimer, with only one phosphorus and one lithium environment. There are, however, four proton signals from the NMe$_2$ groups, indicating that, owing to coordination to lithium, inversion of the nitrogen atoms is slow so that each carries two diastereotopic methyl groups. As the temperature is raised, reversible Li−N bond cleavage and concomitant inversion at nitrogen occur (although each type of NMe$_2$ group retains its identity) and the signals coalesce in pairs, with band shape analysis yielding $\Delta G^\ddagger = 109$ and 118 kJ mol^{-1} at 296 K, $\Delta H^\ddagger = 58.2$ and 62.8 kJ mol^{-1}, and $\Delta S^\ddagger = -171$ and -185 J K^{-1} mol^{-1}, respectively.

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[10] Crystal data for [**4**]$_2$·toluene: $C_{38}H_{52}Li_2N_4P_2 \cdot C_7H_8$, fw = 732.8, triclinic, space group $P\bar{1}$, $a = 9.7384(6)$ Å, $b = 13.1535(8)$ Å, $c = 19.0431(12)$ Å, $\alpha = 70.298(2)°$, $\beta = 81.523(2)°$, $\gamma = 68.833(2)°$, $V = 2140.7(2)$ Å^3, $Z = 2$, $D_{calcd} = 1.137$ g cm^{-3}, $\mu = 0.14$ mm^{-1}, $T = 160$ K, crystal size 0.46 × 0.32 × 0.28 mm. Bruker SMART CCD diffractometer, structure solution by direct methods, refinement on F^2, ($2\theta < 57.4°$); $R_w = \{\sum[w(F_o^2 - F_c^2)^2]/\sum[w(F_o^2)^2]\}^{1/2} = 0.1603$ (all data), conventional $R = 0.0630$ on F values of 6732 reflections with $F_o^2 > 2\sigma(F_o^2)$, goodness of fit = 1.026, final difference synthesis within ±0.53 e Å^{-3}.

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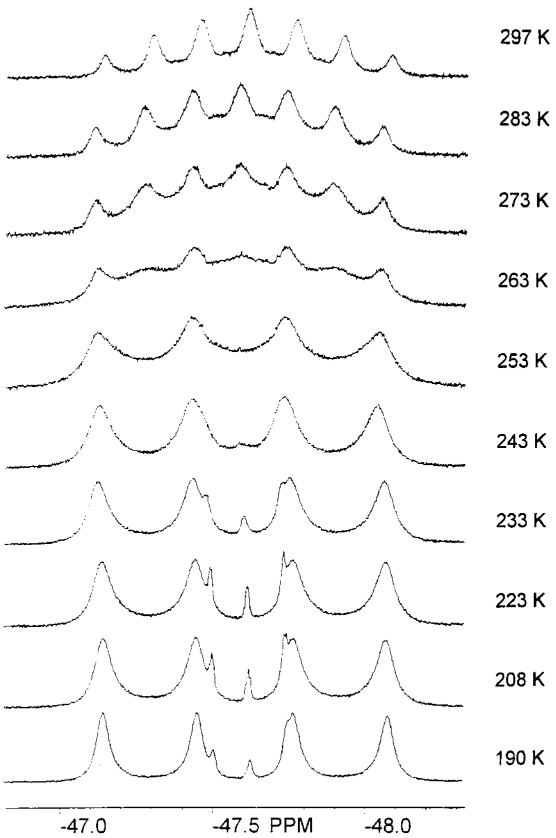

Figure 2. Variable-temperature $^{31}P\{^1H\}$ NMR spectra of [**4**]$_2$. [The sharp triplet observed at low temperature arises from coupling to ^6Li ($I = 1$, 7.42%).]

In addition to this, variable-temperature ^{31}P and ^7Li NMR spectra indicate that [**4**]$_2$ undergoes a highly unusual dynamic process in solution. At 208 K the ^7Li ($I = 3/2$; 92.6%) and ^{31}P ($I = 1/2$; 100%) NMR spectra consist of a doublet ($\delta = 0.93$) and a 1:1:1:1 quartet ($\delta = -47.6$), respectively (Figure 2), indicating the presence of individual LiP units with $^1J(^{31}P-^7Li) = 63.2$ Hz. As the temperature is raised, these signals broaden, and this would normally be attributed to modulation of the coupling by intermolecular exchange so that at higher temperatures the ^7Li and ^{31}P spectra would be expected to be singlets. In fact, at 263 K and above these spectra are a 1:2:1 triplet and a 1:2:3:4:3:2:1 septet, respectively, showing that each phosphorus atom is associated with two lithium atoms and vice versa in a discrete dimeric unit. However, this cannot be a static arrangement involving quasi-symmetrical Li_2P_2 units because (i) these would be expected to be more stable at lower rather than higher temperatures, (ii) they would incorporate five-coordinate phosphorus (unlike the dimer of Ph_2PLi, which has four-coordinate phosphorus), requiring donation from each neutral P^{III} center to *two* lithium atoms, and (iii) the expected $^2J(^{31}P-^{31}P)$ coupling in such a dimer should be large, and the effects of magnetic inequivalence would then lead to additional ^{31}P splittings ("virtual coupling" in an outmoded description) of many of its phenyl proton and ^{13}C resonances [cf. $\{Ph_2PLi\}_2$],[13] whereas ^{31}P decoupling and $^1H/^{13}C$ 2D correlation experiments show that in fact only simple doublets are produced. The proton and ^{13}C methine signals show temperature-dependent broadening due to coupling to ^7Li, but together with the methylene and phenyl resonances are otherwise essentially unaffected by temperature changes; we therefore believe that at higher temperatures an intramolecular dynamic process is occurring that involves reversible P−Li bond cleavage such that each lithium can become associated with either phosphorus (and vice versa) but not both simultaneously. The $^{31}P-^7Li$ splitting is then a time average given by $[^1J(^{31}P-^7Li) + {}^nJ(^{31}P-^7Li)]/2$ ($n > 3$) i.e., $[63.2 + 0]/2 = 31.6$ Hz, as is observed. This behavior has parallels with that of 2-(dimethylaminomethyl)phenyllithium dimer in THF solution, although our dimeric structure is more stable as it persists at room temperature.[14]

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Supporting Information Available: Details of data collection, refinement, atom coordinates, anisotropic displacement parameters, and bond lengths and angles. This material is available free of charge via the Internet at http://www.pubs.acs.org.

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