Reversible Alkylation at the Pyridine Nitrogen in a α,α-Diimine Pyridine Ligand System

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Summary: The reaction of {α,α′-*[2,6-(i-Pr)*$_2$*PhN═C(Me)]*$_2$*-(C*$_5$*H*$_3$*N)}with MeLi resulted in a surprising alkylation at the pyridine nitrogen atom. The MeLi unit may be easily extracted by reaction with i-PrBr to re-form the starting ligand, while rapid thermolysis eliminated methane with deprotonation of one of the two methyl groups attached to the imine function.*

There is something unique in the ability of the popular α,α-diiminopyridine ligand {α,α′-[2,6-(i-Pr)$_2$PhN═C(Me)]$_2$(C$_5$H$_3$N)} to form highly active olefin polymerization catalysts with both late[1] and early transition metals.[2] At first glance, this ligand seems to be a perfectly ancillary one. However, recent work has revealed an unanticipated tendency to be attacked by alkylating agents while coordinated to a variety of metals. Although the remarkable diversity of transformations triggered by this ligand cannot so far be rationalized into a general picture, there are a few trends that can be identified. First, reduction of the metal center seems to be a rather recurrent feature, having been observed for V,[2] Cr,[3] Mn[4] and even for the Co supercatalyst.[5] Second, the ligand system undergoes anionization via either direct alkylation or hydrogen abstraction from one or both of the methyl groups attached to the imine carbon atoms.[3−5] Alkylation may occur at the *ortho*,[2] *meta*,[2] and *para*[3] positions as well as at the imine function.[6] From this complex behavior it is evident that the ligand system is not a spectator one but is instead directly involved in the reactivity of the metal center with possible implications for catalytic activity and performance.

Given the above scenario, we became interested in assessing the reactivity of the free ligand {α,α′-[2,6-(i-Pr)$_2$PhN═C(Me)]$_2$(C$_5$H$_3$N)} itself with alkylating agents *in the absence* of transition metals. In this paper we describe the surprising result of the reaction with MeLi.

The reaction was carried out by adding a solution of MeLi to a suspension of the ligand in diethyl ether, affording a very dark ink-blue/red dichroic solution.[7] Evaporation to dryness and crystallization from heptane yielded dark red crystals of the dimeric {α,α′-[[2,6-(i-Pr)$_2$PhN═C(Me)][C$_5$H$_3$N(Me)]Li}{α,α′-[2,6-(i-Pr)$_2$PhN═C(Me)][C$_5$H$_3$N(Me)]Li(ether)} (**1**). Dark red crystals of **1** dissolved in hexane to re-form the original dark-blue/red dichroic color. The ^{1}H NMR spectrum showed two resonances for the Me groups attached to the N atoms at 2.44 and 2.28 ppm and two sets of pyridine ring protons considerably shifted; in particular, the metalated ring H$_{para}$ appears as a triplet at 5.35 ppm.

An X-ray crystal structure yielded the connectivity (Figure 1).[8] The complex is dinuclear, and it is formed by two nearly identical α,α′-[2,6-(i-Pr)$_2$PhN═C(Me)]$_2$-[(C$_5$H$_3$N(Me)]Li} units. The lithium atom of the first unit coordinates to pyridine C$_{para}$ of the second unit. The second unit has a molecule of ether coordinated to its lithium atom, which prevents further aggregation to a coordination polymer. In both units, the pyridine ring has undergone methylation directly at the pyridine

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(7) A suspension of {α,α′-[2,6-(i-Pr)$_2$PhN═C(Me)$_2$](C$_5$H$_3$N)} (0.1 g, 0.21 mmol) in 5 mL of diethyl ether was treated with a solution of MeLi (0.15 mL, 1.4 M, 0.210 mmol). The color of the solution immediately changed to deep dichroic blue/red. The reaction mixture was allowed to stir at room temperature for 4 h and then evaporated to dryness. The solid residue was redissolved in *n*-heptane (10 mL). The resulting dark blue/red solution was filtered and allowed to stand at room temperature, upon which dark red crystals of **1** separated (0.08 g, 0.15 mmol, 73%). The thermal lability prevented obtaining reproducible analytical data. ^{1}H NMR (500 MHz, toluene-d_8, 23 °C) δ: CH$_{(i-Pr)}$: two septets 4H each at 3.03 and 2.82; Me$_{(i-Pr)}$: six doublets 1:1:1:1:2:2 48H at 1.19, 1.17, 1.15, 1.09, 1.08, 1.01; Me$_{(imino)}$: one singlet 1H at 1.75; Me$_{(N-Me)}$: two singlets 3H each at 2.48 and 2.28; CH$_{(pyridine)}$ two doublets at 7.10 and 6.85 and a triplet at 5.35, and two doublets and one multiplet at 8.40, 7.18, and 7.08 1H each; CH$_{(aromatic)}$ partly overlapping multiplets at 7.20−6.99 12H; ether quadruplet at 3.15 4H and triplet at 0.93 6H. ^{13}C NMR (125.72 MHz, toluene-d_8, 23 °C) δ: (CH$_{(i-Pr)}$): 28.60 and 28.70; (Me$_{(i-Pr)}$): 24.41, 23.95, 23.56, 23.47, 23.22, 22.98; (Me$_{(imino)}$): 16.20; (Me$_{(N-Me)}$): 38.99 and 17.09; (CH$_{(pyridine)}$): 101.10, 119.49, 121.20 122.60, 124.39, 124.03; (CH$_{(aromatic)}$): 121.68, 123.39, 123.45, 123.50, 123.60, 123.99; (CH$_2$ and Me of ether): 31.92 and 16.11; (quaternary C): 131.47, 136.68, 135.90, 137.15, 143.81.

(8) Crystal data. **1**: C$_{36}$H$_{51}$N$_3$LiO$_{0.5}$, M_w = 540.74, triclinic, *P*1̄, a = 13.100(3) Å, b = 15.117(3) Å, c = 18.277(4) Å, α = 78.967(4)°, β = 78.807(4)°, γ = 74.136(4)°, V = 3378.6(12) Å^3, Z = 4, T = 203 K, F_{000} = 1180, R = 0.0776, wR_2 = 0.1550, GoF = 1.074. **2**: C$_{37}$H$_{50}$N$_3$OLi-(toluene)$_{0.5}$, M_w = 606.82, monoclinic, *P*2(1)/*n*, a = 10.8426(14) Å, b = 18.683(3) Å, c = 18.701(3) Å, β = 90.784(2)°, V = 3788.0(9) Å^3, Z = 4, T = 203 K, F_{000} = 1320, R = 0.0722, wR_2 = 0.1988, GoF = 1.37.

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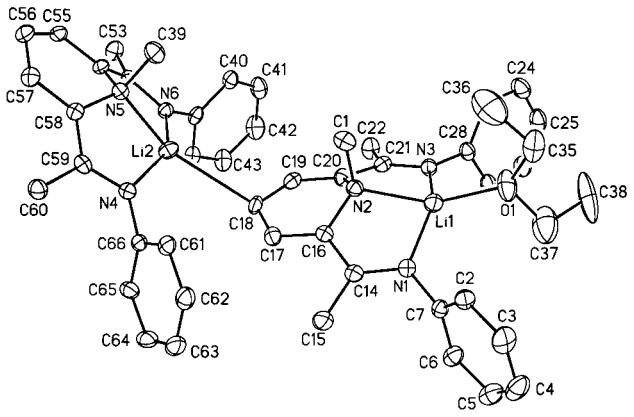


Figure 1. Thermal ellipsoid plot of **1**. Relevant bond distances (Å) and angles (deg) (isopropyl groups have been omitted for clarity): Li(1)−N(1) = 2.17(10), Li(1)−N(2) = 2.055(10), Li(1)−N(3) = 2.133(10), N(2)−C(1) = 1.493(6), N(1)−C(14) = 1.320(6), C(14)−C(15) = 1.518(7), C(21)−C(22) = 1.520(7), C(21)−N(3) = 1.321(6), N(2)−C(16) = 1.477(6), C(16)−C(17) = 1.38(6), C(17)−C(18) = 1.396(7), C(18)−Li(2) = 2.763(10), Li(2)−N(5) = 2.024(10), Li(2)−N(6) = 2.140(10), Li(2)−N(4) = 2.111(10), N(5)−C(39) = 1.501(6), C(59)−C(60) = 1.57(7), C(59)−C(58) = 1.423(7), N(4)−C(59) = 1.328(6).

nitrogen atom [N(5)−C(39) = 1.501(6) Å, N(2)−C(1) = 1.493(6) Å].

The fact that a relatively electron-rich pyridine nitrogen atom was the site of attack of the nucleophilic MeLi adds complexity to the picture of ligand alkylation in its transition metal complexes. For example, is the often observed reduction of the metal center the result of alkyl group radical elimination from the N atom rather than M−C bond homolysis? Is the ring alkylation observed in several instances the result of a merry-go-round type of migration of the alkyl group over the ring and/or imine positions? To probe the robustness of the N−Me bond in **1** and the expected nucleophilicity of the *para* carbon atom, we reacted a solution of freshly prepared analytically pure **1** in hexane with i-PrBr. A reaction took place within a few minutes at room temperature to afford a nearly colorless solution from which colorless crystals of the original {α,α′-[2,6-(i-Pr)$_2$PhN=C(Me)]$_2$(C$_5$H$_3$N)} ligand were isolated in good yield (84%). This implies that the Me group can be abstracted from the nitrogen atom by a mild electrophile, thus indicating that the alkylation at the N atom may be reversible (loss of an alkyl group has also been observed for a C$_{ortho}$-methylated vanadium complex[2]).

Complex **1** is thermally labile, and dark-blue/red solutions in either toluene or heptane turned dark green upon heating for 15 min. The color change is accompanied by a clean modification of the NMR spectrum, clearly indicating transformation into a new species. The formulation as α-[2,6-(i-Pr)$_2$PhN=C(Me)]}-{α′-[2,6-(i-Pr)$_2$PhN−C(=CH$_2$)]}[C$_5$H$_3$N]Li(ether) (**2**) was yielded by NMR and analytical data.[9] The disappearance of the resonances at 2.44 and 2.28 ppm of the methyl groups attached to the pyridine nitrogens of **1** is accompanied by formation of two lines at 4.49 and 3.80 ppm coupled to the same carbon atom at 76.64 ppm and whose identity as CH$_2$ was confirmed by a DEPT experiment.

Suitable crystals of the THF/(toluene)$_{0.5}$ solvate were grown from toluene/heptane/THF mixtures. The crystal

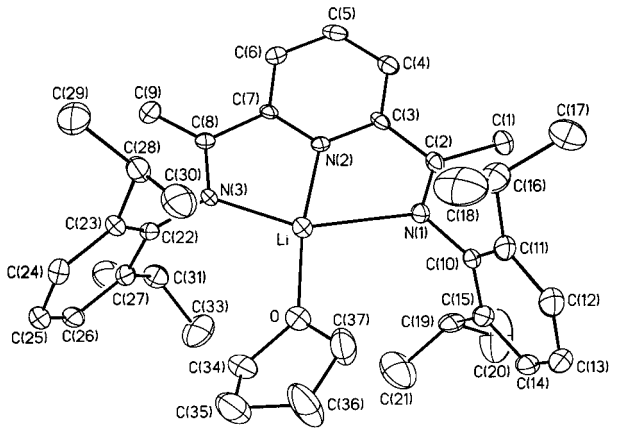


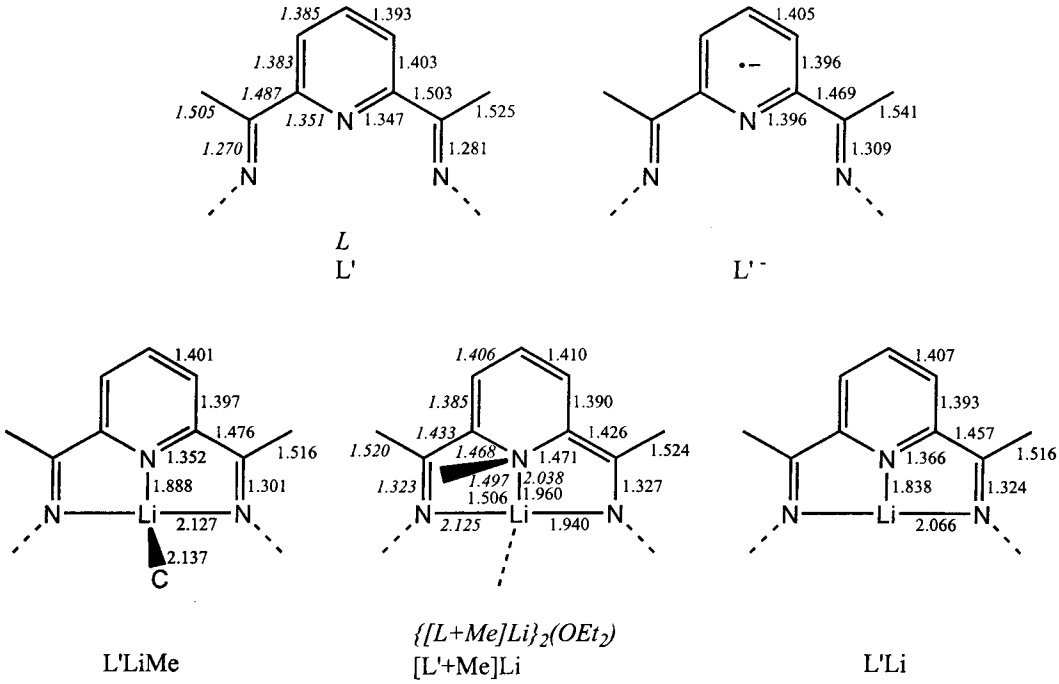
Figure 2. Thermal ellipsoid plot of **2**. Relevant bond distances (Å) and angles (deg): Li−N(1) = 2.364(5), Li−N(2) = 2.033(4), Li−N(3) = 2.013(5), C(1)−C(2) = 1.500-(3), C(8)−C(9) = 1.369(3), N(1)−C(2) = 1.290(3), N(3)−C(8) = 1.355(3), C(2)−C(3) = 1.491(3), C(8)−C(7) = 1.496(3).

structure[8] (Figure 2) showed the frame of a basically intact ligand coordinated to a Li(THF) unit. The only noticeable feature is the significant difference between the C−C bond lengths formed by the C atoms connected to the corresponding C$_{imine}$ atoms (1.369 and 1.500 Å, respectively), clearly showing, in agreement with the NMR spectrum, deprotonation of one of the two methyl groups. Thus, it appears that the methyl group originally bound to the nitrogen atom was lost as methane (clearly observed at 0.17 ppm in NMR experiments carried out in sealed tubes), possibly via reversion to the MeLi coordination complex and deprotonation of the imine methyl by a Li-bound methyl group.

Addition of alkyllithium compounds to pyridines is a fairly common reaction. However, nucleophilic attack at nitrogen is unprecedented. It is likely that alkylation at nitrogen is driven by the buildup of positive charge upon coordination of the Li cation. The formation of the Li−C σ-bond with the pyridine ring *para* carbon atom suggests that charge localization may occur on the ring *para* carbon atom. On the other hand, the fact that the structure is not polymeric and that in a second unit the lithium atom retained a coordinated molecule of ether indicate that the solvation of the alkali cation might play a role by enhancing the charge localization at the ring *para* atom. Thus, density functional theory calculations (B3LYP)[10] were carried out for both the simplified MeLi adduct L′LiMe {L′ = α,α′-[HN=C(Me)$_2$](C$_5$H$_3$N)} and its dimethyl ether solvate, and the two simplified

(9) A solution of **1** (0.25 g, 0.46 mmol) in toluene (10 mL) was boiled for 15 min. The color suddenly changed to dark green. The solvent was evaporated in vacuo and the solid residue redissolved in a heptane (10 mL)/ether (0.2 mL) mixture and allowed to stand at −30 °C for 2 days. Dark green crystals of **2** separated (0.17 g, 0.30 mmol, 65%). Anal. Calcd (Found) for C$_{33}$H$_{42}$N$_3$Li(ether): C 78.96(78.86), H 9.49(9.38), N 7.47(7.39). ^{1}H NMR (500 MHz, toluene-d_8, 23 °C) δ: CH$_{(i-Pr)}$: two septets 2H each at 3.65 (J = 7.1 Hz) and 2.48 (J = 6.9 Hz); Me$_{(i-Pr)}$: four doublets 6H each at 1.47 and 1.20 (J = 7.1 Hz) and at 0.98 and 0.91 (J = 6.9 Hz); Me$_{(imino)}$: one singlet 3H at 1.70; CH$_{(=CH2)}$: two singlets 1H at 3.80 and 4.49; CH$_{(pyridine)}$: two doublets 1H each at 7.81 and 6.83 and one pseudo triplet 1H at 7.06 (J = 7.6 Hz); CH$_{(aromatic)}$: one doublet at 7.34 2H and partly overlapping multiplets at 7.21−7.00 4H; ether: one quadruplet at 3.10 and one triplet at 0.83. ^{13}C NMR (125.72 MHz, toluene-d_8, 23 °C) δ: (CH$_{(i-Pr)}$): 29.19 and 28.79; (Me$_{(i-Pr)}$): 23.69, 23.50, 25.58, 25.50; (Me$_{(imino)}$): 17.18. (CH$_{(=CH2)}$): 76.64; (CH$_{(pyridine)}$): 119.8, 123.75, 126.00; (CH$_{(aromatic)}$): 122.13, 123.59, and 136.98; (quaternary C): 125.34, 125.53, 137.89, 144.15, 148.93, 155.95, 169.60; (ether): 60.01, 18.09.

Chart 1. Calculated (*Observed*) Bond Lengths (Å) for the Diimine−Pyridine Ligand and Its Li Derivatives[a]



[a] Observed bond lengths for free L are averages over the two ligand halves; for $\{[L+Me]Li\}_2(OEt_2)$ they are averages over all corresponding bonds of the two [L+Me]Li units of the complex.

units (with and without coordinated ether) contained in the structure of **1** (Chart 1). The unsolvated adduct L′LiMe has an unusual structure with the Li−C bond nearly orthogonal to the ligand plane. Transfer of the Li-bound CH_3 group to the nitrogen atom has a low barrier of 5 kcal/mol and is exothermic by ca. 26 kcal/mol. Thus, the reverse reaction would have a barrier of 31 kcal/mol, corresponding to a slow reaction at room temperature.[10] The coordination of a molecule of solvent (Me_2O) to lithium did not significantly modify the scenario. The methyl transfer reaction has a barrier (2 kcal/mol) and exothermicity (31 kcal/mol) very similar to that of the unsolvated case. Geometries of complex, transition state, and adduct also remained similar for the solvent-free and ether-coordinated system. The former pyridine ring becomes slightly more folded and receives slightly more negative charge (Mulliken charge on ligand: −0.58/−0.62) on coordination of ether to the Li atom. This may play a role in formation of the curious monosolvated dimer **1**: ether coordinates to one molecule of monomer, which increases the donor capacity of the pyridine ring enough that it wins over free ether in coordinating to a second monomer.

From the results described here, it is clear that even with main-group metal alkyls the reactivity of the diiminopyridine ligand is quite complex. We have not only observed alkylation at the unusual pyridine-N position but also demonstrated its reversibility. In addition, the ligand is easily deprotonated at the imine methyl groups. While this behavior complicates rational catalyst design, it results in interesting chemistry and offers a fascinating insight on the versatility of this unique ligand system to sustain olefin polymerization.

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Supporting Information Available: Complete listing of structural parameters for **1** and **2**.

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(10) Geometry optimizations of the minima and transition states were performed with the GAMESS-UK package[11] using the B3LYP hybrid density functional[12] with the split-valence 3-21G basis set.[13] Improved energies were calculated at the optimized geometries with the 6-311++G(2df,2pd) basis set[14] using the Gaussian-98 package.[15] Geometries were optimized without constraints.

(11) GAMESS-UK is a package of ab initio programs written by M. F. Guest, J. H. van Lenthe, J. Kendrick, K. Schoffel, and P. Sherwood, with contributions from R. D. Amos, R. J. Buenker, H. J. J. van Dam, M. Dupuis, N. C. Handy, I. H. Hillier, P. J. Knowles, V. Bonacic-Koutecky, W. von Niessen, R. J. Harrison, A. P. Rendell, V. R. Saunders, A. J. Stone, D. J. Tozer, and A. H. de Vries. The package is derived from the original GAMESS code due to M. Dupuis, D. Spangler, and J. Wendoloski, NRCC Software Catalog, Vol. 1, Program No. QG01 (GAMESS), 1980.

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