Communication

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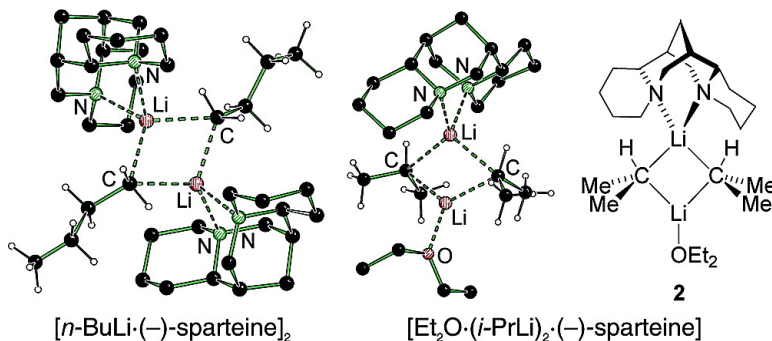
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The Crystal Structures of the Chiral Alkyllithium Bases [*n*-BuLi·(−)-Sparteine]₂ and [Et₂O·(*i*-PrLi)₂·(−)-Sparteine]

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Certain adducts between alkyllithium bases and (−)-sparteine have become chiral bases essential for the generation of enantiomerically enriched organolithium compounds (with a metalated stereogenic carbon center).[1] The most frequently used combination has been *s*-BuLi and (−)-sparteine,[2a] but *n*-BuLi[2a,3] or *i*-PrLi[4] in the presence of this chiral diamine ligand have also been successfully used for kinetically controlled enantiotopos-differentiating deprotonations, usually with high selectivity.[2b] A striking example is a deprotonation reaction which proceeds with opposite stereochemical pathways when switching from *n*-BuLi to *s*-BuLi in the presence of (−)-sparteine.[5] Because the experiments with *n*-BuLi and *i*-PrLi were usually effected in ethers or hydrocarbons, NMR studies have been conducted by Beak and Collum, which suggest an unsymmetric[6] dimer for *i*-PrLi·(−)-sparteine in the solvent Et₂O,[7] whereas a symmetric dimer was predicted for *n*-BuLi·(−)-sparteine in *n*-pentane.[8]

Numerous enantiomerically enriched organolithium compounds have been synthesized by deprotonation since the early 1980s using alkyllithium bases in the presence of (−)-sparteine. However, the enantiomerically enriched organolithium compounds have rarely been characterized in the solid state,[3,9] and the employed adducts of alkyllithium bases and (−)-sparteine have not been characterized in the solid state at all until now. We recently reported the first crystal structure determination of such an adduct, the monomeric *t*-BuLi·(−)-sparteine, which is also the first known instance of a monomeric form of butyllithium in the solid state.[10] The known crystal structures of established organolithium compounds, with or without common external coordinating donor molecules, include dimeric, tetrameric, and hexameric aggregates.[11]

The determination and comparison of the solid-state and solution structures of chiral alkyllithium bases, such as adducts of alkyllithiums with (−)-sparteine, is of great importance when setting up structure/reactivity relationships for this class of compounds. The structure in the reaction medium may differ appreciably from that in the crystal, which tends to represent the energetic minimum of an ordered three-dimensional aggregate state. We report here the dimeric structures [*n*-BuLi·(−)-sparteine]₂ (**1**) and [Et₂O·(*i*-PrLi)₂·(−)-sparteine] (**2**) in the crystal. Both compounds crystallized at −30 °C from an Et₂O/*n*-pentane mixture, with a 1:1 starting ratio of alkyllithium and (−)-sparteine in each case. The symmetric dimer **1** was independently obtained from pure *n*-pentane as well as from *n*-pentane solutions containing a 10-fold excess of Et₂O with respect to the dimeric complex **1**.
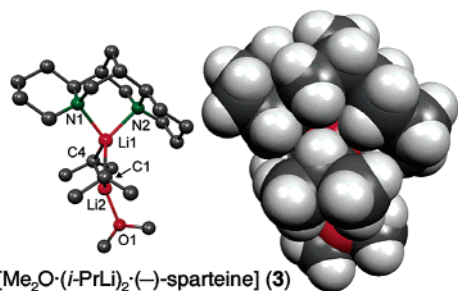
The symmetric dimer **1** crystallized in the monoclinic crystal system, space group *C*2 (one dimeric molecule was detected in the asymmetric unit, Figure 1).[12] The central structural motif of this aggregate is a rhomboid central four-membered Li−C−Li−C ring, typical for dimeric alkyllithium compounds. The sum of angles of 357.0(2)° in this ring shows that there is a slight deformation toward an envelope conformation. The Li−C distances in the central four-membered ring range from 2.230(5) to 2.321(5) Å. The distances
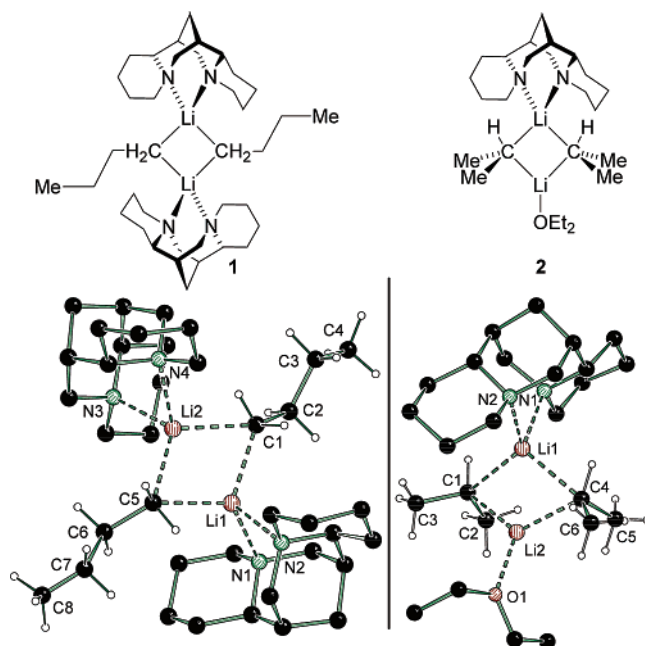
Figure 1. Molecular structures of **1** and **2** (molecule A) in the crystal (*Schakal* plots[13a]). Selected bond lengths (Å) and angles (deg) of **1**: C(1)−Li(1) 2.234(5), C(1)−Li(2) 2.291(5), C(5)−Li(1) 2.321(5), C(5)−Li(2) 2.230(5), Li(1)−N(1) 2.206(4), Li(1)−N(2) 2.207(4), Li(2)−N(3) 2.172-(4), Li(2)−N(4) 2.243(5), Li(1)−C(1)−Li(2) 67.92(15), Li(2)−C(5)−Li(1) 67.45(15), C(1)−Li(1)−C(5) 110.22(18), C(5)−Li(2)−C(1) 111.45(17), N(1)−Li(1)−N(2) 82.34(14), N(3)−Li(2)−N(4) 82.10(14). **2** (molecule A): C(1)−Li(1) 2.302(5), C(1)−Li(2) 2.135(6), C(4)−Li(1) 2.300(5), C(4)−Li(2) 2.140(6), Li(1)−N(1) 2.145(5), Li(1)−N(2) 2.136(4), Li(2)−O(1) 1.994(5), Li(2)−C(1)−Li(1) 64.69(17), Li(2)−C(4)−Li(1) 64.64(18), C(4)−Li(1)−C(1) 106.47(19), C(1)−Li(2)−C(4) 119.2(2), C(1)−Li(2)−O(1)−C(4) 172.63(44).

between the lithium centers and the nitrogen centers of the (−)-sparteine ligand are identical for one unit of the dimer [Li(1)−N(1) = 2.206(4) Å and Li(1)−N(2) = 2.207(4) Å], while for the second unit, different Li−N distances can be found [Li(2)−N(3) = 2.172(4) Å and Li(2)−N(4) = 2.243(5) Å]. Altogether, the lithium centers have four contacts each: two to the nitrogen centers of the (−)-sparteine ligands and two to the lithiated α-carbon centers C(1) and C(5) of the *n*-BuLi units. The result is a distorted tetrahedral coordination sphere for both lithium centers.

The apparent crystallographic *C*₂ symmetry of the dimeric aggregate, resulting from the *C*₂-symmetric arrangement of both (−)-sparteine ligands toward each other, is broken by a disorder of the *n*-Bu chain C(5)−C(8). As a result, two of the possible stereoisomers of the dimer **1**, which are almost congruent, can be detected in the crystal in a 75:25 ratio, refined using a splitting model (the main stereoisomer is shown in Figure 1). Obviously, this statistical distribution is determined by the comparable relative energies of the dimers.

Figure 2. Space-filling model [B3LYP/6-31+G(d)] of **3** (*Molekel* plot[13b]).

The unsymmetric dimer **2** also crystallized in the monoclinic crystal system, space group $P2_1$ (two crystallographically independent dimeric molecules A and B were detected in the asymmetric unit; because of the similarity of the structural parameters, only molecule A is discussed and shown in Figure 1).[12] The formation of this unsymmetric aggregate is most probably due to steric interactions between the methyl groups of the *i*-Pr chains and a second (−)-sparteine ligand in a potential symmetric dimeric aggregate of compound **2**. Moreover, a significant asymmetry can be found in the structural parameters describing the four-membered ring of compound **2**. It is rooted in the difference between the four-coordinate Li(1) [contacts to C(1), C(4), N(1), and N(2)] and the three-coordinate Li(2) [contacts to C(1), C(4), and O(1)]. While a distorted tetrahedral coordination sphere can be found for Li(1), a nearly trigonal planar coordination sphere is found for Li(2). The central four-membered Li−C−Li−C ring is not fully rhomboid as in compound **1**: The sum of angles in this ring amounts only to 355.0(2)°, revealing an increased envelope conformation for compound **2** (as compared to compound **1**). The lack of a second Et₂O molecule, coordinated to Li(2), is again most probably due to unfavorable steric interactions between a second ether ligand and the *i*-Pr chains. This might also be the reason we find only one of the possible stereoisomers of dimer **2** in the crystal: steric hindrance between the *i*-Pr groups and the (−)-sparteine unit would have a strong destabilizing effect on all other isomers, where at least one Me group would be pointing toward the chiral diamine ligand. To the best of our knowledge, compound **2** is the first known unsymmetric dimeric aggregate of a standard alkyllithium base. The angles Li(2)−C(1)−Li(1) = 64.69(17)° and Li(2)−C(4)−Li(1) = 64.64(18)° are equal to within the margins of error, while C(4)−Li(1)−C(1) = 106.47(19)° and C(1)−Li(2)−C(4) = 119.2(2)° are noticeably different. The same is true for C(1)−Li(2) = 2.135(6) Å and C(4)−Li(2) = 2.140(6) Å, while the distances C(1)−Li(1) = 2.302(5) Å and C(4)−Li(1) = 2.300(5) Å are significantly longer.

The molecular structure of compound **2** in the crystal and its structural parameters can be reproduced reliably by quantum-chemical studies of the simplified model compound **3** (with an Et₂O ligand of compound **2** replaced by Me₂O to clearly reduce the number of possible conformers) [B3LYP/6-31+G(d)] (Figure 2).[14] The calculations are in good agreement with the computational studies of Wiberg and Bailey, who took as their starting point a precoordinated *N*-BOC-pyrrolidine at an *i*-PrLi/(−)-sparteine monomer as the reactive species in the deprotonation of a substituted pyrrolidine (CIPE, complex induced proximity effect).[15] The modeling of compound **3**, as well as the crystal structure of **2**, reveal that the section of the dimer containing the coordination sphere of Li(1) is strongly shielded and inflexible. Because of the smaller size of the ether ligand, the coordination sphere of Li(2) is more flexible and more accessible for the precoordination of substrates. Nevertheless, the works of Beak and co-workers show that the stereoselectivity of kinetically controlled deprotonations increases when a ratio of 1:1, rather than 2:1, between *i*-PrLi and (−)-

sparteine is used. This possibly constitutes evidence that an [Et₂O·(*i*-PrLi)₂·(−)-sparteine] dimer is not the reactive species in deprotonation reactions.

If we consider in order the compounds *t*-BuLi·(−)-sparteine (three-fold α-branching at the lithiated carbon center),[10] [Et₂O·(*i*-PrLi)₂·(−)-sparteine] (two-fold α-branching), and [*n*-BuLi·(−)-sparteine]₂ (single α-branching), we see clearly the transition from a monomer to an unsymmetric dimer to a symmetric dimer. An insight into the crystal structures of important chiral alkyllithium bases has now been gained, and, in addition, several enantiomerically enriched organolithium compounds have been studied in the solid state.[3,9] A great challenge for further work in this field would be to "trap" an adduct between a (−)-sparteine-alkyllithium complex and the substrate in the solid state so as to be able to study the involved reactive species more directly.

Supporting Information Available: Crystallographic (CIF) and computational data (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

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