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α-Lithiated (*R*,*R*)-TMCDA as an Efficient Building Block for the Preparation of Chiral N,N,O Ligands by Asymmetric 1,2-Addition

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The chiral diamine (1*R*,2*R*)-*N*,*N*,*N*′,*N*′-tetramethylcyclohexane-1,2-diamine [(*R*,*R*)-TMCDA, **3**] has been selectively deprotonated at one of its methyl groups by a series of alkyllithium bases. Although the enantiomerically pure compound formed a trimeric structure, direct lithiation of the racemic mixture of the amine (*trans*-TMCDA) yielded a tetrameric compound. With 2 equiv. of the deprotonation reagent a mixed aggregate of the lithiated amine and *tert*-butyllithium was formed. The lithiated amine was employed as a building block for the synthesis of novel nitrogen ligands. The asymmetric 1,2-addition of α-lithiated (*R*,*R*)-TMCDA onto different ketones and aldehydes yielded a series of novel N,N,O ligands with different substitution patterns. Depending on the carbonyl compound used, a new stereocentre and different substituents can be introduced. The coordination behaviour of these ligands is illustrated by the formation of metal salt complexes.

Introduction

Nitrogen ligands have found wide application in many fields of chemistry, such as coordination chemistry and catalysis. In organolithium chemistry they are frequently applied to increase the reactivity of the deprotonation reagent used, but also for a more controlled and selective reactivity in, for example, asymmetric synthesis.[1] Access to novel, especially chiral ligand systems is often synthetically challenging. Recently we reported on a series of direct deprotonation reactions of tertiary methylamines leading to α-lithiated amines as intriguing building blocks.[2–5] The direct deprotonation of tertiary amines is mainly limited to polyamines, which enables precoordination of the lithium base. Alternative pathways include transmetallation,[6] reductive C–S bond cleavage[7] or lithiation of the more readily deprotonated aminoboranes.[8]

The precoordination by polyamines is necessary for the activation of the amines towards direct lithiation through the proximity of reactive groups in the intermediate species. Thus, the close proximity of reactive groups in this precoordinated complex also enables selective deprotonation reactions, for example, regioselective α- or β-lithiation reactions. This phenomenon is known as the complex-induced proximity effect (CIPE).[9] Amongst such amines that readily undergo direct deprotonation are the commonly used nitrogen ligands *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TMEDA, **1**),[2] *N*,*N*,*N*′,*N*′′,*N*′′-pentamethylethylenetriamine (PMDTA, **2**)[3] and (1*R*,2*R*)-*N*,*N*,*N*′,*N*′-tetramethylcyclohexane-1,2-diamine [(*R*,*R*)-TMCDA, (*R*,*R*)-**3**; Figure 1].[4] The ready access to amino-functionalised building blocks by direct lithiation prompted us to evaluate the potential of these systems for the preparation of novel nitrogen ligands. In particular, the chiral (*R*,*R*)-TMCDA seemed to be an attractive starting point due to its intrinsic stereoinformation. We were especially interested in the preparation of N,N,O ligands of type **4** with an additional hydroxy function. This class of ligand has already found wide application in many fields of chemistry, such as in transition-metal-catalysed reactions, in coordination chemistry as scorpionate ligands, and also in organolithium and metal–organic chemistry.[10–12] In the latter case, several cyclohexanediamine-based ligands have already been employed in the stereoselective reactions of the tetradentate derivatives **5** and **6** (Figure 2), which feature the same binding site (NCH_2CH_2O) as the target molecules **4** based on lithiated TMCDA. Ligands **5** and **6** were successfully employed by Marson et al. in the asymmetric 1,2-addition of diethylzinc to benzaldehyde with enantiomeric excesses of up to 92%.[12e]

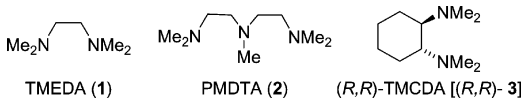
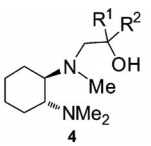


Figure 1. Tertiary amines that undergo direct deprotonation with organolithium bases.



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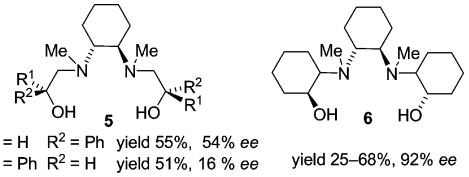


Figure 2. Tetradentate cyclohexanediamine-based ligands applied to the asymmetric 1,2-addition of diethylzinc to benzaldehyde.

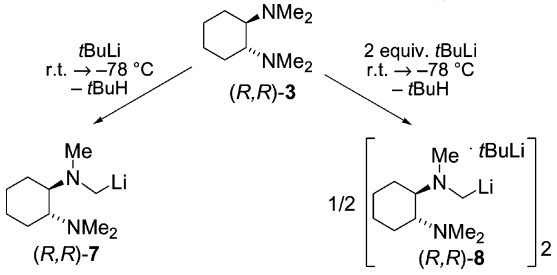
Encouraged by the wide application of such amine ligands with an additional hydroxy function we wanted to evaluate the potential of lithiated TMCDA as a building block for N,N,O ligands. We present herein a detailed investigation of the direct deprotonation of the diamine, also of its racemic mixture and with an excess of the alkyllithium reagent as a starting point for its following application. The subsequent trapping reactions demonstrate the potential of the lithiated amine by the preparation of N,N,O ligands of type **4** with a series of different substituents. Preliminary investigations of the coordination behaviour of the synthesised ligands will give a first insight into their complexation ability.

Results and Discussion

Lithiation of (*R*,*R*)-TMCDA and *trans*-TMCDA

Recently we reported the direct deprotonation of the chiral nitrogen ligand (*R*,*R*)-TMCDA with several organolithium bases.[4a] The deprotonation of one methyl group of the diamine proceeded easily by simple warming a solution of **3** with an equivalent amount of the organolithium base to room temperature. This facile lithiation prompted us to investigate a possible deprotonation of a methyl group at each nitrogen atom. However, these dilithiation attempts were always unsuccessful, providing trapping products of the monolithiated diamine (*R*,*R*)-**7** and the excess alkyllithium. Crystallisation of (*R*,*R*)-TMCDA with an excess of *tert*-butyllithium resulted in the formation of a mixed aggregate with incorporation of the second equivalent of organolithium base into the lithiated amine. Storage of a mixture of (*R*,*R*)-**3** and *t*BuLi in a 1:2 ratio at –30 °C resulted in the formation of colourless crystals of [*t*BuLi·(*R*,*R*)-TMCDA–Li]$_2$ [(*R*,*R*)-**8**]. The same crystals were obtained upon warming the solution to room temperature and subsequent cooling to –78 °C (Scheme 1).

[*t*BuLi·(*R*,*R*)-TMCDA–Li]$_2$ [(*R*,*R*)-**8**] crystallises in the monoclinic crystal system, space group $P2_1$. The adduct (Figure 3) consists of two molecules of *t*BuLi and two molecules of the α-lithiated (*R*,*R*)-TMCDA. The central structural motif is formed by three Li–C–Li–C four-membered rings connected by one common edge. The four-membered rings exhibit a distorted arrangement with strongly varying Li–C distances between 2.138(8) and 2.301(7) Å. The Li–N distances range between 1.971(7) and 2.036(7) Å and are thus in the range of known dimeric organolithium compounds.[13,14] Such a mixed aggregate of an α-lithiated



Scheme 1. Formation of lithiated (*R*,*R*)-TMCDA [(*R*,*R*)-**7**] and the mixed aggregate [*t*BuLi·(*R*,*R*)-TMCDA–Li]$_2$ [(*R*,*R*)-**8**] with excess *tert*-butyllithium.

amine is only known for the cyclic amine *N*,*N*′,*N*′′-trimethyl-1,4,7-triazacyclononan (Me_3tacn).[5e] The formation and thermodynamic stability of (*R*,*R*)-**8** was confirmed by computational studies at the B3LYP/6-31+G(d) level of theory. Thus, [*t*BuLi·(*R*,*R*)-TMCDA-Li]$_2$ shows a preference of 12 kJ mol^{-1} compared to trimeric lithiated (*R*,*R*)-TMCDA [(*R*,*R*)-**7**] (2/3 of the aggregate) and tetrameric (*t*BuLi)$_4$, (1/2 of the tetramer), either of these oligomeric structures having been detected in the crystal structures of *t*BuLi and (*R*,*R*)-**7**.[4a,14g] Analogous structures of α-lithiated (*R*,*R*)-TMCDA with further incorporated alkyllithiums have not been isolated so far, although even *s*BuLi, *n*BuLi and *i*PrLi allow the direct deprotonation of **3**.

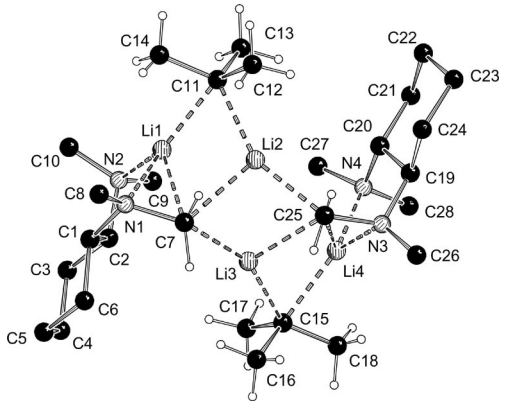


Figure 3. Molecular structure and numbering scheme of [*t*BuLi·(*R*,*R*)-TMCDA–Li]$_2$ [(*R*,*R*)-**8**] (hydrogen atoms of the lithiated TMCDA omitted for clarity – except of those at the metalated carbon atom). Selected bond lengths [Å] and angles [°]: Li1–C11 2.180(7), Li1–C7 2.247(6), Li2–C7 2.301(7), Li2–C11 2.198(7), Li2–C25 2.151(7), Li3–C7 2.138(8), Li3–C15 2.188(8) Li3–C25 2.334(8) Li4–C25 2.240(8), Li4–C15 2.177(8), Li1–N2 2.036(7), Li1–N1 1.975(7), Li4–N3 1.971(7), Li4–N4 2.004(7); Li3–C7–Li2 67.6(3), Li1–C7–Li2 63.9(2), Li1–C11–Li2 66.7(2), Li2–C25–Li3 66.8(2), Li2–C25–Li4 101.8(3), Li3–C25–Li4 63.6(3), Li3–C15–Li4 67.0(3). For crystallographic details, see Table 2.

The formation of the mixed aggregate with *t*BuLi incorporated is also consistent with the non-observed dilithiation. Such a dilithiation has been observed for tetramethylmethylenediamine.[5a] As is obvious from the crystal structure, the distances between the carbanionic centre and the

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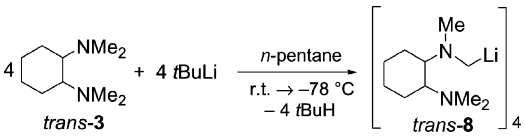
α-carbon atoms are long such that in this rather rigid system sufficient proximity between these groups can not be realised.[15] In addition, starting from **8** as intermediate of the deprotonation of the second NMe_2 moiety, only a transition state is imaginable in which the aggregates open to achieve the required spatial proximity. This leads to cleavage of the stabilising Li–C interactions and thus to an energetic disadvantage of the direct deprotonation. Accordingly, no reasonable transition states can be located for this lithiation reaction.

Attempts to deprotonate the racemic mixture of (*R*,*R*)- and (*S*,*S*)-TMCDA, *trans*-TMCDA (*trans*-**3**), gave results comparable to the enantiomerically pure compound, that is, selective lithiation of the methyl group of the diamine. Warming of a previously cooled mixture of *t*BuLi and *trans*-TMCDA to room temperature and subsequent cooling to –30 °C resulted in the formation of colourless plates of the tetrameric compound (*trans*-TMCDA–Li)$_4$ (*trans*-**7**; Scheme 2).



Scheme 2. Direct deprotonation of *trans*-TMCDA with *tert*-butyllithium to yield tetrameric, lithiated *trans*-TMCDA.

Racemic lithiated TMCDA (*trans*-**7**) crystallises in the tetragonal crystal system in the space group $P\bar{4}2_1/c$. The asymmetric unit contains one lithiated molecule which assembles to the tetrameric structure shown in Figure 4 with S_4 symmetry. In the tetramer both enantiomers (*R*,*R*)- and (*S*,*S*)-TMCDA alternate. The central structural motif consists of a distorted Li–C eight-membered ring, the Li–C distances of which are 2.163(5) and 2.122(4) Å and the Li–N distances are 2.102(5) and 2.021(4) Å and are thus comparable with monomeric and dimeric organolithium compounds and lithiated (*R*,*R*)-TMCDA.[13] Most interestingly, the change from the enantiomerically pure (*R*,*R*)-TMCDA to the racemic mixture *trans*-TMCDA resulted in a structural change from the trimeric adduct, which we found for (*R*,*R*)-**7**, to the highly symmetric tetramer. Analogous to (*R*,*R*)-**7**, *trans*-TMCDA can also be deprotonated with *sec*-butyl-, *n*-butyl and isopropyllithium as lithium bases.

The ready deprotonation of TMCDA to **7** presumably proceeds by a two-step mechanism via the monomeric species *t*BuLi·(*R*,*R*)-TMCDA. In this adduct the amine and the deprotonation reagent are in proximity resulting in a decrease in the reaction barrier thus enabling the lithiation even under mild reaction conditions. This is confirmed by computational studies showing a barrier of 98 kJ/mol for the deprotonation with *tert*-butyllithium and of 94 kJ/mol with *sec*-butyllithium. The monomeric adduct *t*BuLi·(*R*,*R*)-TMCDA could also be isolated from a mixture of *t*BuLi and racemic *trans*-TMCDA, crystallising in the same unit cell. However, the absolute configuration of the amine cannot be assigned due to the deficiency of a heavy atom. This suggests that the use of *trans*-TMCDA results in the formation of a mixture of enantiomorphous crystals of the enantiomers *t*BuLi·(*R*,*R*)-TMCDA and *t*BuLi·(*S*,*S*)-TMCDA.

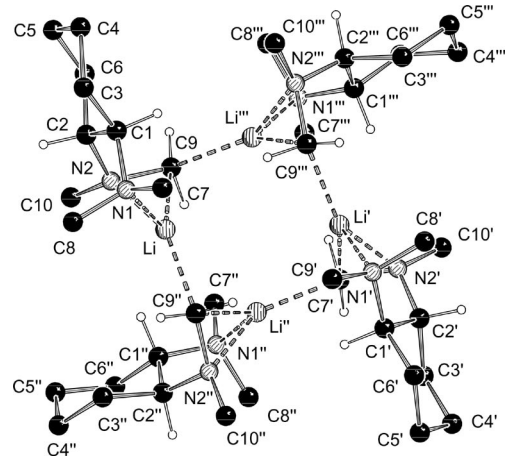
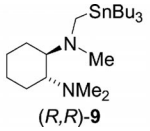


Figure 4. Molecular structure and numbering scheme of (*trans*-TMCDA–Li)$_4$ (*trans*-**7**; hydrogen atoms of the lithiated TMCDA have been omitted for clarity except for those at the metallated carbon atom). Selected bond lengths [Å] and angles [°] (symmetry operations: $y - 1, -x + 1, -z$; $-y + 1, x + 1, -z$): C9–Li′′′ 2.122(4), C9–Li 2.163(5), Li–C9′′ 2.122(4), Li–N2 2.021(4), Li–N1 2.102(5), Li–Li′′ 3.043(6), Li–Li′′′ 3.043(6); N2–C9–Li′′′ 139.9(2), N2–C9–Li 63.97(15), Li′′′–C9–Li 90.52(18), N2–Li–N1 86.42(15), N2–Li–C9′′ 148.2(2), N1–Li2–C9′′ 109.3(2), N2–Li–C9 42.00(10) N1–Li–C9 109.64(17), C9′′–Li–C9 140.4(2), C9–N2–Li 74.03(16), Li′′–Li–Li′′′ 82.76(11). For crystallographic details, see Table 2.

Preparation of the N,N,O Ligands

For the preparation of the desired N,N,O ligands, (*R*,*R*)-TMCDA [(*R*,*R*)-**3**] was treated with 1.2 equiv. of *tert*-butyllithium for 4 h at room temperature to achieve quantitative deprotonation. The lithiated amine (*R*,*R*)-**5** was then trapped with an aldehyde or ketone at low temperatures to yield, after aqueous work-up and kugelrohr distillation, the corresponding alcohol as colourless to slightly yellow oils (see Scheme 3, Table 1). The yields of the thus-prepared N,N,O ligands of type **4** varied only slightly between 61 and 70%. An increase in the yield could not be achieved even by varying the amount of deprotonation reagent, which may be related to a deprotonation of the aldehydes in a side-reaction. The deprotonation of TMCDA itself occurs almost quantitatively, which was shown by trapping the lithiated amine (*R*,*R*)-**7** with tributyltin chloride to give the α-stannylated amine (*R*,*R*)-**9** in over 90% yield after work-up and kugelrohr distillation.



(*R*,*R*)-**9**

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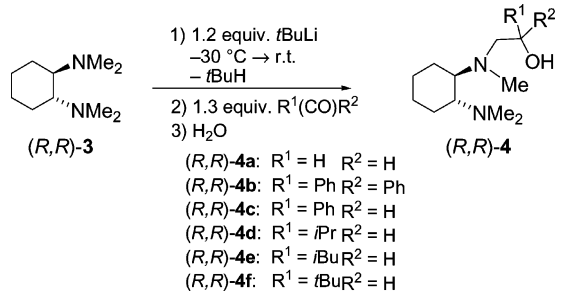


Scheme 3. Preparation of chiral N,N,O ligands **4** by a lithiation/trapping sequence of (*R*,*R*)-TMCDA.

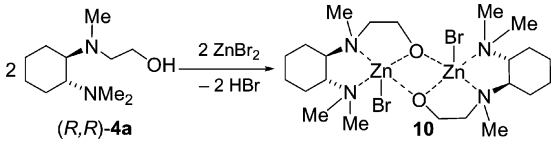
Table 1. Preparation of N,N,O ligands by trapping of lithiated (*R*,*R*)-TMCDA with ketones and aldehydes.

Product	Carbonyl compd.	R	R′	Temp. [°C]	Yield [%]	*dr*[a]
(*R*,*R*)-**4a**	paraformaldehyde	H	H	–30	68	
(*R*,*R*)-**4b**	benzophenone	Ph	Ph	–30	65	
(*R*,*R*)-**4c**	benzaldehyde	Ph	H	–40	68	65:35
(*R*,*R*)-**4c**	benzaldehyde	Ph	H	–90	64	80:20
(*R*,*R*)-**4c**	benzaldehyde	Ph	H	–110	68	82:18
(*R*,*R*)-**4d**	isobutyraldehyde	*i*Pr	H	–40	60	65:35
(*R*,*R*)-**4d**	isobutyraldehyde	*i*Pr	H	–78	70	79:21
(*R*,*R*)-**4d**	isobutyraldehyde	*i*Pr	H	–110	65	82:18
(*R*,*R*)-**4e**	isovaleraldehyde	*i*Bu	H	–110	61	78:22
(*R*,*R*)-**4f**	pivaldehyde	*t*Bu	H	–40	61	55:45
(*R*,*R*)-**4f**	pivaldehyde	*t*Bu	H	–110	62	80:20

[a] Diastereomeric ratio determined by ^{1}H NMR spectroscopy.

By using aldehydes or unsymmetrical ketones the asymmetric 1,2-addition of lithiated (*R*,*R*)-TMCDA according to Scheme 3 led to the introduction of further stereoinformation into the molecule at the α position with respect to the hydroxy function. The facile variation of this introduced substituent is a great advantage of the preparation method described herein. To evaluate the stereoselectivity of the introduction of this additional stereocentre, the lithiated amine was treated with benzaldehyde, isobutyraldehyde, isovaleraldehyde and pivaldehyde. After aqueous work-up the diastereomeric ratio of the crude product was determined by NMR spectroscopy. As can be seen from Table 1, the ratio of the diastereomers is only moderate with ratios of up to 82:18 for (*R*,*R*)-**4c** and (*R*,*R*)-**4d** with phenyl and isopropyl substituents, respectively. The higher selectivities observed at lower trapping temperatures are consistent with a kinetically controlled reaction process typical of such asymmetric addition reactions. Both diastereomers can be separated by column chromatography. Table 1 gives an overview of the reaction conditions and the selectivities and yields obtained.

Studies of the coordination behaviour of the N,N,O ligands towards alkyllithiums resulted in no suitable crystals for structure analysis. This may be related to the higher solubility of the corresponding hydroxy adducts relative to the non-hydroxy-functionalised TMCDA analogue ligands.[4] However, crystallisation of the ethanol derivative **4a** (trapping product with paraformaldehyde) with zinc(II) bromide in dichloromethane resulted in the formation of colourless plate-shaped crystals in 89% yield (Scheme 4, Figure 5). The uniformity of the crystals was verified by CHN analysis. Analogous compound **11** with the same structural features is formed with copper(I) iodide, which is oxidised by air-oxygen to copper(II) (Figure 6). The zinc complex is a part of systematic studies on the catalysis of the ring-opening polymerisation of lactide. Analogous complexes with TMCDA-based diamine ligands have already been revealed to be efficient initiators.



Scheme 4. Formation of zinc complex **10**.

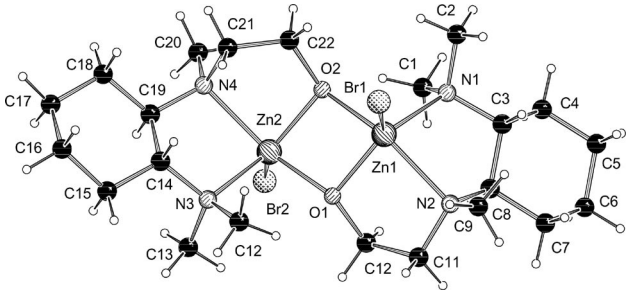


Figure 5. Molecular structure and numbering scheme of the zinc complex **10** with the ethanol derivative **4a** of (*R*,*R*)-TMCDA in the crystal. Selected bond lengths [Å] and angles [°]: Br1–Zn1 22.4080(16), Br2–Zn2 2.4250(15), N1–Zn1 2.150(8), N2–Zn1 2.277(7), N3–Zn2 2.207(8), N4–Zn2 2.212(8), O1–Zn1 1.983(7), O1–Zn2 2.010(7), O2A–Zn2 1.967(9), O2A–Zn1 2.069(10), O2B–Zn1 2.02(2), O2B–Zn2 2.16(2); Zn1–O1–Zn2 101.5(3), Zn2–O2A–Zn1 100.0(4), Zn1–O2B–Zn2 95.6(10), O1–Zn1–O2B 80.5(7), O1–Zn1–O2A 78.3(3), O1–Zn1–N1 126.9(3), O2B–Zn1–N1 77.2(7), O2A–Zn1–N1 95.3(4), O1–Zn1–N2 84.0(3), O2B–Zn1–N2 136.3(8), O2A–Zn1–N2 154.0(4), N1–Zn1–N2 80.2(3), O2A–Zn2–O1 80.1(4), O1–Zn2–O2B 76.5(7), O2A–Zn2–N3 126.6(4), O1–Zn2–N3 90.4(3), O2B–Zn2–N3 145.7(7), O2A–Zn2–N4 80.6(4), O1–Zn2–N4 147.7(3), O2B–Zn2–N4 93.5(7), N3–Zn2–N4 80.8(3). For crystallographic details, see Table 3.

The zinc compound **10** crystallises in the orthorhombic crystal system, space group $P2_12_12_1$, the copper adduct **11** in the monoclinic crystal system, space group $P2_1$. The stereogenic carbon atoms exhibit the *R* configuration, which confirms the retention of the absolute configuration during the lithiation/addition reaction sequence. The central structural motif of both compounds is formed by a planar metal–oxygen four-membered ring [sum of angles: Zn complex **10**: 359.3(4)°; Cu complex **11**: 360(3)°] with M–O bond lengths between 1.982(8) and 2.027(8) Å for **10** and 1.914(10) and 1.977(10) for **11**. The metal atoms exhibit a five-fold coordination with a distorted square-pyramidal arrangement of the ligand atoms. Thus, each metal atom possesses two contacts with the oxygen and nitrogen atoms of

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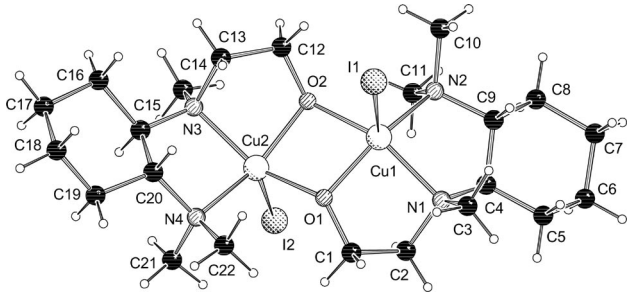

Figure 6. Molecular structure and numbering scheme of the copper complex **11** with the ethanol derivative **4a** of (*R*,*R*)-TMCDA in the crystal. Selected bond lengths [Å)] and angles [°]: Cu1–O1 1.948(9), Cu1–O2 1.977(10), Cu1–N2 2.036(11), Cu1–N1 2.054(12), Cu1–I1 2.884(2), Cu1–Cu2 2.959(2), Cu2–O1 1.914(10), Cu2–O2 1.968(9), Cu2–N3 2.021(12), Cu2–N4 2.096(11), Cu2–I2 2.868(2), O1–C1–N2 157.4(5), O2–Cu1–N2 96.5(4), O1–Cu1–N1 86.7(4), O2–Cu1–N1 154.2(5), N2–Cu1–N1 86.8(5), O1–Cu2–O2 81.6(4), O1–Cu2–N3 151.2(5), O2–Cu2–N3 83.0(4), O1–Cu2–N4 96.8(4), O2–Cu2–N4 154.7(5), N3–Cu2–N4 87.0(5), Cu2–O1–Cu1 100.0(4), Cu2–O2–Cu1 97.2(4), O1–Cu1–O2 80.5(4). For crystallographic details, see Table 3.

the N,N,O ligand and one contact with the halide, which occupies the vertex of the pyramid. Upon coordination of the metal to the ligand the nitrogen atom of the ligand with the ethanol side-arm becomes stereogenic. In the molecular structures of **10** and **11**, *R* and *S* configurations at the corresponding nitrogen atoms are found in each molecule and thus no configuration seems to be preferred in the crystallisation process.

In the molecular structure of the zinc(II) complex **10** a disorder of the ethoxy bridge is found in the crystal (not depicted in Figure 5, see the Supporting Information). Thus, the ethoxy bridge can also be detected at the nitrogen atoms N1 and N3. Regarding the stereogenic nitrogen atoms, only one isomer (with *R* as well as *S* configuration) is present in the crystal, which packs differently in the crystal. NMR studies also indicate the formation of both configurations at the nitrogen atoms in solution, as found in the crystal structure. The ^{1}H NMR spectrum of the zinc complex shows a splitting of the signals of the $N(CH_3)_2$ and the $N(CH_3)CH_2$ moieties into four sharp signals of the same and a fifth of double intensity (overlap of two signals; see the Supporting Information). In the ^{13}C NMR spectrum six signals for each of the six methyl groups are evident. This is expected for the coordination adduct of (*R*,*R*)-**4a** in which the $N(CH_3)_2$ methyl groups become diastereotopic upon coordination of the zinc bromide and additionally differ in the configuration of the second nitrogen atom. The same splitting is also evident in the ^{1}H NMR spectrum for the CH_2OH units (see the Supporting Information).

For the N,N,O ligands with a further stereocentre (**4c**–**f**), no crystals of sufficient quality for X-ray diffraction analysis could be obtained. Instead, with zinc(II) bromide, decomposition reactions with the reformation of (*R*,*R*)-TMCDA were observed. As such, TMCDA-coordinated $ZnBr_2$ could be isolated from a mixture of the methylbutanol derivative **4e** and the metal salt in acetone.[16]

Conclusions

We have reported herein the direct deprotonation of enantiomerically pure (*R*,*R*)-TMCDA and its racemic mixture *trans*-TMCDA with organolithium bases. Although the enantiomerically pure compound forms a trimeric structure, direct lithiation of the racemic mixture of the amine (*trans*-TMCDA) yields a tetrameric compound with both enantiomeric forms in the crystal. With 2 equiv. of the deprotonation reagent, no dilithiation was observed but the formation of the mixed aggregate **8** consisting of the lithiated diamine and incorporated *tert*-butyllithium. On treatment of lithiated TMCDA [(*R*,*R*)-**7**] with carbonyl compounds a series of chiral N,N,O ligands can easily be synthesised by varying the substituents at the α position with respect to the hydroxy function. The employment of aldehydes also led to the introduction of a further stereocentre. Preliminary crystallisation studies showed the formation of zinc bromide and copper iodide complexes. We are currently further investigating the coordination behaviour of the presented N,N,O ligands with special focus on the compounds with a further stereocentre.

Experimental Section

General: All experiments were carried out under dry, oxygen-free argon using standard Schlenk techniques. Solvents were dried with sodium and distilled prior to use. (*R*,*R*)- and *trans*-TMCDA were prepared according to literature procedures by Eschweiler–Clarke reaction of the corresponding amine and enantiomerically pure tartaric salt, respectively.[10c,17] "H_2O" is distilled water. *tert*-Butyllithium was titrated against diphenylacetic acid. ^{1}H, ^{13}C and ^{7}Li NMR spectra were recorded with DRX-300 and AMX-500 Bruker spectrometers at 22 °C. The signals were assigned on the basis of additional DEPT-135 and C,H COSY experiments. All chemical shifts (δ) are given in ppm. All spin–spin coupling constants (*J*) are given in hertz (Hz). GC–MS analyses were performed with a ThermoQuest TRIO-1000 apparatus (EI = 70 eV; column: Zebron; capillary GC column: ZB-1. Optical rotations were determined with a Jasco $P\bar{1}030$ polarimeter (cell path = 1.00 dm, temperature = 20.0 °C, wavelength λ = 589 nm).

[*t*BuLi·(*R*,*R*)-TMCDA–Li]$_2$ [(*R*,*R*)-8]: In a Schlenk vessel, (*R*,*R*)-TMCDA [(*R*,*R*)-**4**; 170 mg, 1.00 mmol] was dissolved in *n*-pentane (5 mL) and cooled to –78 °C. At this temperature *t*BuLi (1.6 M solution in *n*-pentane, 1.3 mL, 2.08 mmol) was cautiously added and kept at –30 °C for crystallisation. Colourless crystals of the mixed aggregate formed after 3 d (175 mg, 0.73 mmol; 73%). NMR studies were not possible due to lithiation of the solvent (benzene, toluene) or insolubility (pentane). The same crystals were obtained on warming to room temperature and subsequent cooling to –78 °C.

(*trans*-TMCDA–Li)$_4$ (7): In a Schlenk vessel, *trans*-TMCDA (*trans*-**3**; 170 mg, 1.00 mmol) was dissolved in *n*-pentane (6 mL) and cooled to –78 °C. At this temperature *t*BuLi (1.6 M solution in *n*-pentane, 1 mL, 1.6 mmol) was cautiously added, the solid formed was dissolved by warming to room temp. and then kept at room temp. for an additional hour. Subsequent cooling to –78 °C gave colourless crystals of the lithiated amine after 24 h (137 mg,0.82 mmol; 82%). ^{1}H NMR (500.1 MHz, [D$_8$]Tol): δ = 0.99–1.04 (m, 5 H, 2 CH_2, CH_2Li), 1.38–1.40 (m, 1 H, CH_2Li),

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1.52–1.60 (m, 2 H, CH_2), 1.66–1.70 (m, 3 H, $LiCH_2NCH_3$), 1.74–1.79 (m, 2 H, CH_2), 2.14 (br. s, 4 H, NCH_3, NCH), 2.54 (br. s, 4 H, NCH_3, NCH) ppm. $\{^1H\}^{13}C$ NMR (125.8 MHz, [D$_8$]Tol): δ = 20.2 (CH_2), 21.4, (CH_2Li), 25.7 (2 CH_2), 25.9 (CH_2), 35.3 ($LiCH_2NCH_3$), 43.4 (NCH_3), 48.7 (NCH_3), 64.8 (CHN), 66.0 (CHN) ppm. ^7Li NMR (194.4 MHz, [D$_8$]Tol): δ = 1.9 ppm. VT NMR studies showed no separation of the mainly broad signals upon cooling to –80 °C.

General Procedure for the Trapping of Lithiated TMCDA with Aldehydes and Ketones: (*R*,*R*)-TMCDA [(*R*,*R*)-**3**] was dissolved in *n*-pentane and cooled to –50 °C. At this temperature a *tert*-butyllithium (1.2 equiv.) solution in *n*-pentane was added, which resulted in the formation of *t*BuLi·(*R*,*R*)-TMCDA as a colourless precipitate. After warming to room temperature the mixture was stirred for 4 h, whereupon the solid dissolved. The mixture was then cooled (temperature see below), trapped with an excess of the corresponding aldehyde/ketone and stirred for further 2 h at room temperature. The alcoholate formed was hydrolysed by the addition of 2.5 M HCl (20 mL). After the addition of diethyl ether (30 mL) the combined organic layers were extracted 2.5 M HCl (3 × 20 mL). The aqueous layers were afterwards basified to pH 12 with NaOH and finally extracted with diethyl ether (3 × 30 mL). The combined organic layers were dried with Na_2SO_4 and after removal of all volatile compounds in vacuo, the crude product was purified through bulb-to-bulb distillation to give the N,N,O ligands as colourless oils. The diastereomeric ratios were determined by NMR spectroscopy.

Ethanol Derivative (*R*,*R*)-4a: By using the above general procedure, (*R*,*R*)-TMCDA [(*R*,*R*)-**3**; 5.00 g, 29.4 mmol] was trapped with paraformaldehyde (1.30 g, 42.9 mmol; suspension in ethyl ether) at –35 °C. Bulb-to-bulb distillation (oven temperature 80 °C, 10^{-3} mbar) gave (*R*,*R*)-**4a** as a colourless oil (3.98 g, 19.9 mmol; 68%). ^1H NMR (400.1 MHz, $CDCl_3$): δ = 0.91–1.20 (m, 4 H, CH_2 cyclohexyl), 1.66–1.75 (m, 2 H, CH_2 cyclohexyl), 1.78–1.82 (m, 1 H, CH_2 cyclohexyl), 1.88–1.94 (m, 1 H, CH_2 cyclohexyl), 2.12–2.18 (m, 1 H, CH_2N), 2.17 [s, 6 H, $N(CH_3)_2$], 2.23–2.29 (m, 2 H, CHN), 2.31 [s, 3 H, $N(CH_3)CH_2$], 2.63–2.73 (m, 1 H, CH_2N), 3.30–3.36 (m, 1 H, CH_2OH), 3.53 (td, $^3J_{HH}$ = 10.7 Hz, 1 H, CH_2OH), 6.20–7.10 (br., 1 H, OH) ppm. $\{^1H\}^{13}C$ NMR (100.6 MHz, $CDCl_3$): δ = 21.3, 23.7, 25.4, 25.5 (CH_2 cyclohexyl), 38.8 [$N(CH_3)_2$], 40.2 (NCH_3), 51.2 (CH_2N), 59.8 (CH_2O), 64.14, 64.17 (CHN) ppm. $[\alpha]_D^{20}$ = –80.0 (*c* = 0.5538 g/100mL, cyclohexane). $C_{11}H_{24}N_2O$ (200.32): calcd. C 65.95, H 12.08, N 13.98; found C 65.20, H 12.29, N 14.32. GC–MS (EI): t_R = 6.85 min [80 °C (2 min) – 10 °C/min – 280 °C (5 min)]: *m*/*z* (%) = 182 (32) [M – H_2O]$^+$, 170 (23) [$C_6H_{10}(NMe_2)_2$]$^+$, 124 (60) [$C_6H_9N(CH_3)CH_2$]$^+$, 84 (72) [C_6H_{12}]$^+$, 71 (80) [$C_4H_{10}N$]$^+$, 58 (100) [$N(CH_3)_2CH_2$]$^+$.

Diphenylethanol Derivative (*R*,*R*)-4b: By using the above general procedure, (*R*,*R*)-TMCDA [(*R*,*R*)-**2**; 5.00 g, 29.4 mmol] was treated with benzophenone (7.50 g, 41.2 mmol) at –40 °C. Work-up and bulb-to-bulb distillation (oven temperature: 225 °C; 1×10^{-2} mbar) gave (*R*,*R*)-**4b** as a slightly yellow, highly viscous oil (6.72 g, 0.19 mmol; 65%). ^1H NMR (400.1 MHz, $CDCl_3$): δ = 1.02–1.14 (m, 4 H, CH_2 cyclohexyl), 1.74 [s, 3 H, $N(CH_3)CH_2$], 1.75–1.79 (m, 2 H, CH_2 cyclohexyl), 1,84–1.87 (m, 1 H, CH_2 cyclohexyl), 1.92–1.97 (m, 1 H, CH_2 cyclohexyl), 2.22–2.29 (m, 1 H, CHN), 2.31 [s, 6 H, $N(CH_3)_2$], 2.36–2.43 (m, 1 H, CHN), 3.06, 3.27 (AB system, $^2J_{AB}$ = 12.2 Hz, 2 H, CH_2N), 7.13–7.15 (m, 2 H, CH_{para}), 7.16–7.21 (m, 4 H, $CH_{arom.}$), 7.23–7.27 (m, 2 H, $CH_{arom.}$), 8.78 (br., 1 H, OH) ppm. $\{^1H\}^{13}C$ NMR (100.6 MHz, $CDCl_3$): δ = 21.3, 23.7, 25.4, 25.5 (CH_2 cyclohexyl), 38.9 [$N(CH_3)_2$], 42.2 (NCH_3), 60.4 (CH_2N), 63.7, 66.1 (CHN), 75.8 (COH), 125.7, 126.3 (CH_{para}), 126.3, 127.3 (CH_{meta}), 127.0, 127.9 (CH_{ortho}), 148.0, 148.2 (C_{ipso}) ppm. $C_{23}H_{32}N_2O$ (352.51): calcd. C 78.37, H 9.15, N 7.95; found C 77.82, H 8.52, N 7.95. GC–MS (EI): t_R = 12.41 min [80 °C (2 min) – 10 °C/min – 280 °C (5 min)]: *m*/*z* (%) = 334 (5) [M – H_2O]$^+$, 181 (25) [$C_6H_{10}(NMe_2)N(CH_3)C_2H_2$]$^+$, 167 (40) [$Ph_2CH$]$^+$, 124 (25) [$C_6H_9N(CH_3)CH_2$]$^+$, 105 (80) [$PhC_2H_4$]$^+$ 84 (55) [C_6H_{12}]$^+$, 77 (100) [C_6H_5]$^+$.

Phenylethanol Derivative (*R*,*R*)-4c: By using the above general procedure, (*R*,*R*)-TMCDA [(*R*,*R*)-**3**; 5.00 g, 29.4 mmol] was treated with benzaldehyde (1.3 equiv.) at low temperatures (see Table 1). Work-up and bulb-to-bulb distillation (oven temperature 171 °C; 1×10^{-2} mbar) gave the product as a colourless oil. NMR studies showed the formation of both diastereomers in ratios that are dependent upon the trapping temperatures. The two diastereomers can be separated by column chromatography on silica gel (*n*-pentane/2-propanol/triethylamine = 11:10:1). For yields and diastereomeric ratios, see Table 1.

Major diastereomer: ^1H NMR (400.1 MHz, $CDCl_3$): δ = 0.87–0.97 (m, 1 H, CH_2 cyclohexyl), 1.08–1.15 (m, 3 H, CH_2 cyclohexyl), 1.71–1.78 (m, 2 H, CH_2 cyclohexyl), 1.87–1.95 (m, 2 H, CH_2 cyclohexyl), 2.23, 2.49 (AB system, $^2J_{AB}$ = 13.8 Hz, 2 H, CH_2N), 2.29 [s, 6 H, $N(CH_3)_2$], 2.37–2.42 (m, 2 H, CHN), 2.50 [s, 3 H, $N(CH_3)CH_2$], 4.64 (dd, $^3J_{HH}$ = 10.4 Hz, 1 H, C*H*OH), 7.17–7.22 (m, 1 H, CH_{para}), 7.27–7.31 (m, 2 H, $CH_{arom.}$), 7.34–7.37 (m, 2 H, $CH_{arom.}$), 7.60–8.00 (br., 1 H, OH) ppm. $\{^1H\}^{13}C$ NMR (100.6 MHz, $CDCl_3$): δ = 21.3, 23.8, 25.3, 25.5 (CH_2 cyclohexyl), 39.0 [$N(CH_3)_2$], 41.0 (NCH_3), 58.7 (CH_2N), 64.1, 64.2 (CHN), 70.9 [*C*H(Ph)OH], 125.9, 126.8, 128.1 ($CH_{arom.}$), 144.0 (C_{ipso}) ppm. $[\alpha]_D^{20}$ = –145.2 (*c* = 0.493 g/100mL, cyclohexane). $C_{17}H_{28}N_2O$ (276.42): calcd. C 73.87, H 10.21, N 10.13; found C 73.81, H 12.16, N 10.86. GC–MS (EI): t_R = 9.65 min [80 °C (2 min) – 10 °C/min – 280 °C (5 min)]: *m*/*z* (%) = 258 (32) [M – H_2O]$^+$, 170 (23) [$C_6H_{10}(NMe_2)_2$]$^+$, 124 (60) [$C_6H_9N(CH_3)CH_2$]$^+$, 84 (72) [C_6H_{12}]$^+$, 71 (80) [$C_4H_{10}N$]$^+$, 58 (100) [$N(CH_3)_2CH_2$]$^+$. R_F = 0.80 (*n*-pentane/2-propanol/Et_3N = 11:10:1).

Minor diastereomer: ^1H NMR (400.1 MHz, $CDCl_3$): δ = 1.08–1.16 (m, 4 H, CH_2 cyclohexyl), 1.71–1.78 (m, 2 H, CH_2 cyclohexyl), 1.84–1.89 (m, 2 H, CH_2 cyclohexyl), 1.93 [s, 3 H, $N(CH_3)CH_2$], 2.27–2.33 (m, 1 H, CHN), 2.38 [s, 6 H, $N(CH_3)_2$], 2.38, 2.99 (AB system, $^2J_{AB}$ = 13.5 Hz, 2 H, CH_2N), 2.39–2.51 (m, 1 H, CHN), 4.70 (br., 1 H, C*H*OH), 7.16–7.19 (m, 1 H, CH_{para}), 7.26–7.29 (m, 2 H, $CH_{arom.}$), 7.33–7.35 (m, 2 H, $CH_{arom.}$), 7.60–8.00 (br., 1 H, OH) ppm. $\{^1H\}^{13}C$ NMR (100.6 MHz, $CDCl_3$): δ = 22.0, 24.1, 25.1, 25.5 (CH_2 cyclohexyl), 39.1 [$N(CH_3)_2$], 40.0 (NCH_3), 59.0 (CH_2N), 63.4, 64.5 (CHN), 71.7 [*C*H(Ph)OH], 126.0, 126.3, 127.9 ($CH_{arom.}$), 144.5 (C_{ipso}) ppm. R_F = 0.57 (*n*-pentane/2-propanol/NEt_3 = 11:10:1). $[\alpha]_D^{20}$ = 18.0 (*c* = 0.382 g/100mL, cyclohexane).

Methylbutanol Derivative (*R*,*R*)-4d: By using the above general procedure, (*R*,*R*)-TMCDA [(*R*,*R*)-**3**; 5.00 g, 29.4 mmol] was treated with isobutyraldehyde (1.3 equiv.) at low temperatures (Table 1). Work-up and bulb-to-bulb distillation (oven temperature 125 °C; 1×10^{-2} mbar) gave the product as a colourless oil. The two diastereomers can be separated by column chromatography on silica gel (*n*-pentane/2-propanol/triethylamine = 11:10:1). For yields and diastereomeric ratios, see Table 1.

Major diastereomer: ^1H NMR (500.1 MHz, $CDCl_3$): δ = 0.89 (d, $^3J_{HH}$ = 6.78 Hz, 3 H, $CHCH_3$), 0.93 (d, $^3J_{HH}$ = 6.85 Hz, 3 H, $CHCH_3$), 0.98–1.16 (m, 4 H, CH_2 cyclohexyl), 1.49–1.60 [m, 1 H, $CH(CH_3)_2$], 1.71–1.75 (m, 2 H, CH_2 cyclohexyl), 1,80–1.83 (m, 1 H, CH_2 cyclohexyl), 1.91–1.95 (m, 1 H, CH_2 cyclohexyl), 2.17 [s, 6 H, $N(CH_3)_2$], 2.08, 2.31 (AB System, $^2J_{AB}$ = 12.1 Hz, 2 H, CH_2N), 2.28–2.34 (m, 2 H, CHN), 2.35 (s, 3 H, NCH_3), 3.28–3.31 (m, 1 H,

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C*H*OH), 8.78 (br., 1 H, OH) ppm. {^{1}H}^{13}C NMR (125.8 MHz, $CDCl_3$): δ = 18.1, 18.8 [CH(*C*H$_3$)$_2$], 21.3, 23.7, 25.4, 25.6 (CH_2 cyclohexyl), 32.0 [*C*H(CH$_3$)$_2$], 38.9 [N(CH$_3$)$_2$], 41.0 (NCH$_3$), 53.0 (NCH$_2$), 64.0, 64.4 (CHN), 73.1 (CHOH) ppm. $[\alpha]_D^{20}$ = –91.5 (*c* = 0.219 g/100mL, cyclohexane). $C_{14}H_{30}N_2O$ (242.40): calcd. C 69.37, H 12.47, N 11.56; found C 69.41, H 12.46, N 11.51. GC–MS (EI): t_R = 7.10 min [80 °C (2 min) – 10 °C/min – 280 °C (5 min)]: *m*/*z* (%) = 224 (5) [M – H_2O]$^+$, 170 (40) [C_6H_{10}(NMe$_2$)$_2$]$^+$, 124 (100) [C_6H_9N(CH$_3$)CH$_2$]$^+$, 84 (55) [C_6H_{12}]$^+$, 77 (100) [C_6H_5]$^+$, 58 (95) [N(CH$_3$)$_2$CH$_2$]$^+$. R_F = 0.65 (*n*-pentane/2-propanol/NEt$_3$ = 11:10:1).

Minor diastereomer: ^{1}H NMR (500.1 MHz, $CDCl_3$): δ = 0.86 (d, $^3J_{HH}$ = 6.80 Hz, 3 H, CHC*H*$_3$), 0.96 (d, $^3J_{HH}$ = 6.70 Hz, 3 H, CHC*H*$_3$), 1.09–1.19 (m, 4 H, CH_2 cyclohexyl), 1.56–1.62 [m, 1 H, C*H*(CH$_3$)$_2$], 1.71–1.75 (m, 2 H, CH_2 cyclohexyl), 1,80–1.83 (m, 1 H, CH_2 cyclohexyl), 1.91–1.95 (m, 1 H, CH_2 cyclohexyl), 2.22, 2.65 (AB system, $^2J_{AB}$ = 12.8 Hz, 2 H, CH_2N), 2.26 [s, 6 H, N(CH$_3$)$_2$], 2.29 (s, 3 H, NCH$_3$), 2.28–2.34 (m, 2 H, CHN), 3.21–3.25 (m, 1 H, C*H*OH), 8.42 (br., 1 H, OH) ppm. {^{1}H}^{13}C NMR (125.8 MHz, $CDCl_3$): δ = 18.6, 19.1 [CH(*C*H$_3$)$_2$], 22.8, 25.4, 25.7 (CH_2 cyclohexyl), 32.3 [*C*H(CH$_3$)$_2$], 37.4 [N(CH$_3$)$_2$], 40.1 (NCH$_3$), 57.7 (NCH$_2$), 64.5, 65.4 (CHN), 72.9 (CHOH) ppm. R_F = 0.45 (*n*-pentane/2-propanol/NEt$_3$ = 11:10:1) ppm. GC–MS (EI): analogous to diastereomer 1 with a retention time of 7.18 min.

Methylpentanol Derivative (*R*,*R*)-4e: By using the above general procedure, (*R*,*R*)-TMCDA [(*R*,*R*)-**3**; 5.00 g, 29.4 mmol] was treated at –110 °C with isovaleraldehyde (1.3 equiv.) at low temperatures (Table 1). Work-up and bulb-to-bulb distillation (oven temperature 171 °C; 2×10^{-2} mbar) gave product (*R*,*R*)-**4e** as a 78:22 mixture of two diastereomers as a colourless oil (4.64 g, 0.18 mmol; 61%).

Major diastereomer: ^{1}H NMR (500.1 MHz, $CDCl_3$): δ = 0.87 [d, $^3J_{HH}$ = 6.62 Hz, 3 H, C(CH$_3$)$_2$], 0.87 [d, $^3J_{HH}$ = 6.63 Hz, 3 H, C(CH$_3$)$_2$], 0.97, 1.27 [m, 2 H, C*H*$_2$CH(CH$_3$)$_2$], 1.05–1.12 (m, 4 H, CH_2 cyclohexyl), 1.71–1.75 (m, 2 H, CH_2 cyclohexyl), 1.74–1.81 [m, 1 H, C*H*(CH$_3$)$_2$], 1.80–1.83 (m, 1 H, CH_2 cyclohexyl), 1.89–1.93 (m, 1 H, CH_2 cyclohexyl), 2.03, 2.27 (AB system, $^2J_{AB}$ = 13.5 Hz, 2 H, CH_2N), 2.18 [s, 6 H, N(CH$_3$)$_2$], 2.28–2.34 (m, 2 H, CHN), 2.36 (s, 3 H, NCH$_3$), 3.57–3.62 (m, 1 H, C*H*OH), 6.75–7.05 (br., 1 H, OH) ppm. {^{1}H}^{13}C NMR (125.8 MHz, $CDCl_3$): δ = 21.1, 23.6, 25.4, 25.6 (CH_2 cyclohexyl), 22.3, 23.6 [CH(*C*H$_3$)$_2$], 24.56 [*C*H(CH$_3$)$_2$], 38.9 [N(CH$_3$)$_2$], 41.2 (NCH$_3$), 44.3 [*C*H$_2$CH(CH$_3$)$_2$], 56.5 (NCH$_2$), 63.9, 64.4 (CHN), 66.4 (CHOH) ppm. GC–MS (EI): t_R = 7.613 min [80 °C (2 min) – 10 °C/min – 280 °C (5 min)]: *m*/*z* (%) = 257 (1) [MH]$^+$, 170 (100) [C_6H_{10}(NMe$_2$)$_2$]$^+$, 128 (40) [C_6H_{11}NH(CH$_3$)$_2$]$^+$, 110 (40) [C_6H_9NHCH$_2$]$^+$, 96 (35) [C_6H_9N]$^+$. $C_{15}H_{32}N_2O$ (256.43): calcd. C 70.26, H 12.58, N 10.92; found C 69.60, H 12.30, N 11.61. R_F = 0.53 (*n*-pentane/2-propanol/Et$_3$N = 11:10:1).

Minor diastereomer: ^{1}H NMR (500.1 MHz, $CDCl_3$): δ = 0.87 [d, $^3J_{HH}$ = 6.62 Hz, 3 H, C(CH$_3$)$_2$], 0.87 [d, $^3J_{HH}$ = 6.63 Hz, 3 H, C(CH$_3$)$_2$], 1.06, 1.38 [AB system, 2 H, C*H*$_2$CH(CH$_3$)$_2$], 1.07–1.16 (m, 4 H, CH_2 cyclohexyl), 1.71–1.75 (m, 2 H, CH_2 cyclohexyl), 1.76–1.84 [m, 1 H, C*H*(CH$_3$)$_2$], 1,80–1.83 (m, 1 H, CH_2 cyclohexyl), 1.89–1.93 (m, 1 H, CH_2 cyclohexyl), 2.14, 2.66 (AB system, $^2J_{AB}$ = 13.1 Hz, 2 H, CH_2N), 2.25 (s, 3 H, NCH$_3$), 2.28 [s, 6 H, N(CH$_3$)$_2$], 2.24–2.29 (m, 2 H, CHN), 3.21 (m, 1 H, C*H*OH), 6.75–7.10 (br., 1 H, OH) ppm. {^{1}H}^{13}C NMR (125.7 MHz, $CDCl_3$): δ = 21.1, 22.5, 25.3, 25.6 (cyclohexyl), 22.3, 23.6 [CH(*C*H$_3$)$_2$], 24.7 [*C*H(CH$_3$)$_2$], 38.9 (NCH$_3$), 40.1 [N(CH$_3$)$_2$], 44.5 (*C*H$_2$CHOH), 56.5 (NCH$_2$), 63.9, 64.6 (CHN), 65.4 (CHOH) ppm. GC–MS (EI): t_R = 7.669 min [80 °C (2 min) – 10 °C/min – 280 °C (5 min)]: *m*/*z* (%) = 257 (1) [MH]$^+$, 238 (3) [M – H_2O]$^+$, 170 (20) [C_6H_{10}(NMe$_2$)$_2$]$^+$, 124 (100) [C_6H_9N(CH$_3$)CH$_2$]$^+$, 84 (45) [C_6H_{12}]$^+$, 58 (52) [N(CH$_3$)$_2$-CH$_2$]$^+$. R_F = 0.39 (*n*-pentane/2-propanol/NEt$_3$ = 11:10:1).

Dimethylbutanol Derivative (*R*,*R*)-4f: By using the above general procedure, (*R*,*R*)-TMCDA [(*R*,*R*)-**3**; 5.09 g, 29.9 mmol] was treated with pivaldehyde (1.3 equiv.) at low temperatures (Table 1). Work-up and bulb-to-bulb distillation (oven temperature 125 °C; 1×10^{-2} mbar) gave a mixture of two diastereomers of (*R*,*R*)-**4f** as a colourless oil. For yields and diastereomeric ratios, see Table 1.

Major diastereomer: ^{1}H NMR (500.1 MHz, $CDCl_3$): δ = 0.88 [s, 9 H, C(CH$_3$)$_3$], 1.05–1.14 (m, 4 H, CH_2 cyclohexyl), 1.71–1.75 (m, 2 H, CH_2 cyclohexyl), 1,80–1.83 (m, 1 H, CH_2 cyclohexyl), 1.93–1.96 (m, 1 H, CH_2 cyclohexyl), 2.12, 2.32 (AB system, $^2J_{AB}$ = 11.8 Hz, 1 H, CH_2N), 2.24 [s, 6 H, N(CH$_3$)$_2$], 2.28–2.37 (m, 2 H, CHN), 2.35 (s, 3 H, NCH$_3$), 23.27 (dd, $^3J_{HH}$ = 11.0 Hz, 1 H, C*H*OH), 8.78 (br., 1 H, OH) ppm. {^{1}H}^{13}C NMR (125.8 MHz, $CDCl_3$): δ = 23.3, 25.5, 25.8, 26.2 (CH_2 cyclohexyl), 25.9 [C(*C*H$_3$)$_3$], 33.6 [*C*(CH$_3$)$_3$], 40.2 [N(CH$_3$)$_2$], 40.6 (NCH$_3$), 56.8 (NCH$_2$), 64.6, 65.2 (CHN), 74.0 (CHOH) ppm. GC–MS (EI): t_R = 7.290 min [80 °C (2 min) – 10 °C/min – 280 °C (5 min)]: *m*/*z* (%) = 257 (1) [MH]$^+$, 199 (15) [M – CCH$_3$]$^+$, 170 (50) [C_6H_{10}(NMe$_2$)$_2$]$^+$, 124 (70) [C_6H_9N(CH$_3$)-CH$_2$]$^+$, 84 (45) [C_6H_{12}]$^+$, 58 (100) [N(CH$_3$)$_2$CH$_2$]$^+$. R_F = 0.67 (*n*-pentane/2-propanol/Et$_3$N = 11:10:1). $C_{15}H_{32}N_2O$ (256.43): calcd. C 70.26, H 12.58, N 10.92; found C 69.55, H 12.62, N 11.88.

Minor diastereomer: ^{1}H NMR (500.1 MHz, $CDCl_3$): δ = 0.86 [s, 9 H, C(CH$_3$)$_3$], 1.05–1.14 (m, 4 H, CH_2 cyclohexyl), 1.71–1.75 (m, 2 H, CH_2 cyclohexyl), 1,79–1.91 (m, 2 H, CH_2 cyclohexyl), 2.19, 2.65 (AB system, $^2J_{AB}$ = 13.1 Hz, 1 H, CH_2N), 2.17 [s, 6 H, N(CH$_3$)$_2$], 2.22 (s, 3 H, NCH$_3$), 2.24–2.29 (m, 2 H, CHN), 3.19 (dd, $^3J_{HH}$ = 10.5 Hz, 1 H, C*H*OH), 8.42 (br., 1 H, OH) ppm. {^{1}H}^{13}C NMR (125.7 MHz, $CDCl_3$): δ = 21.2, 23.7, 25.6, 25.7 (CH_2 cyclohexyl), 25.8 [C(*C*H$_3$)$_3$], 33.3 [*C*(CH$_3$)$_3$], 35.4 (NCH$_3$), 39.0 [N(CH$_3$)$_2$], 50.6 (NCH$_2$), 63.9, 64.6 (CHN), 75.4 (CHOH) ppm. R_F = 0.45 (*n*-pentane/2-propanol/Et$_3$N = 11:10:1). GC–MS (EI): analogous to diastereomer 1 with a retention time of 7.167 min.

Preparation of α-Stannylated Amine (*R*,*R*)-9: By using the above general procedure, (*R*,*R*)-TMCDA [(*R*,*R*)-**3**; 200 mg, 1.17 mmol] was treated with *t*BuLi (1.2 equiv.) and trapped with tributyltin chloride (1.3 equiv.) at –60 °C. Work-up and bulb-to-bulb distillation (oven temperature 160 °C, 2×10^{-2} mbar) gave the stannylated compound (*R*,*R*)-**7** as a colourless oil that solidifies upon storage over weeks (491 mg, 1.07 mmol; 91%). ^{1}H NMR (500.1 MHz, $CDCl_3$, $CDCl_3$): δ = 0.77–0.95 (m, 6 H, SnCH$_2$), 0.88 (t, $^3J_{HH}$ = 7.30 Hz, 9 H, SnCH$_2$CH$_2$CH$_2$C*H*$_3$), 1.07–1.21 [m, 4 H, CH_2 cyclohexyl], 1.30 (sext., $^3J_{HH}$ = 7.26 Hz, 6 H, SnCH$_2$CH$_2$C*H*$_2$CH$_3$), 1.37–1.52 (m, 6 H, SnCH$_2$C*H*$_2$CH$_2$), 1.67–1.72 (m, 2 H, CH_2 cyclohexyl), 1.80–1.83 (m, 1 H, CH_2 cyclohexyl), 1.85–1.87 (m, 1 H, CH_2 cyclohexyl), 2.23 [s, 3 H, N(C*H*$_3$)CH$_2$Sn], 2.34 [s, 6 H, N(CH$_3$)$_2$], 2.34–2.38 (m, 2 H, CHN), 2.43, 2.63 (AB system, $^3J_{AB}$ = 11.9 Hz, NCH$_2$Sn) ppm. {^{1}H}^{13}C NMR (125.8 MHz, $CDCl_3$, $CDCl_3$): δ = 9.7 ($^1J_{117Sn-C}$ = 146.9, $^1J_{119Sn-C}$ = 153.6 Hz, SnCH$_2$), 13.7 (CH$_3$), 23.0, 25.5, 25.7, 26.5 (CH_2 cyclohexyl), 27.4 ($^3J_{Sn-C}$ = 27.0 Hz, SnCH$_2$CH$_2$*C*H$_2$), 26.9 ($^2J_{Sn-C}$ = 10.1 Hz, SnCH$_2$*C*H$_2$), 40.1 ($^1J_{117Sn-C}$ = 174.0, $^1J_{119Sn-C}$ = 180.6 Hz, NCH$_2$Sn), 40.7 [N(CH$_3$)$_2$], 41.2 [$^3J_{Sn-C}$ = 18.7 Hz, N(*C*H$_3$)CH$_2$Sn, 63.9 (*C*HNMe$_2$), 66.6 [*C*HN(Me)CH$_2$Sn] ppm. ^{119}Sn NMR (111.9 MHz, $CDCl_3$, $CDCl_3$): δ = –31.3 ppm.

Zinc(II) Bromide Adduct 10: Zinc(II) bromide (168 mg, 0.75 mmol) and (*R*,*R*)-**4a** (150 mg, 0.75 mmol) were dissolved in dichloromethane (20 mL). After storage at room temp. and slow evaporation of

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the solvent colourless plates of compound **10** (231 mg, 0.34 mmol; 89%) were formed. For crystallographic data, see Table 3. ^{1}H NMR (400.1 MHz, $CDCl_3$, $CDCl_3$): δ = 1.10–1.38 (m, 8 H, CH_2, cyclohexyl), 1.78–1.82 (m, 4 H, CH_2, cyclohexyl), 1.89–2.08 (m, 4 H, CH_2, cyclohexyl), 2.10–2.14 (m, 1 H, CH_2, cyclohexyl), 2.33, 2.35, 2.40, 2.44 [s, 3 H, $N(CH_3)_2$], 2.55 [br., 6 H, NCH_3], 2.49–2.74 [m, 8 H, $N(CH_2)CH_3$, CHN], 3.52–3.57 (m, 1 H, CH_2O), 3.60–3.66 (m, 1 H, CH_2O), 3.84–3.89 (m, 1 H, CH_2O), 3.91–3.95 (m, 1 H, CH_2O) ppm. $\{^1H\}^{13}C$ NMR (100.6 MHz, $CDCl_3$, $CDCl_3$): δ = 21.8, 22.8, 23.5, 24.1, 24.6, 24.8, 25.0 (cyclohexyl), 37.9, 39.4, 40.6, 41.7 [$N(CH_3)_2$], 45.5, 46.8 (NCH_3), 52.9, 56.9 (CH_2N), 58.3, 60.3 (CH_2O), 59.7, 62.9, 63.22, 63.25 (CHN) ppm. $C_{22}H_{46}Br_2N_4O_2Zn_2$ (689.21): calcd. C 38.34, H 6.73, N 8.13; found C 38.45, H 6.10, N 8.15.

Copper Iodide Adduct 11: Copper(I) iodide (45 mg, 0.24 mmol) was dissolved in acetonitrile (2.0 mL) and acetone (1.0 mL) and (*R*,*R*)-**4a** (40 mg, 0.20 mmol) were added. After storage at room temp. and slow evaporation of the solvent, green needles of the adduct were formed (65 mg, 0.08 mmol; 69%).

Crystallographic Analysis: Data collection for (*R*,*R*)-**8** and *trans*-**7** was conducted with a Stoe IPDS diffractometer. Data collection: expose in IPDS (Stoe & Cie, 1999); cell determination and refinement: cell in IPDS (Stoe & Cie, 1999); integration: integrate in IPDS (Stoe & Cie, 1999); numerical absorption correction: Faceit in IPDS (Stoe & Cie, 1999). Data collection for **10** and **11** was conducted with a Bruker APEX-CCD (D8 three-circle goniometer) (Bruker AXS); cell determination and refinement: Smart version 5.622 (Bruker AXS, 2001); integration with SaintPlus version 6.02 (Bruker AXS, 1999); empirical absorption correction with SADABS version 2.01 (Bruker AXS, 1999). Crystals of compounds *trans*-**7** and (*R*,*R*)-**8** were mounted in an inert oil (perfluoropolyalkyl ether) at –60 °C (N_2 stream) using the X-TEMP 2 device.[18]

Table 2. Data collection and structure refinement details for the lithiated compounds (*R*,*R*)-**8** and *trans*-**7**.

	[(*R*,*R*)-**8**]	(*trans*-**7**)
Formula	$C_{28}H_{60}Li_4N_4$	$C_{40}H_{84}Li_4N_8$
Formula weight [g/mol]	480.56	702.91
Temperature [K]	173(2)	173(2)
Wavelength [Å]	0.71073	0.71073
Crystal system	monoclinic	tetragonal
Space group	$P2_1$ (4)	$P\bar{4}2_1/c$
a [Å]	8.483(3)	12.2949(16)
b [Å]	18.650(6)	12.2949(16)
c [Å]	10.622(4)	15.025(4)
β [°]	91.36(8)	90
Volume [Å^3]	1680.0(10)	2271.3(8)
Z	*Z* = 2	*Z* = 2
Calcd. density [Mg/m^3]	0.950	1.031
μ(Mo-K_α) [mm^{-1}]	0.053	0.060
F(000)	536	784
Crystal dimensions [mm]	0.40 × 0.20 × 0.20	0.40 × 0.40 × 0.30
θ range [°]	2.21–24.99	2.14–26.00
Index ranges	$-9 \le h \le 10$	$-15 \le h \le 15$
	$-22 < k < 16$	$-15 < k < 13$
	$-12 < l < 12$	$-18 < l < 10$
Reflections collected	8793	6740
Independent reflections	4589 [R_{int} = 0.0430]	2109 [R_{int} = 0.0421]
Data/restraints/parameters	4589/1/353	2109/0/137
Goodness-of-fit on F^2	1.023	1.008
Final *R* indices	*R*1 = 0.0525	*R*1 = 0.0523
[$I > 2\sigma(I)$]	wR_2 = 0.1083	wR_2 = 0.1278
R indices (all data)	*R*1 = 0.0921	*R*1 = 0.0688
	wR_2 = 0.1220	wR_2 = 0.1388

The crystal structure determinations were effected at –100 °C (type of radiation: Mo-K_α, α = 0.71073 Å). The structures were solved by applying direct and Fourier methods using SHELXS-90[19] and SHELXL-97.[20]

Table 2 gives further details of the data collection and structure refinement of compounds **7** and **8** and Table 3 the details for complexes **10** and **11**. Further information, including ORTEP diagrams and atomic coordinates, are available in the Supporting Information

Table 3. Data collection and structure refinement details for the adducts of **4a** with zinc bromide and copper iodide.

	10[a]	**11**
Formula	$C_{22}H_{46}Br_2N_4O_2Zn_2$	$C_{22}H_{46}Cu_2I_2N_4O_2$
Formula weight [g/mol]	689.19	779.51
Temperature [K]	173(2)	173(2)
Wavelength [Å]	0.71073	0.71073
Crystal system	orthorhombic	monoclinic
Space group	$P2_12_12_1$ (19)	$P2_1$ (4)
a [Å]	8.3789(17)	9.948(5)
b [Å]	10.015(2)	8.405(4)
c [Å]	33.877(7)	16.995(7)
β [°]	90	95.299(11)
Volume [Å^3]	2842.8(10)	1414.9(11)
Z	4	2
Calcd. density [Mg/m^3]	1.610	1.830
μ(Mo-K_α) [mm^{-1}]	4.523	3.710
F(000)	1408	772
Crystal dimensions [mm]	0.40 × 0.20 × 0.10	0.30 × 0.30 × 0.10
θ range [°]	1.20–25.00	1.20–25.00
Index ranges	$-9 \le h \le 9$	$-11 \le h \le 11$
	$-11 \le k \le 11$	$-9 \le k \le 9$
	$-40 \le l \le 40$	$-20 \le l \le 20$
Reflections collected	58862	15797
Independent reflections	4994 [R_{int} = 0.1128]	4962 [R_{int} = 0.0706]
Data/restraints/parameters	4994/0/312	4962/1/295
Goodness-of-fit on F^2	1.089	1.063
Final *R* indices	*R*1 = 0.0629	*R*1 = 0.0613
[$I > 2\sigma(I)$]	wR_2 = 0.1762	wR_2 = 0.1535
Indices (all data)	*R*1 = 0.0740	*R*1 = 0.0709,
	wR_2 = 0.1857	wR_2 = 0.1597
Absolute structure parameter	0.09(3)	0.16(6)

[a] For refinement of disordered **10** a splitting model was used for the position of the ethoxy groups giving a 70:30 ratio of the two isomers (the main isomer is shown in Figure 3).

CCDC-752093 [for (*R*,*R*)-**8**], -752094 (for *trans*-**7**), -752095 (for **10**) and -752096 (for **11**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Computational Details: All calculations were performed without symmetry restrictions. Starting coordinates were obtained directly from the crystal structures. Optimisation and additional harmonic vibrational frequency analyses (to establish the nature of stationary points on the potential energy surface) were performed with the software package Gaussian 03[21] (Revision D.01 and Revision E.01) using B3LYP [Becke's three-parameter exchange functional (B3) and the Lee–Yang–Parr correlation functional (LYP)] and the 6-31+G(d) basis set. The total (SCF) and zero-point energies (ZPE) and the coordinates of all systems are available in the Supporting Information. The vibrational frequency analyses showed imaginary frequencies for the transition states representing the corresponding vibration for the deprotonation. For the starting materials no imag-

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inary frequencies were obtained. For polar compounds entropy is crucially influenced by solvent effects. In addition, calculated Gibbs free energies seem to be less reliable in such large systems due to very low frequencies, the harmonic oscillator model producing significant deviations.[22] Thus, enthalpy values have been discussed. Corrections for basis set superposition errors (BSSE) are not included.

Supporting Information (see also the footnote on the first page of this article): Computational details (coordinates and absolute energies), additional NMR spectra and ORTEP plots of the crystal structures.

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[1] For examples, see: a) D. Hoppe, F. Hintze, P. Tebben, *Angew. Chem.* **1990**, *102*, 1457–1459; *Angew. Chem. Int. Ed. Engl.* **1990**, *29*, 1422–1424; b) S. T. Kerrick, P. Beak, *J. Am. Chem. Soc.* **1991**, *113*, 9708–9710; c) M. C. Whisler, P. Beak, *J. Org. Chem.* **2003**, *68*, 1207–1215; d) I. Coldham, R. C. B. Copley, T. F. N. Haxell, S. Howard, *Org. Biomol. Chem.* **2003**, *1*, 1532–1544; e) C. Metallinos, H. Szillat, N. J. Taylor, V. Snieckus, *Adv. Synth. Catal.* **2003**, *345*, 370–382; f) E.-U. Würthwein, K. Behrens, D. Hoppe, *Chem. Eur. J.* **1999**, *5*, 3459–3463; g) K. B. Wiberg, W. F. Bailey, *Tetrahedron Lett.* **2000**, *41*, 9365–9368; h) P. H. Martinz, K. C. Hueltzsch, F. Hampel, *Chem. Commun.* **2006**, 2221; i) B. Goldfuss, *Synthesis* **2005**, 2271–2280.

[2] a) F. H. Köhler, N. Hertkorn, J. Blümel, *Chem. Ber.* **1987**, *120*, 2081–2082; b) V. H. Gessner, C. Strohmann, *J. Am. Chem. Soc.* **2008**, *130*, 14412–14413.

[3] a) C. Strohmann, V. H. Gessner, *Angew. Chem.* **2007**, *119*, 4650–4653; *Angew. Chem. Int. Ed.* **2007**, *46*, 4566–4569; b) M. Schakel, M. P. Aarnts, G. W. Klumpp, *Recl. Trav. Chim. Pays-Bas* **1990**, *109*, 305–306; c) G. W. Klumpp, H. Luitjes, M. Schakel, E. J. J. de Kanter, R. F. Schmitz, N. J. R. van Eikema Hommes, *Angew. Chem.* **1992**, *104*, 624–626; *Angew. Chem. Int. Ed. Engl.* **1992**, *31*, 633–635; d) I. Kamps, D. Bojer, S. A. Hayes, R. J. F. Berger, B. Neumann, N. W. Mitzel, *Chem. Eur. J.* **2009**, *15*, 11123–11127; e) I. Kamps, A. Mix, R. J. F. Berger, B. Neumann, H.-G. Stammler, N. W. Mitzel, *Chem. Commun.* **2009**, 5558–5560.

[4] a) C. Strohmann, V. H. Gessner, *Angew. Chem.* **2007**, *119*, 8429–8432; *Angew. Chem. Int. Ed.* **2007**, *46*, 8281–8283; b) C. Strohmann, V. H. Gessner, *J. Am. Chem. Soc.* **2007**, *129*, 8952–8953; c) C. Strohmann, V. H. Gessner, *J. Am. Chem. Soc.* **2008**, *130*, 11719–11725; d) C. Strohmann, V. H. Gessner, A. Damme, *Chem. Commun.* **2008**, 3381–3383.

[5] For examples of further α-lithiated amines, see: a) H. H. Karsch, *Chem. Ber.* **1996**, *129*, 483; b) C. Strohmann, V. H. Gessner, *Chem. Asian J.* **2008**, *3*, 1929–1934; c) D. Bojer, I. Kamps, X. Tian, A. Hepp, T. Pape, R. Fröhlich, N. W. Mitzel, *Angew. Chem.* **2007**, *119*, 4254–4257; *Angew. Chem. Int. Ed.* **2007**, *46*, 4176–4179; d) R. D. Köhn, G. Seifert, G. Kociok-Köhn, *Chem. Ber.* **1996**, *129*, 1327–1333; e) J. Arnold, V. Knapp, J. A. R. Schmidt, A. Shafir, *J. Chem. Soc., Dalton Trans.* **2002**, 3273–3274; f) V. H. Gessner, C. Strohmann, *Organometallics* **2010**, *29*, 1858–1861; g) C. Däschlein, V. H. Gessner, C. Strohmann, *Chem. Eur. J.* **2010**, *16*, 4048–4062.

[6] a) D. Seyferth, M. A. Weiner, *J. Org. Chem.* **1959**, *24*, 1395–1396; b) X. Tian, R. Fröhlich, N. W. Mitzel, *Z. Anorg. Allg. Chem.* **2005**, *631*, 1442–1448; c) X. Tian, R. Fröhlich, T. Pape, N. W. Mitzel, *Organometallics* **2005**, *24*, 5294–5298; d) D. J. Peterson, *J. Organomet. Chem.* **1967**, *9*, 373–374; e) D. J. Peterson, *Organomet. Chem. Rev.* **1972**, *A7*, 295; f) D. J. Peterson, *J. Am. Chem. Soc.* **1971**, *93*, 4027–4031; g) C. Bruhn, F. Becke, D. Steinborn, *Organometallics* **1998**, *17*, 2124–2126; h) F. Becke, F. W. Heinemann, T. Rüffer, P. Wiegeleben, R. Boese, D. Bläser, D. Steinborn, *J. Organomet. Chem.* **1997**, *548*, 205–210; i) R. E. Gawley, Q. Zhang, *J. Org. Chem.* **1995**, *60*, 5763–5769, and references cited therein.

[7] a) C. Strohmann, B. C. Abele, *Angew. Chem.* **1996**, *108*, 2515–2517; *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 2378–2380; b) C. A. Broka, T. Shen, *J. Am. Chem. Soc.* **1989**, *111*, 2981–2984; c) S. Florio, V. Capriati, A. Gallo, T. Cohen, *Tetrahedron Lett.* **1995**, *36*, 4463–4466, and references cited therein.

[8] a) S. V. Kessar, P. Singh, *Chem. Rev.* **1997**, *97*, 721–737; b) M. R. Ebden, N. S. Simpkins, D. N. A. Fox, *Tetrahedron Lett.* **1995**, *36*, 8697–8700; c) E. Vedejs, J. T. Kendall, *J. Am. Chem. Soc.* **1997**, *119*, 6941–6942, and references cited therein.

[9] a) P. Beak, A. I. Meyers, *Acc. Chem. Res.* **1986**, *19*, 356–363; b) A. H. Hoveyda, D. A. Evans, G. C. Fu, *Chem. Rev.* **1993**, *93*, 1307–1370; c) B. Breit, *Chem. Eur. J.* **2000**, *6*, 1519–1524; d) M. C. Whisler, S. MacNeil, V. Snieckus, P. Beak, *Angew. Chem.* **2004**, *116*, 2256–2276; *Angew. Chem. Int. Ed.* **2004**, *43*, 2206–2225; e) V. H. Gessner in "Ideas in Chemistry and Molecular Science", *Advances in Synthetic Chemistry* (Ed.: B. Pignataro), Wiley-VCH, Weinheim, **2010**, pp. 95–114.

[10] For transition-metal-catalysed reactions with N,N,O ligands, see: a) P. D. Oldenburg, A. A. Shteinman, L. Que Jr., *J. Am. Chem. Soc.* **2005**, *127*, 15672–15673; b) J. Sun, C. Zhu, Z. Dai, M. Yang, Y. Pan, H. Hu, *J. Org. Chem.* **2004**, *69*, 8500–8503; c) J. F. Larrox, E. N. Jacobsen, *J. Org. Chem.* **1994**, *59*, 1939–1942.

[11] For N,N,O ligands in coordination chemistry, see: a) E. Hübner, G. Türkoglu, M. Wolf, U. Zenneck, N. Burzlaff, *Eur. J. Inorg. Chem.* **2008**, 1226–1235; b) A. Beck, B. Weibert, N. Burzlaff, *Eur. J. Inorg. Chem.* **2001**, 521–527; c) A. Otero, J. Fernández-Baeza, A. Antiñolo, F. Carrillo-Hermosilla, J. Tejeda, E. Díez-Barra, A. Lara-Sánchez, L. Sánchez-Barba, I. López-Solera, M. R. Ribeiro, J. M. Campos, *Organometallics* **2001**, *20*, 2428–2439; d) R. Bagai, S. Datta, A. Betancur-Rodriguez, K. A. Abboud, S. Hill, G. Christou, *Inorg. Chem.* **2007**, *46*, 4535–4547; e) C. González-Arellano, E. Gutiérrez-Puebla, M. Iglesias, F. Sánchez, *Eur. J. Inorg. Chem.* **2004**, 1955–1962; f) W. Klaui, M. Berghahn, W. Frank, G. J. Reiss, T. Schonherr, G. Rheinwald, H. Lang, *Eur. J. Inorg. Chem.* **2003**, 2059–2070.

[12] For reactions with N,N,O ligands and metal–organic compounds, see: a) D. J. Gallagher, S. Wu, N. A. Nikolic, P. Beak, *J. Org. Chem.* **1995**, *60*, 8148–8154; b) P. Beak, S. T. Kerrick, S. Wu, J. Chu, *J. Am. Chem. Soc.* **1994**, *116*, 3231–3239; c) T. Mukaiyama, K. Soai, S. Kobayashi, *Chem. Lett.* **1978**, 219–222; d) E. J. Corey, R. Naef, F. J. Hannon, *J. Am. Chem. Soc.* **1986**, *108*, 7114–7116; e) A. J. A. Cobb, C. M. Marson, *Tetrahedron*: *Asymmetry* **2001**, *12*, 1547–1550.

[13] For reviews on structure principles of organolithium compounds, see: a) T. Stey, D. Stalke in *The Chemistry of Organolithium Compounds* (Eds.: Z. Rappoport, I. Marek), Wiley, Chichester, **2004**, pp. 47–120; b) V. H. Gessner, C. Däschlein, C. Stohmann, *Chem. Eur. J.* **2009**, *15*, 3320–3334; c) R. E. Mulvey, *Chem. Soc. Rev.* **1991**, *20*, 167–209.

[14] For structures of organolithium compounds, see: a) M. A. Nichols, P. G. Williard, *J. Am. Chem. Soc.* **1993**, *115*, 1568–1572; b) C. Strohmann, K. Strohfeldt, D. Schildbach, *J. Am. Chem. Soc.* **2003**, *125*, 13672–13673; c) C. Strohmann, K. Strohfeldt, D. Schildbach, M. J. McGrath, P. O'Brien, *Organometallics* **2004**, *23*, 5389–5391; d) C. Strohmann, S. Dilsky, K. Strohfeldt, *Organometallics* **2006**, *25*, 41–44; e) C. Strohmann, V. H. Gessner, *J. Am. Chem. Soc.* **2007**, *129*, 8952–8953; f) C. Strohmann, T. Seibel, K. Strohfeldt, *Angew. Chem.* **2003**, *115*, 4669–4671; *Angew. Chem. Int. Ed.* **2003**, *42*, 4531–4533; g) T. Kottke, D. Stalke, *Angew. Chem.* **1993**, *105*, 619–621; *Angew. Chem. Int. Ed. Engl.* **1993**, *32*, 580–582; h) C. Strohmann, V. H. Gessner, *Z. Anorg. Allg. Chem.* **2007**, *633*, 2285–2287; i) H. Dietrich, *Acta Crystallogr.* **1963**, *16*, 681–689; j) E. A. C.

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Lucken, E. Weiss, *J. Organomet. Chem.* **1964**, *2*, 197–205; k) S. Schade, G. Boche, *J. Organomet. Chem.* **1998**, *550*, 359–379; l) I. Hoppe, M. Marsch, K. Harms, G. Boche, D. Hoppe, *Angew. Chem.* **1995**, *107*, 2328–2330; *Angew. Chem. Int. Ed. Engl.* **1995**, *34*, 2158–2160; m) B. Goldfuss, P. v. R. Schleyer, F. Hampel, *J. Am. Chem. Soc.* **1996**, *118*, 12183–12189; n) K. Sorger, P. v. R. Schleyer, D. Stalke, *J. Am. Chem. Soc.* **1996**, *118*, 1086–1091; o) T. Kremer, S. Harder, M. Junge, P. v. R. Schleyer, *Organometallics* **1996**, *15*, 585–595; p) P. G. Williard, C. Sun, *J. Am. Chem. Soc.* **1997**, *119*, 11693–11694; q) T. Tatic, K. Meindl, J. Henn, S. K. Pandey, D. Stalke, *Chem. Commun.* **2010**, *46*, 4562–4564.

[15] The distance between the carbanionic centre and the (calculated) α-hydrogen atoms is at least 3.81 Å. In organolithium adducts with amines, which undergo direct deprotonation, this distance was 3.3 Å or even smaller, see ref.[2b,4a,15b]

[16] V. H. Gessner, Ph. D. Thesis, Technische Universität Dortmund, Germany, **2009**.

[17] J.-C. Kizirian, N. Cabello, L. Pinchard, J.-C. Caille, A. Alexakis, *Tetrahedron* **2005**, *61*, 8939–8946.

[18] a) T. Kottke, D. Stalke, *J. Appl. Cryst.* **1993**, *26*, 615; b) T. Kottke, R. J. Lagow, D. Stalke, *J. Appl. Cryst.* **1996**, *29*, 615; c) D. Stalke, *Chem. Soc. Rev.* **1998**, *27*, 171.

[19] G. M. Sheldrick, *SHELXS-90*, University of Göttingen, **1990**.

[20] G. M. Sheldrick, *SHELXL-97*, University of Göttingen, **1997**.

[21] *Gaussian 03* (rev. D.01 and rev. E.01), for full details, see the Supporting Information.

[22] E.-U. Würthwein, D. Hoppe, *J. Org. Chem.* **2005**, *70*, 4443–4451.

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