1,3-Thiazoline-5-thiolates and 1,3-Thiazole-5(2*H*)-thiones by [3+2]-Cycloaddition of Carbon Disulfide to Metalated 4-Alkylidene-4*H*-pyridin-1-ides[‡]

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Dedicated to Professor Dr. Roland Boese on the occasion of his 60th birthday

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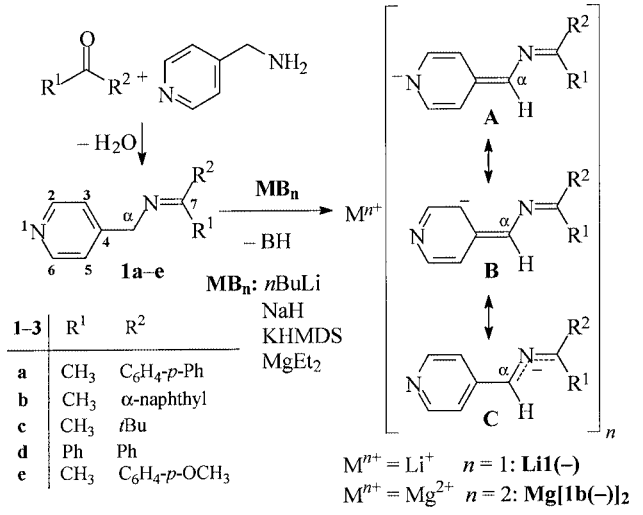
The 4-alkylidene-4*H*-pyridin-1-ides **1(–)**, which are ambident anions derived from azomethines **1a**–**e**, react easily with CS_2 to yield the lithium 2,3-dihydro-1,3-thiazole-5-thiolates **3a**–**e**. Two mechanisms are basically possible for this cyclization: a concerted process similar to a 1,3-dipolar cycloaddition or a two-step reaction which starts with a Cα CS_2 coupling and continues with a ring closure reaction to yield lithium thiazolidine-5-thiones **2**. A proton migration from the Cα position to the previous imino N-atom then follows to form the 2,3-dihydro-1,3-thiazole-5-thiolates **3a**–**e**. Protonation of **3** and a final oxidation of the intermediates **6** results in the formation of 1,3-thiazole-5(2*H*)-thiones **7**. This last step is always accompanied by a hydrolysis which results in 1,3-thiazole-5(2*H*)-ones **8** as side products. In addition, a surprising byproduct **9** was found in the reaction of **1e** with NaH and CS_2 in pyridine.

Introduction

Previous investigations on the azomethines **1** (which can be prepared from 4-picolylamine and various ketones) have opened a convenient synthetic approach to ambident carbanions which exhibit an interesting behavior towards electrophiles, especially heterocumulenes (CO_2, RNCO, RNCS).[1] The benzylic methylene group in **1** is significantly more acidic than the methyl group (R^1 in **1a**–**c**,**e**) and thus can be deprotonated by various metallo-organyl compounds or strong bases (Scheme 1). The formal allyl anion which results is stabilized by charge delocalization into both the pyridine ring and the C–N double bond. Quite a few resonance structures can thus be formulated for these anions **1(–)** with three (Scheme 1) contributing significantly to the resonance hybrid. As clearly supported by extensive NMR investigations and DFT calculations,[1] the most important one of these can be expected to be the 4-alkylidene-1,4-dihydropyridine **A** which is followed by the 4-alkylidene-3,4-dihydropyridine **B** and the 2-azaallyl anion **C**. If R^1 and R^2 are aryl substituents the conjugated system can be extended even further.



1–3	R^1	R^2
a	CH_3	C_6H_4-*p*-Ph
b	CH_3	α-naphthyl
c	CH_3	*t*Bu
d	Ph	Ph
e	CH_3	C_6H_4-*p*-OCH_3

Scheme 1. The ambident anions **1(–)** are obtained by deprotonation of the azomethines **1** [derived from different ketones and 4-(aminomethyl)pyridine].

According to a definition by Pearson and Kauffmann,[2] anions such as **1(–)** can be interpreted as belonging to the class of semistabilized 2-azaallyl anions due to the electronic influence of the heteroaromatic pyridine residue. Stabilized 2-azaallyl anions which bear strong electron-withdrawing substituents such as CN (nitriles), COOR (esters) or O_2POR (phosphonates) can easily be obtained by deprotonation of the corresponding azomethines. Nonstabilized

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2-azaallyl anions possessing only alkyl residues and/or hydrogen atoms are usually not obtained by deprotonating azomethines but by tin/lithium exchange in (2-azaallyl)stannanes.[2] Synthetic applications of (2-azaallyll)ithium compounds include their addition to C=C, C=N, N=N, C=S, and C=O double bonds as well as C≡C and C≡N triple bonds. Cycloadducts are normally obtained except for additions on C=O bonds.[2] Intensive structural studies of these 2-azaallyl anions have been performed mainly on semistabilized systems, e.g. $[PhCHNCHPh]^-$, $[Ph_2CNCHPh]^-$, $[Ph_2CNCH_2]^-$[2b,3,12–14] or $[PhCHNCAlk_2]^-$.[2b,4] However, a few non-stabilized systems, such as $[CH_2NCHAlk]^-$, have also been investigated.[5]

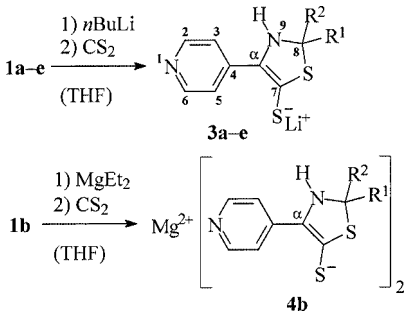
At a first glance, the potential reaction partner, carbon disulfide (CS_2), seems to be a poor electrophile. DFT calculations on this cumulene indicate that the carbon atom carries a small *negative* charge as compared to its oxygen analogue CO_2 in which the carbon atom is significantly positively charged.[6] The sulfur atoms are, however, easily polarizable which enables a significant charge redistribution in a polar environment. CS_2 can thus react as a C-electrophile with suitable nucleophiles, e.g. amines, amides, alkoxides, etc. It is quite often employed as a building block in the synthesis of dithiocarboxylates, dithiocarbamates, (iso)thioureas, amidines, guanidines, etc.[7] The dithiocarbamate moiety generated from secondary *N*-methyl-amines can act as a protecting (and directing) group for the amino function in metalation and subsequent alkylations of the methyl group.[8] Moreover, carbon disulfide has been found to function as a valuable dipolarophile in various 1,3-dipolar cycloadditions like other C=S-containing substrates.[9] Among other cycloadditions (hetero-Diels–Alder reactions, [2+2]-cycloadditions, chelotropic reactions) [3+2]-cycloadditions open various synthetic pathways for obtaining a multitude of five-ring heterocycles.[10] Due to the massive potential applications of thiolate intermediates, quite a few structural investigations of alkali metal and alkaline earth metal thiolate complexes both in the solid state and in solution have been started in the 1980s and 1990s by several research groups.[11]

Continuing our systematic investigation on the reaction behavior of 4*H*-pyridin-1-ide anions **1(–)** towards various electrophiles,[1] we now report on an unusual activation/fixation reaction observed when CS_2 reacts with lithium 4-iminomethylene-4*H*-pyridin-1-ides **Li1(–)** which results in cyclic lithium thiolates. We have investigated the solid-state structure (X-ray analysis) of these products in order to gain more insight into the coordination pattern of these ambident anions towards the metal cation.

Results and Discussion

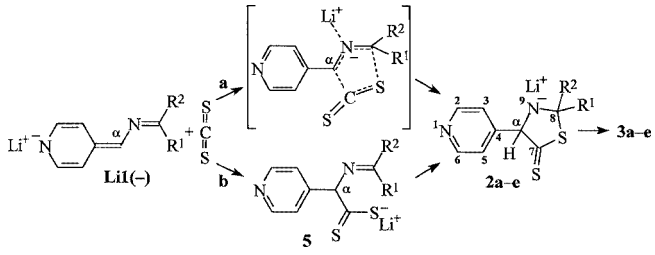
Lithium 2,3-Dihydro-1,3-thiazole-5-thiolates 3

Addition of CS_2 to the Cα atom of a lithium 4-alkylidene-4*H*-pyridin-1-ide **Li1(–)** (Scheme 1) is accompanied by cyclization and a subsequent proton shift which result in the formation of a lithium 4-pyridin-4-yl-2,3-dihydro-1,3-thiazole-5-thiolate **3a–e** (Scheme 2). In case of **1b**, the magnesium bis(4-pyridin-4-yl-2,3-dihydro-1,3-thiazole-5-thiolate) complex **4b** was synthesized since the corresponding lithium compound **3b** could only be prepared in an unreproducible manner in a very poor yield.



Scheme 2. The numbering of **3** does not follow the IUPAC rules, but should facilitate the NMR descriptions; in the case of **4b** $MgEt_2$ was used for deprotonation of **1b**.

Two possible mechanisms must be considered for this cyclization (Scheme 3). A concerted cycloaddition with an asynchronous transition state in which a lithium coordination mode is present that vaguely resembles a metal-assisted azomethine ylide[12] which will be decisive in pathway a. The other possibility (pathway b) is a two-step mechanism in which CS_2 first forms a single bond to the Cα atom to give a dithiocarboxylate intermediate **5**. Under the reaction conditions employed (–65 °C to room temperature, THF), we did not observe the intermediate formation of **5**. After the C–C bond formation, the now negatively charged sulfur atom in the dithiocarboxylate **5** can be expected to attack the positively polarized imino carbon atom in an intramolecular manner. This ring closure releases the products, the lithium 4-pyridin-4-yl-5-thioxo-1,3-thiazolidin-3-ides **2a–e**.



Scheme 3. Only **2e** was isolated: Yield 46%. The numbering of **2** does not follow the IUPAC rules, but should facilitate the NMR descriptions.

While reaction a (Scheme 3) is clearly a 1,3-dipolar cycloaddition, the two-step process can regarded as 1,3-dipolar cyclization, too. Huisgen and Sustmann et al. recently have demonstrated the possibility to switch from concerted to two-step processes via zwitterionic or biradical intermediates. Further, both mechanisms can coexist.[13a,13b] Two-step mechanisms are also discussed for several hetero-Diels–Alder reactions, which belong to the $[_\pi4_s + _\pi2_s]$ type of reactions.[13c–13e]

If one assumes the lithium 4*H*-pyridin-1-ides **Li1(–)** to be examples of 2-azaallyl anions, the reaction can also be

Table 1. Conditions for the reaction of metalated azomethines **1a**–**e** with CS_2.

Starting compound	R^1	R^2	Product	Base *T* [°C]	*T* [°C] of CS_2 addition	Time[a]	Yield (%)
1a	CH_3	C_6H_4-*p*-Ph	**3a**	*n*BuLi –78	–65	3 d	90
1a	CH_3	C_6H_4-*p*-Ph	**3a**	*n*BuLi –78	–20	3 d	35
1a	CH_3	C_6H_4-*p*-Ph	**3a**	*n*BuLi –78	room temp.	3 d	51
1b	CH_3	α-naphthyl	**3b**	*n*BuLi –78	–20	never[b]	10–30
1b	CH_3	α-naphthyl	**4b**	$MgEt_2$ –20	–20	12 h	34
1c	CH_3	*t*Bu	**3c**	*n*BuLi –78	–20	1 h	71
1d	Ph	Ph	**3d**	*n*BuLi –78	–20	3 d	84
1e	CH_3	C_6H_4-*p*-OCH_3	**2e**, **3e**	*n*BuLi –78	–20	**2e**: 1 h **3e**: 2 d	46

[a] Time for precipitation formation of **3** and **4b**, respectively. [b] Longer than 1–2 weeks.

interpreted as a *1,3-anionic* cycloaddition which is defined as a one- or multistep reaction of 1,3-anionophiles with double or triple bonds. This reaction differs from 1,3-dipolar cycloadditions in that the positive charge has been removed from the 1,3-dipole to obtain a negatively charged 4π-electron system (usually stabilized by the presence of a metal cation) which can react in a similar manner as a 1,3-dipole to yield negatively charged five-membered rings.[2b] Some 1,3-anionic cycloadditions have been demonstrated to proceed by two-step mechanisms.[14] Kauffmann et al. reported that 2 equiv. of (1,3-diphenyl-2-azaallyl)lithium Li[PhCHNCHPh] react with CS_2 in a double cycloaddition to yield a spiro compound (each C=S had cyclized with one anion). Isolation of the monocylized product (corresponds to compound **2**) was not successful.[15] Support for the stepwise addition mechanism is provided by the successful isolation of the open-chain adduct when the oxygen analogue CO_2 adds to either **Li1(–)**[1] or (1,3-diphenyl-2-azaallyl)lithium.[16] However, the subsequent cyclization and proton shift must be faster than the C–C bond formation when CS_2 is employed, since we could not detect the corresponding open-chain adduct (the dithiocarboxylate **5**) in this case.

We succeeded in isolating **2e** ($R^1 = CH_3$, $R^2 = C_6H_4$-*p*-OCH_3) due to its poor solubility in THF as compared to the other 5-thioxo-1,3-thiazolidin-3-ides **2a**–**d**. Compound **2e** precipitates spontaneously upon warming a solution to room temperature. In addition, the lithium 4-pyridin-4-yl-2,3-dihydro-thiazole-5-thiolates **3a**–**e** can be crystallized if the solution is allowed to stand for a longer period of time at room temperature (Table 1). These are the products of a proton transfer from Cα to the thiazolidine nitrogen atom N9 and can be considered to be amino-thioenolates (Scheme 2).

In the course of this reaction, various new asymmetric centers are formed (Cα/C8 in **2a**–**c**,**e** and C8/N9 in **3a**–**c**,**e**: $R^1 \neq R^2$). A total of four stereoisomers are conceivable – namely two pairs of diastereomeric enantiomers. The diastereomers are *cis*/*trans* isomers regarding the spatial arrangement of the substituents on the asymmetric atoms of the ring. Compounds **2d** and **3d** ($R^1 = R^2 = Ph$) are exceptions in that only one asymmetric center is formed during the reaction (Cα and N9, respectively). For the compounds **2e** and **3b**,**c**,**e** there are no indications in the NMR spectra for the existence of diastereomers. Either only one diastereomer of **2e** is formed (as a racemate) or both diastereomers have incidentally identical chemical shifts. Furthermore, the ring nitrogen atom N9 in the compounds **3b**,**c**,**e** can be expected to undergo a fast inversion in solution which leads to indistinguishable diastereomers. However, in the case of **3a**, signal doubling for both the methyl carbon atom (R^1) and the quaternary carbon atoms of the five-membered ring are observed (see NMR Investigations as well as Experimetal Section).

If the configuration of the lithium 4*H*-pyridin-1-ides **Li1(–)** can be predefined as being (*E*)[1] the stereochemical outcome of the cyclization could shed additional light on the mechanism of addition. If the 1,3-anionic cycloaddition pathway (a; Scheme 3) is exclusively followed, only the *cis* isomer of compounds **2** will be generated. On the other hand, pathway b generates the dithiocarboxylate **5** as an open-chain intermediate in which the subsequent attack of the negative sulfur atom can occur from both sides of the C=N double bond resulting in the formation of all four stereoisomers.

The mechanism of the proton migration can be discussed either as an intramolecular 1,2-proton transfer or as an intermolecular acid-base reaction. Deprotonation of the remaining acidic Cα proton (which is expected to be more acidic than the corresponding protons in the starting materials **1**) can be affected by the amide nitrogen atom (base) of another anion of **2**. Conjugation of the Cα–C7 double bond with the aromatic pyridine ring and the delocalization of the negative charge over this extended conjugated π-system is assumed to be the driving force for this process. We monitored this proton migration by ^1H NMR measurements (Table 2) for the conversion of **2e** into **3e**. Shortly after dissolving **2e** in [D_6]DMSO, only the signals of **2e** are detectable. After 2 d at room temperature, the proton trans-

fer has proceeded to ca. 60% and in 3–4 d the transfer is complete.

Table 2. ^{1}H and ^{13}C NMR spectroscopic data of the lithium 4-pyridin-4-yl-2,3-dihydro-thiazole-5-thiolates **3a**–**e** and the lithium 4-pyridin-4-yl-5-thioxo-1,3-thiazolidin-3-ide **2e** ([D$_6$]DMSO, room temp., 250/62.5 MHz).[a]

	3					**2**
	a	**b**[c]	**c**	**d**	**e**	**e**
δ_H						
H2/6	8.19	8.23	8.15	8.19	8.15	8.41
H3/5	8.53	8.65	8.41	8.60	8.53	7.80
NH9	4.68	4.80	3.79	4.66	4.55	Hα: 6.04
CH_3	1.85	2.13	1.50	–	1.77	2.23
δ_C						
C2/6	148.0	148.0	147.7	148.0	148.0	148.2
C3/5	117.4	117.3	117.2	117.3	117.3	122.9
C4	143.0	143.1	142.2	143.0	143.1	153.1
Cα	123.1	121.7	123.7	122.8	123.2	85.9
C7[b]	156.4	157.0	151.5	155.8	156.5	163.4
C8[b]	74.0	73.6	79.0	80.9	74.0	(33.6)[d]
CH_3	29.8	30.4	25.8	–	30.4	16.5

[a] The numbering of **3a**–**e** and **2e** follows that in Schemes 2 and 3. [b] The carbon atom C7 of compounds **3** is the newly introduced CS_2 carbon atom, C8 of compounds **3** corresponds to the imino carbon atom (C7) in the starting materials **1**. [c] **4b**: H2/6: 8.21; H3/5: 8.60; NH9: 4.77; CH_3: 2.09; C2/6: 148.0; C3/5: 117.2; C4: 143.1; Cα: 121.7; C7: 157.0; C8: 73.6; CH_3: 30.4. [d] An unambiguous assignment of this signal was not possible, even not by 2D NMR spectroscopy (see text).

In case of **3a**, crystals suitable for X-ray analysis were obtained. Figure 1 depicts the molecular structure of **3a** as being a polymer **[3a(THF)$_2$]$_\infty$**. The lithium cation is coordinated to two thiazole-5-thiolate anions and two solvent molecules (THF). Interestingly enough, one of the anions coordinates to the lithium ion via the negatively charged sulfur end [Li1–S1 2.451(5) Å], the other via the pyridine nitrogen atom [Li1–N1A 2.069(5) Å]. This arrangement allows the formation of molecular chains since each thiazole-5-thiolate anion complexes with two different lithium cations. This results in a distorted N,O,O,S tetrahedron about the lithium ion with the following bond angles: N1A–Li1–S1 122.1(2)°, O1–Li1–S1 118.4(2)° (these are widened presumably due to the spatial demand of the bulky thiazole-5-thiolate ring), S1–Li1–O2 105.1(2)°, N1A–Li1–O2 105.4(2)°, O1–Li1–N2 102.6(2)°, and O1–Li1–O2 100.6(2)°. The latter four angles are somewhat compressed. Structural analyses of Li–S bonds in numerous thiolates have yielded a value of 2.6 Å as being an upper limit for a strong Li–S interaction.[17]

[(PhCH$_2$S)Li(NC$_5$H$_5$)]$_\infty$ and [PhSLi(NC$_5$H$_5$)$_2$]$_\infty$ also build infinite polymers in the solid state. In these related compounds, the monomeric units of the infinite chains are linked together by symmetrical or asymmetrical coordination of three or two lithium ions with one ligating sulfur atom.[18,19] In contrast to this, the bridging in **[3a(THF)$_2$]$_\infty$** is accomplished by two different ligating atoms (S and N) in one 4-pyridin-4-yl-2,3-dihydro-1,3-thiazole-5-thiolate linker. The Li–S and Li–N(pyridine) distances in the benzylthiolate mentioned above are in the range of 2.470–2.508 Å and 2.045–2.068 Å, respectively. In **[3a(THF)$_2$]$_\infty$** the Li1–S1 distance is with 2.451 Å somewhat shorter, but the Li1–N1A distance is similar (2.069 Å).

When 2-benzylpyridine was lithiated and then treated with CS_2 in the presence of TMEDA, a monomeric lithium dithiocarboxylate could be isolated and structurally characterized by single-crystal X-ray analysis.[20] The lithium ion

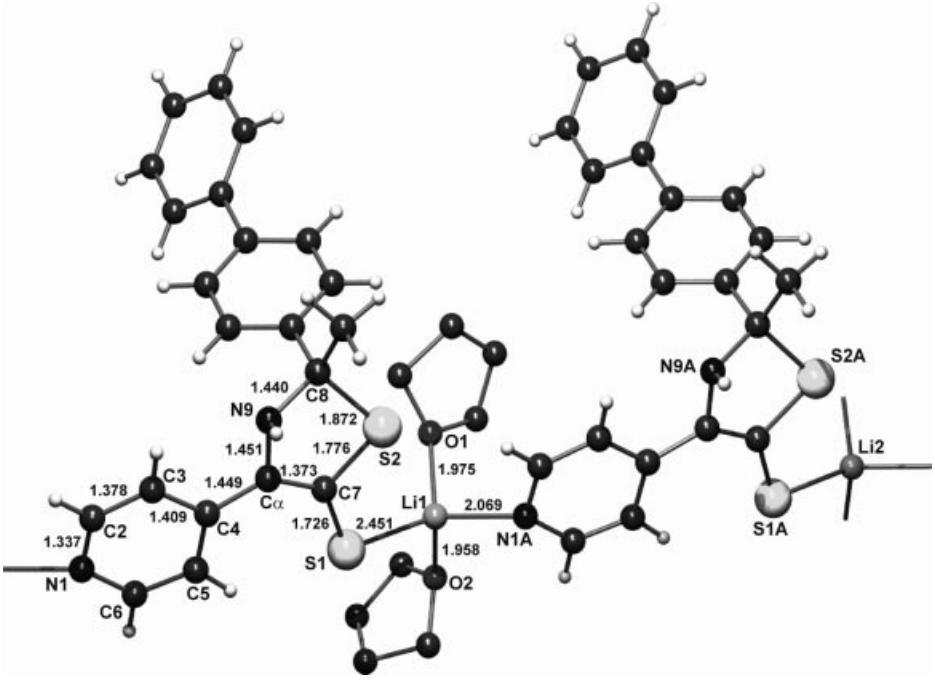


Figure 1. Molecular structure of **[3a(THF)$_2$]$_\infty$** with selected bond lengths [Å] (hydrogen atoms of the solvent molecules are omitted for clarity).

is coordinated by one sulfur atom (2.438 Å), the pyridine nitrogen atom (2.057 Å) and the two nitrogen atoms in TMEDA.[20] This structure compares quite well with **[3a(THF)]$_2$**. The same reaction (lithiation, CS_2, TMEDA) on one methyl group of 2,3-dimethylpyrazine leads to a monomeric lithium dithiocarboxylate complex in which both sulfur atoms are coordinated to the metal ion (2.554/2.688 Å). These monomers are connected to a polymer chain by coordination of one pyrazine nitrogen atom to the lithium ion of another monomer moiety (Li···N 2.129 Å). The C–S bonds in both lithium dithiocarboxylates are almost of the same length (1.687/1.673 Å and 1.687/1.675 Å).[20]

In **[3a(THF)$_2$]$_\infty$** the S1–C7 and S2–C7 bonds (1.726 Å, 1.776 Å) are very similar but longer as compared to the dithiocarboxylates and thus resemble a ketene dithioacetal structure.[20] The S2–C8 bond in **[3a(THF)$_2$]$_\infty$** with 1.872 Å can be defined as a typical C–S single bond. The S1–C7 and S2–C7 bond lengths in **[3a(THF)$_2$]$_\infty$** range between a C–S double (1.67 Å) and a C–S single bond. The S1–S2–C7–Cα–N9 moiety is almost coplanar with the pyridine ring inclosing an angle of 1.8°. The aromatic ring thus clearly contributes to the stabilization of the negative charge on the sulfur atom by forming an extended conjugated π-system (as mentioned above). The sp^3 carbon atom C8 is turned out of the S1–S2–C7–Cα–N9 plane by 27.3°. The biphenyl substituent stands almost perpendicular (89.2°) to the thiazole ring. Both phenyl rings are distorted against each other by 36.2°.

Crystals of **3b** were unfortunately not stable enough to extract more than their structural motif from X-ray analysis (Figure 2). However, this, together with 2D NMR experiments clearly demonstrates its membership to the same class of compounds as **3a**.

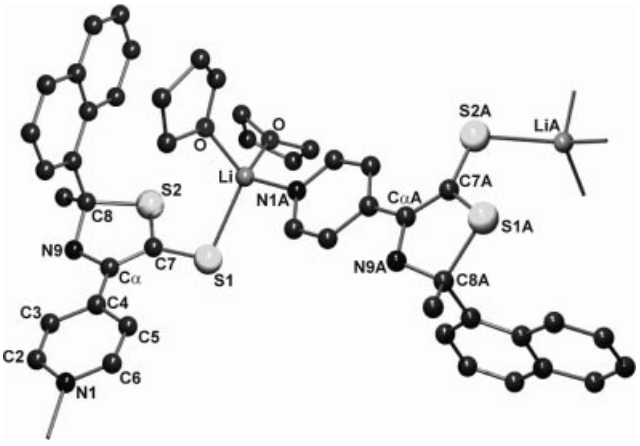


Figure 2. Structure motif of **[3b(THF)$_2$]$_\infty$** (hydrogen atoms are omitted).

Complexes containing Mg–S interactions could possibly be of significant future interest due to the recent elucidation of the solid-state structure of Photosystem I (2.5 Å resolution). In this natural system, the magnesium ion is surprisingly coordinated to the sulfur atom of a methionine group in addition to the four nitrogen atoms of the chlorophyll porphyrin ring.[21] Furthermore, systematical investigations of complexes containing Mg–S and Mg–N interactions are beginning to shed light onto the characteristics of those bonds.[22]

Unfortunately, we have not yet succeeded in isolating the bright orange magnesium thiolate **4b** in crystalline form (prepared by deprotonation of **1b** with $MgEt_2$ and the subsequent reaction with CS_2). In the solid state **4b** is an orange powder that is extremely moisture-sensitive (sudden color change to purple). Even under argon it slowly decomposes to unidentified products accompanied by a strong smell of H_2S and/or other sulfides. Presumably, the magnesium ion binds to the 4-pyridin-4-yl-1,3-thiazole-5-thiolate in a similar manner as the lithium ion; e.g. tetrahedral coordination by the thiolate sulfur atom of one anion, the pyridine nitrogen atom of a second anion and two solvent molecules (THF) or octahedral coordination by four thiolate anions (two via the sulfur atom and two via the pyridine N atom) and two THF molecules, respectively. The signals of these solvent molecules are clearly discernible in the ^{1}H NMR spectrum, even after carefully drying the sample in vacuo. We conclude that THF molecules must be strongly bound to the magnesium ion.

NMR Investigations

Compounds **3c** and **3d** (Table 1) have been subjected to extensive NMR investigations (^{1}H, ^{13}C, DEPT135, HMBC, HMQC) and the resulting spectra compared to those obtained for **3a** and **3b** (known solid-state structures). All results are self-consistent (Table 2) and one can assume that all four of these compounds have similar solution structures.

A comparison of the lithium thiolates **3a**–**e** shows that only small substituent effects on the chemical shifts of the pyridine and thiazole ring are present (Table 2). The NMR signals of the thiolate anions in **3b** (M = Li$^+$] and **4b** (M = Mg^{2+}) are not significantly influenced by the coordinating metal ion (see footnote [c] of Table 2).

Due to the two aliphatic groups at C8 (R^1 = CH_3, R^2 = *t*Bu), the signal of proton H9 in **3c** is noticeably shifted upfield. The small downfield shift of the signals of the methyl group and the proton H9 in **3b** (R^1 = CH_3, R^2 = α-naphthyl) as compared to **3a**,**c**,**e** is presumably the result of the electronic influence of the aromatic residue (α-naphthyl, ring current effect).

A comparison of the tautomers **2e** and **3e** (R^1 = CH_3, R^2 = C_6H_4-*p*-OCH_3) reveals significant differences in their chemical shifts in both ^{1}H and ^{13}C NMR spectra. The signals of protons H2/6 in **2e** are shifted downfield by 0.26 ppm whereas those of protons H3/5 are shifted upfield by 0.73 ppm. The difference of 1.39 ppm between the shifts of the signals of Hα in **2e** and H9 in **3e** indicates a higher acidity for Hα than for NH. In addition, the methyl protons are affected by the charge redistribution. In **2e**, the methyl group is deshielded (signal shifted by +0.46 ppm as compared to **3e**. The signals of the carbon atoms also exhibit

significant differences in their chemical shifts with the exception of C2/6 (see Table 2). The signal location of Cα in both **2e** (δ = 85.9 ppm) and **3e** (δ = 123.2 ppm) reflects its respective hybridization (sp^3 vs. sp^2).

The signal location of the quaternary atom C8 in **2e** cannot unambiguously be assigned, even when 2D NMR techniques are employed. An HMBC (^1H,^{13}C-coupling) experiment shows a crosspeak between the Hα signal and a (not visible) ^{13}C signal at δ = 33.6 ppm. However, crosspeaks between this invisible ^{13}C signal and the signals of either the CH_3 protons or the *ortho*-protons of the 4-methoxyphenyl group are not discernible. Due to the neighborhood of the negatively charged nitrogen atom N9, C8 in **2e** is probably strongly shielded and its signal therefore shifted upfield to δ = 33.6 ppm. Another probable consequence of the negative charge at N9 is the upfield shift by 10–15 ppm observed for the signal of the methyl carbon atom in **2e** ($R^1 = CH_3$) as compared to that of the methyl groups in compounds **3**.

A comparison of the NMR spectroscopic data for the starting compounds **1a**–**e** (Table 3) and the lithium salts **3a**–**e** shows clear distinctions mainly in the ^1H NMR spectra. The NMR spectra of the azomethines **1a**–**e** were recorded in $CDCl_3$, but comparable results were obtained in [D_6]-DMSO. Since some measurements for **1b** had to be carried out at 0 °C, the use of [D_6]DMSO was excluded. The protons H3/5 in **3** are strongly deshielded and their signals thus shifted downfield by 1.06–1.52 ppm. The signals of protons H2/6 in **3** are shifted in the opposite direction (upfield) but not to the same extent as those of H3/5 – the chemical shift differences range between 0.24 and 0.41 ppm. Their relative position to each other is thus reversed in comparison to the imines **1**.

Table 3. ^1H and ^{13}C NMR spectroscopic data of the 4-iminomethyl-pyridines **1a**–**e** ($CDCl_3$; **1a**–**e**: 250/62.5 MHz, room temp.; **1b**: 0 °C, 400 MHz).[a]

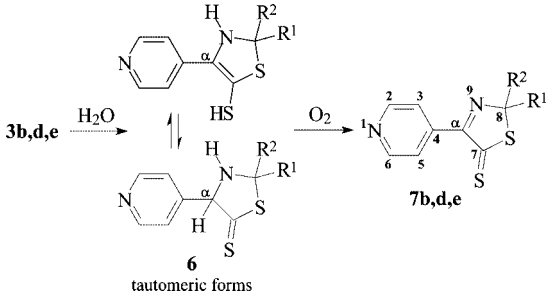
	1					
	a	(*Z*)-**b**[b]	(*E*)-**b**[b]	**c**	**d**	**e**
δ_H						
H2/6	8.57	8.47	8.57	8.53	8.52	8.59
H3/5	[c]	7.13	7.41	7.33	7.28	7.43
Hα	4.70	4.19	4.79	4.43	4.56	4.69
CH_3	2.35	2.49	2.43	1.86	–	2.32
δ_C						
C2/6	149.8	149.7	149.9	149.6	149.7	149.9
C3/5	122.8	122.9	123.0	122.5	122.7	122.8
C4	149.7	149.1	149.2	150.3	149.7	150.0
Cα	54.4	55.2	54.9	53.2	56.1	54.2
C7[d]	166.6	171.6	170.8	177.6	170.2	166.2
CH_3	16.0	29.8	21.1	13.8	–	15.7

[a] The numbering of compounds **1** follows that in Scheme 1. [b] Two signal sets emerge for the (*E*)/(*Z*) mixture. [c] The signal of H3/5 overlaps with the signals of the *meta*- and *para*-protons of the 4-phenyl substituent to a multiplet at δ = 7.34–7.47 ppm. [d] The imino carbon atom C7 in compounds **1** corresponds to the carbon atom C8 in the lithium salts **2** and **3**.

As mentioned above, the 2,3-dihydrothiazole rings in **3** possess two chiral centers (with the exception of **3d**): the carbon atom C8 and the nitrogen atom N9. Thus, the formation of *cis*/*trans* isomers (diastereomers) is conceivable. Usually, a pyramidal nitrogen atom inverts easily in solution. However, the configuration on N9 is frozen in the solid-state structure of **3a** (Figure 1) and the proton H9 is located *trans* to the biphenyl residue. The ^{13}C NMR spectrum of **3a** shows two signals for the methyl carbon atom C10 and all quaternary carbon atoms (C4, Cα, C7, and C8) with very small (0.04–0.15 ppm) shift differences. This splitting can be explained either by the existence of *cis*/*trans* diastereomers (relative to the dihydrothiazole ring) or by a kind of axial chirality regarding the slightly restricted rotation of the biphenyl ring along the C8–C11 bond. This signal doubling was not observed for the other three compounds **3b**,**c**,**e**.

Protonation and Subsequent Oxidation of the Lithium 4-Pyridin-4-yl-2,3-dihydro-1,3-thiazole-5-thiolates 3a–e

Treating of the lithium salts **3** with water leads to interesting 4-pyridin-4-yl-1,3-thiazole-5(2*H*)-thiones **7** (Scheme 4 and Figure 3). The course of this protonation/oxidation reaction presumably includes the initial generation of 4-pyridin-4-yl-1,3-thiazolidine-5-thiones **6** which are then rapidly oxidized (by air oxygen) at the CαH–NH bond (Scheme 4). The yellow salts **3** dissolve in water to form bright orange to deep red solutions. These change color and become gray-green (**3a**–**c**) or blue (**3d**) upon extraction with ethyl acetate (intensive stirring in a beaker). The formation of an extended π-system in **7** over the atoms N9, Cα, C7, and the exocyclic sulfur atom which, in addition, is cross-conjugated with the aromatic pyridine ring is assumed to be decisive for this oxidation.



Scheme 4. The numbering of **2** does not follow the IUPAC rules, but should facilitate the NMR descriptions in the Experimental Section.

An X-ray analysis of **7d** confirms the formation of these thiones (Figure 3). Both sulfur atoms S1/S2, the carbon atoms C7, Cα, and the nitrogen atom N9 span a plane which intersects at an angle of 41.1° with the pyridine ring. Cross-conjugational effects between these two π-systems are thus reduced. Spatial hindrance could be one reason for this somewhat larger dihedral angle than that observed in the solid-state structure of the anion **3a**. The Cα–N9 (1.284 Å) and the C7–S1 (1.596 Å) double bonds are significantly shorter than in **3a** (Cα–N9 1.451 Å, C7–S1 1.726 Å). The system is thus more crowded and the protons H3/5 experi-

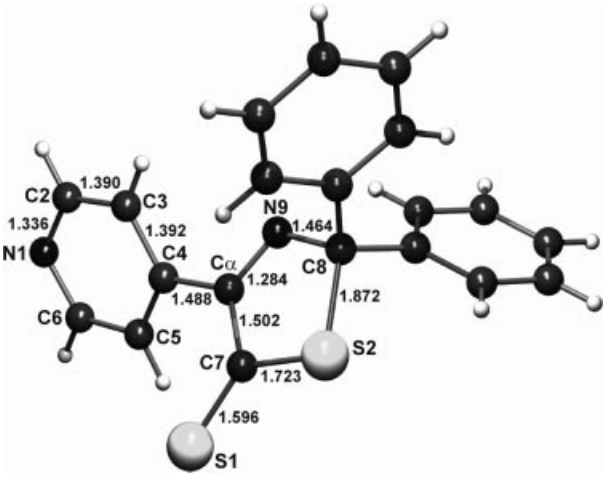
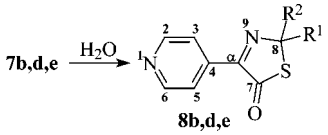


Figure 3. Molecular structure of **7d** with selected bond lengths [Å] and angles [°]: Cα–N9 1.284, Cα–C7 1.502, C7–S1 1.596, C7–S2 1.723, C8–S2 1.872, C8–N9 1.464, Cα–C4 1.488; S1–C2–S2 124.6, N9–Cα–C7 117.6, N9–C8–S2 106.6, C7–S2–C8 92.5.

ence stronger steric interactions with the sulfur atom. Astonishingly, the quaternary sp^3 carbon atom C8 is only negligibly turned out of the dihydrothiazole plane (by 0.8°). The phenyl rings are perpendicular both to each other and to the thiazole ring so that the least possible steric interaction exists among the aryl residues and the five-membered ring.

The protonation/oxidation procedure that generates the 5(2*H*)-thiones **7** is always accompanied by a side reaction: a desulfurization with formation of the 5(2*H*)-ones **8** (Scheme 5). Compounds **8** result from hydrolysis of **7** during the workup and, in addition, from slow degradation by air moisture. Samples of **7** that had been stored a while develop the strong typical smell of H_2S.



Scheme 5. Hydrolyses of **7b**,**d**,**e** to the thiazole-5(2*H*)-ones **8b**,**d**,**e**.

To the best of our knowledge, only one example for a 1,3-thiazole-5(2*H*)-thione has been described in the literature by Huisgen et al.[23] They reported the formation of 2-(4-nitrophenyl)-4-phenyl-1,3-thiazole-5(2*H*)-thione generated by the reaction of *N*-(4-nitrobenzyl)benzimidoyl chloride with triethylamine and carbon disulfide via a nitrile ylide.[23]

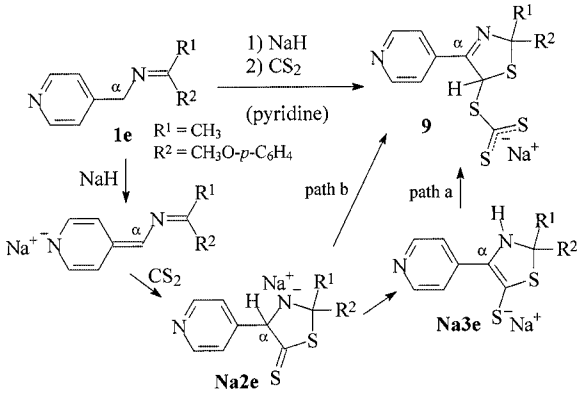
A similar substance class – the 1,3-thiazole-5(4*H*)-thiones – has been synthesized by Heimgartner et al.,[24] in which the C–N and C–S double bonds are opposite to each other in the thiazole ring as compared to our 5(2*H*)-thiones **7** in which the two double bonds are conjugated. These 5(4*H*)-thiones are obtained by an intramolecular cyclization of a dithio-dipeptide with loss of the terminal amide residue as an amine. The thiocarbonyl moiety is a suitable dipolarophile and undergoes a cycloaddition reaction with azomethine ylides to form spiro-attached dithiazolines.

Whereas 1,3-thiazole-5(4*H*)-ones are well-known heterocycles,[25] there are only very few examples of 1,3-thiazole-5(2*H*)-ones. Barrett et al. have synthesized an example of such a 1,3-thiazole-5(2*H*)-one by a Michael addition of acrylonitrile to the active methine group of 2,4-diphenyl-1,3-thiazole-5(4*H*)-one.[26a] In addition, Roesky et al. have studied the 1,3-dipolar cycloaddition of COS to amino-substituted nitrile ylides generated from *N*-(chloromethyl)formamidines.[26b]

The interesting question of an 1,3-thiazole-5-thione/thiol equilibrium suggests the use of aldimines in the reaction sequence of deprotonation, cyclization with CS_2, protonation and oxidation (cf. Scheme 4, R^1 or R^2 = H). However, aldimines derived from aldehydes and 4-(aminomethyl)pyridine (Scheme 1) unfortunately cannot be isolated (hydrolysis or polymerization occurs).[1,27] An in situ generation under mild conditions and instantaneous reaction could possibly result in the corresponding substance class of **7** (R^1 or R^2 = H). Studies in this direction are in progress.

Sodium 2-(4-Methoxyphenyl)-2-methyl-4-(pyridin-4-yl)-2,5-dihydrothiazole-5-trithiocarbonate 9

Surprisingly, sodium 4-(pyridin-4-yl)-2,5-dihydrothiazole-5-trithiocarbonate **9** was found to be a byproduct in the reaction of **1e** with NaH and CS_2 in pyridine (Scheme 6). We assume that compound **9** is generated as a result of a hydrogen migration in **Na2e** or **Na3e** followed by the attachment of a second molecule of CS_2 (Scheme 6). The reaction mixture contains at least four products; we succeeded in isolating a small amount of **9** (approximately 10% total yield) as a crystalline material suitable for X-ray analysis (Figure 4). We assume the other products to be diastereomeric forms of **Na3e** as well as structure **III** in Scheme 7 since the ^{13}C NMR spectrum of this product mixture shows characteristic signals in the range of δ = 70–90 ppm, which are typical for sp^3 carbon atoms bound to two geminal heteroatoms.



Scheme 6. Two possible reaction pathways a and b for the formation of compound **9**.

Unfortunately, the structure of **9** was determined only as a structure motif (Figure 4). The trithiocarbonate **9** is an ionic complex: $\{[Na(py)_6]^+[Na_3(tritihiocarbonate)_4]^-\}_\infty$ (py

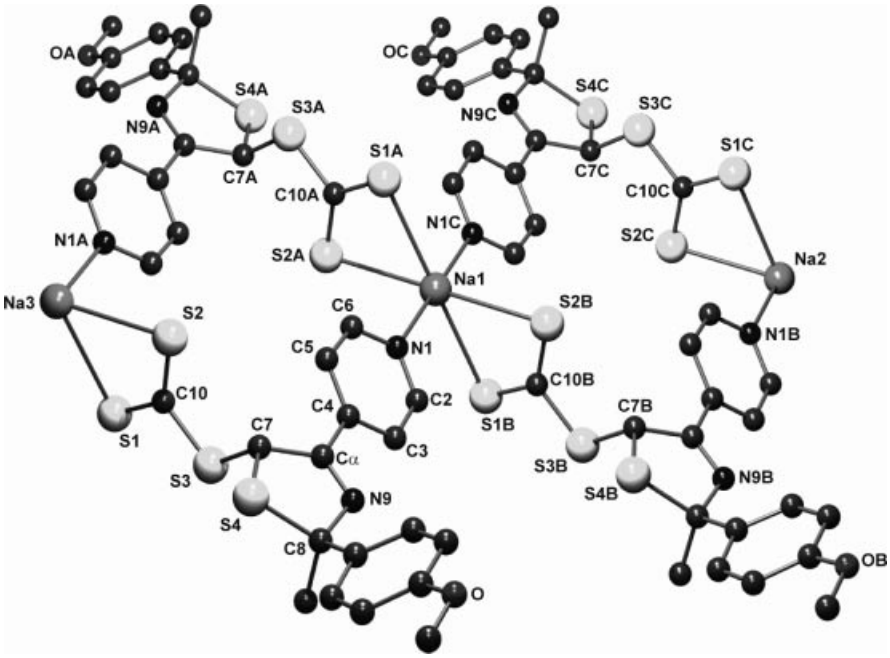
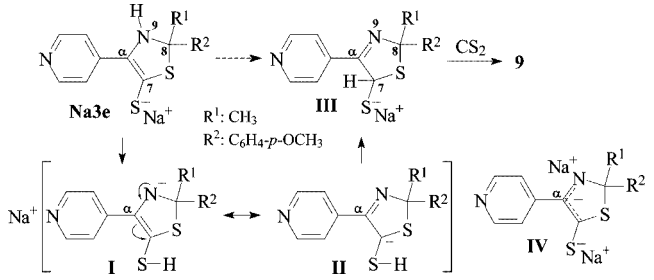


Figure 4. Structure motif of the complex anion $\{[Na_3(trithiocarbonate)_4]^-\}_\infty$ of **9**.



Scheme 7. Possible reaction intermediates in the formation of **9** according to pathway a.

= NC_5H_5). Two sulfur atoms in two trithiocarbonate moieties act as bidentate ligands and chelate one sodium cation (Na1) in a square-planar manner to generate a complex anion. The coordination sphere of Na1 is saturated by two axial coordinated pyridine nitrogen atoms (octahedral coordination for Na1) originating from two additional trithiocarbonate anions. A complex anionic polymer network is thus formed. The N-pyridine end of each ligand **9** is axially coordinated to one sodium ion in the network and the trithiocarbonate at the other end is bound by S1/S2 ligation to the next sodium ion in the network. Although the resolution was not particularly good, we were able to discern that the carbon atom C7 is clearly sp^3-hybridized (S3 is turned out of the plane of the thiazoline ring). The holes in the network are filled by the positive counterions (not shown in Figure 4) which are sodium ions that are coordinated by six pyridine molecules in an octahedral geometry.

Ruhlandt-Senge et al. have described the solid-state structure of a sodium thiolate derived from metalation of 2-mercaptopyridine in the presence of 12-crown-4 and THF, which shows a few coordinational similarities to **9**. A monomeric and a dimeric complex anion are present which show, in contrast to **9**, only a fivefold coordination in a distorted square pyramid. The pyridine-2-thiolate anion acts as bidentate chelate ligand similar to the trithiocarbonate moiety in the complex anion of **9**. In the case of the dimeric complex anion, the sulfur atom bridges to a second sodium ion. The positive counterion is built by a sodium ion coordinated with two crown ether molecules.[17]

In Scheme 7, we propose a mechanism for the proton shift that generates **9**. This reaction is quite likely an intermolecular process. The proton H9 could be abstracted from sodium 2,3-dihydro-1,3-thiazole-5-thiolate **Na3e** either by the S1 atom of a second anion or under participation of a molecule of pyridine (solvent) which would also transfer the proton to the thiolate sulfur atom S1. Proton abstraction and reprotonation could possibly take place simultaneously in analogy to proton relays in enzyme-catalyzed reactions. The doubly negatively charged intermediate **IV** would therefore not necessarily be formed (or its lifetime is too short for direct observation). The resulting 5-thiolo-2,3-dihydrothiazole anion can be considered as an azaenolate or as a metallo-enamine (resonance structure **I**, Scheme 7). The second resonance form **II** can be interpreted as a thioacetal anion, which profits from the stabilization by the two sulfur atoms. The mercapto group is much more acidic than the methine group in structure **III** (Scheme 7) and one can assume a solvent-mediated facile proton transfer from S1 to C7. The outcome is an intramolecular redox reaction – the oxidation of Cα and the reduction of C7. Finally, a further molecule carbon disulfide adds to the sulfur atom S3 to give **9**.

Reaction path b in Scheme 6 starts with the sodium 5-thioxo-1,3-thiazolidin-3-ide **Na2e** and represents a simple intramolecular one-step 1,2-hydride shift in which Hα

moves from Cα to C7 (structure **III**, Scheme 7). This rearrangement could be assisted by the negative charge of N9, the positive partial charge of C7, and the easy polarizability of the sulfur atoms. In a second step, an additional molecule of carbon disulfide reacts with the thiolate sulfur atom.

In the course of the formation of the 2,5-dihydrothiazole-5-trithiocarbonate **9**, two new stereocenters are created: the carbon atoms C7 and C8; *cis*/*trans* diastereomers could therefore be formed. The NMR spectra support this assumption (doubling of C signals is observed). Further support for this is the fact that compound **9** crystallized as the *trans* isomer as clearly seen in its structure motif (Figure 4).

Conclusions

We conclude from our investigations that the anions **1(–)** obtained from the deprotonation of 4-(iminomethyl)pyridines **1** show typical properties of 2-azaallyl anions. They react with CS_2 by a 1,3-anionic cycloaddition reaction in which first the 4-pyridin-4-yl-5-thioxo-1,3-thiazolidine-3-ides **2** and subsequent the 2,3-dihydrothiazole-5-thiolates **3** are formed. The reaction presumably occurs over a two-step addition of CS_2 and continues with a proton migration from the Cα atom of **2** to the amide atom N9. This yields 2,3-dihydro-thiazole-5-thiolates **3a**–**e**, which have been verified by X-ray crystal structure analysis (compounds **3a**/**3b**) as well as by 2D NMR measurements on **3**(**a**),**b**–**e**. Both the sulfur moiety (CS^- in **3a**; CS_2^- in **9**) and the pyridine nitrogen atom act as ligands for the metal cations. This has rarely been observed.

Compound **2e** could be isolated as the only representative of substance class **2** and its transformation to **3e** by a proton migration was investigated with ^1H NMR experiments. When **3** is protonated with mild protic solvents, the 1,3-thiazole-5(2*H*)-thiones **7** and their hydrolysis products – 1,3-thiazole-5(2*H*)-ones **8** – are formed. An interesting by-product – sodium 4-pyridin-4-yl-2,5-dihydrothiazole-5-trithiocarbonate **9** – was obtained in the reaction of **1e** with NaH and CS_2 in pyridine. The mechanism of formation is not known exactly, but can be interpreted either as an intermolecular proton shift from N9 over S1 to C7 (acid-base reaction) or as an intramolecular 1,2-hydride shift from Cα to C7.

Theoretical investigations on the mechanism of carbon disulfide attack on 4*H*-pyridin-1-ide with DFT methods are presently underway. They include comparative studies on the influence of the coordination of CS_2 to the metal ion (lithium) and the attack to the Cα atom or the pyridine nitrogen atom. These results are beyond the scope of this paper and will be presented as a complete study in the near future. Moreover, we intend to investigate the reactivity of CS_2 towards the metalated aldimines – from 4-(aminomethyl)pyridine – as well.

Experimental Section

General Remarks: Spectra were measured with following technical devices: NMR: Bruker AC 250 and AC 400. IR-ATR: BIORAD FTS-25. MS: Finnigan MAT SSQ 710 and Finnigan MAT 900 XL TRAP. Elemental analyses (C, H, N, S): Leco CHNS-932 and Vario EL III. NMR spectra were recorded at 250 or 400 MHz and 62.5 or 100 MHz, for ^1H and ^{13}C, respectively. For ^1H and ^{13}C, [D_8]THF (H: δ = 1.73, 3.58 ppm; C: δ = 25.2, 67.4 ppm) and $CDCl_3$ (H: δ = 7.24 ppm; C: δ = 77.0 ppm) were used as solvents with TMS as internal standard. If not otherwise mentioned, all procedures were carried out under argon to exclude moisture from air. NMR signals were assigned with help of two-dimensional methods (HMQC and HMBC). [D_8]THF and [D_6]DMSO were purified and dried according to standard procedures. CS_2 was purchased from Sigma–Aldrich in a sealed bottle and used without further treatment. The 4-(iminomethyl)pyridines **1a**–**e** were prepared according to literature procedures.[1] The diethylmagnesium solution was also prepared using literature procedures.[28]

General Procedure for Syntheses of 3a–e: A colorless solution of 4.8 mmol of 4-(iminomethyl)pyridine **1** in 20 mL of THF was cooled to –78 °C and 3.0 mL (4.8 mmol) of *n*-butyllithium (1.6 M solution, hexane fraction) was added through a syringe over the course of 30–45 min. The color changed immediately to dark blue (**1a**,**b**), deep red (**1c**), or magenta (**1d**,**e**). The cooling was removed and the solution was allowed to react overnight at room temp. 4.8 mmol of CS_2 was then added at –20 °C; the solution was stirred for 15 min at this temperature before the cooling bath was removed. After 10–20 min, the color turned bright orange. Crystallization began at room temperature. In case of **3a**,**b**, a sample of the crystals was given to X-ray analysis; the rest of the precipitate was filtered off and the product dried in vacuo.

Lithium 2-(Biphenyl-4-yl)-2-methyl-4-(pyridin-4-yl)-2,3-dihydro-1,3-thiazole-5-thiolate (3a): Precipitate formation: 3 d, dirty yellow/orange. Yield: 90% (CS_2 addition at –65 °C; containing 2.2 equiv. of THF); 34.6% (CS_2 addition at –20 °C; containing 3.0 equiv. of THF); 51% (CS_2 addition at room temperature; containing 1.79 equiv. of THF). ^1H NMR ([D_6]DMSO, 250 MHz, room temp.): δ = 1.85 (s, 3 H, CH_3), 4.68 (s, 1 H, NH, H9), 7.31 (t, 1 H, ^3J = 7.25 Hz, Ph), 7.42 (t, 2 H, ^3J = 7.10 Hz, Ph), 7.51 (d, 2 H, ^3J = 8.38 Hz, Ph), 7.58–7.63 (m, 4 H, Ph), 8.19 (d, 2 H, ^3J = 6.03 Hz, H2/6), 8.53 (d, 2 H, ^3J = 6.30 Hz, H3/5) ppm. ^{13}C NMR ([D_6]DMSO, 62.5 MHz, room temp.): δ = 29.8 (CH_3), 73.9/74.0 (C8), 117.4 (C3/5), 123.0/123.1 (Cα), 125.7 (2 C, Ph), 126.0 (2 C, Ph), 126.6 (2 C, Ph), 127.0 (Ph), 128.8 (2 C, Ph), 138.1 (Ph), 140.3 (Ph), 143.0/143.1 (C4), 148.0 (C2/6), 149.2 (Ph), 156.3/156.5 (C7) ppm. IR (ATR): $\tilde{\nu}$ = 3242 (NH), 3029 (=C–H, aryl), 2972, 2871 (alkyl), 1596, 1523, 1496 (aryl, ring), 1451, 1416 (alkyl), 1251, 1045 (C–S) cm^{-1}. MS (FAB in DMBA, negative): *m*/*z* (%) = 361 (97) $[C_{21}H_{17}N_2S_2]^-$.

Lithium 2-Methyl-2-(1-naphthyl)-4-(pyridin-4-yl)-2,3-dihydro-1,3-thiazole-5-thiolate (3b): The yield (10–30%) cannot be given exactly because of the poor reproducibility of the lithium thiolate. Precipitate formation: 3 d, 1–2 weeks or by no means, dirty yellow/orange. ^1H NMR ([D_6]DMSO, 250 MHz, room temp.): δ = 2.11 (s, 3 H, CH_3,), 4.77 (s, 1 H, NH, H9), 7.35 (t, 1 H, ^3J = 8.05 Hz, α-naph), 7.42–7.56 (m, 2 H, α-naph), 7.74 (d, 1 H, ^3J = 8.20 Hz, α-naph), 7.85 (dd, 1 H, ^3J = 7.28, ^4J = 1.25 Hz, α-naph), 7.91 (dd, 1 H, ^3J = 7.73, ^4J = 1.75 Hz, α-naph), 8.22 (d, 2 H, ^3J = 6.33 Hz, H2/6), 8.62 (d, 2 H, ^3J = 6.30 Hz, H3/5) ppm. ^{13}C NMR ([D_6]DMSO, 62.5 MHz): δ = 30.4 (CH_3), 73.6 (C8), 117.3 (C3/5), 121.8 (Cα), 123.3 (α-naph), 124.8 (3C, α-naph), 127.5 (α-naph), 129.0 (α-naph), 129.6 (α-naph), 134.5 (α-naph), 143.1 (C4), 143.4 (α-naph), 148.1 (C2/6), 157.0 (C7) ppm. Because of poor reproducibility in obtaining the lithium compound **3b**, the corresponding magnesium compound (see below) was synthesized which allowed an exact

characterization of the α-naphthyl-substituted thiazole-5-thiolate anion.

Magnesium Bis[2-methyl-2-(1-naphthyl)-4-(pyridin-4-yl)-2,3-dihydro-1,3-thiazol-5-thiolate] (4b): To a solution of 0.276 g (1.06 mmol) of **1b** in 20 mL of THF (cooled to –20 °C) 1.0 mL (0.53 mmol) of an $MgEt_2$[28] solution (c = 0.53 mol/ L, THF) was added over a period of 30 min. During this addition the solution turned red-violet. After the addition was completed, the mixture was allowed to come to room temperature and to stand overnight. Crystallization of the magnesium bis(4*H*-pyridin-1-ide) **Mg[1b(–)]$_2$** took place.[1] To this suspension, 0.13 mL (0.165 g, 2.162 mmol) of carbon disulfide was added at room temperature. The suspension then turned a dirty dark green. After removal of the cooling bath, the suspension gradually changed its color from dark green over bright green, yellow-green and yellow to finally bright orange over a period of 1–1.5 h. After 12 h of standing at room temperature, the precipitate was filtered off under inert conditions and dried in vacuo for 1 d. Traces of moisture turn the color of the precipitate and the filtrate to purple. Yield: 0.599 g, 52.6% (containing 2.28 equiv. of THF per Mg^{2+}). ^{1}H NMR ([D$_6$]DMSO, 250 MHz, room temp.): δ = 2.09 (s, 3H, CH_3), 4.77 (s, 1 H, NH, H9), 7.34 (t, 1 H, ^3J = 7.72 Hz, α-naph), 7.40–7.98 (m, 2 H, α-naph), 7.73 (d, 1 H, ^3J = 8.06 Hz, α-naph), 7.79–7.96 (m, 2 H, α-naph), 8.21 (d, 2 H, ^3J = 5.91 Hz, H2/6), 8.23 (d, 1 H, α-naph, overlapped with H2/6), 8.60 (d, 2H, 6.4 Hz, H3/5) ppm. ^{13}C NMR ([D$_6$]DMSO, 62.5 MHz, room temp.): δ = 30.4 (CH_3), 73.6 (C8), 117.2 (C3/5), 121.7 (Cα), 123.2 (α-naph), 124.7 (α-naph), 124.8 (α-naph), 125. 7 (α-naph), 127.4 (α-naph), 128.9 (α-naph), 129.6 (α-naph), 134.4 (α-naph), 143.1 (C4), 143.3 (α-naph), 148.0 (C2/6), 157.0 (C7) ppm. IR (ATR): $\tilde{\nu}$ = 3172 (NH), 3053 (=C–H, aryl), 2976, 2878 (alkyl), 1687, 1607, 1552, 1507 [(het)aryl, ring], 1417, 1371, 1332, 1294, 1221, 1184, 1013, 802, 775 cm^{-1}. MS (Micro-ESI, THF/methanol): m/z (%) = 335 (52) $[C_{19}H_{15}N_2S_2]^+$.

Lithium 2-*tert*-Butyl-2-methyl-4-(pyridin-4-yl)-2,3-dihydro-1,3-thiazole-5-thiolate (3c): Precipitate formation: 1 h, yellow. Yield: 1.587 g, 71.0% (containing 1.95 equiv. of THF). ^{1}H NMR ([D$_6$]DMSO, 250 MHz, room temp.): δ = 0.97 (s, 9 H, *t*Bu), 1.48 (s, 3 H, CH_3), 3.77 (s, 1 H, NH, H9), 8.09 (d, 2 H, ^3J = 6.30 Hz, H2/6), 8.38 Hz (d, 2 H, ^3J = 6.48 Hz, H3/5) ppm. ^{13}C NMR ([D$_6$]DMSO, 62.5 MHz, room temp.): δ = 25.75 (*t*Bu), 25.78 (CH_3), 39.2 (**C**(CH_3)$_3$), 79.1 (C8), 117.2 (C3/5), 123.7 (Cα), 142.4 (C4), 147.7 (C2/6), 151.5 (C7) ppm. IR (ATR): $\tilde{\nu}$ = 3185 (N–H), 3067, 3043 (=C–H, aryl), 2967, 2871 (CH_3, CH_2/THF), 1683, 1565, 1550, 1524, 1496 (aryl, ring), 1457, 1411, 1368 (CH_3, CH_2/THF), 1290, 1156, 1055, 1002 (C–S), 979, 831 cm^{-1}. MS (FAB in DMBA): m/z (%) = 265 (76) for $[C_{13}H_{17}N_2S_2]^-$.

Lithium 2,2-Diphenyl-4-(pyridin-4-yl)-2,3-dihydro-1,3-thiazole-5-thiolate (3d): Precipitate formation: 3 d, bright yellow. Yield: 1.416 g, 84.1% (containing 2.37 equiv. of THF). ^{1}H NMR ([D$_6$]DMSO, 250 MHz, room temp.): δ = 4.66 (s, 1 H, NH, H9), 7.15 (t, 2 H, ^3J = 7.10 Hz, Ph), 7.24 (t, 4 H, ^3J = 6.95 Hz, Ph), 7.49 (d, 4 H, ^3J = 6.95 Hz, Ph), 8.19 (d, 2 H, ^3J = 6.15 Hz, H2/6), 8.60 (d, 2 H, ^3J = 6.30 Hz, H3/5) ppm. ^{13}C NMR ([D$_6$]DMSO, 62.5 MHz, room temp.): δ = 80.9 (C8), 117.3 (C3/5), 122.8 (Cα), 126.6 (2 C, Ph), 126.8 (4 C, Ph), 127.6 (4 C, Ph), 143.0 (C4), 147.2 (2 C, Ph), 148.0 (C2/6), 155.8 (C7) ppm. IR (ATR): $\tilde{\nu}$ = 3240 (NH), 3058 (=C–H, aryl), 2977, 2874 (CH_2, THF), 1595, 1523, 1494 (aryl, ring), 1446 (CH_2, THF), 1414, 1213, 1044, 1001 (C–S), 982, 892, 834, 749, 697 cm^{-1}. MS (FAB in DMBA): m/z (%) = 348 (24) $[C_{20}H_{16}N_2S_2]^+$.

Lithium 2-(4-Methoxyphenyl)-4-(pyridin-4-yl)-5-thioxo-1,3-thiazolidine-3-ide (2e): Precipitate formation: 30 min to 1 h, yellow. Yield: 0.569 g, 46.1% (containing 0.9 equiv. of THF). ^{1}H NMR ([D$_6$]-DMSO, 250 MHz, room temp.): δ = 2.23 (s, 3 H, CH_3), 3.78 (s, 3 H, OCH_3), 6.04 (s, 1 H, NH, H9), 6.94 (d, 2 H, ^3J = 8.83 Hz, Ph), 7.80 (d, ^3J = 4.40 Hz, 2 H, ^4J = 1.58 Hz, H3/5), 7.87 (d, 2 H, ^3J = 8.83 Hz, Ph), 8.41 (d, ^3J = 4.58 Hz, 2 H, ^4J = 1.58 Hz, H2/6) ppm. ^{13}C NMR ([D$_6$]DMSO, 62.5 MHz, room temp.): δ = 16.5 (CH_3), 33.6 (C8 ?), 55.2 (OCH_3), 85.9 (Cα), 113.2 (2 C, Ph), 122.9 (C3/5), 128.4 (2 C, Ph), 133.8 (Ph), 148.2 (C2/6), 153.1 (C4), 160.3 (Ph), 163.4 (C7) ppm. IR (ATR): $\tilde{\nu}$ = 2979, 2868 (CH_3, CH), 1603, 1567, 1509 (aryl, ring), 1417, 1365 (CH, CH_3), 1247, 1018 (C–S) cm^{-1}. MS (DCI, negative): m/z (%) = 314 (100) $[C_{16}H_{14}N_2OS_2]^-$.

Lithium 2-(4-Methoxyphenyl)-2-methyl-4-(pyridin-4-yl)-2,3-dihydro-1,3-thiazole-5-thiolate (3e): Yield: 46.1% (containing 0.9 equiv. of THF, corresponds to **2e** after complete rearrangement). ^{1}H NMR ([D$_6$]DMSO, 250 MHz, room temp.): δ = 1.77 (s, 3 H, CH_3), 3.68 (s, 3 H, OCH_3), 4.55 (s, 1 H, NH, H9), 6.78 (d, 2 H, ^3J = 8.85 Hz, Ph), 7.41 (d, 2 H, ^3J = 8.85 Hz, Ph), 8.15 (d, 2 H, ^3J = 6.15 Hz, H2/6), 8.53 (d, 2 H, ^3J = 6.51 Hz, H3/5) ppm. ^{13}C NMR ([D$_6$] DMSO, 62.5 MHz, room temp.): δ = 30.4 (CH_3), 55.0 (OCH_3), 74.0 (C8), 112.7 (2 C, Ph), 117.3 (C3/5), 123.2 (Cα), 126.5 (2 C, Ph), 141.8 (Ph), 143.1 (C4), 148.0 (C2/6), 156.5 (C7), 157.7 (Ph) ppm.

General Procedure for the Synthesis of 7 (and 8): Precipitates of the lithium thiolates **3** were stirred into 30 mL of water. The resulting yellow to red solution was stirred in a beaker for 30 min and extracted with 3 × 30 mL of ethyl acetate (the solution can take on a blue note during this step). The organic layer was dried with Na_2SO_4 and concentrated to almost dryness. The following purification is described individually for each thiazole-5(2*H*)-thione **7**. The thiones **7** are always accompanied by varying amounts of hydrolysis side products, the thiazole-5(2*H*)-ones **8**, which are formed during the workup. Moreover, the thiazole-5(2*H*)-thiones **7** are slowly hydrolyzed upon prolonged exposure to air (storage) to **8**. Stored samples of **8** develop the typical strong smell of H_2S over time.

2-(Biphenyl-4-yl)-2-methyl-4-(pyridin-4-yl)-1,3-thiazole-5(2*H*)-thione (7a): From 0.679 g of **3a** (containing 1.79 equiv. of THF). After complete removal of the solvent (ethyl acetate), a blue-brown viscous residue was obtained, which consisted of ca. 90% of **7a** according to its ^{1}H NMR spectrum. With column chromatography (silica gel 60, ethyl acetate/chloroform, 1:1), three fractions were isolated: F1 (beige): 4-phenylacetophenone (0.060 g); F2 (blue): **7a/8a** (0.234 g, 55:45); F3 (yellow): **7a/8a** (0.117 g, 80:20); i.e. slow hydrolysis of the C=S bond takes place on the silica gel. Upon longer storing in air, the typical smell of hydrogen sulfide becomes noticeable. Yield (relating to **3a**): 45.2% of **7a**; 27.4% of **8a** (not pure, but as mixture of both compounds). ^{1}H NMR ([D$_6$]DMSO, 200 MHz, room temp.): **7a**: δ = 2.32 (s, 3 H, CH_3), 7.39–7.51 (m, 4 H, Ph), 7.57–7.73 (m, 5 H, Ph), 7.85 (dd, 2 H, ^3J = 4.4, ^4J = 1.6 Hz, H3/5), 8.76 (dd, 2 H, ^3J = 4.4, ^4J = 1.8 Hz, H2/6) ppm; **8a**: δ = 2.25 (s, 3 H, CH_3), 7.39–7.51 (m, 4 H, Ph), 7.57–7.73 (m, 5 H, Ph), 8.08 (dd, 2 H, ^3J = 4.4, ^4J = 1.6 Hz, H3/5), 8.81 (dd, 2 H, ^3J = 4.6, ^4J = 1.6 Hz, H2/6) ppm. ^{13}C NMR ([D$_6$]DMSO, 50 MHz, room temp.): **7a**: δ = 28.5 (CH_3), 94.9 (C8), 124.5 (C3/5), 126.4, 126.7, 127.2, 127.7, 128.9 (9 C, Ph), 138.5, 139.28, 140.2, 140.4 (C4; 3 C, Ph), 149.1 (C2/6), 165.1 (Cα), 219.7 (C7) ppm; **8a**: δ = 30.1 (CH_3), 86.8 (C8), 123.3 (C3/5), 126.4, 126.7, 127.0, 127.69, 128.9 (9 C, Ph), 137.0, 138.9, 139.33, 140.3 (C4; 3 C, Ph), 149.9 (C2/6), 160.8 (Cα), 192.5 (C7) ppm. MS (Micro-ESI, Methanol): **7a**: m/z (%) = 361 (100) $C_{21}H_{17}N_2S_2$ [M + H]$^+$; exact molecular mass for $C_{21}H_{17}N_2S_2$: calcd. 361.083; found 361.083; **8a**: m/z (%) = 345 (100) $C_{21}H_{17}N_2OS$ [M + H]$^+$; exact molecular mass for $C_{21}H_{17}N_2OS$: calcd. 345.106; found 345.106.

2,2-Diphenyl-4-(pyridin-4-yl)-1,3-thiazole-5(2*H*)-thione (7d): From 1.416 g of **3d** (containing 2.37 equiv. of THF). After complete re-

moval of the solvent, a blue foam was obtained which could be recrystallized from methanol with a little chloroform added. Deep blue needles resulted. According to the ^{1}H NMR spectrum, these needles consisted of the 1,3-thiazole-5(2*H*)-thione **7d** and its hydrolysis product [1,3-thiazole-5(2*H*)-one] **8d** in a 87:13 ratio. Chromatographic separation (silica gel; chloroform/ethyl acetate, 6:1) was not possible because the thione **7d** hydrolyses to **8d** on SiO_2. Yield (related to **3d**): 28.8% (**7d** + **8d**, 87:13). ^{1}H NMR ([D$_6$]-DMSO, 250 MHz, room temp.): **7d**: δ = 7.39–7.57 (m, 10 H, Ph), 7.87 (dd, 2 H, ^3J = 4.51, ^4J = 1.53 Hz, H3/5), 8.77 (d, 2 H, ^3J = 5.66 Hz, H2/6) ppm; **8d**: δ = 7.39–7.57 (m, 10 H, Ph), 8.22 (d, 2 H, ^3J = 6.12 Hz, H3/5), 8.84 (d, 2 H, ^3J = 5.96 Hz, H2/6) ppm. ^{13}C NMR ([D$_6$]DMSO, 62.5 MHz, room temp.): **7d**: δ = 100.0 (C8), 124.6 (C3/5), 127.3, 128.8, 129.0 (10 C, Ph), 137.8 (C4), 140.3 (2 C, Ph), 149.4 (C2/6), 164.5 (Cα), 218.4 (C7) ppm; **8d**: δ = 97.8 (C8), 123.4 (C3/5), 128.6, 128.7, 128.8 (10 C, Ph), 137.0 (C4), 141.7 (2 C, Ph), 150.2 (C2/6), 160.1 (Cα), 191.9 (C7) ppm. MS (Micro-ESI, $CHCl_3$/CH_3OH): **7d**: *m*/*z* (%) = 347 (100) $C_{20}H_{15}N_2S_2$ [M + H]$^+$; exact molecular mass for $C_{20}H_{15}N_2S_2$: calcd. 347.068; found 347.068; **8d**: *m*/*z* (%) = 331 (10) $C_{20}H_{15}N_2OS$ [M + H]$^+$. UV/Vis ($CHCl_3$, room temp., **7d** + **8d**; *c* = 5.414 mg/25 mL): λ_{max} = 379, 575 nm. IR (ATR): $\tilde{\nu}$ = 3065, 3022, 3003 (=C–H, aryl), 1673 (C=S, C=O), 1587, 1548, 1465 (aryl, ring), 1444, 1406, 1284, 1148, 1053 (C–S), 751, 693 cm^{-1}. $C_{20}H_{14}N_2S_2$ (**7d**, 346.48) and $C_{20}H_{14}N_2OS$ (**8d**, 330.41) (87:13): calcd. C 69.76, H 4.11, N 8.14, S 17.37; found C 69.28, H 4.02, N 8.08, S 17.37.

2-(4-Methoxyphenyl)-2-methyl-4-(pyridin-4-yl)-2,3-dihydro-1,3-thiazol-5(2*H*)-thione (7e) and 2-(4-Methoxyphenyl)-2-methyl-4-(pyridin-4-yl)-2,3-dihydro-1,3-thiazol-5(2*H*)-one (8e): From 0.569 g of **3e** (containing 0.9 equiv. of THF). After complete removal of the solvent, a bluish-brown, viscous foam was obtained which consisted of 60% of **7e** and 15% of **8e** according to the ^{1}H NMR spectrum. Chromatographic purification (silica gel; ethyl acetate/chloroform, 1:1) gave one fraction of 4-methoxyacetophenone and five minor fractions with varying composition of **7e** and **8e**. After that, the main fraction was eluted with methanol, which showed almost the same composition as before the purification. An exact yield cannot be given because of the rapid hydrolysis of the C=S bond and the partial decomposition of the heterocyclic system which is discernible by the typical smell of released 4-methoxyacetophenone. ^{1}H NMR ($CDCl_3$, 400 MHz, room temp.): **7e**: δ = 2.23 (s, 3 H, CH_3), 3.80 (s, 3 H, OCH_3), 6.87–6.91 (m, 2 H, Ph), 7.35–7.39 (m, 2 H, Ph), 7.77 (dd, 2 H, ^3J = 4.43, ^4J = 1.65 Hz, H3/5), 8.72 (d, ^3J = 4.43 Hz, 2 H, ^4J = 1.64 Hz, H2/6) ppm; **8e**: δ = 2.19 (s, 3 H, CH_3), 3.80 (s, 3 H, OCH_3), 6.87–6.91 (m, 2 H, Ph), 7.35–7.39 (m, 2 H, Ph), 8.11 (d, 2 H, ^3J = 6.14 Hz, H3/5), 8.77 (d, 2 H, ^3J = 6.14 Hz, H2/6) ppm. ^{13}C NMR ($CDCl_3$, 100 MHz, room temp.): **7e**: δ = 29.9 (CH_3), 55.3 (OCH_3), 94.1 (C8), 114.1 (2 C, Ph), 124.4 (C3/5), 127.0 (2 C, Ph), 132.1 (Ph), 138.4 (C4), 149.5 (C2/6), 159.6 (Ph), 164.4 (Cα), 219.1 (C7) ppm; **8e**: δ = 31.7 (CH_3), 55.3 (OCH_3), 87.0 (C8), 114.3 (2 C, Ph), 123.1 (C3/5), 127.0 (2 C, Ph), 133.4 (Ph), 136.8 (C4), 150.4 (C2/6), 159.6 (Ph), 160.3 (Cα), 192.8 (C7) ppm.

Sodium {[2-(4-Methoxyphenyl)-2-methyl-4-(pyridin-4-yl)-2,5-dihydro-1,3-thiazol-5-yl]sulfan-yl}(thioxo)methanethiolate (9): The azomethine **1e** (0.574 g, 2.39 mmol) was added to a suspension of sodium hydride (0.064 g, 2.67 mmol) in dry pyridine (20 mL) at room temp. After stirring of the mixture at room temperature for 48 h, CS_2 (0.182 g, 0.144 mL, 2.39 mmol) was added at room temperature to the deeply magenta-colored solution, whereupon the color immediately turned dirty orange. Overlayering of the pyridine solution with diethyl ether resulted in an orange oil, from which a few crystals of **9** slowly grew. The following NMR spectroscopic data are taken from the spectra of the reaction mixture since the yield of pure compound **9** was too small for NMR investigations. ^{1}H NMR ([D$_6$]DMSO, 250 MHz, room temp.): δ = 1.78 (s, CH_3), 1.97 (s, CH_3), 2.03 (s, CH_3), 3.69, (s, OCH_3), 3.74 (s, OCH_3), 3.76 (s, OCH_3), 3.80 (s, OCH_3), 4.54 (s, NH or CαH), 4.67 (s, NH or CαH), 6.77–6.94 (m), 7.33–7.41 (m), 7.75–7.86 (m), 8.56–8.65 (m) ppm. ^{13}C NMR ([D$_6$]DMSO, 62.5 MHz, room temp.): δ = 30.8 (CH_3), 33.1 (CH_3), 55.4 (OCH_3), 55.5 (OCH_3), 72.2, 72.5, 74.3, 89.77, 89.84, 113.1, 113.9, 117.7, 123.0, 123.5, 126.9, 139.5, 142.1, 143.4, 148.3, 150.6, 156.8, 158.0, 158.6, 165, 195 ppm. IR (ATR): $\tilde{\nu}$ = 3079 (=C–H), 2837 (OCH_3), 1594, 1550, 1507, 1406, 1249, 1133, 1001, 878, 702, 678 cm^{-1}.

Crystal Structure Determinations: The intensity data for the compounds were collected with a Nonius KappaCCD diffractometer, using graphite-monochromated Mo-K_α radiation. Data were corrected for Lorentz and polarization effects, but not for absorption effects.[29,30] The structures were solved by direct methods (SHELXS[31]) and refined by full-matrix least-squares techniques against F_o^2 (SHELXL-97[32]). All hydrogen atoms were included at calculated positions with fixed thermal parameters. All non-hydrogen atoms were refined anisotropically.[32] The quality of the data of compounds **[3b(THF)$_2$]$_\infty$** and **9** are not good; we therefore publish only the conformation of the molecules and the crystallographic data; these data are not being deposited with the Cambridge Crystallographic Data Centre. XP (SIEMENS Analytical X-ray Instruments, Inc.) was used for structure representations.

Crystal Data for 3a(THF)$_2$:[33] $C_{29}H_{35}LiN_2O_2S_2\times0.5C_4H_8O$, *Mr* = 548.69 g mol^{-1}, colorless prism, size 0.10×0.08×0.06 mm, triclinic, space group $P\bar{1}$, *a* = 9.6538(3), *b* = 10.0533(2), *c* = 16.0045(5) Å, *α* = 76.581(1), *β* = 81.498(1), *γ* = 73.629(1)°, *V* = 1443.95(7) Å, *T* = –90 °C, *Z* = 2, $\rho_{calcd.}$ = 1.262 g cm^{-3}, μ(Mo-K_α) = 2.17 cm^{-1}, *F*(000) = 584, 10555 reflections in *h*(–12/12), *k*(–12/13), *l*(–20/20), measured in the range 2.29° ≤ Θ ≤ 27.44°, completeness Θ_{max} = 99.3%, 6540 independent reflections, R_{int} = 0.028, 4610 reflections with $F_o > 4\sigma(F_o)$, 341 parameters, 0 restraints, R_{1obs} = 0.060, wR_{2obs} = 0.154, R_{1all} = 0.0923, wR_{2all} = 0.171, GOOF = 1.043, largest difference peak/hole: 0.808/–0.721 e Å^{-3}.

Crystal Data for [3b(THF)$_2$]$_\infty$: $C_{27}H_{30}LiN_2O_2S_2$, *Mr* = 485.59 g mol^{-1}, colorless prism, size 0.03×0.03×0.03 mm, triclinic, space group $P\bar{1}$, *a* = 12.5396(5), *b* = 12.9335(6), *c* = 16.1319(6) Å, *α* = 89.076(3), *β* = 89.858(2), *γ* = 86.364(2)°, *V* = 2610.68(19) Å^3, *T* = –90 °C, *Z* = 4, $\rho_{calcd.}$ = 1.235 g cm^{-3}, μ(Mo-K_α) = 2.3 cm^{-1}, *F*(000) = 1028, 17009 reflections in *h*(–16/16), *k*(–16/15), *l*(–19/20), measured in the range 4.32° ≤ Θ ≤ 27.50°, completeness Θ_{max} = 94.3%, 11311 independent reflections.

Crystal Data for 7d:[33] $C_{20}H_{14}N_2S_2$, *Mr* = 346.45 g mol^{-1}, green prism, size 0.03×0.03×0.02 mm, triclinic, space group $P\bar{1}$, *a* = 9.7358(6), *b* = 10.4742(6), *c* = 10.5330(8) Å, *α* = 118.840(3), *β* = 109.725(3), *γ* = 97.280(3)°, *V* = 829.28(9) Å^3, *T* = –90 °C, *Z* = 2, $\rho_{calcd.}$ = 1.387 g cm^{-3}, μ(Mo-K_α) = 3.24 cm^{-1}, *F*(000) = 360, 5636 reflections in *h*(–11/12), *k*(–13/12), *l*(–13/13), measured in the range 2.37° ≤ Θ ≤ 27.50°, completeness Θ_{max} = 97.1%, 3705 independent reflections, R_{int} = 0.043, 2850 reflections with $F_o > 4\sigma(F_o)$, 217 parameters, 0 restraints, R_{1obs} = 0.059, wR_{2obs} = 0.144, R_{1all} = 0.082, wR_{2all} = 0.160, GOOF = 1.050, largest difference peak and hole: 0.367/–0.586 e Å^{-3}.

Crystal Data for 9: $C_{65}H_{60}N_{10}Na_2O_2S_8$, *Mr* = 1315.69 g mol^{-1}, yellow prism, size 0.12×0.12×0.10 mm, triclinic, space group $P\bar{1}$, *a* = 9.6997(7), *b* = 13.9990(10), *c* = 15.850(2) Å, *α* = 81.551(5), *β* = 76.952(5), *γ* = 81.579(6)°, *V* = 2059.5(3) Å^3, *T* = –90 °C, *Z* = 1, $\rho_{calcd.}$ = 1.061 g cm^{-3}, μ(Mo-K_α) = 2.69 cm^{-1}, *F*(000) = 686, 13235 reflections in *h*(–12/12), *k*(–17/18), *l*(–18/20), measured in the range

$1.48° \leq \Theta \leq 27.45°$, completeness Θ_{max} = 93.8%, 8853 independent reflections.

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