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# Potassium–zinc induced synergic enhancement of the basicity of hexamethyldisilazide (HMDS) towards methylbenzene molecules

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**While neither KHMDS nor $Zn(HMDS)_2$ can unilaterally metallate toluene under the conditions studied, the bilateral base '$KZn(HMDS)_3$' can smoothly do so to produce the benzyl product $[\{KZn(HMDS)_2(CH_2Ph)\}_\infty]$, which exists in the crystal as an infinite spiral chain of benzyl (ambi-σ, π)-linked (KNZnN) rings.**

Bulky lithium amides, and to a lesser extent, those of sodium and potassium have long been workhorses of the synthetic chemist, carrying out a multitude of deprotonation reactions in both achiral[1] and chiral[2] systems. The lower polarity magnesium amides[3] have also been recently accepted into this service, promising a greater degree of selectivity in compensation for a reduction in reactivity. While these homometallic amides have been the subject of numerous studies, the possibility of developing a separate class of mixed-metal amides has been barely studied at all.[4] Our work in this pursuit has uncovered some remarkable demonstrations of synergy, which suggest that mixed-metal amides can display unique chemistries that could also be exploited in synthesis.[5] Most significant, to date, has been the co-operative action between sodium and magnesium in combination with diisopropylamide ($Pr^i{}_2N^-$) to effect the regioselective and fourfold deprotonation of ferrocene, manifested in the 16-membered inverse crown ring complex $[Na_4Mg_4(Pr^i{}_2N)_8\{Fe(C_5H_3)_2\}]$.[6] Neither sodium diisopropylamide nor magnesium bis(diisopropylamide) can unilaterally replicate this impressive multimetallation reaction. In the company of the even more sterically demanding 2,2,6,6-tetramethylpiperidide $[\{Me_2C(CH_2)_3C(Me_2)N\}^-]$ ligand (TMP), the same metal–metal partnership can subject toluene to twofold deprotonation at kinetic sites on the aromatic ring (2,5-positions), manifested in the 12-membered inverse crown ring complex $[Na_4Mg_2(TMP)_6(C_6H_3CH_3)]$.[7] Significantly, when the weaker base 1,1,1,3,3,3-hexamethyldisilazide $[(Me_3Si)_2N^-]$ (HMDS) is employed as the amide 'linker' for the two metal atoms, no metallocene or arene deprotonation is forthcoming, though an 8-membered inverse crown 'ether' with an oxo/peroxo core $[Na_2Mg_2(HMDS)_4(O)_x(O_2)_y]$[8] has proved accessible. In this paper we report a new, unexpected example of synergy, namely, that HMDS can be activated towards effecting arene deprotonation through the co-operation of potassium and zinc, which is a surprise given that zinc, on its own, is generally considered to be of inferior reactivity compared to magnesium.

The synergy can operate over a range of arenes including, in order of increasing substitution, toluene, *m*-xylene and mesitylene. Taking the reaction with toluene as a representative example, a mixture of KHMDS/$Zn(HMDS)_2$ (10 mmol of each) in toluene (20 ml) was stirred for 15 min. During this time the pale yellow solution deposited a precipitate. Applying vigorous heat for 5 min achieved its complete redissolution. Slow cooling of the resulting solution afforded colourless needle crystals identified as the benzyl product $[\{KZn(HMDS)_2(CH_2Ph)\}_\infty]$, **1**.† This procedure must be carried out under scrupulously dry and oxygen-free conditions or else the known oxygen-contaminated species $[\{K_2Zn_2(HMDS)_4(O)_x(O_2)_y\}_\infty]$,[9] which is inert towards toluene, will form as a by-product. As a control reaction, we treated KHMDS (which is sold commercially by Aldrich as a 0.5 M solution in toluene!) and $Zn(HMDS)_2$ individually with excess toluene under harsher conditions than that employed above (heating the mixtures to reflux for several hours), and found that no reaction occurred in each case. Thus this confirms unequivocally that the deprotonative metallation behind the synthesis of **1** is synergic in origin. In general pure zinc amides are poor bases, but it is significant that the precomplexation of $Bu^t{}_2Zn$ with LiTMP affords a '$Li^+\{Zn(TMP)(Bu^t)_2\}^-$' zincate, which acts as a highly chemoselective base for metallation of aromatic compounds with electrophilic substituents such as alkoxycarbonyl or cyano groups.[10] Trialkylzincates, of which $[KZn(CH_2Bu^t)_3]$[11] is a germane example, also show improved basicity (over their monometallic zinc analogues) towards arenes. What is perhaps most intriguing in our case is that the synergism appears to switch off when zinc is replaced by magnesium. This is evident from the earlier finding that the mixed potassium–magnesium HMDS formulation does not deprotonate toluene, but instead utilises it as a π-arene ligand in dimeric ($n = 2$) or polymeric ($n = \infty$) polymorphs of the magnesate $[\{[K(toluene)_2]^+[Mg(HMDS)_3]^-\}_n]$.[12] For the potassium–magnesium partnership to effect arene deprotonation the base strength of the amide must be increased as illustrated by the TMP-induced deprotonation manifested in the twenty-four-membered inverse crown complex $[K_6Mg_6(TMP)_{12}(C_6H_4CH_3)_6]$.[13] Note that here, as in the sodium analogue $[Na_4Mg_2(TMP)_6(C_6H_3CH_3)]$, deprotonation occurs selectively at kinetic sites on the aromatic ring, whereas in **1** the proton is lost from the thermodynamic Me site to generate the benzyl group, the form of the carbanion which maximises the resonance energy contribution to the bonding. This metal-dependent distinction implies that a different mechanistic pathway is followed in each case. Differences in polarity (Mg > Zn), electrophilicity (Zn > Mg) or bond length (Mg–C > Zn–C) may well contribute to this distinction but, given the mysterious nature of the synergic effect, the full explanation is likely to involve a subtle combination of factors. Our subsequent syntheses of $[\{KZn(HMDS)_2[CH_2(C_6H_4)CH_3\text{-}3]\}_\infty]$ **2** and $[\{KZn(HMDS)_2[CH_2(C_6H_3)Me_2\text{-}3,5]\}_\infty]$ **3** established that the synergy-driven deprotonation is extendable to *m*-xylene and mesitylene respectively.† Here there is a diminishing opportunity for ring deprotonation, due to the increased steric hindrance of substituting extra Me substituents upon it; thus following suit with **1**, **2** and **3** both lose a Me proton. In contrast the synergic base appears ineffective with *o*-xylene, as the arene remains intact but π-bound to the alkali metal in the previously reported dimer $[\{[K(o\text{-xylene})_2]^+[Zn(HMDS)_3]^-\}_2]$:[12] the implication is that the proximate Me substituents mutually shield each other and by doing so raise substantially the energy barrier to deprotonation.

Seeking clues as to why the toluene deprotonation takes place, we determined the crystal structure of **1**.‡ Viewing its dinuclear substructure (Fig. 1) and the polymeric arrangement (Fig. 2), it is clear that both metal atom types benefit from the benzyl for HMDS substitution. Thus the benzyl carbanion fills the zinc terminus of the rhomboidal $[K(\mu\text{-HMDS})_2Zn]$ ring. The σ-character of the Zn–C bond is reflected by its short length

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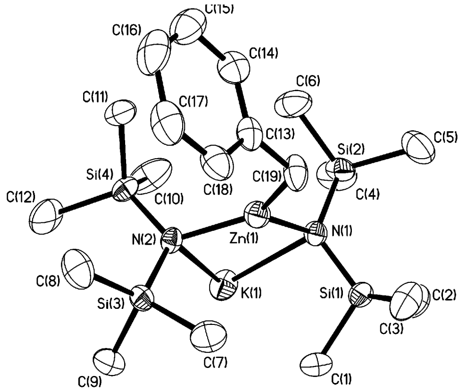

**Fig. 1** Asymmetric unit of the structure of **1** with atom labels and 50% probability displacement ellipsoids. Hydrogen atoms have been omitted for clarity. Key dimensions not in text (Å and °): N–Si; 1.703(4)–1.724(4); N(1)–K(1)–N(2) 72.82(9), N(1)–Zn(1)–N(2) 114.06(13), N(1)–Zn(1)–C(19) 115.59(15), N(2)–Zn(1)–C(19) 130.30(15), Zn(1)–C(19)–C(13) 117.0(3).

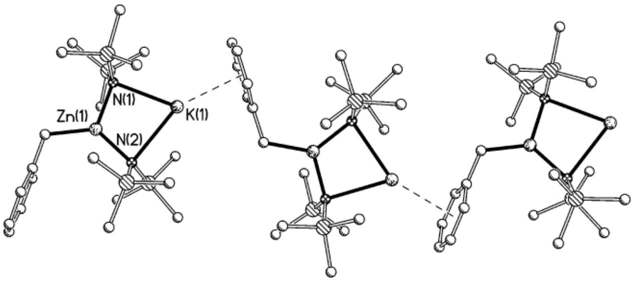

**Fig. 2** A three-unit section of the extended chain structure of **1** highlighting the glide plane.

[2.014(4) Å], which is comparable to the Zn–N bond lengths [Zn–N(1), 2.010(3); Zn–N(2), 1.985(3) Å] and, most significantly, is decidedly shorter than the Mg–C(benzyl) terminal bond lengths (mean, 2.243 Å) in $[\{Li{\cdot}TMEDA\}^{+}\{Mg(CH_2Ph)_4Li{\cdot}TMEDA\}^{-}]$.[14] Electron-rich from the negative charge, the π-face of the benzyl group coordinates to the $K^+$ cation in the next (KNZnN) ring, to extend the structure supramolecularly through a chain with a glide plane. However, the spread of bond lengths involved [K–C(13), 3.019(4); –C(14), 3.120(4); –C(15), 3.328(5); –C(16), 3.429(5); –C(17), 3.347(5); –C(18), 3.126(4); –C(centroid), 2.919Å] is of the same magnitude as that in the aforementioned magnesate $[\{[K(toluene)_2]^{+}[Mg(HMDS)_3]^{-}\}_n]$ (range of K–C bond lengths, 3.124–3.345 Å; range of K–C centroid lengths, 2.884–2.937 Å), where the arene is neutral. Though long known experimentally and much studied theoretically, alkali metal-π (arene) interactions have recently taken on a new significance with the suggestion that intramolecular cationic interactions with (electron-rich) aromatic centres can influence protein structures.[15] The $K^+$ coordination sphere in **1** is completed by two μ-N atoms from HMDS [lengths, 2.782(3) and 2.863(3) Å] and two short intramolecular $K\cdots C(H_3)SiMe_2$ (agostic) contacts [to C(1), 3.082, to C(10), 3.089 Å]. Regarding the latter contacts as significant, the K-HMDS interactions could be interpreted as a four-membered (KNSiC) 'chelate' ring, but the marked distortion from linearity of the NSiC angles involved (both < 90°) in such intramolecular contacts is usually characteristic of extremely weak dipole–dipole contacts.[16]

The new compounds **1**–**3** can be classified by the general formula $[(M)(Zn)(amide)_x(organide)_{3-x}]$, where $x = 2$. As such they represent stoichiometric-variant stablemates of the zincates (where $x = 1$ and M = Li) developed by Kondo *et al.*, which are proving to be excellent reagents for selective proton abstraction in for example the synthesis of substituted bromopyridines and of asymmetrical benzynes.[17] Thus looking to the future, it would be interesting to compare the performance of our amide-rich compounds with these amide-poor ones and, with the option of changing the M, amide and organide components, it may be possible to tune reagents for specific applications.

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## Notes and references

† **2** and **3** were prepared in a similar manner to **1** by replacing toluene by *m*-xylene and mesitylene respectively. Yields of first batches, 39%, 55% and 42% for **1**, **2** and **3** respectively. All form as colourless crystals and give satisfactory (C, H, N) analyses. $^1$H NMR data ([$^2H_8$]-THF, 25 °C, 400.13 MHz) **1**: $\delta$ = 6.92 (d, 2H, *o*-Ar), 6.79 (t, 2H, *m*-Ar), 6.42 (t, 1H, *p*-Ar), 1.68 (s, 2H, $CH_2$), −0.05 (s, 36H, $SiMe_3$); **2**: 6.79 (s, 1H, *o*′-Ar), 6.72-6.66 (overlapping m, 2H, *o*- and *m*-Ar), 6.27 (d, 1H, *p*-Ar), 2.12 (s, 3H, Me), 1.64 (s, 2H, $CH_2$), −0.05 (s, 36H, $SiMe_3$); **3**: 6.57 (s, 2H, *o*-Ar), 6.11 (s, 1H, *p*-Ar), 2.08 (s, 6H, Me), 1.60 (s, 2H, $CH_2$), −0.05 (s, 36H, $SiMe_3$). $^{13}$C NMR data ([$^2H_8$]-THF, 25 °C, 100.61 MHz) **1**: $\delta$ = 155.0 (*ipso*-C), 127.5 (*m*-C), 127.1 (*o*-C), 118.2 (*p*-C), 30.0 ($CH_2$), 6.8 ($SiMe_3$); **2**: 154.7 (*ipso*-C($CH_2$)), 136.0 (*ipso*-C($CH_3$)), 128.1 (*o*′-C), 127.4(*o*-C), 124.3 (*m*-C), 119.2 (*p*-C), 29.7 ($CH_2$), 22.0 ($CH_3$), 6.8 ($SiMe_3$); **3** 154.4 (*ipso*-C($CH_2$)), 135.6 (*ipso*-C($CH_3$)), 125.3 (*o*-C), 120.3 (*p*-C), 29.5 ($CH_2$), 21.9 ($CH_3$), 6.8 ($SiMe_3$). Assignments confirmed by $^1$H/$^{13}$C HMQC experiments.

‡ Crystal data for **1**: $C_{19}H_{43}KN_2Si_4Zn$, $M$ = 516.4, monoclinic, space group $P2_1/n$, $a$ = 9.2390(18), $b$ = 20.764(4), $c$ = 15.064(3) Å, $\beta$ = 91.90(3)°, $U$ = 2888.3(10) Å$^3$, $Z$ = 4, $T$ = 160 K; $R(F; F^2 > 2\sigma)$ = 0.057, $R_w(F^2$, all data) = 0.177 for 4975 unique data and 257 refined parameters. CCDC 198623. See http://www.rsc.org/suppdata/cc/b2/b211392a/ for crystallographic files in CIF or other electronic format.

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