Inverse Crowns

Synthesis and Crystal Structure of [{*n*BuMg(μ-TMP)}$_2$] and of a Homometallic Inverse Crown in Tetranuclear [{*n*BuMg$_2$[μ-N(H)Dipp]$_2$(μ$_3$-O*n*Bu)}$_2$]**

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Although the first substantial studies of organomagnesium amides "RMgN(R^1)(R^2)" took place in the 1960s through the pioneering work of Coates et al.,[1] their impact on synthesis since then has been almost invisible in comparison to that of Grignard reagents or lithium organoamides. However, recent communications by Eaton and co-workers thrusting "BuMgN*i*Pr$_2$" into the limelight as a new Brønsted base for regioselective deprotonation of cyclopropane and cyclobutane carboxamides[2,3] could mark a watershed in the appreciation and utilization of these hitherto largely friendless organometallics. "BuMgN*i*Pr$_2$" is now sold commercially in the form of a THF solution by the chemical company Aldrich, but not as a single, well-defined compound as it contains a mixture of *n*-butyl and *sec*-butyl components.[4] For the complete picture, it should be noted that predating the paper by Eaton et al., "*n*BuMgN*i*Pr$_2$" was found to exhibit high Cram selectivity as it adds to α-chiral 2-phenylpropanal to form the *n*Bu-substituted alcohol,[5] while "*n*BuMgN*i*Pr$_2$" and "*s*BuMgN*i*Pr$_2$" are mentioned in a patent[6] to be useful in the manufacture of catalysts employed in the polymerization of rubber, although no details are presented. It struck us that there was an urgent need for fundamental development of this impoverished class of compound, a point reinforced by three recent reports[7,8] of the use of specialized chiral organomagnesium amides in enantioselective methodology. Thus, we begin this process here by describing a novel synthetic strategy to alkylmagnesium amides, illustrated by the synthesis of a new, potentially exciting reagent based on the classical secondary amide ligand TMP, (2,2,6,6-tetramethylpiperidide, (Me)$_2$CCH$_2$CH$_2$CH$_2$C(Me)$_2$N$^-$). The application of this strategy to a primary-amide system unexpectedly produced a remarkable trianionic (alkoxo-alkyl-amido)magnesium complex. Discussion focuses on how this latter complex is best viewed from the perspective of earlier work on mixed-metal amide inverse crowns[9] as the first homometallic (magnesium–magnesium′) inverse crown.

Seeking to synthesize new alkylmagnesium amides with classical utility ligands, we were surprised to learn that "*n*BuMgTMP" (a "magnesium hybrid" of the important commercial lithium reagents *n*BuLi and LiTMP) had hitherto not been prepared in its own right though it may have "passed by" during the twofold amination of dibutylmagnesium (MgBu$_2$) on the way to bis(amido) Mg(TMP)$_2$.[10] Our alternative approach of treating the Grignard reagent *n*BuMgCl with NaTMP in ether solution readily produces the target compound [{*n*BuMg(μ-TMP)}$_2$], **1**, in an isolable, pure crystalline, single-alkyl form, ideal for employment in subsequent synthetic applications. The outstanding aspect of this method is the cleavage of the ether–Mg dative bonds of the starting Grignard reagent to leave **1** with wholly ether-free Mg centers (thus giving **1** an immediate advantage over Grignard reagents, as its solution chemistry is not limited to donor solvents such as ethers or amines). Though no precedent exists for this method of preparing alkylmagnesium amides that involves a Grignard reagent, sodium amide, and ether, Veith et al. reported the reaction of MeMgCl in ether solution with the dilithium disilazide Li$_2$L (L = (*t*BuN)(Me)Si(N*t*Bu)$_2$Si(Me)(N*t*Bu)) to afford L(MgMe)$_2$,[11] while Coates noted ether desolvation in forming [*i*PrMgN(*i*Pr)$_2$][1] by the standard route of hemiamination of the bis(alkyl) (*i*Pr)$_2$Mg. With a view to future deprotonation/magnesiation utility, it is noteworthy that **1** does not carry hydrogen atoms on its amido α-C atoms: hence reduction side reactions of the Meerwein–Ponndorff–Verley type[12] cannot compete as they can do with bases that contain N(*i*Pr)$_2$. The molecular structure of **1** (Figure 1)[13] has bridging TMP and terminal *n*Bu ligands surrounding the Mg center in a non-centrosymmetric, dimeric (MgN)$_2$ planar-ring arrangement. Wide exocyclic NMgC(Bu) bond angles (mean value 132.69°) mark the highly distorted trigonal-planar primary coordination sphere of the Mg center. The most interesting feature is the presence of secondary contacts from each Mg atom to two Me substituents on different TMP ligands (mean length to C

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TMP = 2,2,6,6-tetramethylpiperidide; Dipp = 2,6-diisopropylphenyl.

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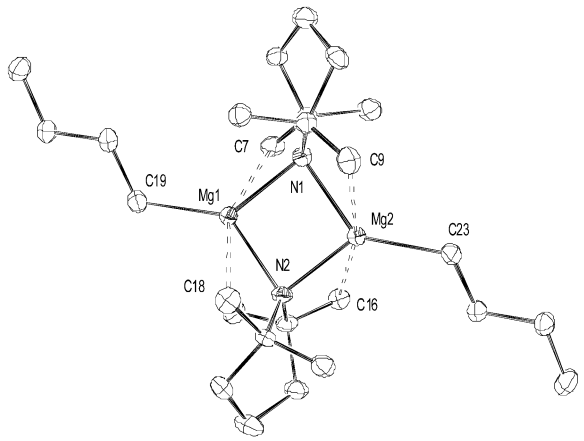


Figure 1. Molecular structure of **1** with hydrogen atoms omitted for clarity. Selected dimensions [Å and °]: Mg(1)-C(19) 2.126(4), Mg(1)-N(1) 2.121(4), Mg(1)-N(2) 2.117(4), Mg(1)-C(7) 2.773(5), Mg(1)-C(18) 2.792(5), Mg(2)-C(23) 2.130(4), Mg(2)-N(1) 2.130(4), Mg(2)-N(2) 2.122(4), Mg(2)-C(16) 2.843(5), Mg(2)-C(9) 2.860(5), N(2)-Mg(1)-N(1) 94.50(14), N(2)-Mg(1)-C(19) 132.15(18), N(1)-Mg(1)-C(19) 133.02(18), Mg(1)-N(1)-Mg(2) 85.56(15), N(2)-Mg(2)-C(23) 131.72(17), N(2)-Mg(2)-N(1) 94.08(14), C(23)-Mg(2)-N(1) 133.98(17), Mg(1)-N(2)-Mg(2) 85.85(14).

atom, 2.817 Å; compare with 2.128 Å for primary Mg–C bonds). These weaker interactions are accompanied by a severe twisting of the hexagonal TMP rings from their characteristic chair shape. Enveloped by this set of three primary (C, $N\times2$) and two secondary ($C\times2$)atoms, the Mg coordination spheres have no space available for additional ligands, hence the desolvation process observed during the preparation of **1** must be sterically driven.

Replacing NaTMP by the primary amide NaN(H)Dipp (Dipp = 2,6-diisopropylphenyl) in Equation (1) fortuitously

$$n\text{BuMgCl} + \text{NaTMP} \xrightarrow{\text{hexane/ether}} n\text{BuMgTMP} + \text{NaCl} \quad (1)$$

first led us to synthesize the novel trianionic complex $[\{n\text{BuMg}_2[\mu\text{-N(H)Dipp}]_2(\mu_3\text{-O}n\text{Bu})\}_2]$, **2**.

Compound **2** crystallized preferentially in low yield from the reaction of impure *n*BuMgCl in ether solution with a hydrocarbon suspension of NaN(H)Dipp. The presence of the adventitious alkoxo ligand was traced unequivocally to the starting Grignard reagent through a combination of Wittig–Harborth double titrations[14] and ^{1}H/^{13}C NMR spectra.[15] Interpreting **2** as a composite of the amide-alkoxide *n*BuMgO*n*Bu and the bis(amide) Mg[N(H)Dipp]$_2$, we then reprepared it rationally in a much improved yield by mixing together $MgBu_2$, Mg[N(H)Dipp]$_2$ and *n*BuOH in a 1:1:1 stoichiometry. The molecular structure of **2** (Figure 2 and Figure 3)[16] bears a close resemblance to that of alkoxide-encapsulated inverse crowns, most pertinently the sodium–magnesium-based complex $[Na_2Mg_2(\mu\text{-N}i\text{Pr}_2)_4(\mu_3\text{-O}n\text{Bu})_2]$,[17] **3**. In **2**, an octagonal $\{(MgNMg'N)_2\}$ cationic ring, μ_3-capped top and bottom by butoxo O atoms, is chair-shaped with the Mg2 atoms displaced on either side of the plane defined by NMg1N···NMg1N. The angle between the NMg2N chair back and this plane is 100.51(13). These features are shared by **3** (the corresponding interplane angle is 154.64°) with the

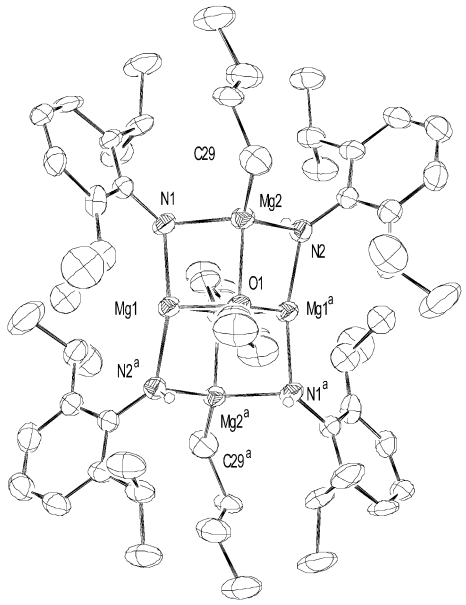


Figure 2. Molecular structure of **2** without carbon-attached hydrogen atoms and disorder components. Selected dimensions [Å and °]. Mg(1)-N(1) 2.041(3), Mg(1)-O(1) 2.037(3), Mg(1)-N(2)^a 2.037(3), Mg(1)-O(1)^a 2.068(2), Mg(2)-N(1) 2.168(4), Mg(2)-C(29) 2.109(5), Mg(2)-O(1) 2.121(3), N(2)^a-Mg(1)-O(1) 100.17(13), N(2)^a-Mg(1)-N(1) 166.77(14), O(1)-Mg(1)-N(1) 90.86(13), N(2)^a-Mg(1)-O(1)^a 90.29(12), O(1)-Mg(1)-O(1)^a 87.55(10), O(2)-Mg(2)-N(1) 85.24(11), N(2)-Mg(2)-N(1) 104.46(15), C(29)-Mg(2)-N(1) 121.06(17), O(1)-Mg(2)-N(2) 85.44(11), C(29)-Mg(2)-N(2) 123.03(17), C(29)^a-Mg(2)-O(1) 127.58(17), Mg(1)-O(1)-Mg(1)^a 92.45(10), Mg(1)-O(1)-Mg(2) 92.42(10).

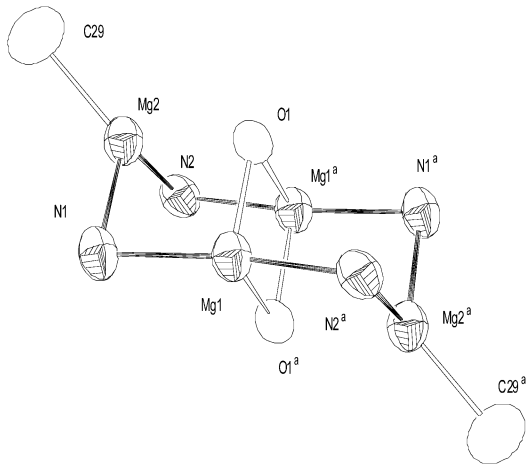
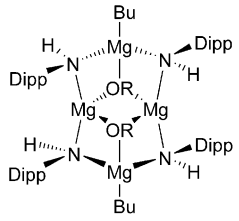


Figure 3. Alternative view of **2** highlighting the elongated chair-shape of the {MgNMgNMgN} core.

significant distinction that the butyl-carrying Mg2 sites are occupied by Na atoms free of exosubstituents. Noting that $(MgBu)^+$ is isovalent with Na^+, we regard **2** as an isovalent analogue of **3** and thus may be considered the first homometallic inverse crown. The structures are sterically compatible because the extra steric hindrance created by the introduction of the *exo*-Bu substituents in **2** is offset by the reduced steric bulk of the amide (i.e., in switching from a

secondary to a primary type). These amido H atoms (and concomitantly the aryl substituents) lie transoid to each other along the N1Mg1N2[a] chair edge and across the chair seat (on N1 and N1[a]).



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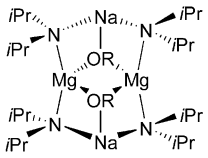

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With respect to the future, **1** is now readily available in a convenient crystalline form for use/exploration by synthetic chemists; the method used to synthesize it merits more investigation as it may apply generally to ether-free organomagnesium amides with sterically demanding substituents, and this first demonstration of the isovalent relationship in inverse crown chemistry expands yet further the opportunities for development within this intriguing class of compounds.

Experimental Section

Preparation of [{*n*BuMg(μ-TMP)}$_2$] (**1**): NaBu (10 mmol, 0.8 g) was suspended in hexane (20 mL) to which TMPH (10 mmol, 1.7 mL) was added. The resulting pale yellow suspension was stirred at room temperature for two hours. BuMgCl (10 mmol, 5 mL of a 2 M solution in ether) was then added. The reaction mixture was stirred at ambient temperature overnight. This resulted in the formation of a white suspension in an orange solution. The solid was removed by filtering the mixture through celite. The filtrate was reduced in volume in vacuo, then placed in the freezer at −28 °C. Overnight this solution deposited a crop of colorless crystals. Yield (first batch): 0.57 g, 26 %. Satisfactory elemental analyses (C, H, N) were obtained. ^{1}H NMR (400.16 MHz, [D$_6$]benzene solution; 25 °C): $\delta = 1.91$ (m, 2H, TMP), 1.72 (m, 2H, CH_2, Bu), 1.51 (m, 4H, TMP), 1.32 (m, 2H, CH_2, Bu), 1.29 (s, 12H, CH$_3$, TMP), 1.29 (t, 3H, CH_3, Bu), 0.05 ppm (m, 2H, Mg-*CHH′*, Bu). ^{13}C{H}NMR (100.61 MHz, [D$_6$]benzene solution; 25 °C): $\delta = 53.41$ (*C*Me$_2$, TMP), 39.05(*C*H$_2$, TMP), 36.10 (*C*H$_3$, TMP), 33.20 (*C*H$_2$, Bu), 32.63 (*C*H$_2$, Bu), 17.86 (*C*H$_2$, TMP), 15.03 (*C*H$_3$, Bu), 13.04 ppm (Mg*C*H$_2$, Bu).

Preparation of [{*n*BuMg$_2$[μ-N(H)Dipp]$_2$(μ-O*n*Bu)}$_2$] (**2**): MgBu$_2$ (10 mmol, 10 mL of a 1 M solution in heptane) was added to a suspension of Mg(NHDipp)$_2$ in heptane (prepared in situ by the reaction of MgBu$_2$ (10 mmol) and NH$_2$Dipp (20 mmol)). To the resulting colorless solution *n*BuOH (10 mmol, 0.9 mL) was added. The solution was stirred for 30 minutes and concentrated by removing some solvent in vacuo. Freezer cooling of the remaining solution at −28 °C produced a crop of colorless crystals of **2**. Yield (first batch): 1.8 g, 35 %. Compound **2** was also obtained serendipitously in the reaction of BuMgCl with Na(NHDipp), in this case the yield was only 2 %. Satisfactory elemental analyses (C, H, N) were obtained. ^{1}H NMR (400.16 MHz, [D$_6$]benzene solution; 25 °C): $\delta = 7.07$ (m, 2H, Ar, Dipp), 6.91 (m, 2H, Ar, Dipp), 6.85 (m, 2H, Ar, Dipp), 4.35 (m, 2H, OC*HH′*CH$_2$), 3.30 (septet, 2H, C*H*MeMe′, Dipp), 3.19 (s, broad, 2H, N*H*), 3.03 (septet, 2H, C*H*MeMe′, Dipp), 2.16 (m, 2H, OCHH′CH_2), 1.42–1.34 (overlapping m′s, 18H, CH_3, Dipp), 1.21 (m, 2H, CH$_2$, Bu), 1.01 (t, 3H, CH$_3$, Bu), 0.92–0.84 (overlapping m′s, 7H, CH_3, Dipp and 2CH$_2$, Bu's), 0.66 (t, 3H, CH$_3$, Bu), 0.26 ppm (m, 2H, Mg*CHH′*CH$_2$). ^{13}C{H}NMR (100.61 MHz, [D$_6$]benzene solution; 25 °C): $\delta = 146.13$, 135.47, 134.37, 124.18, 123.97, 120.00 (Ar, Dipp), 67.39 (O*C*HH′),37.78 (OCHH′*C*H$_2$), 31.87, 31.73 (*C*HMeMe′, Dipp), 30.24, 29.75 (CH$_2$'s, Bu's), 24.78, 24.54, 24.15, 23.59 (CH$_3$'s, Dipp), 19.95 (CH$_2$, Bu),14.83, 14.46 (CH$_3$'s, Bu's), 7.61 ppm (Mg*C*H$_2$, Bu).

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[13] *Crystal data* for **1**: $C_{26}H_{54}Mg_2N_2$; A colourless tabular crystal of approximate dimensions $0.50 \times 0.35 \times 0.12$ mm gave a monoclinic space group $P2_1$, $a = 8.1149(3)$, $b = 11.6498(4)$, $c = 14.5535(6)$ Å, $\beta = 92.055(1)°$, $V = 1375.0(1)$ Å^3, $T = 123$ K, $Z = 2$, $\rho_{calc} = 1.071$ Mg m^{-3}, $2\theta_{max} = 55°$, Mo$_{K\alpha}$ $\lambda = 0.71073$ Å. The structure was solved and refined on F^2 by using programs of the SHELX family to convergence at $R1 = 0.0563$ (for 2857 reflections with $I > 2\sigma(I)$) $wR2 = 0.1473$ and $S = 1.105$ for 325 parameters and 3287 unique reflections. Highest residual electron density 0.602 e Å^{-3}. H atoms of the four methyl groups in close contact with the Mg center were refined isotropically but all other H atoms were placed in calculated positions and in riding modes.
[14] In a typical experiment the total alkalinity was found to be 10 % percent higher than the alkalinity attributed exclusively to the BuMgCl. We assume that this is due to the presence of alkoxide in the solution, as was later confirmed by the NMR data, see reference [15]. For details of the double titration method see: M. Schlosser, *Organometallics in Synthesis*, Wiley, Chichester, **2002**, p. 295.
[15] The ^{1}H NMR spectrum of BuMgCl in [D$_8$]THF shows a multiplet at $\delta = 3.39$ ppm, while in the ^{13}C{H} NMR spectrum a signal at $\delta = 62.64$ ppm corresponding to a OCH$_2$ group is found.
[16] Crystal data for **2**: $C_{64}H_{108}Mg_4N_4O_2$; A colorless tabular crystal of approximate dimensions $0.50 \times 0.20 \times 0.10$ mm gave a monoclinic space group $C2/c$, $a = 19.8470(3)$, $b = 17.0270(4)$, $c = 19.9194(6)$ Å, $\beta = 105.503(1)°$, $V = 6486.5(3)$ Å^3, $T = 123$ K, $Z = 4$, $\rho_{calcd} = 1.088$ Mg m^{-3}, $2\theta_{max} = 52°$, Mo$_{K\alpha}$ $\lambda = 0.71073$ Å. The same methodology was used as for **1** and gave $R1 = 0.0803$ (for 3433 reflections with $I > 2\sigma(I)$) $wR2 = 0.2456$ and $S = 1.027$ for 387 parameters and 6368 unique reflections. Highest residual electron density 0.523 e Å^{-3}. The quality of the structure solution is adversely affected by disorder in one butyl group and one

amide ligand. Each was modeled as disordered over two sites. The N*H* atoms were refined isotropically but all other H atoms were placed in calculated positions and in riding modes. CCDC-223758 (**1**) and CCDC-223759 (**2**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB21EZ, UK; fax: (+44)1223-336-033; or deposit@ccdc.cam.ac.uk).

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