**Chemistry – the Key to Novel Solid State Batteries**

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Hydrogen has an extremely interesting chemistry and form compounds with most elements in the periodic table and with a variety of different types of bonds. Metal hydrides has recently become very interesting as new classes of energy materials for batteries and hydrogen storage [1]. Synthesis and characterisation of novel battery materials is the fundament for our research and we have discovered a range of new solid state electrolytes with fast cationic conductivity [2].

Recently, we synthesised a new metal borohydride, Mg(BH4)2⋅NH3, with high Mg2+ ionic conductivity. Density functional theory calculations (DFT) reveal that the neutral molecule (NH3) is exchanged between the lattice and interstitial Mg2+ facilitated by a highly flexible structure, mainly owing to a network of di-hydrogen bonds, N–Hδ+⋅⋅⋅−δH–B, and the versatile coordination of the BH4− ligand [3]. Di-hydrogen bonds in inorganic matter is a new tool for materials design and have similar bond strengths and bond lengths as hydrogen bonds in biological materials. A composite material consisting of two crystalline compounds, Mg(BH4)2⋅NH3−Mg(BH4)2⋅2NH3, is eutectic melting (~55 °C) and the melt can be stabilised to form a functional solid material with σ(Mg2+) ~ 10−3 S cm−1 at *T* = 70 °C using inert, insulating MgO nanoparticles as an additive. Solid state NMR reveal that the properties of the eutectic molten state is stabilised to form a solid with high thermal stability up to 200 °C [4]. An analogue lithium compound, LiBH4⋅0.5NH3 have a similar Li+ conductivity mechanism [5], and MgCl2⋅2NH3, which lack dihydrogen bonds is an insulator.

These new phenomena is generally applicable for rational design of new electrolytes for multivalent solid state batteries. This is demonstrated by design and synthesis of series of novel cationic conductors, e.g. Mg(BH4)2⋅R, R = NH3, CH3NH2, (CH3)2CHNH2, (CH2)4O (THF), with extreme cationic conductivities, etc. [3,6-8]. Recently, we created the first inorganic magnesium battery that was charged and discharged for ten cycles, Mg|Mg(BH4)2⋅1.5THF−MgO(75 wt%)|TiS2 [8]. A new type of a solid state lithium battery, Li|LiBH4·CH3NH2|TiS2 was also made based on hydride materials from our laboratory.

We conclude, that the chemistry of hydrides is very divers, towards rational design of multi-functional materials, including new electrolytes for future all-solid-state multi-valent batteries created completely from inorganic materials.

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