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Foto: Anne Günther / FSU

Philipp Adelhelm is a materials scientist and received his education at the University of Stuttgart and the Max-Planck-Institute for Metals Research. After graduation in 2004, he joined the group of Prof. Markus Antonietti at the Max-Planck-Institute of Colloids and Interfaces in Potsdam, Germany, and worked on the synthesis and characterization of carbon materials with tailored porosity. He received his PhD in physical chemistry in 2007 and continued his academic career as a post doc at the Debye Institute of Nanomaterials Science in Utrecht, The Netherlands, under supervision of Prof. Petra de Jongh and Prof. Krijn de Jong studying sodium and magnesium based hydrogen storage materials. During his stay as group leader at the Justus-Liebig-University Giessen, Germany (Institute of Physical Chemistry, RG Prof. Juergen Janek) his research aimed at exploring the cell chemistry of sodium based battery systems with the focus on carbon materials, conversion reactions, sodium/air and low temperature sodium/sulfur systems. On 1st of April 2015, he was appointed professor at the Institute for technical chemistry and environmental chemistry (ITUC) at the Friedrich-Schiller-University Jena. He is also part of the newly established Jena Center for Energy and Environmental Chemistry (CEEC) that was inaugurated in fall 2015. He is also member of the directorate of the Working group „Chemistry and Energy“ of the GDCh (www.gdch.de/chemie-und-energie)

Research interests:

- Carbon materials (synthesis, modification and characterization)
- Electrochemistry
- Lithium-ion and sodium-ion batteries, next generation battery systems
- Hydrogen storage

Current research projects are supported by the Friedrich-Schiller-University Jena, the state of Thuringia (Pro Excellence program), the German Research Foundation DFG and the German Federal Ministry of Education and Research BMBF.

Interested? – Feel free to contact us for more information

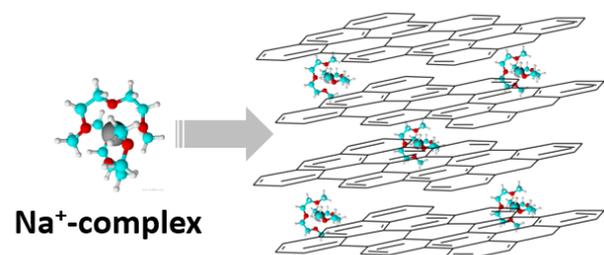
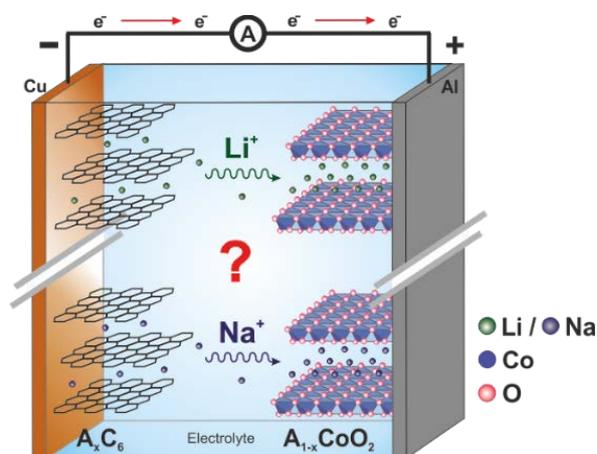
Selected research projects and publications:

Sodium as alternativ to Lithium?

Lithium-ion and sodium-ion batteries share many common features but also many surprising differences. Understanding the influence of ion size on the cell chemistry of batteries is an intriguing research field. Moreover, the abundance of sodium is highly attractive for developing low cost, large scale energy stores.

P. Adelhelm; *Alternative Natrium*, Nachrichten aus der Chemie 62, 2014 (Perspective)

Adelhelm P, Hartmann P, Bender CL, Busche MR, Eufinger C, Janek J, *From lithium to sodium: cell chemistry of room temperature sodium–air and sodium–sulfur batteries*, Beilstein Journal of Nanotechnology 6, 2015 (open access)



Graphite for sodium-ion batteries

Although being the standard anode material in lithium-ion batteries (LIBs), graphite so far is considered to fail application in sodium-ion batteries (NIBs) because the Na-C system lacks suitable binary intercalation compounds. Here we show that this limitation can be circumvented by using co-intercalation phenomena

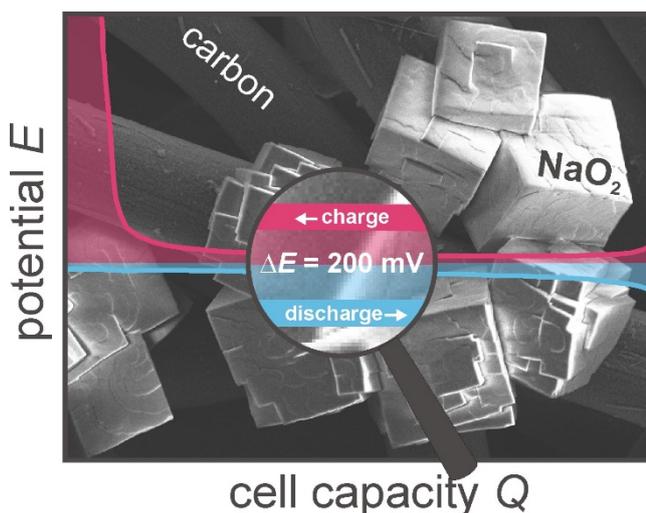
in a diglyme-based electrolyte. Highlights of the electrode reaction are its high energy efficiency, the small irreversible loss during the first cycle, and a superior cycle life with capacities close to 100 mAh g⁻¹ for 1000 cycles and coulomb efficiencies >99.87 %.

Jache B and Adelhelm P; *Use of Graphite as a Highly Reversible Electrode with Superior Cycle Life for Sodium-Ion Batteries by Making Use of Co-Intercalation Phenomena*, Angew. Chemie Int. Ed. 53, 2014

Jache B, Binder J, Abe T, *A comparative study on the impact of different glymes and its derivatives as electrolyte solvents for graphite co-intercalation electrodes in lithium-ion and sodium-ion batteries*; Phys. Chem. Chem. Phys., 2016, DOI: 10.1039/C6CP00912C,

The sodium superoxide battery

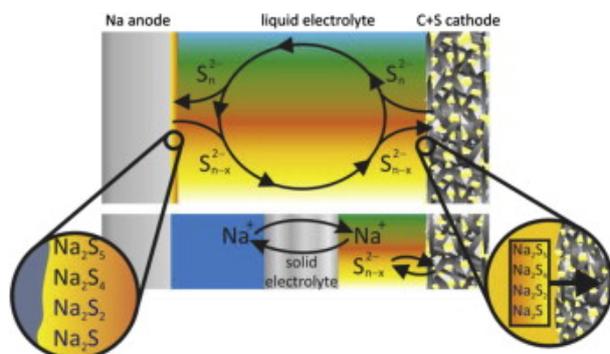
In the search for room-temperature batteries with high energy densities, rechargeable metal–air (more precisely metal–oxygen) batteries are considered as particularly attractive owing to the simplicity of the underlying cell reaction at first glance. Here we report on a Na–O₂ cell reversibly discharging/charging at very low overpotentials (< 200 mV) and current densities as high as 0.2 mA cm⁻² using a pure carbon cathode without an added catalyst. Crystalline sodium superoxide (NaO₂) forms in a one-electron transfer step as a solid discharge product. This work demonstrates that substitution of lithium by sodium may offer an unexpected route towards rechargeable metal–air batteries.



Hartmann P, Bender CL, Vračar M, Dürr AK, Garsuch A, Janek J, Adelhelm P, *A rechargeable room-temperature sodium superoxide (NaO₂) battery*, *Nature Materials* 12, **2013**

Bender CL, Hartmann P, Vracar M, Adelhelm P, Janek J *On the Thermodynamics, the Role of the Carbon Cathode, and the Cycle Life of the Sodium Superoxide (NaO₂) Battery*, *Adv. Energy Mater.* 4, **2014**

Bender CL, Schroeder D, Pinedo R, Adelhelm P, Janek J, *One- or Two-Electron Transfer? The Ambiguous Nature of the Discharge Products in Sodium–Oxygen Batteries*, *Angewandte Chemie Int. Ed.*, **2016**



Room-temperature sodium-sulfur batteries

The cell chemistry of sodium/sulfur cells operating at room temperature (RT-Na/S cells) is being studied electrochemically and structurally. We show by means of X-ray photoelectron spectroscopy that the cell reaction is incomplete but prove that the end members of the cell reaction (S and Na₂S) form among

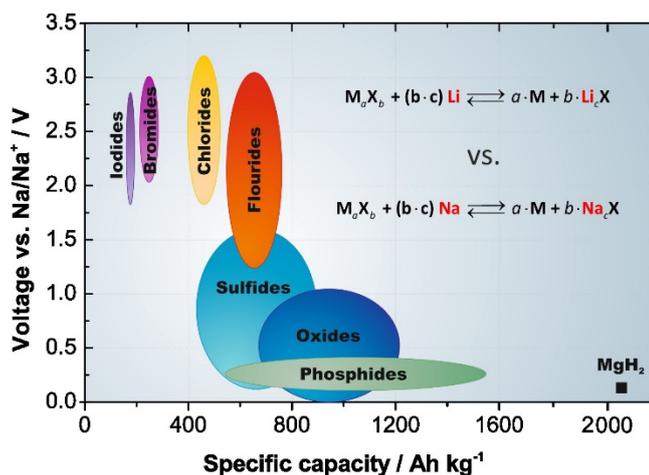
the expected polysulfide species Na₂S_x. The sulfur utilization can be improved by employing a solid electrolyte membrane (beta"-alumina) that prevents the diffusion of the soluble polysulfide species toward the sodium side. As an important finding, the Na⁺ conduction within the solid electrolyte phase and across the two liquid/solid interfaces results in only small overpotentials. Also, the thermodynamic properties of RT-Na/S cells operating at room temperature are discussed and compared with the currently much more studied RT-Li/S cells.

Wenzel S, Metelmann H, Reiß C, Dürr AK, Janek J, Adelhelm P, *Thermodynamics and cell chemistry of room temperature sodium/sulfur cells with liquid and liquid/solid electrolyte*, *Journal of Power Sources* 243, **2013**

Adelhelm P, Hartmann P, Bender CL, Busche MR, Eufinger C, Janek J, *From lithium to sodium: cell chemistry of room temperature sodium–air and sodium–sulfur batteries*, *Beilstein Journal of Nanotechnology* 6, **2015** (open access)

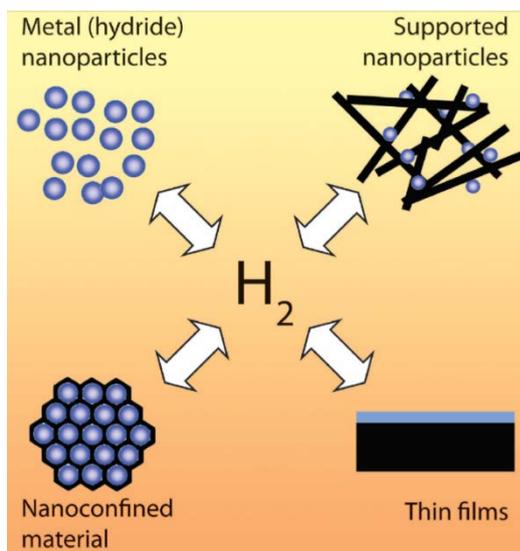
Conversion reactions for sodium-ion batteries

Research on sodium-ion batteries has recently been rediscovered and is currently mainly focused on finding suitable electrode materials that enable cell reactions of high energy densities combined with low cost. Naturally, an assessment of potential electrode materials requires a rational comparison with the analogue reaction in lithium-ion batteries. In this paper, we systematically discuss the broad range of different conversion reactions based on their basic thermodynamic properties and compare them with their lithium analogues. Capacities, voltages, energy densities and volume expansions are summarized to sketch out the scope for future studies in this research field. We show that for a given conversion electrode material, replacing lithium by sodium leads to a constant shift in cell potential $\Delta E^\circ_{(\text{Li}-\text{Na})}$ depending on the material class. For chlorides $\Delta E^\circ_{(\text{Li}-\text{Na})}$ equals nearly zero. Next to the thermodynamic assessment, results on several conversion reactions between copper compounds (CuS, CuO, CuCl, CuCl₂) and sodium are being discussed.



Klein F, Jache B, Bhide A, Adelhelm P, *Conversion reactions for sodium-ion batteries*, *Phys. Chem. Chem. Phys.*, 15, 2013

Klein F, Pinedo R, Hering P, Polity A, Janek J, Adelhelm P, *Reaction Mechanism and Surface Film Formation of Conversion Materials for Lithium- and Sodium-Ion Batteries: A XPS Case Study on Sputtered Copper Oxide (CuO) Thin Film Model Electrodes*, *J. Phys. Chem. C*, 12, 2016



Hydrogen storage

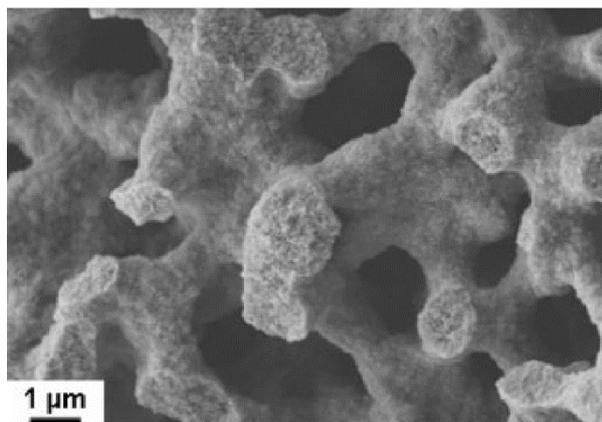
Hydrogen is expected to play an important role as an energy carrier in a future, more sustainable society. However, its compact, efficient, and safe storage is an unresolved issue. One of the main options is solid-state storage in hydrides. Unfortunately, no binary metal hydride satisfies all requirements regarding storage density and hydrogen release and uptake. In this Review we discuss the large impact of nanosizing and –confinement on the hydrogen sorption properties of metal hydrides. We illustrate possible preparation strategies, provide insight into the reasons for changes in kinetics, reversibility and thermodynamics, and highlight important progress in this field.

de Jongh PE, Adelhelm P.; *Nanosizing and Nanoconfinement: New Strategies Towards Meeting Hydrogen Storage Goals*. *ChemSuschem* 3, 2011 (Review)

Adelhelm P, de Jongh PE; *The impact of carbon materials on the hydrogen storage properties of light metal hydride*, *J. Mater Chem.*, 21, 2011

Carbon materials and nanostructures

In this paper, we report on Li storage in hierarchically porous carbon monoliths with a relatively higher graphite-like ordered carbon structure. Macroscopic carbon monoliths with both mesopores and macropores were successfully prepared by using meso-/macroporous silica as a template and using mesophase pitch as a precursor. Owing to the high porosity (providing ionic transport channels) and high electronic conductivity, this porous carbon monolith with a mixed conducting 3D network shows a superior high-rate performance if used as anode material in electrochemical lithium cells. A challenge for future research as to its applicability in batteries is the lowering of the irreversible capacity.



Hu YS, Adelhelm P, Smarsly BM, Hore S, Antonietti M, Maier J., *Synthesis of hierarchically porous carbon monoliths with highly ordered microstructure and their application in rechargeable lithium batteries with high-rate capability*, *Adv. Funct. Mater.* 17, **2007**

Adelhelm P, Hu YS, Chuenchom L, Antonietti M, Smarsly BM, Maier J.; *Generation of hierarchical meso- and macroporous carbon from mesophase pitch by spinodal decomposition using polymer templates*, *Adv. Mater.* 19, 2007

Jache A, Neumann C, Becker J, Smarsly BM, Adelhelm P. *Towards commercial products by nanocasting: characterization and lithium insertion properties of carbons with a macroporous, interconnected pore structure*, *J. Mater. Chem.* 22, **2012**

Adelhelm P, Cabrera K, Smarsly BM. *On the use of mesophase pitch for the preparation of hierarchical porous carbon monoliths by nanocasting*, *Sci. Technol. Adv. Mater.* 13, **2011**

Raiß C, Peppler K, Janek J, Adelhelm P, Pitfalls in the characterization of sulfur/carbon nanocomposite materials for lithium-sulfur batteries, *Carbon*, 79, **2014**

Curriculum vitae

- **Since 4.2015** **Full professor (W3)**
Institute for Technical Chemistry and Environmental Chemistry (ITUC), Friedrich-Schiller-University Jena, Germany
- **11.2009–03.2015** **Research group leader (Akademischer Rat a.Z.)**
Institute of Physical Chemistry, RG Janek, Justus-Liebig-University Giessen, Germany.
- **10.2007–10.2009** **Postdoctoral Researcher**
Debye Institute for NanoMaterials Science, Department of Inorganic Chemistry and Catalysis (Prof. K. P. de Jong, P. E. de Jongh); Utrecht University, The Netherlands
Research field: Nanomaterials for hydrogen storage
- **02.2005–07.2007** **Doctoral thesis in Physical Chemistry, summa cum laude**
Max-Planck-Institute for Colloids and Interfaces, Colloid Chemistry Department (Prof. M. Antonietti); Potsdam, Germany
Title: „Novel carbon materials with hierarchical porosity: Templating strategies and advanced characterization“
- **10.1998–08.2004** **Studies Materials Science, Dipl.-Ing.**
University of Stuttgart (Chemistry Department) und Max-Planck-Institute for Metals Research Stuttgart (now MPI for Intelligent Systems), Germany
07.2002-01.2003: Semester abroad (extracurricular), University of Auckland, New Zealand
02.2004-08.2004: Diploma thesis, Institute for Surface Chemistry, YKI (Campus KTH Stockholm), Sweden

Awards:

2014: Finals Science Award Electrochemistry by BASF und Volkswagen
2013: Award of the Justus-Liebig-University Giessen
2012: ADUC-Award (Working committee of the German professorate)
2007: Brian Kelly Award 2007 (British Carbon Group)

Memberships:

Gesellschaft Deutscher Chemiker GDCh (German Chemical Society); Verein Deutscher Ingenieure (German Engineering Society); Deutsche Bunsengesellschaft für Physikalische Chemie (German Bunsen Society for Physical Chemistry), Deutscher Hochschulverband (German Association of University Professors)

2015 – 2017: Member of the directorate of the Working group „Chemistry and Energy“ of the GDCh (www.gdch.de/chemie-und-energie).