Inexpensive and safe:

Magnesium or sodium instead of lithium

Researchers from Empa have teamed up with scientists from the University of Geneva, the Paul Scherrer Institute (PSI) and the Henryk Niewodniczański Institute of Nuclear Physics in Poland on a research project, “Novel Ionic Conductors”. The latest studies headed by Empa researcher Arndt Remhof (see also p.19) reveal that sodium and magnesium are just the ticket for developing new, pure solid-state batteries. Functional sodium-based prototype cells have already yielded highly promising results. What’s more, the electrolyte is non-toxic, non-flammable and remains chemically stable, even above 300 degrees, which makes it particularly safe. In parallel, the team headed by Hans Hagemann at the University of Geneva devised a more cost-effective technique for producing the new solid electrolytes.

Meanwhile, the team has also developed a solid electrolyte for magnesium. Previous research projects in this field can be counted on one hand. Although setting magnesium in motion is difficult, it is all the more interesting: it is light and available in abundance But more importantly, a magnesium ion has two positive charges, whereas lithium only has one. Essentially, this means that it stores almost twice as much energy in the same volume.

“These initial projects were primarily proof-of-concept studies,” says Empa researcher Elsa Roedern. “We are still a long way from having a complete and functional prototype, but we have taken the first important step towards achieving our goal.”

Low-cost and long-lasting:

Aluminum battery with graphite as a cathode

Kostiantyn Kravchykworks in the group of Maksym Kovalenko. This research group is based atat both ETH Zurich and in Empa’s Laboratory for Thin Films and Photovoltaics. The two researchers’ ambitious goal at the Empa branch is to make a battery out of the most common elements in the Earth’s crust – such as magnesium or aluminum. These metals offer a high degree of safety, even if the anode is made of pure metal. This also offers the opportunity to assemble the batteries in a very simple and inexpensive way and to rapidly upscale the production.

In order to make such batteries run, the liquid electrolyte needs to consist of special ions that do not crystallize at room temperature – i.e. form a kind of melt. The metal ions move back and forth between the cathode and the anode in this “cold melt”, encased in a thick mantle of chloride ions. Alternatively, large but lightweight organic anions, which are metal-free, could be used. This does come with a problem, though: where are these “thick” ions supposed to go when the battery is charged? What could be a suited cathode material? By way of comparison: in lithium ion batteries, the cathode is made of a metal oxide, which can easily absorb the small lithium cations during charging (see p.13). This does not work for such large ions, however. In addition, these large anions have an opposite charge to the lithium cations.

To solve the problem, Kovalenko’s team had a trick up their sleeves: the researchers turned the principle of the lithium ion battery upside down. In conventional Li-ion batteries, the anode (the negative pole) is made of graphite, the layers of which (in a charged state) contain the lithium ions (see p. XY).In Kovalenko’s battery, on contrary, the graphite is used as acathode (the positive pole). The thick anions are deposited in-between the graphene layers. In Kovalenko’s battery, the anode is made of metal.

Kravchyk made a remarkable discovery while searching for the “right” graphite: he found that waste graphite produced in steel production, referred to as ”kish graphite”, makes for a great cathode material. Natural graphite also works equally well – if it is supplied in coarse flakes and not ground too finely or into folded, non-flake shapes. The reason: the graphite layers are open at the flakes’ edges and the thick anions are thus able to slip into the structure more easily. The fine-ground graphite normally used in lithium ion batteries, however, is ill-suited for Kovalenko’s battery: by grinding the graphite particles, the layers become creased like crumpled-up paper. Only small lithium ions are able to penetrate this crumpled graphite, not the new battery’s thick anions.

The graphite cathode battery constructed from steel production “kish graphite” or raw, natural graphite flakes has the potential to become highly cost-effective. And if the first experiments are anything to go by, it is also long-lasting. For several months, a lab system survived thousands of charging and discharging cycles. “The aluminum chloride – graphite cathode battery could last decades in everyday household use,” explains Kravchyk and adds “similar demonstrations, but further increased battery voltages, without compromising capacities, and of even lighter elements are on the way and will offer further increase in energy densities from current 60 Wh kg-1 to above   
150 Wh kg-1”