Stars, jets and batteries: Multi-faceted magnetic phenomenon confirmed in the laboratory for the first time

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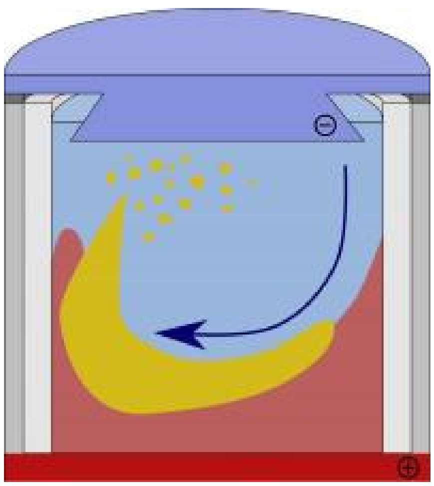

The Tayler instability also affects large-scale liquid metal batteries, which, in the future, could be used for renewable energy storage. Credit: HZDR

Magnetic instabilities play a crucial role in the emergence of black holes and other cosmic phenomena. At the Helmholtz- Zentrum Dresden-Rossendorf, confirmation of such a magnetic instability - the Tayler instability - was successfully achieved for the first time in collaboration with the Leibniz Institute for Astrophysics in Potsdam. The findings should be able to facilitate construction of large liquid-metal batteries, which are under discussion as cheap storage facilities for renewable energy.

The Tayler instability is being discussed by astrophysicists in reference to, among other things, the emergence of neutron-stars. Neutron stars, according to the theory, would have to rotate much faster than they actually do. The mysterious braking-effect has meanwhile been attributed to the influence of the Tayler instability, which reduces the rotation rate from 1,000 rps down to approximately 10 to 100 rps. Structures similar in appearance to the double-helix of DNA have been occasionally observed in cosmic jets, i.e. streams of matter, which emanate vertically out of the rotating accretion discs near black holes.

Liquid Metal Batteries – Energy Storage Facilities for the Future?

The magnetic phenomenon, observed for the first time in the laboratory at the Helmholtz-Zentrum Dresden-Rossendorf, was predicted in theory by R.J. Tayler in 1973. The Tayler instability always appears when a sufficiently strong current flows through an electrically conductive liquid. Starting from a certain magnitude, the interaction of the current with its own magnetic field creates a vortical flow structure. Ever since their involvement with liquid-metal batteries, HZDR scientists have been aware of the fact that this phenomenon can take effect not only in space but on earth as well. The future use of such batteries for renewable energy storage would be more complicated than originally thought due to the emergence of the Tayler instability during charging and discharging.

American scientists have developed the first prototypes and assume that the system could be easily scaled up. The HZDR physicist Dr. Frank Stefani is skeptical: "We have calculated that, starting at a certain current density and battery dimension, the Tayler instability emerges inevitably and leads to a powerful fluid flow within the metal layers. This stirs the liquid layers, and eventually a short circuit occurs." In the current edition of the "*Physical Review Letters*", the team directed by Stefani – together with colleagues from AIP led by Prof. Günther Rüdiger – reported on the first successful experiment to prove the Tayler instability in a liquid metal. Here a liquid alloy at room temperature consisting of indium, gallium and tin is deployed, through which a current as high as 8,000 amps is sent. In order to exclude other causes for the observed instability such as irregularities in conductivity, the researchers intentionally omitted the implementation of velocity sensors; instead, they used 14 highly-sensitive magnetic field sensors. The data collected indicate the growth rate and critical streaming effects of the Tayler instability, and these data remarkably correspond to the numerical predictions.

How liquid batteries work

In the context of the smaller American prototypes the Tayler instability does not occur at all, but liquid batteries have to be quite large in order to make them economically feasible. Frank Stefani explains: "I believe that liquid-metal batteries with a base area measured in square meters are entirely possible. They can be manufactured quite easily in that one simply pours the liquids into a large container. They then independently organize their own layer structure and can be recharged and discharged as often as necessary. This makes them economically viable. Such a system can easily cope with highly fluctuating loads." Liquid-metal batteries could thus always release excessive-supply current when the sun is not shining or the wind turbines are standing still.

The basic principle behind a liquid-metal battery is quite simple: since liquid metals are conductive, they can serve directly as anodes and cathodes. When one pours two suitable metals into a container so that the heavy metal is below and the lighter metal above, and then separates the two metals with a layer of molten salt, the arrangement becomes a galvanic cell. The metals have a tendency to form an alloy, but the molten salt in the middle prevents them from direct mixing. Therefore, the atoms of one metal are forced to release electrons. The ions thus formed wander through the molten salt. Arriving at the site of the other metal, these ions accept electrons and alloy with the second metal. During the charging process, this process is reversed and the alloy is broken up into its original components. In order to avoid the Tayler instability within big batteries – meaning a short circuit – Stefani suggests an internal tube through which the electrical current can be guided in reverse direction. This allows the capacity of the batteries to be considerably increased.

Cosmic magnetic fields in a laboratory experiment

Rossendorf researchers together with colleagues from Riga were equally successful in 1999 in their first-time-ever experimental proof of the homogenous dynamo-effect, which is responsible for the creation of the magnetic fields in both the earth and the sun. In a joint project with the Leibniz-Institut für Astrophysik Potsdam, it was possible in 2006 to recreate the so-called magneto-rotational instability in the laboratory, which enables the growth of stars and black holes. In the context of the future project DRESDYN, the researchers are currently preparing two large experiments with liquid sodium, with which the dynamo-effect is to be examined under the influence of precession, on the one hand, and a combination of magnetic instabilities on the other.

More information: Martin Seilmayer, Frank Stefani et al: Evidence for transient Tayler instability in a liquid metal experiment, in: *Physical Review Letters* 108, (2012), S. 244501, DOI: 10.1103/PhysRevLett.108.244501, link.aps.org/doi/10.1103/PhysRevLett.108.244501

Frank Stefani u.a.: How to circumvent the size limitation of liquid metal batteries due to the Tayler instability, in: *Energy Conversion and Management* 52 (2011), 2982-2986, DOI: 10.1016/j.enconman.2011.03.003.2