Realization of the building block of a Hund's metal

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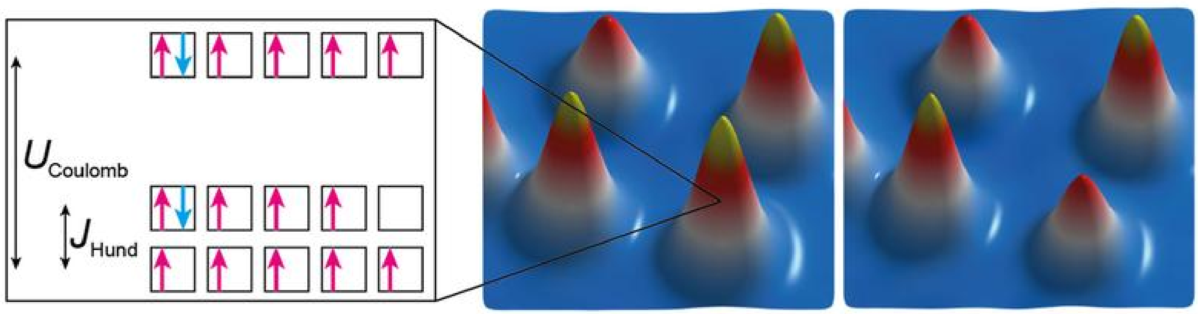

Left panel: Occupation of five electron orbitals (boxes) of an atom with five or six spin up (magenta colored arrows) or spin down (cyan colored arrows) electrons according to Hund's rules. For adding the sixth electron to the orbitals the energy of UCoulomb has to be paid due to the mutual electrostatic repulsion of the negatively charged electrons. However, if one of the electrons changes its spin from up to down, an energy also has to be paid (JHund). Center panel: Scanning tunneling microscope image of an iron atom (cone with red tip) and three iron-hydrogen-molecules (cones with yellow tips) on the surface of platinum. Right panel: The hydrogen of the bottom right iron-hydrogen-molecule has been removed by using the tip of the scanning tunneling microscope as a tool.

Understanding the physical mechanism for high temperature superconductors is a key step toward a room temperature superconductor. One characteristic aspect of these materials is the simultaneous presence of charges which fluctuate but also behave interact with magnets. In *Nature Nanotechnology*, Prof. Alex Khajetoorians from the Radboud University SPM lab is first author of the article, reports a new step in understanding these physical mechanisms. The international team have experimentally realized and studied the basic building block of an electron phase refered to as Hund's metal, which is an electronic phase commonly found in high-temperature superconductors.

The electronic properties of solid state materials used in today´s electronic devices are governed by the properties of the electrons in their basic constituents, the atoms. As already realized almost ninety years ago by German physicist Friedrich Hund (1896 - 1997) the occupation of the atomic orbitals with electrons (see Figure), which is governed by their mutual repulsion due to their negative charge, leads to a peculiar ordering of the spin of these electrons which, in layman's terms, is the sense of rotation of the spinning motion of the electrons: the electrons all tend to spin with the same sense of rotation, a rule of thumb which is called Hund's rule.

Hopping electrons

Since the electron current in electronic devices consists precisely of these electrons hopping from one atom to the neighboring atom, the consolidation of the spinning motion of electrons due to Hund's rule may have profound consequences for the electronic properties of the device. Metallic materials in which the electron motion is governed by Hund's rule are called Hund's metals. Indeed, theorists have argued that the electrons in a recently heavily studied class of superconductors behave like Hund's metals. In these materials, the electrons are hopping without any resistance and thus can flow through the material without any loss of energy.

Superconducting

So far, the superconducting electron flow does only survive at very low temperatures in these materials, and the corresponding devices therefore need to be cooled down to temperatures which are usually present in outer space only. The research community is therefore frantically searching for new materials, hopefully showing superconductivity under ambient conditions, which would solve some of the most pressing problems of the current era of information technology. However, for a target-oriented search of such materials, the electron properties of the basic constituents of Hund's metals need to be understood in detail, and this requirement was lacking so far.

Detailed understanding

A team of experimentalists and theoreticians of the University of Hamburg in cooperation with the University of Bremen, the Radboud University in Nijmegen and the Institute of Physics of the Czech Academy of Sciences have now experimentally realized such a basic constituent, which they coined Hund's impurity, by depositing iron-hydrogen-molecules on the surface of platinum (see Figure).

Tip as a tool

Moreover, they were able to intentionally remove hydrogen from such a Hund's impurity by using the tip of a scanning tunneling microscope as a tool. The team found that attaching or removing the hydrogen has profound consequences for the electronic properties of the Hund's impurity which they studied in great detail by comparing the experimental data to cutting edge computer simulations of the system. In a next step, the researchers hope to be able to couple many Hund's impurities by moving them closer, again by using the tip of a scanning tunneling microscope as a tool. This would enable a bottom-up assembly of a Hund's metal and its study hopefully will give relevant insight for the targeted development of novel high-temperature superconducting materials.

More information: "Tuning emergent magnetism in a Hund's impurity." *Nature Nanotechnology* (2015) DOI: 10.1038/nnano.2015.193

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