A thermoelectric materials emulator: Behavior of thermoelectric materials simulated

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Converting heat directly into power could be a major source of renewable energy. A novel approach to study this so called thermoelectricity may help to design new materials that are highly efficient. In an experiment with cold atoms trapped by lasers at ETH Zurich an international group of physicists precisely simulates the behavior of thermoelectric materials.

Discovered in the 19th century, thermoelectric materials have the remarkable property that heating them creates a small electrical current. But enhancing this current to a level compatible with the needs of modern technologies has revealed an extraordinary challenge for scientists of the last decades, despite important theoretical and experimental efforts. Now a novel approach could lead to substantial progress. At ETH Zurich the quantum optics group of Tilman Esslinger has created a key model to better understand the fundamental phenomena – "a thermoelectric material emulator".

It happened almost by chance: In Zurich group member Jean-Philippe Brantut and his colleagues had just set up a new experiment when visiting professor Antoine Georges from the Collège de France and University of Geneva had a look at the laboratory and was thrilled. "We didn't really think that in our experiment we could have efficient thermoelectricity", remembers Jean-Philippe Brantut, "but then he told us, that our setup was extremely interesting, something he and his colleagues Corinna Kollath (University of Bonn) and Charles Grenier (Ecole Polytechnique - CNRS) had been looking for for years."

Antoine Georges returned the very next day with a bunch of equations to convince the researchers that their experiment was an ideal way to study thermoelectricity. This triggered a fruitful collaboration between theorists in Paris, Bonn and Geneva and experimentalists in Zurich. The results of the international team are now presented in "*Science*".

From heat to electricity

The generation of electricity from heat usually involves burning a combustible, which then heats a fluid that brings a mechanical turbine into motion, which eventually produces an electrical current. In thermoelectric materials, the entire cycle that is performed by a heat engine occurs naturally. However, this effect is weak and for the materials known so far, the efficiency of thermoelectric generators is much smaller than that of electrical power plants.

At the moment the technology is mainly used for powering space probes like rover Curiosity exploring planet Mars or for small devices like self-powered sensors. But experts expect a wide range of possible applications in the future. In any engine there is a lot of heat wasted. Car companies are already testing different systems to recover energy from the exhaust gas expecting fuel savings of 3 to 5 %. Other consumer applications could be powering mobile phones or watches by body heat. A highly efficient thermoelectric material would be a major source of renewable energy, since heat is usually wasted by human activities.

At ETH the thermoelectric material emulator sits in a vacuum chamber made out of glass. Enclosed is a gas of Lithium atoms. Using lasers the gas is cooled down to very low temperatures close to absolute zero below minus 273 degree Celsius. Under these conditions the atoms in the gas behave like the electrons in a material. To simulate thermoelectricity the atoms are trapped by a set of laser beams. These create a spatially varying structure in which the atoms move like electrons in a material.

A big surprise

Using atoms trapped by lasers to simulate the behavior of complex materials is a well-tested method in Zurich. For the last ten years the ETH quantum optics group has studied superconductors or magnets, and even devices attached to leads and conducting currents. But the researcher didn't expect their new experiment to be such a big success. "With simple ingredients we simulate thermoelectricity that is as high in efficiency as in natural materials", explains Tilman Esslinger, Professor for Quantum Optics. "That was a big surprise."

Although it is still basic research the experiment may have a stronger impact on materials science than the team thought at the beginning. "Our experiment could serve as a kind of benchmark", says Jean-Philippe Brantut who will continue with his research founded by the Swiss National Science Foundation. In the next two years the team will try to bring the original experiment forward in order to study more complex systems. But already now the cold atom emulation shines a new light on thermoelectricity: comparison between theory and experiments, which are often hard for natural materials due to their high complexity, can now be precisely performed on the atoms. Even the effects of defects and disorder in materials have been successfully explored with the cold atom emulator.

With these new findings, the fundamental processes underlying thermoelectricity can be studied in a controlled way. This may help the simulation and design of thermoelectric materials in the future, in particular where experiments on natural materials still lack theoretical interpretation.

More information: J.P. Brantut, C. Grenier, J. Meineke, D. Stadler, S. Krinner, C. Kollath, T. Esslinger and A. Georges: A thermoelectric Heat Engine with Ultra-Cold Atoms, *Science*, Online Publication Oct 24, 2013, DOI: 10.1126/science.1242308

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