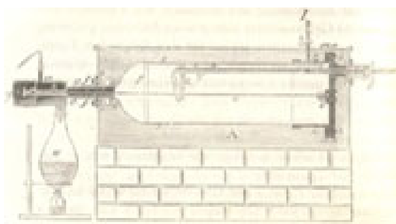
Bristol physicists break 150-year-old law

July 20 2011



Apparatus from the original 1853 paper in which the Wiedemann-Franz Law was first established

(PhysOrg.com) -- A violation of one of the oldest empirical laws of physics has been observed by scientists at the University of Bristol. Their experiments on purple bronze, a metal with unique one-dimensional electronic properties, indicate that it breaks the Wiedemann-Franz Law. This historic discovery is described in a paper published today in *Nature Communications*.

In 1853, two German physicists, Gustav Wiedemann and Rudolf Franz, studied the thermal conductivity (a measure of a system's ability to transfer heat) of a number of elemental metals and found that the ratio of the thermal to electrical conductivities was approximately the same for different metals at the same temperature.

The origin of this empirical observation did not become clear however until the discovery of the electron and the advent of quantum physics in the early twentieth century. Electrons have a spin and a charge. When they move through a metal they cause an electrical current because of the moving charge. In addition, the moving electrons also carry heat through the metal but now it is via both the charge and the spin. So a moving electron must carry both heat and charge: that is why the ratio does not vary from metal to metal.

For the past 150-plus years, the Wiedemann-Franz law has proved to be remarkably robust, the ratio varying at most by around 50 per cent amongst the thousands of metallic systems studied.

In 1996, American physicists C. L. Kane and Matthew Fisher made a theoretical prediction that if you confine electrons to individual atomic chains, the Wiedemann-Franz law could be strongly violated. In this one-dimensional world, the electrons split into two distinct components or excitations, one carrying spin but not charge (the spinon), the other carrying charge but not spin (the holon). When the holon encounters an impurity in the chain of atoms it has no choice but for its motion to be reflected. The spinon, on the other hand, has the ability to tunnel through the impurity and then continue along the chain. This means that heat is conducted easily along the chain but charge is not. This gives rise to a violation of the Wiedemann-Franz law that grows with decreasing temperature.

The experimental group, led by Professor Nigel Hussey of the Correlated Electron Systems Group at the University of Bristol, tested this prediction on a purple bronze material comprising atomic chains along which the electrons prefer to travel.

Remarkably, the researchers found that the material conducted heat 100,000 times better than would have been expected if it had obeyed the Wiedemann-Franz law like other metals. Not only does this remarkable capability of this compound to conduct heat have potential from a technological perspective, such unprecedented violation of the

Wiedemann-Franz law provides striking evidence for this unusual separation of the spin and charge of an electron in the one-dimensional world.

Professor Hussey said: “One can create purely one-dimensional atomic chains on substrates, or free-standing two-dimensional sheets, like graphene, but in a three-dimensional complex solid, there will always be some residual coupling between individual chains of atoms within the complex that allow the electrons to move in three-dimensional space.

“In this purple bronze, however, nature has conspired to limit this coupling to such an extent that the electrons are effectively confined to individual chains and thus creating a one-dimensional world inside the three-dimensional complex. The goal now is to find a way, for example, using pressure or chemical substitution, to increase the ability of the electrons to hop between adjacent chains and to study the evolution of the spin and charge states as the three-dimensional world is restored within the material.”

More information: ‘Gross violation of the Wiedemann-Franz law in a quasi-one-dimensional conductor’ by Nicholas Wakeham, et al. in Nature Communications

Provided by University of Bristol