Spinons -- confined like quarks

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The concept of confinement is one of the central ideas in modern physics. The most famous example is that of quarks which bind together to form protons and neutrons. Now Prof. Bella Lake from Helmholtz-Zentrum Berlin (Germany) together with an international team of scientists report for the first time an experimental realization and a proof of confinement phenomenon observed in a condensed matter system.

The concept of confinement states that in certain systems the constituent particles are bound together by an interaction whose strength increases with increasing particle separation. In the case of quarks they are held together by the so called strong force, a force that grows stronger with increasing distance. As a consequence individual particles like quarks don't exist in a free state and their properties can be observed only indirectly.

In the 1990s Prof Alexei Tsvelik from Brookhaven National Laboratory (USA) and co-workers predicted an analogous confinement process in systems known as spin-ladders found in condensed mat-ter physics. Experimental confirmation of this phenomenon has however only been achieved recently as described by Bella Lake et al in the current issue of the journal Nature Physics.

Spin-ladders consist of two chains of copper oxide chemically bonded together. This makes the electrons interact strongly with each other. A remarkable feature of a single chain is that the individual electrons, which behave as an elementary charge combined with magnetic spin, co-operate in concert to separate into independent spin and charge parts.

According to Bella Lake "The spin parts, known as spinons, have different properties to those of the original electrons. In fact they are analogous to quarks, the building blocks of protons and neutrons." On coupling two chains together to form a spin ladder the spin parts are found to recombine, but in a new way. "We have found, that excitations of individual chains, so called spinons, are confined in a similar way to that in which elementary quarks are held together", Bella Lake said.

The team of scientists have found evidence for the confinement idea by neutron scattering experiments on magnetic crystals of calcium cuprate (a copper-oxide material synthesized at the Leibniz Institute for Solid State and materials research in Dresden). The neutron experiments were performed using the MAPS spectrometer at the ISIS pulsed neutron source at Rutherford Appleton Laboratory, UK. Further the crystal and magnetic structure were investigated from neutron data collected on the E5 instrument at the research reactor BER II in Berlin.

The neutron scattering data show that the electrons essentially first split into spins and charges on the chains, then the spinons pair up again due to ladder effects. Prof Alan Tennant, the head of "Institute Complex Magnetic Materials" at HZB, explained: "The geometry of the ladder in fact plays a special role: the spinons always appear in pairs and when they move apart, they force a reorganisation of the intervening electrons that costs energy. The energy cost grows with separation - like a rubber band." According to Bella Lake "This strong pairing up of two spinons is like quarks binding together to form subatomic particles like hadrons and mesons."

Prof Alexei Tsvelik who developed the theoretical description explained "The formation of hadrons is well established on a qualitative level, but its quantitative aspects remain unresolved. It is unknown how to relate the theoretical parameters to the observed hadron masses. This is one of the reasons why condensed matter analogues are interesting. They provide examples of confinement for which detailed descriptions have been achieved."

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