Quantum Effects Make the Difference

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The atomic constituents of matter are never still, even at absolute zero. This consequence of quantum mechanics can result in continuous transition between different material states. Physicists at the Max Planck Institute for Chemical Physics of Solids have studied this phenomenon using ytterbium, rhodium and silicon at very low temperatures under the varying influence of a magnetic field.

Until now, it has been assumed that the properties of a transition of this nature can be described completely with the fluctuations of one parameter, in this case, magnetic order. However, the experiments that have now been published reveal, completely unexpectedly, an additional change to the electronic properties of the transition. It confirms again that quantum effects can result in phenomena that are inconceivable in classical physics. On the one hand, the results extend the general understanding of phase transitions and, on the other, are also relevant to complex systems, such as high-temperature superconductors. The research is published in journal *Science*.

A better understanding of complex interactions in metals is still one of the key challenges of modern physics. For example, the mechanism that results in the creation of high-temperature superconductivity is still not understood, more than 20 years after its discovery. Global interest has concentrated in recent years on the examination of quantum phase transitions - phase transitions that are dictated by the laws of quantum mechanics and on which new, complex behaviour can be examined under controlled conditions.

Unlike classical physics, quantum physics reveals astonishing and fascinating new phenomena. For example, atomic particles still move about at absolute zero - a consequence of Heisenberg's Uncertainty principle. These quantum fluctuations can result in transformations between different material states. If these phase transitions occur at absolute zero they are referred to as quantum-critical points, the study of which has delivered many surprising new findings in recent years.

The Dresden-based physicists examined the metal compound $YbRh_2Si_2$, which arranges itself in a specific way at very low temperatures of 0.07 Kelvin above absolute zero. If the arrangement is suppressed at extremely low temperatures with a small, externally-applied magnetic field, it is possible to examine the effects of the quantum critical point.

The compound $YbRh_2Si_2$, synthesised by the group working with Prof. Frank Steglich in Dresden, has been subjected to such intense and successful examination in recent years that researchers now view it as a model substance. Three years ago, the group caused a sensation with their observation of the splitting of the charge carrier in magnetic and current-conducting components. Subsequent examination of the Hall effect demonstrated a further property of the quantum critical point: a dramatic change of the Hall resistance indicates strong fluctuations of the Fermi volume i.e. the charge carrier density.

The current measurements of magnetisation and length changes when a magnetic field is applied to $YbRh_2Si_2$ gave the researchers proof of the fundamental difference of quantum phases compared to classical phase transitions, such as vaporisation at the boiling point of water. Whereas in the latter example, the physics can be described fully by the fluctuation of one order parameter, in this case the molecule density, there is an additional change to the properties at the quantum critical point in $YbRh_2Si_2$.

"Our measurements," says Phillip Gegenwart, who until recently headed the Low Temperatures competence group at the Max Planck Institute in Dresden and is now Professor at the 1st Physical Institute at the University of Göttingen, "prove the existence of another energy scale at the quantum critical point that cannot be explained by the fluctuations of magnetic order parameters".

The analysis shows that the additional energy scale can be traced back to a change in the electronic properties, or more precisely, a change of the Fermi volume. In classical phase transition, these effects do not occur - for example, water does not change its colour when vaporising.

The results show that unexpected behaviour, which cannot be reconciled with the current theoretical model, occurs repeatedly in the quantum world. This motivates theoreticians, such as the participating American researchers Qimiao Si from Rice University and Elihu Abrahams from Rutgers University, to search for new approaches in order to gain a better understanding of quantum systems. New theoretical models are needed to better understand the complicated behaviour of modern complex systems, such as the high-temperature superconductor.

Source: Max-Planck-Institute for Chemical Physics of Solids

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