Echos from the quantum world

A collaboration of experimental and theoretical groups lead by Johann Kroha of the Physikalische Institut at the University of Bonn and Manfred Fiebig of the Materials Department at the ETH shows that certain materials emit optical echo pulses that reveal direct information about the quantum-mechanical nature of these systems.

When we go from the meter scale of our daily life to the length scale of (sub-) atomic particles, the world becomes really strange --- quantum mechanics takes over! Particles no longer bounce off each other like solid billiard balls. Instead, they become fuzzy and may pass through each other without noticing. In fact, it is not even possible to say where exactly each particle is and how fast it is moving. Cooling a system promotes its quantum-mechanical behavior. In a hot system, particles have a lot of energy and whizz around in a classical way. Towards absolute zero temperature (where zero is -273°C on the Celsius scale), this energy goes away. Nevertheless, the particles do not come to a standstill, because now quantum-mechanical motion, the aforementioned built-in fuzziness, takes over.

Under the dominance of such quantum-mechanical fluctuations, a material may develop rather peculiar properties. For example, its electrical resistivity may drop to zero, a state called "superconducting". In a superconductor, electrical currents flow without energy loss and heat waste -- a very useful material property. Although quantum mechanics is generally the realm of low temperatures, such a superconducting state can live on towards higher temperatures, as long as the quantum motion dominates over the classical motion. Thus, the seemingly abstract low-temperature quantum world can become very relevant to real-life device applications.

But how do we gain access those exotic quantum states? For example, one can measure magnetic, electric or other physical properties as function of temperature and use the deviations from the classical behavior to draw conclusions on the processes going on in the quantum world. Or we use high-energy radiation and blow our system into pieces, attempting to derive the quantum-mechanical properties from the observed debris. Not surprisingly, the indirectness of these approaches leads to controversial interpretations of the nature of such a quantum state.

In a theory-experiment collaboration involving (among others) the Physikalische Institut (Johann Kroha) at the University of Bonn and the Laboratory of Multifunctional Ferroics (Manfred Fiebig) at the Eidgenössische Technische Hochschule (ETH) Zürich, a much more direct look at the quantum world has been developed. They excite the quantum state with a light pulse at extremely low energy, an energy range denoted as terahertz regime. (Terahertz radiation is familiar from airports where it is used in full-body scanners.) The terahertz light pulse jiggles the quantum many-body state just slightly, without destroying its quantum mechanical nature, called coherence. In return to this non-destructive excitation the system emits a time-delayed terahertz pulse, a visual "echo", whose shape and time delay bear direct information about the stability and composition of the quantum state. This method is especially sensitive to the interactions between electrons or between atomic-scale magnets (so-called spins) in a material. Up to now, the researchers have applied it to a certain class of materials, called heavy-fermion compounds, where they have been able to uncover peculiar properties of quantum-mechanically dominated phase transitions. However, the method may have much wider use. In a bold transfer from the quantum world to every-day life, it is as if we would shine a camera flash on a person, and minutes later the person emits another light pulse which, for example, carries information about the person's state of health.

You can read the more scientific information on this experiment in the current issue of *Nature Physics* at www.nature.com/articles/s41567-018-0228-3.

Christoph Wetli, Shovon Pal, Johann Kroha, Kristin Kliemt, Cornelius Krellner, Oliver Stockert, Hilbert von Löhneysen, Manfred Fiebig: *Time-Resolved Collapse and Revival of the Kondo State Near a Quantum Phase Transition*, Nature Physics (2018), DOI 10.1038/s41567-018-0228-3.