Weyl particles detected in strongly correlated electron systems

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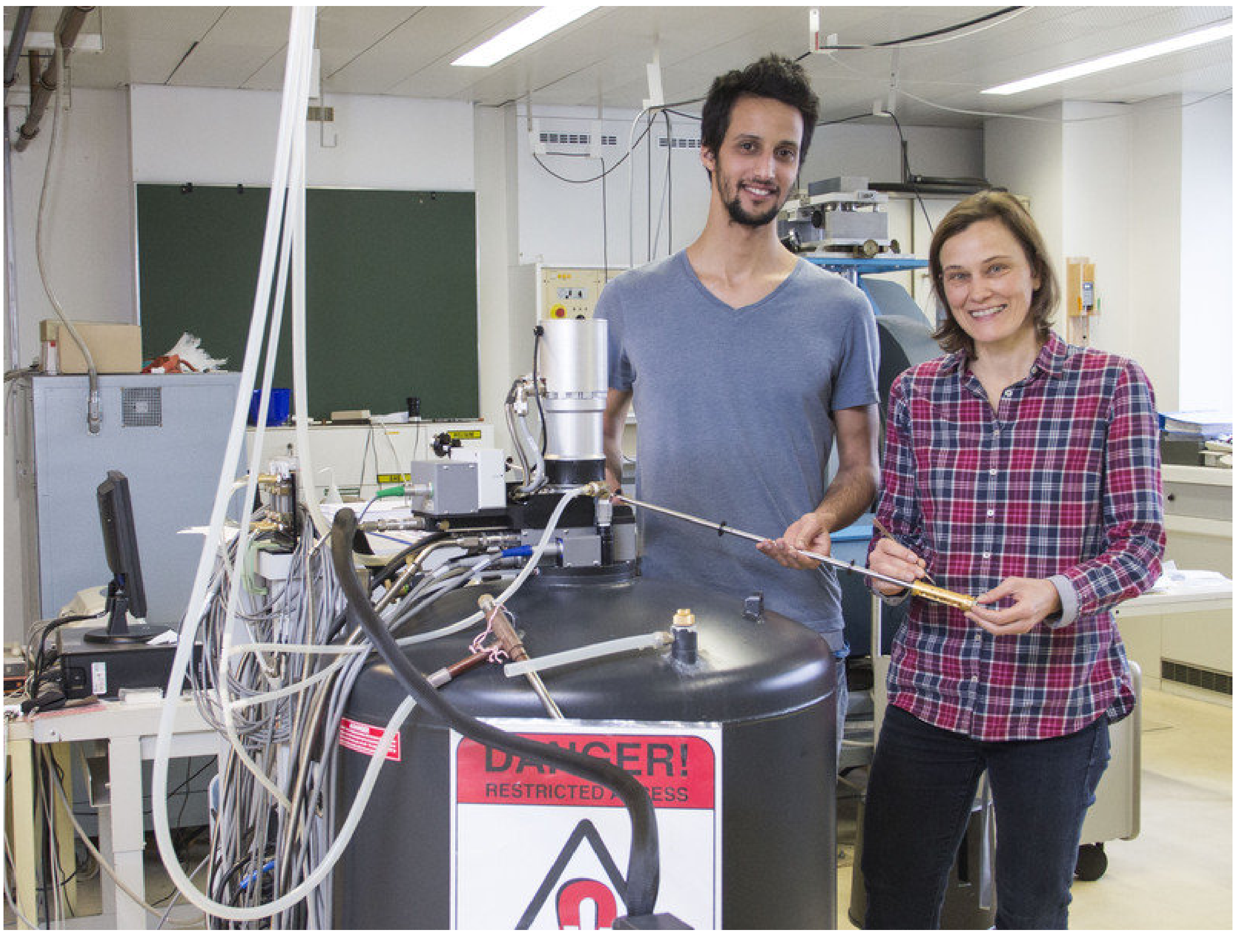

Sami Dzsaber and Prof. Silke Bühler-Paschen. Credit: Rice University

At TU Wien recently, particles known as 'Weyl fermions' were discovered in materials with strong interaction between electrons. Just like light particles, they have no mass but nonetheless they move extremely slowly.

There was great excitement back in 2015, when it was first possible to measure these 'Weyl fermions' – outlandish, massless particles that had been predicted almost 90 years earlier by German mathematician, physician and philosopher, Hermann Weyl. Now, once again, there has been a breakthrough in this field of research, with researchers at TU Wien being the first to successfully detect Weyl particles in strongly correlated electron systems – that is, materials where the electrons have a strong interaction with each other. In materials like this, the Weyl particles move extremely slowly, despite having no mass. The discovery should now open the door to an entirely new area of physics, and enable hitherto unimagined material-physical effects.

Quasiparticles: only possible in a solid state

After physician Paul Dirac had arrived at his Dirac equation in 1928, which can be used to describe the behaviour of relativistic electrons, Hermann Weyl found a particular solution for this equation – namely for particles with zero mass, or 'Weyl fermions'. The neutrino was originally thought to be such a massless Weyl particle, until it was discovered that it does indeed have mass. The mysterious Weyl fermions were, in fact, detected for the first time in 2015; they turned out not to be free particles like the neutrino, which can move through the universe independently from the rest of the world, but rather 'quasiparticles' in a solid state.

"Quasiparticles are not particles in the conventional sense, but rather excitations of a system consisting of many interacting particles," explains Prof. Silke Bühler-Paschen from the Institute of Solid State Physics at TU Wien. In some sense, they are similar to a wave in water. The wave is not a water molecule, rather it is based on the movement of many molecules. When the wave moves forward, this does not mean that the particles in the water are moving at that speed. It is not the water molecules themselves, but their excitation in wave form that spreads.

However, although the quasiparticles in a solid state are the result of an interplay between many particles, from a mathematical perspective they can be described similarly to a free particle in a vacuum.

Credit: Rice University

A "light speed" of just 100 m/s

The remarkable thing about the experiment, conducted by Sami Dzsaber and other members of the research group for quantum materials led by Silke Bühler-Paschen at TU Wien, is the fact that the Weyl particles were discovered in a strongly correlated electron system. This type of material is of particular interest for the field of solid state physics: their electrons cannot be described as separate from one another; they are strongly interconnected and it is precisely this that lends them extraordinary properties, from high-temperature superconductivity through to new kinds of phase transitions.

"The strong interactions in such materials usually lead, via the so-called Kondo effect, to particles behaving as if they had an extremely large mass," explains Sami Dzsaber. "So it was astonishing for us to detect Weyl fermions with a mass of zero in this particular type of material." According to the laws of relativity, free massless particles must always spread at light speed. This is, however, not the case in solid states: "Even though our Weyl fermions have no mass, their speed is extremely low," says Bühler-Paschen. The solid state lends them its own fixed 'light speed' to a certain extent. This is lower than 1000 m/s, i.e. only around three millionth of the speed of light in a vacuum. "As such, they are even slower than phonons, the analogue to the water wave in the solid state, and this makes them detectable in our experiment."

In search of new effects

At the same time as these measurements were being made at TU Wien, theoretical investigations were being carried out under the leadership of Qimiao Si at Rice University in Texas – Bühler-Paschen was a visiting professor there at the time – which looked at the question of how these Weyl fermions could even exist in a strongly correlated material. This combination of experiment and theory thus produced a conclusive picture of the new effect, which is now enabling new research to be carried out.

The newly detected quasiparticles are interesting for a number of reasons: "Even if Weyl fermions were initially found in other materials, it is much easier to control the effect in our strongly correlated materials ," says Silke Bühler-Paschen. "Due to their low energy, it is significantly easier to influence them using parameters such as pressure or an external magnetic field." This means the Weyl fermions can also be used for technological applications.

The Weyl fermions are only dispersed in the material to a minimal extent, meaning they can conduct electrical current almost without loss – this is of great significance for electronics. They are also likely to be extremely interesting to the field of spintronics, an advancement in electronics where not only the electrical charge of the particles but also their spin is used. Weyl fermions will be of interest here due to their particularly robust spin. The particle should also be especially well suited for use in quantum computers. "This is a really exciting development," says Bühler-Paschen.

More information: Hsin-Hua Lai et al. Weyl–Kondo semimetal in heavy-fermion systems, *Proceedings of the National Academy of Sciences* (2017). DOI: 10.1073/pnas.1715851115

S. Dzsaber et al. Kondo Insulator to Semimetal Transformation Tuned by Spin-Orbit Coupling, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.118.246601

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