Quantum dance draws unexpected guests

It was always thought to be restricted to everyday types, with no magnetic sorts allowed in the door. But the quantum dance party's guest list just got bigger.

In a paper that appeared Friday in the online edition of *Physical Review Letters*, University of Florida physicists report that — contrary to expectations — electrons in magnetic metals exhibit the same quantum tendencies as their counterparts in ordinary metals at extremely low temperatures. Rather than acting like particles that move independently of each other, they behave as waves, influencing each other's paths and trajectories.

The effect is a bit like a roomful of dancers performing, arm-in-arm, a frenetic set piece.

The electrons push and pull each other around, then return to the spot where they started off, as though completing a choreographed finale.

Call it "the wave."

"They move around and have these elastic collisions, and then they remember they are waves, and they end up back in the same place they started," said Art Hebard, a UF professor of physics and one of four co-authors of the paper.

It is an accepted fact in condensed matter physics, the branch of physics that studies the physical properties of matter, that electrons in ordinary metals can act as waves. This behavior is seen at extremely low temperatures of hundreds of degrees below zero, when random collisions are reduced to a minimum. "Quantum" refers to the electrons' schizophrenic ability to behave both as the independent particles they are, and as waves, with each electron's "ripple" affecting those of neighboring electrons and vice versa.

Physicists had long suspected that electrons in magnetic metals would not share this trait, since magnetic fields would interfere or, in Hebard's words, "scramble up" the peaks and troughs in the waves.

Add the magnetic field, they thought, and it would be like Judas Priest crashing a waltz. All the dancers would scatter.

But Hebard and the other scientists found to their surprise that the dancing electrons in magnetic iron kept up their routines, seemingly oblivious to the change in atmospherics.

With the aid of a one-of-a-kind apparatus called Sample Handling in Vacuum, or SHIVA, they grew extremely thin films of iron — films thousands of times thinner than a human hair. The stainless steel apparatus maintains an ultra high vacuum to guard against humid air, which would cause them to rust immediately and become useless. The physicists relied on such thin films because they could observe the quantum effects much more easily in near two-dimensional samples, rather than the three dimensions that would come with thicker samples.

The scientists then wielded multiple mechanical arms within the $180,000 machine — the SHIVA name is intentionally reminiscent of the many-armed Indian god — to transfer the films to a test chamber. There, at a temperature of minus 452 degrees Fahrenheit, they submitted the films to tests, including applying magnetic fields as strong as 140,000 times the earth's magnetic field.

The end result: The physicists observed a "signature response" as electrical currents flowed through the films, giving away the fact that the electrons were doing the quantum dance.

"What I find most remarkable about this work is that it shows that electrons do not really have one-to-one encounters," said Dmitrii Maslov, a UF professor of physics. "The 'collective' versus 'one-to-one' interactions are now being seen in many materials of practical interest, and Prof. Hebard's study gives an important contribution to this emerging field."

Hebard said physicists believe the electrons in the magnetic iron continue to act like waves because of the presence of magnetic interactions that previously were not considered relevant.

The findings have no immediate practical application. But with computer chips and other modern electronics based on thin metals and how they interact, that could change in the future. "We're asking fundamental questions about magnets," Hebard said. "And magnetic materials are used in many applications."

The lead author of the *Physical Review Letters* paper is Partha Mitra, who performed the experimental research as a doctoral student at UF and who is now a postdoctoral associate at The Pennsylvania State University. The other authors are UF doctoral student Rajiv Misra, Khandker Muttalib, a UF faculty member in theoretical physics, and Peter Wolfle, also a theoretical physicist, of the Universitat Karlsruhe in Germany.

Source: University of Florida