Researchers develop new insight into the enigmatic realm of 'strange metals'

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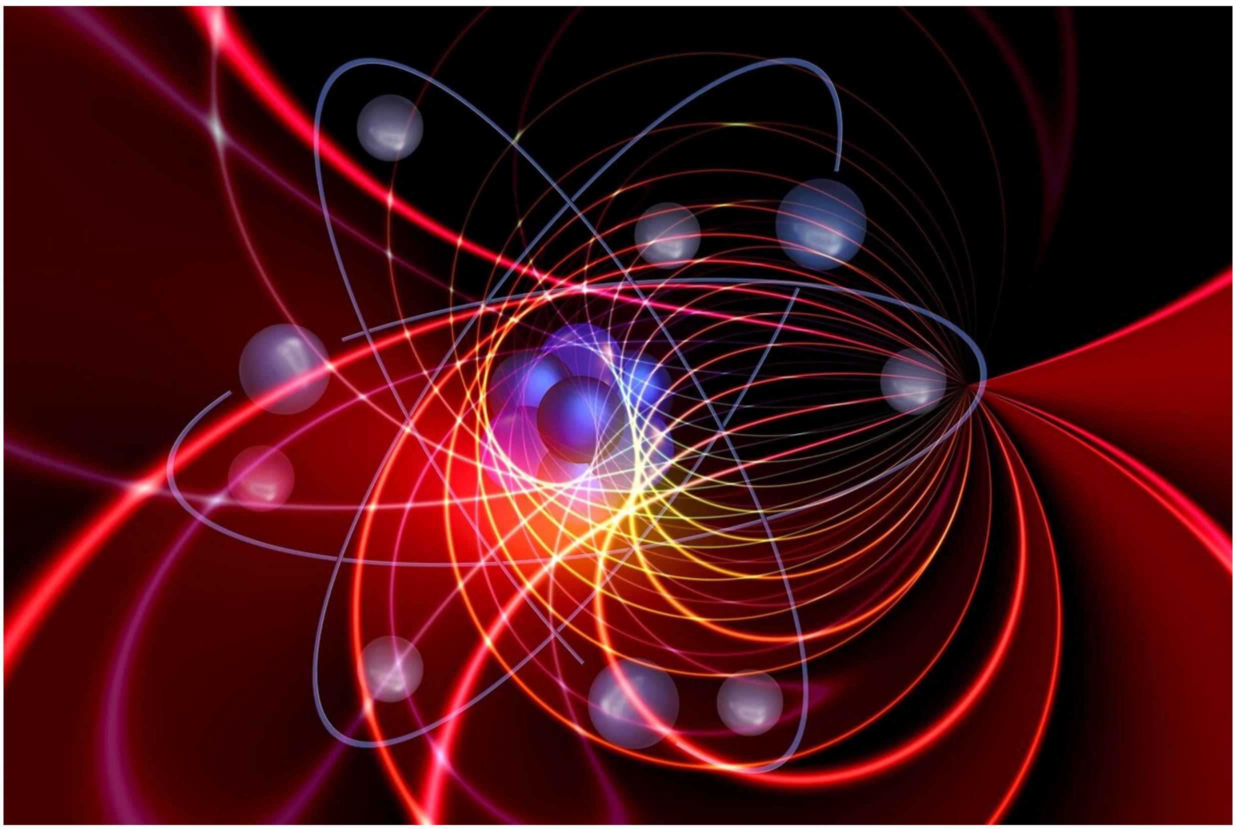

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The behavior of so-called "strange metals" has long puzzled scientists—but a group of researchers at the University of Toronto may be one step closer to understanding these materials.

Electrons are discrete, subatomic particles that flow through wires like molecules of water flowing through a pipe. The flow is known as electricity, and it is harnessed to power and control everything from lightbulbs to the Large Hadron Collider.

In quantum matter, by contrast, electrons don't behave as they do in normal materials. They are much stronger and the four fundamental properties of electrons—charge, spin, orbit and lattice—become intertwined, resulting in complex states of matter.

"In quantum matter, electrons shed their particle-like character and exhibit strange collective behavior," says condensed matter physicist Arun Paramekanti, a professor in the U of T's department of physics in the Faculty of Arts & Science. "These materials are known as non-Fermi liquids, in which the simple rules break down."

Now, three researchers from the university's department of physics and Centre for Quantum Information & Quantum Control (CQIQC) have developed a theoretical model describing the interactions between subatomic particles in non-Fermi liquids. The framework expands on existing models and will help researchers understand the behavior of these "strange metals."

Their research was published in the journal *Proceedings of the National Academy of Sciences (PNAS)*. The lead author is physics Ph.D. student Andrew Hardy, with co-authors Paramekanti and post-doctoral researcher Arijit Haldar.

"We know that the flow of a complex fluid like blood through arteries is much harder to understand than water through pipes," says Paramekanti. "Similarly, the flow of electrons in non-Fermi liquids is much harder to study than that in simple metals."

Hardy adds, "What we've done is construct a model, a tool, to study non-Fermi liquid behavior. And specifically, to deal with what happens when there is symmetry breaking, when there is a phase transition into a new type of system."

"Symmetry breaking" is the term used to describe a fundamental process found in all of nature. Symmetry breaks when a system—whether a droplet of water or the entire universe—loses its symmetry and homogeneity and becomes more complex.

For example, a droplet of water is symmetrical no matter its orientation—rotate it in any direction and it looks the same. But its symmetry is broken when it undergoes a phase transition and freezes into an ice crystal. As a snowflake, it is still symmetrical but only in six different directions.

The same thing happened with all subatomic particles and forces following the Big Bang. With the explosive birth of the cosmos, all particles and all the forces were the same, but symmetry breaking immediately transformed them into the manifold particles and forces we see in the cosmos today.

"Symmetry breaking in non-Fermi liquids is much more complicated to study because there isn't a comprehensive framework for working with non-Fermi liquids," says Hardy. "Describing how this symmetry breaking occurs is hard to do."

In a non-Fermi liquid, interactions between electrons become much stronger when the particles are on the brink of symmetry breaking. As with a ball poised at the top of a hill, a very gentle nudge one way or the other will send it in opposite directions.

The new research provides insight into these transitions in non-Fermi liquids and could lead to new ways to tune and control the properties of quantum materials. While still a serious challenge for physicists, the work is important for the new quantum materials that could shape the next generation of quantum technology.

These technologies include high-temperature superconductors that achieve zero resistance at temperatures much closer to room temperature, making them much more practical and useful. There are also graphene devices—technologies based on one-atom thick layers of carbon atoms which have a myriad of electronic applications.

"Quantum materials exhibit both unusual electron flow and complex types of symmetry breaking which can be controlled and tuned," Hardy says. "It is exciting for us to be able to make theoretical predictions for such systems which can be tested in new experiments in the lab."

More information: Andrew Hardy et al, Nematic phases and elastoresistivity from a multiorbital non-Fermi liquid, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2207903120

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