Newly discovered type of 'strange metal' could lead to deep insights
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Scientists understand quite well how temperature affects electrical conductance in most everyday metals like copper or silver. But in recent years, researchers have turned their attention to a class of materials that do not seem to follow the traditional electrical rules. Understanding these so-called "strange metals" could provide fundamental insights into the quantum world, and potentially help scientists understand strange phenomena like high-temperature superconductivity.

Now, a research team co-led by a Brown University physicist has added a new discovery to the strange metal mix. In research published in the journal Nature, the team found strange metal behavior in a material in which electrical charge is carried not by electrons, but by more "wave-like" entities called Cooper pairs.

While electrons belong to a class of particles called fermions, Cooper pairs act as bosons, which follow very different rules from fermions. This is the first time strange metal behavior has been seen in a bosonic system, and researchers are hopeful that the discovery might be helpful in finding an explanation for how strange metals work—something that has eluded scientists for decades.

"We have these two fundamentally different types of particles whose behaviors converge around a mystery," said Jim Valles, a professor of physics at Brown and the study's corresponding author. "What this says is that any theory to explain strange metal behavior can't be specific to either type of particle. It needs to be more fundamental than that."

Strange metals

Strange metal behavior was first discovered around 30 years ago in a class of materials called cuprates. These copper-oxide materials are most famous for being high-temperature superconductors, meaning they conduct electricity with zero resistance at temperatures far above that of normal superconductors. But even at temperatures above the critical temperature for superconductivity, cuprates act strangely compared to other metals.

As their temperature increases, cuprates' resistance increases in a strictly linear fashion. In normal metals, the resistance increases only so far, becoming constant at high temperatures in accord with what's known as Fermi liquid theory. Resistance arises when electrons flowing in a metal bang into the metal's vibrating atomic structure, causing them to scatter. Fermi-liquid theory sets a maximum rate at which electron scattering can occur. But strange metals don't follow the Fermi-liquid rules, and no one is sure how they work. What scientists do know is that the temperature-resistance relationship in strange metals appears to be related to two fundamental constants of nature: Boltzmann's constant, which represents the energy produced by random thermal motion, and Planck's constant, which relates to the energy of a photon (a particle of light).

"To try to understand what's happening in these
strange metals, people have applied mathematical
to understand
black holes," Valles said. "So there's some very
fundamental physics happening in these materials."

Of bosons and fermions

In recent years, Valles and his colleagues have
been studying electrical activity in which the charge
carriers are not electrons. In 1952, Nobel Laureate
Leon Cooper, now a Brown professor emeritus of
physics, discovered that in normal superconductors
(not the high-temperature kind discovered later),
electrons team up to form Cooper pairs, which can
glide through an atomic lattice with no resistance.
Despite being formed by two electrons, which are
fermions, Cooper pairs can act as bosons.

"Fermion and boson systems usually behave very
differently," Valles said. "Unlike individual fermions,
 bosons are allowed to share the same quantum
state, which means they can move collectively like
water molecules in the ripples of a wave."

In 2019, Valles and his colleagues showed that
Cooper pair bosons can produce metallic behavior,
meaning they can conduct electricity with some
amount of resistance. That in itself was a surprising
finding, the researchers say, because elements of
quantum theory suggested that the phenomenon
shouldn't be possible. For this latest research, the
team wanted to see if bosonic Cooper-pair metals
were also strange metals.

The team used a cuprate material called yttrium
barium copper oxide patterned with tiny holes that
induce the Cooper-pair metallic state. The team
cooled the material down to just above its
superconducting temperature to observe changes
in its conductance. They found, like fermionic
strange metals, a Cooper-pair metal conductance
that is linear with temperature.

The researchers say this new discovery will give
theorists something new to chew on as they try to
understand strange metal behavior.

"It's been a challenge for theoreticians to come up
with an explanation for what we see in strange
metals," Valles said. "Our work shows that if you're

Ultimately, a theory of strange metals could have
massive implications. Strange metal behavior could
hold the key to understanding high-temperature
superconductivity, which has vast potential for
things like lossless power grids and quantum
computers. And because strange metal behavior
seems to be related to fundamental constants of
the universe, understanding their behavior could
shed light on basic truths of how the physical world
works.

More information: Jie Xiong, Signatures of a
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