Physicists turn toward heat to study electron spin

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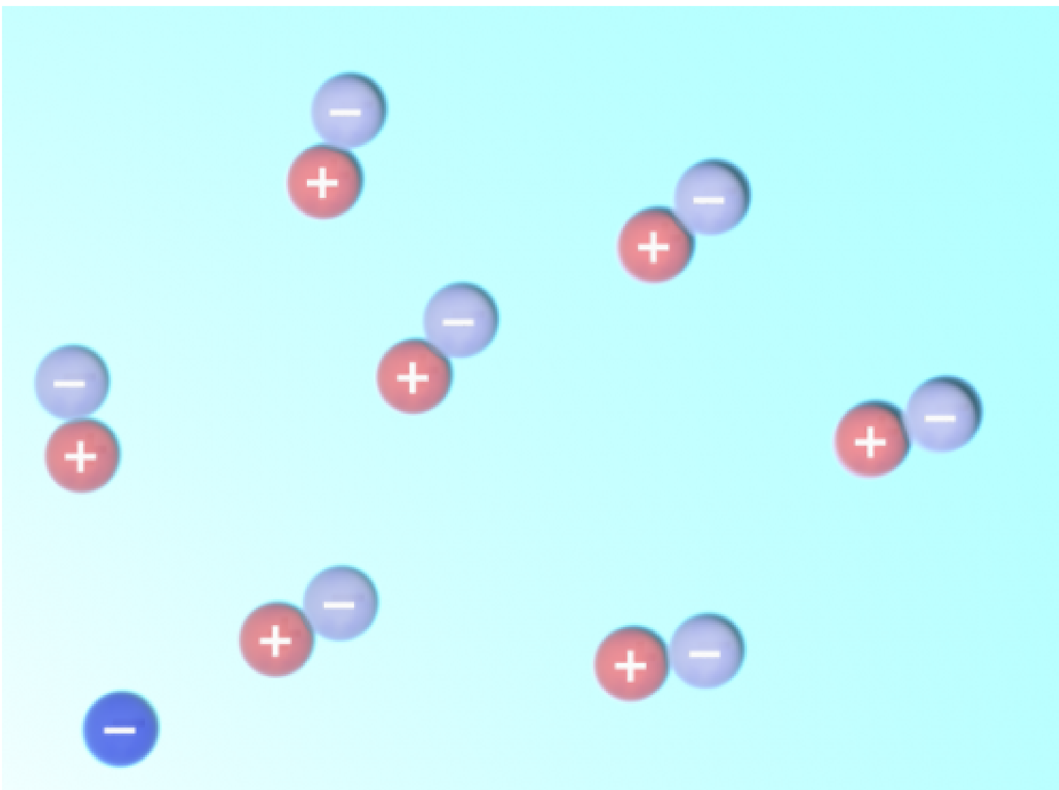

A schematic depiction of virtual electron–positron pairs appearing at random near an electron (at lower left). Credit: RJHall/Wikipedia

The quest to control and understand the intrinsic spin of electrons to advance nanoscale electronics is hampered by how hard it is to measure tiny, fast magnetic devices.

Applied physicists at Cornell offer a solution: using heat, instead of light, to measure magnetic systems at short length and time scales.

Researchers led by Greg Fuchs, assistant professor of applied and engineering physics, detail this new way to directly measure magnetic moments and how it may be used to break fundamental limits of spatial resolution that are imposed in purely optical magnetic measurements. Such a breakthrough, if perfected, could lead to a novel tabletop magnetic measurement technique and new, nanoscale electronic devices based on electrical spin, rather than charge. Their technique, which they call TRANE (Time-Resolved Anomalous Nernst Effect) microscopy, is detailed in the journal *Nature Communications*.

Why the interest in electron spin? In physics, electron spin is the well-established phenomenon of electrons behaving like a quantum version of a spinning top, and the angular momentum of these little tops pointing "up" or "down." An emerging field called spintronics explores the idea of using electron spin to control and store information using very low power. Technologies like nonvolatile magnetic memory could result with the broad understanding and application of electron spin. Spintronics, the subject of the 2007 Nobel Prize in Physics, is already impacting traditional electronics, which is based on the control of electron charge rather than spin.

"Direct imaging is really hard to do," Fuchs said. "Devices are tiny, and moving really fast, at gigahertz frequencies. We're talking about nanometers and picoseconds."

Scientists have been unable to directly image magnetic motion in nanoscale spintronic devices without hugely expensive X-ray sources at national facilities. In their own labs, the best they could do was infer magnetic properties from electrical measurements.

The current state of the art that is accessible to ordinary laboratories is to use optical polarization microscopy to make magnetic measurements. The technique relies on analysis of reflected light from short laser pulses to gain information about magnetization. Unfortunately, the physics of optical diffraction limit how small a laser spot can be used, which ultimately limits the resolution of the technique.

In their paper, the Cornell researchers show that by using heat, the spatial resolution of their measurements isn't limited by optical focusing, and their results suggest a method to achieve vastly improved spatial resolution. They also show that heat-based microscopy doesn't sacrifice the time resolution that they need for applications. They were able to observe that the heat diffusion time can be picoseconds, allowing them to measure magnetization in gigahertz ranges.

"This is an entirely new approach to studying magnetization, by using pulsed heating," said co-first author Jason Bartell, graduate student in the field of applied physics. "It's an exciting area to start looking at and seeing what new types of studies we can do." For instance, Bartell and colleagues will be looking at using tricks from nanophotonics, such as fabricating gold antennae to excite thermal excitations confined to nanoscale dimensions.

The paper is titled "Toward a table-top microscope for nanoscale magnetic imaging using picosecond thermal gradients."

More information: "Towards a table-top microscope for nanoscale magnetic imaging using picosecond thermal gradients." *Nature Communications* 6, Article number: 8460 DOI: 10.1038/ncomms9460

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