Tiny magnetic tremors unlock exotic superconductivity

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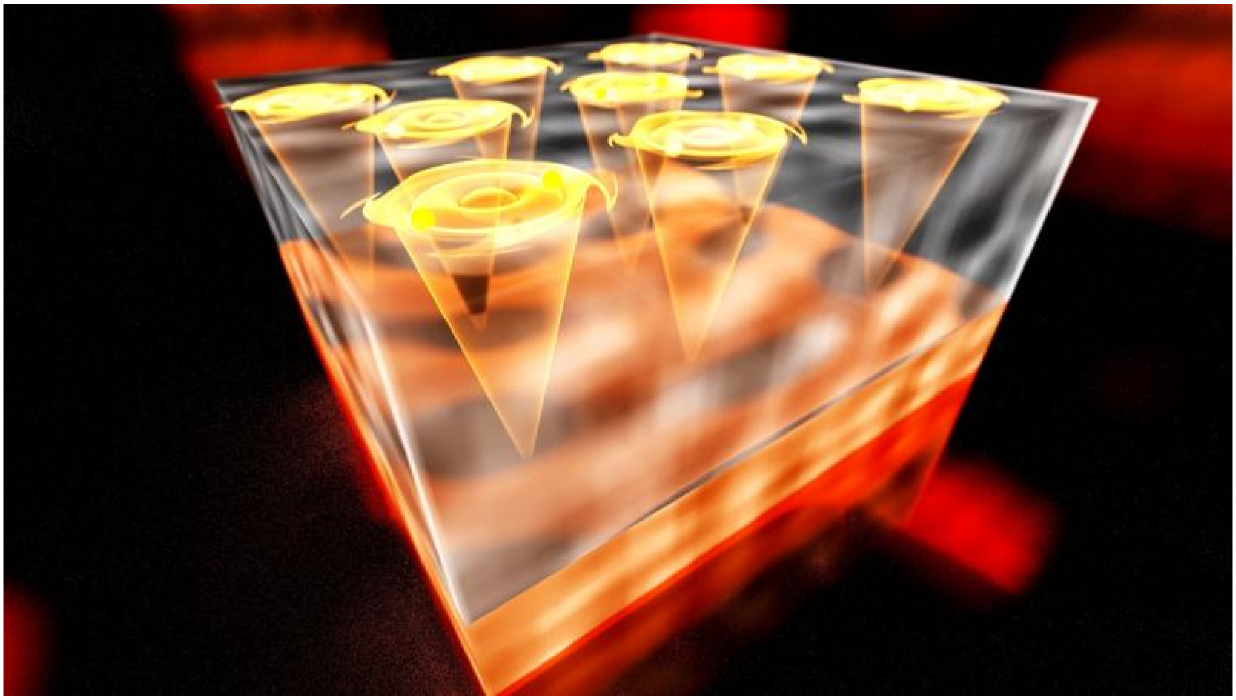

Artistic rendering of exotic 2D superconductivity in a material made from nanolayers of nickel (bottom layer) and bismuth (top layer). Magnetic fluctuations from the nickel layer allow electrons to pair up on the surface of bismuth. These pairs move losslessly in a phenomenon called superconductivity. Credit: E. Edwards

Deep within solids, individual electrons zip around on a nanoscale highway paved with atoms. For the most part, these electrons avoid one another, kept in separate lanes by their mutual repulsion. But vibrations in the atomic road can blur their lanes and sometimes allow the tiny particles to pair up. The result is smooth and lossless travel, and it's one way to create superconductivity.

But there are other, less common ways to achieve this effect. Scientists from the University of Maryland (UMD), the University of California, Irvine (UCI) and Fudan University have now shown that tiny magnetic tremors lead to superconductivity in a material made from metallic nano-layers. And, beyond that, the resulting electron pairs shatter a fundamental symmetry between past and future. Although the material is a known superconductor, these researchers provide a theoretical model and measurement, which, for the first time, unambiguously reveals the material's exotic nature.

In quantum materials, breaking the symmetry between the past and the future often signifies unconventional phases of matter. The nickel-bismuth (Ni-Bi) sample studied here is the first example of a 2-D material where this type of superconductivity is intrinsic, meaning that it happens without the help of external agents, such as a nearby superconductor. These findings, recently published in *Science Advances* , make Ni-Bi an appealing choice for use in future quantum computers. This research may also assist scientists in their search for other similarly strange superconductors.

Mehdi Kargarian, a postdoctoral researcher at UMD and a co-author of the paper, explains that even after a century of study, superconductivity remains a vibrant area of research. "It is a rather old problem, so it is surprising that people are still discovering types of superconductivity in the lab that are unprecedented," Kargarian says, adding that there are typically two questions scientists ask of a new superconductor. "First, we want to understand the underlying electron pairing—what is causing the superconductivity," he says. "The second thing, related to applications, is to see if superconductivity is possible at higher temperatures."

Superconductors, particularly the exotic types, largely remain shackled to unwieldy cryogenic equipment. Scientists are searching for ways to push superconducting temperatures higher, thus making these materials easier to use for things like improved electricity distribution and building quantum devices. In this new research, the team tackles Kargarian's first question and the material hints at a positive outlook for the second question. Its exotic superconductivity, although still cryogenic, occurs at a higher temperature compared to other similar systems.

Ni-Bi superconductivity was first observed in the early 1990s. But later, when Fudan University scientists published studies of an ultrapure, ultra-thin sample, they noticed something unusual happening.

The strangeness starts with the superconductivity itself. Bismuth alone is not a superconductor, except under extraordinarily low temperatures and high pressure—conditions that are not easy to achieve. Nickel is magnetic and not a superconductor. In fact, strong magnets are known to suppress the effect. This means that too much nickel destroys the superconductivity, but a small amount induces it.

UMD theorists proposed that fluctuations in nickel's magnetism are at the heart of this peculiar effect. These tiny magnetic tremors help electrons to form pairs, thus doing the work performed by vibrations in conventional superconductors. If there is too much nickel, magnetism dominates and the effect of the fluctuations diminishes. If there is too much bismuth, then the top surface, where superconductivity takes place, is too far away from the source of magnetic fluctuations.

The goldilocks zone occurs when a twenty-nanometer-thick bismuth layer is grown on top of two nanometers of nickel. For this layer combination, superconductivity happens at around 4 degrees above absolute zero. While this is about as cold as deep space, it is actually quite lab-friendly and reachable using standard cryogenic equipment.

The idea that magnetic fluctuations can promote superconductivity is not new and dates back to the end of the 20th century. However, most earlier examples of such behavior require strict operating conditions, such as high pressure. The researchers explain that Ni-Bi is different because straightforward cooling is enough to achieve this type of exotic superconductivity, which breaks time symmetry.

The researchers employed a highly customized apparatus to search for signs of the broken symmetry. Light should rotate when reflected from samples that have this property. For Ni-Bi, the expected amount of light rotation is tens of nanoradians, which is about 100 billionths of a tick on a watch face. Jing Xia, a co-author of the paper and a professor at UCI, has one of the only devices in the world capable of measuring such an imperceptible light rotation.

In order to measure this rotation for Ni-Bi, light waves are first injected into one end of a single special-purpose optical fiber. The two waves travel through the fiber, as if on independent paths. They hit the sample and then retrace their paths. Upon return, the waves are combined and form a pattern. Rotations of the light waves—from, say, symmetry breaking—will show up in the analyzed pattern as small translations. Xia and his colleagues at UCI measured around 100 nanoradians of rotation, confirming the broken symmetry. Importantly, the effect appeared just as the Ni-Bi sample became a superconductor, suggesting that the broken time symmetry and the appearance of superconductivity are strongly linked.

This form of superconductivity is rare and researchers say that there is still no recipe for making it happen. But, as Xia points out, there is guidance in the math behind the electron behavior. "We know mathematically how to make electron pairs break time-reversal symmetry," Xia says. Practically, how do you achieve this formulaically? That is the million-dollar question. But my instinct is that when you do get magnetic fluctuation-mediated superconductivity, like in this material, then it is highly likely you get break that symmetry."

More information: Xinxin Gong et al. Time-reversal symmetry-breaking superconductivity in epitaxial bismuth/nickel bilayers, *Science Advances* (2017). DOI: 10.1126/sciadv.1602579

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