# A 'breath of nothing' provides a new perspective on superconductivity

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Zero electrical resistance at room temperature? A material with this property, i.e. a room temperature superconductor, could revolutionize power distribution. But so far, the origin of superconductivity at high temperature is only incompletely understood. Scientists from Universität Hamburg and the Cluster of Excellence "CUI: Advanced Imaging of

Matter" have succeeded in observing strong evidence of superfluidity in a central model system, a two-dimensional gas cloud for the first time. The scientists report on their experiments in the journal *Science*, which allow to investigate key issues of high-temperature superconductivity in a very well-controlled model system.

There are things that aren't supposed to happen. For example, water cannot flow from one glass to another through the glass wall. Surprisingly, quantum mechanics allows this, provided the barrier between the two liquids is thin enough. Due to the quantum mechanical tunneling effect, particles can penetrate the barrier, even if the barrier is higher than the level of the liquids. Even more remarkably, this current can even flow when the level on both sides is the same or the current must flow slightly uphill. For this, however, the fluids on both sides must be superfluids, i.e. they must be able to flow around obstacles without friction.

This striking phenomenon was predicted by Brian Josephson during his doctoral thesis, and it is of such fundamental importance that he was awarded the Nobel Prize for it. The current is driven only by the wave nature of the superfluids and can, among other things, ensure that the superfluid begins to oscillate back and forth between the two sides—a phenomenon known as Josephson oscillations.

The Josephson effect was first observed in 1962 between two superconductors. In the experiment—in direct analogy to the water flow without level difference—an electric current could flow through a tunnel contact without an applied voltage. With this discovery, an impressive proof had been provided that the wave nature of matter in superconductors can be observed even at the macroscopic level.

Now, for the first time, the scientists in Prof. Henning Moritz's group have succeeded in observing Josephson oscillations in a two-dimensional

(2-D) Fermi gas. These Fermi gases consist of a "breath of nothing," namely a gas cloud of only a few thousand atoms. If they are cooled to a few millionth of a degree above absolute zero, they become superfluid. They can now be used to study superfluids in which the particles interact strongly with each other and live in only two dimensions—a combination that seems to be central to high-temperature superconductivity, but which is still only incompletely understood.

"We were amazed at how clearly the Josephson oscillations were visible in our experiment. This is clear evidence of phase coherence in our ultracold 2-D Fermi gas," says first author Niclas Luick. "The high degree of control we have over our system has also allowed us to measure the critical current above which the superfluidity breaks down."

"This breakthrough opens up many new opportunities for us to gain insights into the nature of strongly correlated 2-D superfluids," says Prof. Moritz, "These are of outstanding importance in modern physics, but very difficult to simulate theoretically. We are pleased to contribute to a better understanding of these quantum systems with our experiment."

**More information:** Niclas Luick et al, An ideal Josephson junction in an ultracold two-dimensional Fermi gas, *Science* (2020). DOI: 10.1126/science.aaz2342

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