Narrowing down the “hidden symmetry” of an enigmatic superconductor
Probing the essence of superconductivity in ruthenium oxides

Abstract

By applying force to an object and inducing strain, its electrical properties can be significantly altered. In recent years, techniques for controlling strain in samples using devices based on piezoelectric elements, by adjusting the voltage applied to the piezo elements, have advanced dramatically. In particular, uniaxial strain can change a material’s symmetry and thereby produce large changes in its properties. A representative example is the unconventional superconductor and quantum material ruthenium oxide Sr_2RuO_4, in which the temperature at which superconductivity occurs is known to double under uniaxial strain.

A research group led by Giordano Mattoni, program-specific assistant professor, Thomas Johnson, JSPS postdoctoral fellow, and Yoshiteru Maeno, affiliated professor and Toyota Riken Fellow, at the Toyota RIKEN–Kyoto University Collaboration Center (TRiKUC), Institute for Advanced Study, Kyoto University, has achieved new progress in understanding the long-standing mystery of the nature of the superconducting state in Sr_2RuO_4 by adopting a new approach that applies shear strain to superconductors. It had previously been established that the superconducting transition temperature of ruthenium oxides shows large changes in response to homogeneous strain and uniaxial strain. In this study, it was revealed that shear strain has almost no effect on the superconducting transition, indicating that the behavior cannot be explained by an exotic two-component superconducting state. The method newly developed in this research, which uses shear strain to narrow down the intrinsic nature of material properties, is expected to be applicable to studies of a wide variety of quantum materials. These research results have been published online in the international scientific journal *Nature Communications* on 16th December, 2025.

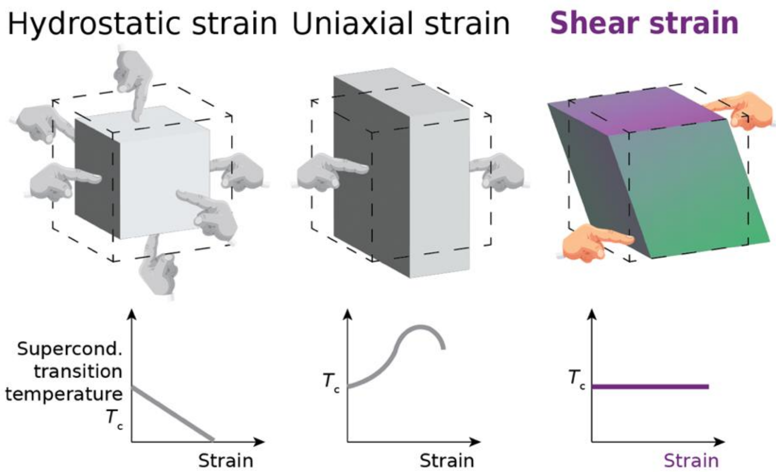

Figure 1: T_c of Sr_2RuO_4 remains unchanged under shear strain. In Sr_2RuO_4, hydrostatic pressure is known to suppress the superconducting transition temperature T_c, whereas uniaxial pressure enhances T_c. In this study, an important and intriguing result for understanding the superconducting mechanism was obtained: shear strain does not change T_c. *Image credit: Giordano Mattoni*

1. Background

Superconductivity in the ruthenium oxide Sr_2RuO_4 was discovered in 1994 by Maeno and colleagues (currently Affiliated Professor at the Toyota RIKEN–Kyoto University Collaboration Center). Because it exhibits unconventional superconductivity characteristic of quantum materials, Sr_2RuO_4 has become an important subject of research in condensed matter physics. However, the symmetry of its superconducting state remains unresolved, and has been the subject of long-standing debate among researchers. In particular, muon and ultrasound experiments have suggested the possibility of an exotic superconducting state described by a two-component order parameter. In contrast, specific-heat measurements and experiments under uniaxial strain have indicated a one-component superconducting state, and the controversy between these interpretations has persisted. Therefore, experiments that directly address the core of this problem have long been awaited.

2. Research Methods and Results

To resolve the debate over whether the superconducting order parameter is one-component or two-component, the research group developed a new approach that directly applies *shear strain*, which couples to a two-component superconducting order parameter, rather than relying on combinations of results from experiments under hydrostatic and uniaxial strain. Using this method, they successfully performed high-precision measurements of changes in the superconducting transition temperature.

The team also developed a new technique to precisely apply different types of shear strain to ultrathin Sr_2RuO_4 crystals and compare their superconducting responses. The measurements revealed that the superconducting transition temperature is almost unaffected by shear strain. This result is inconsistent with theoretical predictions for two-component superconductivity. Instead, it indicates that the unusual behaviour of Sr_2RuO_4 needs to be explained within the framework of a one-component superconducting state. These findings provide a new direction for future theoretical and experimental studies toward a complete understanding of superconductivity in this material.

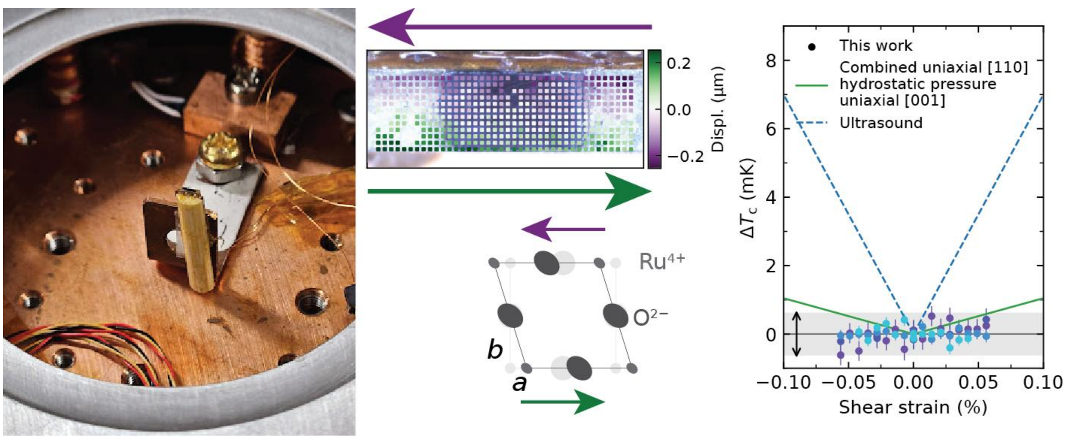

Figure 2: A device for "visualizing" shear strain. Optical imaging results of the shear displacement applied to an Sr_2RuO_4 crystal, together with a schematic illustration showing how the lattice is displaced. The right panel compares the T_c measured in this study, which remains unchanged under shear strain, with previous results (green line) obtained by combining pressures applied along the [110] direction, hydrostatic pressure, and pressure along the [001] direction, as well as predictions from ultrasonic measurements (blue dashed line). *Image credit: Giordano Mattoni*

3. Impact and Future Plans

The shear-strain control technique developed in this study can be applied not only to Sr_2RuO_4 but also to other materials in which multicomponent superconductivity has been suggested, such as UPt_3. Moreover, this approach is not limited to superconductors and is expected to be useful for studies of magnetic materials, dielectrics, and other systems. As such, it has the potential to provide new insights across a broad range of condensed matter physics. In addition, understanding how discrepancies with results from muon and ultrasonic experiments arise remains an important open question. Addressing this issue will require further experimental investigations and theoretical analyses.

4. Research Project

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Glossary

- **Superconducting transition temperature (T_c):** The temperature at which a material enters the superconducting state with zero electrical resistance.
- **Shear strain:** A type of deformation in which parts of a crystal are displaced laterally relative to each other.

Researcher's Comment

Experiments probing the "hidden symmetry" of the ruthenium oxide Sr_2RuO_4 using shear strain required the application of highly precise strain to extremely thin crystals, involving continuous trial and error. When we first confirmed that the superconducting transition temperature changed very little, we felt that we had made a meaningful contribution to a long-standing debate. This method can be applied to studies of other quantum materials and is expected to open new paths toward a deeper understanding of quantum materials.
(Giordano Mattoni)

Paper Title and Authors

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Authors:
Giordano Mattoni, Thomas Johnson, Atsutoshi Ikeda, Shubhankar Paul, Jake Bobowski, Manfred Sigrist, Yoshiteru Maeno

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