Unraveling the mechanism of superconductivity strong against magnetic field realized in uranium compound

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Superconductivity is a practical phenomenon expected to be utilized as a wide range of application, such as superconducting (SC) power transmission and a linear motor car, because electric resistance goes to completely zero and a superconductor completely repel a magnetic field. However, Superconductivity requires a very low temperature. Moreover superconductivity is usually weak against magnetic field and easily destroyed by a magnetic field. These properties are obstacles in practical application of superconductivity in a wider field. For that reason, many researches are still exploring superconductors that possesses a higher transition temperature and a capability to withstand a stronger magnetic field.

Superconductivity of the uranium compound URu_2Si_2, on which we are actively researching recent years, has the property of being extremely strong to a magnetic field, and therefore to clarify its mechanism has been an important subject. However, handling this compound is strictly restricted due to its radio activity, and the experiments with sufficient accuracy has not been done so far. Therefore, by utilizing the facility of JAEA, we synthesized the ultra-pure single crystal of URu_2Si_2 and formed it into a shape suitable for measurement. As a result, we successfully measured the nuclear magnetic resonance in the SC state of uranium compounds at cryogenic temperatures with the highest precision in the world. Nuclear magnetic resonance is a technique for microscopically examining electrons surrounding nuclei through magnet-like property of nuclei (nuclear spins), and enables us to explore electronic states of superconductivity.

Electrons in material have a magnet-like property called an electron spin, and each electron spin is randomly oriented in the normal state. When an attractive force dominates between two electrons at low temperatures, the electrons make pairs called the Cooper pairs with their spins coupled to be antiparallel directions and become SC states by creating aligned wave-like states (Fig. 1). When a strong magnetic field is applied to Cooper pairs, it is known that electron spin reorients to the direction of the magnetic field, so that superconductivity breaks accompanied by breaking of Cooper pairs (Fig. 2 a). In the URu_2Si_2 case, however, by using the high resolution nuclear magnetic resonance measurements we have demonstrated that the electron spin of URu_2Si_2 is uniaxially oriented and its uniaxial orientation is robust with respect to the magnetic field (strong spin anisotropy). This strong spin anisotropy of URu_2Si_2 in SC state was experimentally probed for the first time (Fig. 2 b).

This achievement is expected to deepen the understanding of superconductivity and provides guidelines for exploring more practical superconductors. In addition, such an exotic electronic state of the very strong spin anisotropy is thought to originates from uranium, which contains many electrons, and thus our findings are expected to contribute to the progress of fundamental material physics and of fundamental nuclear science.

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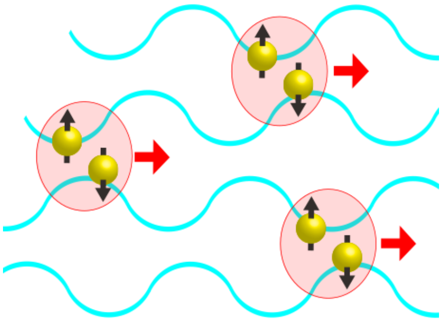

Fig.1 Schematic image of superconductivity. Electrons (yellow spheres) in material have a magnet-like character called electron spin (black arrow). A pair called Cooper pair is formed by directing this electron spin in antiparallel direction, and it flows like a wave, resulting superconducting state.

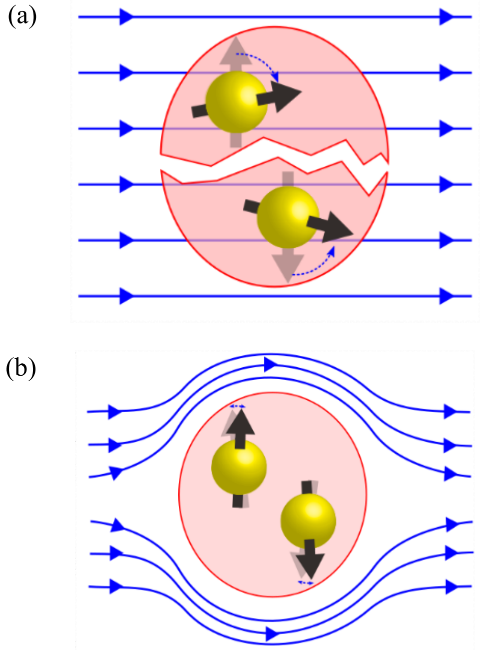

Fig.2 Cooper pairs' behaviours when magnetic field (blue solid line) is applied.
(a) Normally, electron spin reorients to the magnetic field direction, and the Cooper pair breaks.
(b) In the uranium compound URu_2Si_2, electron spin is aligned to one direction, and it does not tilt in the magnetic field, so Cooper pairs are maintained even under a strong magnetic field.

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References

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