Superconductivity of mercury

January 21, 2023

In news– A century later, a clearer picture of how mercury becomes a superconductor was discovered.

About Superconductivity mercury-

- **In 1911, Heike Kamerlingh Onnes discovered superconductivity in mercury.**

- Onnes had invented a way to cool materials to absolute zero – the lowest temperature possible.
- **Using his technique, he found that at a very low temperature, called the threshold temperature, solid mercury offers no resistance to the flow of electric current.** It was a watershed moment in the history of physics.
- Later, **scientists classified mercury as a conventional superconductor,** meaning its superconductivity could be explained by the concepts of **Bardeen-Cooper-Schrieffer (BCS) theory.**
- But while **scientists have used BCS theory to explain superconductivity in various materials, they have never fully understood how it operates in mercury itself,** the oldest superconductor.
- The reason probably is because it seemed like the behaviour of mercury had been completely understood and the discovery of new superconducting materials with greater critical temperatures became the focus of attention.
- Even when computational tools capable of solving the superconductivity problem became available, they were not used to try to understand the behaviour of mercury.

The BCS picture-

- Imagine a material with a grid of atoms. The nuclei, or ions, are fixed in a pattern whereas their electrons move through the material, conducting electricity.

- **In the BCS theory, superconductivity emerges in three steps.**

- First, an electron exerts an “impulsive force” on the lattice.
- Second, the atomic lattice releases vibrational energy when its atoms oscillate in their positions; physicists call packets of this energy ‘phonons’ (like packets of electromagnetic energy are called photons).
- Third, the phonons exert a force on the electrons that encourages them to overcome their mutual repulsion and pair up (over a relatively large distance). This last bit happens when the material below is its threshold temperature.
- These electron pairs move through the material like water in a stream – a state that is forbidden for individual electrons.
- This stream-like movement isn’t easily scattered by the grid of ions, thus diminishing resistance to their flow. This is the BCS picture of superconductivity.
- The researchers found that certain previously excluded factors allowed their estimates to improve significantly on previous attempts. One was spin-orbit coupling (SOC): the way an electron’s energy is affected by the relationship between its spin and its momentum.
- Including SOC gave the group a better view of the phonons’ energies and explain why mercury has such a low threshold temperature (approx. –270º C).
- This isn’t the first time a study has accounted for the effects of SOC on superconductivity.
- There are a few works that included **spin-orbit coupling in mercury**, focusing on [the impact of] the relativistic effects on structural properties and melting temperature.
- **‘Relativistic’ refers to the effects that arise as a**

result of the special theory of relativity: e.g. a particle’s mass increases as it accelerates.

- But it is the first time the relativistic effects have been included on the dynamical and superconducting properties of mercury.
- According to the researchers, mercury represents one of the rare cases in which the relativistic effects have such important effects on the dynamical properties of a system… without SOC, mercury is dynamically unstable.
- **Another factor was the Coulomb repulsion** (a.k.a. ‘like charges repel’) between two electrons in each pair.
- **The superconducting state is determined by a balance between an attractive interaction between electrons, mediated by phonons,** and the repulsive Coulomb interaction (electrostatic repulsion between negative charges).
- The electrons are able to overcome their repulsion and pair up because the phonons have very low frequency and the electrons have a relatively higher frequency, allowing the interacting electrons to avoid each other in time.
- The group found that, in mercury, one electron in each pair occupied a higher energy level than the other, a detail that reduced the Coulomb repulsion and nurtured superconductivity.
- **In these and other ways, the group has reported that it can explain how mercury becomes a superconductor below its threshold temperature.**
- In a testament to their strategy, they were able to work out a theory that predicted mercury’s threshold temperature to within 2.5% of its observed value.
- Their methods and findings signal that we could have missed similar anomalous effects in other materials, leading to previously undiscovered ones that can be exploited for new or better real-world applications.

Note:

Mercury is a chemical element with the symbol Hg and atomic number 80. It is also known as quicksilver and was formerly named hydrargyrum from the Greek words hydor and argyros.