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Superconductivity

By: Yakovitskiy Stanislav

Levitation of a magnet above a high temperature superconductor illustrating the Meissner Effect.

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A physical state of matter that occurs at low temperatures with two key characteristics: Zero Resistivity. Expulsion(вытеснение) of Magnetic Flux(поток) from within the material. (Meissner Effect)

What is Superconductivity?

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In 1911 Kamerlingh Onnes measured the electrical conductivity of pure metals ([mercury](https://en.wikipedia.org/wiki/Mercury_(element)), and later [tin](https://en.wikipedia.org/wiki/Tin) and [lead](https://en.wikipedia.org/wiki/Lead)) at very low temperatures. Some scientists, such as [William Thomson](https://en.wikipedia.org/wiki/William_Thomson,_1st_Baron_Kelvin) (Lord Kelvin), believed that [electrons](https://en.wikipedia.org/wiki/Electron) flowing through a [conductor](https://en.wikipedia.org/wiki/Electrical_conductor) would come to a complete halt or, in other words, metal resistivity would become infinitely large at absolute zero. Others, including Kamerlingh Onnes, felt that a conductor's electrical resistance would steadily decrease and drop to nil. [Augustus Matthiessen](https://en.wikipedia.org/wiki/Augustus_Matthiessen) said that when the temperature decreases, the metal conductivity usually improves or in other words, the electrical resistivity usually decreases with a decrease of temperature. Onnes was awarded the NobEl prize

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In Onnes’s original experiment, the resistivity of mercury(ртуть) abruptly(резко) disappeared at ~ 4.2 K. The Meissner Effect was discovered by W. Meissner and R. Ochsenfeld in 1933. First successful theory proposed by Bardeen, Cooper, and Schrieffer in 1957.

Discovery & Theory of Superconductivity

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BCS Theory

Electrons form pairs called Cooper Pairs. Electrons move in resonance with lattice (решетка) vibrations.

The complete microscopic theory of superconductivity was finally proposed in 1957 by [John Bardeen](https://en.wikipedia.org/wiki/John_Bardeen), [Leon N. Cooper](https://en.wikipedia.org/wiki/Leon_Cooper), and [Robert Schrieffer](https://en.wikipedia.org/wiki/John_Robert_Schrieffer). This [BCS theory](https://en.wikipedia.org/wiki/BCS_theory) explained the superconducting current as a superfluid of [Cooper pairs](https://en.wikipedia.org/wiki/Cooper_pair), pairs of electrons interacting through the exchange of [phonons](https://en.wikipedia.org/wiki/Phonons). For this work, the authors were awarded the [Nobel Prize in Physics](https://en.wikipedia.org/wiki/Nobel_Prize_in_Physics) in 1972. The BCS theory was set on a firmer footing in 1958, when [Nikolay Bogolyubov](https://en.wikipedia.org/wiki/Nikolay_Bogolyubov) showed that the BCS wavefunction, which had originally been derived from a variational argument, could be obtained using a canonical transformation of the electronic [Hamiltonian](https://en.wikipedia.org/wiki/Hamiltonian_(quantum_mechanics)). In 1959, [Lev Gor'kov](https://en.wikipedia.org/wiki/Lev_Gor%27kov) showed that the BCS theory reduced to the Ginzburg-Landau theory close to the critical temperature.

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Cooper Pairs

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Critical Temperature

At some critical temperature Tc, resistivity abruptly drops to zero. Electrons flow freely through the lattice(решетка) structure of the material.

Resistivity of superconducting Tin(олово) drops to zero at a critical temperature, whereas the normal conductor platinum does not.

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Meissner Effect

The Meissner effect (or Meissner–Ochsenfeld effect) is the expulsion of a magnetic field from a superconductor during its transition to the superconducting state when it is cooled below the critical temperature. The German physicists Walther Meissner and Robert Ochsenfeld discovered this phenomenon in 1933 by measuring the magnetic field distribution outside superconducting tin and lead samples. The samples, in the presence of an applied magnetic field, were cooled below their superconducting transition temperature, whereupon the samples cancelled nearly all interior magnetic fields. They detected this effect only indirectly because the magnetic flux is conserved by a superconductor: when the interior field decreases, the exterior field increases. The experiment demonstrated for the first time that superconductors were more than just perfect conductors and provided a uniquely defining property of the superconductor state. The ability for the expulsion effect is determined by the nature of equilibrium formed by the neutralization within the unit cell of a superconductor.

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Critical Field

The Meissner effect only works within a range. If the applied field is too large, magnetic flux does penetrate the superconductor, and superconductivity is lost.

A superconductor can be Type I, meaning it has a single critical field, above which all superconductivity is lost and below which the magnetic field is completely expelled from the superconductor; or Type II, meaning it has two critical fields, between which it allows partial penetration of the magnetic field through isolated points. These points are called vortices. Furthermore, in multicomponent superconductors it is possible to have a combination of the two behaviours. In that case the superconductor is of Type-1.5. As we see at the graph field depends on a temperature

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Integrated circuits in computers Would not lose power like semiconductor based circuits Currently the cost of superconducting computers is too high.

Higher temperature superconductors may reduce cost Magnetic Levitation of Trains (Maglev)Electromagnetic system; EMS (attractive maglev) Unstable equilibrium (равновесие) Electrodynamics system; EDS (repulsive maglev) More stable Requires expensive superconducting magnets Future Contributions

Electrical generators and motors Decrease power losses.  
Lighter superconducting magnets could replace heavy iron cores to create larger generators

Superconducting transmission lines Energy saved due to no resistive loss.

Scientific research Particle accelerators Higher temperature magnets lower costs since liquid nitrogen costs less than liquid helium Ceramic superconductors produce larger magnetic fields

Future Contributions cont.