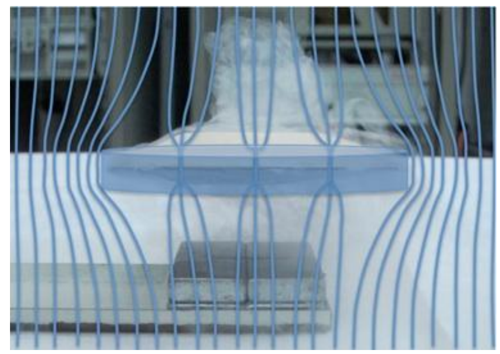
# DEVIL PHYSICS
# BADDEST CLASS ON CAMPUS

**SUPPLEMENTAL READING**

**QUANTUM LEVITATION**

***From: http://www.quantumlevitation.com/levitation/The_physics.html***

## The physics behind



We start with a single crystal *sapphire* wafer and coat it with a thin (~1µm thick) ceramic material called yttrium barium copper oxide (YBa2Cu3O7-x ). The ceramic layer has no interesting magnetic or electrical properties at room temperature. However, when cooled below -185ºC (-301ºF) the material becomes a superconductor. It conducts electricity without resistance, with no energy loss. Zero.

Superconductivity and magnetic field do not like each other. When possible, the superconductor will expel all the magnetic field from inside. This is the Meissner effect. In our case, since the superconductor is extremely thin, the magnetic field DOES penetrates. However, it does that in discrete quantities (this is quantum physics after all! ) called flux tubes.

Inside each magnetic flux tube superconductivity is locally destroyed. The superconductor will try to keep the magnetic tubes pinned in weak areas (e.g. grain boundaries). Any spatial movement of the superconductor will cause the flux tubes to move. In order to prevent that the superconductor remains "trapped" in midair.

***From: http://en.wikipedia.org/wiki/Meissner_effect***

## Meissner effect

From Wikipedia, the free encyclopedia

The **Meissner effect** is the expulsion of a magnetic field from a superconductor during its transition to the superconducting state. The German physicists Walther Meissner and Robert Ochsenfeld discovered the phenomenon in 1933 by measuring the magnetic field distribution outside superconducting tin and lead samples.[1] The samples, in the presence of an applied magnetic field, were cooled below what is called their superconducting transition temperature. Below the transition temperature the samples canceled nearly all magnetic fields inside. They detected this effect only indirectly; because the magnetic flux is conserved by a superconductor, when the interior field decreased the exterior field increased. The experiment demonstrated for the first time that superconductors were more than just perfect conductors and provided a uniquely defining property of the superconducting state.

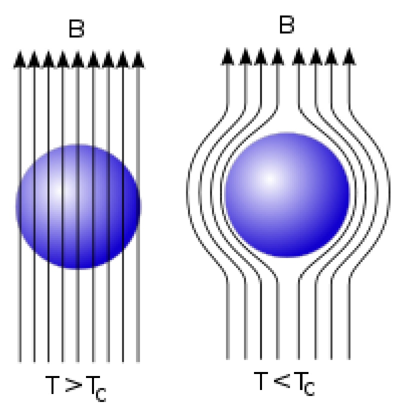
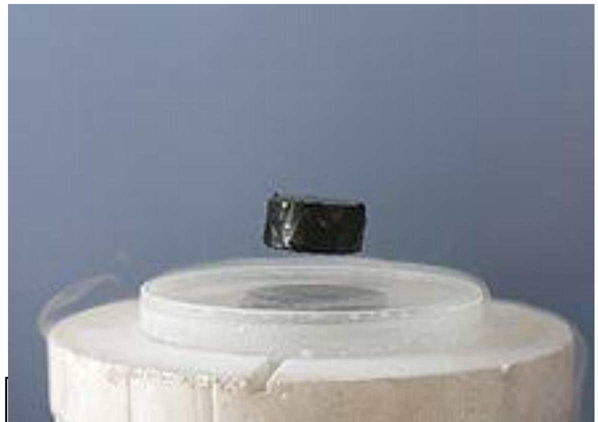



Diagram of the Meissner effect. Magnetic field lines, represented as arrows, are excluded from a superconductor when it is below its critical temperature.

## Explanation



cooled by liquid nitrogen.

In a weak applied field, a superconductor "expels" nearly all magnetic flux. It does this by setting up electric currents near its surface. The magnetic field of these surface currents cancels the applied magnetic field within the bulk of the superconductor. As the field expulsion, or cancellation, does not change with time, the currents producing this effect (called persistent currents) do not decay with time. Therefore the conductivity can be thought of as infinite: a superconductor.

Near the surface, within a distance called the London penetration depth, the magnetic field is not completely canceled. Each superconducting material has its own characteristic penetration depth.

Any perfect conductor will prevent any change to magnetic flux passing through its surface due to ordinary electromagnetic induction at zero resistance. The Meissner effect is distinct from this: when an ordinary conductor is cooled so that it makes the transition to a superconducting state in the presence of a constant applied magnetic field, the magnetic flux is expelled during the transition. This effect cannot be explained by infinite conductivity alone. Its explanation is more complex and was first given in the London equations by the brothers Fritz and Heinz London.

## Perfect diamagnetism

Superconductors in the Meissner state exhibit perfect diamagnetism, or superdiamagnetism, meaning that the total magnetic field is very close to zero deep inside them (many penetration depths from the surface). This means that their magnetic susceptibility, $\chi_v = -1$. Diamagnetics are defined by the generation of a spontaneous magnetization of a material which directly opposes the direction of an applied field. However, the fundamental origins of diamagnetism in superconductors and normal materials are very different. In normal materials diamagnetism arises as a direct result of the orbital spin of electrons about the nuclei of an atom induced electromagnetically by the application of an applied field. In superconductors the illusion of perfect diamagnetism arises from persistent screening currents which flow to oppose the applied field (the meissner effect); not solely the orbital spin.

Very recently, it has been shown theoretically that the Meissner effect may exhibit paramagnetism in some layered superconductors but so far this paramagnetic intrinsic Meissner effect has not been experimentally observed. Mario Rabinowitz and his colleagues showed that a virtual violation of the Meissner effect is possible.[citation needed]

## Consequences

The discovery of the Meissner effect led to the phenomenological theory of superconductivity by Fritz and Heinz London in 1935. This theory explained resistanceless transport and the Meissner effect, and allowed the first theoretical predictions for superconductivity to be made. However, this theory only explained experimental observations—it did not allow the microscopic origins of the superconducting properties to be identified. Nevertheless, it became a requirement on all microscopic theories to be able to reproduce this effect. This was done successfully by the BCS theory in 1957. However, both phenomenological Londons' theory and microscopic BCS one describe the Meissner effect in its steady state only and cannot explain the transient stage when the supercurrent grows from zero to its steady value. Indeed, under initial conditions of the Meissner effect, Lorentz force equals to zero, and there are no other electromotive forces in superconductor to accelerate the electrons. This fundamental problem of the conventional theory of the Meissner effect has been pointed out by J. E. Hirsch in *The Lorentz force and superconductivity* [2] . He has also proposed the dynamical explanation of the Meissner effect in *Spin Meissner effect in superconductors and the origin of the Meissner effect* [3].