



Will a magnet fall freely in a superconducting tube?

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Abstract

A common demonstration of Lenz's law and of Faraday's law of Magnetic Induction is to drop a strong rare earth magnet through a tube of conducting material, typically copper.



FIGURE 1: Check out the video on Youtube! Use the search terms, "neodymium magnet copper pipe". The magnet seems to take forever traversing the pipe. Very cool

If in normal conductors, the breaking work is ultimately the same as the I^2R losses, what would happen in the case of a superconducting tube? There is a theoretical research[?] answer: the magnet should fall freely (once inside) the tube. We have performed the experiment, for the first time we believe, and we show that the magnet remains suspended indefinitely, so long as superconductivity is maintained in the tube.

Background

- Superconductors exhibit no electrical resistance.
- An induced current will eventually damp out, decrease in strength, due to electron collisions with lattice ions, this turns the current into kinetic energy of the lattice, which is heat.
- Currents have been observed to persist in superconducting rings for years at a time.
- Lenz's Law[?] states that an induced electromotive force (EMF) always gives rise to a current whose magnetic field opposes the original change in magnetic flux.
- Faraday's law of Induction states that the EMF generated is proportional to the rate of change of the magnetic flux.

- The Meissner effect is the expulsion of a magnetic field from a superconductor during its transition to the superconducting state.
- One mechanism for superconductivity is Cooper pairing wherein phonon-electron coupling occurs, this allows the electrons to drop into energy states which are lower than the fermi energy.
- In type II superconductors, there is a regular array of superconducting grains surrounded by nonsuperconducting material. There is 'flux pinning'. Magnets can be levitated above HTS (high temperature superconductors), but there are lateral restoring forces not present in type I superconductors.

Experimental Installation

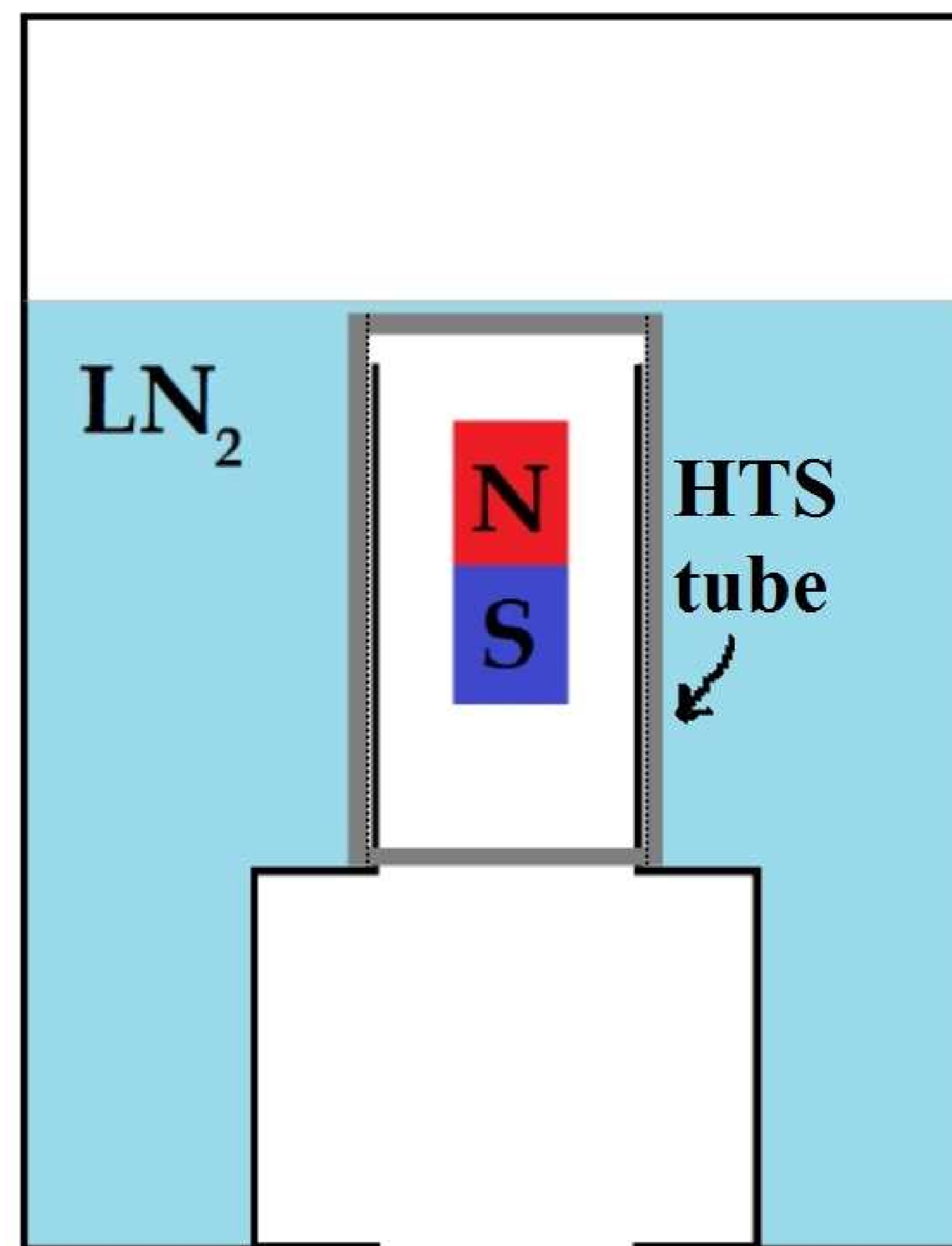


FIGURE 2: We acquired a Bi-2223 superconducting[?] tube with dimensions (length=120mm, diam.=21mm, wall thickness=2.5mm). And as controls, we tried tubes with the same dimensions made of copper, and PVC. We constructed a dewar of PVC such that the inner and outer walls of the HTS tube could be submerged in liquid nitrogen while still passing the magnet through an air cavity so as not to skew results.

The tube levitates the magnet!



FIGURE 3: The magnet, seemingly with arbitrary orientation, is trapped everywhere within the tube, and does not fall, as long as the tube is superconducting. A view of the tube itself is blocked by the PVC. The boiling LN_2 looks black.

Theory disagrees! Perhaps we've learned something new?

In their[?] paper, "Superconducting pipes and levitating magnets", Levin et al. find that

- work is required to insert the magnet into the tube,
- as long as the pipe length \gg its diameter, the magnet will then continue its descent *unhindered*.
- the effects of flux trapping (for 6g neodymium magnet with radius 6.35 mm, tube radius of 8 mm, with $B \sim 1kG$ at the tube wall) is negligible.

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