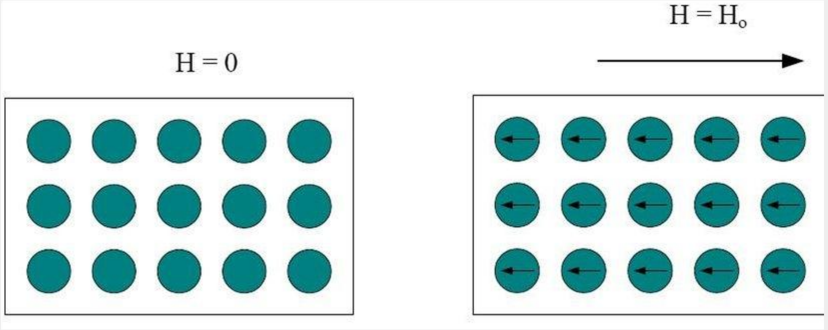
Diamagnetism: From Theory to Fabrication

Marcel Blaut

What exactly diamagnetism is?

“Diamagnetism is the property of materials that are repelled by a magnetic field; an applied magnetic field creates an induced magnetic field in them in the opposite direction causing a repulsive force” ~Wikipedia



Alignment of magnetic moments in direction opposite to the applied magnetic field.

What exactly isn't:

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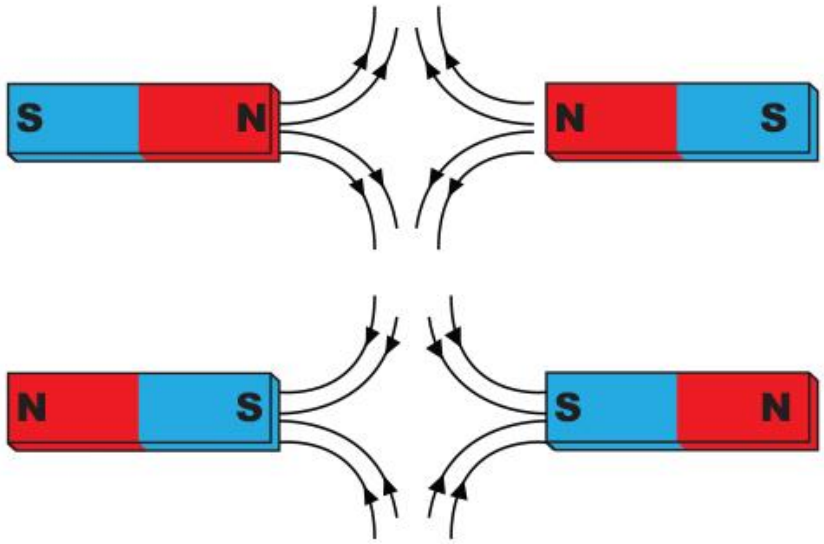
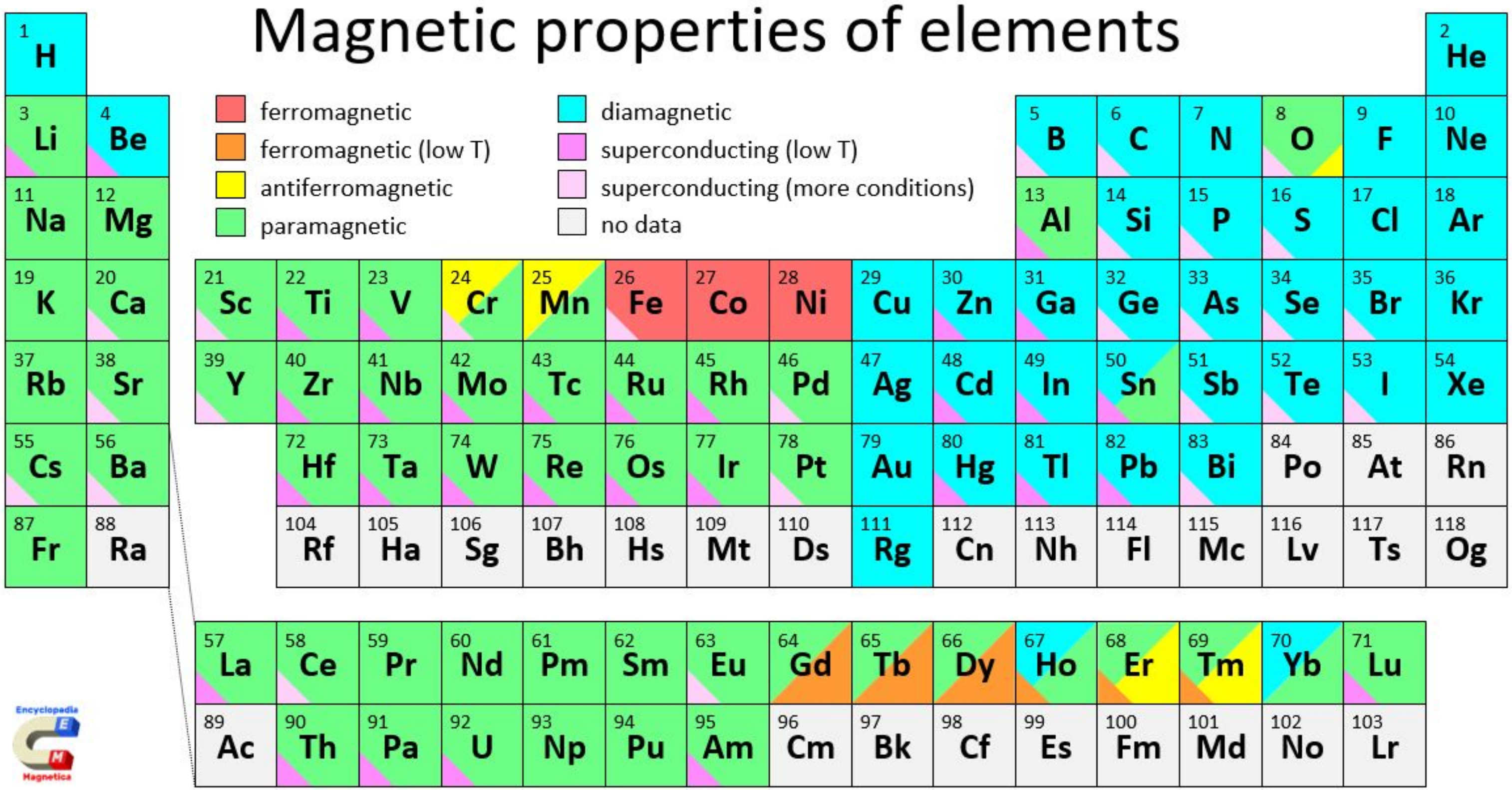
Diamagnetism is a property of all materials, and always makes a weak contribution to the material's response to a magnetic field. On a large scale, this response results from the sum of all the individual magnetic dipole moments induced by the magnetic field.





What causes magnetic field repulsion?

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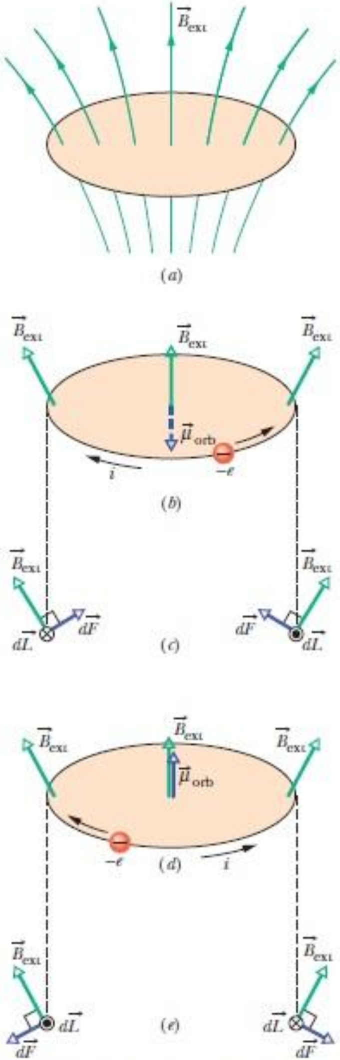
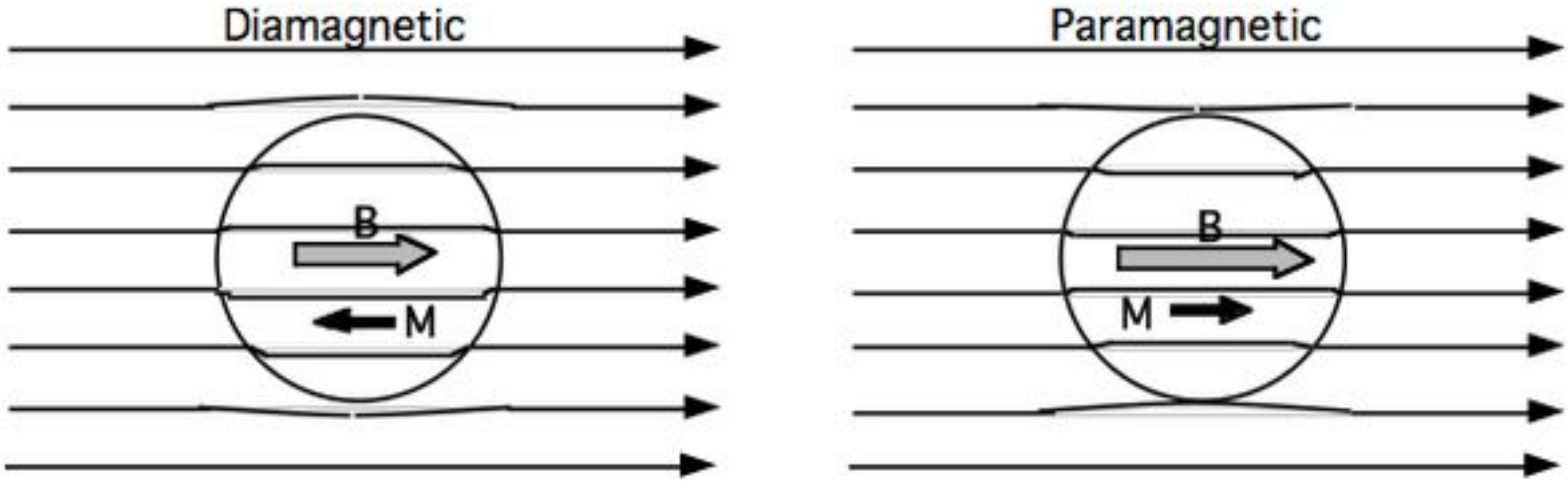
$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

$$\mathbf{M} = \mathbf{R} \times \mathbf{F}$$




Diamagnetic
B
M
Paramagnetic
B
M

That's just classical explanation

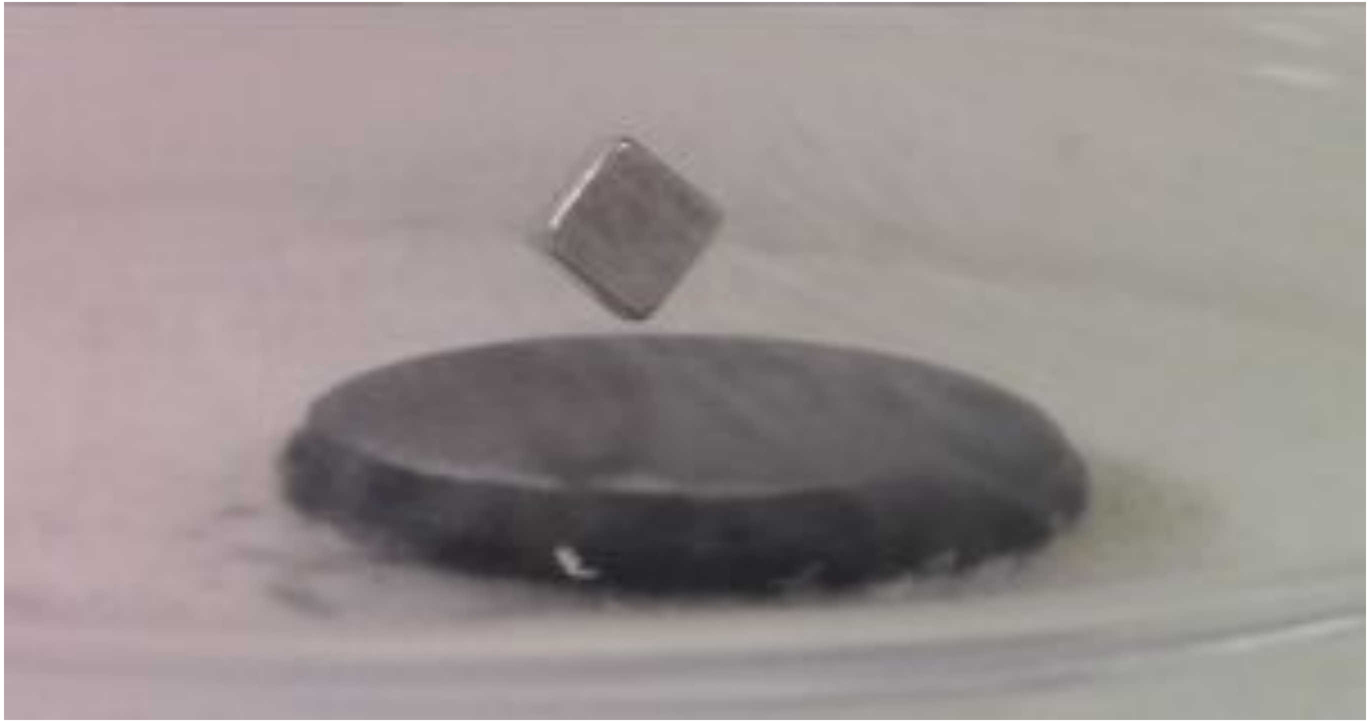
Classical physics gives neither diamagnetism nor paramagnetism

If you follow the classical mechanics far enough, there are no such magnetic effects—they all cancel out.

Prove: Energy of a system, whether it is in a magnetic field or not, is always given by the kinetic energy plus the potential energy. Since the probability of any motion depends only on the energy—that is, on the velocity and position—it is the same whether or not there is a magnetic field. For thermal equilibrium, therefore, the magnetic field has no effect.

To get a better understanding, we must go back and start over with quantum mechanics. In an atom we cannot really say where an electron is, but only know the probability that it will be at some place.

$$\Delta\mu = -\frac{q_e^2}{6m}\langle r^2\rangle_{\text{av}} B$$



UC Santa Cruz

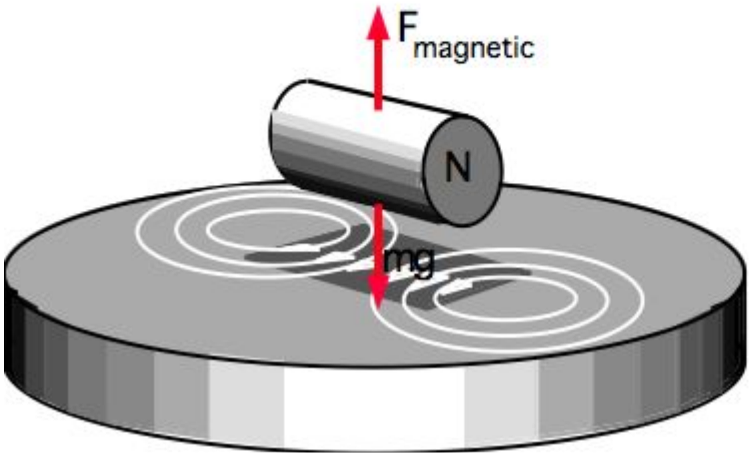
Is superconductor a diamagnet?

Meissner effect

If you have a piece of the metal at a high temperature and establish a magnetic field through it, and then you lower the temperature below the critical temperature (where the metal becomes a superconductor), the field is expelled. In other words, it starts up its own current—and in just the right amount to push the field out.

Why magnet above superconductor is stationary?

Simple answer: it maintains equilibrium here due to induced magnetic fields.



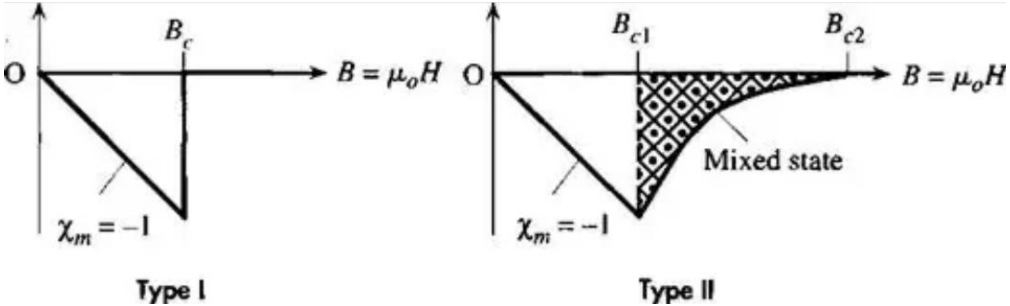
Quora.com

Why magnet above superconductor is stationary?

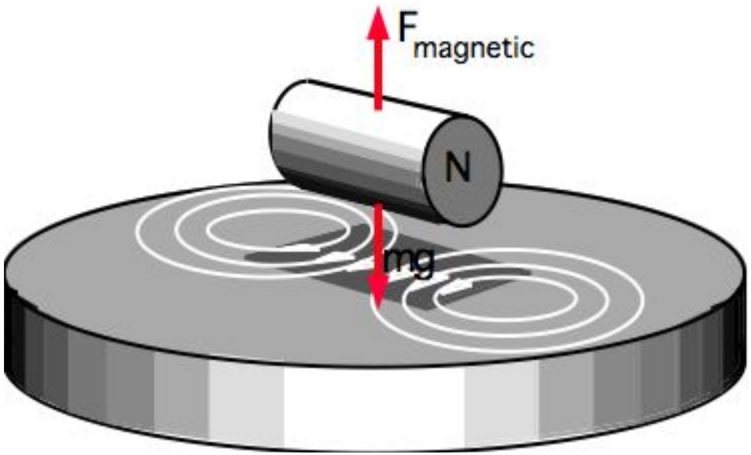
Simple answer: it maintains equilibrium here due to induced magnetic fields.

Better answer:

$$\hbar \frac{\partial \theta}{\partial t} = -\frac{m}{2} v^2 - q\phi + \frac{\hbar^2}{2m}\left\{\frac{1}{\sqrt{\rho}} \nabla^2(\sqrt{\rho})\right\}.$$



Magnetization curves for type 1 and type 2 superconductors. Negative magnetization = levitation



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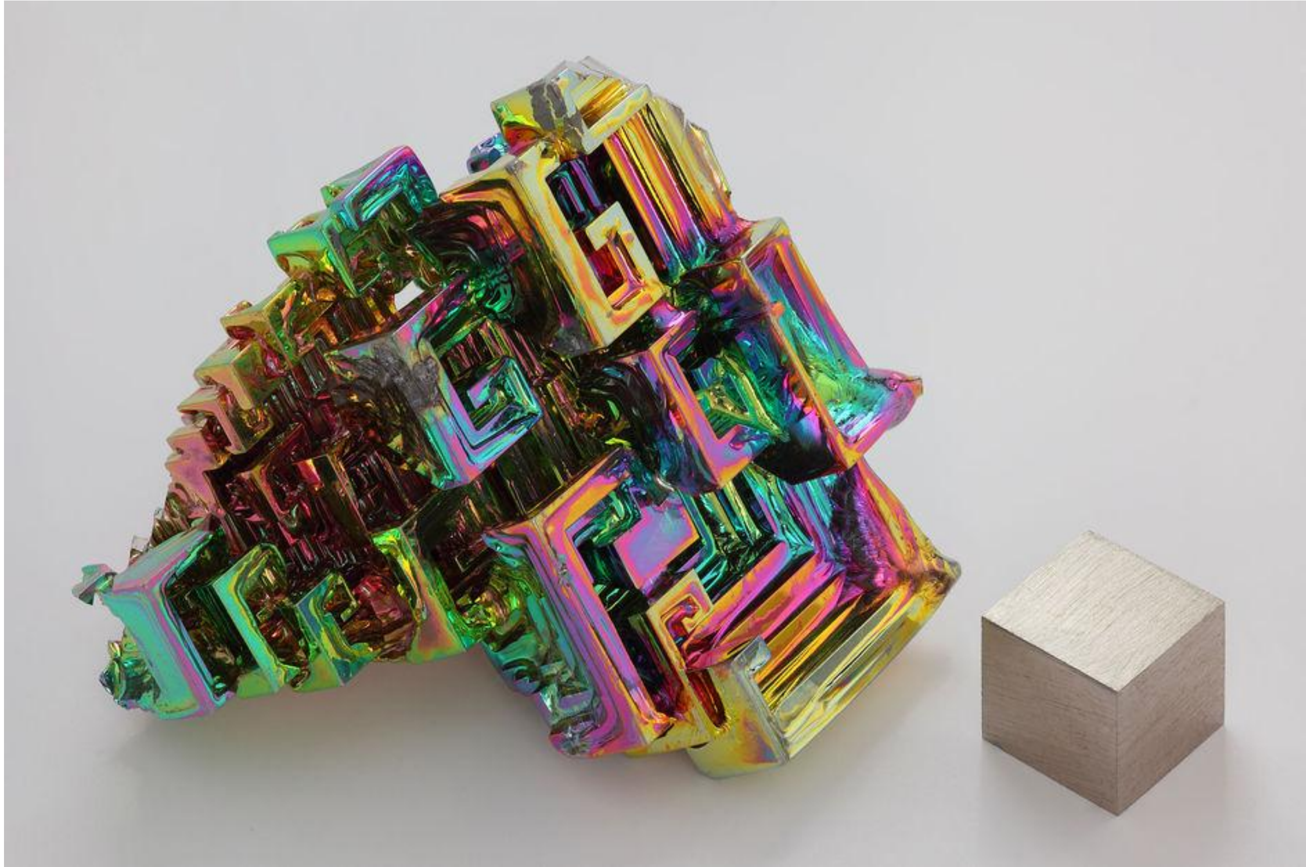
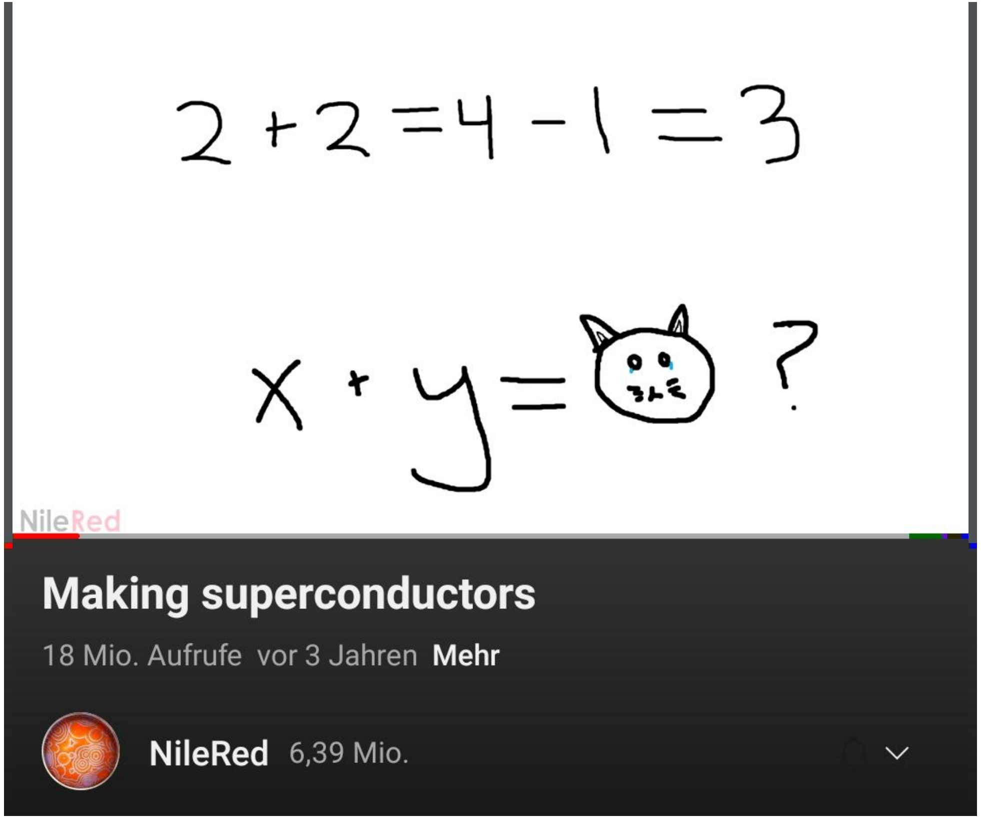




Guidance on making own perfect diamagnet

Why would we even use that?

Potential and actual usage:

Japan’s MagLev Train is Fast, Very Fast.
~ Kyle Maxey, engineering.com

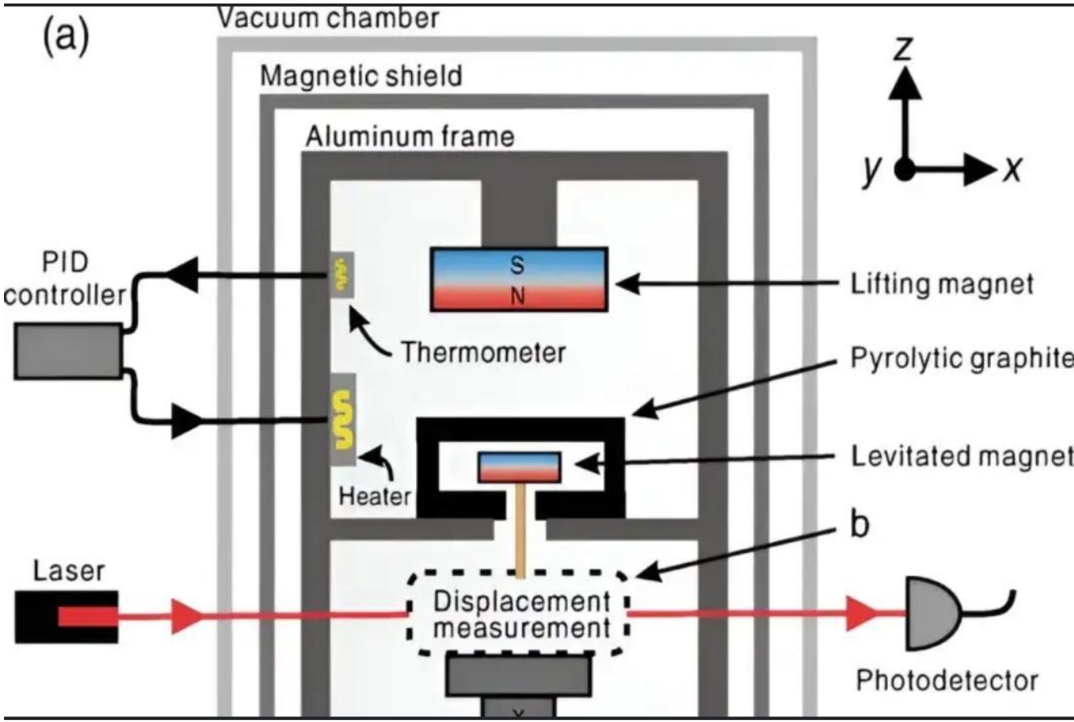
Physics \ General Physics   Editors' notes

New design for a small, highly sensitive gravimeter that can operate stably at room temperature

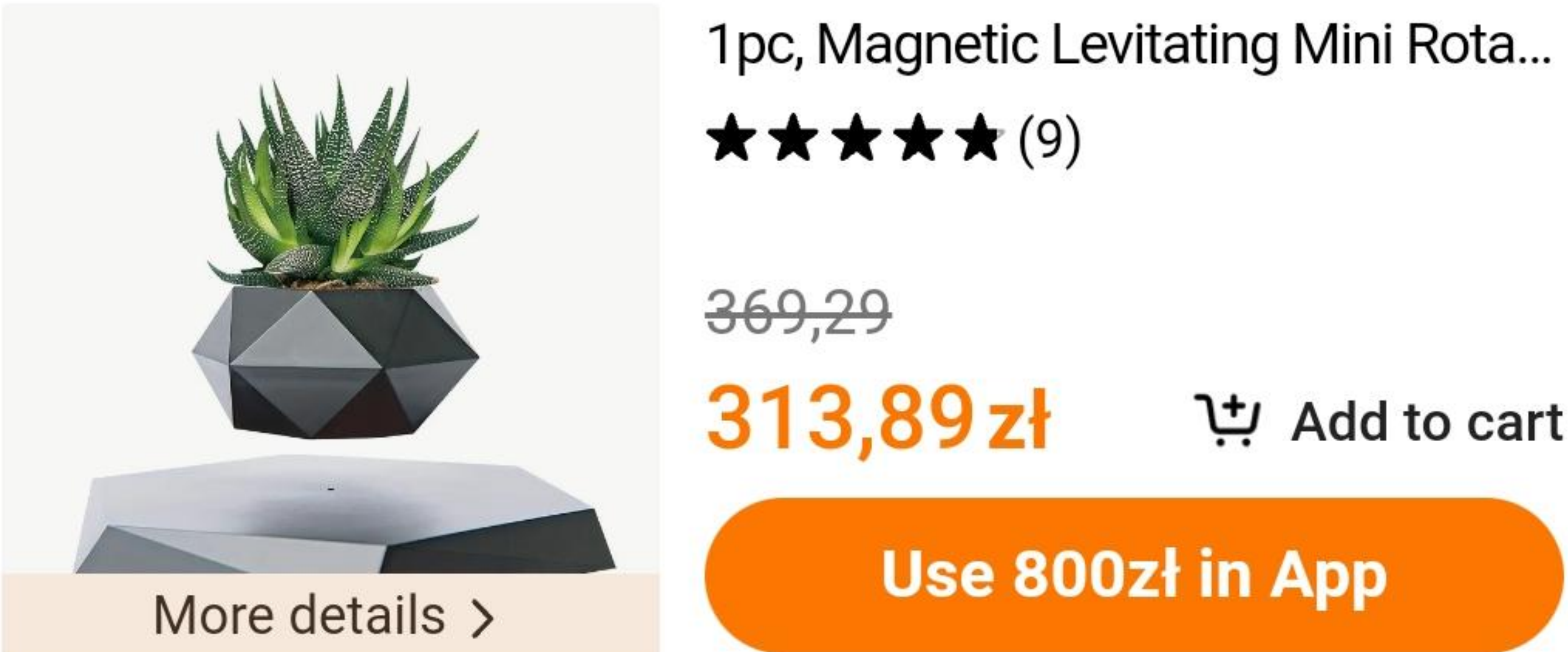
by Bob Yirka , Phys.org   REPORT

The team tested their device by putting it in a vacuum chamber for several weeks, allowing it to settle. They then used it to take measurements of gravity from the moon and sun over the following five days. They then compared the results with predicted values and found their signal displayed oscillations that represented variations in gravitational acceleration of up to about 10−7 of the standard value, which they describe as highly accurate.

The team describes their work as a proof-of-concept device and suggests that further work would likely lead to refinement, which in turn should lead to even greater precision. They also plan to make the device more physically robust so that it can withstand being moved from site to site.



(a) Schematic of the diamagnetic levitation gravimeter. (b) Schematic of oscillator displacement detection. The laser beam is focused by a lens. The copper wire is placed on the focal point, where displacement sensitivity in the Z direction is maximum. (c) The measured response curve of voltage to displacement in the Z direction of (b). Credit: Physical Review Letters (2024). DOI: 10.1103/PhysRevLett.132.123601

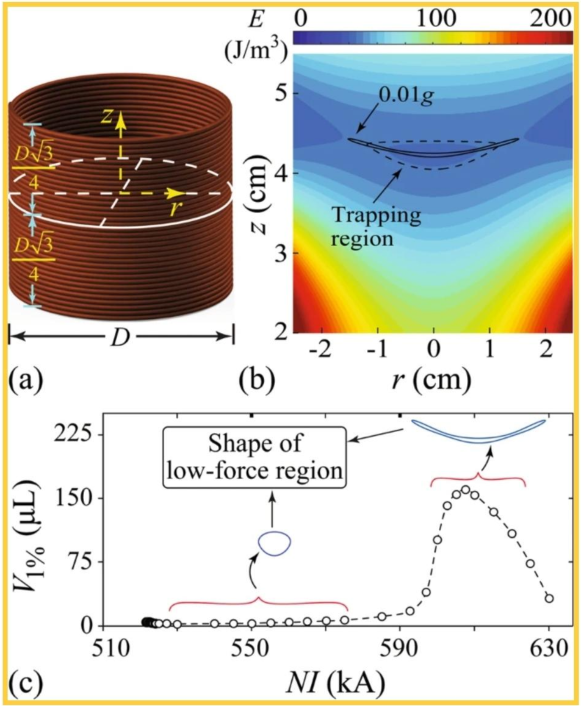


Temu.com

Note: not exactly using diamagnetism

A magnetic levitation based low-gravity simulator with an unprecedented large functional volume

Low gravity environment is known to have a profound impact on the behaviors of biological systems, the dynamics and heat transfer of fluids, and the growth and self-organization of materials. Systematic research on the effects of gravity is crucial for advancing our knowledge and for the success of space missions. But due to the high cost and the limitations in the payload size and mass in spaceflight missions, ground-based low-gravity simulators have become indispensable.



https://communities.springernature.com/posts/a-magnetic-levitation-based-low-gravity-simulator-with-an-unprecedented-large-functional-volume

In 1997, Scientists Made A Frog Levitate

The 2000 Ig Nobel Prize in physics was awarded to Andre Geim, Radboud University Nijmegen, and Michael Berry, University of Bristol, UK, for the magnetic levitation of a live frog. Geim was awarded an actual Nobel Prize in Physics in 2010.

Thank you

References:
The Feynman Lectures on Physics (https://www.feynmanlectures.caltech.edu/)
Encyclopedia magnetica, Dr Stan Zurek (https://e-magnetica.pl)
https://physics.stackexchange.com