Gravity Measurement Based on a Levitating Magnet

A new gravimeter is compact and stable and can detect the daily solar and lunar gravitational oscillations that are responsible for the tides.

By **Mark Buchanan**

Gravity measurements can help with searches for oil and gas or with predictions of impending volcanic activity. Unfortunately, today's gravimeters are bulky, lack stability, or require extreme cooling. Now researchers have demonstrated a design for a small, highly sensitive gravimeter that operates stably at room temperature [**1**]. The device uses a small, levitated magnet whose equilibrium height is a sensitive probe of the local gravitational field. The researchers expect the design to be useful in field studies, such as the mapping of the distribution of underground materials.

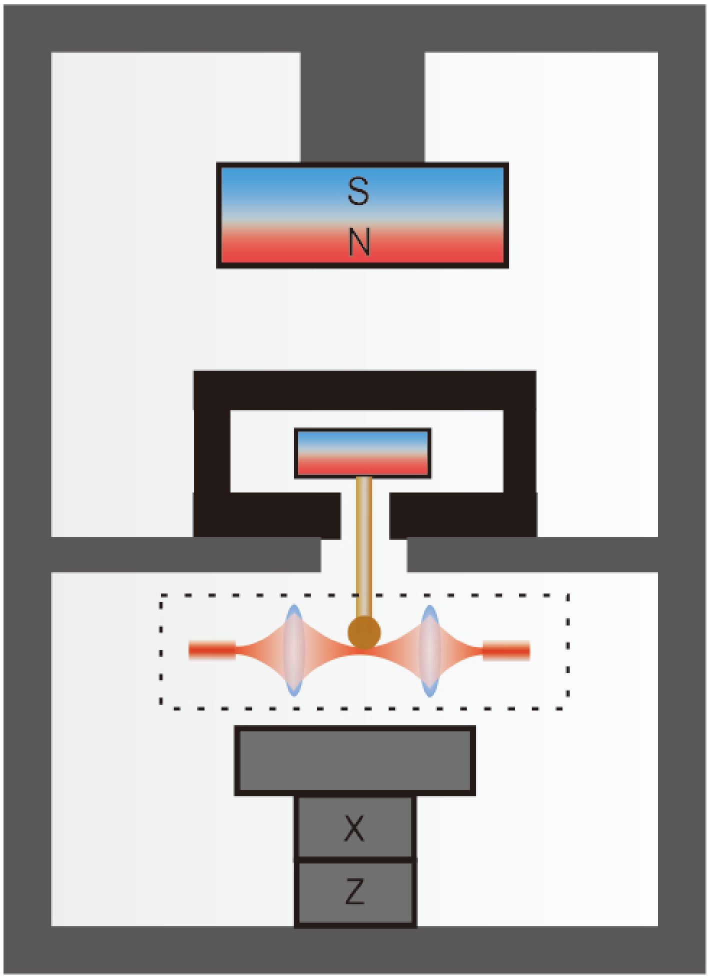
Several obstacles have impeded the development of compact gravimeters, says Pu Huang of Nanjing University in China. Room-temperature devices generally use small mechanical oscillators, which offer excellent accuracy. However, they are made from materials that exhibit aging effects, so these gravimeters can lose accuracy over time. Much higher stability can be achieved with superconducting devices, but these require cryogenic conditions and so consume lots of power and are hard to use outdoors.

Not just the oceans. The Sun and Moon have major effects on the oceans, but even on land their effects can be detected by a sensitive gravimeter.
Credit: Sue/stock.adobe.com

Superconducting systems have exceptional sensitivity partly because they use levitation—a small oscillating system is made to float in space and so remains free from many disturbances, such as vibrations, Huang says. He, along with Jiangfeng Du of Zhejiang University in China and their colleagues, wanted a design that would also employ levitation but without the cooling requirements of superconductivity or the need for materials that age.

Their new device is based on a magnetic-levitation concept developed more than two decades ago [**2**]. It involves two magnets—a large magnet, fixed in position, and a smaller, 200-mg test magnet located a few centimeters below, with field-repelling (diamagnetic) slabs of graphite positioned above and below the test magnet. The upward force supplied by the fixed magnet balances the weight of the test magnet, so it can levitate. The slight repulsion between the test magnet and the two graphite surfaces allows the magnet to oscillate stably in the vertical direction. The team adjusted the spacing between the surfaces to reduce this oscillation frequency to about 1 Hz. (The lower the frequency, the more sensitive the measurements can be.)

Any change in the strength of gravity changes the equilibrium height of the test magnet. To detect such changes, a small copper wire connected to the test magnet hangs down so that



Travel sized. This room-temperature device could potentially be highly portable and sensitive. The magnetic field of a large, fixed magnet (colored, with north and south poles shown) levitates a smaller magnet (also colored). The copper wire hanging down has an L shape at the bottom, with the horizontal portion partially obscuring a laser beam (red) that is focused with lenses and that is fed in and out of the device via optical fibers. The output fiber goes to a photodetector (not shown). Changes in the small magnet's height lead to changes in the amount of light reaching the photodetector, which determines the detector's output voltage. The nearly complete rectangle surrounding the small magnet represents graphite slabs that stabilize the magnet in all three dimensions. The mechanism at the bottom allows precise positioning of the displacement-detection system in the *x* and z directions.
Credit: Adapted from Y. Leng *et al.* [**1**]

its end partially obscures a laser beam traveling to a photodetector. Small changes in gravity raise or lower the magnet and the wire, which changes the amount of light hitting the photodetector, which in turn determines the detector's output voltage.

To test the device, Huang and colleagues used it to measure the tiny variations in the force of gravity caused by the apparent motion of the Sun and the Moon, the same variations that cause the tides. After setting up their device in a vacuum chamber, they waited several weeks for conditions inside the device to stabilize before conducting continuous measurements for five days. Their signal displayed a series of oscillations representing variations in the local gravitational acceleration of up to about 10^{-7} of the standard value (g, approximately 10 m/s^2). The results show a close correspondence between the predicted gravitational variations and the experimental data. Overall, says Huang, the gravimeter demonstrated a sensitivity roughly 3 times better than small solid-state gravimeters, with much higher stability.

"What we have achieved so far is a proof-of-principle experiment," says Huang. To improve the performance, the team plans to reduce the test mass to below 1 mg. "We also want to replace the lifting magnet with microcoils on a circuit board, so we can build a gravimeter on a chip," he says. The team also aims to prepare the gravimeter for work outside of the laboratory, so it can function on drones or other platforms.

"I really like this work," says Peter Barker of University College London, an expert in levitated optomechanical states. "The very clever design is an advance over existing technologies, gives impressive sensitivity and stability over time, and requires no cryogenics or complex fabrication techniques. This is likely to have significant impact."

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REFERENCES

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