A new effect in electromagnetism discovered – 150 years later

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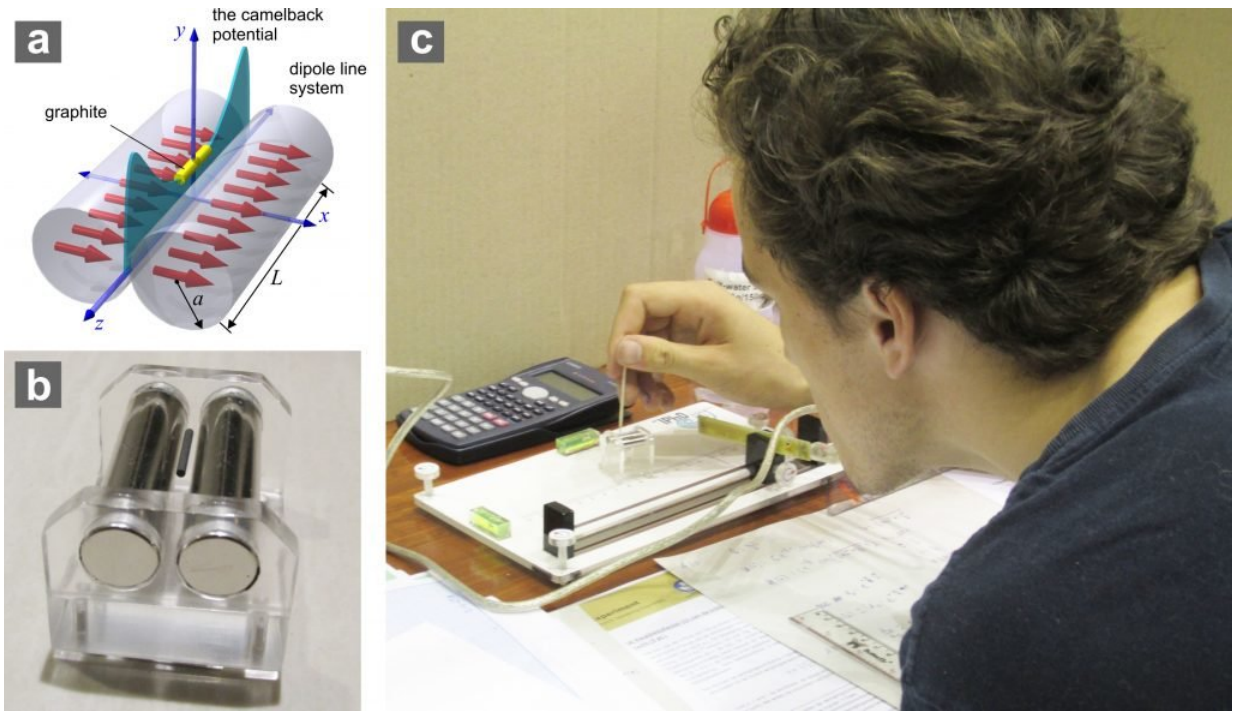

Fig. (a) The “camelback” field confinement effect in the parallel dipole line (PDL) system. (b) The IBM PDL magnetic trap system. A graphite rod gets trapped and levitates perpetually without any input power. (d) A member of The Netherlands Physics Olympiad Team, Julian Sanders, performing an experiment with the IBM PDL trap in The 2017 International Physics Olympiad. Credit: IBM Blog Research

Electromagnetism is a branch of physics that deals with all phenomena of electricity and magnetism. This field is the key foundation of our modern age of electricity and information technology. It is governed by a set of fundamental principles encoded in four equations called Maxwell equations, which have been known for approximately 150 years. Every time we harness fundamental effects as prescribed or predicted by this theory, we reap immense benefits in terms of technological advances. Things like electric machines, motors, various electronics devices, circuits, computers, display, sensors and wireless communication all operate based on the basic principles of electromagnetism. This subject is actually considered "classical physics," which seems to suggest that we have known everything we need to know about it.

However, our IBM Research team recently discovered a subtle hidden feature in electromagnetism—a previously unknown field confinement effect that we've named the "camelback effect" in a system of two lines of transverse dipoles.

In electromagnetism, the elementary source of electric field and magnetic field can be respectively modeled as a point charge—a hypothetical charge located at a single point in space—and a dipole, a pair of equal and oppositely charged or magnetized poles separated by a distance. Imagine we line up two rows of magnetic dipoles as shown in Fig (a), and we try to measure the strength of the magnetic field along the center axis. The magnetic field is certainly stronger at the center and diminishes away from it. However, if the length of the dipole line exceeds certain critical length, a surprising effect occurs: the field gets slightly stronger near the edges and produces a field confinement profile that looks like a camel's back—hence the name of the effect. The IBM team has reported this discovery with detailed experimental and theoretical studies in two recent publications and patents.

This surprising discovery is exciting for a few reasons. First, it represents a new elementary one-dimensional confinement potential in physics, joining the list of well-known potentials such as Coulomb, parabolic, and square well. Second, this effect becomes the key feature that enables this system to serve as a new class of natural magnetic trap called parallel dipole line (PDL) trap as shown in Fig. (b) with many possible exciting applications. This camelback effect and the related PDL magnetic trap can be realized using special cylindrical magnets whose poles are on the curved side as shown in Fig. (b) and a graphite rod as the trapped object.

This natural magnetic trap also demonstrates "particle-in-one dimensional potential" system, thus serving as a novel platform for pedagogical physics experiments. For this reason, after a rigorous selection process, the IBM discovery was recently featured as an experimental problem in the International Physics Olympiad (IPhO) recently held in Yogyakarta, Indonesia in July. IPhO is a premier international physics competition at pre-college level which has been running since 1967 (first held in Warsaw, Poland). Each participating country sends their top five physics students to compete in solving three theoretical and two experimental problems. The problems presented are typically very challenging and original and, more importantly, they must present fundamental ideas or concepts in physics.

In this year's IPhO, about 396 students from 86 countries—one of the largest IPhO ever—performed experiments using the IBM PDL magnetic trap to determine the magnetic property of the trapped graphite and the air viscosity. The students also investigated its applications as earthquake and volcanic tiltmeter sensor. This is actually an ongoing project between IBM Research and the Italian Institute of Geophysics and Volcanology (INGV). The overall exposition was appreciated by the international team leaders for its novel, fascinating and rich physics content as well as its noble applications.

This IBM magnetic trap research has now been included as a new lecture note material in Electrodynamics course in Princeton University. It has also produced practical technology as a new high sensitivity semiconductor characterization tool called "Rotating PDL Hall system" that has served many groups in IBM Research that work with semiconductors. It has also been operating at the Harvard Center of Nanoscale System laboratory.

On a side note, the international impact of this work for physics pedagogy is rather unexpected, as the research was originally intended for semiconductor technology development. The IBM team were exploring ways to trap tiny cylindrical objects like nanowires for next generation transistors. Nevertheless, the adoption of our research work in a premier international event, such as IPhO, exemplifies our mission in IBM Research "to be famous for our science and vital to the world."

More information: O. Gunawan, Y. Virgus, and K. Fai Tai, A parallel dipole line system, Appl. Phys. Lett. 106, 062407 (2015).

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K. T. McDonald, Diamagnetic Levitation, (Princeton University) www.hep.princeton.edu/~mcdonal … ples/diamagnetic.pdf.

Long Rod with Uniform Magnetization Transverse to its Axis www.physics.princeton.edu/~mcd … /examples/magrod.pdf

Rotational stability of a diamagnetic rod

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