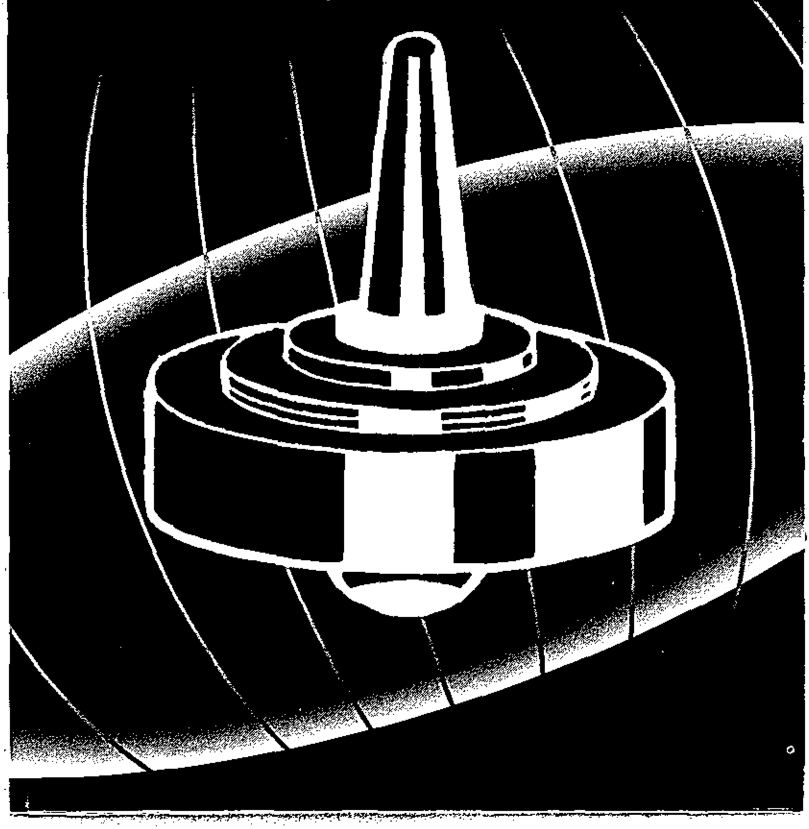
LEVITRON® PHYSICS



How Does The Levitron® Work?

Now that you have acquired your Levitron and have (presumably) mastered the art of spinning the top and placing it in its position of stable levitation, you are perhaps beginning to feel the full sense of wonderment that the Levitron excites in many people. We receive numerous queries from Levitron owners asking for an explanation of how the Levitron works. Many express puzzlement that it works at all, often citing a theorem due to Earnshaw (1,2) as proof that it should not work.

Interest in the Levitron has always run high among scientists. Recently, analogies of the Levitron to traps for microscopic particles (e.g., electrons, neutrons) have been recognized by scientists working in the fascinating area of research where matter is manipulated and examined, one such microscopic particle at a time. The first to recognize the analogy was Dr. Michael V. Berry of the University of Bristol. Dr. Berry, inspired by this recognition, set forth a thorough exposition of the physics of the Levitron's operation in a paper (3) that is soon to be published. Dr. Berry's paper is the best existing explanation of how the Levitron works and he kindly prepared for us a brief encapsulation of its major themes, which we present below. Those wishing to read the full exposition should request a copy of the paper from Dr. Berry (c/o the H. H. Wills Physics Laboratory, Royal Fort, Tyndall Avenue, Bristol, BS8 1TL, United Kingdom).

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Some Frequently Asked Questions About Levitron® Physics

Michael V. Berry

1. What holds the top up?

The 'antigravity' force that repels the top from the base is magnetism. Both the top and the heavy slab inside the base box are magnetized, but oppositely. Think of the base as a magnet with its north pole pointing up, and the top as a magnet with its north pole pointing down (Fig. 1). The principle is that two similar poles (e.g., two norths) repel, and two different poles attract, with forces that are stronger when the poles are closer. There are four magnetic forces on the top: on its north pole, repulsion from the base's north and attraction from the base's south, and on its south pole, attraction from the base's north and repulsion from the base's south. Because of the way the forces depend on distance, the north-north repulsion dominates, and the top is magnetically repelled. It hangs where this upward repulsion balances the downward force of gravity, that is, at the point of equilibrium where the total force is zero.

2. Why does it need to spin?

To prevent the top from overturning. As well as providing a force on the top as a whole, the magnetic field of the base gives a torque tending to turn its axis of spin. If the top were not spinning, this magnetic torque would turn it over. Then its south pole would point down and the force from the base would be attractive - that is, in the same direction as gravity - and the top would fall. When the top is spinning, the torque acts gyroscopically and the axis does not overturn but rotates about the (nearly vertical) direction of the magnetic field. This rotation is called precession (Fig. 2). With the Levitron, the axis is nearly vertical and the precession is visible as a shivering that gets more pronounced as the top slows down.

3. Why doesn't the top slip sideways?

For the top to remain suspended, equilibrium alone is not enough. The equilibrium must also be stable, so that a slight horizontal or vertical displacement produces a force pushing the top back toward the equilibrium point. For the Levitron, stability is difficult to achieve. It depends on the fact that as the top moves sideways, away from the axis of the base magnet, the magnetic field of the base, about which the top's axis precesses, deviates slightly from vertical (Fig. 2). If the top precessed about the exact vertical, the physics of magnetic fields would make the equilibrium unstable. Because the field is so close to vertical, the equilibrium is stable only in a small range of heights - between about 1.25 inches and 1.75 inches above the center of the base. The Earnshaw theorem is not violated by the behavior of the Levitron. That theorem states that no static arrangements of magnetic (or electric) charges can be stable, alone or under gravity, it does not apply to the Levitron because the magnet (in the top) is spinning and so responds dynamically to the field from the base.

4. Why is the weight so critical, and why must it be adjusted so often?

The weight of the top and the strength of magnetization of the base and the top determine the equilibrium height where magnetism balances gravity. This height must lie in the stable range. Slight changes of temperature alter the magnetization of the base and the top (as the temperature increases, the directions of the atomic magnets randomize and the field weakens). Unless the weight is adjusted to compensate, the equilibrium will move outside the stable range and the top will fall. Because the stable range is so small, this adjustment is delicate - the lightest washer is only about 0.3% of the weight of the top.

5. Why are the magnets ceramic and not metal?

The magnetic field of the base pushes sideways on the electrons in the top as they spin through the field. In a metal top, which conducts electricity, the electrons would flow. Resistance in the metal would damp these 'eddy currents' and dissipate the top's rotational energy, causing it to slow down and eventually fall. The ceramic top is an insulator, so the eddy currents cannot flow.

6. Why does the top eventually fall?

The top spins stably in the range from about 20 to 26 revolutions per second (rps). It is completely unstable above 30 rps and below 18 rps. After the top is spun and levitated, it slows down because of air resistance. After a few minutes it reaches the lower stability limit (18 rps) and falls. The spin lifetime of the Levitron can be extended by placing it in a vacuum. In some vacuum experiments, the top falls after about 30 minutes. Why it does so is not clear; perhaps the temperature changes, pushing the equilibium out of the stable range; perhaps there is some tiny residual long-term instability because the top is not spinning fast enough; or perhaps vibrations of the vacuum equipment jog the field and gradually drive the precession axis away from the field direction. Levitation can be greatly prolonged by blowing air against an appropriately serrated collar placed around the top's periphery so as to maintain the spin frequency in the stable range. Recently, a Levitron top was kept rotating for several days in this way.

7. Is the Levitron Principle used elsewhere?

In recent decades, microscopic particles have been studied by trapping them with magnetic and/or electric fields. There are several sorts of traps. For example, neutrons can be held in a magnetic field generated by a system of coils. Neutrons are spinning magnetic particles, so the analogy of such a neutron trap with the Levitron is close.

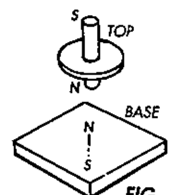

FIG. 1.

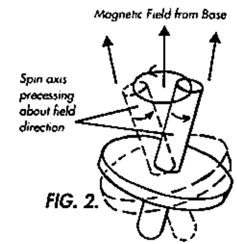

FIG. 2.

References

1. S. Earnshaw, On the nature of the molecular forces which regulate the constitution of the luminiferous ether, Trans. Cambridge Phil. Soc. 7, 97-112, 1842.
2. L. Page and N.I. Adams Jr., Principles of Electricity, 3rd edition p.24, D. Van Nostrand Co., New York, 1958.
3. M. V. Berry, The Levitron™: an adiabatic trap for spins, Proc. Roy. Soc. Lond., to be published, 1996.