

A photograph of a magnetic levitation experiment. A dark, cylindrical object is suspended in the air above a dark, rectangular base. A bright blue, ethereal glow surrounds the levitating object, suggesting a magnetic field. The background is a gradient of blue and purple.

RISING FORCE

THE MAGIC OF MAGNETIC LEVITATION

JAMES D. LIVINGSTON

Rising Force

The Magic of Magnetic Levitation

James D. Livingston



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Preface

My earlier popular-science book, *Driving Force: The Natural Magic of Magnets* (Harvard University Press, 1996), covered a wide variety of topics in the history, science, and technology of magnets. Most of the history and basic science presented there remains accurate, but many of the technology areas have advanced considerably since 1996. Technology is a moving target. In particular, magnetic levitation, that is, the use of magnetic forces to combat gravity and friction, has recently advanced in a wide variety of technology areas.

The world's first commercial maglev train line was constructed in China to link the Shanghai airport to the city center, and, since 2003, millions of passengers have already experienced the excitement of traveling at speeds up to 250 miles per hour. A less visible but much wider application of magnetic levitation is in magnetic bearings. Here maglev applications have greatly increased in recent years and include their use in artificial hearts, energy storage, wind turbines, integrated-circuit manufacture, and ultracentrifuges to enrich uranium. (The recent assembly of large cascades of such centrifuges in Iran has become a major issue of international politics.)

"Flying frogs," the levitation of living frogs in high magnetic fields, drew much public attention in 1997 and stimulated greatly increased attention to the general area of diamagnetic levitation—levitation of matter repelled by magnetic fields. Superconductors, the ultimate diamagnetic materials, have seen increased use in maglev devices and demonstrations, including the levitation of a Japanese

sumo wrestler and, of considerably more scientific importance, a half-ton superconducting ring for fusion research.

The Levitron, a very popular toy in which a spinning magnet achieves stable levitation through gyroscopic action, became widely distributed in the late 1990s, and improved models, with higher levitation heights, have appeared in recent years. Many aesthetically striking items employing sophisticated electrical circuitry to achieve desktop levitation of globes and other magnetic objects have been developed and have even appeared in the form of a floating sculpture in an art museum.

All these and other recent developments have convinced me that it would be timely to write a full-length popular-science book focused on one particular aspect of “the natural magic of magnets”—the topic of magnetic levitation. To quote from *Driving Force*, “Does gravity get you down? Magnets can lift you up! Does friction slow you down? Magnets can speed you up! Fighting the forces of gravity and friction is one of the things that magnets do best.”

I should perhaps note here that some authors reserve the term *magnetic levitation* for cases where the magnetic antigravity force is *repulsive*, delivered from below, and prefer the term *magnetic suspension* for cases where the magnetic antigravity force is *attractive*, delivered from above. But most regard the words “suspension” and “levitation” as virtual synonyms. In this book, I will use the term *magnetic levitation* for magnetic antigravity forces of all types, in part because I much prefer the shortened form “maglev” to “magsusp.”

We’ll start in Chapter 1 with examples of humankind’s longtime fascination with levitation from the worlds of literature, films, television, theater, magic, and religion, and then briefly describe various physical but *nonmagnetic* means that humankind has developed to combat gravity. Since magnetic levitation involves the use of magnetic forces to combat gravitational forces, we’ll review in Chapter 2 the basics of those two competing forces, and in Chapter 3 the fundamentals of maglev, including the central problems of force bal-

ance and stability. Later chapters describe the various types of magnetic levitation that have been developed and their applications, finally reaching in Chapters 11 and 12 the topic of maglev trains, one of the most dramatic examples of magnets “fighting the forces of gravity and friction. . . one of the things that magnets do best.”

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Fictional and Illusional Levitation

A few years ago I was in Manhattan on a short business trip, staying in a hotel in the theater district. I had a free evening, decided to see a musical, and chose a performance of *Mary Poppins*, hoping to relive some of the fun of the earlier movie version starring Julie Andrews and Dick Van Dyke. I enjoyed the show, but the most memorable and magical moment came at the very end. After Mary Poppins had said her goodbyes to the Banks family, she opened her umbrella and flew away. And this time she didn't just fly across the stage and into the wings, as she had done earlier in the show. This time she held up her umbrella and casually flew off the stage, up and high over the theater audience, up and high over the balcony, and out of sight. It was a wonderful effect, and its magical impression on me was enhanced by the wonder expressed in the face of the 6-year-old girl who happened to be sitting next to me. There's something about seemingly conquering the ubiquitous force of gravity that is especially magical to most of us.

I was well aware that the flight of Mary Poppins above my head was not really magic, not really a miracle. The rational part of my brain knew that she was supported by a harness attached to an array of many fine wires, wires fine enough that they would not be visible to us in the limited lighting in the heights of the theater above our heads. Nevertheless, I enjoyed the feeling of magic. Suspension of disbelief can be an important part of enjoying the theater. I'm not

sure of the thinking of the 6-year-old girl who sat next to me. The world remains full of mysteries at that age, and I suspect she was not then thinking about harnesses and arrays of wires. During intermission, her mother had bought her a replica of the magical umbrella that seemed to be an important part of the flying ability of Mary Poppins, and probably in the following weeks, the girl often opened her umbrella and pretended to fly. Pretense and imagination are important parts of the gifts of childhood, a gift we adults often lose. If the girl took any time at all to wonder about how Mary Poppins was able to fly, she perhaps explained it to herself by the effects of a special wind on the unfurled umbrella. After all, the flying of kites was an important part of the play, and isn't it wind that makes kites fly?

In the book and stage versions of *Peter Pan*, the ability to fly was explained by Peter Pan as requiring only fairy dust and happy thoughts. (In Disney's movie version, "fairy dust" was converted to "pixie dust," probably because pixies were considered more politically correct.) In the TV series *The Flying Nun*, Sally Field wore an unusual winglike headdress that perhaps allowed a magical wind to levitate and propel her through the air. Disney's *Aladdin* used a flying carpet, and Harry Potter and other students at Hogwarts flew on broomsticks, as did the scary Wicked Witch of the West in *The Wizard of Oz* (who doesn't seem quite so scary in "Wicked," where she sings "Defying Gravity."). From the Middle Ages on, broomsticks have been portrayed as the preferred flying mechanisms for witches, the flying power of the broomsticks often enhanced by application of magical ointments. (Most modern attempts to explain the origin of this long-held superstition have a sexual component, with the broomstick a phallic symbol, a notion not stressed in the Harry Potter books.) In the *Star Wars* films, Yoda and other Jedi Masters are able to levitate objects with the use of "The Force," while Chinese martial arts films like *Crouching Tiger, Hidden Dragon* feature warriors battling in graceful gravity-defying displays with no attempted explanation of the source of their abilities. To fly around the world on Christmas Eve, Santa Claus requires a team of magical reindeer, but

Superman and many other superheroes in the world of fiction somehow levitate and fly on their own power, with no reindeer, broomsticks, umbrellas, winged hats, flying carpets, pixie dust, or even happy thoughts required. The ability to counteract the downward pull of the earth clearly exerts a powerful attraction to our imagination.

Demonstrations of levitation have also long been a popular tool for magicians to display their powers. One famous illusion was the “ethereal suspension” introduced by French magician Jean Eugene Robert-Houdin in 1847. As Robert-Houdin himself described it in his memoirs,

I placed three stools upon a wooden bench. My son stepped on the middle one; I had him extend his arms so I could support him with two canes, each of which rested on a stool . . . I removed the stool so the child was supported only by the two canes. This strange balancing already evoked great surprise among the spectators. It grew even more when they saw me remove one of the two canes and the stool that supported it, and it reached its peak when, after having raised my child to a horizontal position using my little finger, I left him sleeping in space, and to defy the laws of gravity, I also removed the feet of the bench at the base of this impossible edifice.

His son was of course supported by the other “cane,” which was actually a strong iron bar connected at the bottom to a firm base and at the top to a mechanical harness worn by the son but hidden underneath his clothes. The harness and cane were joined with a complex but invisible linkage that allowed the magician to swing his son from vertical to horizontal. The illusion was featured on a 1971 postage stamp of France honoring the centennial of Robert-Houdin’s death. It shows his son horizontal in the air, supported under his arm by a thin cane standing on a stool mounted on a seemingly unsupported bench. (Both the son and the bench were cantilevered.)

This trick has evolved to the current day in various forms, one of which is the “broomstick suspension” in which Robert-Houdin’s

two canes are replaced by two broomsticks with their bristles facing up. This version even appeared in one episode of TV's *I Love Lucy*, with Orson Welles as the magician and Lucille Ball as "Princess Lu Cy" seemingly supported only underneath one arm by the bristles of a broomstick (containing a concealed iron bar). Harry Houdini later honored the memory of Robert-Houdin by borrowing part of his name, but in *The Unmasking of Robert-Houdin*, wrote that Robert-Houdin stole the "ethereal suspension" and others of his famous tricks from earlier magicians.

An earlier and simpler illusion, involving no body harness and no complex linkage to the vertical rod, consisted simply of a metal platform cantilevered a few feet above the ground, supported on one end by a firmly anchored vertical iron rod. The levitated person wears loose clothing to conceal the platform, and the clothing often hangs down to conceal the supporting rod. Where full concealment of the rod is not possible, he simply puts one hand on the upper end of the rod/cane "to keep his balance." This simple illusion is considerably older than Robert-Houdin's "ethereal suspension," but it created a sensation at an outdoor exhibition in South India in 1936, largely because photographs were taken and published in the *Illustrated London News*. The pictures, which can be seen today on the Web, show Yogi Subbayah Pullavar seemingly levitating a few feet above the ground in front of a crowd of 150 witnesses. Before the demonstration, Pullavar, platform, and rod support were inside a tent so that the assembly of the illusion could not be observed. Once it was ready, the tent flaps were opened for several minutes to amaze the audience with the levitating Yogi, and then closed again to allow the illusion to be disassembled. Recently a Dutch magician with the stage name of Ramana has revived this "Indian magic," performed the illusion on television, and even demonstrated it in Times Square.

Of course, more effective are levitation illusions in which there is no visible supporting cane or rod or broomstick, illusions in which the levitated body appears to be completely unsupported, simply floating in air. John Nevil Maskelyne, an English magician of the

nineteenth century, is usually credited with the invention of the first effective illusion of this kind. Here the magician's assistant could actually be seen to rise into the air (aided, of course, by magical hand gestures of the magician). It involved an assembly of fine wires to lift the platform on which the magician's assistant reclined. The structure was cantilevered and supported by an iron pillar that stood about a foot behind the platform and could slide up and down through the stage. The curvature of the rod connecting the platform to the pillar allowed Maskelyne to stand in front of the pillar and obscure it from the audience. The audience's view of the pillar was often also partly blocked by the assistant's loose clothing that hung below the platform as he or she was lifted. The most important component of the illusion was the "gooseneck" in the rod of the support structure, which allowed Maskelyne to pass a circular hoop over the levitated body "not once, but twice" to convince skeptics in the audience that no wires or pillars were involved. This was possible because although the hoop did indeed pass over the levitated body from head to toe, it avoided the wires and the pillar. After the first pass, the hoop was still linked into the gooseneck of the support structure, but by pulling it back through the gooseneck and passing it over the levitated body again, the hoop became free. So passing the hoop over the body "not once, but twice" was an absolutely necessary part of the illusion.

In *Levitation: Physics and Psychology in the Service of Deception*, Jim Ottaviani and Janine Johnston diagram in detail the Maskelyne "levi" trick, report how it was stolen by American magician Harry Kellar (Figure 1), and show how Kellar improved it, replacing the pillar with a second array of fine wires invisible to the audience. With no pillar to hide, the magician could now walk completely around the levitated body, usually the body of an attractive young woman appearing in Oriental clothing and introduced as Princess Karnak "from the mysterious East." (It was helpful if the "princess" was not only attractive and young but also not too heavy, thereby limiting the stress on the wires.) As with most illusions presented by magicians, the levitation was introduced and accompanied by an extensive

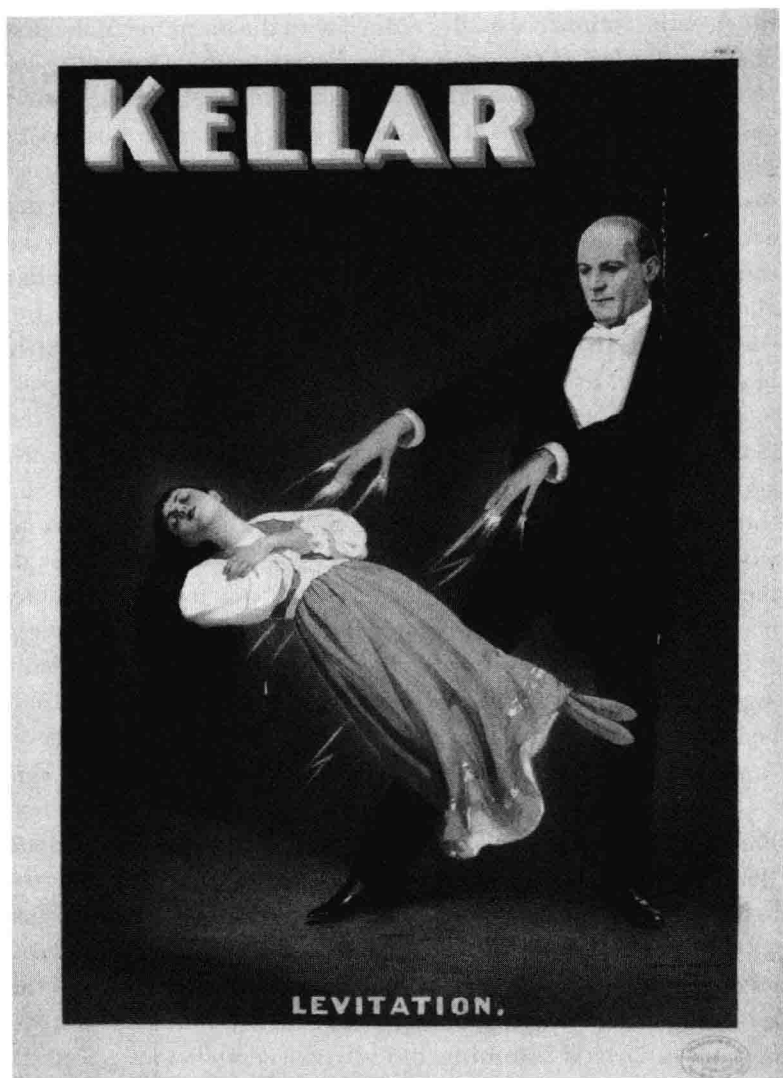


Figure 1. 1894 poster advertising famed levitation trick of magician Harry Kellar.