Floating Frogs

Magnets help living organisms defy gravity

By CORINNA WU

Asked to think of an animal that can fly, most people don't picture a frog. Nonetheless, in April, a team of British and Dutch researchers announced success in levitating a live frog by using a powerful magnet. According to one of the human observers, the frog emerged from the flight unharmed and "happily joined his fellow frogs in a biology department."

The amusing video image of the frog hovering in midair circulated widely and captured many people's fancy. The researchers received letters from all over the world inquiring about the demonstration. Their favorite came from the leader of a church who wanted to levitate himself to attract new members. "We have the One True Word to save the world," the letter read, "but we have to do magic tricks to get the people to listen."

The seeming ability to defy gravity is what delights most people, but the demonstration also highlights a more subtle idea that is often overlooked in everyday life—that many objects considered nonmagnetic do, in fact, possess magnetic properties. The water, proteins, and organic molecules that make up frogs and other living things are diamagnetic, which means that in the presence of a magnetic field they become weakly magnetized in such a way as to oppose the applied field.

Diamagnetism is what allowed the researchers to float the frog. Scientists are now looking into this phenomenon to simulate zero gravity and thus provide a low-cost substitute for experiments now possible only in outer space. They plan to tease out how the absence of gravity affects biological systems, especially developing embryos.

The National Aeronautics and Space Administration's obvious interest in low-gravity situations has fueled the myth that astronauts prepare for their missions in a top-secret antigravity chamber. Accordingly, many visitors to the Johnson Space Center in Houston are disappointed to find that NASA's low-gravity chamber is nothing more than a large swimming pool.

A pool is one of the few ways to simulate low gravity on Earth. Astronauts training for a mission wear weights to achieve what they call neutral buoyancy, a position under the water but not touching the pool bottom. Underwater suspension doesn't truly mimic weightlessness, however, says James M. Valles Jr., a physicist at Brown University in Providence, R.I. The water still pushes on the body, so the cells continue to experience stresses due to gravity.


Geim

A frog floats in the hollow core of an electromagnet.

Another low-gravity method involves an airplane nicknamed "the Vomit Comet," which flies up and down roller-coaster-style. The quick transitions from climbs to descents provide about half a minute of weightlessness at the top of each arc. Lengthier low-gravity experiments must be performed on the Space Shuttle or another such station in orbit.

Magnets can levitate small objects without the need for space flight. A popular toy known as a Levitron keeps a spinning top afloat above a special base. The permanent magnets in the top and the base are oriented so that similar poles—either two north or two south poles—point toward each other and therefore repel. That repulsive force makes it possible for the top to spin in midair.

With the advent of high-temperature superconductors, magnetic levitation of nonmagnetic material became an easy tabletop demonstration too. A chunk of superconductor can hover above an ordinary refrigerator magnet when cooled to liquid nitrogen temperatures or lower. A superconductor acts as a perfect diamagnet and excludes an applied magnetic field, says Simon Foner, former associate director of the Massachusetts Institute of Technology's Francis Bitter Magnet Laboratory. In effect, electrons within the superconductor move in a way that generates a field equal and opposite to the applied field. Because superconductors are such good diamagnets, a relatively weak magnetic field is enough to make them float.

Frogs are much poorer diamagnets. In the presence of a magnetic field, the electrons orbiting a frog's atoms generate an opposing field that has only a tiny fraction of the applied field's strength. It therefore takes a stronger applied field combined with a change in magnetic field, or gradient, to create enough repulsion to support a frog's weight.

To perform their trick, the researchers—from the University of Nijmegen in the Netherlands, the University of São Carlos in Brazil, and the University of Nottingham in England—used a powerful water-cooled solenoid magnet, a cylindrical coil wound from a few hundred turns of wire. Current passing through the wire creates a field whose north-south axis lies along the center of the coil and whose strength varies along the axis.

Placed in the hollow core of the coil, a vertical tube a few inches in diameter, the frog generates a diamagnetic field that could theoretically be detected by a compass, says Nijmegen's Andre Geim.

When the frog is in an area of the magnet where it experiences a large combined effect between the gradient in the applied magnetic field and field strength, a repulsive force pushes the frog up. At the point where magnetic repulsion and gravity exactly counterbalance each other, the frog floats.

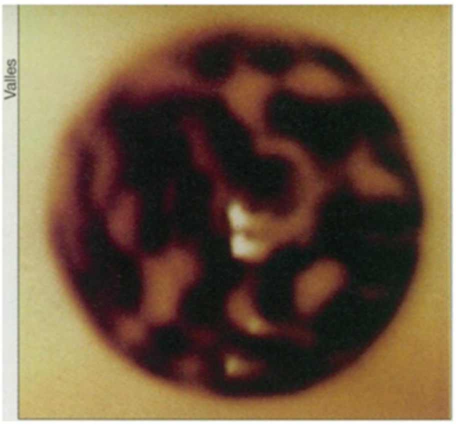
Even though the magnetic field needed to levitate the frog is much larger than that of a household magnet, it's still low enough to be reproduced easily in a laboratory. "It takes only 100 times higher fields" than for the superconductor demonstration, says Geim. The relative ease of levitating a frog "appeared to be strikingly counterintuitive for many, including myself and my colleagues."

Many scientists tend to discount the effect of magnetic fields on water and organic materials, Geim notes, because the response of those materials to a magnetic field is a billionth of iron's response. A sufficiently strong magnetic field can levitate almost anything—and do it at room temperature, the researchers argue.

Geim says that he and his colleagues have levitated frogs, grasshoppers, plants, and water droplets to "break down the prejudice that the world around us is nonmagnetic." They aren't planning on pursuing the research much further; however, Valles, along with biologist Kimberly L. Mowry and their colleagues at Brown, has been focusing on magnetic levitation as a way of studying gravity's effect on the development of frog embryos.

The group's preliminary results show that magnets may provide a way to cheat the maxim that any experiment performed on Earth comes under the influence of gravity. Working at Bitter Lab, the researchers first levitate water droplets in a solenoid magnet, then add frog embryos to them.

They keep the embryos suspended in the magnet long enough to see the single cells divide into eight. By measuring the density of the embryos, the researchers determined that the gravitational forces on the embryos were one-tenth of normal values. Valles, Mowry, and their colleagues reported their findings in the August BIOPHYSICAL JOURNAL.


Valles

Free of gravitational stresses, a levitating water droplet filled with frog embryos assumes the shape of a perfect sphere.

More recent experiments have shown developmental effects, which the researchers plan to describe in future publications. Interpreting the results is more complicated than analyzing Space Shuttle experiments, which showed no abnormalities in frogs raised in zero gravity.

The magnetic fields themselves may have some effect on the frogs' development, says Valles. Previous studies by other groups showed that fields less than half as strong as those in the Brown experiments don't affect frog development.

Valles and his colleagues are separating the effects of gravity from those of the magnetic field by comparing the floating embryos to controls placed in the center of the coil, where embryos experience the magnetic field but do not float.

If frogs can float, why can't humans? No reason, says Geim. The magnetic field wouldn't need to be any stronger, since the levitation acts atom by atom. As long as the magnet is strong enough to magnetize each atom in a person, that person will float.

Constructing a magnet large enough to fit a human would be very expensive, however. "I believe that it is not a good idea to levitate a human—a complete waste of money for no reason," Geim says. "But technically, it is possible."

Nevertheless, since time and space are at a premium on space flights, magnetic levitation may be a good way to test proposed experiments before sending them on such an expensive mission. "The magnet would cost such a miserable fraction of the costs of a microgravity space lab launch that even one fault found in a setup of a single experiment would be worth it," Geim says.

"In any case, a space mission would [need to] be the final proof for any observation," he adds.

Geim doesn't consider the floating frogs a "scientific discovery," since the physics that explains it has been known for years. The demonstration does show, however, that scientists may not need to leave the ground to see their ideas fly. □