PHYSICS

Textbook Electrodynamics May Contradict Relativity

A basic equation of electricity and magnetism is wrong, one scientist claims. The classic formula for the force exerted by electric and magnetic fields—the so-called Lorentz force—clashes with Einstein's special theory of relativity, says Masud Mansuripur, an electrical engineer at the University of Arizona in Tucson. Others doubt the claim but have not found a flaw in the simple argument that challenges century-old textbook physics.

"If it's true, it's astonishing," says Stephen Barnett, a theorist at the University of Strathclyde in Glasgow, U.K. "I suspect there is something subtle going on here" that doesn't contradict relativity. But Rodney Loudon, a theorist retired from the University of Essex in the United Kingdom, says, "As far as I can tell, [the analysis] is right."

The Lorentz force formula describes how electric and magnetic fields push around a charged particle. The electric field pushes the particle with a force proportional to the particle's charge and the field's strength. (A negatively charged particle feels a pull.) The magnetic field shoves the particle sideways in a direction perpendicular to both the field and the particle's velocity. That magnetic force is proportional to the charge, the velocity, and the field strength.

Ironically, physicists invoke the Lorentz force in the textbook example of how electrodynamics and relativity mesh. A positively charged particle moves parallel to a wire carrying current in the same direction (see figure, top left). The current produces a magnetic field that wraps around the wire. As the particle crosses the field, it feels a magnetic force pulling it toward the wire.

From the particle's perspective, things look very different. In that "frame of reference," the particle stands still while the wire moves. The wire still exudes a magnetic field, but because the particle has no velocity it feels no magnetic force. Yet relativity demands that if an observer in one frame of reference sees a force, an observer in another frame should see an equal force.

A contradiction? Not quite, thanks to special relativity's weird prediction that observers moving at different speeds perceive lengths differently. Those lengths include the distances between the positively charged ions that form the wire and the negatively charged electrons that flow to produce the current. In the lab frame, the wire is stationary, and the ions and electrons are equally spaced. In the particle's frame, however, the wire moves and its ions appear more closely spaced than they are in the lab frame. But the oncoming electrons move faster still and appear even closer together. The wire thus has a net negative charge (see figure, top right). That charge draws the particle with *electric* force equal to the magnetic force seen in the lab frame. Paradox averted.

Now, an equally simple example shows how the Lorentz force trips up when applied to magnetic particles, Mansuripur argues in a paper in press at *Physical Review Letters*. A charged particle and a tiny magnet sit apart in the lab frame (see figure, bottom left). The uncharged magnet cannot feel the charged particle's electric field, and the motionless particle cannot feel the magnet's magnetic field. So no forces are at work.

Now consider how things appear to an observer in a "moving frame" in which the magnet and the charge glide past together (figure, bottom right). The magnet appears to be electrically polarized, with a positive charge on one side and a negative charge on the other. That's because in classical electrodynamics, magnetism originates from hypothetical loops of "bound" current within a material. So the magnet is equivalent to a ring of wire carrying current in a circle. As the ring coasts by the observer, contraction effects will redistribute the charges in it just as they did in the current-carrying wire in the first example. On the side of the loop in which current flows in the same direction as the loop's motion, a positive charge appears. On the other side, a negative charge appears.

The charged particle interacts with these charges, pulling on one side of the magnet and pushing on the other to create a twisting "torque." The moving charge also produces a magnetic field, but that field does not counteract the twisting. So there's a net torque not seen in the lab frame, Mansuripur calculates. That violates relativity.

There is a way out, Mansuripur says: No torque appears in either frame if he uses a more complicated formula for forces in polarized and magnetized materials that Einstein and Jakob Laub proposed in 1908 but Einstein later repudiated. Some theorists say that's fine with them. "Einstein-Laub is correct—shock and horror!" says Daniel James of the University of Toronto in Canada.

But there's a deeper issue. In classical electrodynamics, physicists assume that magnetization and polarization originate in microscopic bound currents and charges within materials. If that's true and the Lorentz formula is correct on the microscopic level, then they must apply it to macroscopic materials, too, and run afoul of relativity, Mansuripur argues. So, he says, physicists must scrap bound charges and currents and consider polarization and magnetization fundamental entities themselves.

Them's fighting words to some. "The microscopic picture of electrodynamics is clear," James says, "and if the macroscopic picture of electrodynamics doesn't follow from that, I'd be surprised." Somehow, the Einstein-Laub equation for macroscopic materials must follow from the Lorentz force applied on the microscopic level, he says. Barnett says "there's going to be a heated debate about this result." Undoubtedly.

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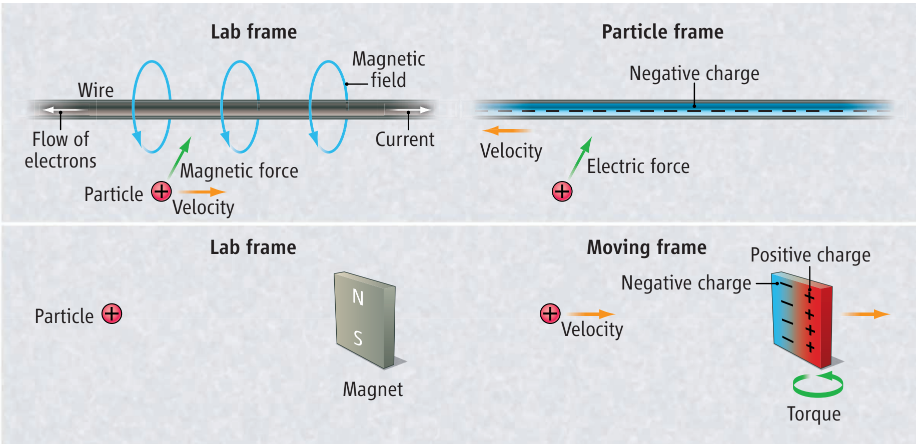

Hit and miss. Simple examples show how the Lorentz force jibes (*top*) and clashes with relativity.

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