Lenz's Law Magic Trick

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The demonstration of Lenz's law by dropping a powerful magnet down a nonmagnetic metal pipe has become a classic lecture-hall demonstration.[1,2] An inexpensive version is packaged as a professional magic trick[3] called "Newton's Nightmare." Combining sleight-of-hand with a demonstration of Lenz's law is a surefire way to heighten student interest. The subsequent student discussion motivated by a desire to understand the magic trick can lead to a memorable physics lesson. This paper will discuss Lenz's law magic and review literature that reveals the subtlety of the physics.

My interest in combining magic with the Lenz's law demonstration began when local magician Ricky D. Boone[4] of Magic Central emailed me a description of a new magic trick called "Newton's Nightmare." I immediately recognized the Lenz's law demonstration and was in the magic shop before the end of the afternoon.

I obtained "Newton's Nightmare" for about $20, which includes a coated (blue anodized) aluminum pipe about 25 cm (10 in) in length with four "flute-like" holes so that the observer can see the magnet fall slowly down the hollow cylinder. In addition, I received two small solid cylindrical objects to drop through the pipe: a brass one and a strong neodymium magnet made to look just like the brass one. The brass object takes

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2\ (25\,\text{cm})}{980\ \text{cm}/\text{s}^2}} = 0.23\ \text{s}$$

to fall through the pipe, while the magnet majestically "floats" down, taking a long 3.3 s to fall through the aluminum pipe.

As I considered the possibility of performing the trick for my physics class, I feared the maneuvers to exchange the two small cylindrical objects at will were too simple to be convincing. I would most likely bungle the moves anyway. However, most magical effects are indeed simple. The professional magician practices so that simple moves go effortlessly undetected with effective results.

Fig. 1. Alicia Henry (UNCA staff) and "Newton's Nightmare."
(Photo by author)

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The trick is called "Newton's Nightmare" because the recommended routine has the magician claiming to "remove gravity" from inside the tube. But that claim is too naive for any physics class. Instead, I misdirect students' attention so that the sleight of hand will be least expected. I ask them what they know about gyroscopes and stability. I tell them that if you gently spin a brass cylinder within anodized walls, a strange effect will be observed as the cylinder falls. I ask a student to give the brass cylinder a slight spin and release it into the tube at the same time.

Of course it falls straight through quickly. I then execute the switch and explain that the spin was not quite right. I appear to spin it and the object cruises down 10 times slower. I switch the objects again and ask my volunteer to retry the drop. Of course, it doesn't work. That's because I am the magician with the magic touch.

Enough about magic. What about the physics? What is the kinematic description of the motion? Careful measurement in this type of demonstration shows that the magnet reaches terminal velocity almost immediately and drops at constant velocity.[5] So for most of the trip we have $a = 0$ and a terminal velocity essentially equal to

$$v = \frac{h}{t} = \frac{25\ \text{cm}}{3.3\ \text{s}} \approx 8\ \text{cm/s}.$$

A student can quickly verify constant velocity in an approximate sense by clapping each time the magnet passes one of the four holes. The claps are very regular. A musician can help here, ascertaining the steadiness of the tempo. This is one advantage of the holes in the pipe. One can also proceed to illustrate Newton's third law with a scale in the usual way.[6]

The insertion of the magnet into the cylinder produces a magnetic field inside the pipe. A magnetic field appearing in a section of pipe during the trip induces currents in the cylinder that produce a magnetic field to oppose the falling magnet. Terminal velocity is arrived at since a greater speed produces a greater change of magnetic flux, which in turn produces a stronger retarding force.

More advanced students can be asked the following questions: Why is it reasonable to take the retarding force proportional to the velocity? What can be said about the constant of proportionality (the drag coefficient) if the terminal velocity is reached quickly? What is the solution of the differential equation involving the gravitational force and the drag force? The graph of the solution resembles the charging of a capacitor.[7]

Some students viewing the demonstration from afar may erroneously conclude that the pipe has magnetic properties. It can be readily demonstrated that the pipe is nonmagnetic by placing together the magnet and pipe. There is no effect. For comparison, have the student place the strong magnet on the side of a steel filing cabinet and attempt to pull it off. Students can then be led to discuss the importance of the electrical properties (conductive) of the cylindrical pipe, Faraday's law, Lenz's law, and Ampère's law.

The concluding example in Saslow's comprehensive paper on Maxwell's equations and eddy currents provides a detailed formula for the terminal velocity of a magnet falling down a conducting tube.[8] Pelesko, Cesky, and Huertas cleverly arrive at the terminal velocity formula within a constant proportionality factor using a combination of elementary physics and dimensional arguments.[9] Related models with innovative data techniques and analysis can also be found in the literature.[5,7,10]

The magic version of the Lenz's law demonstration was put together by magician William J. Schmeelk of Wellington Enterprises and presented in its larger deluxe form at the 2003 Convention of the Society of American Magicians. The smaller demonstration discussed in this article became available afterward. As you can see by its size in Fig. 1, the trick makes for an inexpensive demonstration very rich in physics for classrooms that are not too large.

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References

1. Examples include the Lenz's Law Demonstrator from PASCO (MG-8600, a 1.5-meter tube) and the Lenz's Law Apparatus (CENCO) available from Sargent-Welch (CP32691-00, a 91.4-cm tube). These are constructed so that an attached spring scale can be used to also demonstrate Newton's third law.
2. Lenz's Law Apparatus (P8-8400) from Arbor Scientific. This is a small version with a viewing-window slot along most of one side of the pipe. I first learned about

this one from my departmental colleague Forest Davenport.

3. "Newton's Nightmare," created by William J. Schmeelk of Wellington Enterprises for FUN Inc., 2100 N. Major Ave., Chicago, IL 60639, can be purchased from magic shops (both local and online).
4. Magician Ricky D. Boone, Magic Central, 175 Weaverville Highway, Suite L, Asheville, NC 28804.
5. Jhules A. M. Clack and Terrence P. Toepker, "Magnetic induction experiment," *Phys. Teach.* **28**, 236–238 (April 1990).
6. The aluminum pipe has a mass of 72 g and it can be placed vertically on a laboratory electronic balance. The magnet, which has a mass of 12 g, can gently be released without tipping over the pipe. The scale rapidly jumps to 72 + 12 = 84 g as the magnet makes its way down the hollow cylinder.
7. Joseph Priest and Bryant Wade, "A Lenz law experiment," *Phys. Teach.* **30**, 106–108 (February 1992).
8. W. M. Saslow, "Maxwell's theory of eddy currents in thin conducting sheets, and applications to electromagnetic shielding and MAGLEV," *Am. J. Phys.* **60**, 693–711 (Aug. 1992).
9. John A. Pelesko, Michael Cesky, and Sharon Huertas, "Lenz's law and dimensional analysis," *Am. J. Phys.* **73**, 37 (Jan. 2005).
10. Charles A. Sawicki, "Lenz's law: Feel the force," *Phys. Teach.* **34**, 38–39 (January 1996); "A Lenz's law experiment revisited," *Phys. Teach.* **38**, 439–441 (Oct. 2000).

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