ANSWER KEY. Values match the simulation readouts for the settings in each step.

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Faraday's Law Virtual Lab

Physics | ANSWER KEY

Open **activities.zornscience.org/faraday-lab/** and follow each step. Use g = 9.81 m/s^2. Show your work with units.

Objective

Drop a magnet through copper and plastic tubes to find how a **changing magnetic field** produces currents, and how those currents slow the magnet (**Lenz's law**).

NGSS alignment: HS-PS2-5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

Practices and concepts: Carrying out investigations; Constructing explanations; Cause and effect; Energy and matter.

Meet the simulation

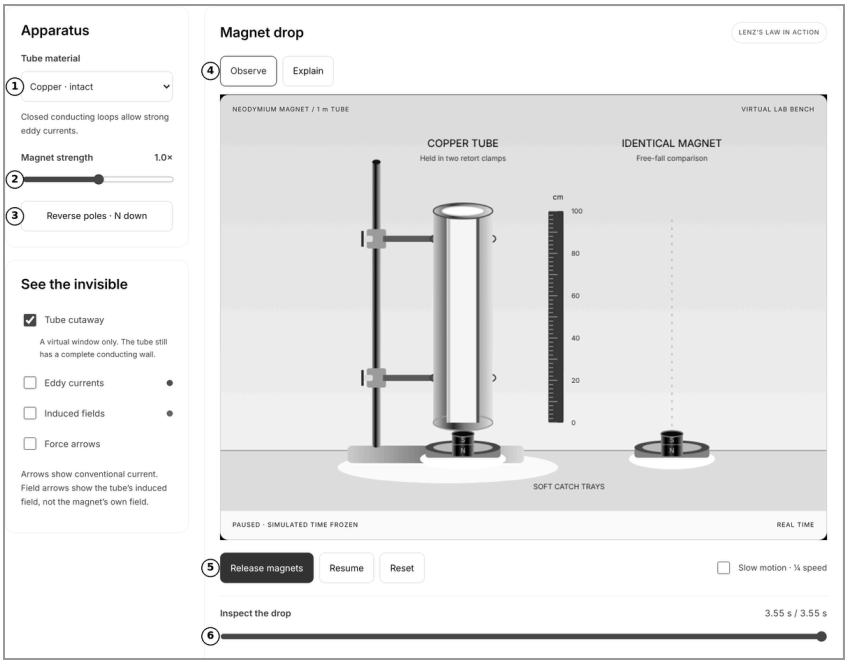


Figure 1. The magnet drop after a copper drop. The scene is shown inverted for printing.

(1) Tube material: intact copper, slotted copper or plastic.

(2) Magnet strength, 0.5× to 1.5×. Mass stays the same.

(3) Reverse poles: N down or S down.

(4) Observe hides overlays. Explain shows currents, fields and forces.

(5) Releases both magnets together.

(6) Inspect the drop: drag to pause. Readout: time / total drop time.

The right magnet falls freely for comparison. Changing a setting resets the drop.

Pre-lab

1. Copper is not attracted to a magnet. Predict: will a magnet dropped through a copper tube fall faster, slower, or at the same rate as one in free fall? Explain.

Any reasoned prediction. Correct result: much slower. The moving magnet induces currents in the copper, and their magnetic fields push up on the magnet.

2. Faraday's law says a current is induced in a loop when the **magnetic flux** through it changes. What is magnetic flux? Name two ways to change it.

The amount of magnetic field passing through a loop. Change it by moving the magnet closer or farther, changing the field strength, changing the loop's area, or turning the loop.

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3. Calculate how long a magnet takes to free fall 1.00 m from rest.

$d = \frac{1}{2}gt^2$, so $t = \sqrt{(2d/g)} = \sqrt{(2(1.00\ m) / 9.81\ m/s^2)} = \underline{0.452\ s}$

Part A. Copper, slotted copper and plastic

1. Keep **Magnet strength** at 1.0× and the poles at **N down**. Select **Observe**.
2. Choose each tube material. Select **Release magnets** and watch both magnets.
3. When both magnets are caught, record the total drop time (the second number in the **Inspect the drop** readout).

Tube material	Which magnet lands first?	Total drop time (s)	Braking: strong, weak or none?
Copper, intact	**free magnet**	**3.55**	**strong**
Copper, lengthwise slot	**free magnet, barely (nearly a tie)**	**0.50**	**weak**
Plastic, insulating	**tie**	**0.48**	**none**

4. Compare the plastic drop time with your answer to question 3. Why does plastic not slow the magnet at all?

0.48 s is close to 0.452 s (the magnets fall slightly past the 1 m tube into the trays). Plastic is an insulator, so no current can flow in it, and without current there is no magnetic force on the magnet.

5. The copper drop takes how many times longer than the plastic drop? The slotted tube is still copper. Why does the slot remove almost all of the braking?

3.55 s / 0.48 s = <u>7.4 times</u> longer. The slot breaks the circular path around the tube, so large loops of current cannot flow. Only small local currents remain, so the braking is weak.

Part B. Magnet strength

1. Choose **Copper, intact**. Set **Magnet strength** to each value below and release. Record the total drop time.

Magnet strength (×)	0.6	0.8	1.0	1.2	1.4
Total drop time (s)	**1.40**	**2.33**	**3.55**	**5.03**	**6.78**

6. Is drop time directly proportional to magnet strength? Doubling the strength from 0.6× to 1.2× multiplies the drop time by what factor? Why would a stronger magnet brake harder?

No. 5.03 s / 1.40 s = <u>3.6</u>, much more than 2 and close to 4 (2^2). A stronger magnet makes a larger change in flux, which induces a larger current, and that larger current pushes back on a stronger magnet. Both effects grow, so braking grows about as strength squared.

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Part C. Lenz's law at one ring of the tube

1. Set **Copper, intact**, strength **1.0×**, **N down**. Select **Explain**, then **Release magnets**.
2. Drag the **Inspect the drop** slider until the readout shows **1.00 s**, then **2.00 s**. At each time, read the ruler at the magnet's center (the line between S and N) and read the panel **At the fixed copper ring** under the slider.
3. Select **Reverse poles** (now S down), release, and drag to **1.00 s** again.

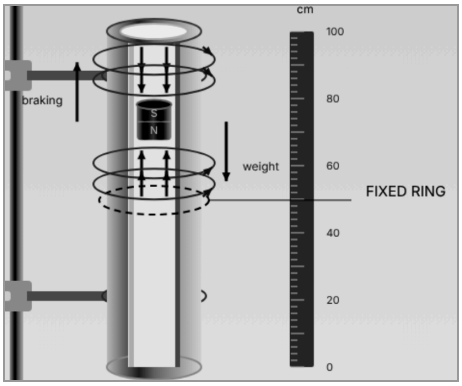


Figure 2. N down at 1.00 s.

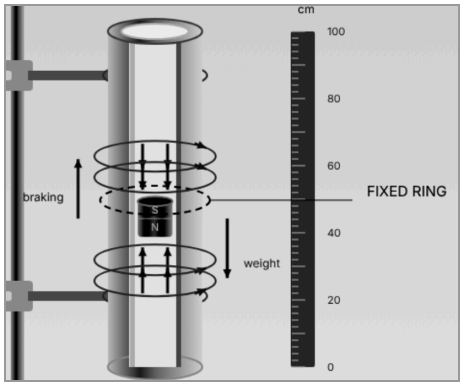


Figure 3. N down at 2.00 s.

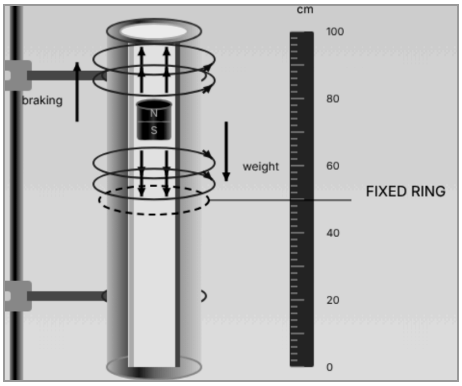


Figure 4. S down at 1.00 s.

Rings: eddy currents. Arrows inside the tube: induced field. The dashed ring is the fixed ring at the 50 cm mark.

Setting	Magnet position on ruler (cm)	Approaching or leaving the ring?	Flux through ring: increasing or decreasing?	Induced field: up or down?	Current viewed from above
N down, 1.00 s	**about 73**	**approaching**	**increasing**	**up**	**counterclockwise**
N down, 2.00 s	**about 44**	**leaving**	**decreasing**	**down**	**clockwise**
S down, 1.00 s	**about 73**	**approaching**	**increasing**	**down**	**clockwise**

7. Lenz's law says the induced current makes a magnetic field that opposes the *change* in flux. Use the first two rows to show this. Why does the current reverse as the magnet passes the ring?

The N pole's field points down. Approaching: downward flux is increasing, so the induced field points up to oppose the increase. Leaving: downward flux is decreasing, so the induced field points down to replace what is lost. The change in flux switches from increasing to decreasing at the ring, so the current reverses.

8. Reversing the poles reversed the current. Did it change the braking force (Figures 2 and 4)? Explain why the force on the magnet is up either way.

No. Braking is still upward and the drop time is still 3.55 s. The current loop below acts like a magnet that repels the pole coming toward it, and the loop above attracts the pole moving away. Flipping the magnet flips both the poles and the currents, so the force always opposes the motion.

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9. Use your ruler readings to estimate the magnet's speed between 1.00 s and 2.00 s. What does the force arrow diagram show about the forces at this speed?

$v = \Delta d / \Delta t = (0.73\ m - 0.44\ m) / (1.00\ s) \approx$ <u>0.29 m/s</u> (answers from 0.27 to 0.31 m/s are fine). The upward braking arrow is equal to the downward weight arrow: the forces are balanced, so the magnet falls at a constant terminal speed.

10. A 50.0 g magnet falls 1.00 m through the copper tube at a terminal speed of 0.29 m/s. Calculate its loss of gravitational potential energy and its kinetic energy. Where did the rest of the energy go?

$\Delta PE = mgh = (0.0500\ kg)(9.81\ m/s^2)(1.00\ m) =$ <u>0.491 J</u>. $KE = \frac{1}{2}mv^2 = \frac{1}{2}(0.0500\ kg)(0.29\ m/s)^2 =$ <u>0.0021 J</u>. About 0.49 J became thermal energy in the copper, through the eddy currents.

11. The simulation leaves out air resistance and uses a simple model of the braking. Give one way a real copper-tube drop might differ from the simulation, and one real use of magnetic braking.

Differences (any one): the real time depends on the tube's wall thickness, the magnet's real strength and size, and temperature; the magnet can rub the wall; air resistance adds a little drag. Uses (any one): roller coaster and train brakes, exercise bikes, metal sorting in recycling, damping in balances.

Conclusion

12. Write a claim that explains why a magnet falls slowly through a copper tube but not through a plastic tube. Support it with evidence from Parts A and C, then explain your reasoning with Faraday's law and Lenz's law.

Claim: The falling magnet changes the magnetic flux through the copper, which induces eddy currents. Their magnetic fields oppose the change and push up on the magnet. Plastic cannot carry current, so there is no braking.
Evidence: Copper took 3.55 s, slotted copper 0.50 s, and plastic 0.48 s (same as free fall). At one ring the current was counterclockwise as the N-down magnet approached and clockwise as it left, and braking stayed upward when the poles were reversed.
Reasoning: Faraday's law: a changing flux induces a current in a closed conducting loop. Lenz's law: the induced field opposes the change in flux, so the force opposes the motion. Breaking the loop (slot) or using an insulator (plastic) stops the current, and the braking disappears. The magnet's lost potential energy becomes thermal energy in the copper.

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