Generating induced currents

Activity 1 explanation sheet

Varying the magnetic field

Experiment A

When the magnet is dropped through the tube with the three coils, the light bulbs are observed to flash one after another.

As the magnet falls through the tube, it produces a change in the magnetic flux through each coil, thereby inducing an electromotive force (EMF) that generates a current in each coil. It is this generated current that causes the observed flashes in the light bulbs. Note that the induced current only lasts while the magnetic flux through the coil is changing. Once the flux returns to zero and remains there, the current ceases.

The brightness of the flashes from the three bulbs is not the same. We observe that the lower the coil, the more intense the flash. As the magnet drops, it undergoes uniformly accelerated motion. This means that the rate of change in magnetic flux through the upper coil is smaller than that through the lower coils. In other words, as the velocity of the falling magnet increases, so does the variation in flux through successive coils, resulting in a greater induced current and brighter flash. From this we can conclude that the induced EMF is proportional to the rate of change of the magnetic flux.

Experiment B

In the case of the three PVC tubes with different numbers of turns in their coils (400, 230 and 110 turns) fastened to their lower ends, the falling magnets produce flashes of different intensity in each tube. The greater the number of turns in the coils, the brighter the flash. Therefore, we can conclude that the induced EMF is proportional to the number of turns in the coil.

Experiment C

In the case of the tube with the red and green LEDs, we observe that, when the magnet is dropped through the tube, one LED turns on first, followed by the other. Since LEDs are diodes, current can only flow through them in one direction. As the red and green LEDs are connected in parallel and in opposite directions, one or the other will light up depending on the direction of the induced current in the coil. The direction of the induced current follows Lenz's law and depends on whether the magnetic flux through the coil is increasing or decreasing (i.e., whether the falling magnet is approaching the coil or receding from it) and the direction of the magnetic field producing this flux.

The situation is illustrated in figure S1 for the case of a downward-pointing magnetic field B_{stack}. Panel (a) shows the moment just before the magnet is dropped. At this point, the magnetic flux through the coil is zero, as is the induced current. In panel (b), the magnet is falling towards the coil and is close enough to it to generate a magnetic flux through it. As the magnet approaches the coil, the flux increases ($d\varnothing/dt > 0$) and, following Lenz's law, the induced current opposes this increase by generating a magnetic field B_{ind} that is opposite to the original field B_{stack}. This results in a counterclockwise current that lights up the green LED. In panel (c), the stack has fallen past the coil and is moving away from it. The flux decreases ($d\varnothing/dt < 0$), and, following Lenz's law, the induced current opposes this decrease by generating a magnetic field B_{ind} that reinforces the original field B_{stack}. This results in a clockwise current that lights up the red LED.

If the stack of magnets were turned upside down before being dropped through the tube so that the magnetic field B_{stack} pointed upwards, the order of the flashes would reverse.

From this we can conclude that the induced EMF generates a current that always opposes the change in flux. (Lenz's law)

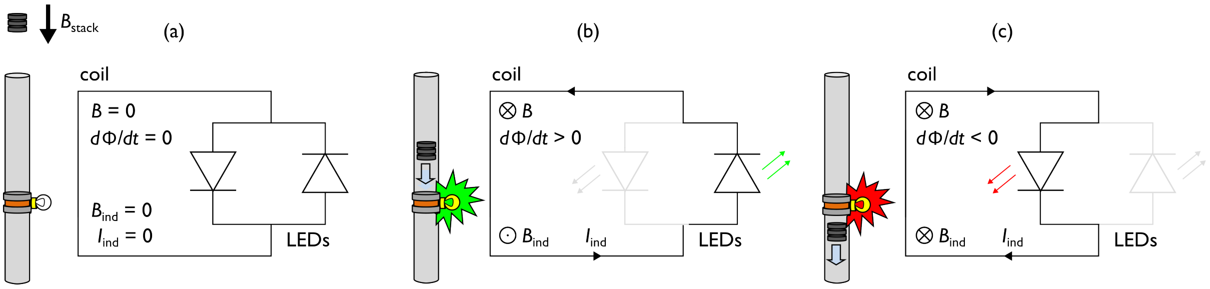

Figure S1: Diagram of experiment C showing the circuit made up of the coil and the two LEDs as seen from above. The magnetic field of the stack of magnets B_{stack} points downwards (i.e., into the page when viewing the circuit diagrams). The stack's magnetic field of the coil B, the sign of $d\varnothing/dt$ and the induced field and current (B_{ind} and I_{ind}) are shown in (a) before the magnet is dropped, (b) as the magnet approaches the coil and (c) as the magnet recedes from the coil. The direction of the induced current follows Lenz's law and changes the moment the magnets fall past the coil.
Image courtesy of the authors

As stated previously, the magnitude of the induced EMF in the experiments described above is given by the magnetic flux through a coil of *N* turns is:

$$\emptyset_m = N \cdot \vec{B} \cdot \vec{S} = N \cdot B \cdot S \cdot \cos\Theta.$$

The magnet's magnetic field *B* is approximately perpendicular to the coil's surface (see figure 6 in the main text) so we can set θ = 0 and the equation above reduces to

$$\emptyset_m = N \cdot B \cdot S$$

Combining Faraday's law with this, we can obtain the induced EMF in terms of *N, S* and *dB/dt*:

$$\varepsilon_{ind} = -\frac{\Delta\emptyset_m}{\Delta t} = \frac{d(N \cdot B \cdot S)}{dt} = -N \cdot S \cdot \frac{dB}{dt} \ .$$

In our experiment, it is the rate of change of the magnet which determines the change in flux and therefore the induced EMF. Furthermore, the EMF is proportional to <u>N</u>.

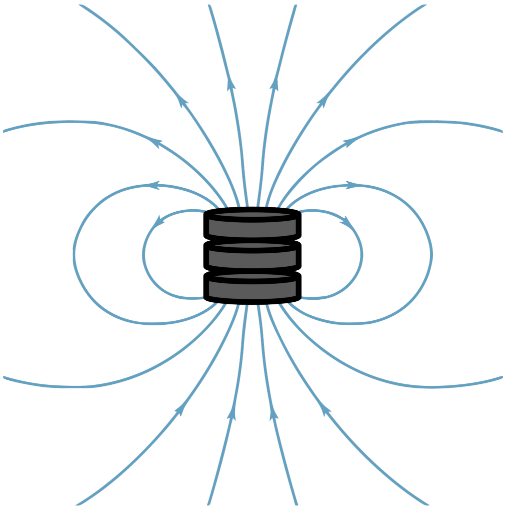

Figure S2: The magnetic field of the stack of magnets is shown. Near the magnet's surface, the magnetic field is perpendicular to the stack.

Image courtesy of the authors