

MAGNET FALLING THROUGH A METAL PIPE

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References: Griffiths, David J. (2007), Introduction to Electrodynamics, 3rd Edition; Pearson Education - Problem 7.14.

You might think that if you dropped a magnet down a pipe made of some non-magnetic metal such as aluminum or copper, that the magnet would just fall straight through at the same rate as if it were dropped in air. However, if we think about the situation using Faraday's law and Lenz's law we can get an idea of what really happens. Faraday's law states that the emf generated in a circuit is determined by the rate of change of magnetic flux through that circuit, according to

$$\mathcal{E} = -\frac{d\Phi}{dt}$$

and Lenz's law states that the direction of the induced current is such that its magnetic field opposes the change in flux.

Consider a thin cross-sectional slice through the pipe; this essentially constitutes a circular loop of wire. Before the magnet is dropped into the pipe, the magnetic flux through all such slices is essentially zero. As the magnet falls through the pipe, the flux in a given slice increases as the leading edge of the magnet approaches, so a current is induced in the slice. The magnetic field due to this current attempts to oppose the flux change, so it produces a flux opposing that from the magnet. In terms of the magnetic field lines, if the field emanating from the magnet points downwards at the leading edge (it also spreads out, but the overall effect is a downward pointing field), the induced current produces field lines pointing upwards. Thus the two fields repel each other, slowing the magnet's descent.

As the mid-section of the magnet passes a slice, the flux remains essentially constant, since the field inside the magnet is pretty well constant (as in the interior of a solenoid), so no current is induced in slices as the mid-section of the magnet passes.

When the trailing end passes, the flux decreases, so the induced current attempts to counter this by providing a field that increases the flux. The field due to the magnet points into the trailing edge, so still points downwards. Since this flux is decreasing, the induced current produces a field in the same direction as that from the magnet, so the direction of the current is

opposite to that at the leading edge. This time, the two fields attract, so the force again reduces the speed of the magnet as it falls. Thus the two induced currents at either end of the magnet both slow the magnet down.