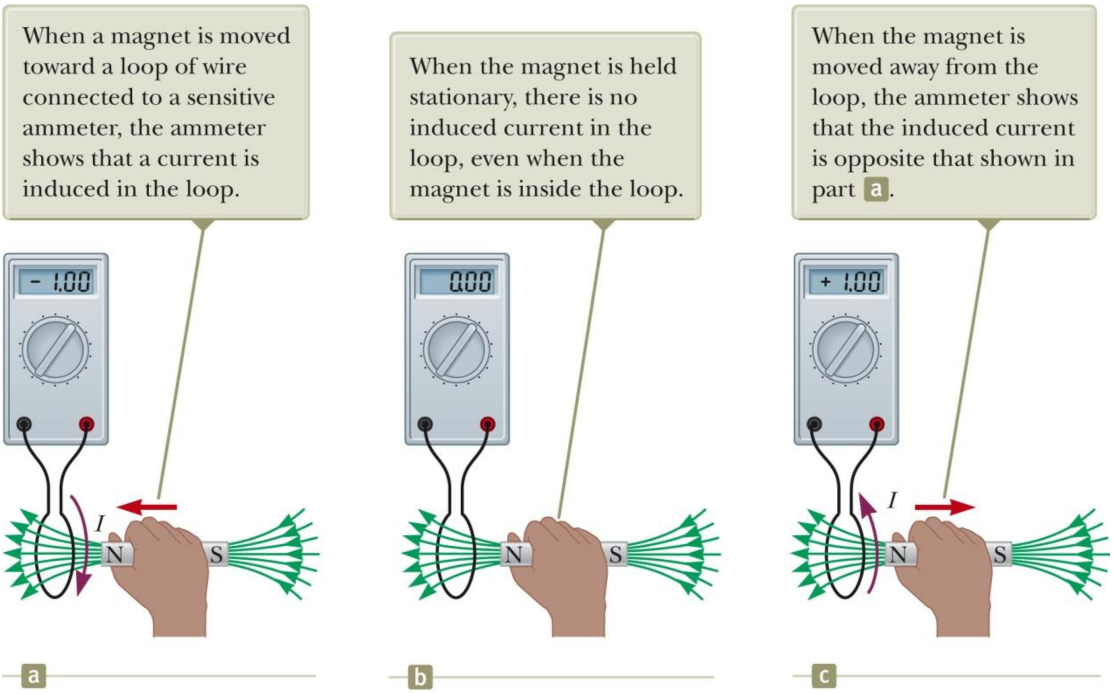
Chapter 30

Faraday's Law

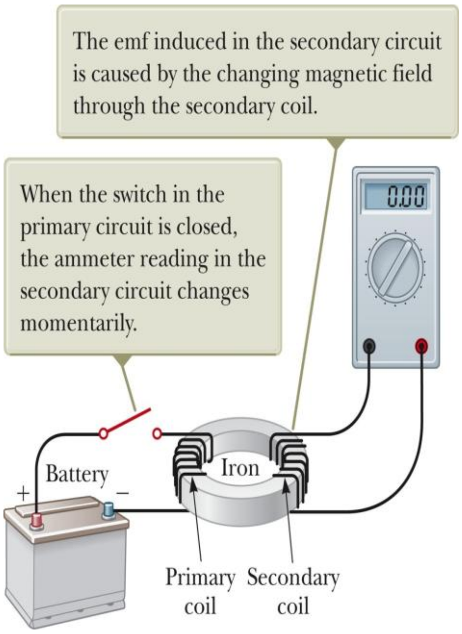
30.1 Faraday's Law of Induction



Simulation: https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_all.html

Faraday's Experiment:

Experimentalists, including Faraday and Henry et al., found that an emf is induced in a circuit when the magnetic flux through the circuit's surface changes.



- The emf induced in a circuit is directly proportional to ***the time rate of change of the magnetic flux through the circuit***.

Mathematically,

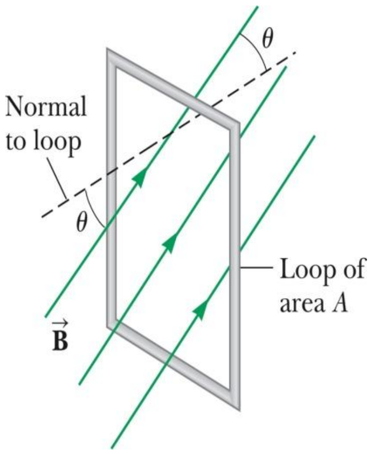
$\varepsilon = -\frac{d\Phi_B}{dt}$

Remember, Φ_B is the magnetic flux through the circuit and is found by:

$$\Phi_B = \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$$

If the circuit or coil consists of N loops, all of the same area, and if Φ is the flux through one loop, an emf is induced in every loop, and Faraday's law becomes

$$\varepsilon = -N\frac{d\Phi_B}{dt}$$



Assume a loop enclosing an area A lies in a uniform magnetic field.

The magnetic flux through the loop is

$$\Phi_B = BAcos_\theta$$

Then, the induced emf can be written as:

$$\varepsilon = -\frac{d}{dt}(BAcos_\theta)$$

Ways of Inducing an EMF:

- ✓ The magnitude of the magnetic field can change with time.
- ✓ The area enclosed by the loop can change with time.
- ✓ The angle between the magnetic field and the normal to the loop can change with time.
- ✓ Any combination of the above can occur.

Why the Negative Sign? (Lenz's Law)

The negative sign is there to represent Lenz's Law, which states:

The induced emf (and the resulting current) always acts in such a direction that it opposes the change in magnetic flux that produced it.

Physical Meaning

If the magnetic flux through a loop increases, the induced current creates a magnetic field that opposes the increase (tries to reduce the flux).

If the flux decreases, the induced current creates a magnetic field that reinforces it (tries to increase the flux again).

This opposition is a direct consequence of energy conservation — if the induced current aided the change, energy would appear out of nowhere.

Example1 :

A coil consists of 200 turns of wire. Each turn is a square of side 18 cm, and a uniform magnetic field directed perpendicular to the plane of the coil is turned on. If the field changes linearly from 0 to 0.50 T in 0.80 s, what is the magnitude of the induced emf in the coil while the field is changing?

Solution:

Induced emf.

$\varepsilon = -N\,(d\Phi B / dt) = -N\,A\,(dB / dt)$

$A = (0.18\,)^2 = 0.0324\ m^2$

$\varepsilon = -200 \times 0.0324 \times (0.50 / 0.80) = 4.05\ V$

Example 2:

A flat loop of wire consisting of a single turn of cross-sectional area 8.00 cm² is perpendicular to a magnetic field that increases uniformly in magnitude from 0.500 T to 2.50 T in 1.00 s. What is the resulting induced current if the loop has a resistance of 2.00 Ω?

Given

Area: $A = 8.00\ cm^2 = 8.00 \times 10^{-4}\ m^2$

Magnetic field change: $\Delta B = 2.50\ T - 0.500\ T = 2.00\ T$

Time interval: $\Delta t = 1.00\ s$

Resistance: $R = 2.00\ \Omega$

Solution

Use Faraday's Law for a single-turn loop:

$|\varepsilon| = |\Delta\Phi_B/\Delta t| = |\Delta(B\cdot A)/\Delta t| = A\cdot(\Delta B/\Delta t)$

Compute the magnitude of the induced emf:

$|\varepsilon| = (8.00 \times 10^{-4}\ m^2) \times (2.00\ T / 1.00\ s) = 1.60 \times 10^{-3}\ V = 1.60\ mV$

Ohm's law gives the induced current (magnitude):

$I = |\varepsilon| / R = (1.60 \times 10^{-3}\ V) / (2.00\ \Omega) = 8.00 \times 10^{-4}\ A = 0.800\ mA$

Note: The direction of the current follows Lenz's law, but only the magnitude is requested here.

Answer: I = 0.800 mA (magnitude).

Conceptual Questions (Faraday's Law)

Q: When the north pole of a magnet is pushed toward a coil, what is the direction of the induced current?

A: Opposite to the motion of the magnet (Lenz's Law).

Q: If a loop is rotated in a constant magnetic field, is an emf induced?

A: Yes, because the orientation of the loop changes the flux.

Q: Which of the following will NOT induce emf in a loop: changing area, changing angle, or moving parallel to field lines?

A: Moving parallel to the field lines.

You can also review this lecture by watching the following video: