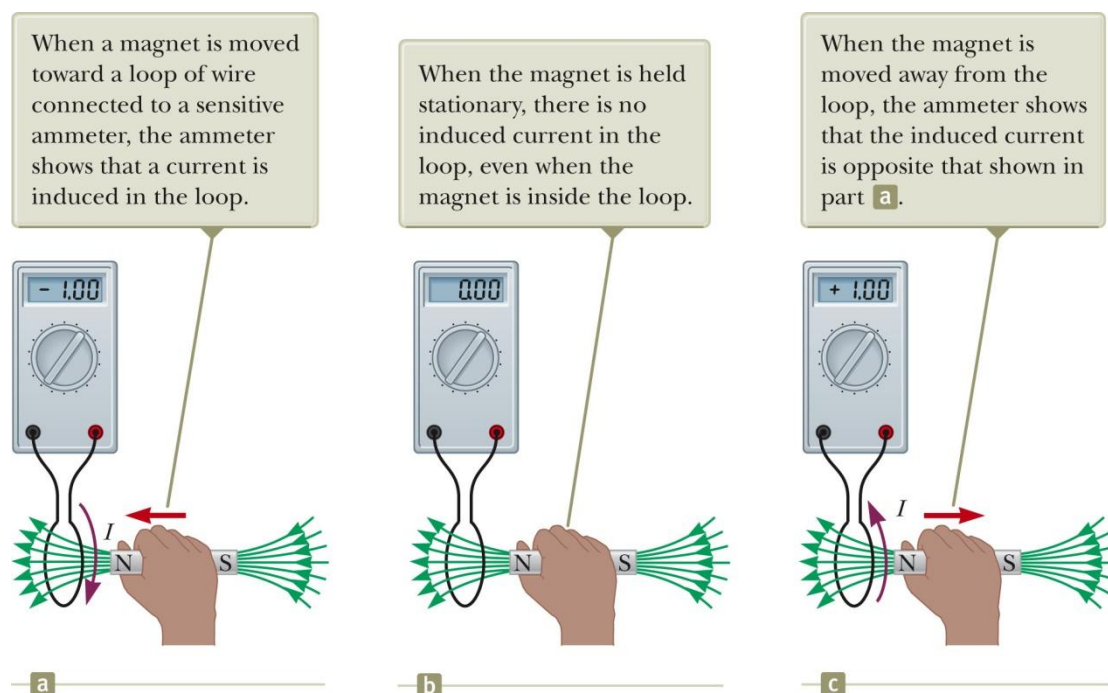


Chapter 30

Faraday's Law

30.1 Faraday's Law of Induction

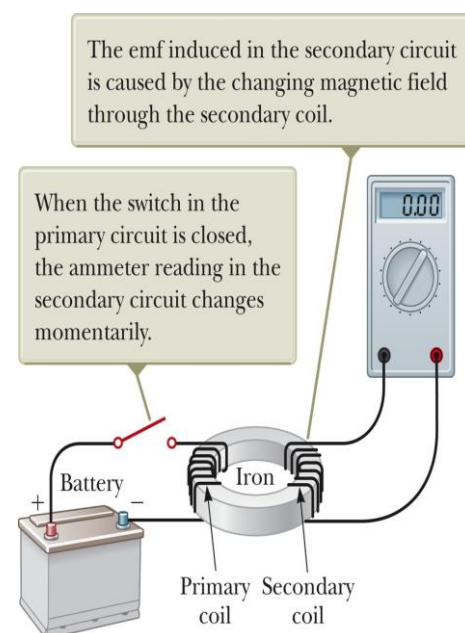


Simulation:

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:

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

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

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

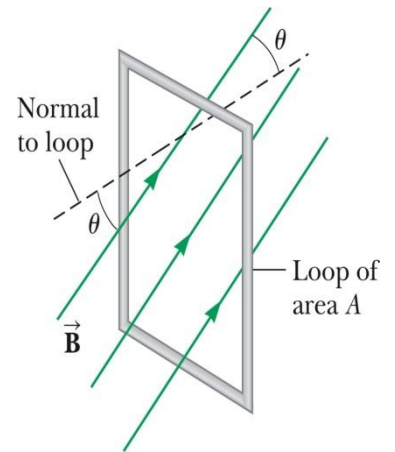
Assume a loop enclosing an area A lies in a uniform magnetic field.

The magnetic flux through the loop is

$$\Phi_B = BA \cos \theta$$

Then, the induced emf can be written as:

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



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.

Example 1 :

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.

$$\varepsilon = -N (d\Phi_B / dt) = -N A (dB / dt)$$

$$A = (0.18 \text{ m})^2 = 0.0324 \text{ m}^2$$

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

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

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

Time interval: $\Delta t = 1.00 \text{ s}$

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:

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

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

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

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

Answer: $I = 0.800 \text{ mA}$ (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:

Overview
Faraday's law of induction
The emf induced in a coil is proportional to the rate of change of the magnetic flux through the coil.

Set Up
Have you ever seen the metal detectors at airports?
BEEP BEEP!
NOW DOES THAT WORK?
Transformers
Generators
Motors
Michael Faraday

Explanation
Bar magnet plunged into coil
Coil of wire
ammeter
THE ELECTROMOTIVE FORCE INDUCED IN A COIL IS PROPORTIONAL TO THE RATE OF CHANGE OF THE MAGNETIC FLUX THROUGH THE COIL.
Magnetic Flux
The number of magnetic field lines passing through a closed surface of
The magnetic field through the closed surface of
The angle between the magnetic field and the normal to the plane of the loop
 $\Phi = BA \cos \theta$

Common mistakes
Do not think that there will be an induced emf only when the magnetic field is changing.
Three parameters
1. The angle between the magnetic field and the normal to the plane of the loop
2. The area of the loop
3. The magnetic field through the loop

Worked examples
A coil with 200 turns
5 cm
Perpendicular magnetic field
Calculate the emf induced in the coil if the magnetic field is decreasing by 5 T in 4 s.
1.96 V

Consider a coil of wire of N identical turns, each with magnetic flux of Φ the induced emf in the coil is given as:
the induced emf
the change in the magnetic flux
 $\epsilon = -N \frac{\Delta \Phi}{\Delta t}$
time
Thus, the emf will be induced only when there is a change in the magnetic flux. If the magnetic flux is constant, then there will be no induced emf.
Emil Lenz
THE DIRECTION OF THE INDUCED CURRENT IN A CIRCUIT IS SUCH THAT IT OPPOSES THE CHANGE IN THE MAGNETIC FLUX

$\epsilon = -N \frac{\Delta(BA \cos \theta)}{\Delta t}$
 $\epsilon = -N \frac{\Delta \Phi}{\Delta t}$
 $\epsilon = -N A \cos \theta \frac{\Delta B}{\Delta t}$
 $\epsilon = -(200) \left(\pi (0.05 \text{ m})^2 \right) \cos 0^\circ \frac{(-5 \text{ T})}{4 \text{ s}}$
 $= 1.96 \text{ V}$