

# PHYS12 CH: 23.1-23.7

## Electromagnetic Induction and Its Applications

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April, 2025

# Outline

- 1 Learning Objectives
- 2 Magnetic Flux and Induction
- 3 Faraday's Law and Lenz's Law
- 4 Types of Induced EMF
- 5 Devices Based on Induction
- 6 Practical Applications
- 7 Summary

# Learning Objectives

By the end of this presentation, you will be able to:

- Define magnetic flux and explain electromagnetic induction
- State and apply Faraday's Law and Lenz's Law
- Calculate motional emf in a conductor moving through a magnetic field
- Explain the concepts of eddy currents and magnetic damping
- Describe the operation of electric generators
- Understand the concept of back emf in motors
- Analyze transformer operation and calculate voltage/current relationships

# Magnetic Flux

## Definition

Magnetic flux ( $\Phi$ ) is a measure of the total magnetic field passing through a given area.

$$\Phi = BA \cos \theta \quad (1)$$

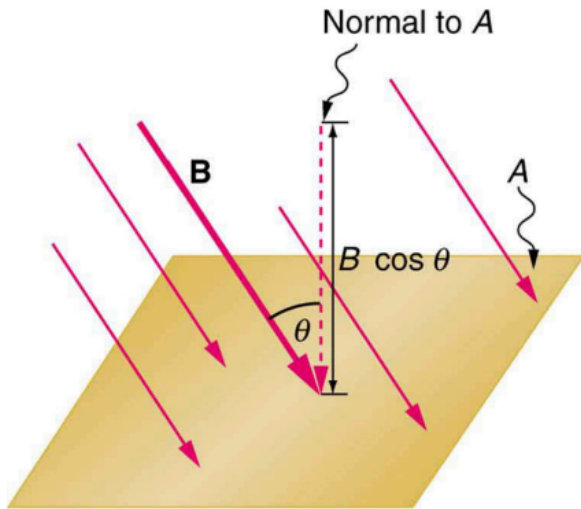
where: (2)

$B$  = magnetic field strength (3)

$A$  = area (4)

$\theta$  = angle with perpendicular (5)

- Units: Tesla·meter<sup>2</sup> (T·m<sup>2</sup>)
- Maximum when  $\theta = 0$  (field perpendicular to area)
- Zero when  $\theta = 90$  (field parallel to area)



$$\Phi = BA \cos \theta = B_{\perp} A$$

# Electromagnetic Induction

## Fundamental Principle

Any change in magnetic flux induces an electromotive force (emf).

- Discovered independently by Michael Faraday and Joseph Henry
- The induced emf can drive current through a circuit
- The induced current creates its own magnetic field
- Basis for generators, transformers, and many electrical devices

## Key Insight

It's the **change** in magnetic flux that induces emf, not the flux itself.

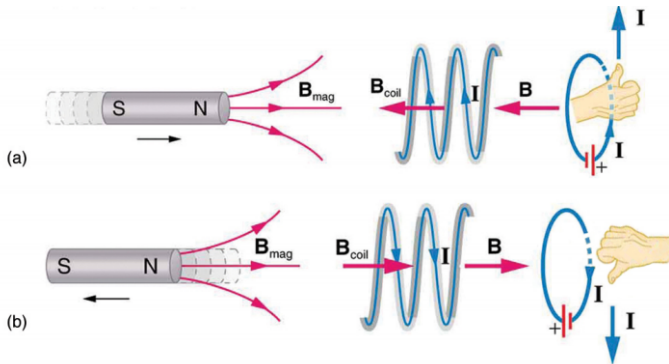
[PHET showing a magnet moving through a coil and the resulting induced current]

# Faraday's Law of Induction

## Mathematical Form

$$\text{emf} = -N \frac{\Delta\Phi}{\Delta t} \quad (6)$$

- $N$  = number of turns in a coil
  - $\Delta\Phi$  = change in magnetic flux
  - $\Delta t$  = time interval for the change
  - The negative sign is due to Lenz's Law
- Ways to change flux:
    - Change  $B$  (field strength)
    - Change  $A$  (area)
    - Change  $\theta$  (orientation)





# Lenz's Law

## The Minus Sign in Faraday's Law

The induced emf creates a current that produces a magnetic field opposing the change in flux that induced it.

- Conservation of energy principle
- If flux is increasing, induced field opposes the increase
- If flux is decreasing, induced field opposes the decrease
- Works against the cause of the flux change

## Important Note

Lenz's Law explains why work must be done against the induced magnetic force to maintain flux changes.

# Motional EMF

## Definition

EMF induced by motion of a conductor through a magnetic field.

For a straight conductor:

$$\text{emf} = B\ell v \quad (7)$$

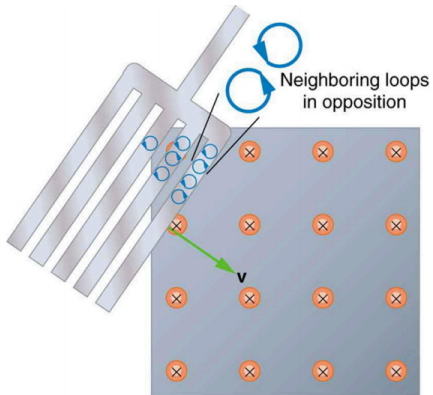
- $B$  = magnetic field strength
- $\ell$  = length of conductor
- $v$  = velocity of conductor
- Applies when  $B$ ,  $\ell$ , and  $v$  are mutually perpendicular
- Causes charge separation in the conductor
- Creates potential difference across the conductor

phys12-magnetism-electromagnetic-field-magnitude.png

## Definition

Current loops induced in moving conductors or changing magnetic fields.

- Occur in solid conductors moving through magnetic fields
- Flow in closed loops within the conductor
- Can cause significant heating ( $I^2R$  losses)
- Used in induction heating and cooking
- **Magnetic Damping:**
  - Drag force from eddy currents
  - Opposes the motion that created it
  - Used in braking systems
  - Can be reduced by slotting conductors



# Electric Generators

## Working Principle

A coil rotating in a magnetic field induces a time-varying emf.

$$\text{emf} = NAB\omega \sin(\omega t) \quad (8)$$

where: (9)

$N$  = number of turns (10)

$A$  = area of coil (11)

$B$  = magnetic field strength (12)

$\omega$  = angular velocity (13)

- Peak emf:  $\text{emf}_0 = NAB\omega$
- Produces sinusoidal AC voltage
- Converts mechanical energy to electrical energy
- Basis for power generation worldwide

phys12-magnetism-electric-generator-diagram.png

# Back EMF in Motors

## Definition

Induced emf in a motor that opposes the applied voltage.

- Motors are generators in reverse: convert electrical to mechanical energy
- When a motor rotates, it also acts as a generator
- This self-generated emf opposes the applied voltage
- Magnitude increases with motor speed
- Limits current in a running motor
- Back emf = 0 when motor is first starting (why starting current is high)

## Safety Note

The high starting current is why motors need special starters or current limiters.



# Transformers

## Basic Purpose

Transform AC voltage from one value to another using electromagnetic induction.

### Voltage Relationship:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \quad (14)$$

### Current Relationship:

$$\frac{I_s}{I_p} = \frac{N_p}{N_s} \quad (15)$$

- Primary coil: Connected to AC source
- Secondary coil: Delivers transformed voltage
- $N_p, N_s$ : Number of turns in primary and secondary
- $V_p, V_s$ : Primary and secondary voltages
- $I_p, I_s$ : Primary and secondary currents

- **Step-up transformer:**  $N_s > N_p$  (increases voltage, decreases current)

# Example Problem: "I do"

## Motional EMF Problem

A metal rod of length 1.0 m moves at 2.0 m/s perpendicular to a magnetic field of 0.50 T. Calculate the induced emf.

- **Given:**

- Length of rod:  $\ell = 1.0 \text{ m}$
- Speed of rod:  $v = 2.0 \text{ m/s}$
- Magnetic field:  $B = 0.50 \text{ T}$

- **Find:** The induced emf

# Example Problem: "I do"

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- Magnetic field:  $B = 0.50 \text{ T}$

- **Find:** The induced emf

$$\text{emf} = B\ell v \quad (16)$$

$$= (0.50 \text{ T})(1.0 \text{ m})(2.0 \text{ m/s}) \quad (17)$$

$$= 1.0 \text{ V} \quad (18)$$

# Example Problem: "We do"

## Generator Problem

A generator has 100 turns of wire in a coil with area  $0.05 \text{ m}^2$  and rotates in a magnetic field of  $0.75 \text{ T}$  at  $60 \text{ Hz}$ . Calculate the peak emf.

- **Given:**

- Number of turns:  $N = 100$
- Area of coil:  $A = 0.05 \text{ m}^2$
- Magnetic field:  $B = 0.75 \text{ T}$
- Frequency:  $f = 60 \text{ Hz}$

- **Find:** The peak emf ( $\text{emf}_0$ )

Let's work through this together:

$$\omega = 2\pi f = 2\pi(60 \text{ Hz}) = 377 \text{ rad/s} \quad (19)$$

$$\text{emf}_0 = NAB\omega \quad (20)$$

$$= 100 \times 0.05 \text{ m}^2 \times 0.75 \text{ T} \times 377 \text{ rad/s} \quad (21)$$

$$=? \quad (22)$$

# Example Problem: "You do"

## Transformer Problem

A transformer has 400 primary turns and 100 secondary turns. If the primary voltage is 120 V, what is the secondary voltage?

- **Given:**

- Primary turns:  $N_p = 400$
- Secondary turns:  $N_s = 100$
- Primary voltage:  $V_p = 120 \text{ V}$

- **Find:** Secondary voltage ( $V_s$ )

## Hint

Use the voltage relationship for transformers:  $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

Try to solve this problem on your own!

# Key Equations

Concept	Equation
Magnetic Flux	$\Phi = BA \cos \theta$
Faraday's Law	$\text{emf} = -N \frac{\Delta \Phi}{\Delta t}$
Motional EMF	$\text{emf} = B\ell v$
Generator EMF	$\text{emf} = NAB\omega \sin(\omega t)$
Peak Generator EMF	$\text{emf}_0 = NAB\omega$
Transformer Voltage	$\frac{V_s}{V_p} = \frac{N_s}{N_p}$
Transformer Current	$\frac{I_s}{I_p} = \frac{N_p}{N_s}$

# Summary of Key Concepts

- **Electromagnetic Induction:** Process by which changing magnetic flux induces an emf
- **Faraday's Law:** Quantifies the relationship between changing flux and induced emf
- **Lenz's Law:** Determines the direction of induced current to oppose the change
- **Motional EMF:** Produced when a conductor moves through a magnetic field
- **Eddy Currents:** Closed loops of current induced in solid conductors
- **Generators:** Convert mechanical energy to electrical energy using induction
- **Back EMF:** Self-induced voltage in motors that opposes applied voltage
- **Transformers:** Convert AC voltage levels using mutual induction

# Real-World Applications

## Power Generation & Distribution

- Electric generators in power plants
- Step-up transformers at power plants
- Step-down transformers near consumers

## Transportation

- Electric motors in vehicles
- Magnetic braking systems
- Induction sensors

## Consumer Electronics

- Induction cooktops
- Wireless charging systems
- Microphones and speakers

## Medical Technology

- MRI machines
- Electromagnetic flow meters
- Transcranial magnetic stimulation



Thank you for your attention!

Any questions?