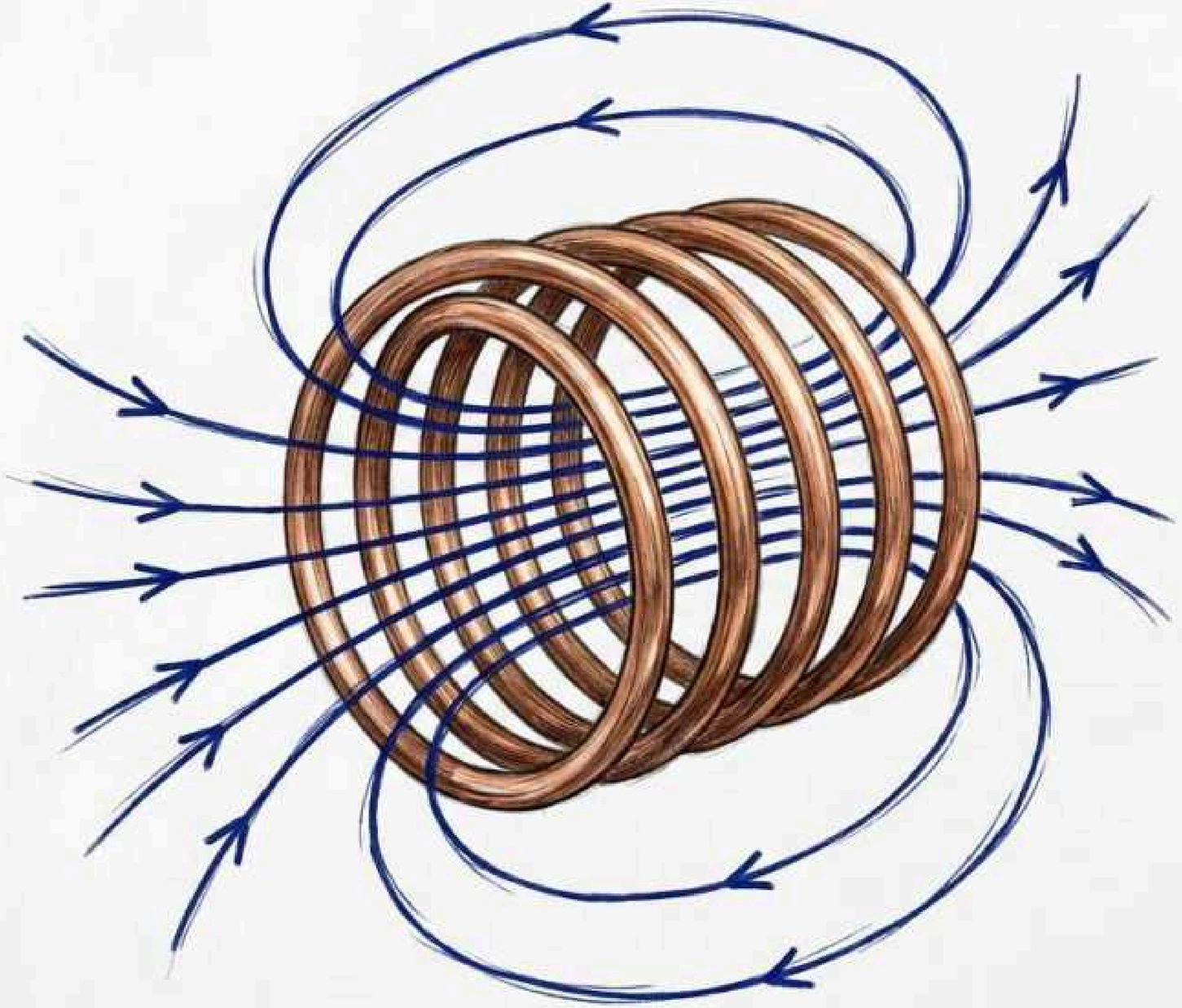


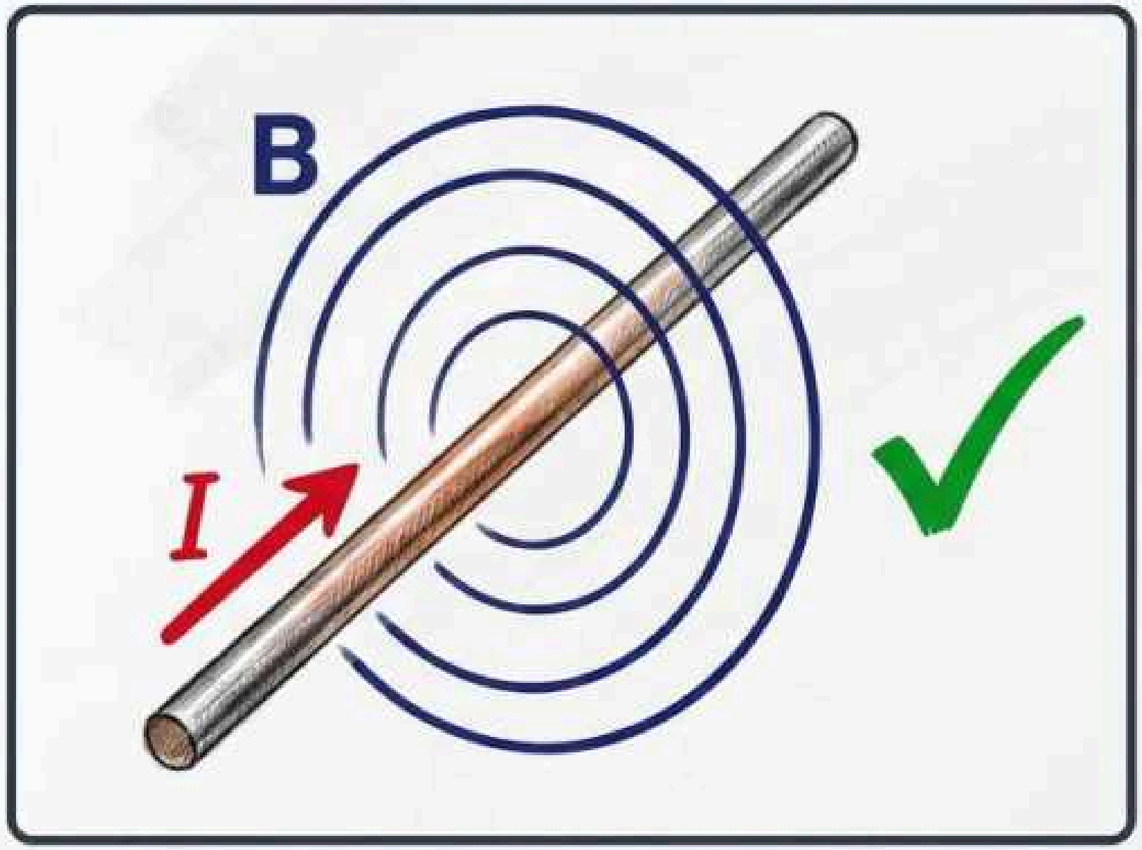
Electromagnetic Induction and Faraday's Law

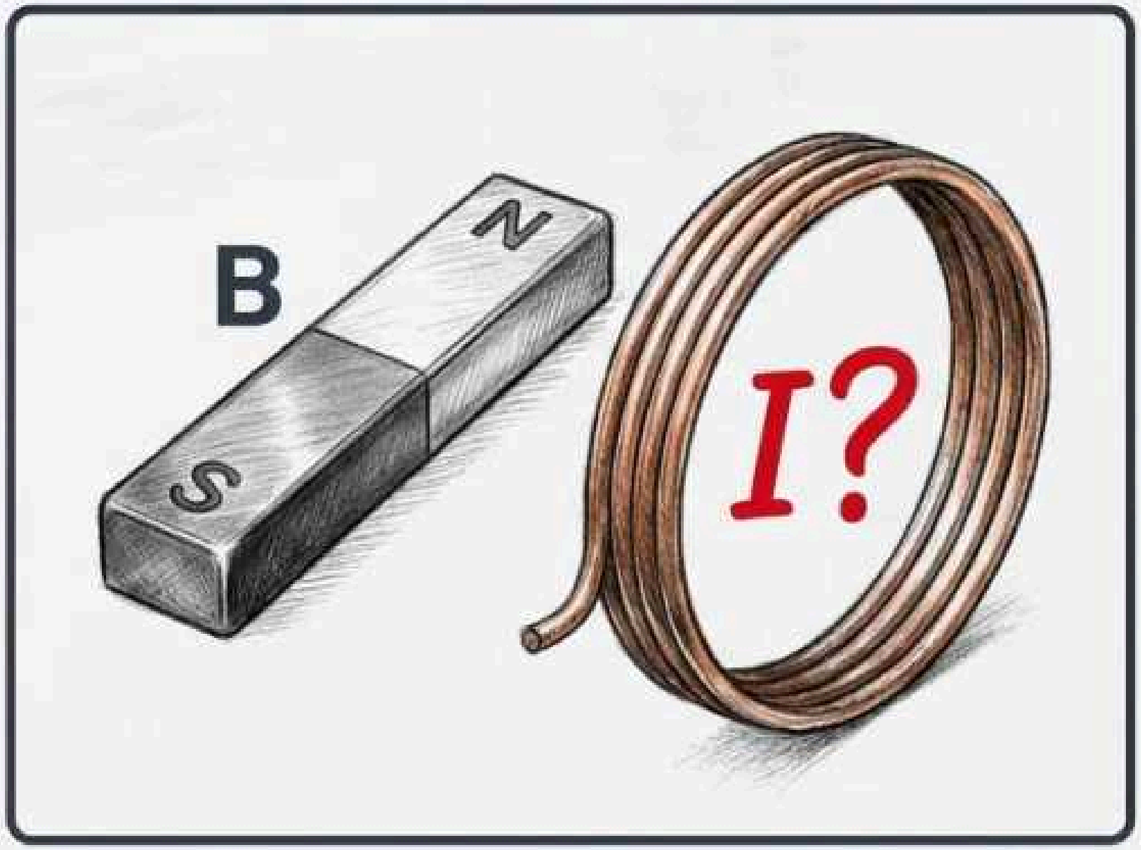
Lecture 5 | Physics 102 B

[Faraday's Law • Lenz's Law • Generators • Transformers • Power Transmission]

Gemini Notebook

Can a magnetic field create a current?

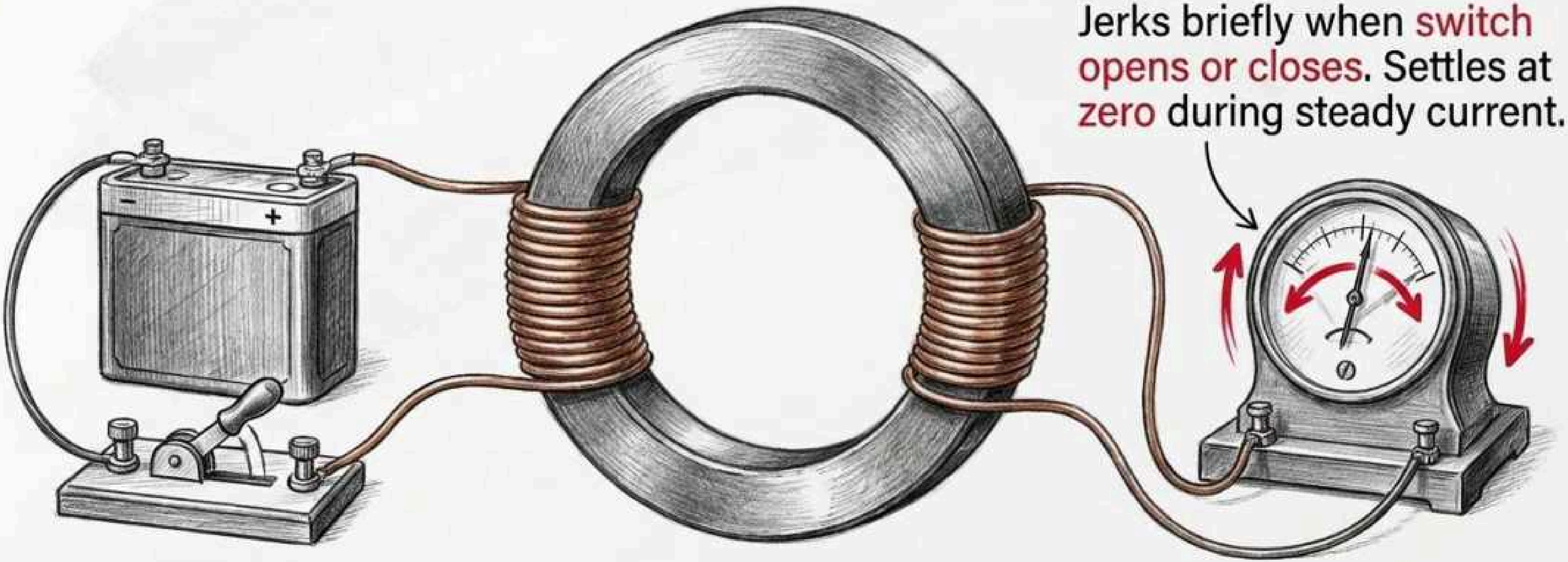




The answer is yes—but only if the field changes.
This discovery made large-scale electric power possible.

Gemini Notebook

1831: Faraday's Iron Ring Experiment

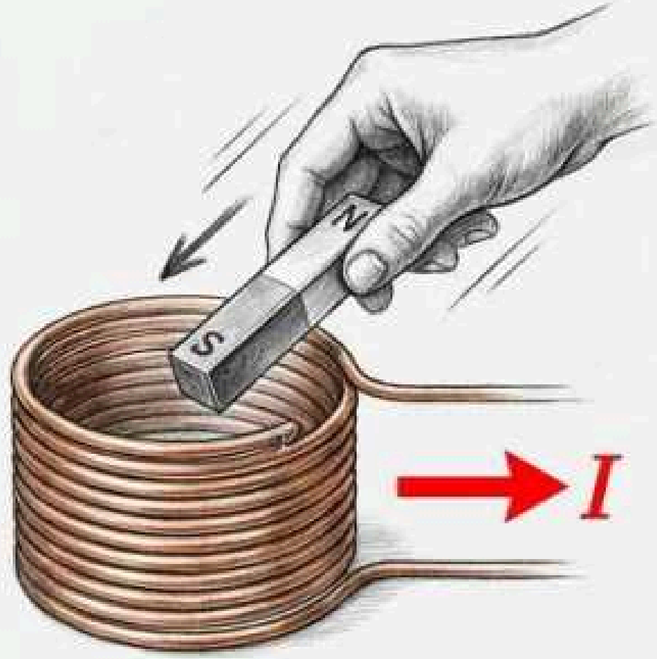


Steady current produced nothing.
Only the change produced an effect.

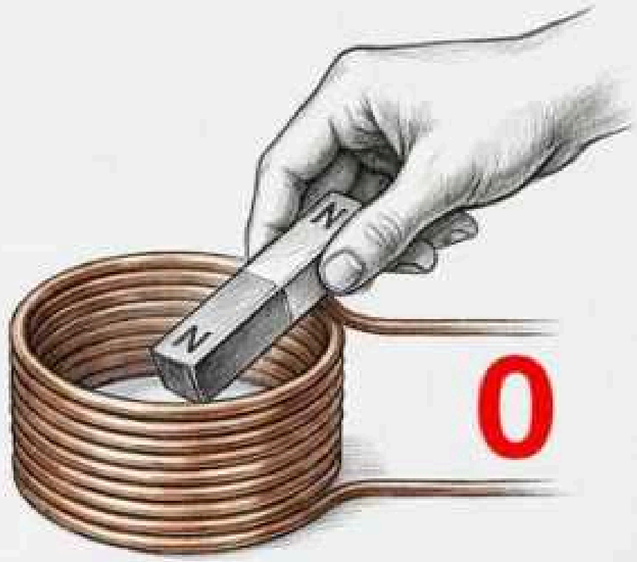
Gemini Notebook

The Catalyst of Motion

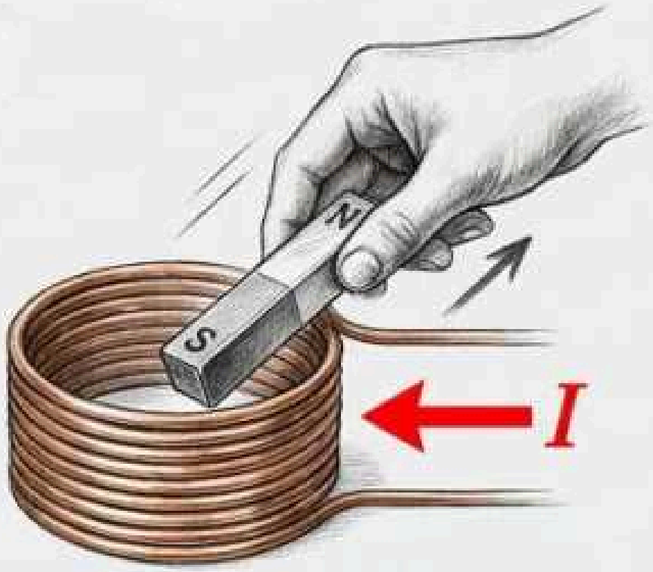
¶ 5.4



Pushing In



Holding Still



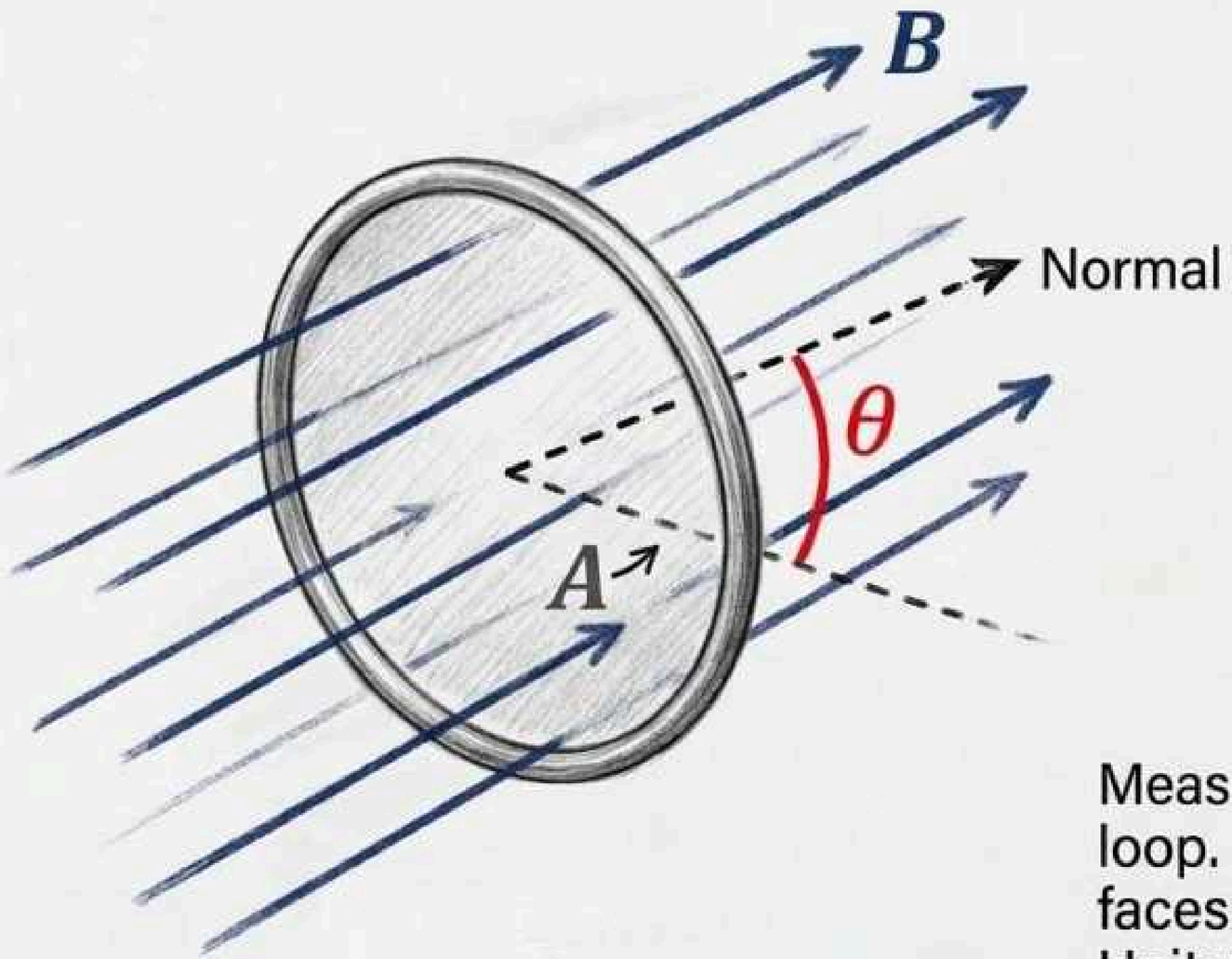
Pulling Out

Electromotive Force (EMF) — The voltage induced when the magnetic field through a coil changes over time.

Gemini Notebook

Defining Magnetic Flux (Φ)

¶ 5.5



$$\Phi = \boldsymbol{B} \cdot \boldsymbol{A} \cdot \cos(\theta)$$

$\boldsymbol{B}$ = Magnetic Field

$\boldsymbol{A}$ = Area of the loop

θ = Angle between field and loop's normal

Measures how much field passes through the loop. Maximum flux occurs when the loop faces the field squarely.
Unit: Weber (1 Tesla · m^2).

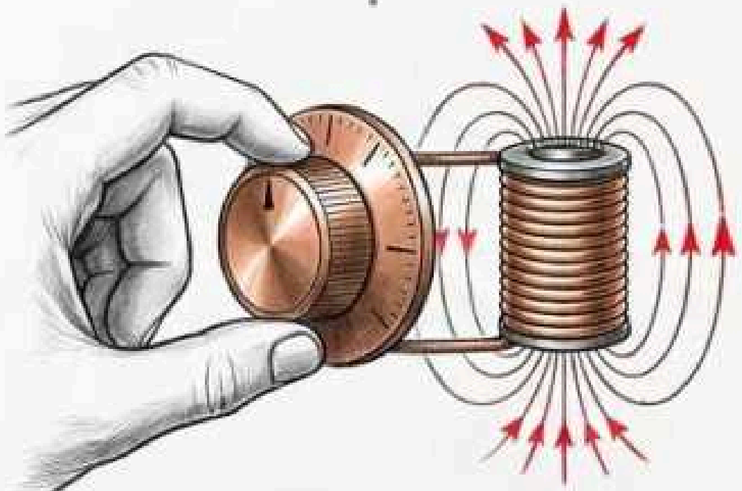
Gemini Notebook

Faraday's Law Formalized

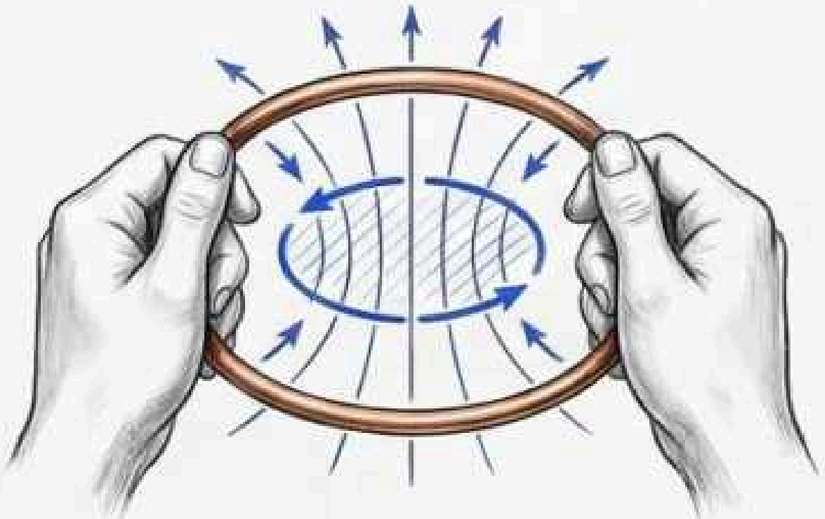
¶ 5.6

Induced EMF equals the rate of change of flux, multiplied by the number of turns (N).

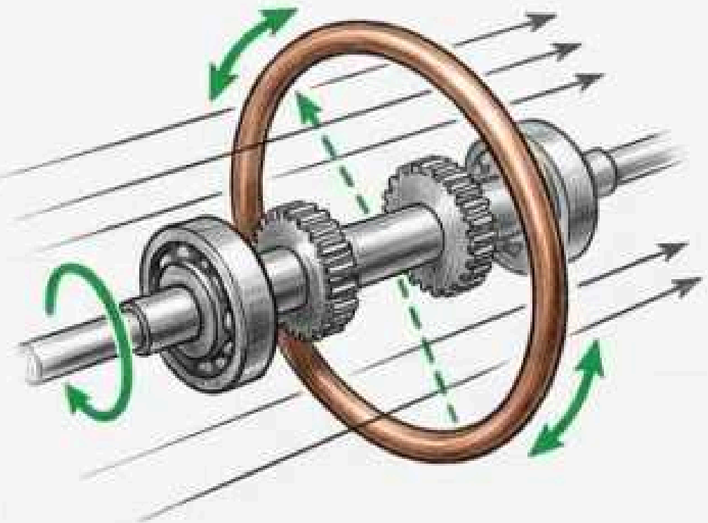
$$\text{EMF} = -N\frac{\Delta\Phi}{\Delta t}$$



Changing Field Strength (ΔB)



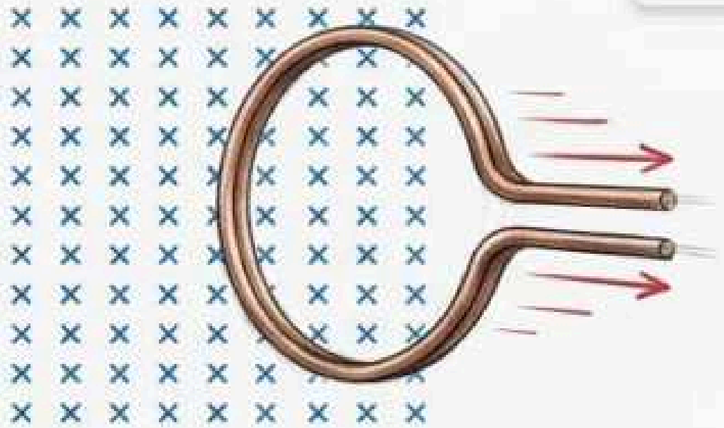
Changing Area (ΔA)



Changing Angle ($\Delta\theta$)

Gemini Notebook

Calculating Induced Voltage



Givens:

Area (A) = 0.02 m^2

Field (B) = 0.5 Tesla

Time (Δt) = 0.1 seconds.

Solution:

Step 1: Flux (Φ) = $0.02 \times 0.5 = 0.01$ Webers.

Step 2: EMF = $\frac{0.01}{0.1} = 0.1$ Volts.

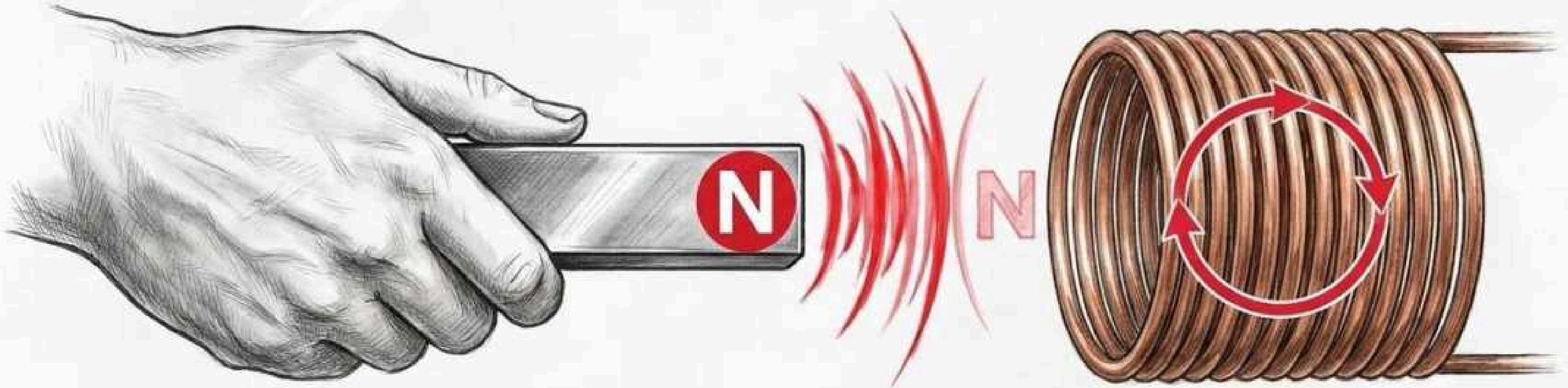
Scale to 100 turns (N=100) → EMF becomes 10 Volts.

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Lenz's Law and the Minus Sign

¶ 5.8

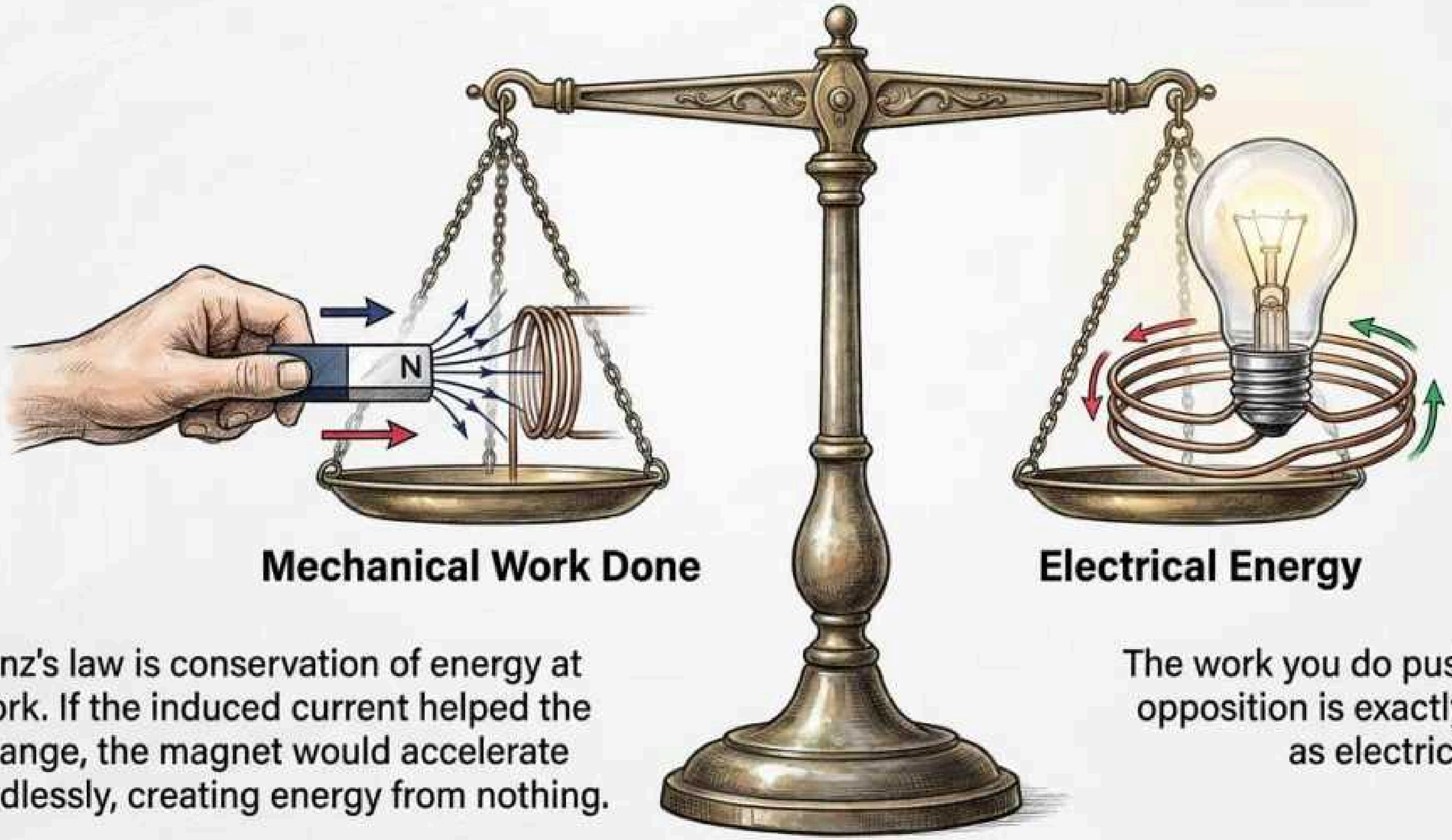
The induced current always flows in the direction that opposes the change that caused it.



Push a North pole toward a coil, and the coil makes its own North pole to push back. You must do work to push the magnet in.

Gemini Notebook

The Necessity of Opposition

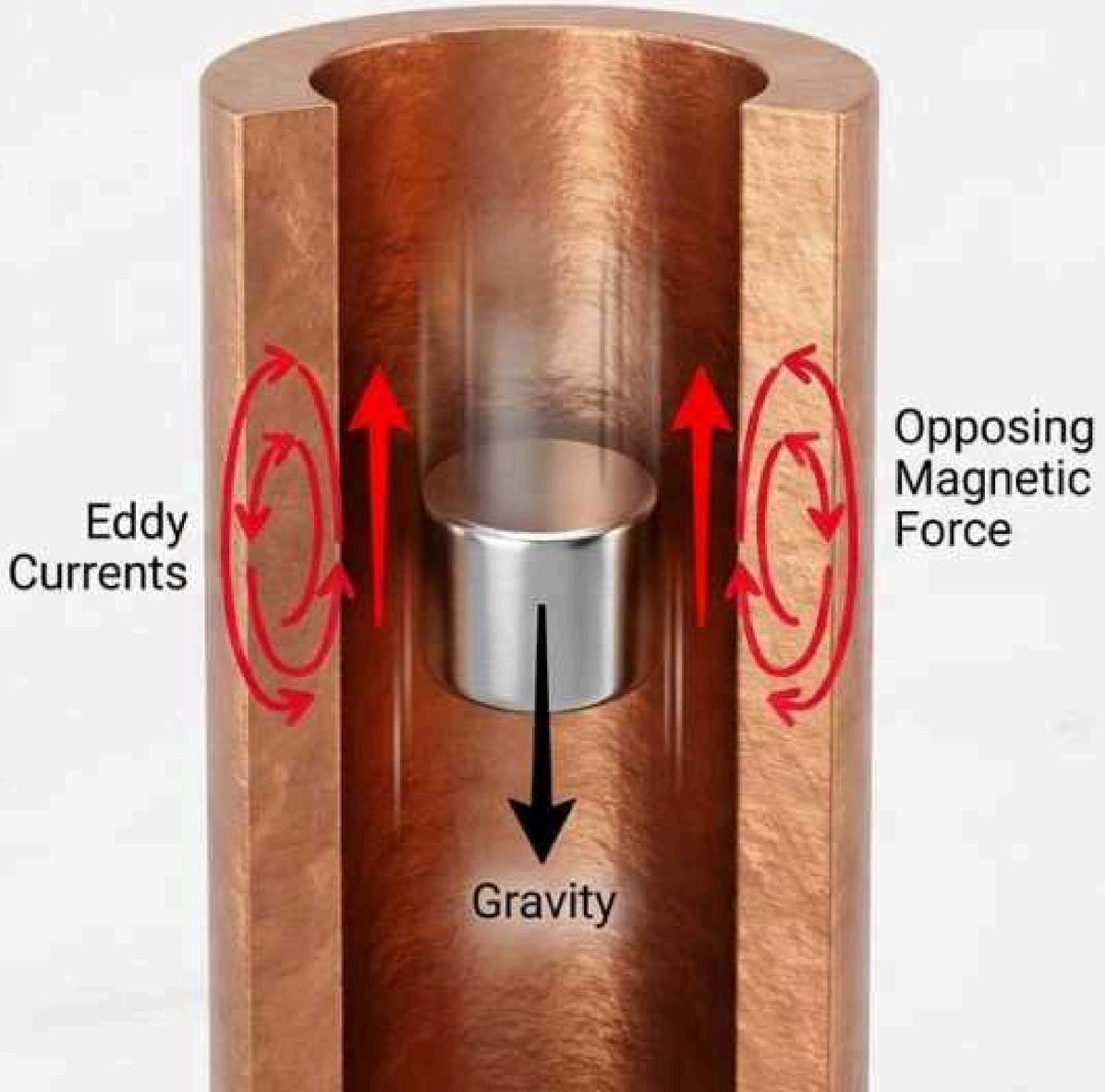


Lenz's law is conservation of energy at work. If the induced current helped the change, the magnet would accelerate endlessly, creating energy from nothing.

The work you do pushing against the opposition is exactly what appears as electrical energy.

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The Falling Magnet Demonstration

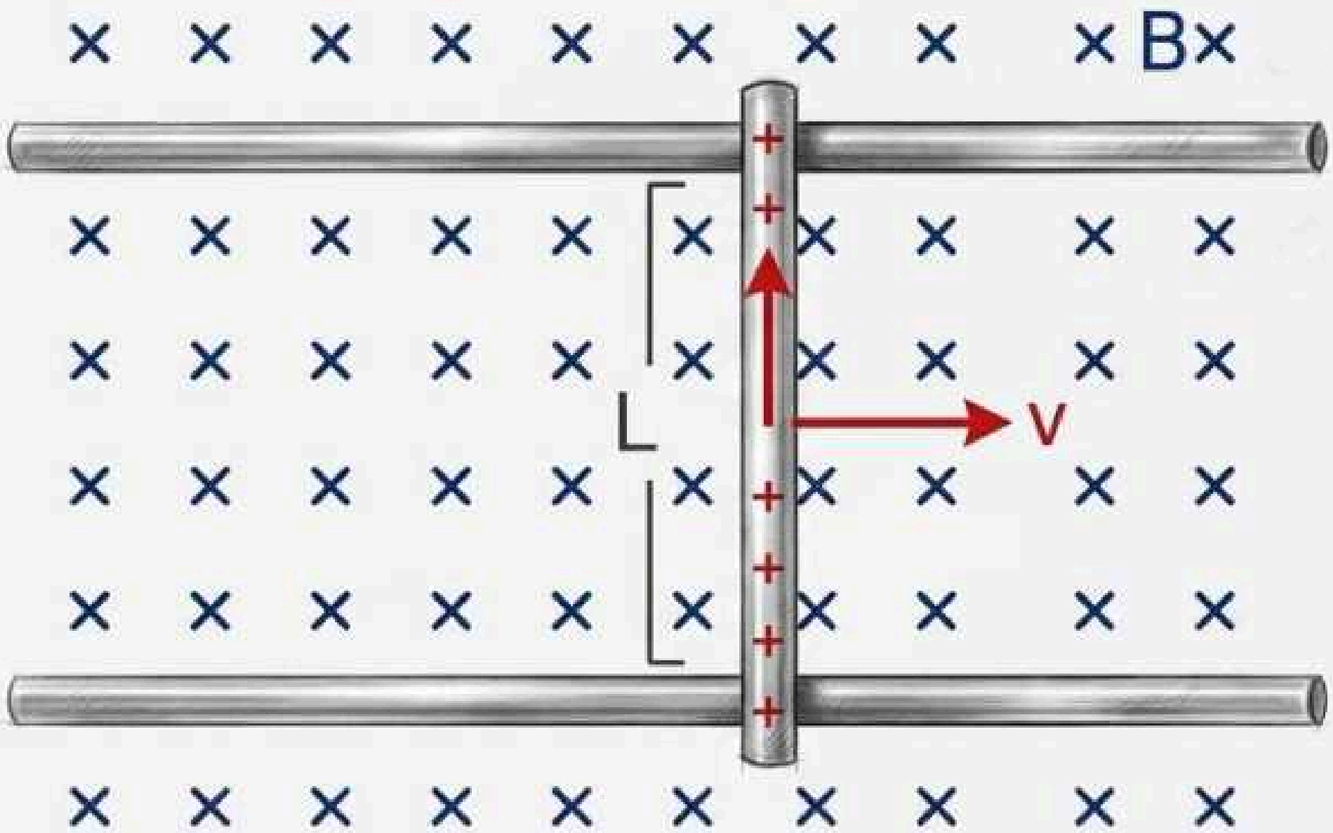


Copper is non-magnetic, yet the magnet falls in slow motion. The falling magnet induces circulating eddy currents in the tube. By Lenz's law, these currents oppose the motion, converting kinetic energy into into a little heat.

Gemini Notebook

Motional EMF: The Sliding Rod

¶ 5.11



$$\text{EMF} = B \cdot L \cdot v$$

Field (0.3 T)

× Length (0.5 m)

× Speed (4 m/s)

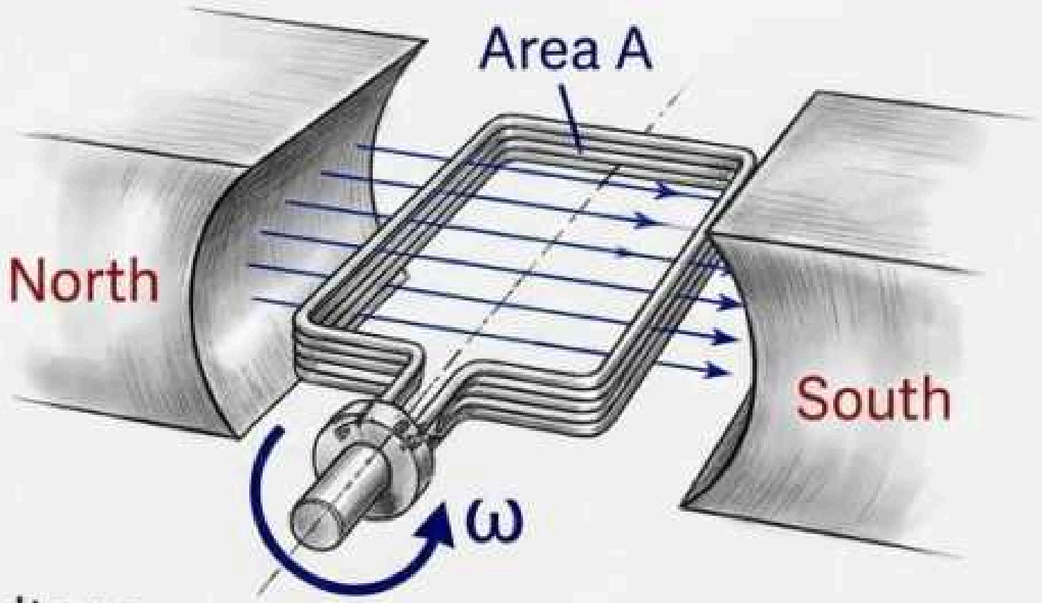
= 0.6 Volts.

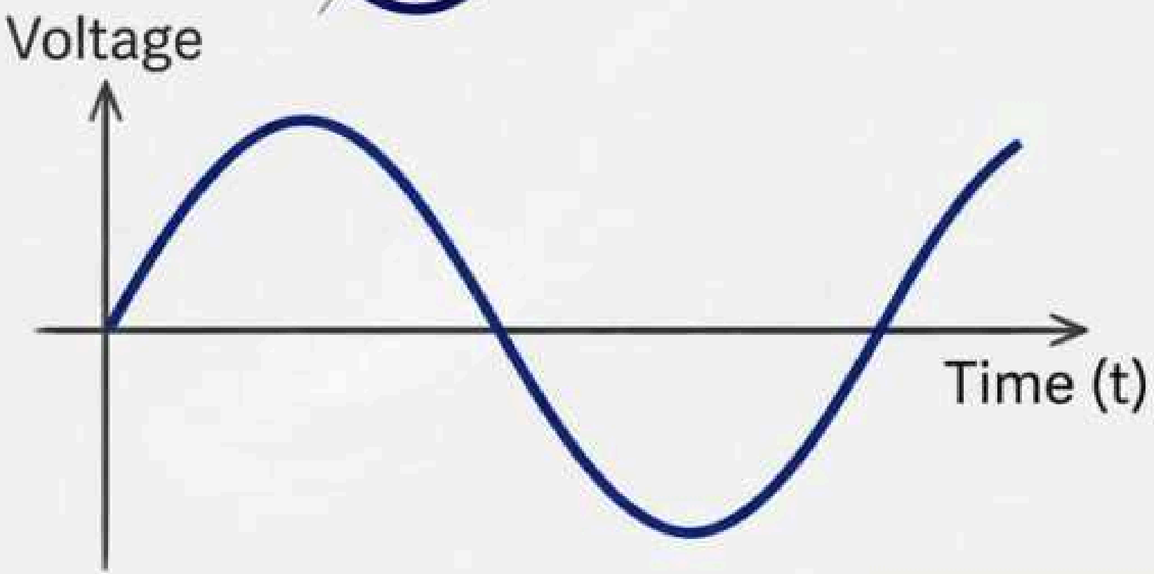
The rod pushes charges along itself.

Gemini Notebook

The Generator Principle

¶ 5.12





$$EMF = N \cdot B \cdot A \cdot \omega \cdot \sin(\omega t)$$

As the flux changes continuously, the voltage swings in a smooth wave.

This is Alternating Current (AC)—the entire principle of the power station.

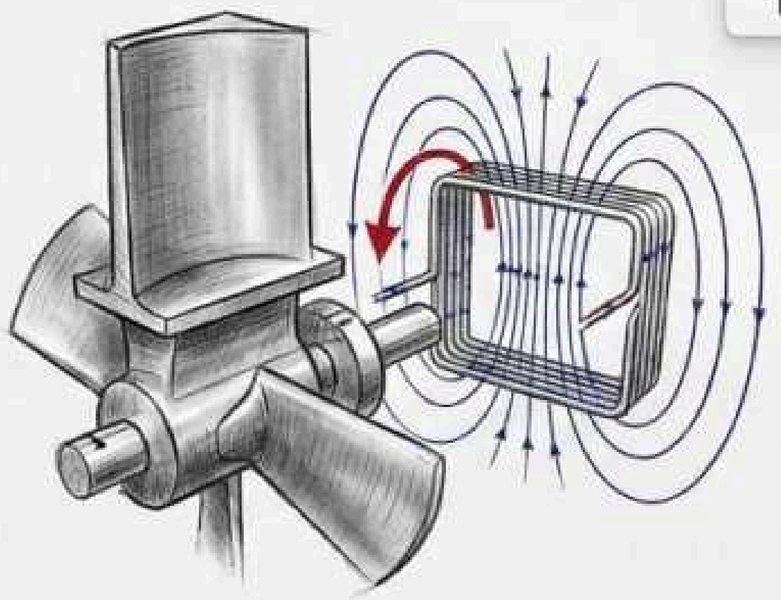
Gemini Notebook

Calculating Turbine Output

Inputs List: Turns (N) = 200

Area (A) = 0.05 m^2

Field (B) = 0.2 T



Frequency Conversion: 60 cycles/second → ω = 377 radians/second.

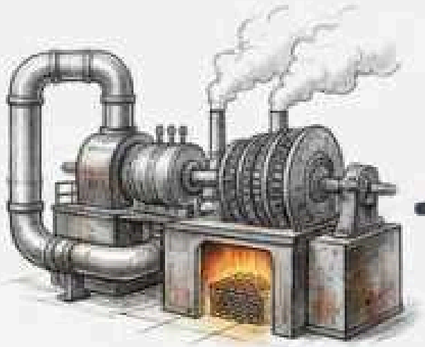
$$EMF_{peak} = N \cdot B \cdot A \cdot \omega$$

Result: 200 × 0.2 × 0.05 × 377 ≈ **754** Volts.

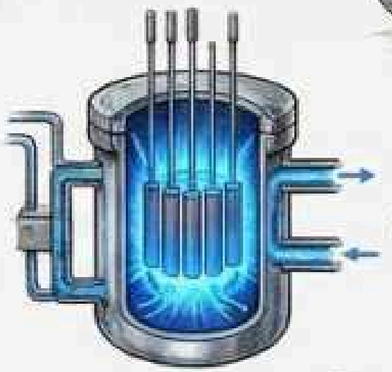
Different turbines turn the coil, but the physics is the same.

Gemini Notebook

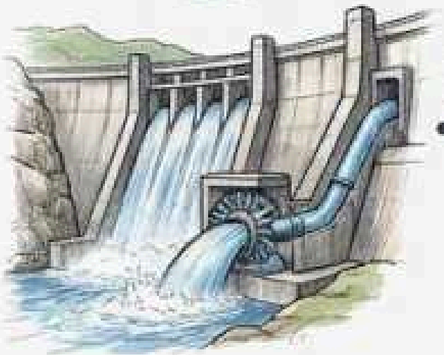
Energy Sources and Conversion



Steam (Coal/Gas)



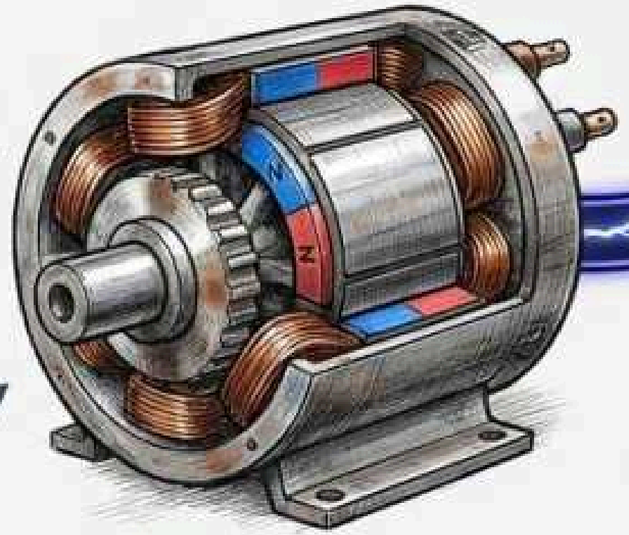
Nuclear

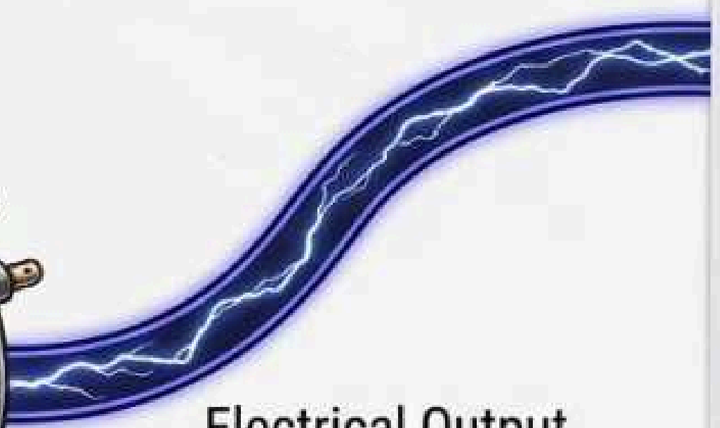


Hydroelectric



Wind



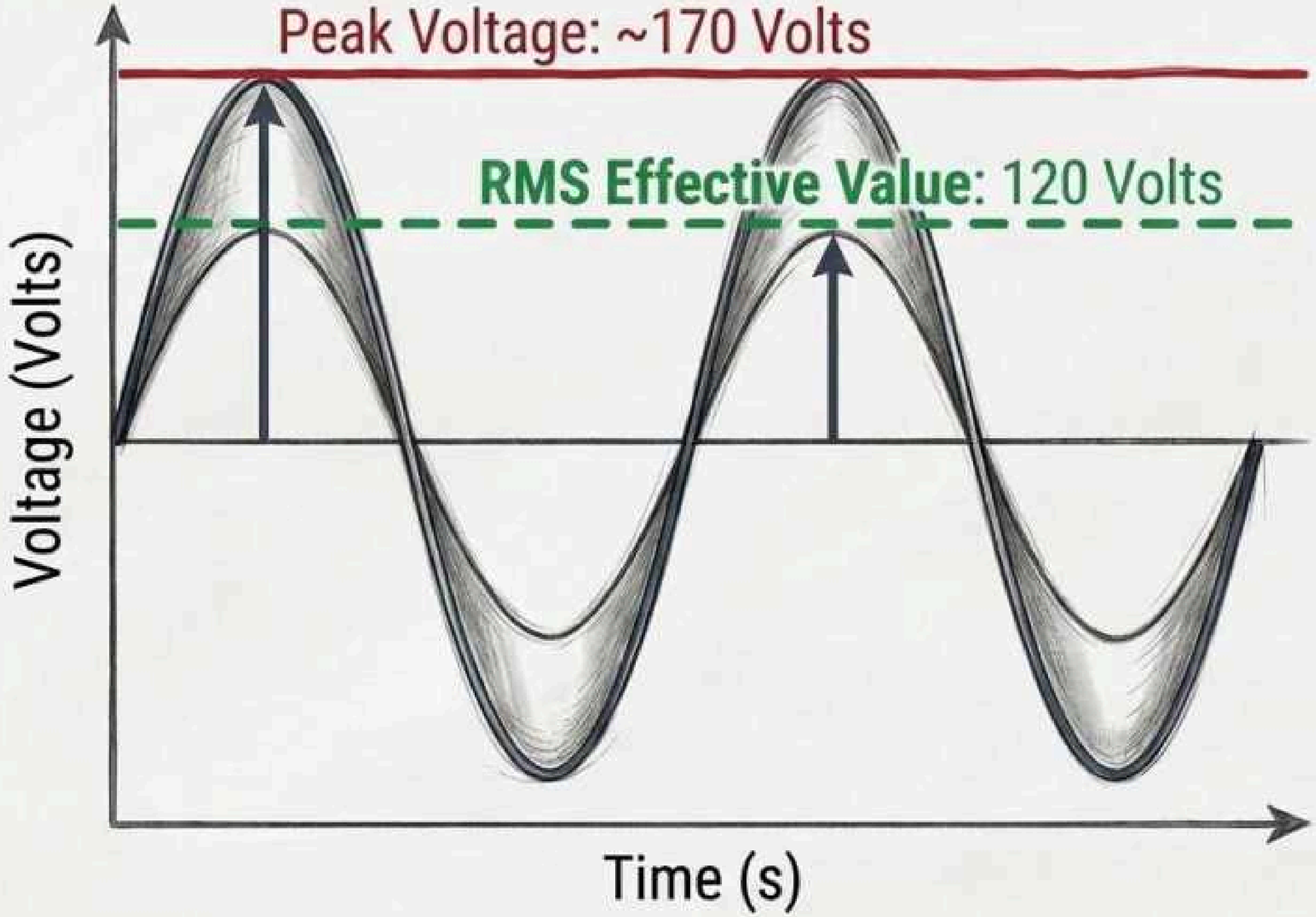


Electrical Output

A **generator does not make energy**. It converts a turbine's **mechanical energy** into **electrical energy**, working entirely through the opposition described by **Lenz's law**.

Gemini Notebook

Alternating Current (AC) Basics

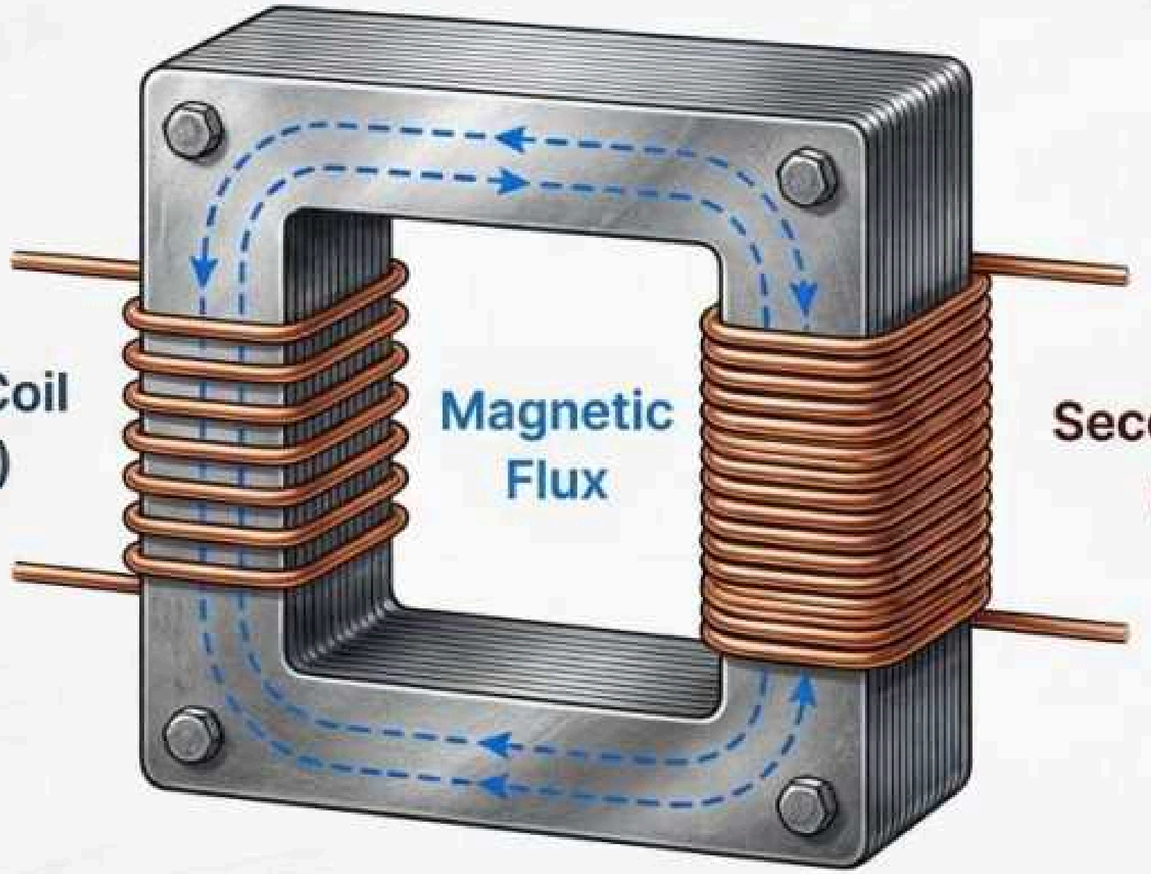


Frequency Data:
Alternates at 50 or 60 cycles per second (depending on country).

Definition:
The 120V nominal voltage is the Root-Mean-Square (RMS) value. This steady effecivy effective value delivers the exact same heating power as a Direct Current (DC) of 120 volts.

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The Transformer Advantage



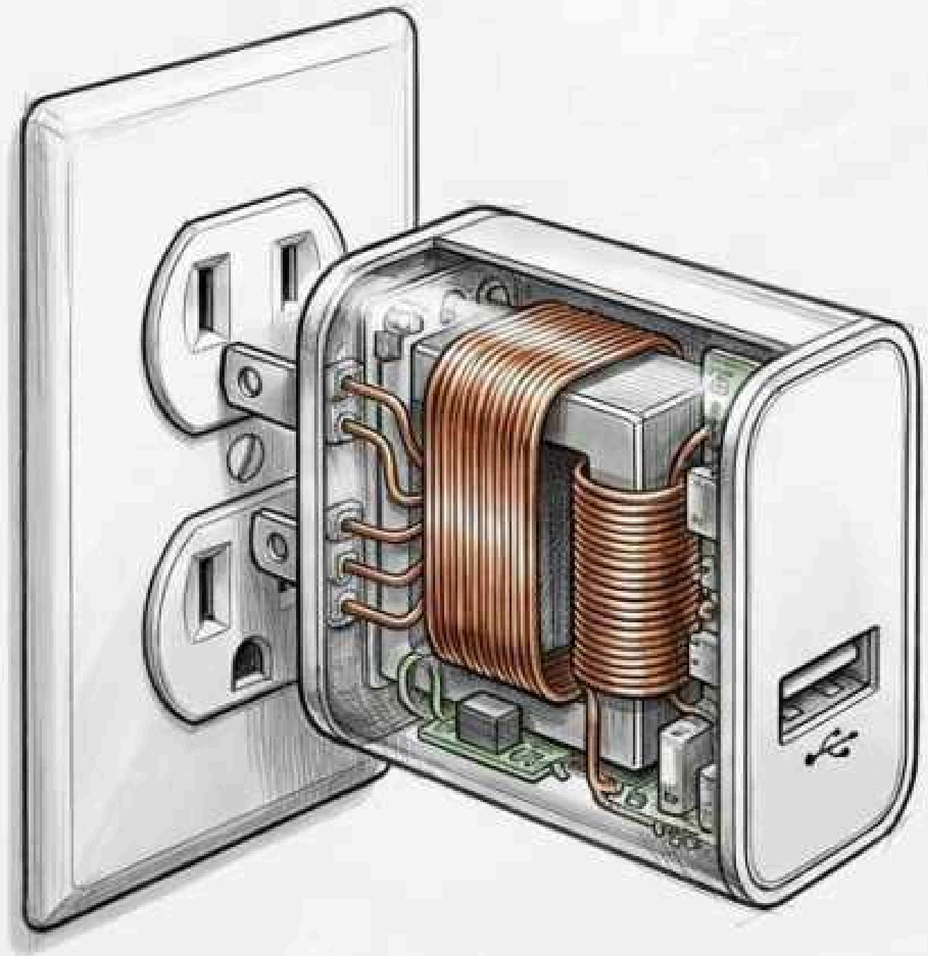
$$\left(\frac{V_s}{V_p}\right) = \left(\frac{N_s}{N_p}\right)$$

Mechanism: Alternating current in the primary coil creates a changing flux, inducing alternating voltage in the secondary coil in proportion to the turns. (Requires changing currents to work!).

Gemini Notebook

Stepping Down Voltage

¶ 5.17



Input (Wall):
120 Volts → **Primary Coil:**
1000 Turns

Output (Phone):
12 Volts → **Secondary Coil:**
100 Turns

(A 10:1 ratio)

Efficiency Note: An ideal transformer wastes no power. As voltage falls, current rises proportionally. Real transformers are over 95% efficient.

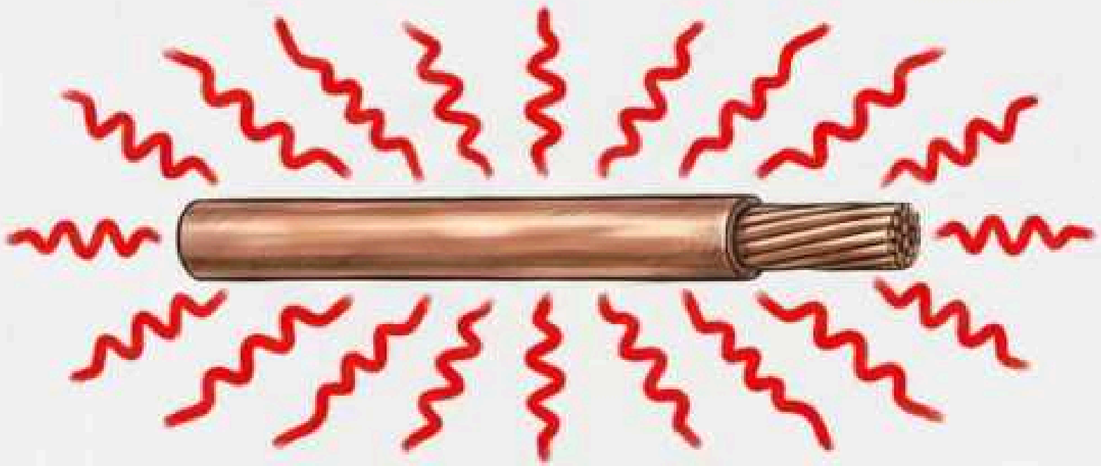
Gemini Notebook

Power Transmission & Heat Loss (I^2R)

Sending **100 kW** of power down a **5 ohm** transmission line:

Scenario A: Low Voltage

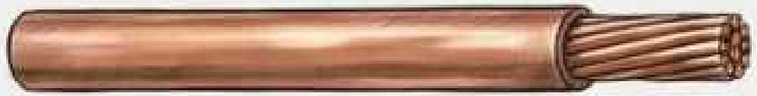
Voltage = 1,000 V | Current = 100 A



50 kW wasted as heat.

Scenario B: High Voltage

Voltage = 10,000 V | Current = 10 A



Only 0.5 kW wasted.

High voltage **minimizes current**, drastically reducing energy lost as **heat** over long distances.

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The Grid & Everyday Applications

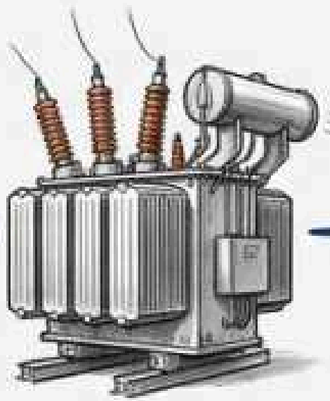
¶ 5.19

Every step relies on turning a changing magnetic field into a voltage.

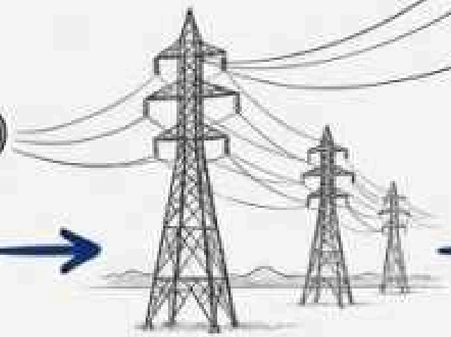
Macro Scale



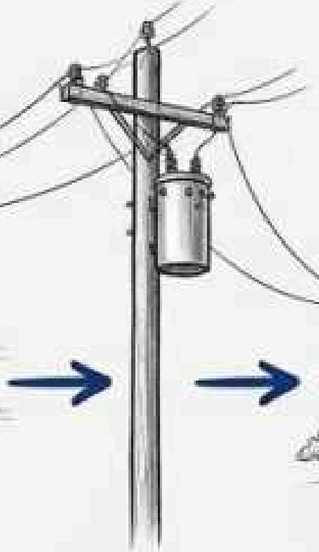
Power Plant



Step-Up Transformer



High-Voltage Transmission Towers



Step-Down Transformer

Micro Scale



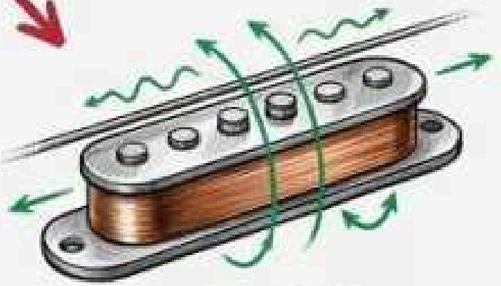
House



Induction Cooktop



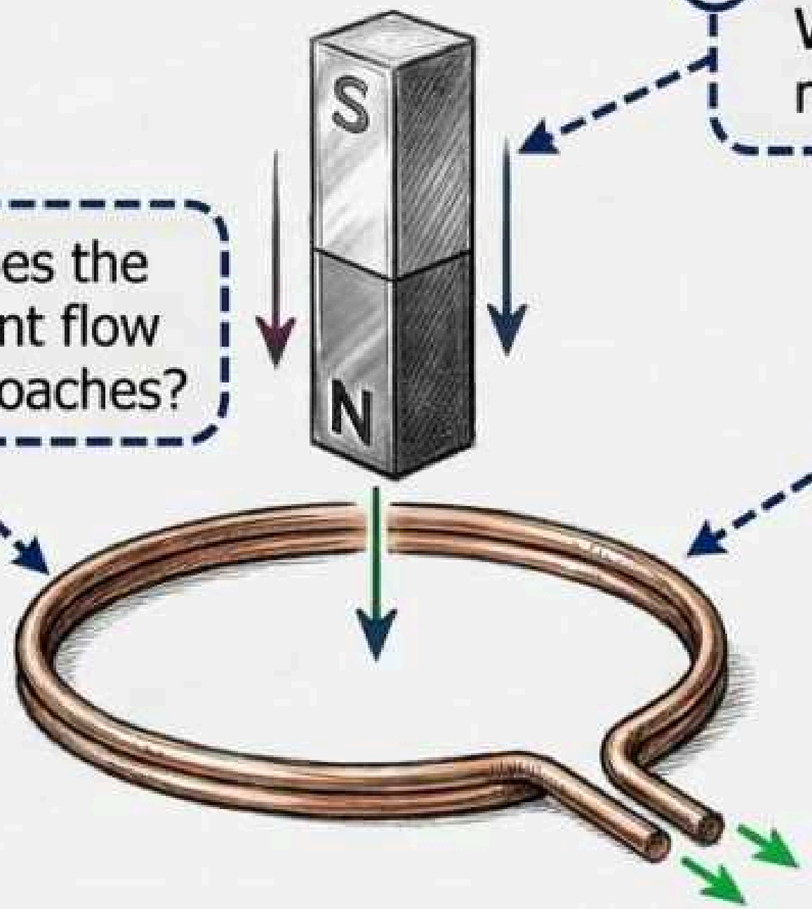
Wireless Charger



Guitar Pickup

Gemini Notebook

Lecture Review Question

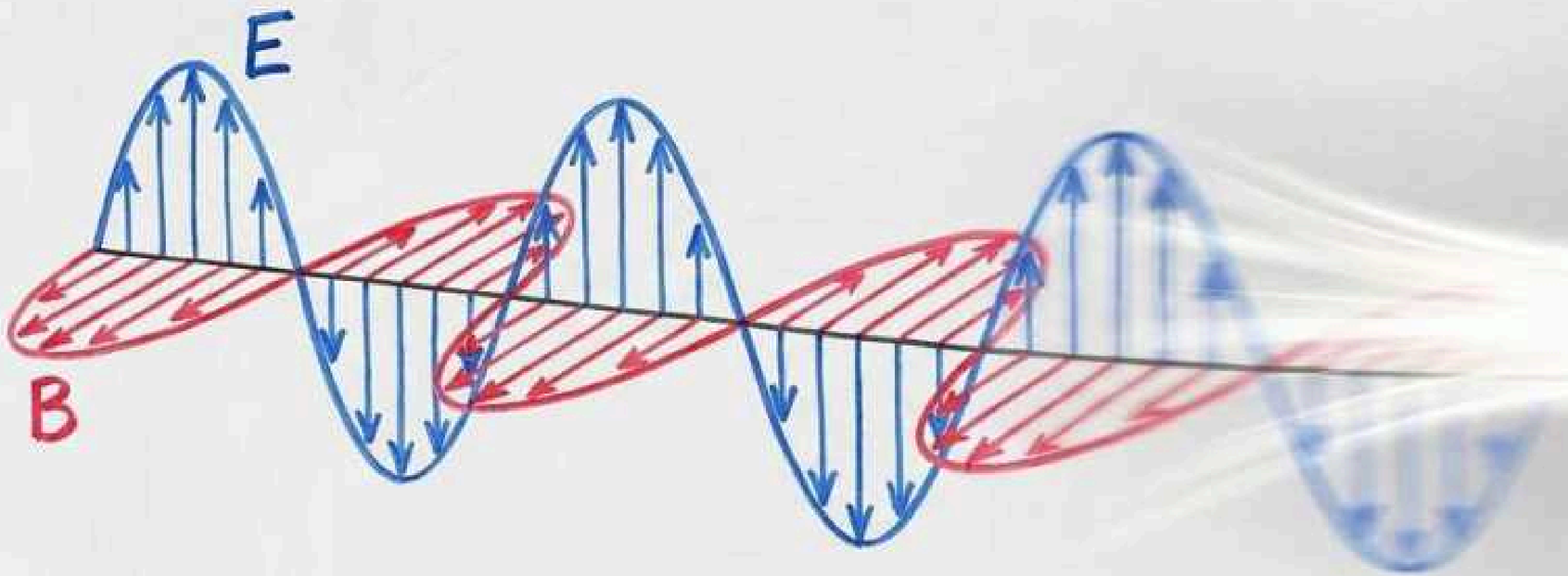


1. Which way does the induced current flow as North approaches?
2. Why exactly is the magnet's fall slowed?
3. Where does the lost kinetic energy go?

Ensure your answers obey the conservation of energy.

Gemini Notebook

Looking Ahead to Lecture 6



When we put all four ideas together, the result is electromagnetic waves—and the profound discovery that waves–and the profound discovery that light itself is one of them.