Electromagnetic Induction

AP Physics C: E&M ▪ Unit 13

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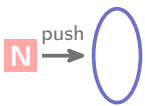
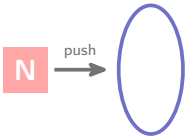


What we will cover

1. Magnetic flux
2. Faraday's law and Lenz's law
3. Induced currents and forces
4. Inductance
5. LR and LC circuits



Magnetic flux and Faraday's law

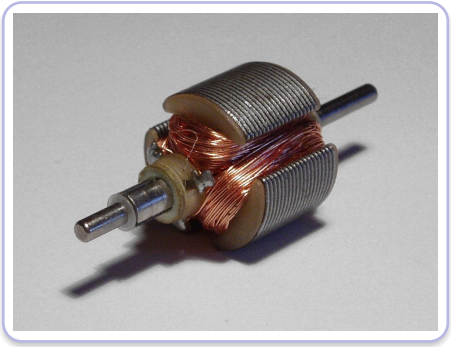
Flux, then Faraday

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

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

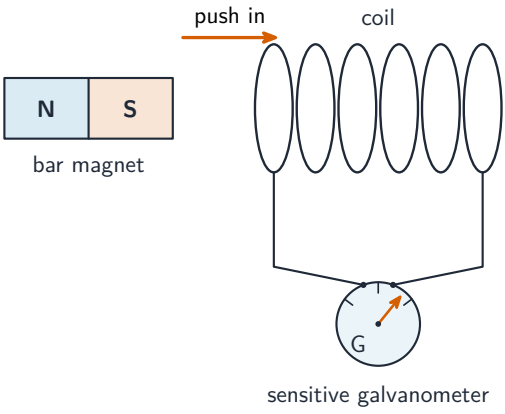
The minus sign is **Lenz's law** 楞次定律: the induced current opposes the change – energy conservation.

Motional emf: $\varepsilon = BLv$; a coil of N turns: $\times N$.



motor Rotor

Magnetic flux and Faraday's law



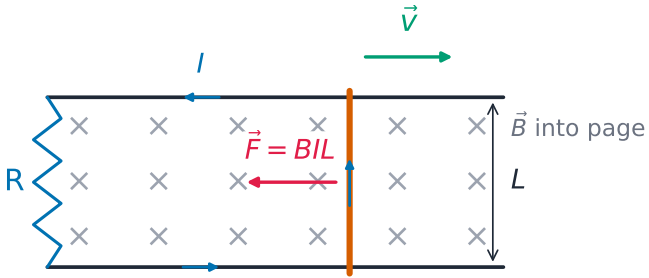
Induced currents and forces

The **induced current** 感应电流 (Lenz's law) always creates a **retarding force** 阻碍力 that resists the motion causing it.

- mechanical work → electrical energy → heat
- **eddy currents** 涡电流 in solid metal damp motion (magnetic braking)

substation Transformer

Induced currents and forces



Inductance

An **inductor** 电感 resists a change in current, creating a **back emf** 反电动势:

Back emf and stored energy

$$\varepsilon = -L\frac{dI}{dt}, \qquad U = \tfrac{1}{2}LI^2$$

Energy density $u = \dfrac{B^2}{2\mu_0}$ – the magnetic mirror of $\tfrac{1}{2}\varepsilon_0 E^2$.

Worked example

$2\,\mathrm{H}$ with I rising at $3\,\mathrm{A/s}$:

$$\varepsilon = L\tfrac{dI}{dt} = 2 \times 3 = 6\,\mathrm{V}$$

At a steady $4\,\mathrm{A}$: $U = 16\,\mathrm{J}$, and the back emf vanishes.

LR and LC circuits

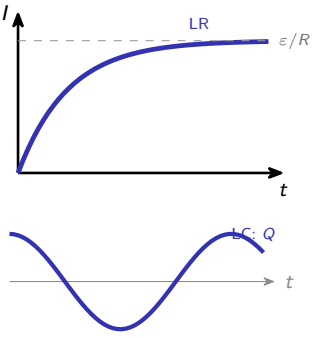
LR: smooth growth

$$\tau = \frac{L}{R},\ I = \frac{\varepsilon}{R}\left(1 - e^{-t/\tau}\right)$$

An inductor blocks current at first, passes it freely later – opposite to a capacitor.

LC: oscillation

$$\omega = \frac{1}{\sqrt{LC}}$$



Unit 13 – key takeaways

1 Faraday

$\varepsilon = -d\Phi_B/dt$; Lenz opposes the change

2 Induced force

always retarding; eddy currents damp motion

3 Inductance

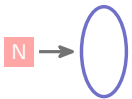
$\varepsilon = -L\,dI/dt$; stores $U = \frac{1}{2}LI^2$

4 Circuits

LR grows with $\tau = L/R$; LC oscillates at $1/\sqrt{LC}$

Check yourself

1. Write Faraday's law for the induced emf.
2. Which law fixes the direction of the induced current?
3. At the first instant, how does an inductor behave?
4. What sets the oscillation frequency of an LC circuit?



Answers **1.** $\varepsilon = -d\Phi_B/dt$ **2.** Lenz's law **3.** it blocks current (open) **4.** $\omega = 1/\sqrt{LC}$