Induction

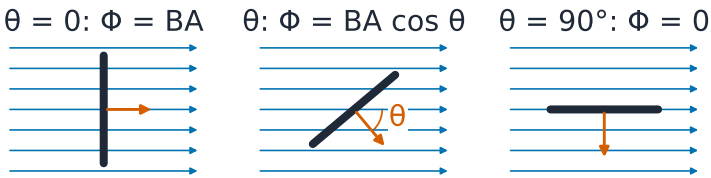
D.4 · AHL

How does a phone charge without a cable?

A changing **magnetic flux** through a circuit induces an emf in it.

- A coil in the pad carries alternating current.
- The changing field through a coil in the phone induces an emf.
- This unit: flux $\rightarrow$ Faraday $\rightarrow$ moving conductors $\rightarrow$ Lenz $\rightarrow$ generators.

Magnetic flux



edge-on view: black = coil, red = normal to the coil, blue = field B

- θ is the angle between the field and the **normal** to the area.
- Unit the **weber**, 1 Wb $=$ 1 T m^2; **flux linkage** is $N\Phi$.

Flux in numbers

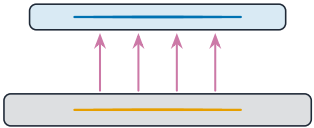
- $0.20 \times 2.0 \times 10^{-3} = 4.0 \times 10^{-4}$ Wb face-on.
- At 60° to the **normal**, 2.0×10^{-4} Wb.

$$\Phi = BA\cos\theta$$

Greatest when the field passes straight through; zero when it lies along the surface.

Wireless charging is induction

phone: the changing flux induces an emf



flux through both coils
rises and falls 100 000 times a second

charging pad: alternating current in the coil

> A changing flux induces an e.m.f.

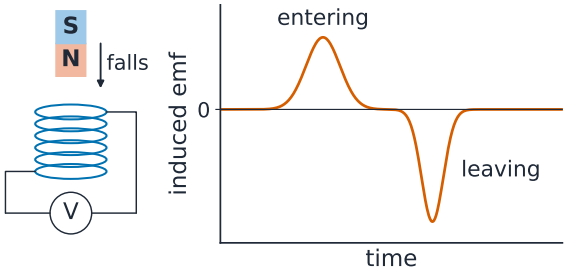
Faraday's law

- Change B, change the area, or rotate the coil.
- 200 turns, 4.0×10^{-4} Wb to zero in 0.050 s gives 1.6 V.

$$\overline{\varepsilon} = -\frac{\Delta(N\Phi)}{\Delta t}$$

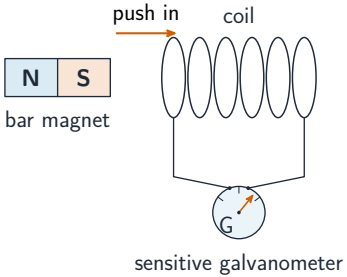
Compare meter signs as the same magnet enters and leaves a coil; hold it still for no signal. Use approved low-voltage supplies for motor demonstrations.

A magnet falling through a coil



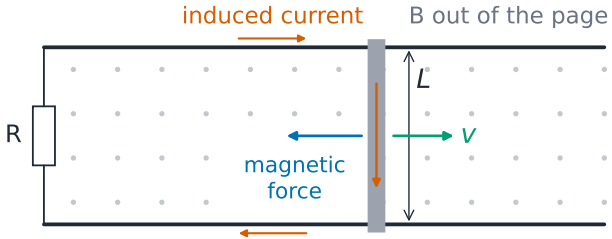
- Opposite linkage changes produce opposite emf pulses.
- A faster exit in a weakly loaded fall can give a taller, narrower pulse; equal endpoint linkage makes total signed area zero.

A magnet into a coil



Faster motion: a larger e.m.f.

A rod moving on rails



- $\varepsilon = BvL$; 0.30 T, 4.0 m s^{-1}, 0.50 m gives 0.60 V.
- The force on the **induced current** opposes the motion.

Check: the opposing force

Your turn

A 0.25 m rod moves at 6.0 m/s in 0.50 T, with rod, velocity and field mutually perpendicular. Rails close through total resistance 1.5 Ω. Neglect friction and inductive transients. What force keeps the rod moving at constant speed?

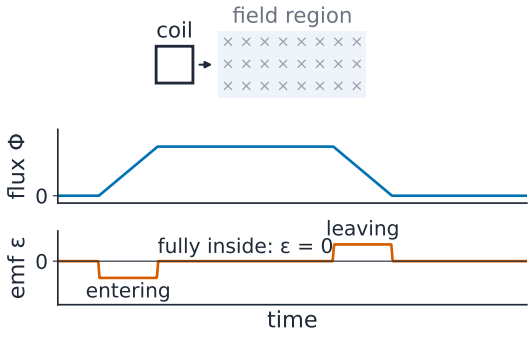
A. 0.031 N

B. 0.063 N

C. 0.38 N

D. 0.75 N

A coil through a field region



- Entering or leaving: $\varepsilon = NBvL$, opposite directions.
- Fully inside: the flux is constant, so $\varepsilon = 0$.

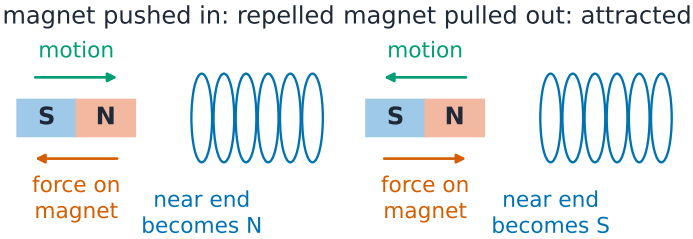
Worked example: a square coil

1. **Known.** 50-turn square coil, side 0.10 m, speed 2.0 m/s, field 0.40 T, field-region width 0.30 m.
2. **Entering.** $\varepsilon = 50 \times 0.40 \times 2.0 \times 0.10 = 4.0$ V for 0.050 s.
3. **Check.** $\Delta(N\Phi) = 0.20$ Wb in 0.050 s gives 4.0 V.

Decision

4.0 V entering, 0 inside, 4.0 V the other way leaving

Lenz's law



- Pushed in, the near end becomes N and repels the magnet.
- Pulled out, the near end becomes S and attracts it back.

Lenz's law is energy conservation

Eddy-current braking

Currents in a moving metal plate oppose its motion.

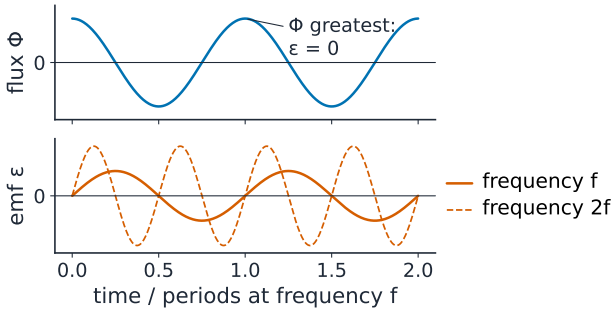
Kinetic energy becomes thermal energy.

Magnet in a copper pipe

Induced currents in the walls oppose the fall.

A comparable plastic pipe lacks strong eddy-current braking.

A rotating coil



- Emf is zero at positive and negative linkage extrema; its magnitude is greatest at zero crossings.
- Twice the frequency gives twice the peak emf.

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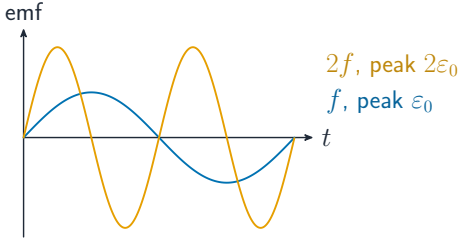
Check: a slower generator

Your turn

A generator's rotation frequency halves while coil area, turns and uniform field stay fixed. What happens to its emf frequency and peak?

A. Same frequency, half the peak
B. Half the frequency, same peak
C. Half the frequency, half the peak
D. Half the frequency, a quarter of the peak

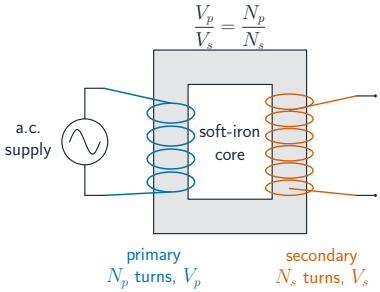
Spin a coil twice as fast



$\varepsilon_0 = NBA\omega$: more N, B or A raises the peak but not the frequency

$$\varepsilon_0 = BAN\omega$$

The transformer



- The shared changing flux links both coils in the ideal model.
- A steady current gives no continuing secondary emf; switching can induce a transient.

Self-induction

Switching on

The current rises gradually.

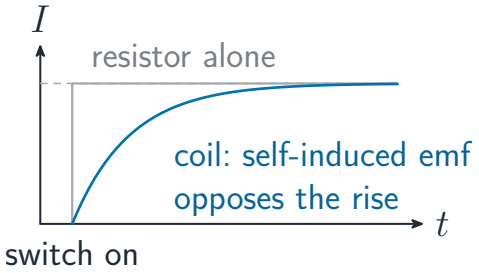
The emf opposes the rise.

Switching off

The emf tries to keep the current flowing.

It can make a spark at the switch.

Self-induction slows the rise



The self-induced e.m.f. opposes the rise

Exam tips

> Emf depends on how fast the flux changes, not on how big it is.

- Use the angle to the **normal** in $\Phi = BA\cos\theta$.
- Remember N; reversing a flux changes it by twice its value.
- Fully inside a uniform field, a moving coil has zero emf.

Check yourself

Try these

HL. 500 turns, 3.0×10^{-4} Wb reversed in 0.020 s. Find the emf.

HL. Explain why a magnet falls slowly through a copper pipe.

HL. A generator's frequency is halved. State two effects on the emf.