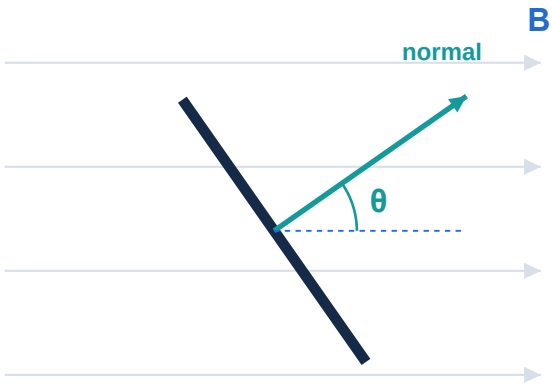
LESSON 4.2.3

Electromagnetic Induction and Alternating Currents

A changing magnetic flux linkage induces an e.m.f. The key is how quickly the linkage changes, not simply how strong the magnetic field is.

MEASURE THE ANGLE FROM THE NORMAL



Coil plane shown edge-on

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

Flux through one turn depends on field strength, area and orientation. The normal is perpendicular to the coil plane.

At 0°: flux is BA. At 90°: flux is zero. Do not use the angle to the plane in the cosine formula.

$$\text{Flux linkage} = N\Phi = NBA\cos\theta$$

For N identical turns, each linked by the same flux. B is in tesla; A is in square metres. Flux is in webers (Wb); linkage is often written in Wb turns.

$$1\ \text{Wb} = 1\ \text{T m}^2 = 1\ \text{V s}$$

EXAMPLE: 200 TURNS, 0.100 T, AREA 30.0 cm², ANGLE 60°

$$A = 3.00 \times 10^{-3}\ \text{m}^2 \qquad \Phi = 1.50 \times 10^{-4}\ \text{Wb}$$

$$N\Phi = 200 \times 1.50 \times 10^{-4} = 0.0300\ \text{Wb turns}$$

An e.m.f. can exist in an open circuit; a sustained current needs a closed path.

1 Rate sets size; Lenz sets direction

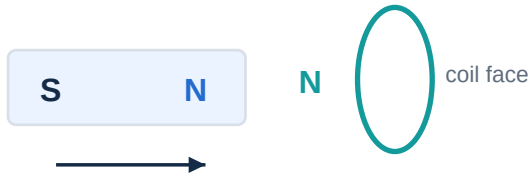
Changing B, linked area, or coil orientation can change magnetic flux linkage.

$$\varepsilon = -\frac{d(N\Phi)}{dt} \qquad |\varepsilon_{avg}| = \frac{|\Delta(N\Phi)|}{\Delta t}$$

Instantaneous e.m.f. is the negative gradient of a flux-linkage versus time graph. The finite-change expression gives the average e.m.f. over the interval.

The minus sign means the induced effect opposes the CHANGE in linkage.

N POLE APPROACHES



Repels: anticlockwise current

Current viewed from the magnet side.

N POLE MOVES AWAY



Attracts: clockwise current

Current viewed from the magnet side.

For a closed coil: an approaching north pole increases rightward flux, so the coil creates a leftward field. When it moves away, the coil reinforces the decreasing rightward flux.

A stationary magnet gives no e.m.f. if linkage stays constant. Moving faster usually increases the rate of change and hence the e.m.f. More turns increase e.m.f. for the same flux-change rate per turn.

EXAMPLE: FLUX PER TURN FALLS FROM 0.30 mWb TO 0.10 mWb

A 500-turn coil experiences this change in 0.0400 s.

$$|\varepsilon_{avg}| = \frac{500 \times (0.30 - 0.10) \times 10^{-3}}{0.0400} = 2.50\ \text{V}$$

Multiply by N once only. If a graph already shows NΦ, use its gradient directly.

Energy check: the induced magnetic force resists the motion. External work supplies the electrical energy transferred to the circuit; induction does not create energy.

2 Rotation produces alternating e.m.f.

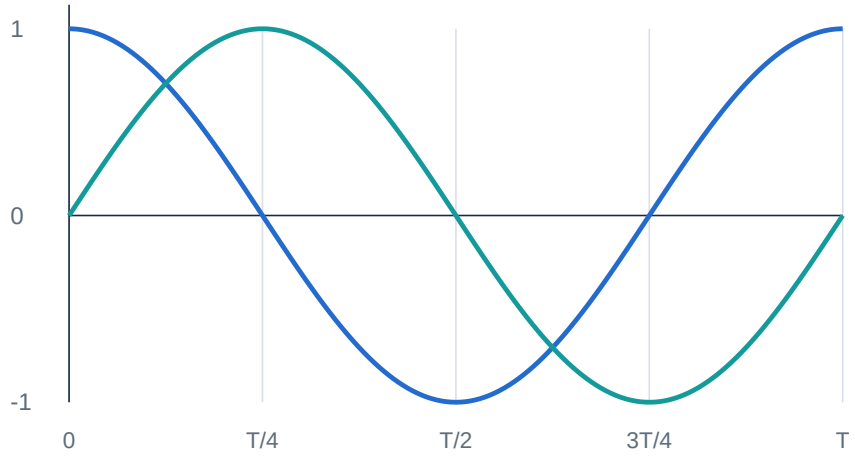
Rotate steadily about an axis perpendicular to uniform B. The e.m.f. reverses every half-turn.

$$N\Phi = NBA\cos(\omega t)$$

$$\varepsilon = NBA\omega\sin(\omega t) \qquad \varepsilon_0 = NBA\omega$$

Choose t = 0 when the normal is aligned with B; ω = 2πf, with angles in radians.

Normalised values



Flux linkage / NBA

E.m.f. / peak e.m.f.

T = one rotation period. The two curves are a quarter-cycle apart.

Maximum |flux|: zero e.m.f. Zero flux: maximum |e.m.f.|.

Slip rings and brushes keep the rotating coil connected to the external circuit. With a resistive load, current alternates in phase with the e.m.f. Mechanical input maintains rotation.

$$V_{rms} = \frac{V_0}{\sqrt{2}} \qquad I_{rms} = \frac{I_0}{\sqrt{2}}$$

For a sine wave only. RMS is the DC-equivalent heating value in the same resistor. The mean voltage over a full cycle is zero, but mean power is not.

$$P_{avg} = I_{rms}^2 R = \frac{V_{rms}^2}{R}$$

Do not use peak voltage in the average-power equation. At fixed N, B and A, faster rotation increases both the frequency and the peak e.m.f.

3 Transfer energy through changing flux

Mutual induction: a changing current in one coil changes the flux linked by a nearby coil.

NO RELATIVE MOTION IS REQUIRED

Switching the primary current on or off induces a brief secondary e.m.f. A steady DC current gives no continuing e.m.f. once the field is steady. An alternating current keeps the flux changing.

A transformer uses two coils linked by a common core. Stronger coupling, more secondary turns, or a faster change of shared flux increases the secondary e.m.f. The coils need not be electrically connected.

Ideal model: both coils link the same flux and no power is lost.

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad V_p I_p = V_s I_s$$

p = primary; s = secondary. Use RMS values for sinusoidal AC with a resistive load.

EXAMPLE: IDEAL STEP-DOWN TRANSFORMER

Primary: 240 V, 1000 turns. Secondary: 12.0 V, supplying 2.00 A.

$$N_s = 1000 \times \frac{12.0}{240} = 50 \text{ turns}$$

$$I_p = \frac{12.0 \times 2.00}{240} = 0.100 \text{ A}$$

EXAMPLE: COIL GENERATOR AT 50.0 Hz

N = 200, B = 0.100 T, A = 0.00300 m²; ω = 2πf = 100π rad/s.

$$\varepsilon_0 = (200)(0.100)(0.00300)(100\pi) = 18.8 \text{ V}$$

$$\varepsilon_{rms} = \frac{18.8}{\sqrt{2}} \approx 13.3 \text{ V}$$

Source: Pearson IAL Physics, Unit 4 p. 30, points 105 and 108-110.

AC and ideal-transformer applications extend the induction laws. Course lesson numbering.