

How changing flux creates an emf

Physics grades 11-12 (A Level · IB · Class 11-12) · Lesson

Quick answer: Electromagnetic induction is the creation of an emf in a circuit when the magnetic flux linked with it changes. The size is $\varepsilon = N \Delta\Phi/\Delta t$ (Faraday's law), where flux $\Phi = BA \cos \theta$, and the induced current opposes the change (Lenz's law). Generators use a rotating coil to produce alternating emf.

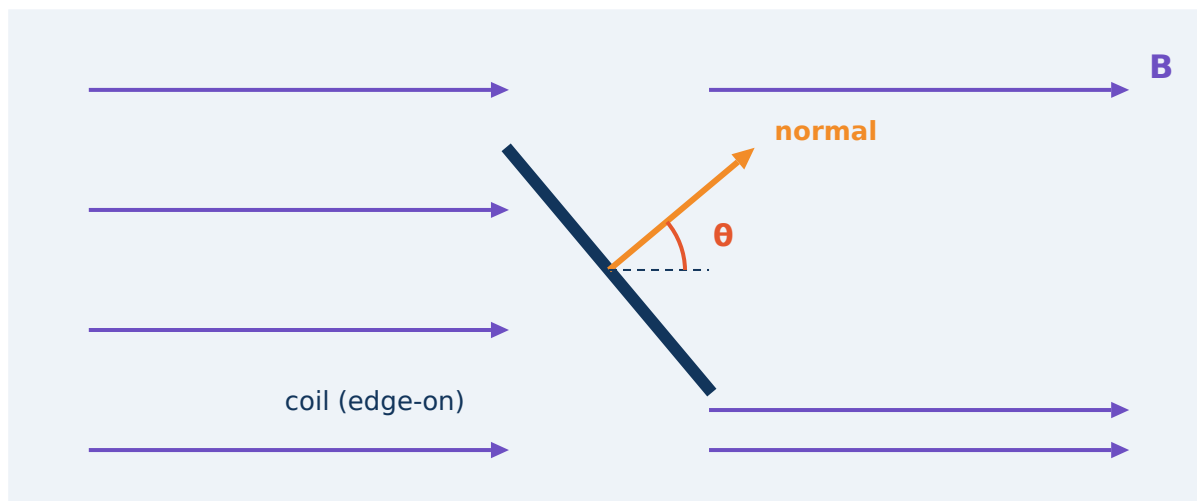
Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB D.4

What is magnetic flux?

Hold a hoop in a stream of water and the amount flowing through depends on the hoop's size and tilt. Magnetic flux works the same way for field lines. It counts how much magnetic field passes through a surface, and it is the quantity whose change creates an emf.

Definition

Magnetic flux Φ through a flat surface of area A in a uniform field B is $\Phi = BA \cos \theta$, where θ is the angle between the field and the normal to the surface. The unit is the **weber** (Wb): $1 \text{ Wb} = 1 \text{ T m}^2$.



Flux depends on the angle θ between the field and the normal to the coil: $\Phi = BA \cos \theta$. It is largest when the coil faces the field and zero when the coil is edge-on.

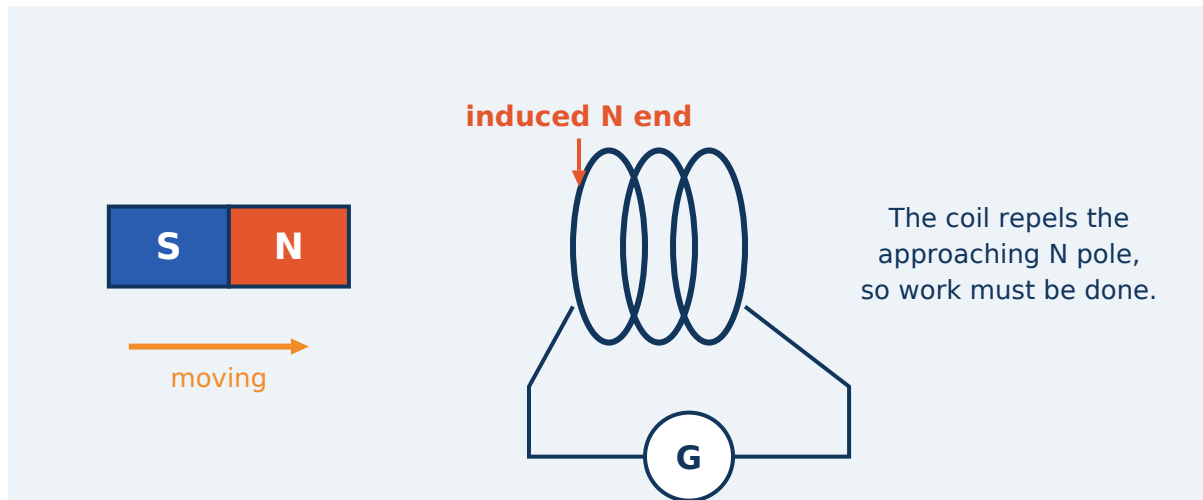
What do Faraday's and Lenz's laws say?

An emf appears in a circuit whenever the flux linked with it changes, whether the field changes, the area changes or the angle changes. Michael Faraday found that the size depends on how fast the change happens, and Heinrich Lenz found the direction.

Key law

Faraday: $\varepsilon = -N \Delta\Phi/\Delta t$. The induced emf equals the rate of change of flux linkage $N\Phi$.

Lenz: the minus sign shows that the induced current opposes the change that causes it.



Lenz's law: the induced current makes the near end of the coil a north pole, which opposes the approach of the magnet.

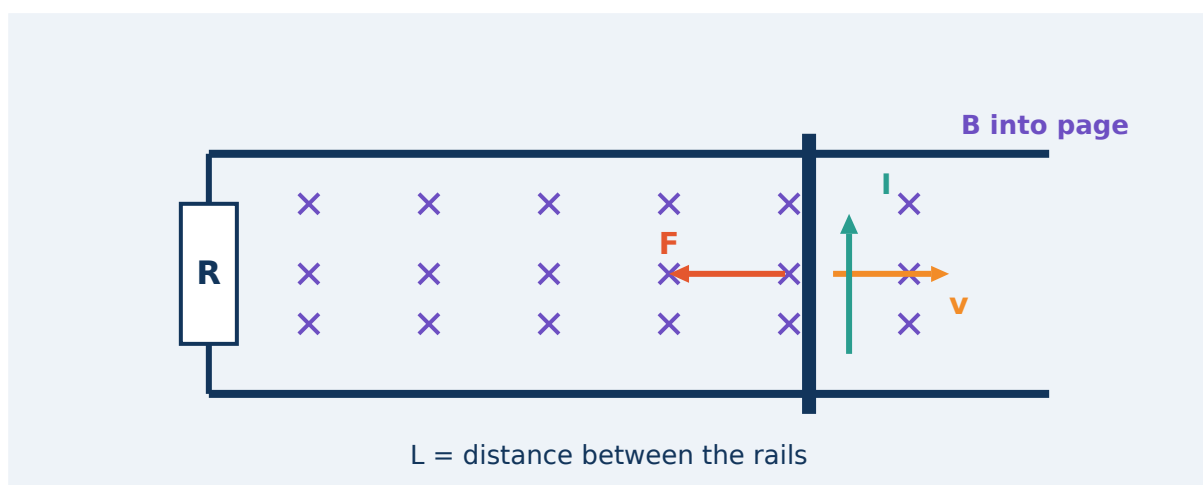
Worked example

A coil of 200 turns and area 25 cm^2 faces a field that rises from 0 to 0.40 T in 0.050 s . Calculate the average emf.

$A = 25 \times 10^{-4} = 2.5 \times 10^{-3} \text{ m}^2$. $\Delta\Phi = BA = 0.40 \times 2.5 \times 10^{-3} = 1.0 \times 10^{-3} \text{ Wb}$. $\varepsilon = N\Delta\Phi/\Delta t = 200 \times 1.0 \times 10^{-3} / 0.050 = \mathbf{4.0 \text{ V}}$.

How is an emf made by a moving conductor?

A rod of length L moving at speed v across a field sweeps out area at the rate Lv , so the flux through the circuit changes at the rate BLv . The emf is therefore $\varepsilon = BLv$, and if the rod is part of a closed circuit a current flows.



The moving rod creates an emf BLv . The induced current flows anticlockwise (up the rod) and the magnetic force on the rod opposes its motion.

Formula

$\epsilon = \mathbf{B L v}$ (rod perpendicular to $\mathbf{B}$ and to its motion)

ϵ = emf (V), B = flux density (T), L = length of rod in the field (m), v = speed (m/s).

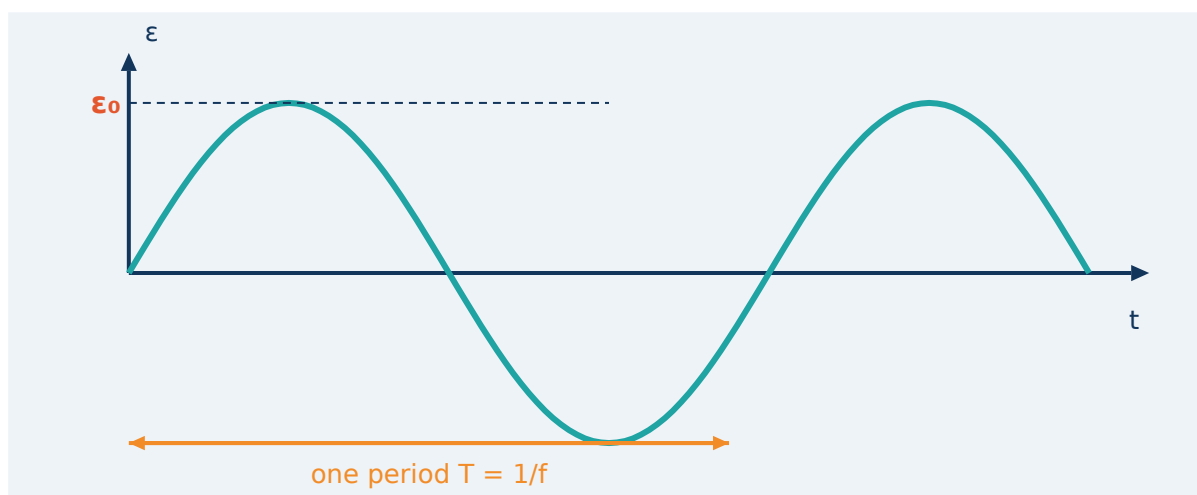
Worked example

A rod 0.60 m long slides at 5.0 m/s across a 0.25 T field in a circuit of total resistance 1.5 Ω . Calculate the current and the force needed to keep it moving.

$\epsilon = BLv = 0.25 \times 0.60 \times 5.0 = 0.75$ V. $I = \epsilon/R = 0.75 / 1.5 = \mathbf{0.50}$ A. The magnetic force opposing the motion is $F = BIL = 0.25 \times 0.50 \times 0.60 = \mathbf{0.075}$ N, so the pushing force must be 0.075 N. Check: $Fv = 0.375$ W = I^2R .

How does a generator work?

A coil turning in a field has a flux that varies with the angle, so an emf is induced all the time. The result is a sinusoidal alternating emf whose peak value depends on the number of turns, the field, the area and the angular speed.



A coil turning at a steady rate gives $\epsilon = \epsilon_0 \sin \omega t$, where $\epsilon_0 = NBA\omega$ and $\omega = 2\pi f$.

How do the factors compare?

Change made	Effect on peak emf of a generator	Effect on frequency
Double the turns N	doubles	unchanged
Double the field B	doubles	unchanged
Double the rotation rate	doubles	doubles
Replace coil with one of half the area	halves	unchanged

Common mistake

Students think a large flux gives a large emf. It is the **rate of change** of flux that matters: a strong steady field linked with a stationary coil induces nothing.

Lina's tip

Ask “what is changing?” first: B , A or θ . Then ask “which way would the induced field have to point to resist it?” That second step is Lenz's law and it gives the current direction.

Key points to remember

- Flux: $\Phi = BA \cos \theta$, measured in weber ($1 \text{ Wb} = 1 \text{ T m}^2$).
- Faraday's law: $\varepsilon = -N \Delta\Phi/\Delta t$.
- Lenz's law: the induced current opposes the change that causes it.
- Moving rod: $\varepsilon = BLv$.
- Generator: $\varepsilon = NBA\omega \sin \omega t$, peak $\varepsilon_0 = NBA\omega$.

How changing flux creates an emf: frequently asked questions

What is the difference between flux and flux density?

Flux density B is the field strength in tesla. Flux $\Phi = BA \cos \theta$ is the amount of field passing through a surface and is measured in weber.

Why is there a minus sign in Faraday's law?

The minus sign expresses Lenz's law. The induced emf drives a current whose magnetic effect opposes the change of flux, which is also a consequence of energy conservation.

Can a steady magnetic field induce a current?

Not by itself. An emf is induced only while the flux through the circuit is changing, for example when the coil moves, rotates or the field varies.

How can a generator's emf be increased?

Use more turns, a stronger magnet, a larger coil area or a faster rotation. Each of these increases the peak value $\varepsilon_0 = NBA\omega$.

How does Lenz's law relate to conservation of energy?

If the induced current helped the change, energy would appear from nothing. Because it opposes the change, work must be done to move the magnet or rod, and that work becomes electrical energy.