Faraday's Law: the magnitude of the induced e.m.f. ϵ is directly proportional to the rate of change of magnetic flux linkage or rate of cutting of magnetic flux.

$$\varepsilon \propto \frac{d\Phi}{dt}$$

For constant or average induced emf:

$$|\varepsilon| = \frac{\Delta\Phi}{\Delta t}$$

Examples of induced emf:

a) AC generator

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

Where N: number of turns, ω: angular freq.

b) Rod cutting flux

$$\varepsilon = BLv$$

Where L: length of rod, v: velocity

c) Faraday's disc

$$\varepsilon = BAf$$

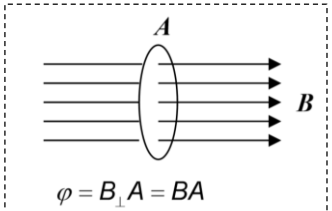
Where f: frequency of rotation, A: area of disc

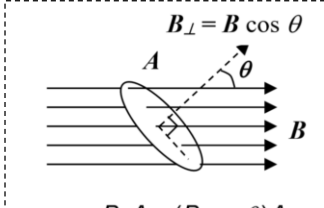
Magnetic Flux Φ: The magnetic flux through a plane surface is the product of the magnetic flux density normal to the surface and the area of the surface.

$$\Phi = B_{\perp}A$$

Where B is the magnetic flux density. SI unit: **weber (Wb).** Note that B is a vector but Φ is a scalar.

The Weber is defined as the magnetic flux through a surface of 1 m^2 if a magnetic field of flux density 1 T exists perpendicular to the area.





Magnetic Flux linkage: The magnetic flux linkage $\Phi_{linkage}$ is defined as the product of the number of turns of the coil and the magnetic flux linking each turn.

$$\Phi_{linkage} = NB_{\perp}A$$

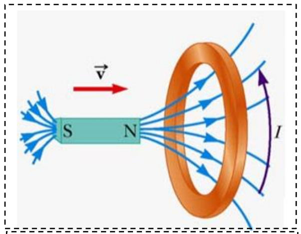
Lenz's Law: the polarity of the induced e.m.f. is such that it tends to produce a current that creates a magnetic field so as to oppose the change in magnetic flux

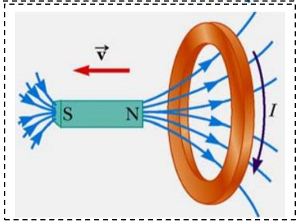
Lenz's law is a statement of the **conservation of energy** where the mechanical energy is converted into electrical energy.

Lenz's law allows us to determine the polarity of the induced emf and predict the direction of the induced current.

Closed loops without motion (changing flux linkage):

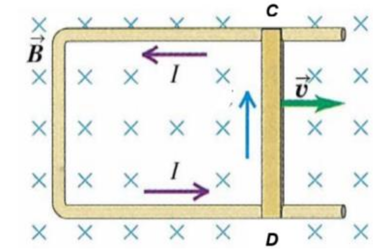
Identify the **CHANGE** in flux linkage experienced by loop. The induced current will flow to produce a B-field to **OPPOSE THE CHANGE**. Use **RHGR**.





Motional emf (cutting of flux)

Apply FRHR, which predict the direction of induced current (if circuit is closed). The current inside the rod "flows" from low potential to high potential. In the diagram below, C is at higher potential than D.



Exam Tip 1: Graphical Method (sketch a ϵ-t graph.)

The magnetic field produced by the current is proportional to the current, hence the graph of B vs t looks the same.

If the area of the second coil does not change then the linkage through the second coil will be proportional to the magnetic field produced y the first coil. Hence graph of Φ vs t for the second coil will have the same trend.

Apply Faraday's Law: ϵ vs t will be given by negative of the gradient of the Φ vs t graph.

Exam Tip 2: Material

Non-ferromagnetic conductor, experiencing a changing magnetic flux linkage, will have induced e.m.f., induced current and hence resistance to motion. (Eg. Aluminium, Copper)

Ferromagnetic conductor, when placed in a magnetic field. Whether changing or not, will become a magnet itself and the outcome will be different. (Eg. Iron, Steel)

Exam Tip 3: (explain why there is an induced e.m.f/ current/damping/terminal V)

Give the cause for changing magnetic flux or cutting of magnetic flux.

Apply Faraday's law to conclude that emf proportional to rate of change of flux will be induced in conductor.

If the loop is closed, there will be induced current flowing.

By Lenz's law, the induced current flows in the direction to oppose the changing flux that created it.

Induced current results in a magnetic force that opposes motion. Mechanical energy converted to Electrical energy.

Magnetic Field VS Magnetic Flux Density VS Magnetic Flux VS Magnetic Flux Linkage

Magnetic field is the region around the magnet where the moving charge experiences a force
Magnetic flux density (B) is a vector field, indicating the strength of the magnetic field at a given point in a medium.
Magnetic flux (Φ) is a scalar value, which represents the amount of B flowing through a cross-sectional area, bounded by a closed loop.
Magnetic flux linkage ($\Phi_{linkage}$) is equal to the product of B and the number of turns in the coil placed within the magnetic field. A magnetic field can only induce an emf across a coil if the magnetic flux changes with time. This mean that if the magnetic field changes with time, the magnetic flux which induces a current in the coil, is known as the magnetic flux linkage (it links a magnetic flux between the coil and the source of the magnetic field).