TIME-VARYING FIELDS

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Time-Varying Fields

So far, we have discussed time invariant fields.

$\vec{\mathrm{E}}(x, y, z)$ and $\vec{\mathrm{H}}(x, y, z)$ are independent.

$\vec{\mathrm{E}}(x, y, z, t)$ and $\vec{\mathrm{H}}(x, y, z, t)$ are dependent.

We will see that time varying fields produce radiation.

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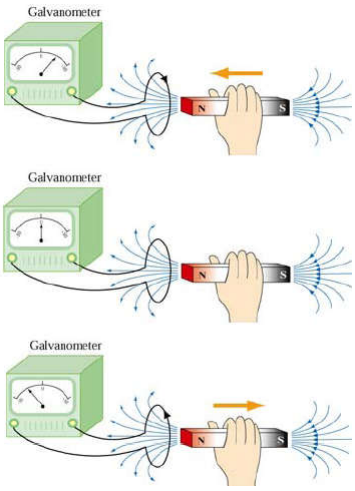
Electromagnetic Induction

Steady current produces magnetic field.

Can the process be reversed?

Faraday's Experiment

- No current when bar magnet is stationary with respect to the loop.
- Electric current is induced in the loop by changing magnetic field.



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Faraday's Law

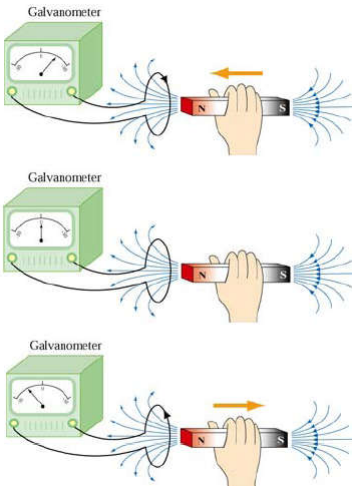
Induced emf (in volts) in any closed circuit is equal to the time rate of change of the magnetic flux linkage by the circuit.

$$V_{\text{emf}} = -\frac{d\psi}{dt}.$$

ψ : flux linkage in the loop

If there are N turns in the loop:

$$V_{\text{emf}} = -N\frac{d\psi}{dt}$$



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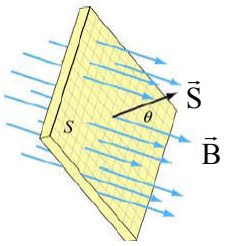
Magnetic Flux

Magnetic flux through a surface S

$$\psi = \int_S \vec{\mathrm{B}} \cdot d\vec{\mathrm{S}} = BS\cos\theta$$



$$V_{\text{emf}} = -\frac{d\psi}{dt}$$
$$= -\frac{d}{dt}(BS\cos\theta)$$
$$= -\left(\frac{dB}{dt}\right)S\cos\theta - B\left(\frac{dS}{dt}\right)\cos\theta + BS\sin\theta\left(\frac{d\theta}{dt}\right)$$

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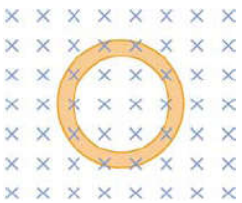
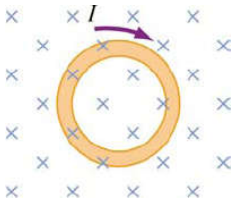
Inducing EMF

a. By varying magnitude of *B* with time



$\vec{\mathrm{B}}(t_1)$



$\vec{\mathrm{B}}(t_2)$

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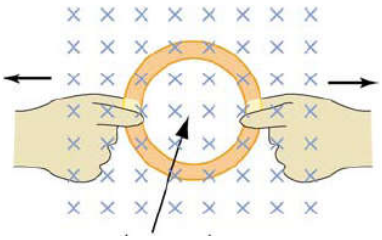
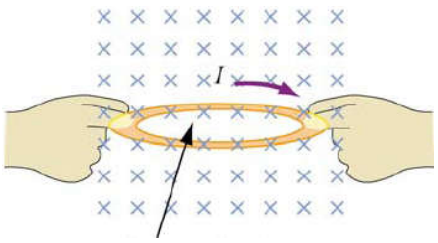
Inducing EMF

b. By varying magnitude of *S* with time



Area = S_1



Area = S_2

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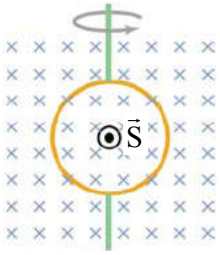
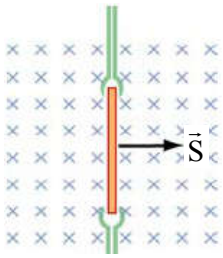
Inducing EMF

c. By varying angle between *B* and *S* with time



$\vec{B}$



$\vec{B}$

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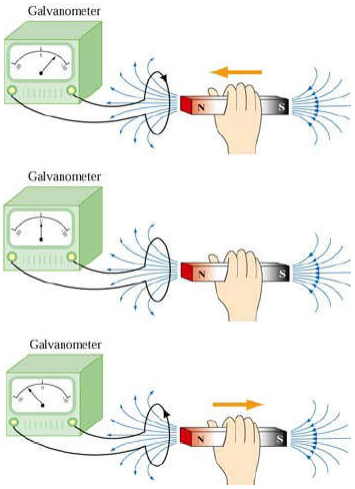
Lenz's Law

The induced current produces magnetic fields which tend to oppose the change in magnetic flux that induces currents.



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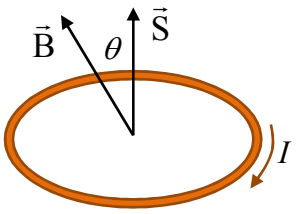
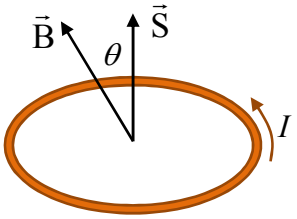
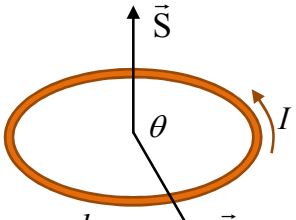
Direction of Induced Current



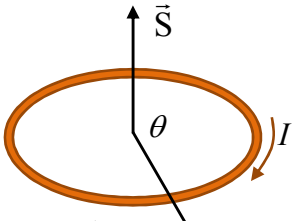
$\psi > 0, \quad \frac{d\psi}{dt} > 0$



$\psi > 0, \quad \frac{d\psi}{dt} < 0$



$\psi < 0, \quad \frac{d\psi}{dt} < 0$



$\psi < 0, \quad \frac{d\psi}{dt} > 0$

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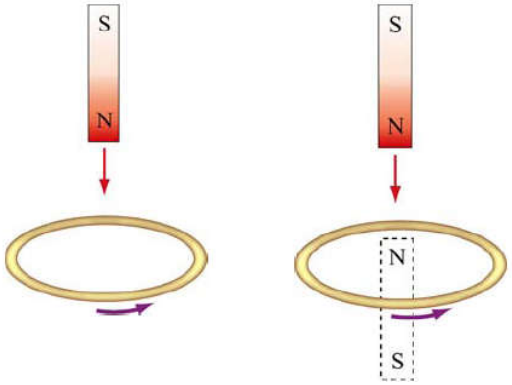
Direction of Induced Current

The direction of the induced current can also be determined from the point of view of magnetic force.



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