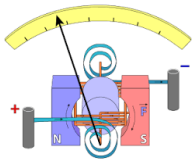
4.5 Induced emf: Faraday's & Lenz's Laws

Induced emf (Electromotive Force)

Moving magnets induce emf (voltage) in conductors.

This can be seen in this crude galvanometer (current meter) as a magnet moves towards and away from it. DEMO.



Magnetic Flux (Φ)

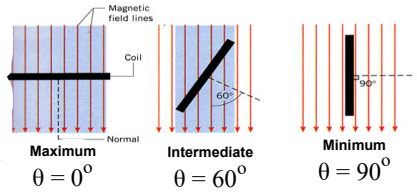
Loops induce emf when the B-field passing through the loop's area fluctuates - called magnetic flux.

$$\Phi_B = \vec{B} \bullet \vec{A}$$

$$\Phi_B = |\vec{B}| \bullet \cos\theta \bullet |\vec{A}|$$

AP Equations

Φ = flux (webers: Wb = T•m²)
B = Magnetic Field (T)
A = Coil Area (m²)
θ = angle betwen B field & perpendicular line (degrees)



Maximum $\theta = 0^o$ | Intermediate $\theta = 60^o$ | Minimum $\theta = 90^o$

Faraday's Law of Induction

Emf depends on the rate of magnetic flux's change:

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$$

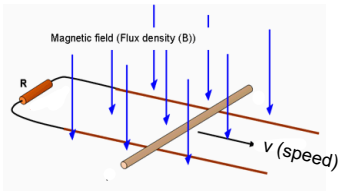
AP Equation (N is added)

ε = emf (V)
N = Number of Turns
Φ = Wb (T•m²)
t = time (s)

Negative sign indicates induced emf direction.

Motional RHR

Current in conductors moving through a B-field is subject to RHR: index finger is direction; middle finger is B-field; thumb is the force positive charges (current) experiences.



Which way is current going?

Current is counterclockwise

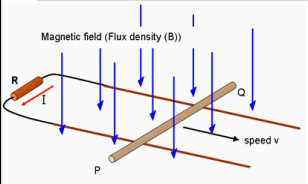
Motional emf Math

As the conductor moves through the field, loop area changes, making flux and inducing emf:

$$\varepsilon = B\ell v$$

AP Equation

ε = emf (V)
B = magnetic field (T)
l = conductor length (m)
v = velocity of conductor (m/s)

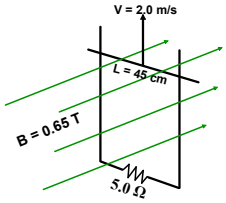


Area changes as the conductor moves, so the flux changes too.

Motional emf Examples

A 45 cm wire moves upwards at 2.0 m/s along two metal rails connected to a 5.0 Ω resistor in a perpendicular magnetic field of 0.65 T.

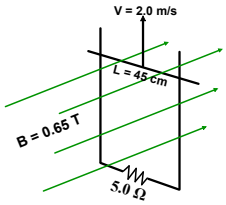
1. In what direction is the current?



By the Right Hand Rule, the current goes left through the wire, and counterclockwise overall through the circuit.

Motional emf Examples

2. What emf is produced?



$$\varepsilon = B\ell v$$
$$= 0.65\,T \bullet 0.45\,m \bullet 2.0\,m/s$$
$$= 0.59\,V$$

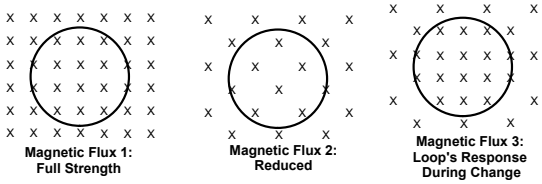
3. How much power is dissipated by the resistor?

$$P = \frac{V^2}{R} = \frac{0.59V^2}{5.0\Omega} = 0.070W$$

Lenz's Law

A reaction to charge movement caused by emf yields Lenz's Law:

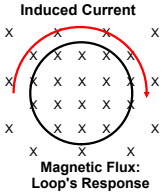
"Induced emf in a loop has a direction so the current it creates then produces its own B-field opposing the *change* in magnetic flux through that loop." (What does that mean?)



RHR: Current in Loops

To make a field, a current travels through the loop.

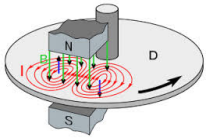
RHR: thumb points in the direction of the induced field; curled fingers indicate current direction.



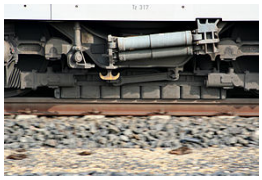
Lenz's Law Application

As magnetic fields are induced in conductors, eddy current is produced.

Resistance heats the conductor, and system's energy is lost.



This is used to slow roller coasters & trains through eddy current braking.

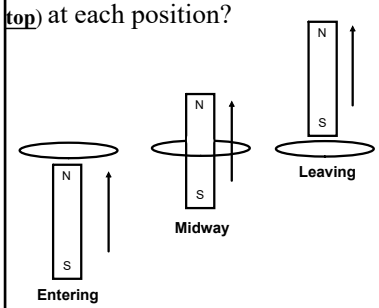


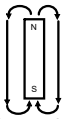
Magnet/copper tube DEMO.

4. Current Example

A magnet passes through a loop.

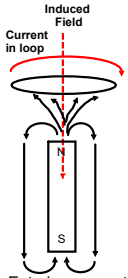
What direction is the induced current (viewed **from the top**) at each position?



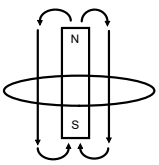


Remember: B-Field lines go from North to South.

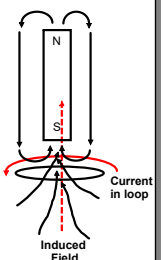
Current Answer



Entering, current makes field opposite the arrowheads entering it: **clockwise current.**



Midway, flux changes direction briefly: at that point there's **no current.**



Leaving, current's field makes up for field line reduction: **counterclockwise.**

Homework 4.5

4.5 Booklet Problems
Due: Next Class