Lecture 33
(Induced EMF)

Physics 161-01 Spring 2012

Douglas Fields

Faraday's Law

- We now have an equation that relates a change in magnetic flux through a surface to an induced electromotive force around the surface:

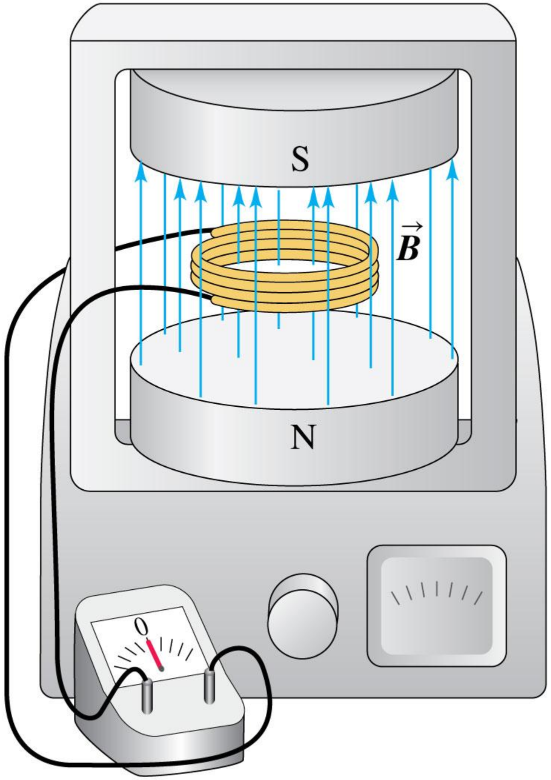
$$\mathcal{E} = -\frac{d\Phi_B}{dt},$$

$$\Phi_B = \int_{\text{Surface}} \vec{B} \cdot d\vec{A}$$

- We want now to explore this relationship, try to understand it a bit more, and then look for applications.

Induced EMF

- Remember our set of experiments on a coil in a magnetic field.
- We can break these down into two types of situations:
    - A static (non-moving) coil in a changing magnetic field.
    - A coil that is undergoing some type of motion in a static magnetic field.
- While both of these are explained by Faraday’s Law as we have stated it, there are some situations where another formulation of Faraday’s Law will help us to understand what is happening.



Warning

- The following can be confusing.
- When in doubt, always revert to:

$$\mathcal{E} = -\frac{d\Phi_B}{dt},$$

$$\Phi_B = \int_{\text{Surface}} \vec{B} \cdot d\vec{A}$$

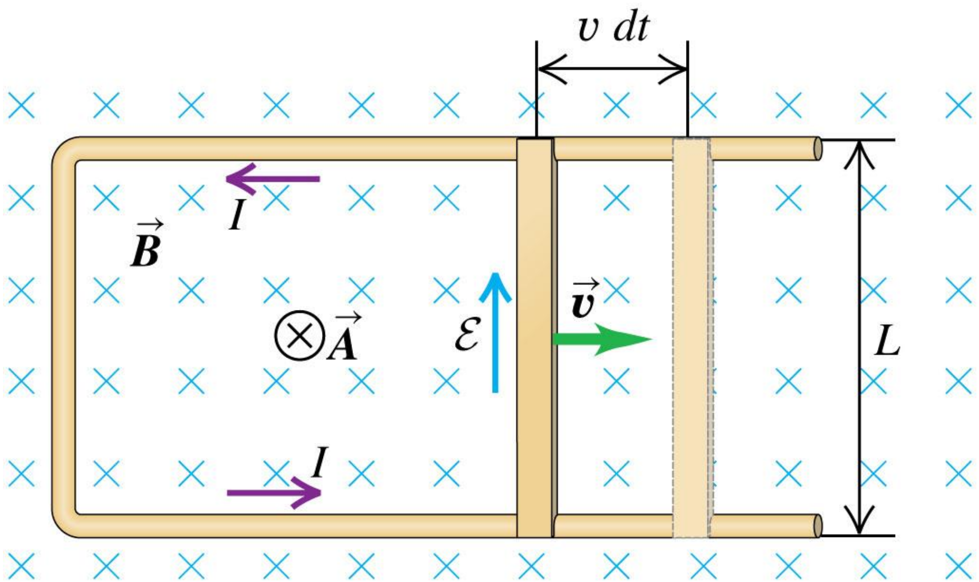
Motional EMF

- Let's look at a fixed U-shaped conductor in a constant magnetic field with a movable slide.
- Let's now move the slide to the right at some velocity v and examine the situation with Faraday's Law.

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

$$\Phi_B = \int_{\text{Surface}} \vec{B}\cdot d\vec{A} = BL\left(x_0 + vt\right) \Rightarrow$$

$$\mathcal{E} = -\frac{d}{dt}\left[BL\left(x_0+vt\right)\right] = -BLv$$



Motional EMF

- Now, let's just examine the moving rod.
- There is a magnetic force on the charges as they move with the rod.
- This force creates a separation of charges on each end of the rod, until there is an electric force caused by the electric field of these separated charges.
- The electric field then is just:

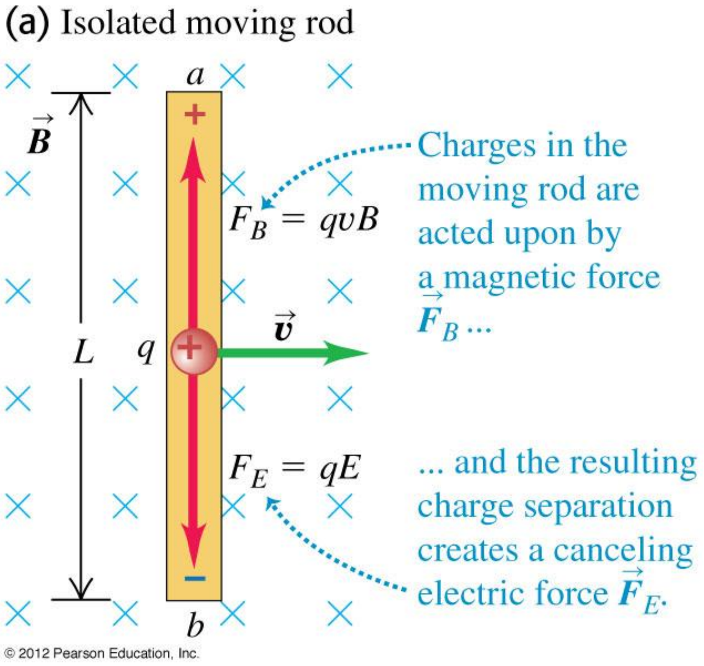
$$qvB = qE \Rightarrow$$

$$E = Bv$$

- And then the potential difference across the rod is just:

$$V = -\int_a^b \vec{E} \cdot d\vec{l} = -BvL$$

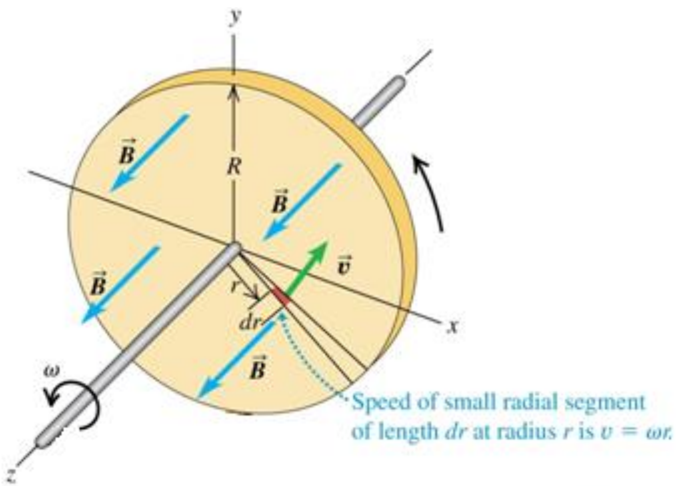
- As before.
- In general:



$$\mathcal{E}_{ab} = -\int_a^b \left(\vec{v} \times \vec{B}\right) \cdot d\vec{l}$$ Equivalent to Faraday's Law for constant B

WHY???

- Why learn two ways to look at something?
- There are some situations where it is easier to look at the motional EMF rather than the changing flux.
- The picture at right shows a rotating disk in a constant magnetic field.
- Is there an induced EMF?
- In which direction?
- If so, where is the changing flux?



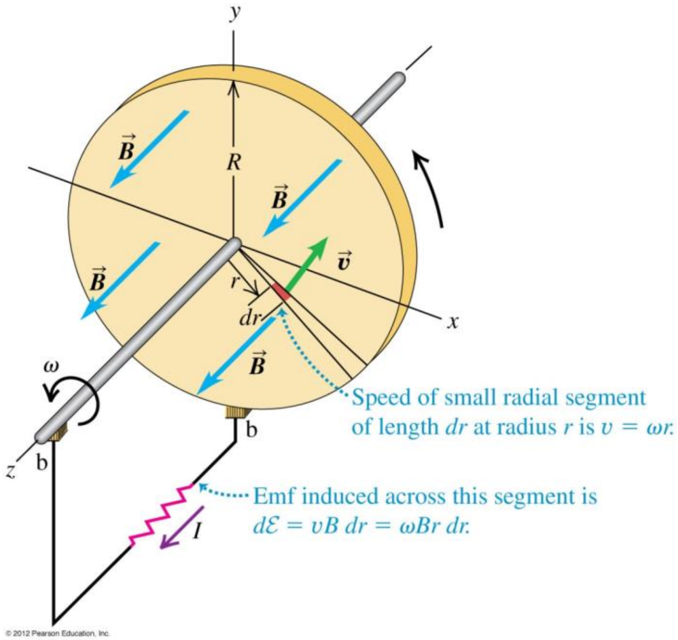
WHY???

- Let’s connect a circuit around the disk and axel with brushes.

$$\mathcal{E}_{ab} = -\int_a^b \left(\vec{v} \times \vec{B}\right) \cdot d\vec{l}$$

$$= -B\int_0^R \omega r dr$$

$$= -\frac{1}{2}\omega B R^2$$



- But how can we understand this using the changing flux?

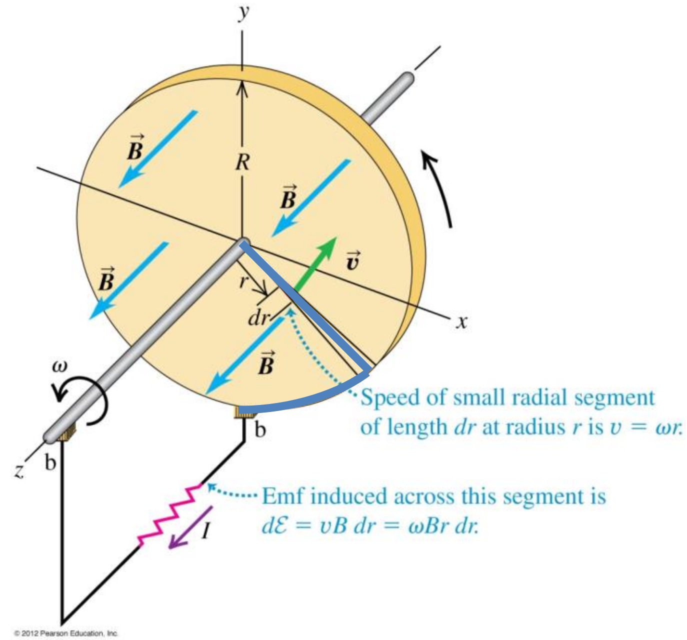
Equivalence

- Let's draw the complete circuit!

$$\mathcal{E} = -\frac{d\Phi_B}{dt},$$

$$\Phi_B = \int_{\text{Surface}} \vec{B}\cdot d\vec{A} = B\frac{1}{2}R^2\theta \Rightarrow$$

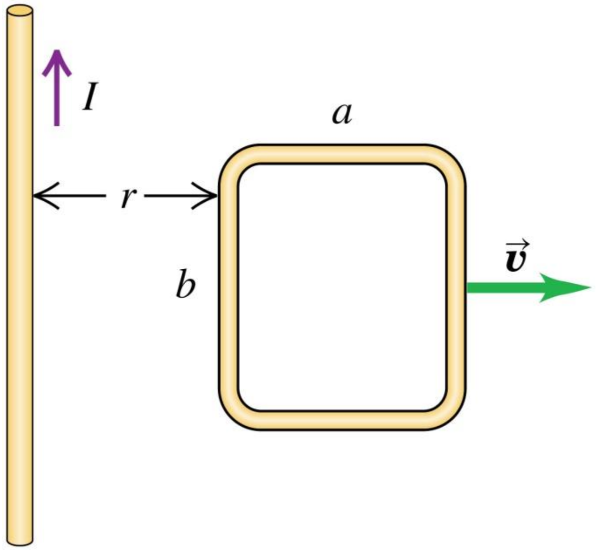
$$\mathcal{E} = -\frac{d}{dt}\left(B\frac{1}{2}R^2\theta\right) = -B\frac{1}{2}R^2\frac{d\theta}{dt} = -\frac{1}{2}BR^2\omega$$



- Make the brush at the disk side fixed and see what happens…

CPS 33-1

The loop of wire is being moved to the right at constant velocity. A constant current *I* flows in the long straight wire in the direction shown. The current induced in the loop is



A. clockwise and proportional to *I.*

B. counterclockwise and proportional to *I.*

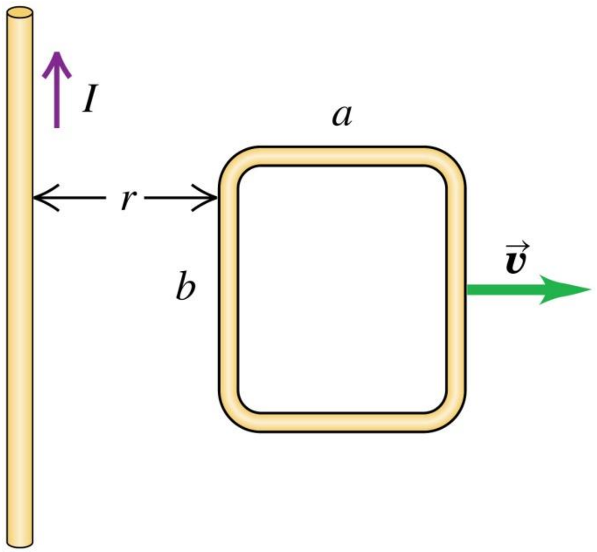
C. clockwise and proportional to I^2.

D. counterclockwise and proportional to I^2.

E. zero.

CPS 33-1

The loop of wire is being moved to the right at constant velocity. A constant current *I* flows in the long straight wire in the direction shown. The current induced in the loop is



A. clockwise and proportional to *I.*

B. counterclockwise and proportional to *I.*

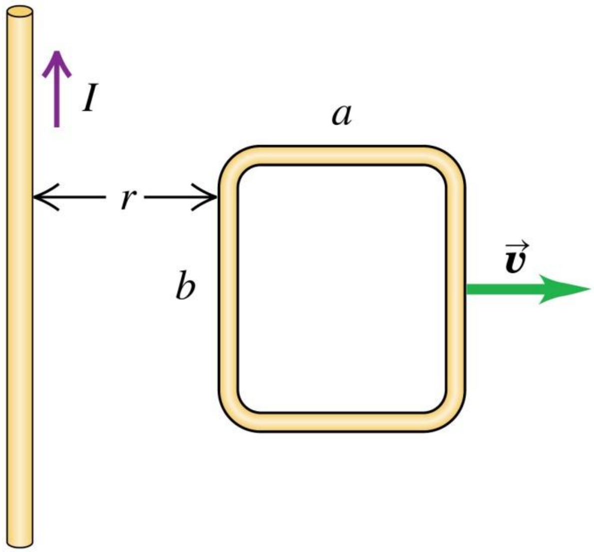
C. clockwise and proportional to I^2.

D. counterclockwise and proportional to I^2.

E. zero.

CPS 33-2

The rectangular loop of wire is being moved to the right at constant velocity. A constant current *I* flows in the long wire in the direction shown. What are the directions of the magnetic forces on the left-hand (L) and right-hand (R) sides of the loop?



A. L: to the left; R: to the left

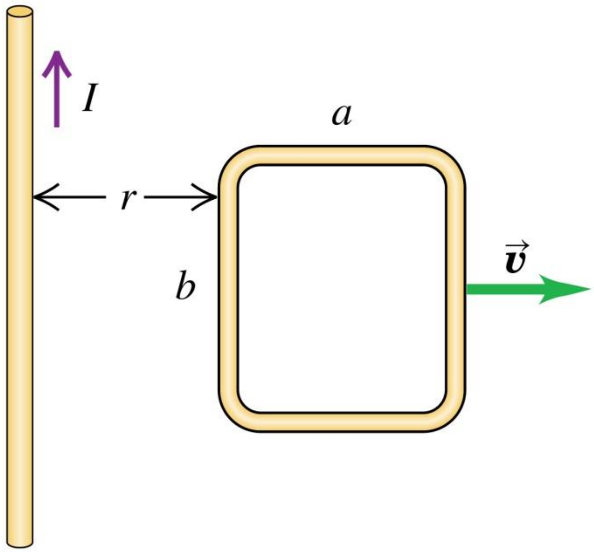
B. L: to the left; R: to the right

C. L: to the right; R: to the left

D. L: to the right; R: to the right

CPS 33-2

The rectangular loop of wire is being moved to the right at constant velocity. A constant current *I* flows in the long wire in the direction shown. What are the directions of the magnetic forces on the left-hand (L) and right-hand (R) sides of the loop?



A. L: to the left; R: to the left

B. L: to the left; R: to the right

C. L: to the right; R: to the left

D. L: to the right; R: to the right

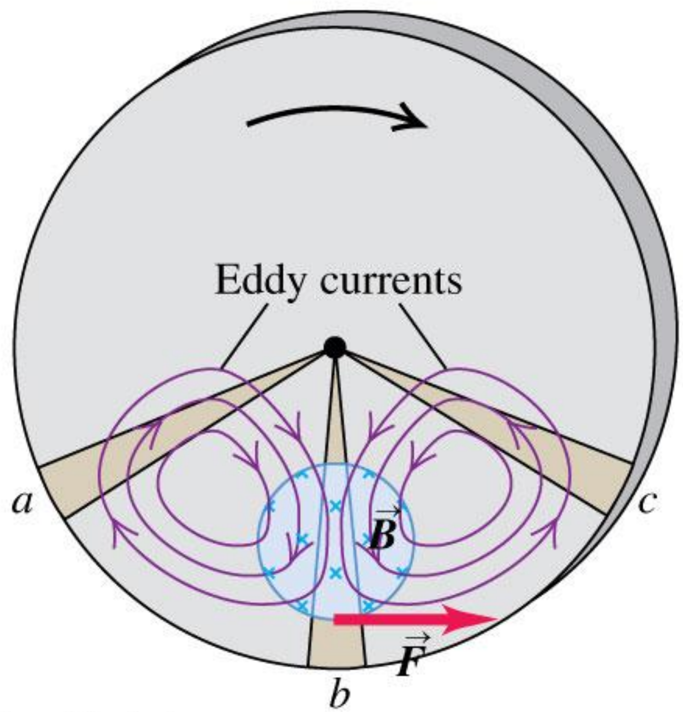
Applying Faraday's Law

- Induction can be used for many applications:
- Heating (cooking)
- Detection (guitar pick-ups)
- Digital storage

Applying Faraday's Law

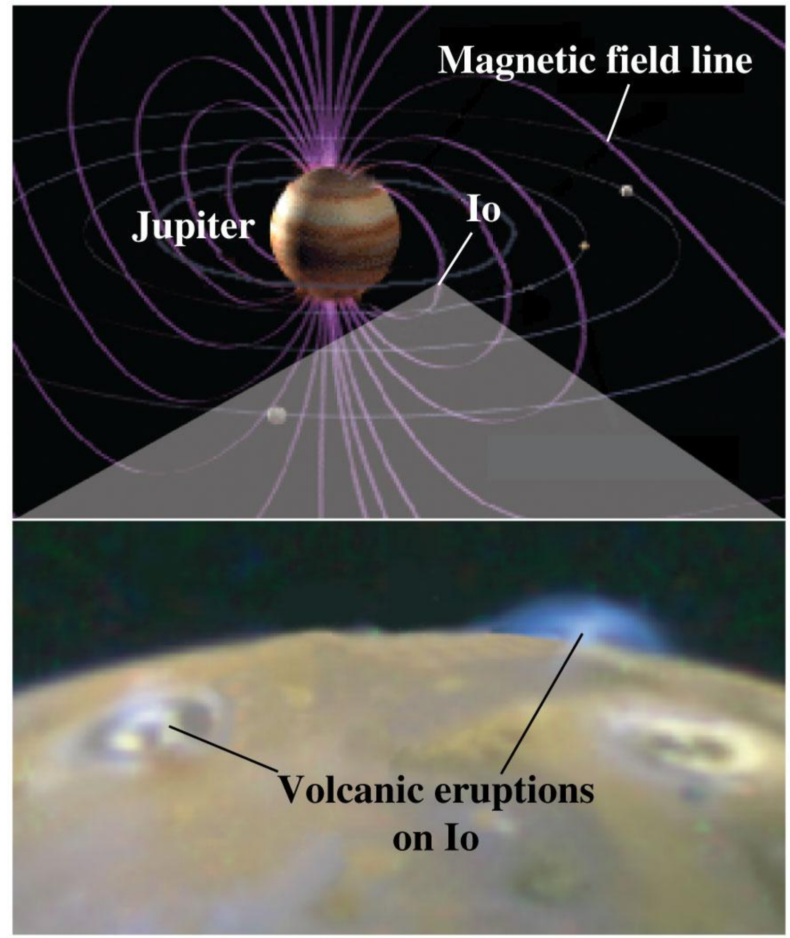
- Eddy currents can be created in a conductor where the magnetic field is changing.
- They can play both a constructive and destructive role.

(b) Resulting eddy currents and braking force



Applying Faraday's Law

- Eddy currents on Io are probably responsible for the volcanic activity there.



Applying Faraday's Law

- And, we can use them to detect the presence of conductors: