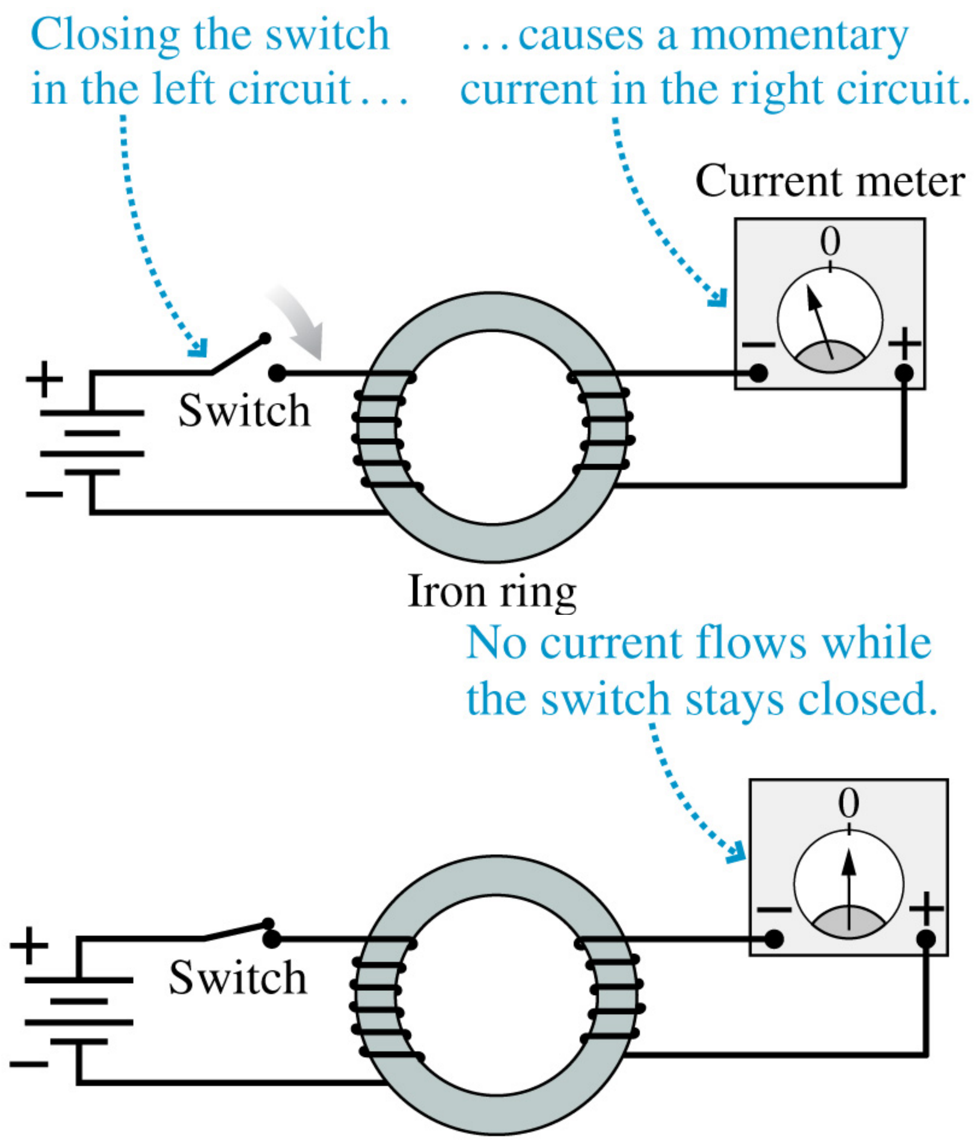
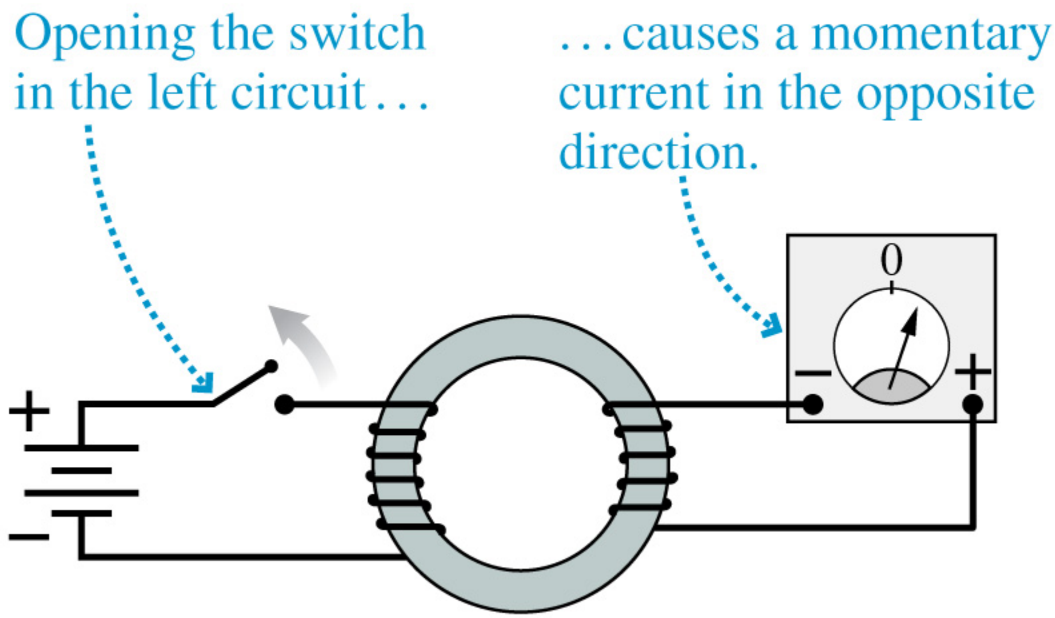
Lecture 17: Chapter 33, November 1 2005



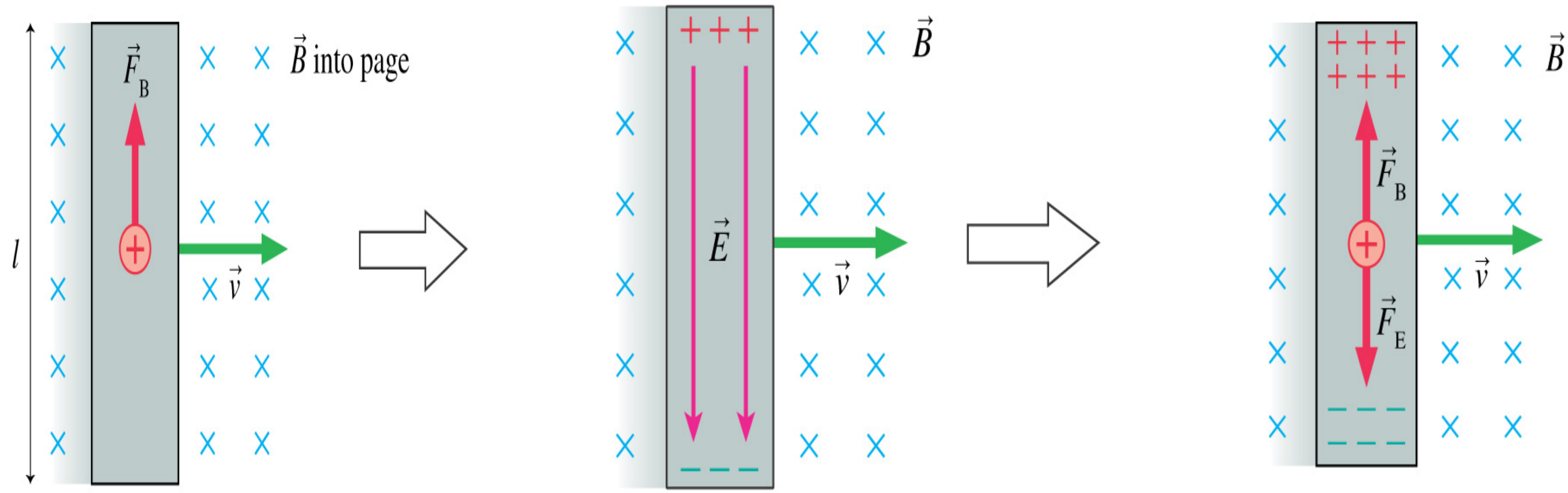
- There is a current in a coil of wire if and only if the magnetic field passing through the coil is *changing*

Electromagnetic Induction



- The current in a circuit due to changing ***B*** is called an *induced current*

Moving Wire in a Magnetic Field
First Property: Motional emf



Charge carriers in the wire experience an upward force of magnitude $F_B = qvB$. Being free to move, positive charges flow upward (or, if you prefer, negative charges downward).

charge separation creates an electric field in conductor. $\vec{E}$ increases as more charge flows.

The charge flow continues until the downward electric force $\vec{F}_E$ is large enough to balance the upward magnetic force $\vec{F}_B$. Then the net force on a charge is zero and the current ceases.

Magnetic Force $\Rightarrow$ Creates Electric Field $\Rightarrow$ In a steady state $\boldsymbol{F}_E$ balances $\boldsymbol{F}_B$

Calculating induced potential difference

$$\vec{F}_B = q\vec{v}\times\vec{B} \Rightarrow F_B = qvB$$

$$F_E = qE$$

$$F_E = F_B \Rightarrow E = vB$$

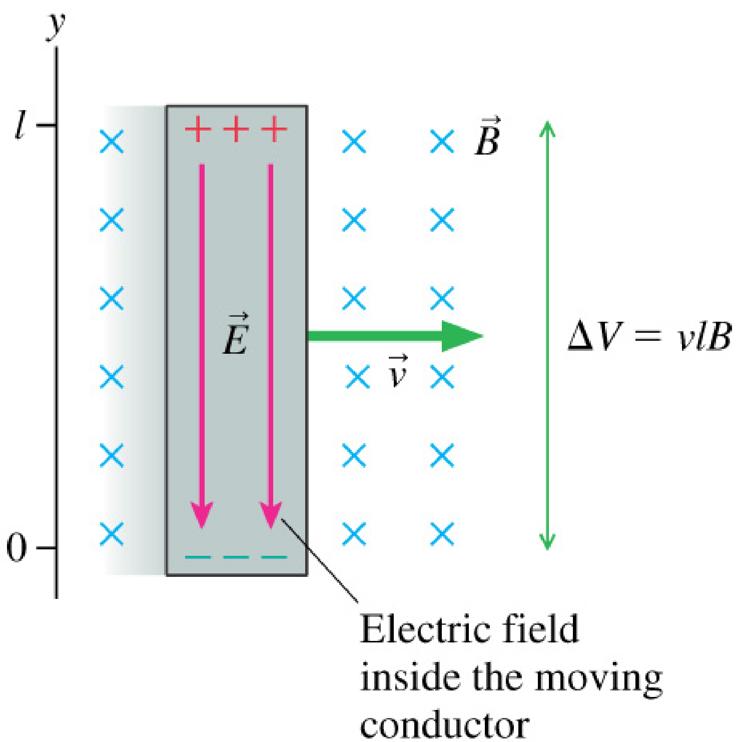
$$\Delta V = V_{top} - V_{bottom} = -\int_0^l E_y dy = -\int_0^l (-vB) dy = vlB$$

- Motional emf as a "battery": $\varepsilon = vlB$

Comparison with the Battery

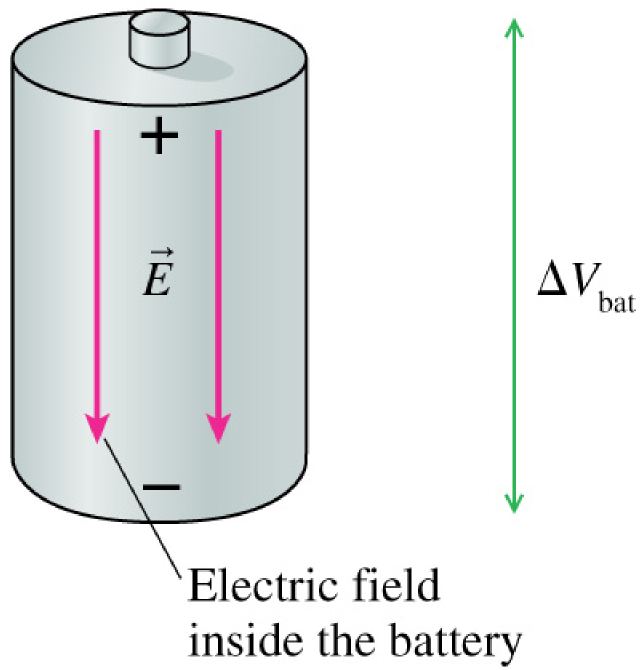
Moving wire in Magnetic Field

(a) Magnetic forces separate the charges and cause a potential difference between the ends. This is a motional emf.



Battery

(b) Chemical reactions separate the charges and cause a potential difference between the ends. This is a chemical emf.

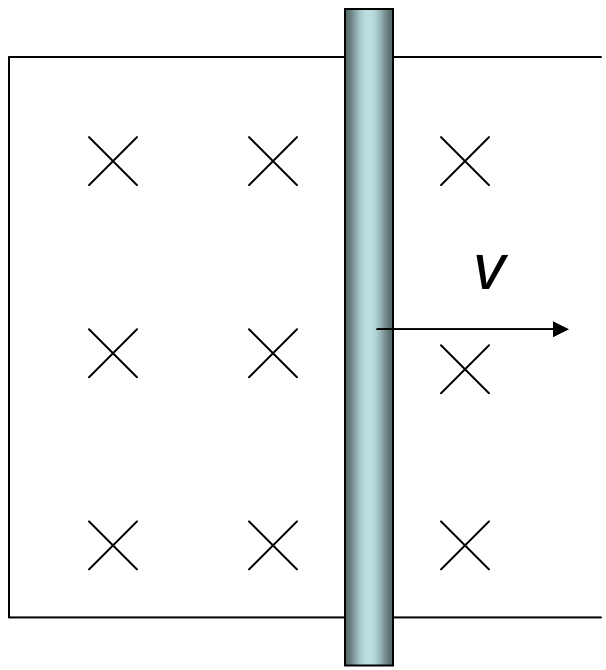


Magnetic Forces play the part of “foreign” forces

Chemical Forces play the part of “foreign” forces

- Moving wire in magnetic field behaves similar to the battery

Moving Wire in a Magnetic Field
Second Property: Induced Current

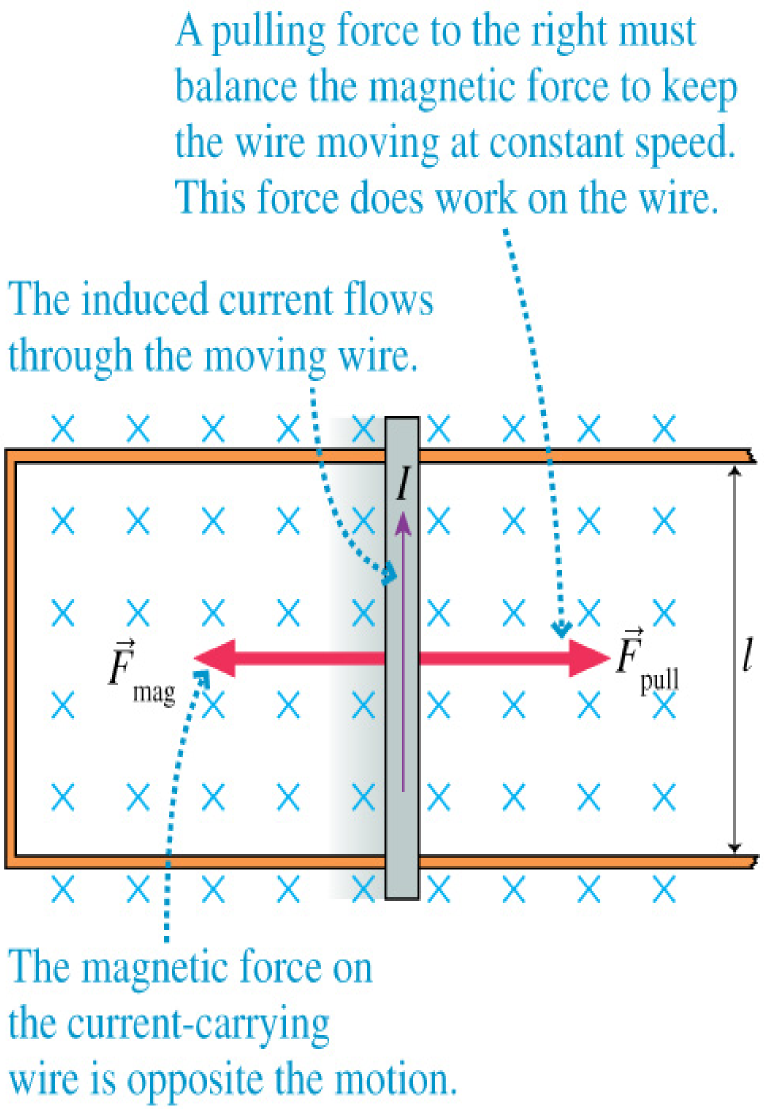


What is the direction of the induced current?

If our moving wire is a part of a circuit it will be an induced current

$I = \mathcal{E} / R$, where R – total resistance of the circuit

Moving Wire in a Magnetic Field
Third Property: Magnetic Force



- *Pulling_at_speed_v_creates:*

$$I = \varepsilon / R = \frac{vlB}{R}$$

- *Because_we_have_I,*

a_second_F_{mag}_appears:

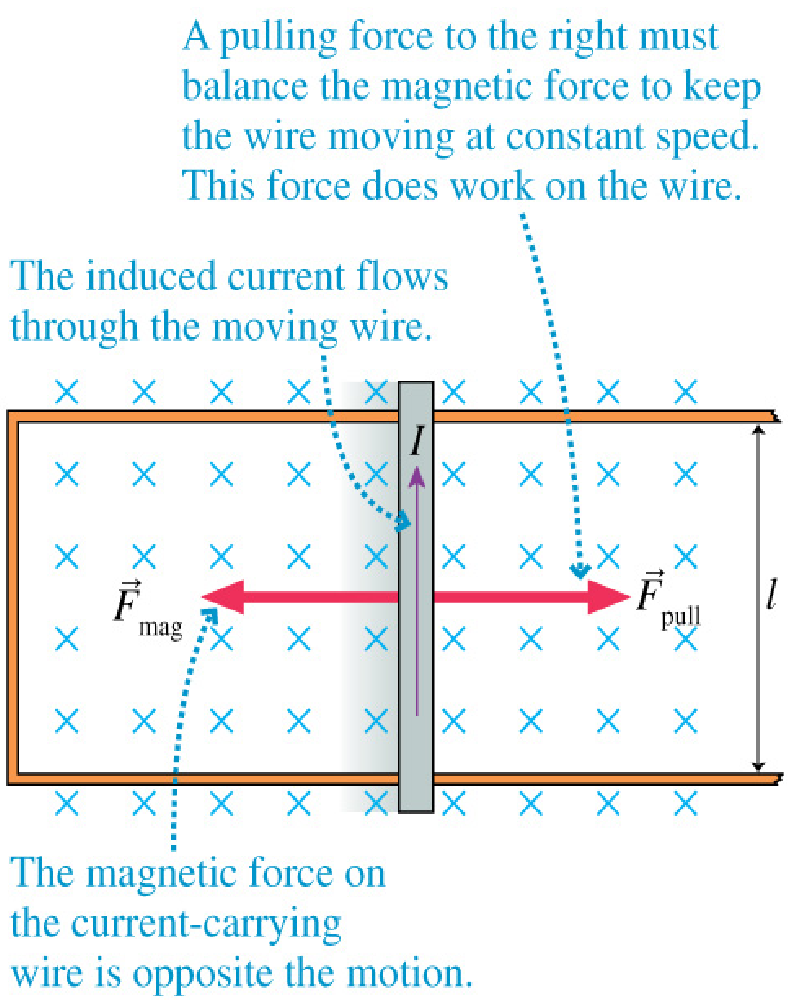
$$F_{mag} = IlB = \left(\frac{vlB}{R}\right) lB = \frac{vl^2 B^2}{R}$$

- *To_keep_the_wire_moving*

at_const_speed:

$$F_{pull} = F_{mag}$$

Energy Considerations



Mechanical_Power:

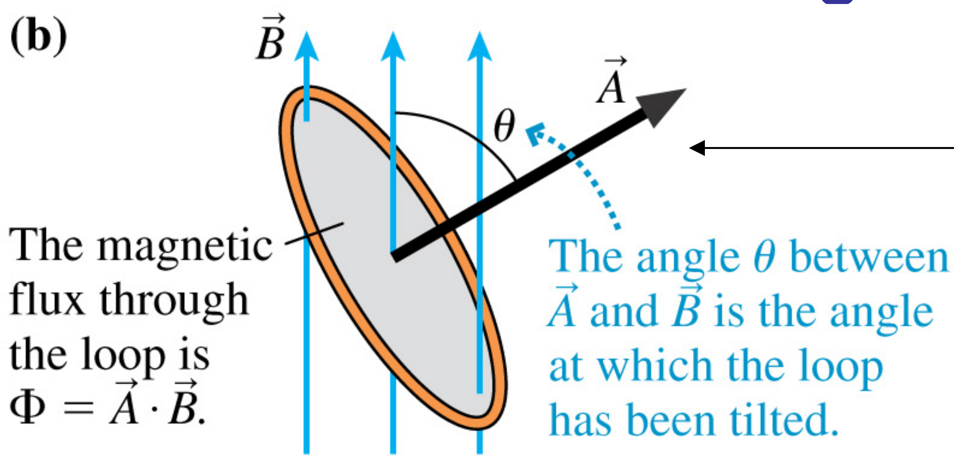
$$P_{input} = F_{pull} v = \frac{v^2 l^2 B^2}{R}$$

Electrical_Power:

$$P_{dissipated} = I^2 R = \frac{v^2 l^2 B^2}{R}$$

The rate at which the work is done on the circuit exactly balances the rate at which energy is dissipated: $P_{input} = P_{dissipated}$

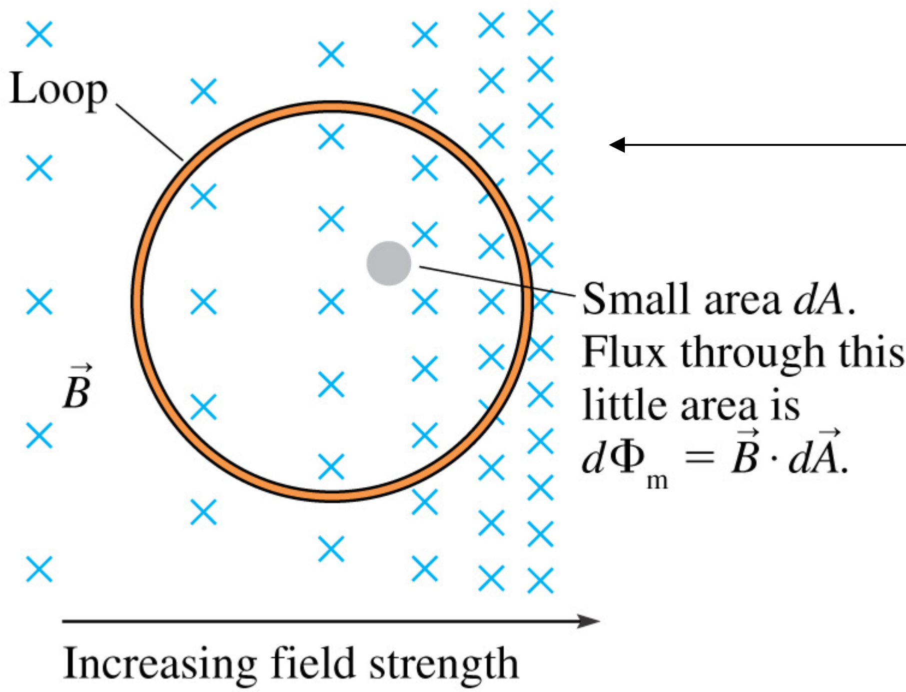
Magnetic Flux



Flux in a Uniform Field:

$$\Phi_{in} = \vec{A} \cdot \vec{B} = AB\cos\theta$$

$$1weber = 1Wb = 1Tm^2$$



Flux in a Nonuniform Field:

$$d\Phi_{in} = \vec{B} \cdot d\vec{A}$$

$$\Phi_{in} = \int_{area\_of\_loop} \vec{B} \cdot d\vec{A}$$

Faraday's Law

An emf $\mathcal{E}$ is induced in a conducting loop if the magnetic flux through the loop changes. The magnitude of the emf is

$\mathcal{E} = | d\Phi_m/dt |$

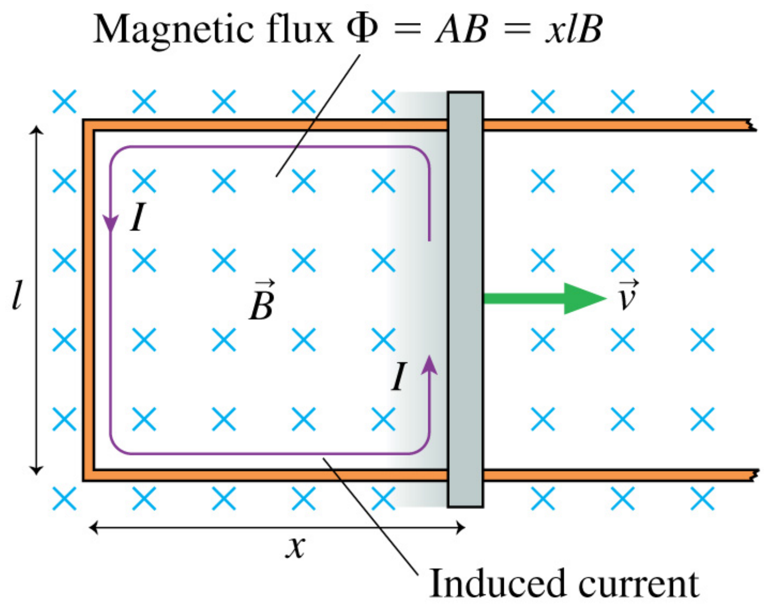
and the direction of the emf is such as to drive an induced current in the direction given by Lenz's law.

- True for any loop and any distribution of $\boldsymbol{B}(x,y,z,t)$
- Describes only the magnitude of $\mathcal{E}$

Faraday's Law

Describes what we already know

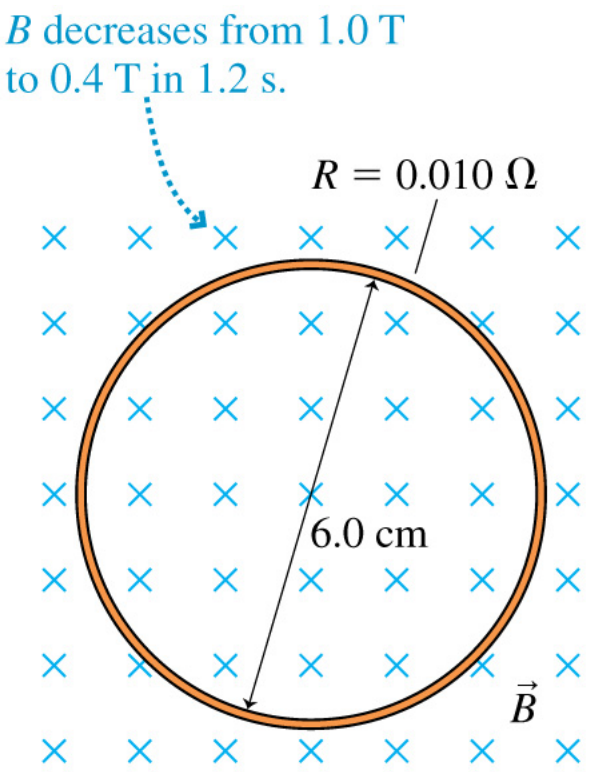
Predicts new effects



$\Phi_m = AB = xlB$

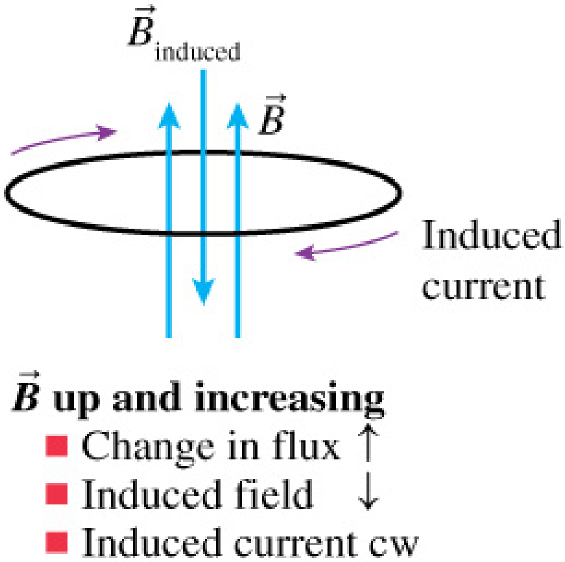
$\varepsilon = | d\Phi_m/dt | = vlB$

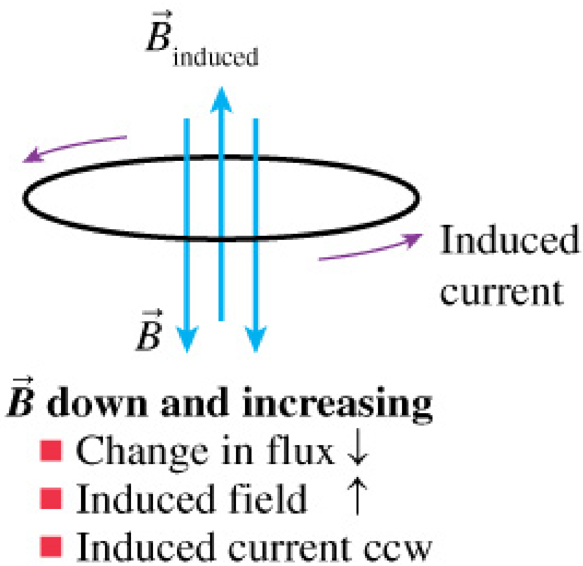
$I = \varepsilon / R$



We can describe the case with *B* depending on time

Lenz's Law





- The direction of the induced current (*I*) is such that the induced magnetic field ($\boldsymbol{B}_{induced}$) opposes the change in the flux.

End of Lecture 17
Reading: Chapter 33
Review for Quiz 8
HW8