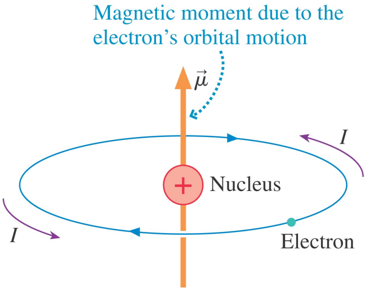
Magnetic Properties of Matter



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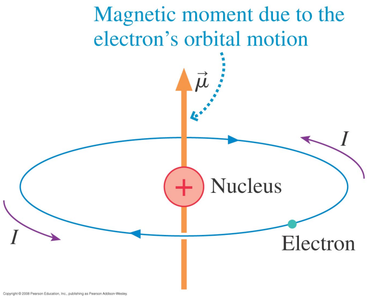

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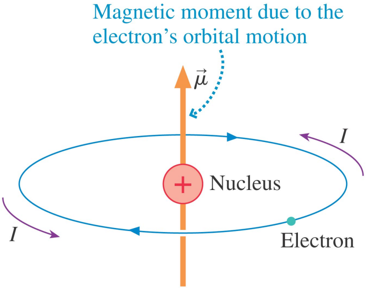

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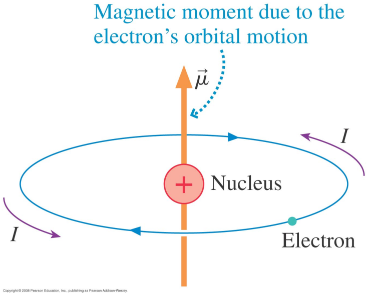

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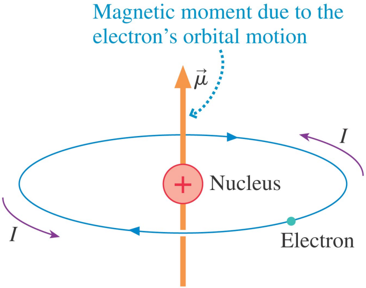

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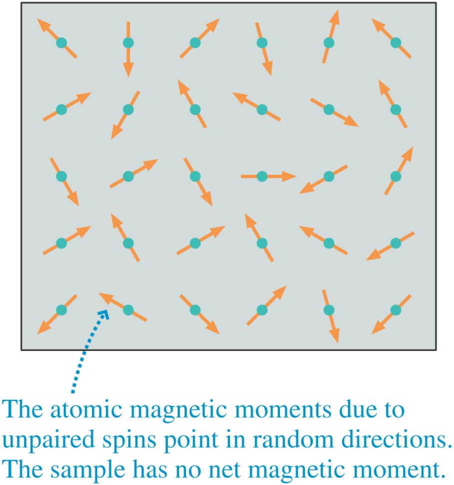
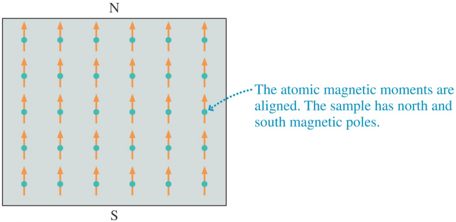
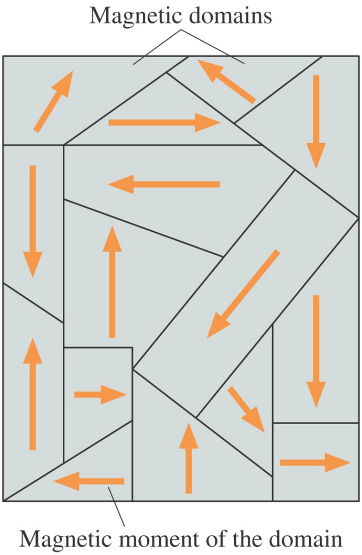
- In most substances these little bar magnets are randomly oriented with respect to each other.

Spin and Ferromagnetism





Induced Magnetic Dipoles



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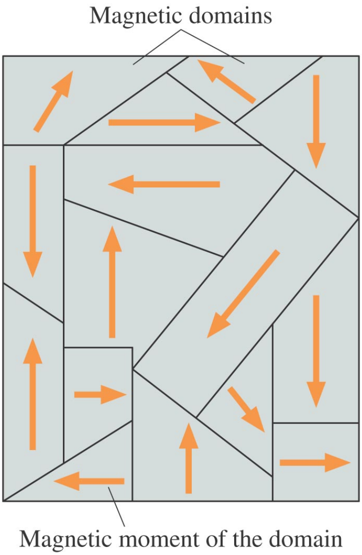

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- Each domain (0.1mm) is a strong magnet but they are randomized with respect to each other.

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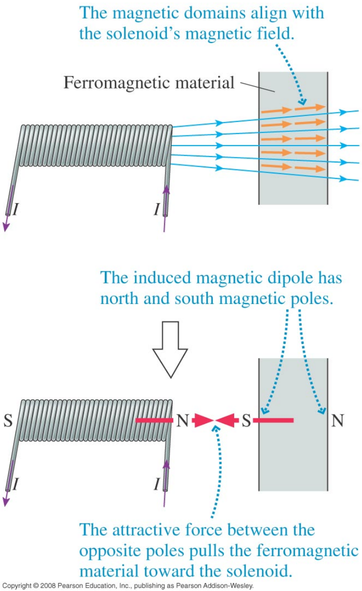

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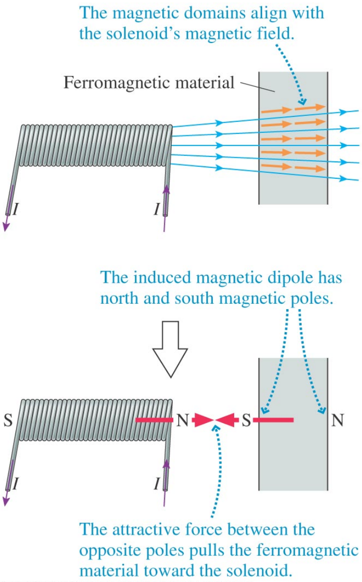

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- We have made a chunk of iron into a permanent magnet.

Chapter 34: Electromagnetic Induction

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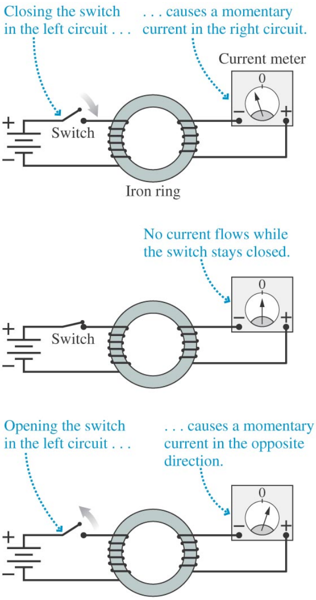
- Worth spending our last couple of classes on...

Faraday's Discovery



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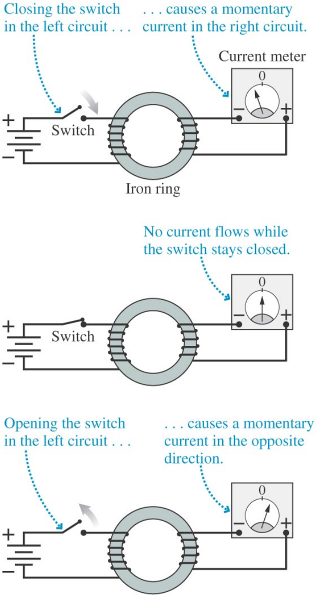

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- He was attempting to use the left-most circuit to magnetize the iron ring, which he thought would induce a current on the right-most coil. It didn't work.

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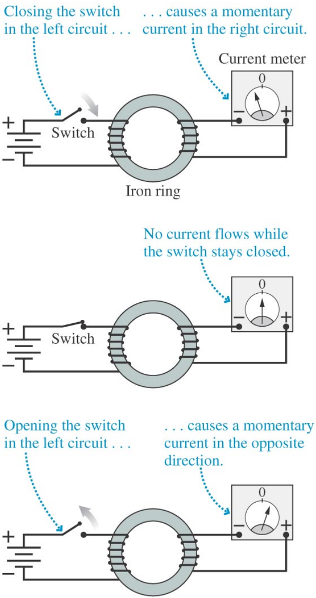

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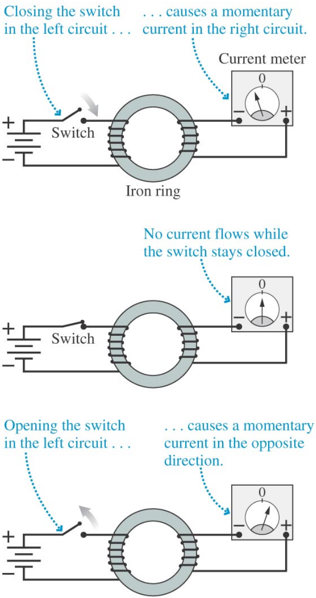

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- He set up a series of experiments to test this.

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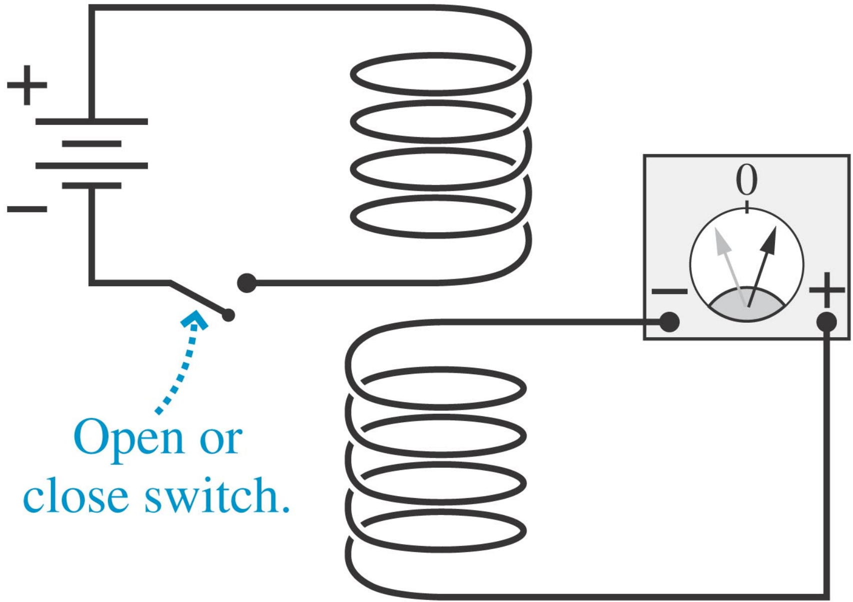

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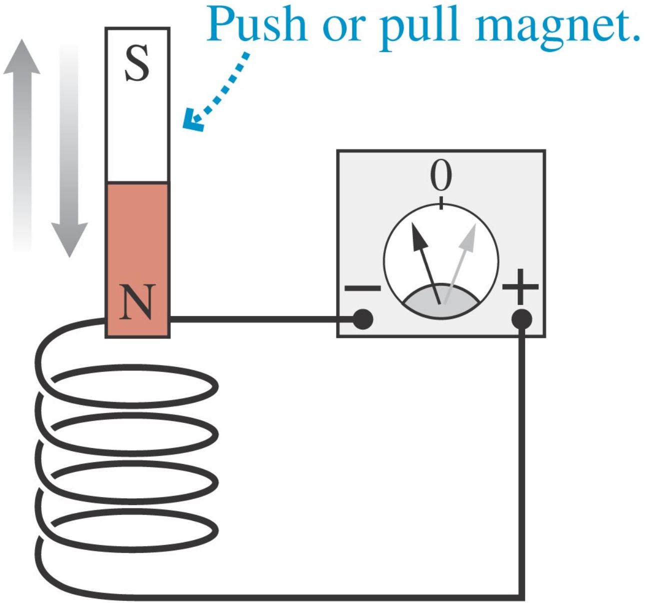

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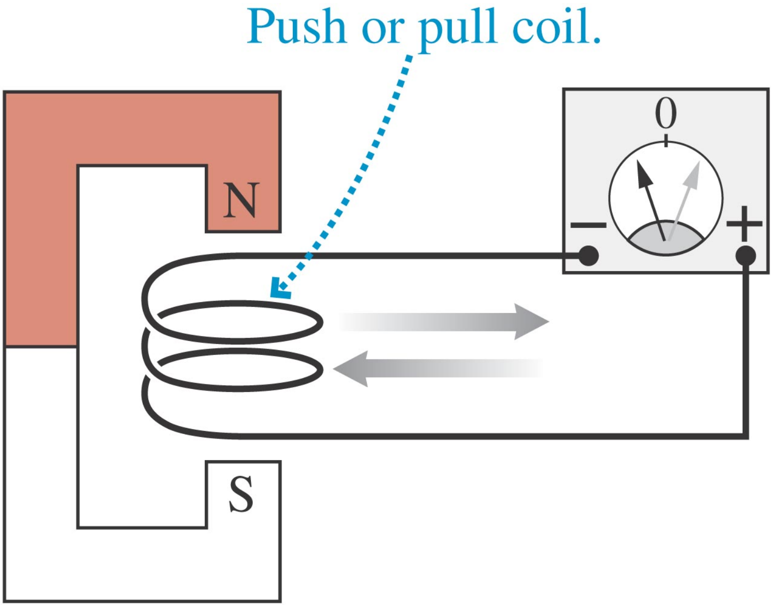

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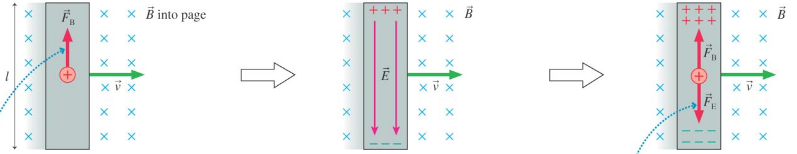
Faraday's Law

- So, Faraday discovered that there is only current in the coil in the magnetic field through the coil is changing.
- It doesn't matter whether the change is "turning on" or "turning off" or changing direction or strength. The change is the important thing.
- We call this an induced current

Motional EMF

- An induced current can be created by



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).

The charge separation creates an electric field in the 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.

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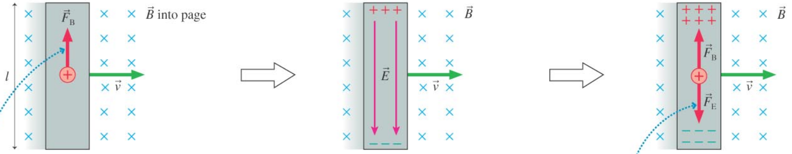
- An induced current can be created by
  1. changing the size or orientation of a circuit in a stationary magnetic field



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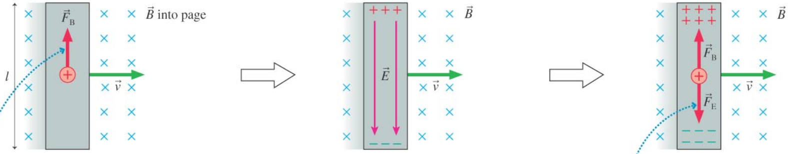

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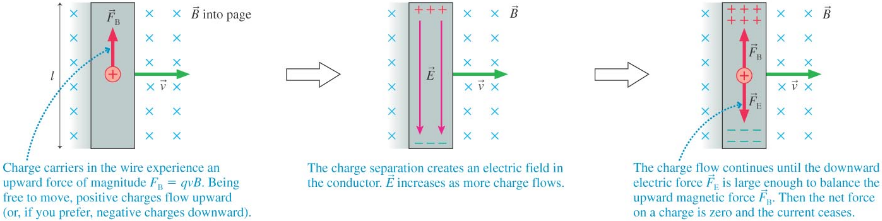

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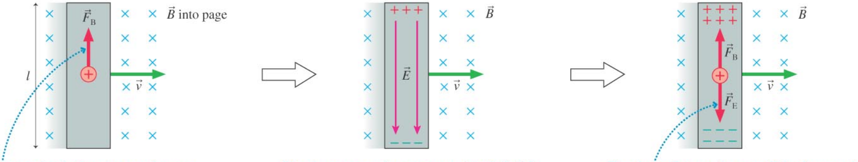

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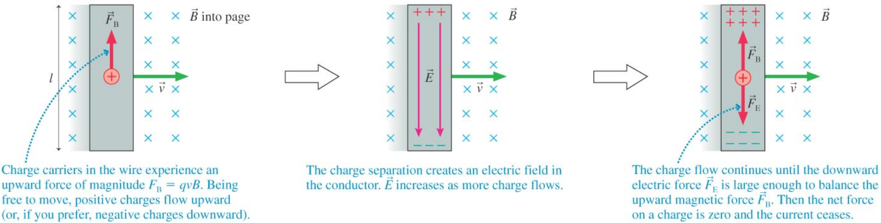

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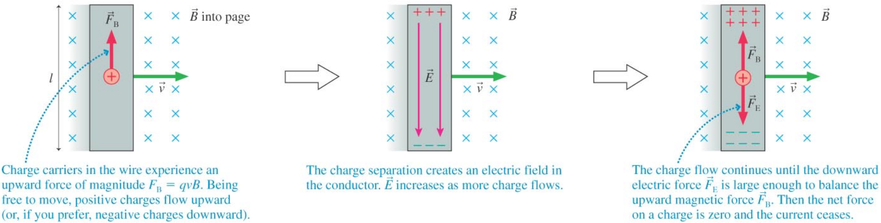

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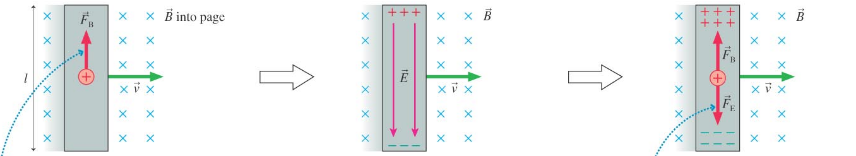

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- The force on the charges cause positive charges to move to the top and a potential difference to exist between top and bottom.
- They stop accumulating at the top when the electric repulsive forces balance the magnetic force pushing the charges.
- The potential difference is

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

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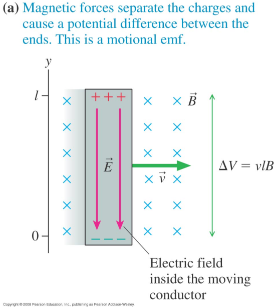

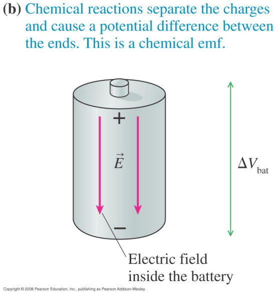

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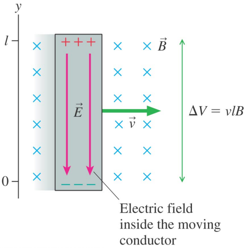
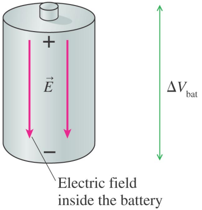
Motional EMF

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



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



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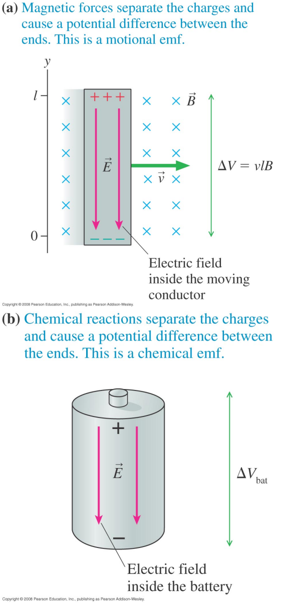
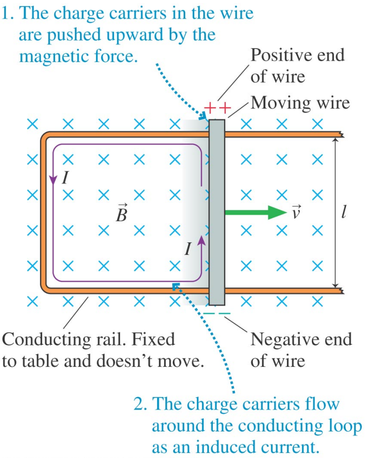


- For a battery we use a charge escalator model for chemical emf
- Now we can also generate a potential difference from mechanical energy - motional emf
- The motional emf created by a conductor of length L moving with velocity v perpendicular to a magnetic field B is

$$\mathcal{E} = vLB$$

Induced Current in a Circuit



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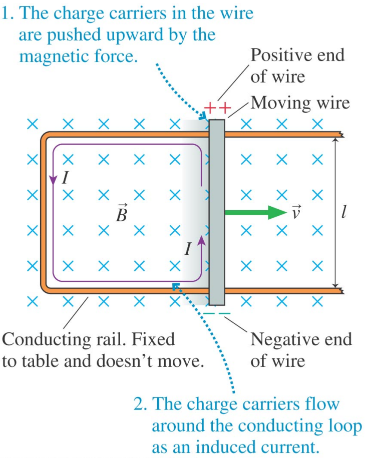

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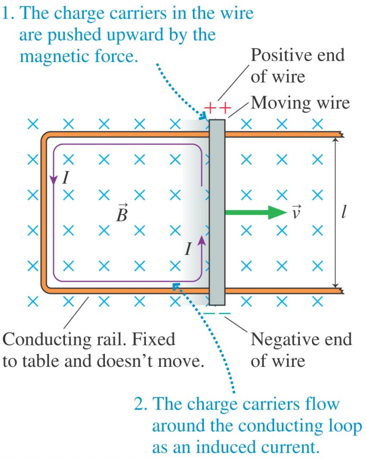
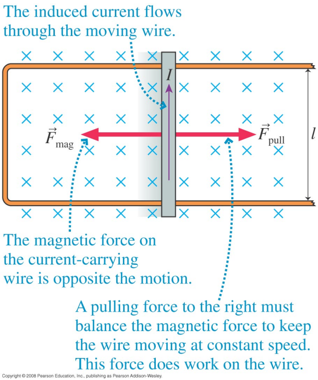


- Now we should include that moving conductor in a circuit!
- If we hook-up a conducting rail we can get a current flowing through the circuit.
- The current induced in the circuit of resistance R is given by Ohm's Law as

$$I = \frac{\mathcal{E}}{R} = \frac{vLB}{R}$$

(induced by magnetic forces on moving charges - charges moving left to right)

Induced Current in a Circuit



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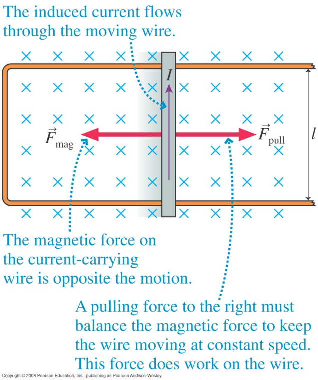
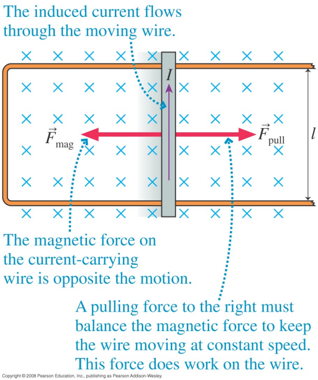


- We assumed the conductor was moving at constant velocity. However, there is a force opposing the motion!
- As the conductor moves through the magnetic field the charges inside are moved by the field, creating a current. However, that current is now a flow of charges from bottom to top in a magnetic field!!

Induced Current in a Circuit



- Now we do another $q\vec{v} \times \vec{B}$ with the direction of $\vec{v}$ being along the conductor. The force works against the motion.

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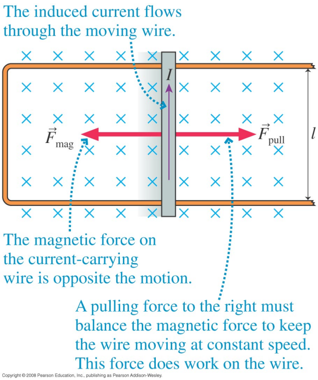

- Now we do another $q\vec{v} \times \vec{B}$ with the direction of $\vec{v}$ being along the conductor. The force works against the motion.
- If you reverse the direction (turn your pull into a push) then the new magnetic force also turns around. It always is opposite to the motion and has magnitude

$$F_{pull} = F_{mag} = ILB = \left(\frac{vlB}{R}\right) LB = \frac{vL^2 B^2}{R}$$

Energy Considerations

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- Heyyyyy, those are the same! Hmmmm, I guess energy is conserved or something...