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In most substances these little bar magnets are randomly oriented with respect to each other.
The atomic magnetic moments due to unpaired spins point in random directions. The sample has no net magnetic moment.
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Each domain (0.1mm) is a strong magnet but they are randomized with respect to each other.
Induced Magnetic Dipoles

We can line-up the domains using an electromagnet. This is an induced magnetic dipole.
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- We have made a chunk of iron into a permanent magnet.
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Chapter 34: Electromagnetic Induction

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Worth spending our last couple of classes on...
Faraday’s Discovery

Faraday set up the experiment on the left.

- Closing the switch in the left circuit... causes a momentary current in the right circuit.
- No current flows while the switch stays closed.
- Opening the switch in the left circuit... causes a momentary current in the opposite direction.
Faraday’s Discovery

- Faraday set up the experiment on the left.
- 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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He set up a series of experiments to test this.
Open or close switch.
Faraday’s Discovery

Push or pull magnet.
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We call this an induced current
Motional EMF

An induced current can be created by

- Changing the size or orientation of a circuit in a stationary magnetic field
- Changing the magnetic field through a stationary circuit

Consider moving a conductor of length $L$ through a magnetic field $\vec{B}$ at velocity $\vec{v}$. The force on a charge inside is $\vec{F} = q \vec{v} \times \vec{B}$.

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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The potential difference is

$$
\Delta V = V_{top} - V_{bottom} = - \int_{0}^{t} E_y \, dy = - \int_{0}^{t} (-vB) \, dy = vLB
$$
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.

- For a battery we use a charge escalator model for chemical emf
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- 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

1. The charge carriers in the wire are pushed upward by the magnetic force.

2. The charge carriers flow around the conducting loop as an induced current.

Now we should include that moving conductor in a circuit!

The current induced in the circuit of resistance $R$ is given by Ohm’s Law as

\[ I = \frac{E}{R} = \frac{vLB}{R} \]

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

$$F_{\text{pull}} = F_{\text{mag}} = ILB = \left( \frac{vLB}{R} \right) LB = \frac{vL^2B^2}{R}$$
Of course, to keep the conductor moving we have to supply energy. How much?

Let's do it in terms of power. The power exerted by a force pushing or pulling an object with velocity $v$ is $P = Fv$, so the power is $P_{\text{input}} = F_{\text{pull}} v = v^2 L B^2 R$.

How much energy is dissipated by the circuit? $P_{\text{dissipated}} = I^2 R = v^2 L B^2 R$.

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

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