Electric Generators and Motors
Reading Quiz:
Look at the demonstration of the large electromagnet. Observe what happens (spark) when the switch is opened. What best explains this?
A) The battery voltage is leaking through.
B) The steady current passing through the magnet.
C) The back emf of the inductor.
D) $V > \mathcal{E}$ in this case.
Answer: C

Nature doesn’t want the magnetic flux to change, so it induces a large current (back emf) to produce a magnetic field. This emf results in the spark across the switch.
Last Time

Reviewed previous results.

A conductor moving in a magnetic field can induce a current. **Motional emf.**

Eddy currents.

Transformers and power distribution.
Today

Electric generators and motors
Back emf
Applications
Generalize Faraday’s Law
A generator is the opposite of a motor – it transforms mechanical energy into electrical energy. This is an ac generator:

The axle is rotated by an external force such as falling water or steam. The brushes are in constant electrical contact with the slip rings. See next slide.
An Electrical Generator

- Current is induced
- Produces AC power
- Falling water, steam
- Magnetic flux changes!
Do electric motor demos

Good electric motor/generator reference:

If the loop is rotating with constant angular velocity $\omega$, the induced emf is sinusoidal:

$$\mathcal{E} = -BA \frac{d}{dt} (\cos \omega t) = BA\omega \sin \omega t = \mathcal{E}$$

For a coil of $N$ loops,

$$\mathcal{E} = NBA\omega \sin \omega t$$

$$\mathcal{E} = \mathcal{E}_0 \sin \omega t$$

$$\mathcal{E}_0 = NBA\omega$$

Induced power:

$$P = \mathcal{E}I = \frac{\mathcal{E}^2}{R} = \frac{(NAB\omega)^2}{R} \sin^2 \omega t$$
A Simple Electric Motor/Generator

Do demo
A dc generator is similar, except that it has a split-ring commutator instead of slip rings. Can use capacitors to smooth out bumps.
Automobiles now use alternators rather than dc generators, to reduce wear.
An electric motor turns because there is a torque on it due to the current. We would expect the motor to accelerate unless there is some sort of drag torque.

That drag torque exists, and is due to the induced emf, called a back emf.

When a motor (refrigerator, air blower) turns on, you often see lights dim. This is because a large current is initially drawn until back emf builds up.
A similar effect occurs in a generator – if it is connected to a circuit, current will flow in it, and will produce a counter torque. This means the external applied torque must increase to keep the generator turning.

Look at bicycle generator.
Induced currents can flow in bulk material as well as through wires. These are called eddy currents, and can dramatically slow a conductor moving into or out of a magnetic field.
A Dynamic Microphone

The American Idol

Coil moves with diaphragm

Sound

Diaphragm

To amplifier

Stationary bar magnet

To amplifier
The Pickup on an Electric Guitar

- Metal guitar string
- Magnetized portion of string
- Pickup coil
- Permanent magnet
- To amplifier
A ground fault circuit interrupter (GFCI) will interrupt the current to a circuit that has shorted out in a very short time, preventing electrocution. (Circuit breakers are too slow.)
Differently magnetized areas on an audio tape or disk induce signals in the read/write heads.
A seismograph has a fixed coil and a magnet hung on a spring (or vice versa), and records the current induced when the Earth shakes.
A changing magnetic flux induces an electric field; this is a generalization of Faraday’s law. The electric field will exist regardless of whether there are any conductors around:

$$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$$

**Generalized Faraday’s Law**
Changing Current in an Inductor

Switch open. No current flowing.

Switch closed. Inductor opposes magnetic flux change. Induces current to oppose battery current; current rises more slowly.
The Back emf of an Inductor – do demo

\[ |\mathcal{E}| = N \left| \frac{d\Phi_B}{dt} \right| \]

Direction of increasing current

Induced or "back" emf

Increasing magnetic field

\[ R \]
Conceptual Quiz

A generator has a coil of wire rotating in a magnetic field. If the rotation rate increases, how is the maximum output voltage of the generator affected?

A) increases
B) decreases
C) stays the same
D) varies sinusoidally
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The maximum voltage is the leading term that multiplies \( \sin(\omega t) \) and is given by \( \varepsilon_0 = NBA\omega \). Therefore, if \( \omega \) increases, then \( \varepsilon_0 \) must increase as well.
A wire loop is in a uniform magnetic field. Current flows in the wire loop, as shown. What does the loop do?

A) moves to the right
B) moves up
C) remains motionless
D) rotates
E) moves out of the page
A wire loop is in a uniform magnetic field. Current flows in the wire loop, as shown. What does the loop do?

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There is no magnetic force on the top and bottom legs, since they are parallel to the $B$ field. However, the magnetic force on the right side is into the page, and the magnetic force on the left side is out of the page. Therefore, the entire loop will tend to rotate.

This is how a motor works!!
Earth’s Magnetic Field. When a car drives through the Earth’s magnetic field, an emf is induced in its vertical 75.0-cm-long radio antenna. If the Earth’s field (5 x 10^{-5} T) points north with a dip angle of 45°, what is the maximum emf induced in the antenna and which direction(s) will the car be moving to produce this maximum value? The car’s speed is 30.0 m/s on a horizontal road.
Battery-less Flashlight. A flashlight can be made that is powered by the induced current from a magnet moving through a coil of wire. The coil and magnet are inside a plastic tube that can be shaken causing the magnet to move back and forth through the coil. Assume the magnet has a maximum field strength of 0.05 T. Make reasonable assumptions and specify the size of the coil and the number of turns necessary to light a standard 1-watt, 3-V flashlight bulb.
**Conceptual Quiz**

If a coil is rotated as shown, in a magnetic field pointing to the left, in what direction is the induced current?

A) clockwise
B) counterclockwise
C) no induced current
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A) clockwise
B) counterclockwise
C) no induced current

As the coil is rotated into the $B$ field, the magnetic flux through it *increases*. According to Lenz’s law, the induced $B$ field has to *oppose this increase*, thus the new $B$ field points *to the right*. An induced *counterclockwise* current produces just such a $B$ field.
Conceptual Quiz

If there is induced current, doesn’t that cost energy? Where would that energy come from in case 2?

A) induced current doesn’t need any energy
B) energy conservation is violated in this case
C) there is less KE in case 2
D) there is more gravitational PE in case 2
Conceptual Quiz

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In both cases, the magnet starts with the same initial gravitational PE. In case 1, all the gravitational PE has been converted into kinetic energy. In case 2, we know the magnet falls slower, thus there is less KE. The difference in energy goes into making the induced current.