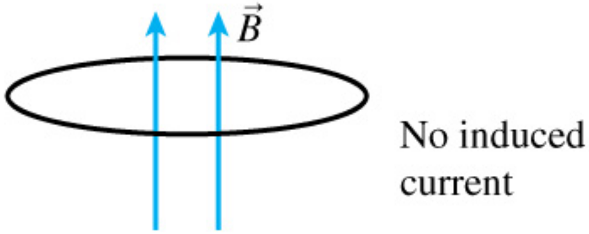
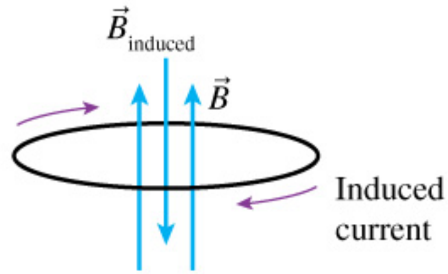
PHY294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **hand-in problem for next Wed: 32.80**
- Quizzes by iclicker (sometimes hand-written)
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

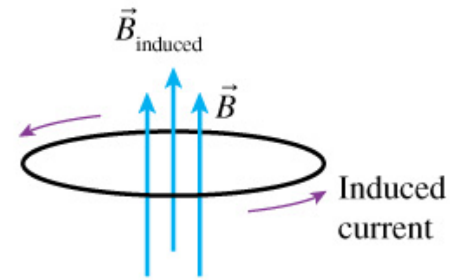
Summary



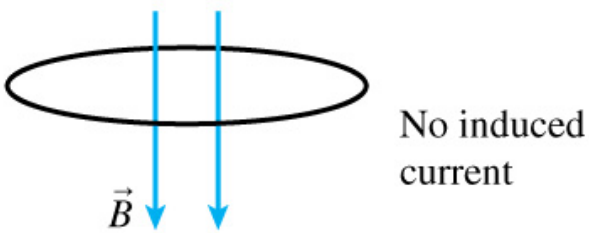
$\vec{B}$ up and steady
- No change in flux
- No induced field
- No induced current



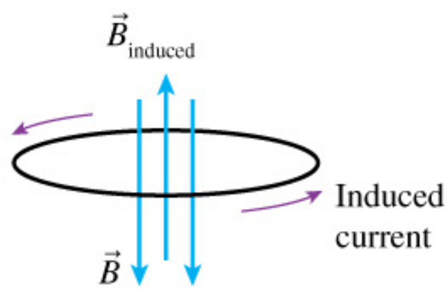
$\vec{B}$ up and increasing
- Change in flux ↑
- Induced field ↓
- Induced current cw



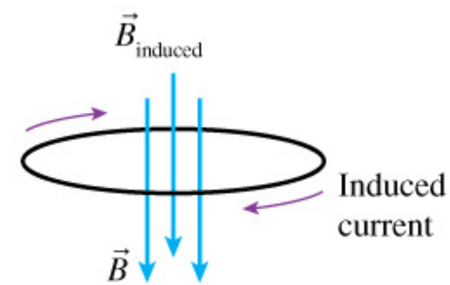
$\vec{B}$ up and decreasing
- Change in flux ↓
- Induced field ↑
- Induced current ccw



$\vec{B}$ down and steady
- No change in flux
- No induced field
- No induced current



$\vec{B}$ down and increasing
- Change in flux ↓
- Induced field ↑
- Induced current ccw



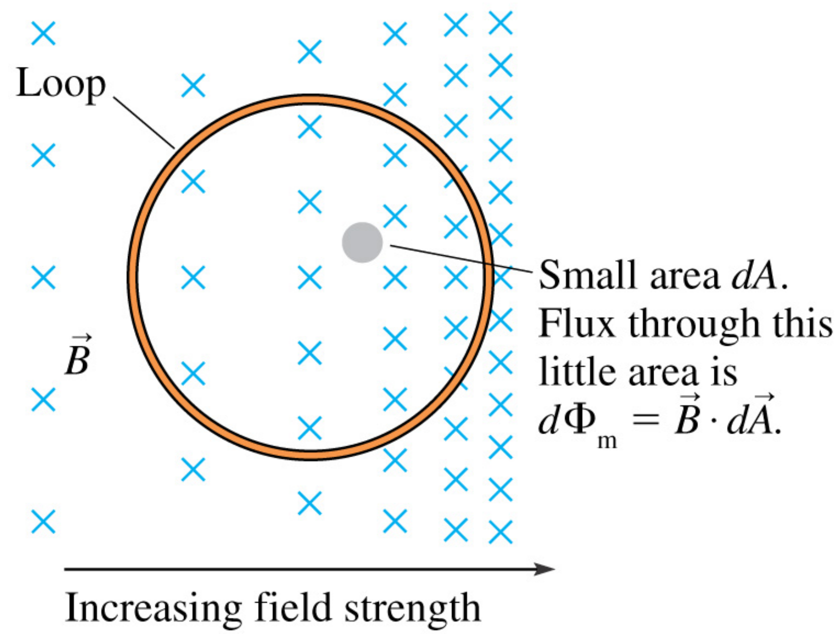
$\vec{B}$ down and decreasing
- Change in flux ↑
- Induced field ↓
- Induced current cw

Flux in non-uniform field

- The situations we've been considering so far have had a uniform field, so it's easy to calculate the flux
- But we may encounter situations where the field is not uniform, and we can still calculate the flux

$$d\Phi_B = \vec{B} \bullet d\vec{A}$$

$$\Phi_B = \int \vec{B} \bullet d\vec{A}$$



The induced emf around this loop is

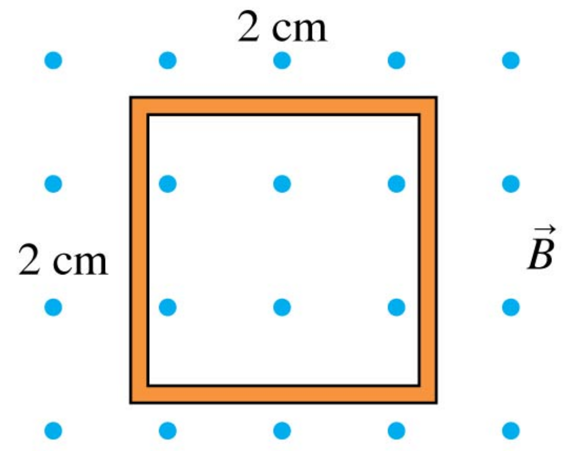
A. 200 V.

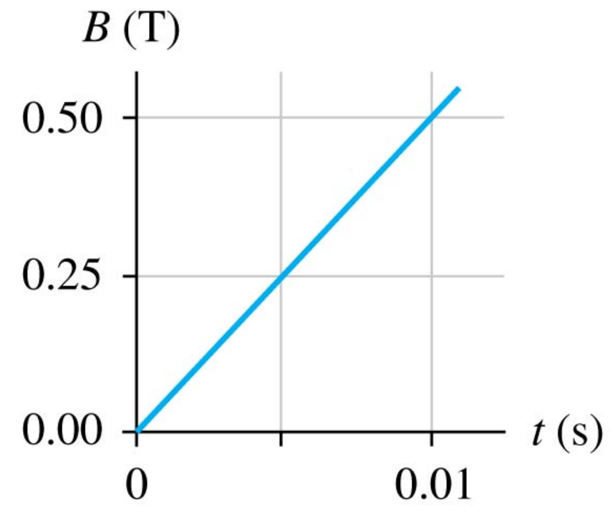
B. 50 V.

C. 2 V.

D. 0.5 V.

E. 0.02 V.





The induced emf around this loop is

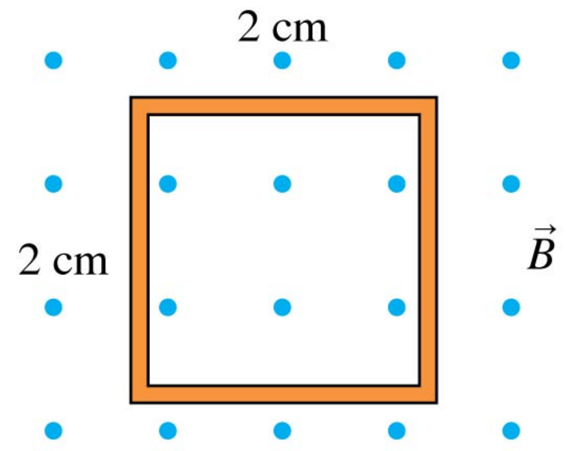
A. 200 V.

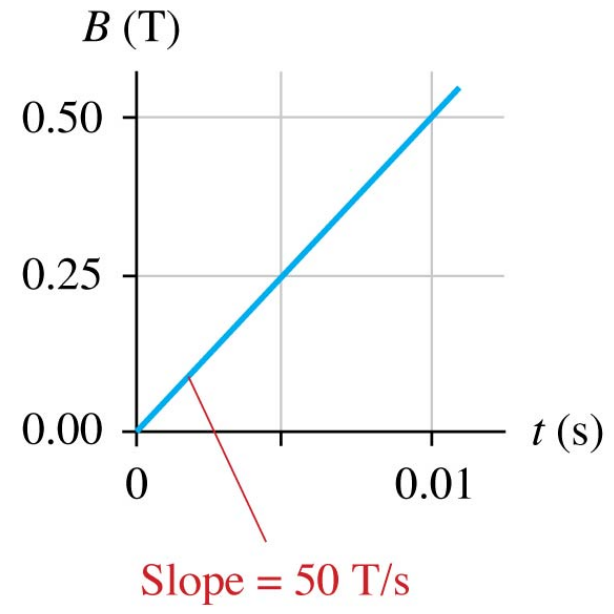
B. 50 V.

C. 2 V.

D. 0.5 V.

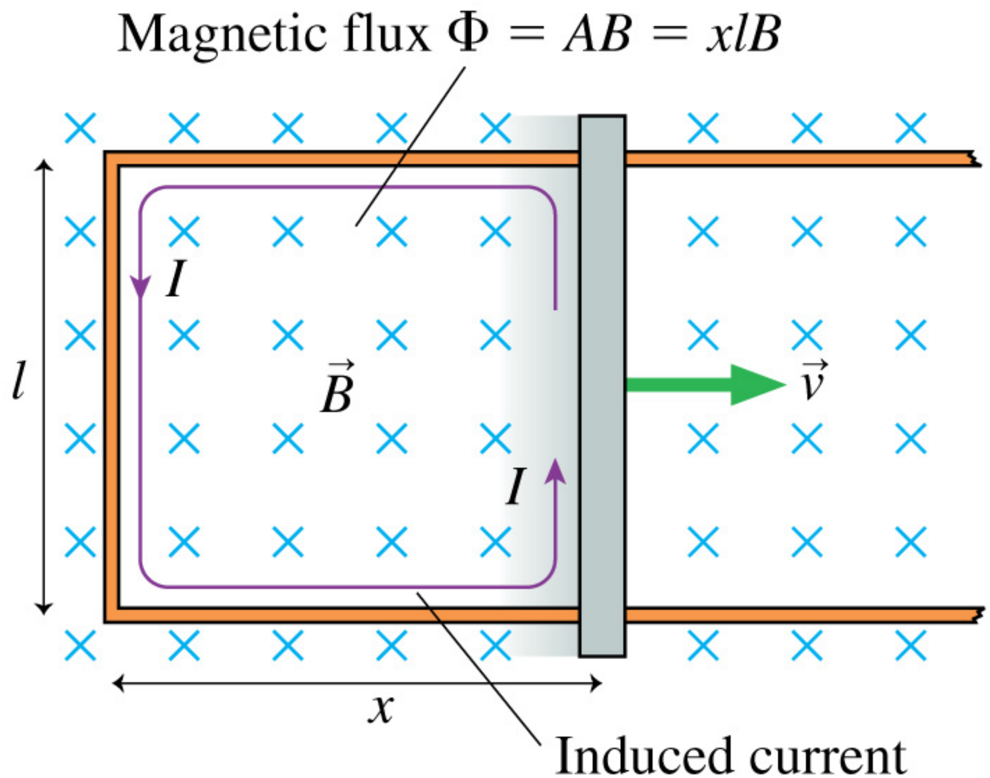
✔ **E. 0.02 V.** $\mathcal{E} = \frac{d\Phi_m}{dt} = A\frac{dB}{dt} = A \times \text{slope of graph}$





Let's consider another example

- I have a conducting bar sliding to the right on a U-shaped conducting rail
- What is the emf induced in the loop? What is the current, if the conducting loop has a resistance R?



$$\phi = BA = Blx$$

$$\varepsilon = -\frac{d\phi}{dt} = -Bl\frac{dx}{dt} = Blv$$

$$I = \frac{\varepsilon}{R} = \frac{Blv}{R}$$

Example

- What is the emf induced in the loop? What is the current?

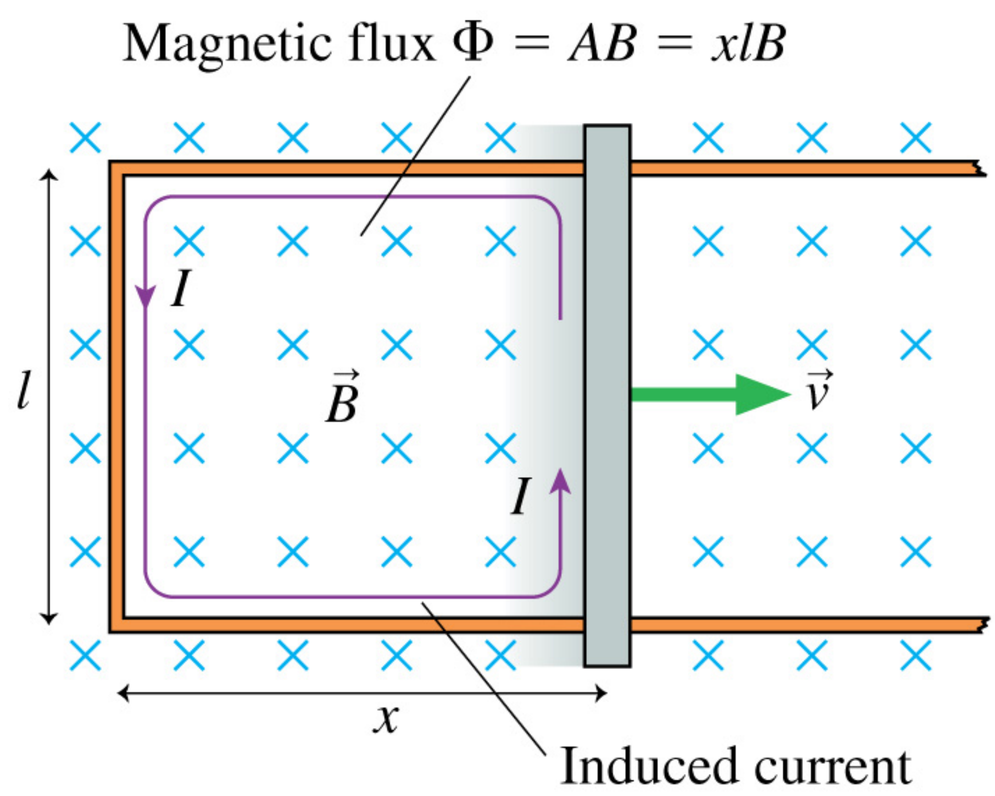
$$\phi = BA = Blx$$

$$\varepsilon = -\frac{d\phi}{dt} = -Bl\frac{dx}{dt} = Blv$$

$$I = \frac{\varepsilon}{R} = \frac{Blv}{R}$$

- What is the force on the bar? In what direction?

$$F = IlB = \frac{B^2 l^2 v}{R}$$



Example

- What is the force on the bar? In what direction?

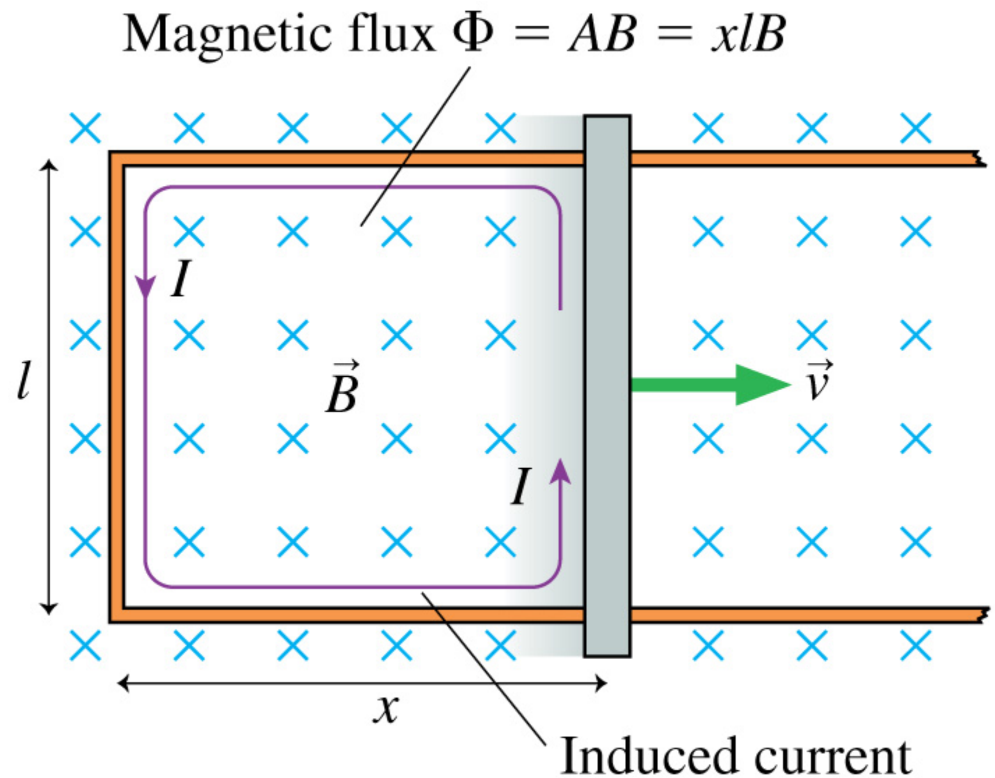
$$F = IlB = \frac{B^2 l^2 v}{R}$$

- What is the power it takes to move the bar?

$$P = Fv = \frac{B^2 l^2 v^2}{R}$$

- What is the power consumed in the resistance?

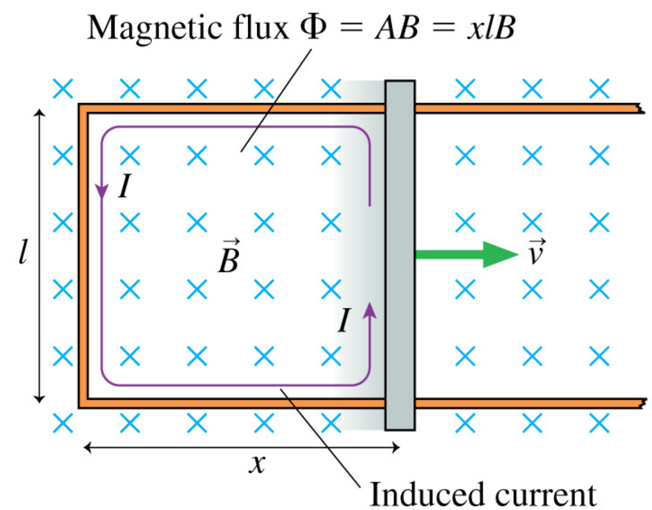
$$P = I^2 R = \frac{B^2 l^2 v^2}{R}$$

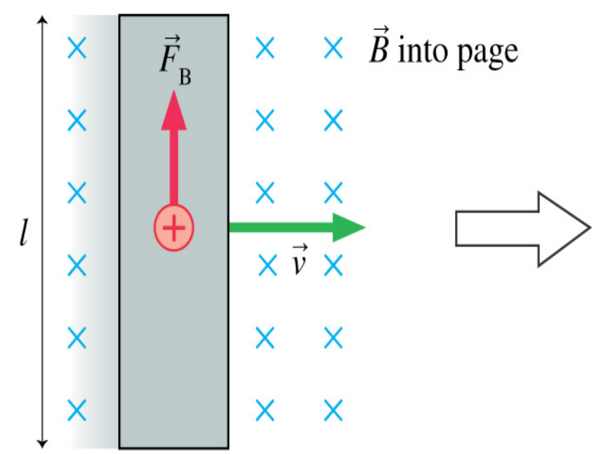


Coincidence? I think not.

Motional emf: a different perspective

- Let's get rid of the U-shaped conductor and let the conducting bar move to the right with a speed v
- There's going to be a magnetic force on the mobile charge carriers in the bar
  - F=qvB





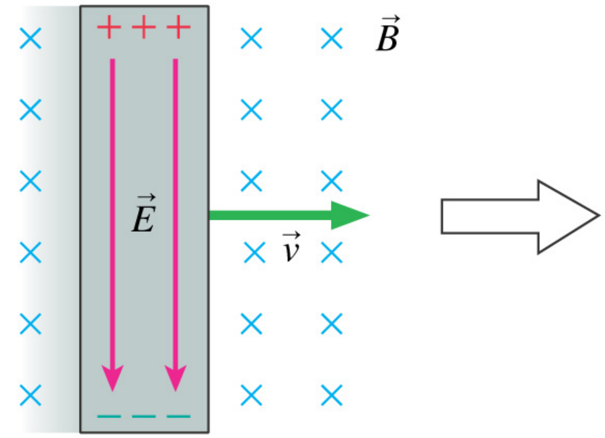
Charge carriers in the wire experience an upward force of magnitude $F_B = qvB$. Being free to move, positive charges flow upward (or, if you prefer, negative charges downward).

Motional emf

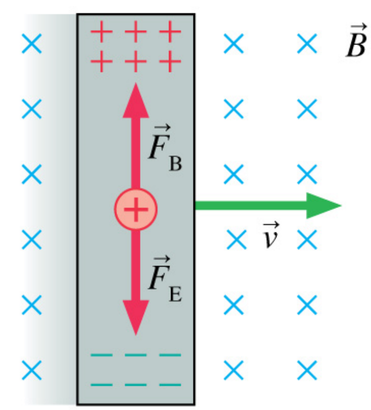
- The separation of charges creates an electric field
- The separation continues until the electric force and the magnetic force balance each other
  - $F_E = FB$
  - $qE = qvB$
  - $E = vB$

…as we saw in the Hall effect

- The potential from the top of the bar to the bottom is given by
  - $\Delta V = El = Blv$
  - the same answer we got using Faraday's law



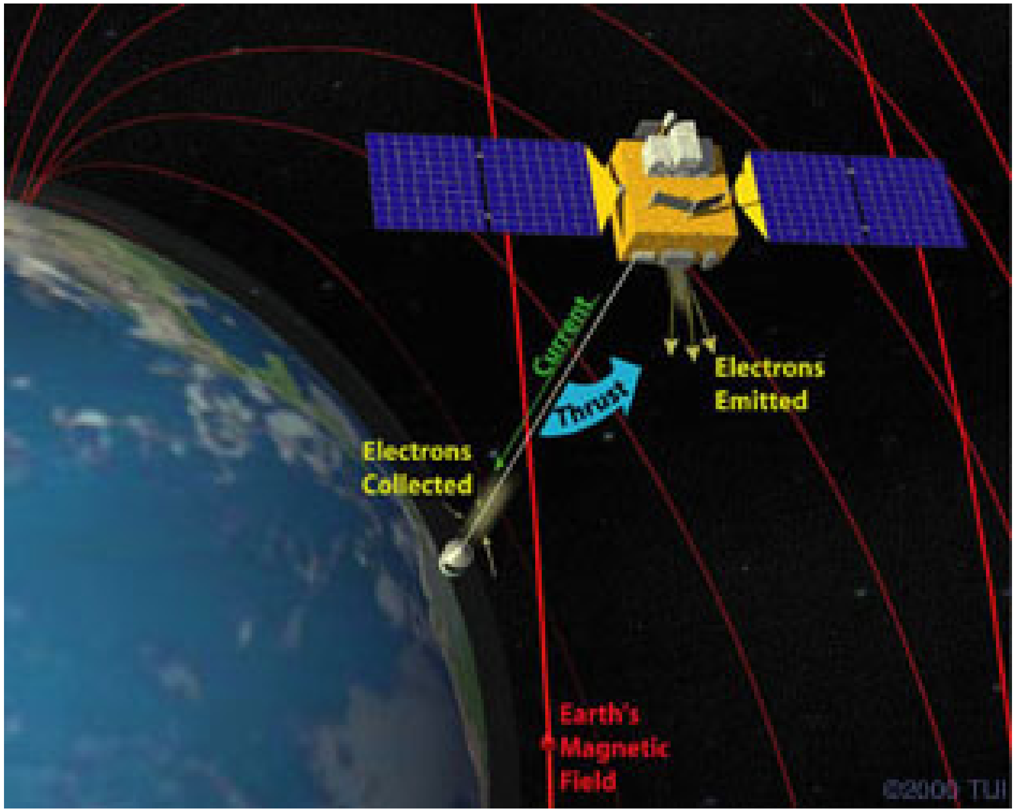
The charge separation creates an electric field in the conductor. $\vec{E}$ increases as more charge flows.



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.

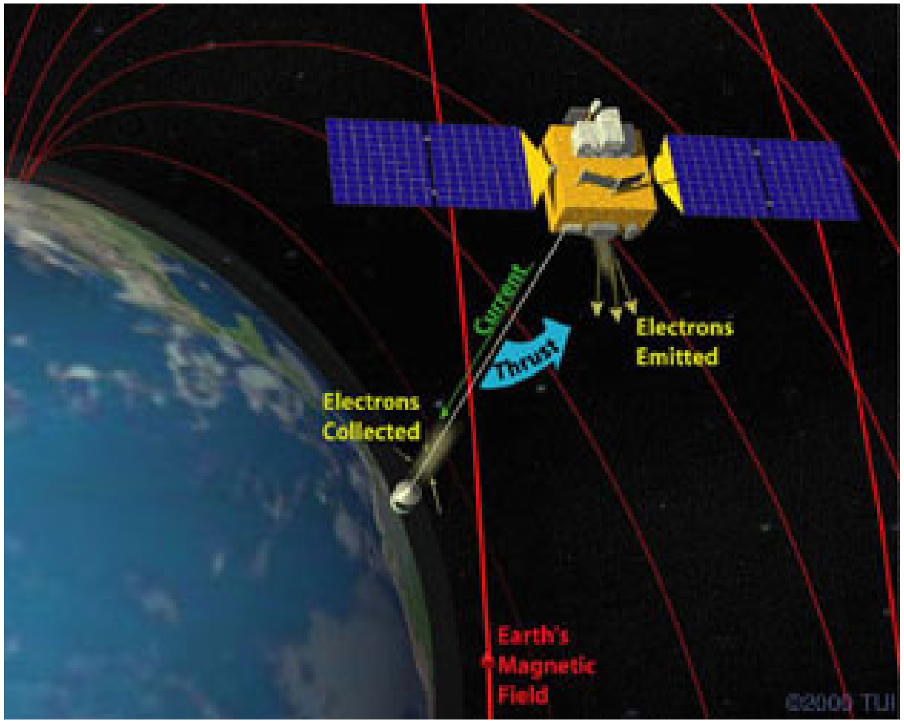
Space tethers

- An **electrodynamic tether** is essentially a long conducting wire extended from a spacecraft. The gravity gradient field (also known as the "tidal force") will tend to orient the tether in a vertical position. If the tether is orbiting around the Earth, it will be crossing the Earth's magnetic field lines at orbital velocity (7-8 km/s!). The motion of the conductor across the magnetic field induces a voltage along the length of the tether. This voltage can be up to several hundred volts per kilometer.In an "electrodynamic tether drag" system, such as the Terminator Tether, the tether can be used to reduce the orbit of the spacecraft to which it is attached.



Space tethers

- If the system has a means for collecting electrons from the ionospheric plasma at one end of the tether and expelling them back into the plasma at the other end of the tether, the voltage can drive a current along the tether. This current will, in turn, interact with the Earth's magnetic field to cause a Lorentz force which will oppose the motion of the tether and whatever it is attached to. This "electrodynamic drag force" will decrease the orbit of the tether and its host spacecraft. Essentially, the tether converts the orbital energy of the host spacecraft into electrical power, which is dissipated as ohmic heating in the tether.



Satellite Is Lost as Space Shuttle Tether Breaks

February 26, 1996 | MIKE CLARY and LIANNE HART | SPECIAL TO THE TIMES

HOUSTON — A 12-mile tether connecting a half-ton satellite to the space shuttle Columbia broke without warning Sunday, allowing the $443-million satellite and its dangling leash to drift off into the void.

The seven astronauts aboard Columbia were not in any immediate danger as a result of the mishap, according to Mission Control at Johnson Space Center in Houston.

But the announcement from astronaut Jeffrey Hoffman that the cable had snapped nearly five hours into an electricity-generating experiment sent a shiver of anxiety through Mission Control.

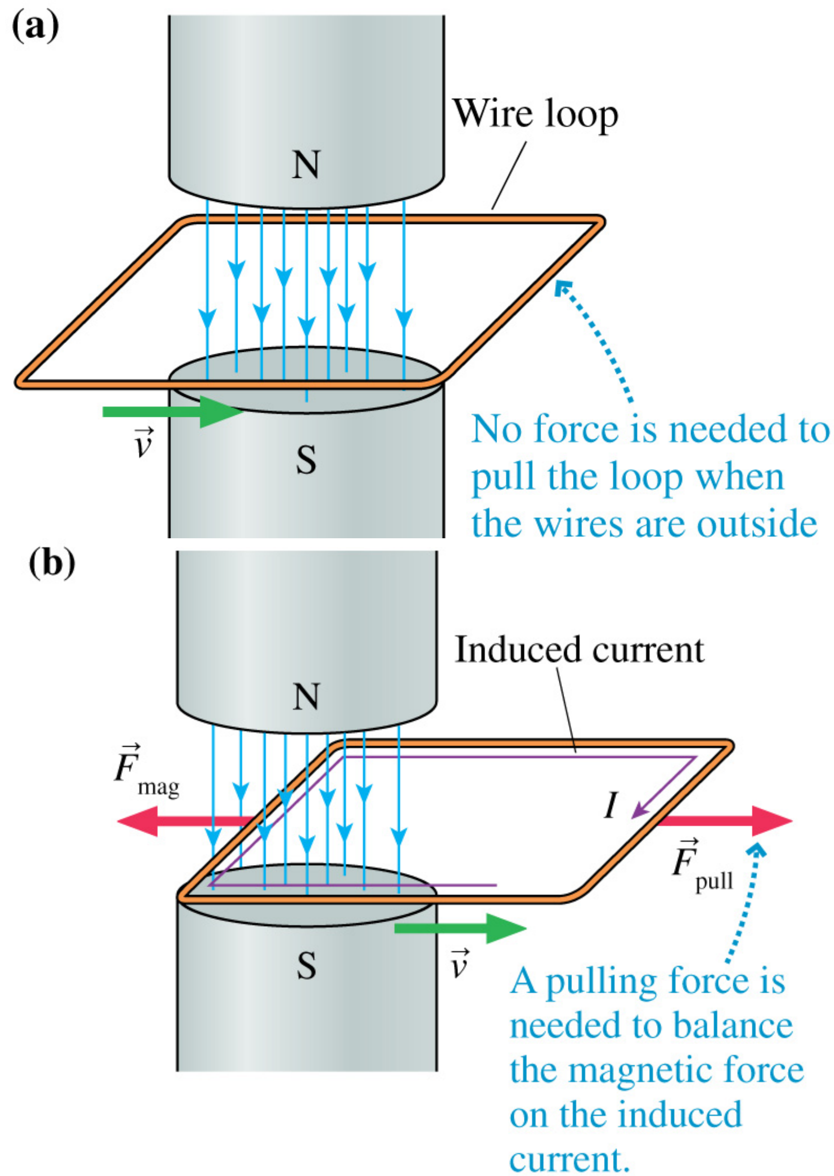
"The tether has broken at the boom! The tether has broken! It is going away from us!" Hoffman reported about 5:30 p.m. PST.

Boosting space station orbit

Run it in the opposite direction to boost the orbit

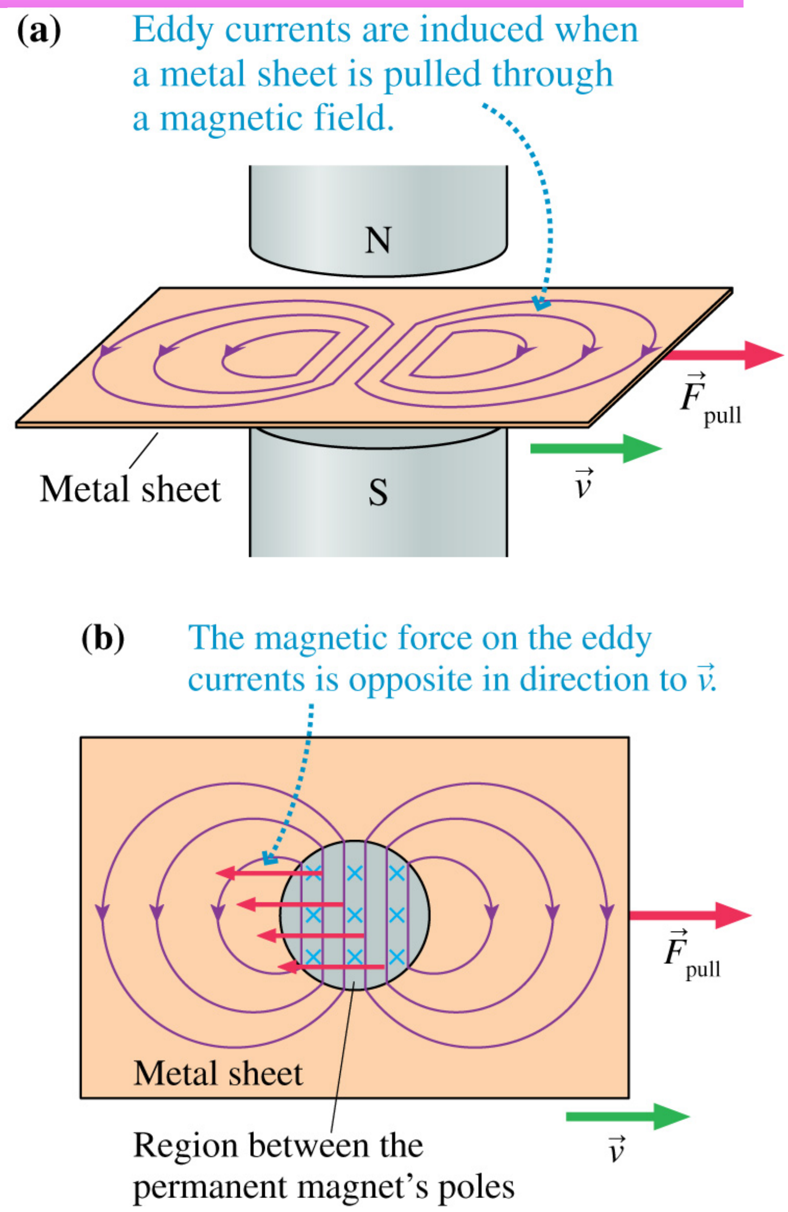
Eddy currents

- If I pull a conducting loop through a magnetic field, a current will be induced when the magnetic flux changes
- This is called an eddy current



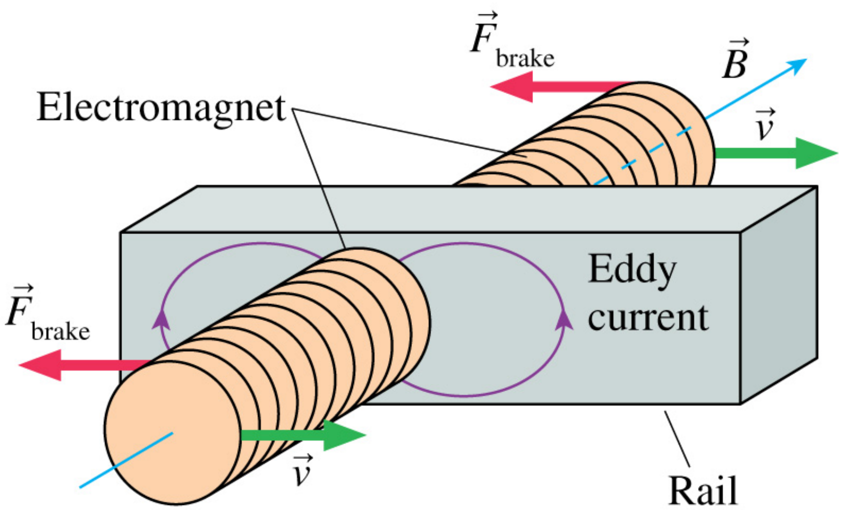
Eddy currents

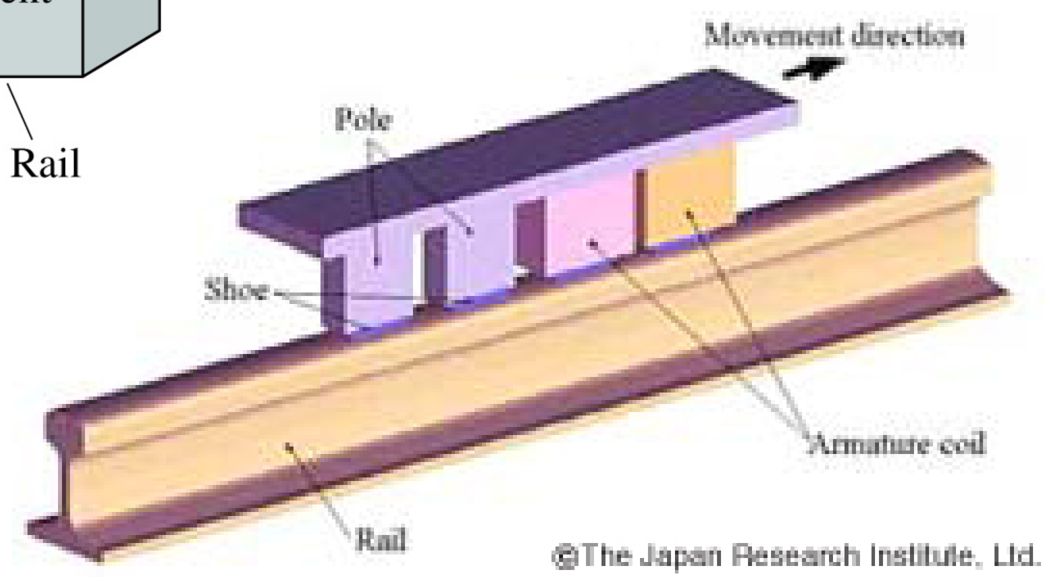
- Same thing happens if I pull a solid conducting sheet through a magnetic field



Eddy current braking

- Used in trains and in swim suit dryers

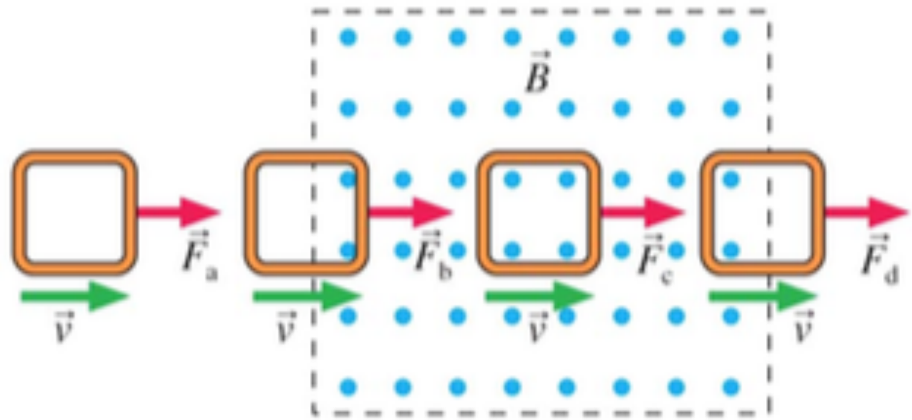




iclicker question

A square loop of copper wire is pulled through a region of magnetic field. Rank in order, from strongest to weakest, the pulling forces F_a, F_b, F_c and F_d that must be applied to keep the loop moving at constant speed.

A. $F_b = F_d > F_a = F_c$
B. $F_c > F_b = F_d > F_a$
C. $F_c > F_d > F_b > F_a$
D. $F_d > F_b > F_a = F_c$
E. $F_d > F_c > F_b > F_a$



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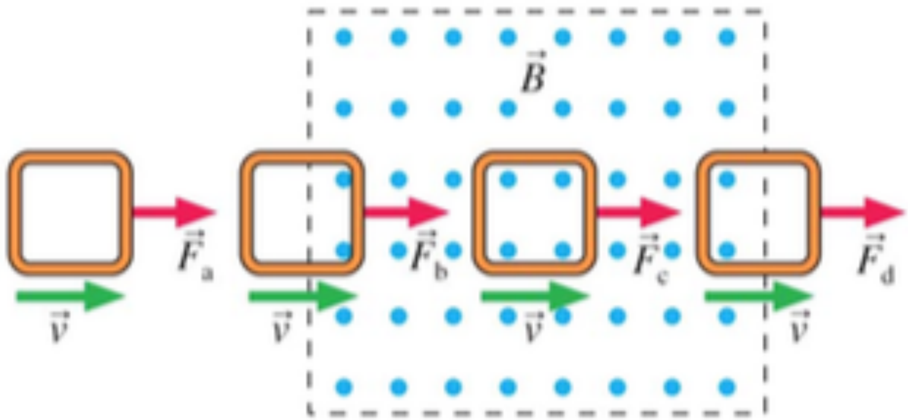
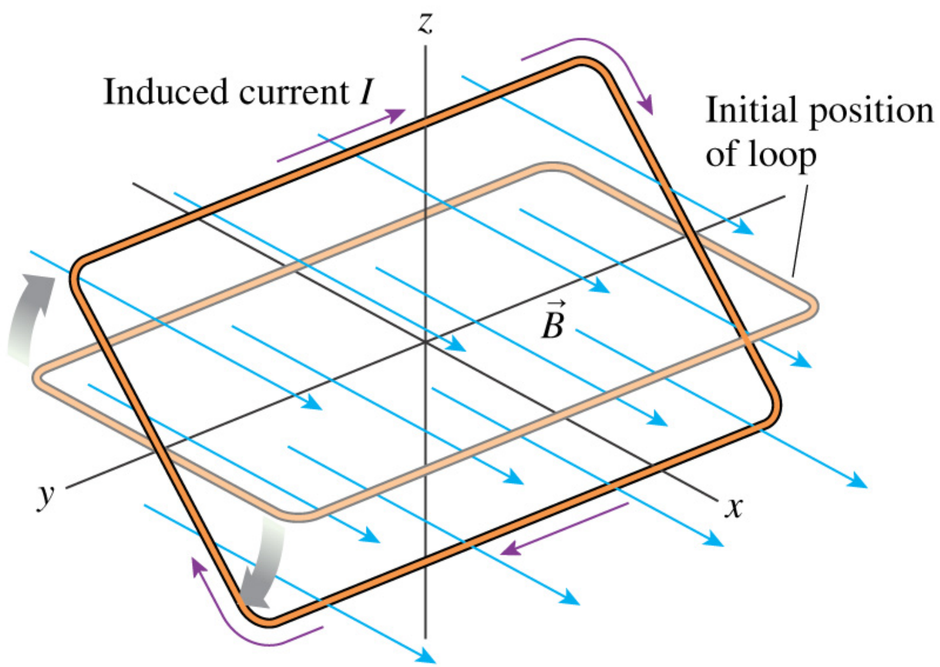
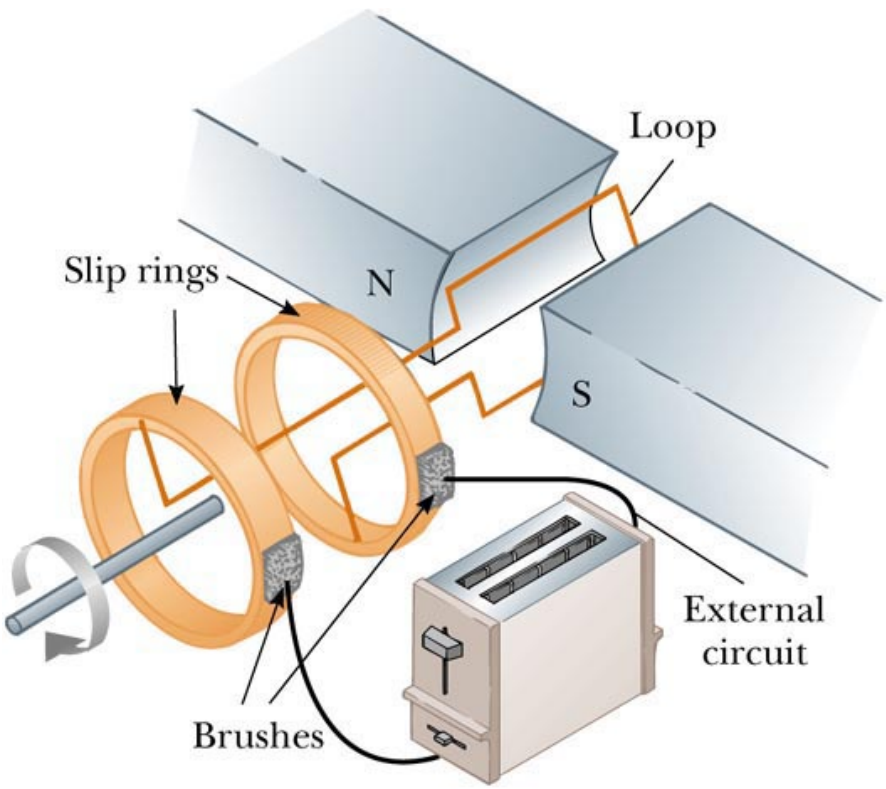


Rotating loop

- The magnetic flux through a loop can also change if the relative orientation of the magnetic field and the loop change as for example when I have a rotating loop

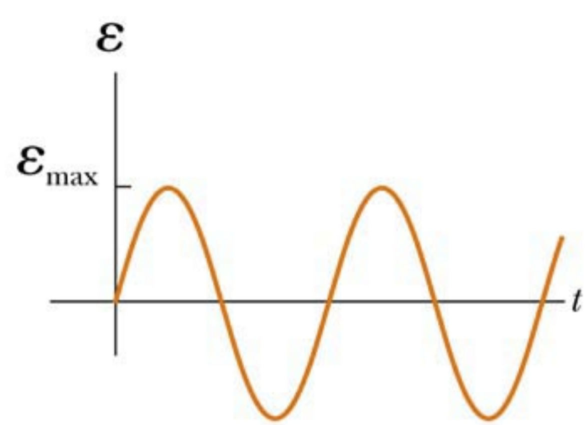


A case where B and A stay the same but θ changes



(a)

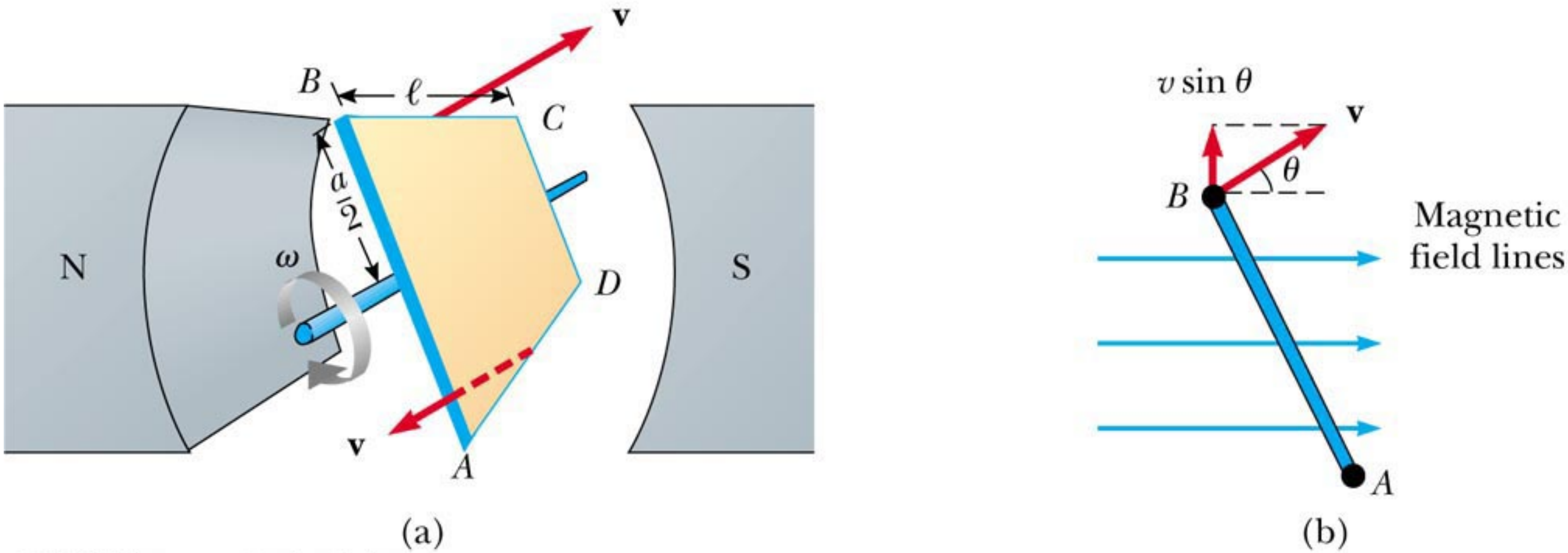
an electrical generator consists of a coil rotating inside of a constant magnetic field



(b)

it produces an emf that varies sinusoidally with time

Electrical generator



$\Phi_B = B\ A \cos\theta = \ B\ A \cos \omega t$

$\varepsilon = -\ N\ \Delta\Phi_B/\Delta t = -\ N\ B\ A\ \omega \sin\omega t$

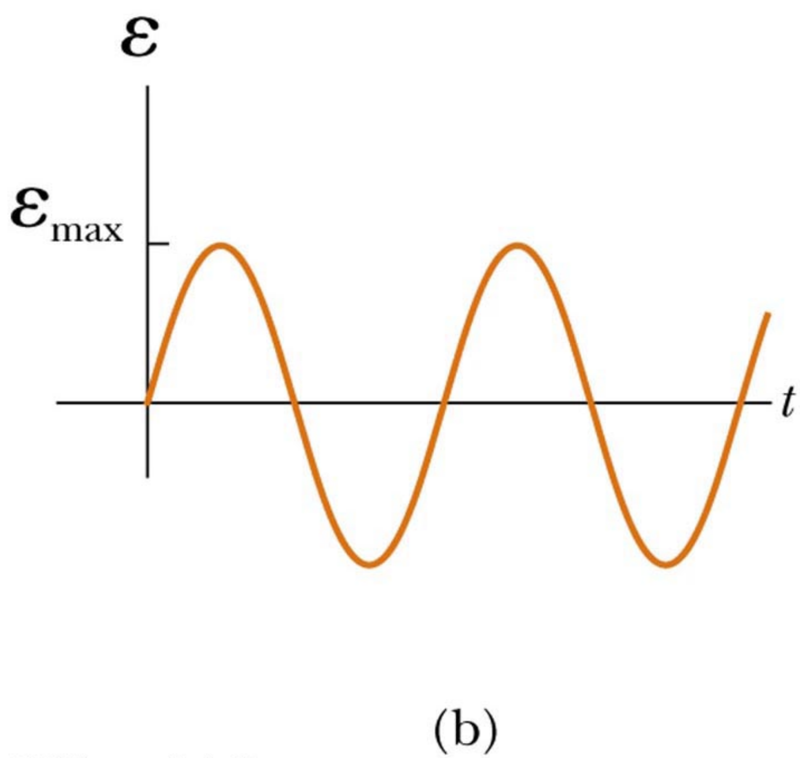
emf from a generator

$\varepsilon = - N \Delta\Phi_B/\Delta t$

$= - N B A \omega \sin\omega t$

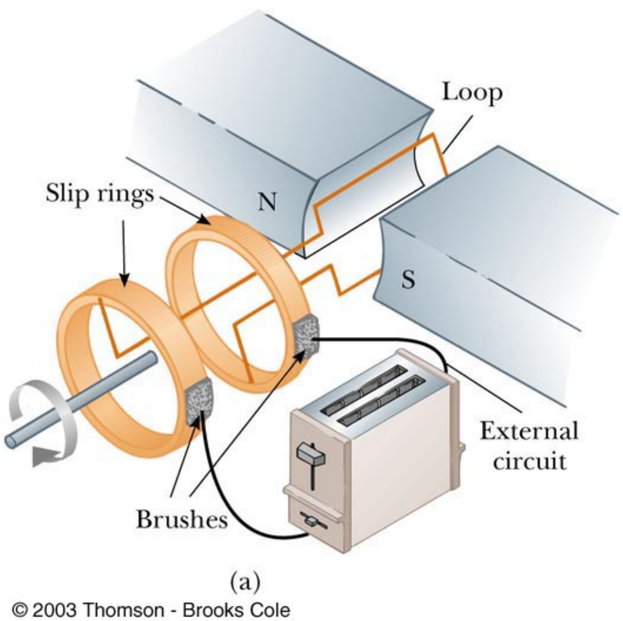
$\varepsilon_{max} = N B A \omega$

$T = 2\pi/\omega$

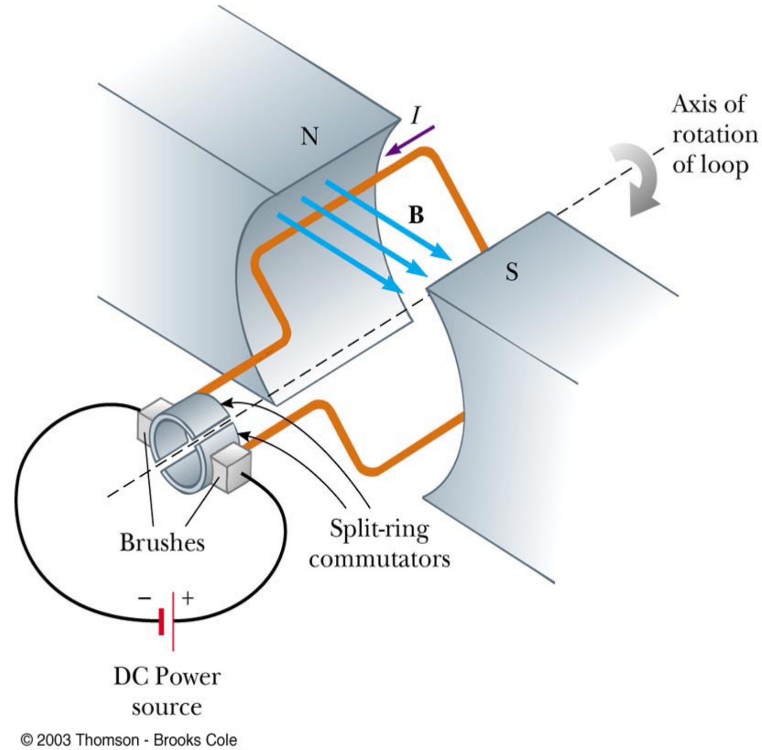


Generators and motors

What' s the difference between them?



ε_{ma}



A generator turns mechanical work into electrical energy.
A motor turns electrical energy into mechanical work.

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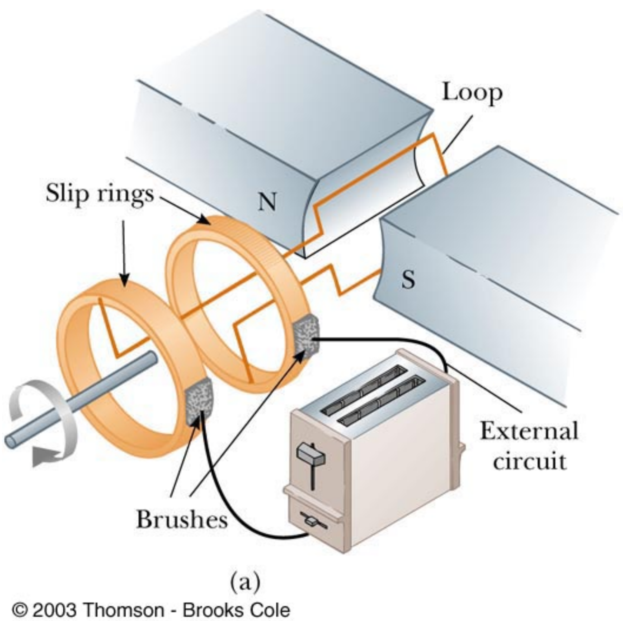
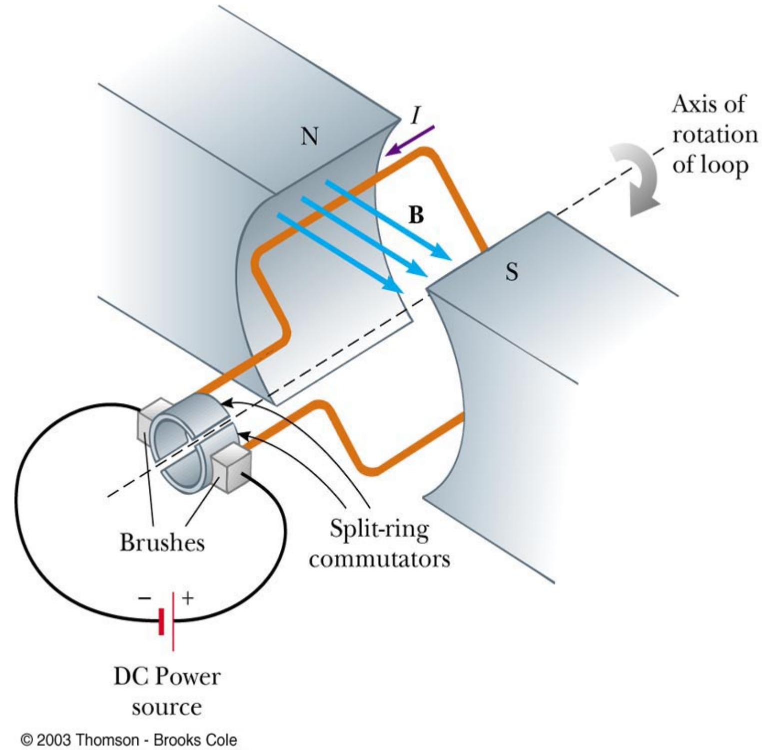
Demo

Generators and motors

What's the difference between them?





A generator turns mechanical work into electrical energy.
A motor turns electrical energy into mechanical work.
A motor is a generator run in reverse.

Demo

Eddy currents and metal detectors

- A high frequency AC current in the transmitter coil generates an alternating magnetic field along the axis
- The varying magnetic field creates a changing flux through the receiver coil and thus an induced current
- A piece of metal passing between the two coils will experience eddy currents
- The field produced by the eddy currents affects the field seen by the receiver coil and thus the current induced, which then sets off an alarm