Announcement

EXAM I is TONIGHT

8:00-9:30 PM –WEDNESDAY NOV. 7 in

ELLIOT HALL OF MUSIC

Material: Through Chapter 20 in the book.

Exam 1 - Tonight, Nov. 7, 8:00-9:30 PM in ELLIOT HALL OF MUSIC

1. Absences must be excused in advance by filing an Absentee Report form in Rm 144 PHYS. See the syllabus on Blackboard Learn (BBL) at mycourses.purdue.edu . For emergencies, contact Prof. Carlson by email as soon as possible, ewcarlson@purdue.edu .

2. Students approved for separate test environments must contact Prof. Carlson as soon as possible for further instructions. ewcarlson@purdue.edu

3. You may NOT bring equations sheets, books, etc. It is a closed book exam. Necessary equations and constants will be provided. DO bring pencils and a calculator which cannot access the internet. Graphing Calculator is okay.

4. You must show your **Purdue Student ID card** when turning in your completed exam to your recitation TA.

5. The exam covers all assigned material in this course through Chapter 20 in the book, including lectures, labs, recitations, and homework.

8:00-10:00 PM -THURS SEP 16, Elliott Hall

Exam 1 - Tonight, Nov. 7, 8:00-9:30 PM in ELLIOT HALL OF MUSIC

6. 10 multiple choice questions + 1 hand graded question

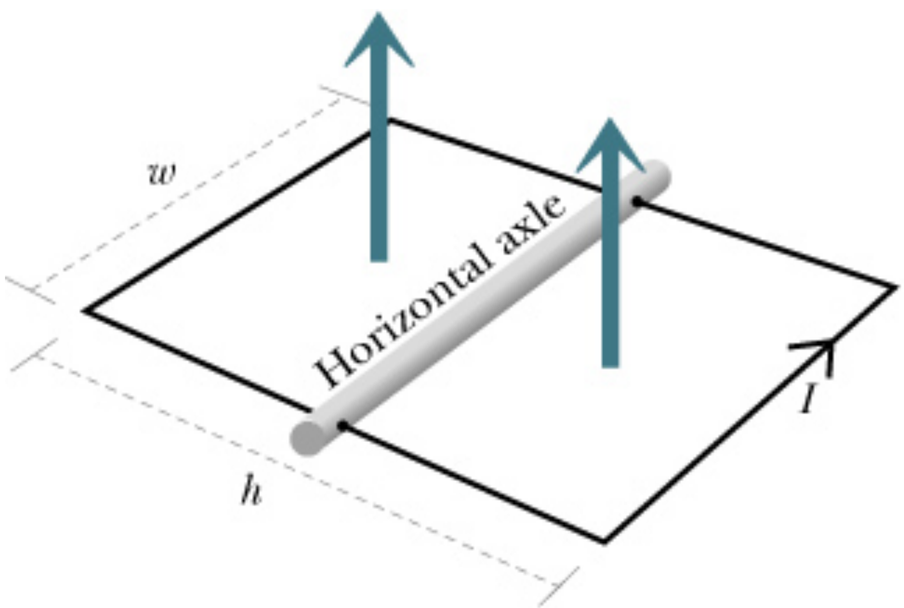
7. Practice Exam + Answers to machine-graded portion + Equation Sheet are posted on BBL.

8. Exam scores will be uploaded to BBL

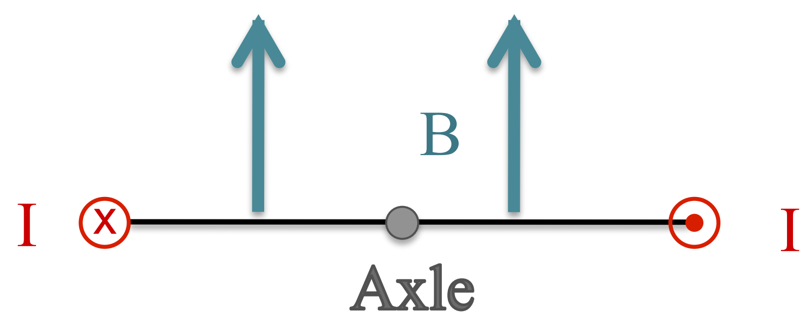
9. STUDY HARD AND GOOD LUCK!

Magnetic Torque

$$\Delta\vec{F}_{\rm mag} = I\Delta\vec{l} \times \vec{B}$$ **MAGNETIC FORCE -- current in a wire**



Seen from the side:



Magnetic Torque

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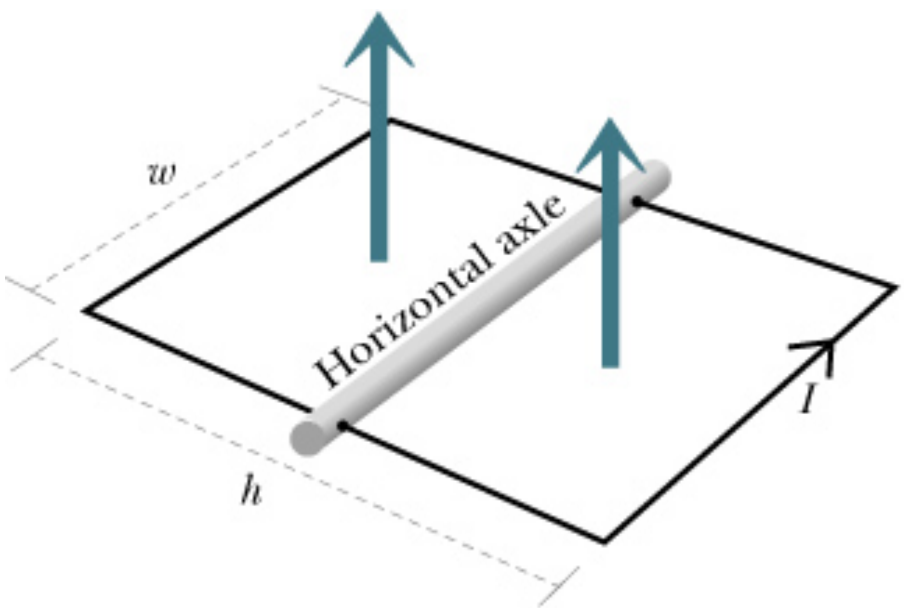
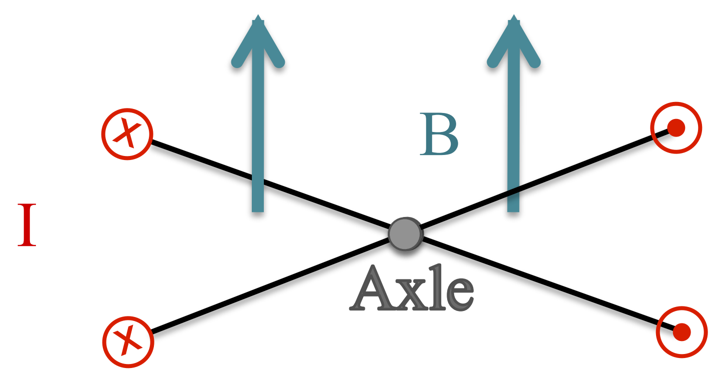


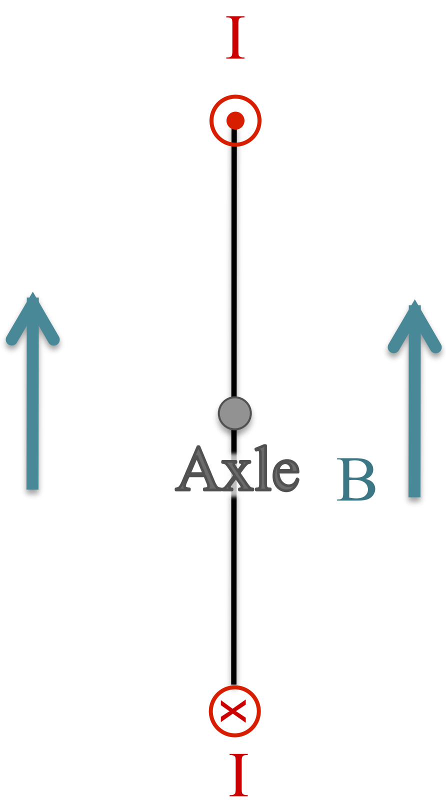
The current loop can rotate on its axle:



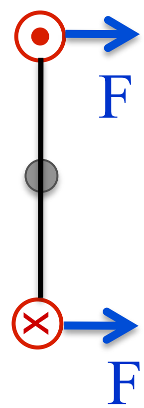
Magnetic Torque - iClicker

$$\Delta \vec{F}_{\text{mag}} = I \Delta \vec{l} \times \vec{B}$$ **MAGNETIC FORCE -- current in a wire**

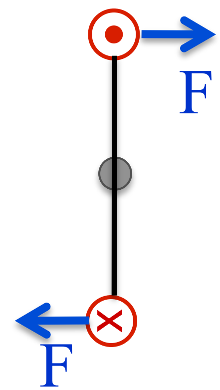
At this instant, which diagram represents the magnetic forces on the wire?



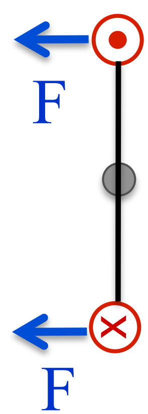
A)



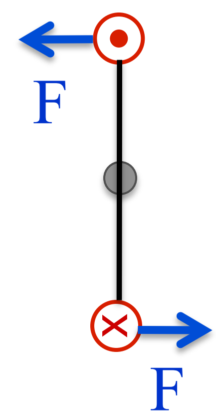
B)



C)



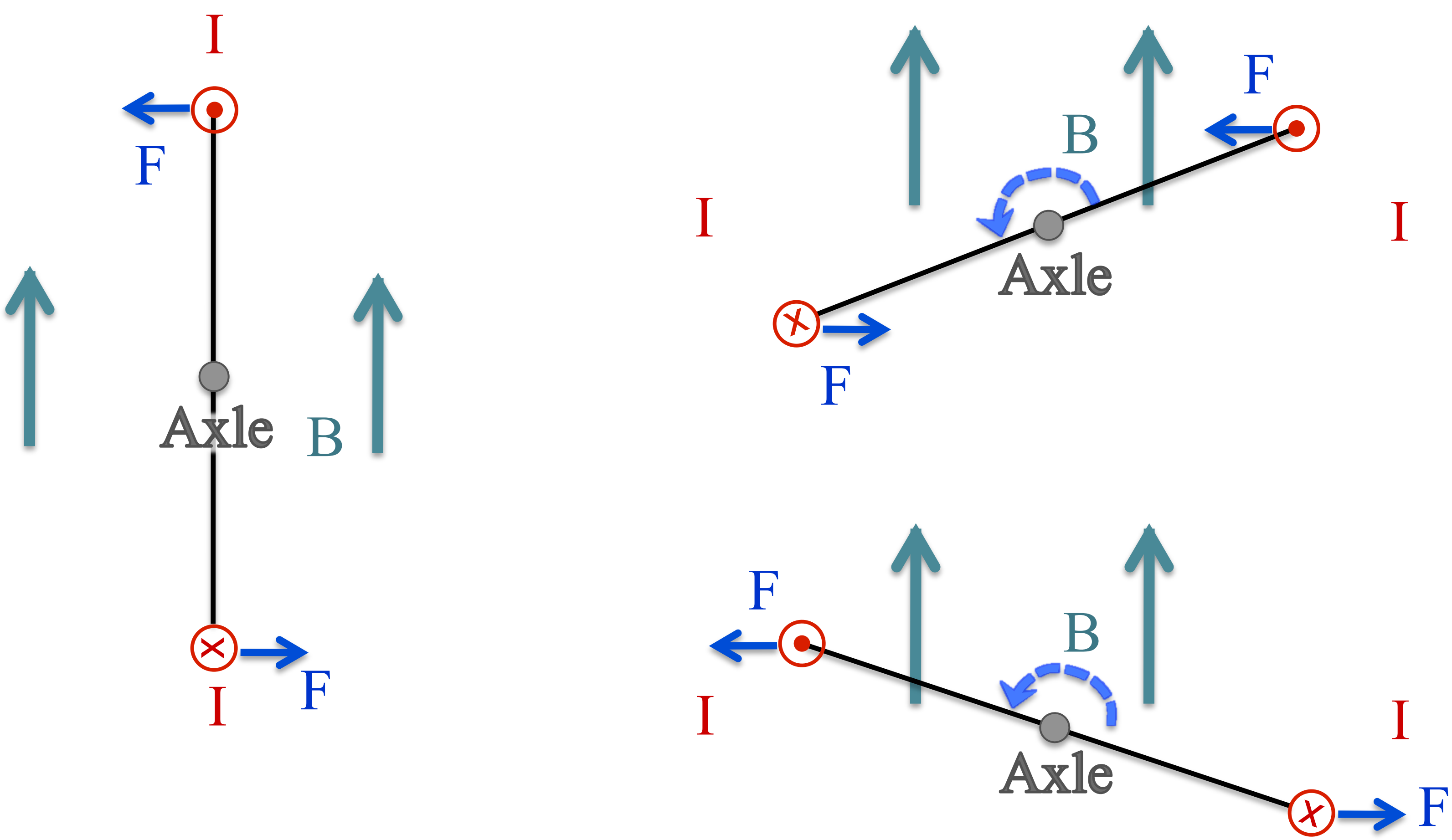
D)



Magnetic Torque

$$\Delta\vec{F}_{\rm mag} = I\Delta\vec{l} \times \vec{B}$$ **MAGNETIC FORCE -- current in a wire**

In these orientations, the loop twists **counterclockwise**.



Magnetic Torque

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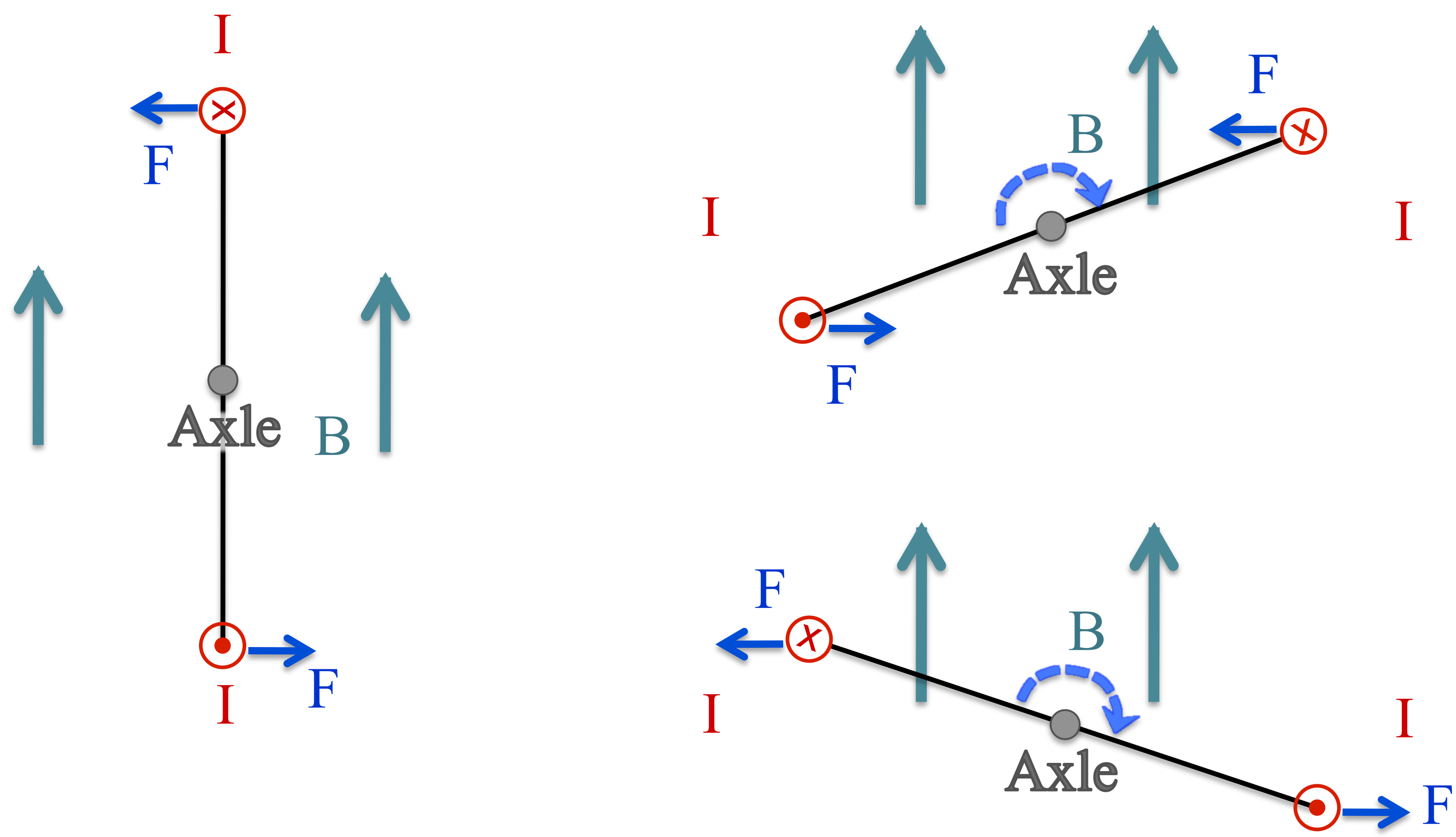
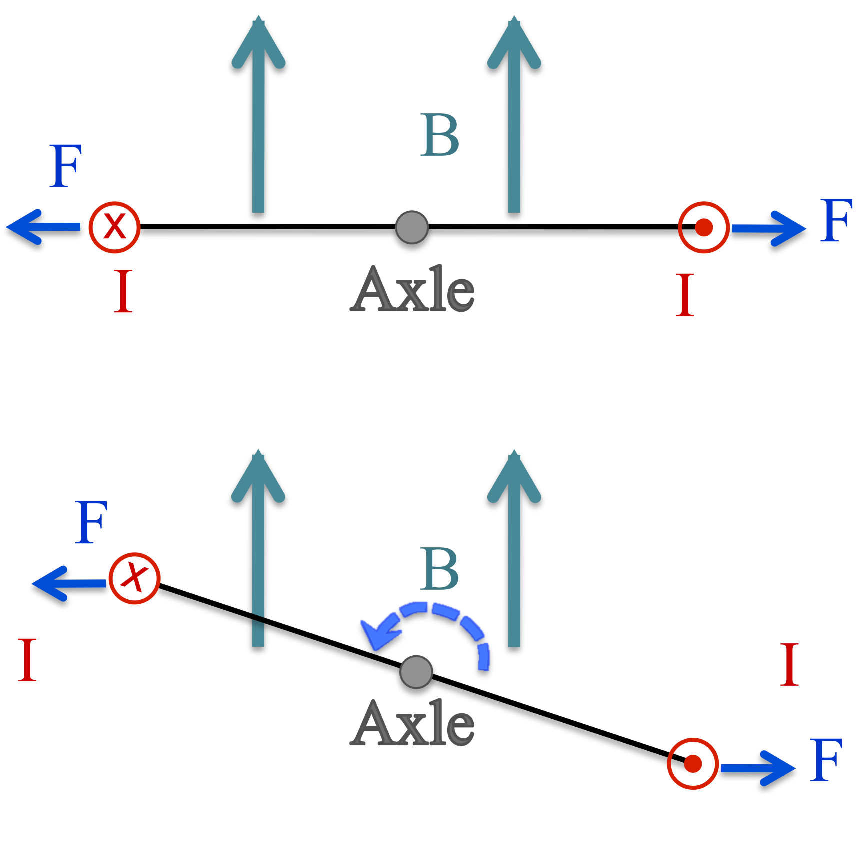


Stable or Unstable?

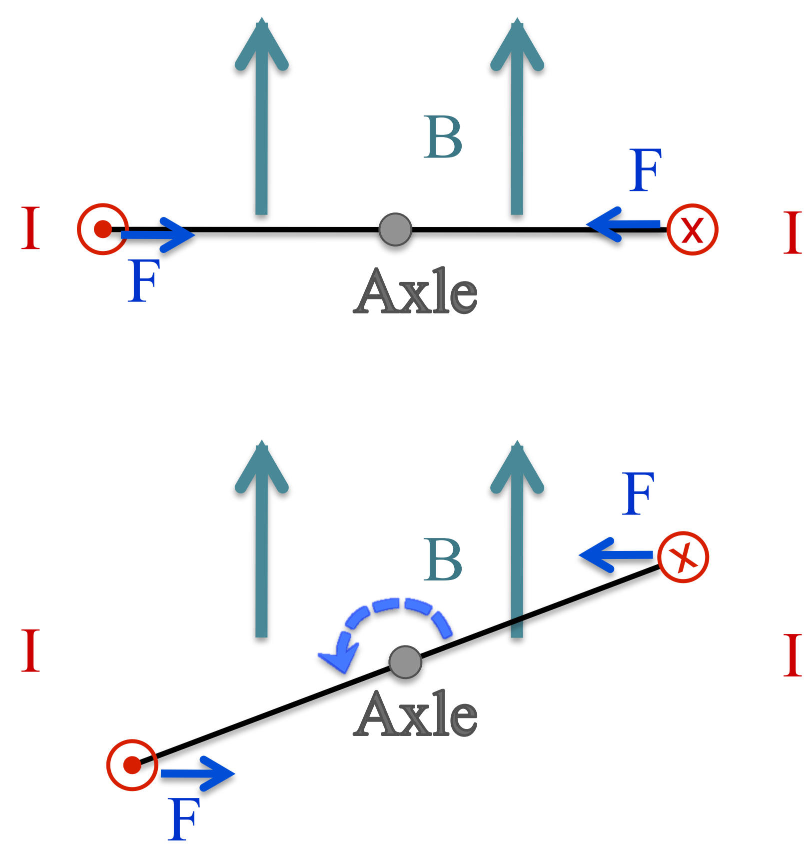
$$\Delta\vec{F}_{\mathrm{mag}} = I\Delta\vec{l} \times \vec{B}$$ **MAGNETIC FORCE -- current in a wire**

STABLE EQUILIBRIUM

UNSTABLE EQUILIBRIUM

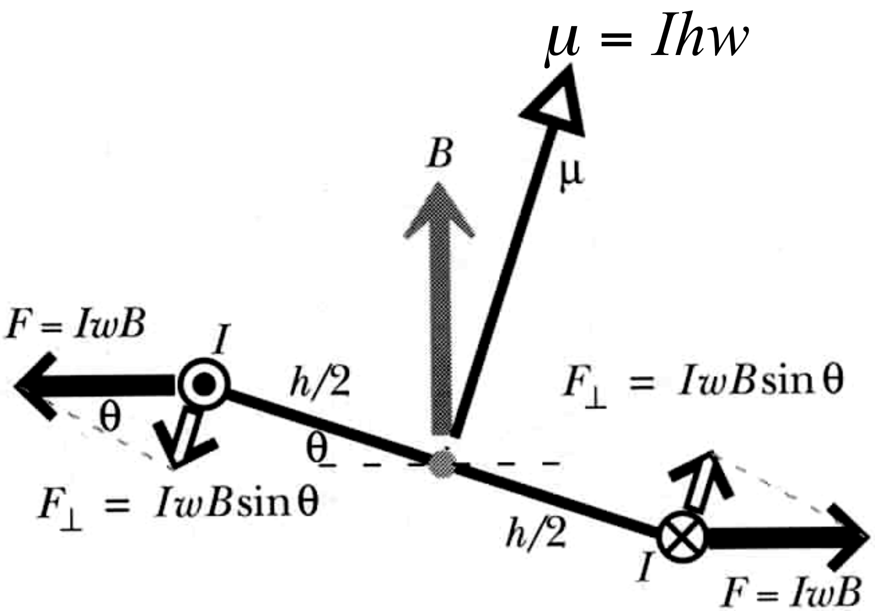


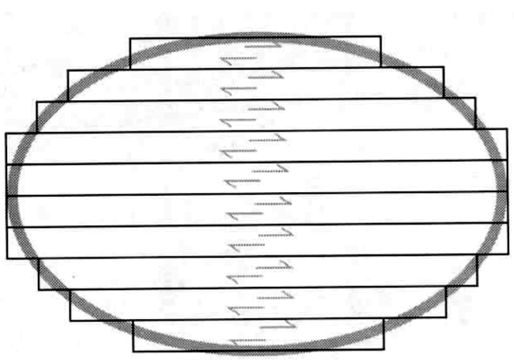
Slight deviation returns



Slight deviation does not return

Magnetic Torque: Quantitative Analysis





Torque (τ) = distance from the axle (lever arm) times perpendicular component of the force.

$$\vec{F}_m = I\Delta\vec{l} \times \vec{B}$$ small piece of wire

$$\left|\vec{F}_m\right| = IwB$$ wire of length w

$$F_\perp = IwB\sin\theta$$

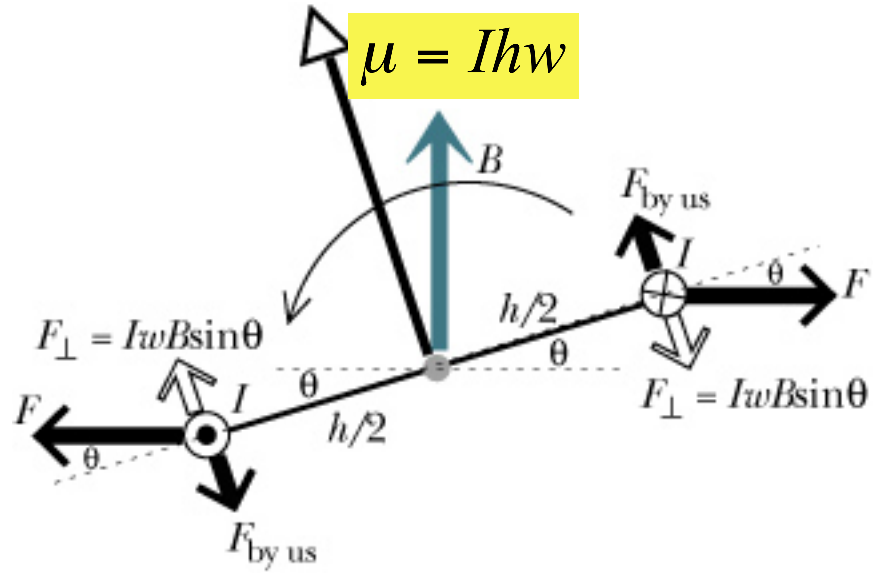
$$\tau = 2\left(\frac{h}{2} IwB\sin\theta\right) = IwhB\sin\theta$$

$$\tau = \mu B\sin\theta$$ Use μ=IA

$$\boxed{\vec{\tau} = \vec{\mu} \times \vec{B}}$$ Always true

Works with loops of any shape!

Magnetic Dipole Moment: Potential Energy



Calculate amount of work needed to rotate from angle θ_I to θ_f:

arclength = r θ

$$dW = 2\left[F_{\perp}\left(\frac{h}{2}d\theta\right)\right]$$

$$W = \Delta U_m = \int_{\theta_i}^{\theta_f} 2IwB\sin\theta\left(\frac{h}{2}d\theta\right)$$

$$\Delta U_m = IwhB\int_{\theta_i}^{\theta_f}\sin\theta d\theta = IwhB\left[-\cos\theta\right]_{\theta_i}^{\theta_f}$$

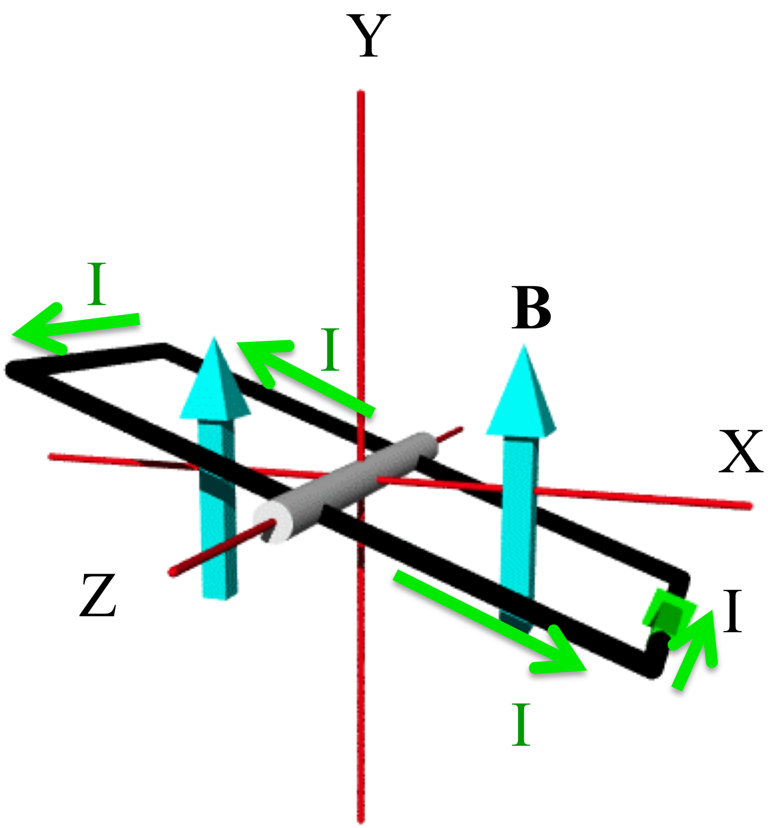
$$\Delta U_m = -\mu B\left[\cos\theta_f - \cos\theta_i\right]$$

$$U_m = -\mu B\cos\theta$$

Potential energy for a magnetic dipole moment

$$U_m = -\vec{\mu}\cdot\vec{B}$$

iClicker Question



What is the direction of

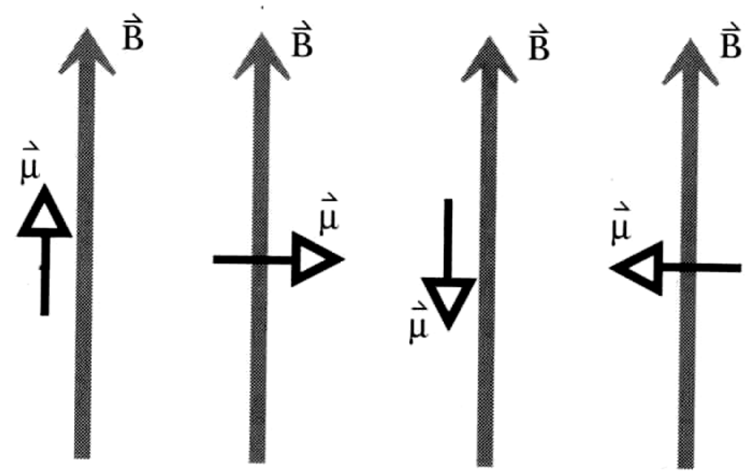
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

A) +Z
B) -Z
C) +Y
D) -Y
E) None of above

Magnetic Dipole Moment: Potential Energy

Potential energy for a magnetic dipole moment

$$U_m = -\vec{\mu} \cdot \vec{B}$$

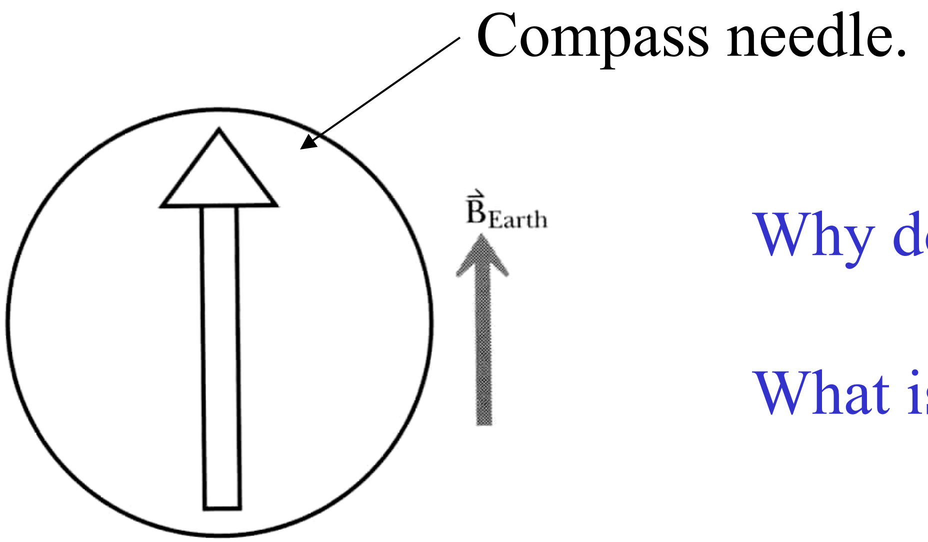


$U=$ min $-\mu B$ 0   max μB 0

What is the energy difference between the highest and the lowest state?

Picture of the U and μ in magnetic field – important in atomic and nuclear physics.

Compass

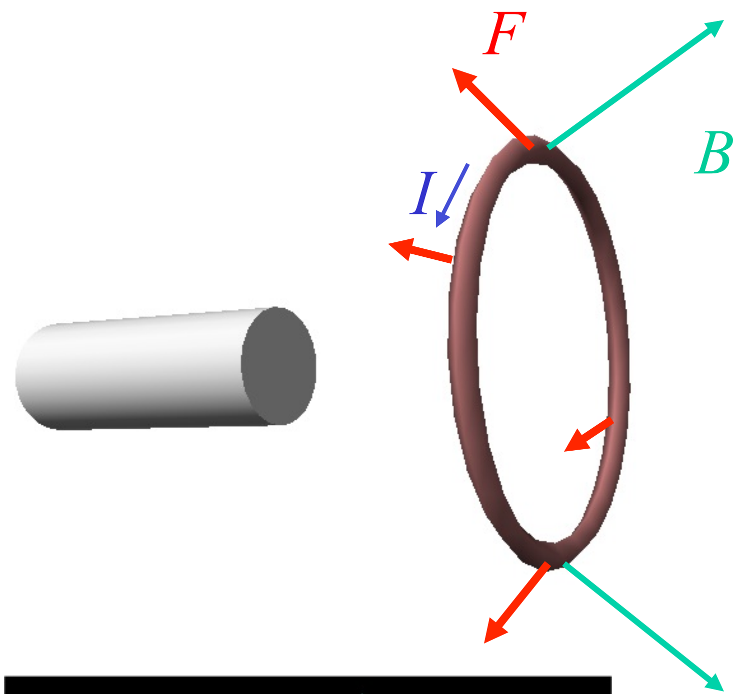


Why does it point to north?

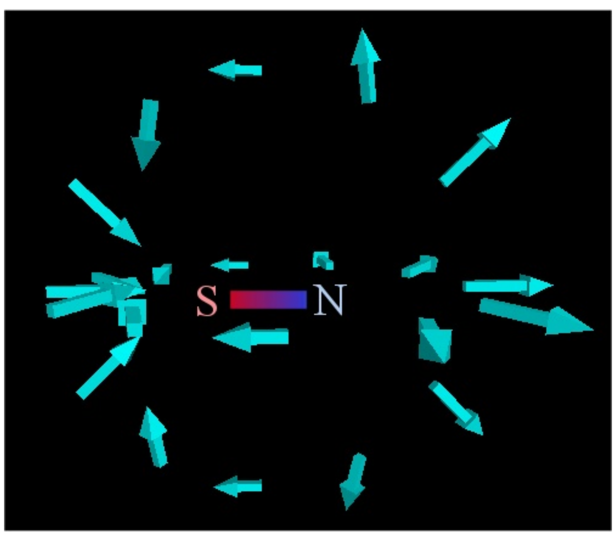
What is the direction of μ?

What will happen if the needle is moved away and released?

Experiment



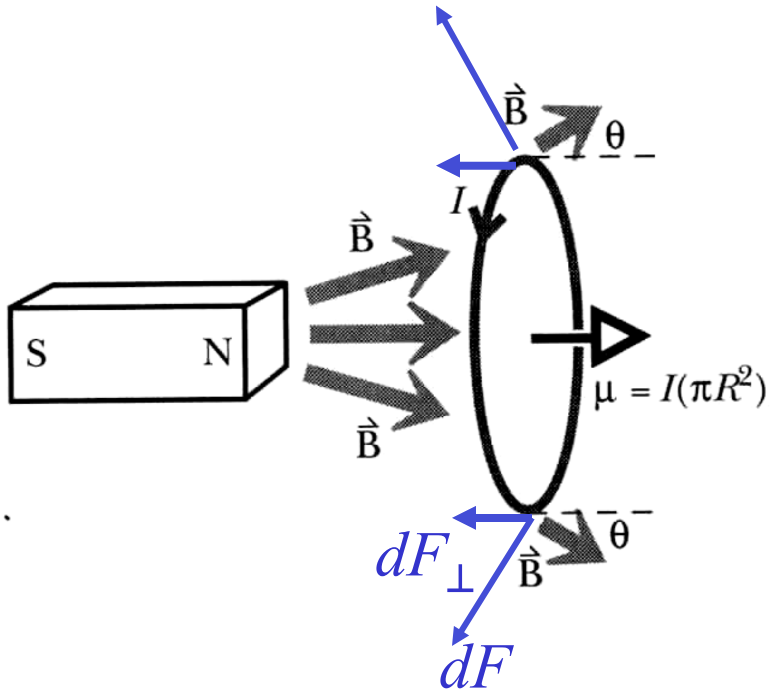
$$\vec{F}_m = I\Delta\vec{l} \times \vec{B}$$



What will happen if current is reversed?

What will happen if magnet is reversed?

Force on a Magnetic Dipole



$$d\vec{F} = I d\vec{l} \times \vec{B}$$

$$dF = IBdl$$

$$dF_{\perp} = IBdl\sin\theta$$

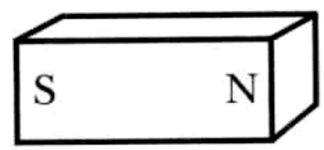
$$F_{net} = IB\sin\theta \int dl$$

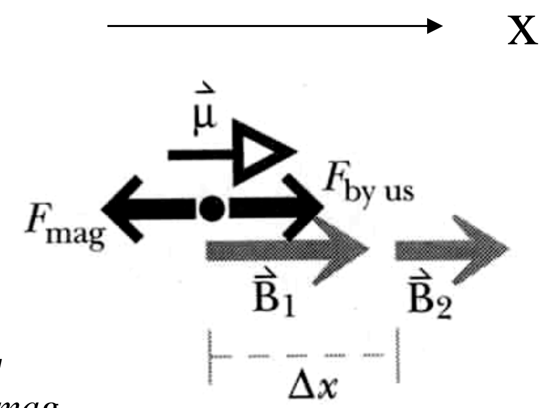
$$F_{net} = 2\pi RIB\sin\theta$$

$$\boxed{F_{net} = \frac{2\mu B}{R}\sin\theta}$$

Too bad we don't know θ...
We need a different method!

Force on a Magnetic Dipole





$$\boxed{U_m = -\vec{\mu} \cdot \vec{B}}$$

$$F_{by\_us} \Delta x = \Delta U_m = -\mu \Delta B > 0$$

$$\vec{F}_{by\_us} = -\vec{F}_{mag}$$

$$F_{by\_us} = \frac{\Delta U_m}{\Delta x} = -\mu \frac{\Delta B}{\Delta x} \rightarrow -\mu \frac{dB}{dx}$$

$$U_{m,1} < U_{m,2}$$

$$F_x = -\frac{dU}{dx}$$

$$F_x = \mu \frac{dB}{dx} \quad < 0$$

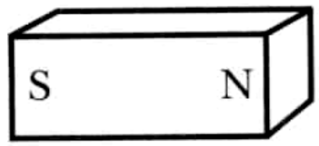
$$F_x = -\frac{d(-\vec{\mu} \bullet \vec{B})}{dx}$$

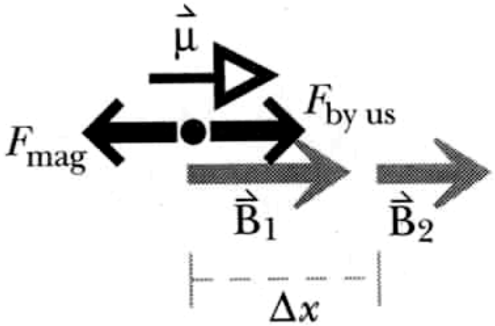
Force exerted on dipole by magnetic field

There is no force if field is uniform!

Force on a Magnetic Dipole

$$F_x = \mu \frac{dB}{dx}$$



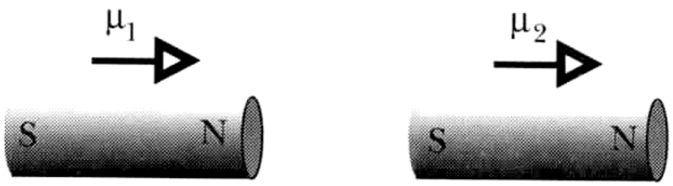


$$F_x \approx \mu \frac{d}{dx}\left(\frac{\mu_0}{4\pi}\frac{2\mu_{bar}}{x^3}\right)$$

$$B_x \approx \frac{\mu_0}{4\pi}\frac{2\mu_{bar}}{x^3}$$

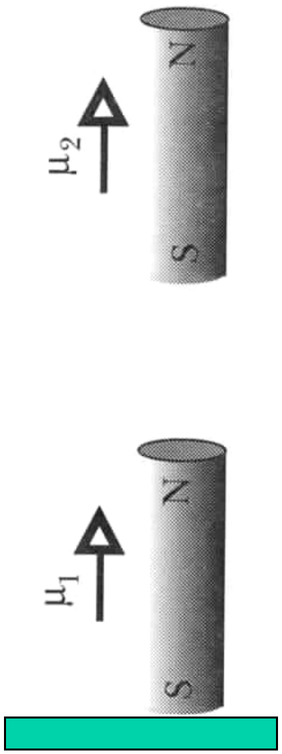
$$\boxed{F_x \approx -\frac{\mu_0}{4\pi}\frac{6\mu\mu_{bar}}{x^4}}$$

Two magnets



$$\boxed{F_x \approx -\frac{\mu_0}{4\pi}\frac{6\mu_1\mu_2}{x^4}}$$

Exercise



What is the distance at which one magnet can pick up another?

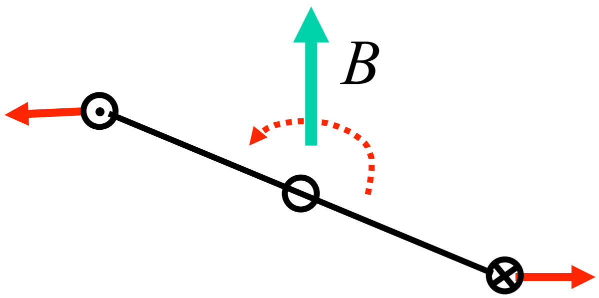
$$\boxed{F_x \approx \frac{\mu_0}{4\pi}\frac{6\mu_1\mu_2}{x^4}} = mg \approx 0.1\ N$$

$$\mu_1 = \mu_2 \approx 0.2\ \text{Am}^2$$

$$x \approx \sqrt[4]{\frac{\mu_0}{4\pi}\frac{6\mu_1\mu_2}{F_x}} \approx 0.02\ \text{m}$$

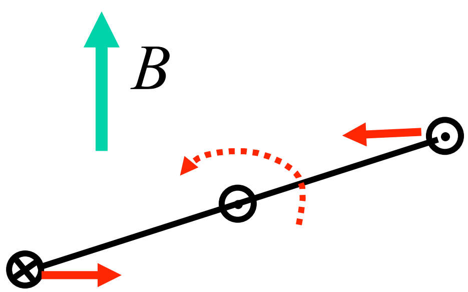
How to Make an Electric Motor

$$\vec{F}_m = I\Delta\vec{l} \times \vec{B}$$

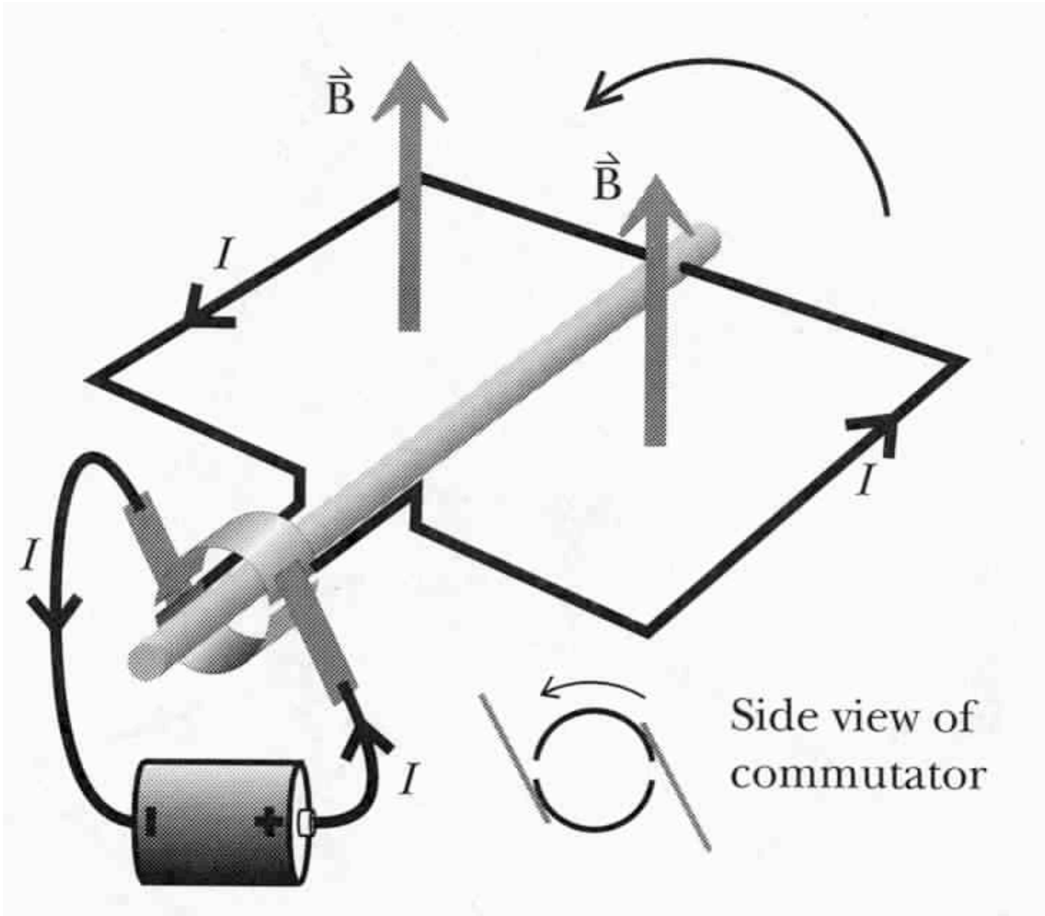


Run the current one way

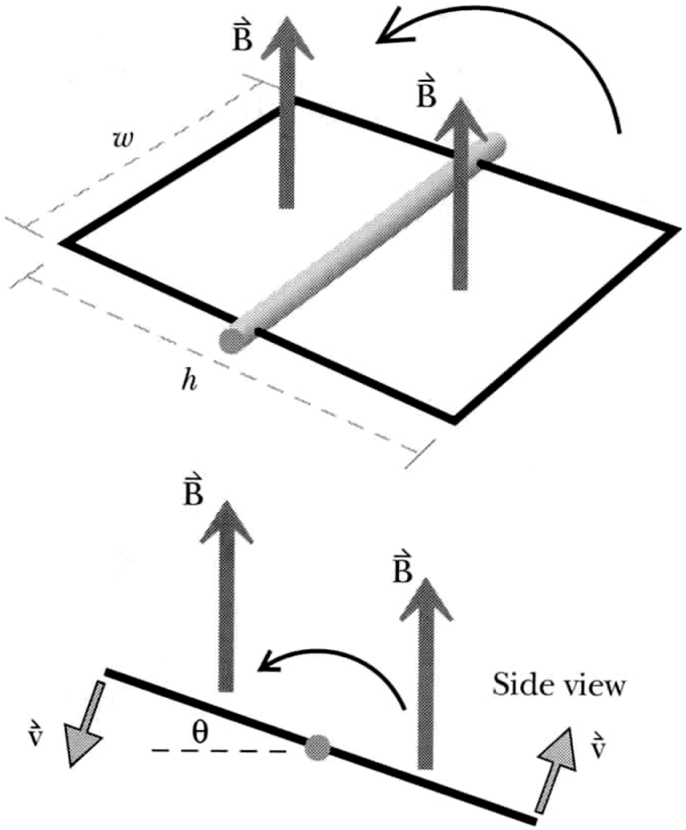
Then reverse the current



Torque is in same direction



Electric Generators



Tangential speed: $v = \omega(h/2)$

Force on charges: $\vec{F}_m = q\vec{v} \times \vec{B}$

$$F_m = qvB\sin\theta$$

$$F_e = qE = F_m$$

$$E = vB\sin\theta$$

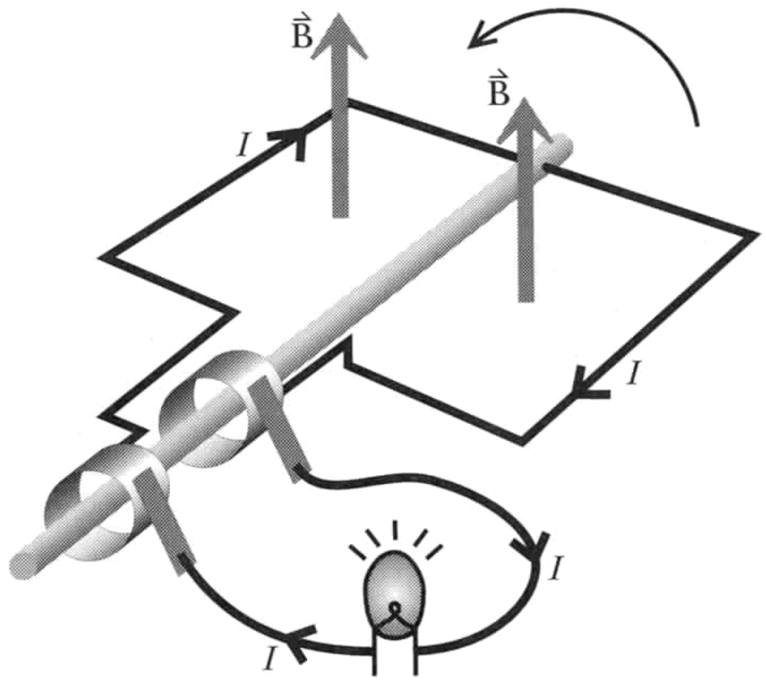
$$emf_{left} = \Delta V = wE = wvB\sin\theta$$

$$emf_{total} = 2wvB\sin\theta$$

$$emf_{total} = wh\omega B\sin\theta$$

$$emf(t) = A\omega B\sin\omega t$$

Electric Generators

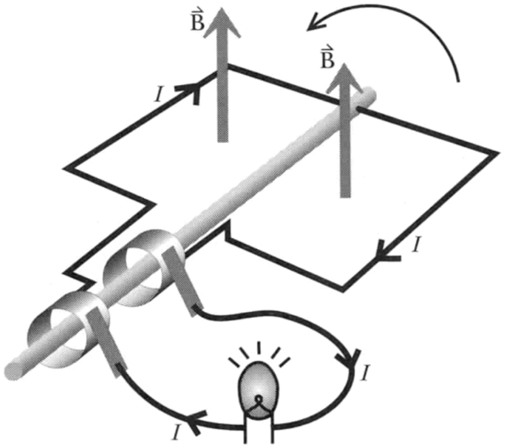


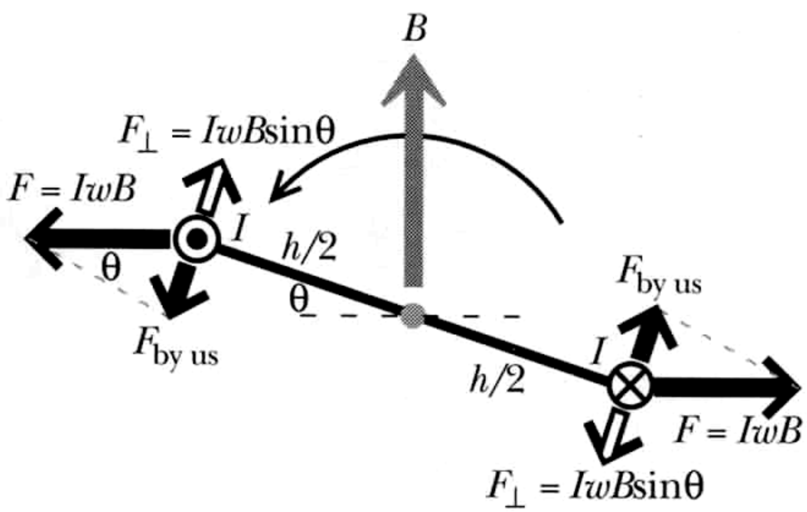
$$emf(t) = A\omega B \sin \omega t$$

$$I(t) = \frac{emf(t)}{R} = \frac{A\omega B}{R} \sin \omega t$$

AC generator

Power Required to Turn a Generator





$$emf(t) = A\omega B\sin\omega t$$

$$I(t) = \frac{A\omega B}{R}\sin\omega t$$

$$\Delta W = 2(IwB\sin\theta)\left(\frac{h}{2}\Delta\theta\right)$$

$$P = \frac{dW}{dt} = IwhB\sin\theta\frac{d\theta}{dt}$$

$$P = IAB\omega\sin\omega t$$

$$P = I\cdot emf = I^2R$$

$$P \sim \sin^2\omega t$$