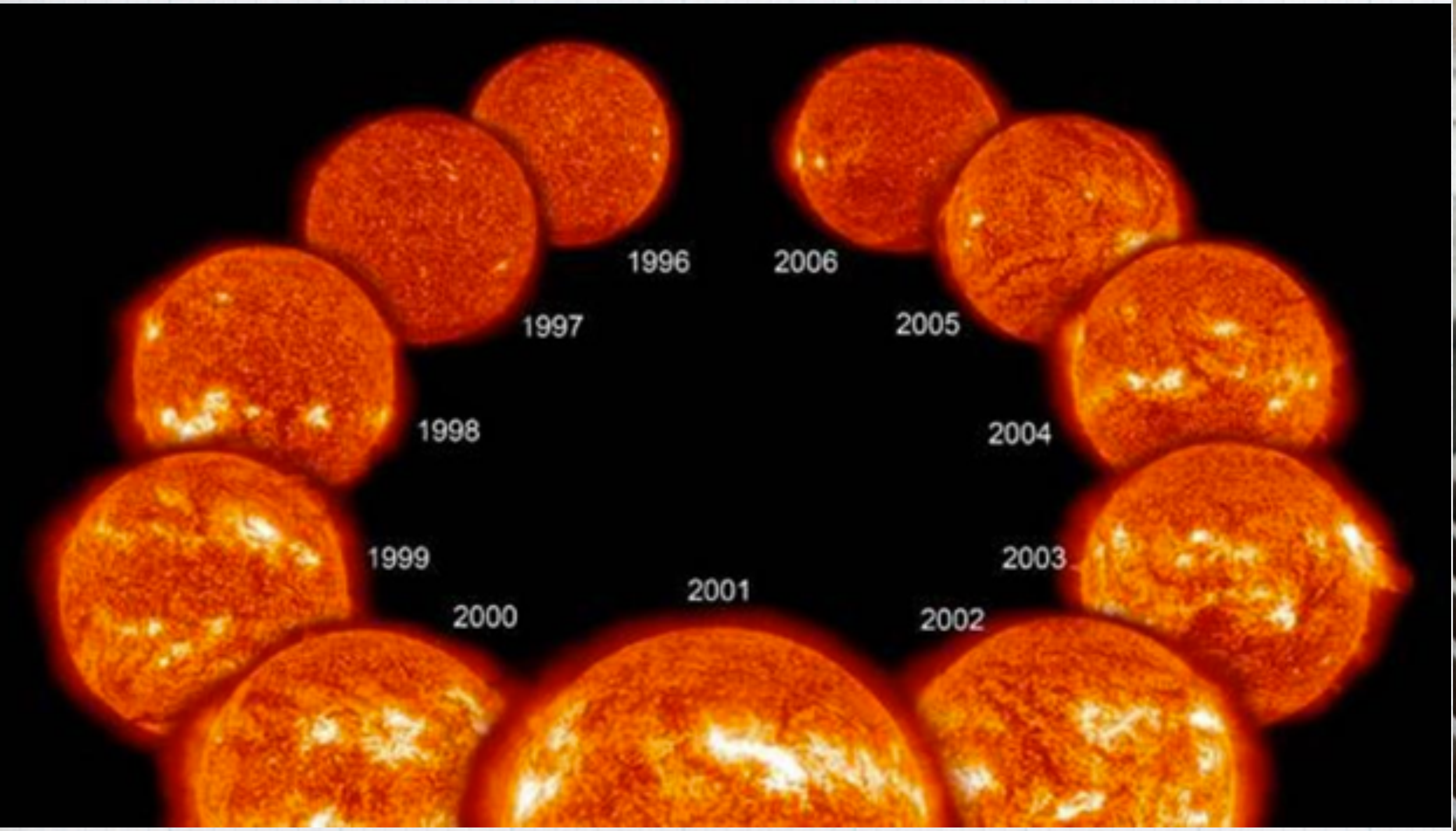
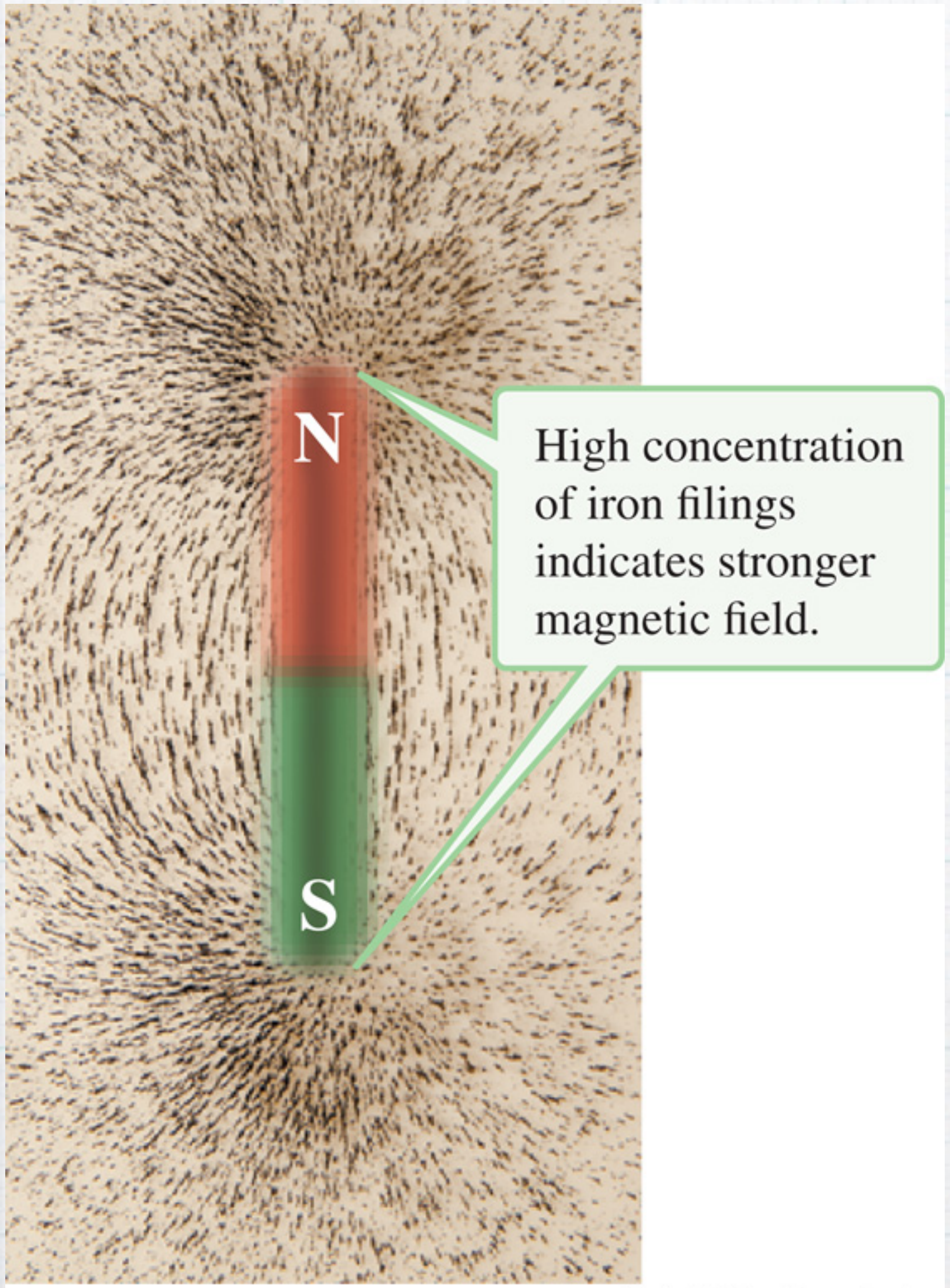
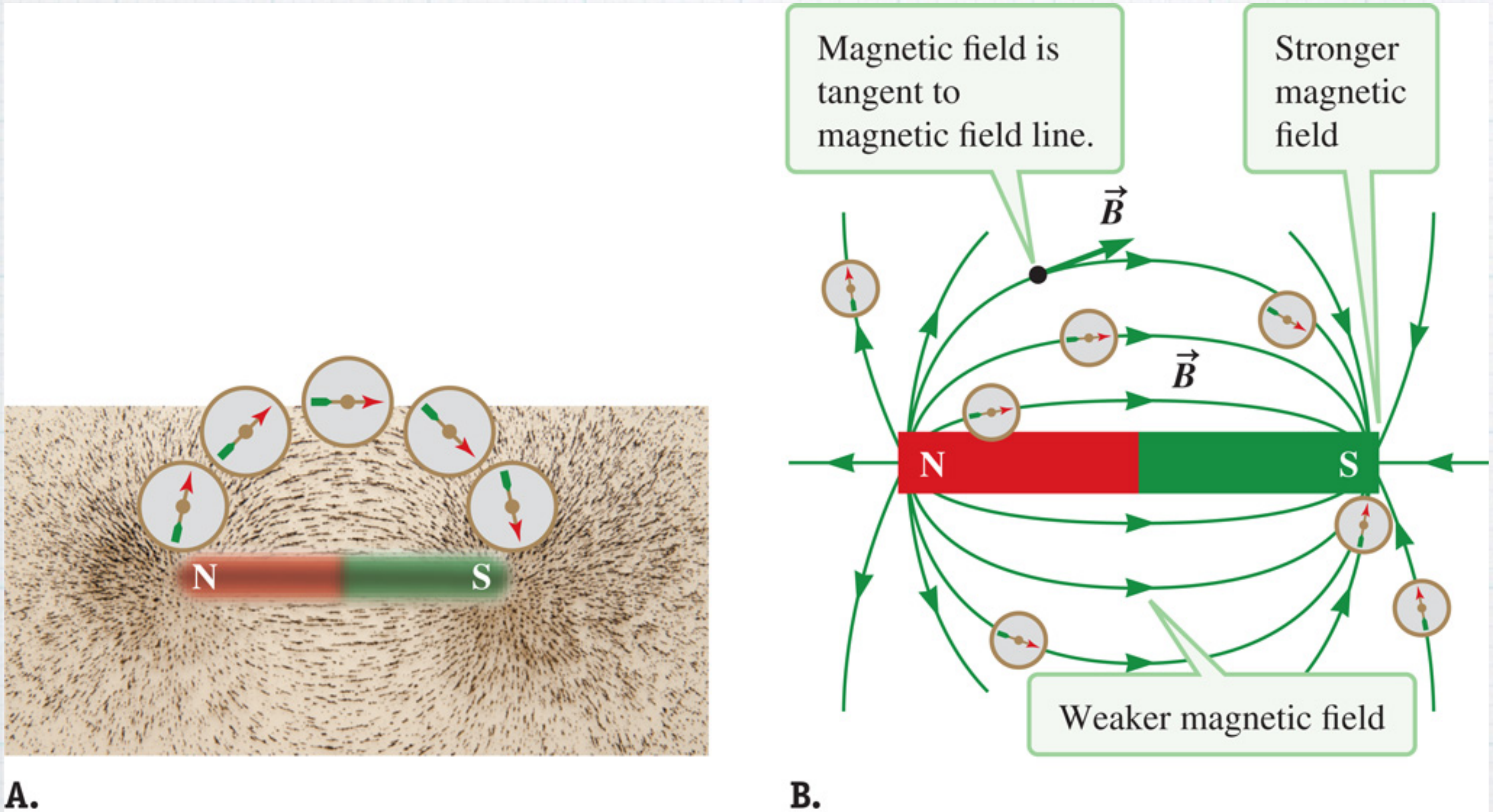
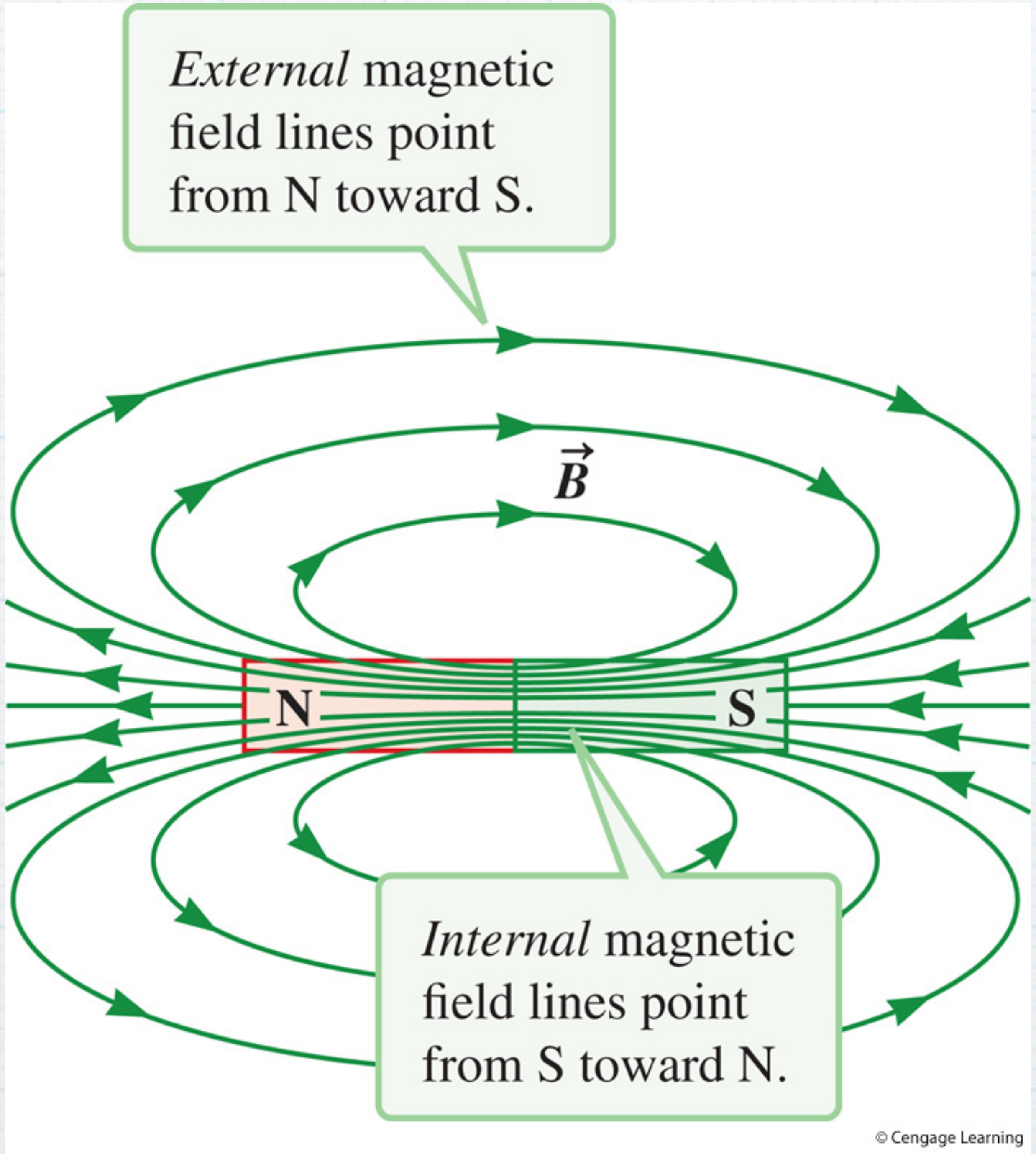
Magnetic Fields and Forces



Dr. Jenny Spinner /St. Joseph's University


N
S
High concentration of iron filings indicates stronger magnetic field.


N
S
A.
Magnetic field is tangent to magnetic field line.
Stronger magnetic field
$\vec{B}$
$\vec{B}$
N
S
Weaker magnetic field
B.


External magnetic field lines point from N toward S.
$\vec{B}$
N
S
Internal magnetic field lines point from S toward N.
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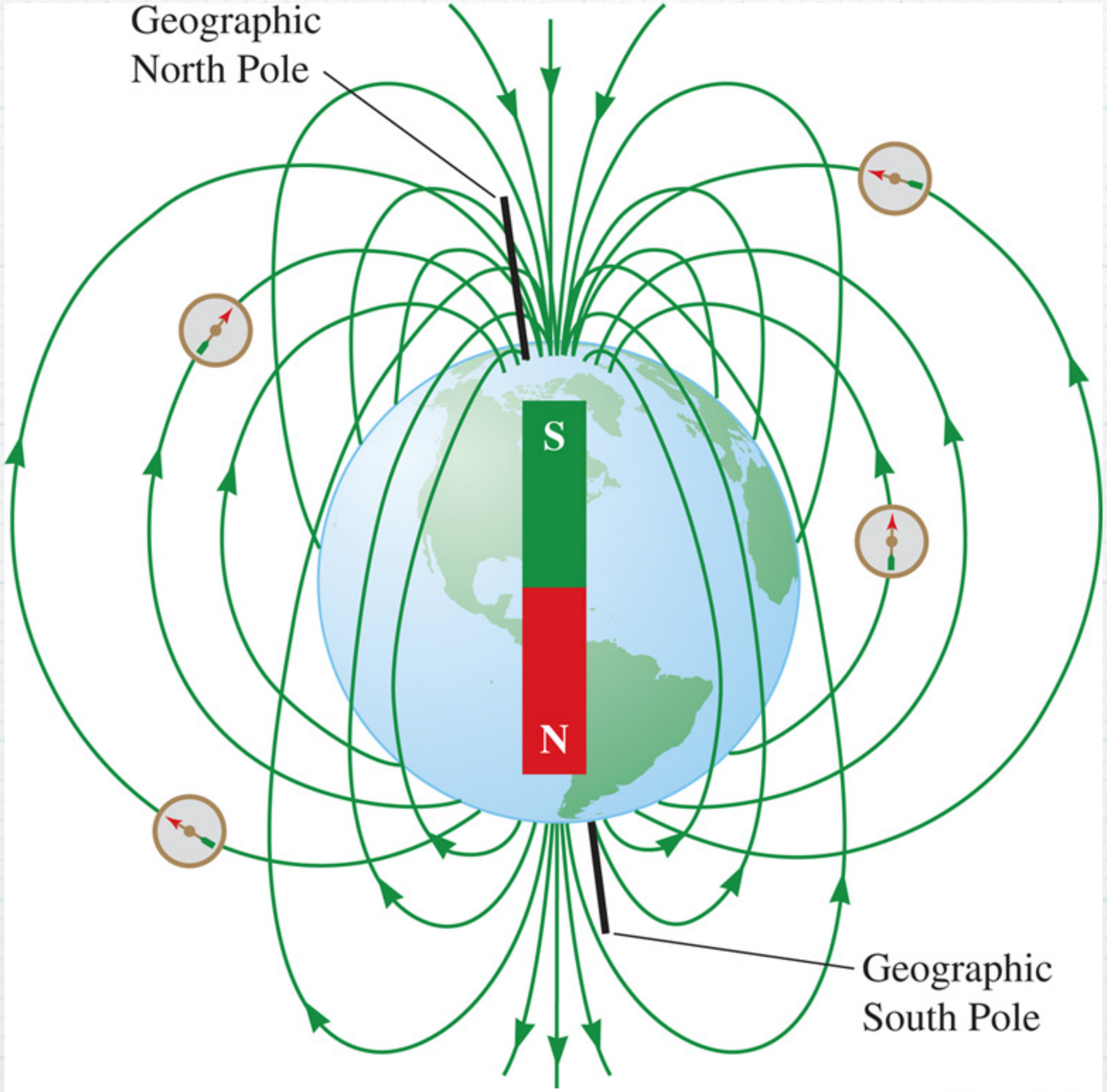
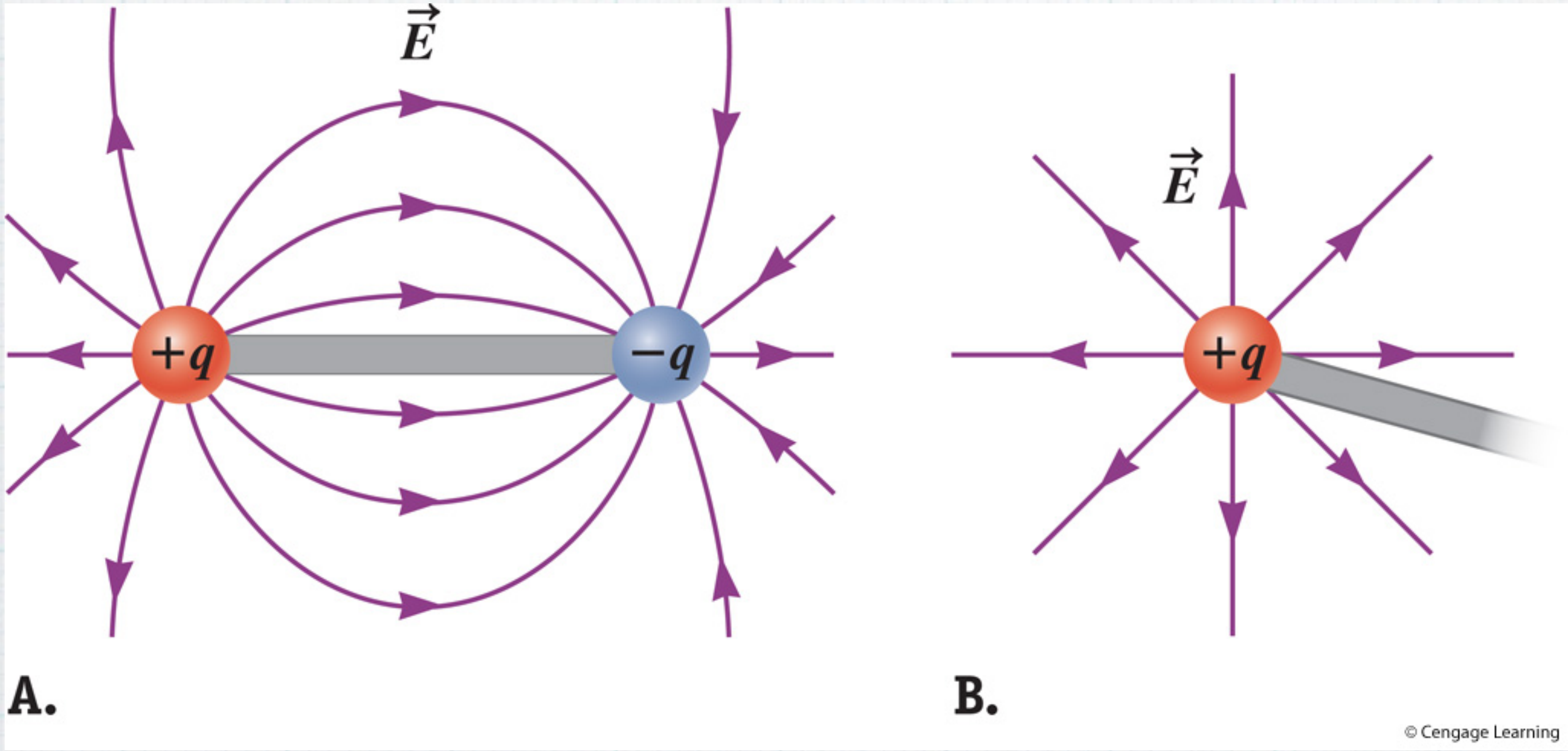

Geographic
North Pole
S
N
Geographic
South Pole



$\vec{E}$
+q
−q
A.
$\vec{E}$
+q
B.
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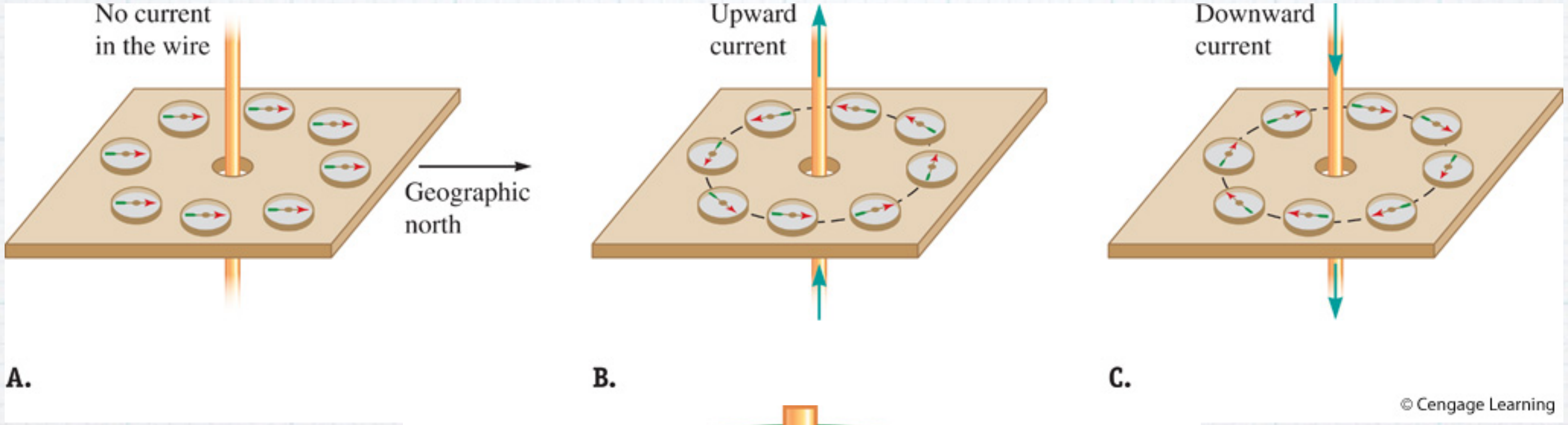
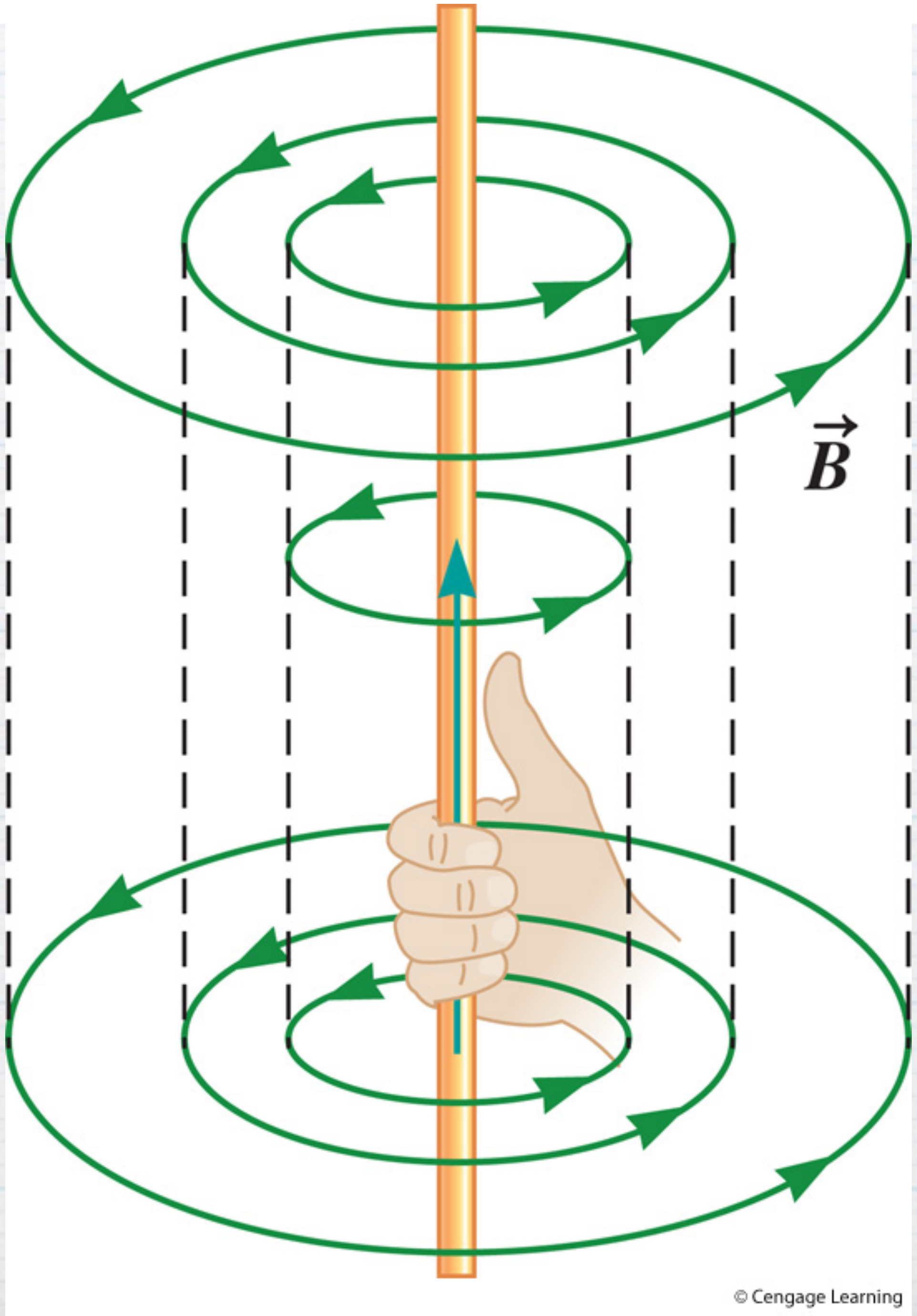
Currents make fields





* Right Hand Rule #1

Example

Typical Field Strengths

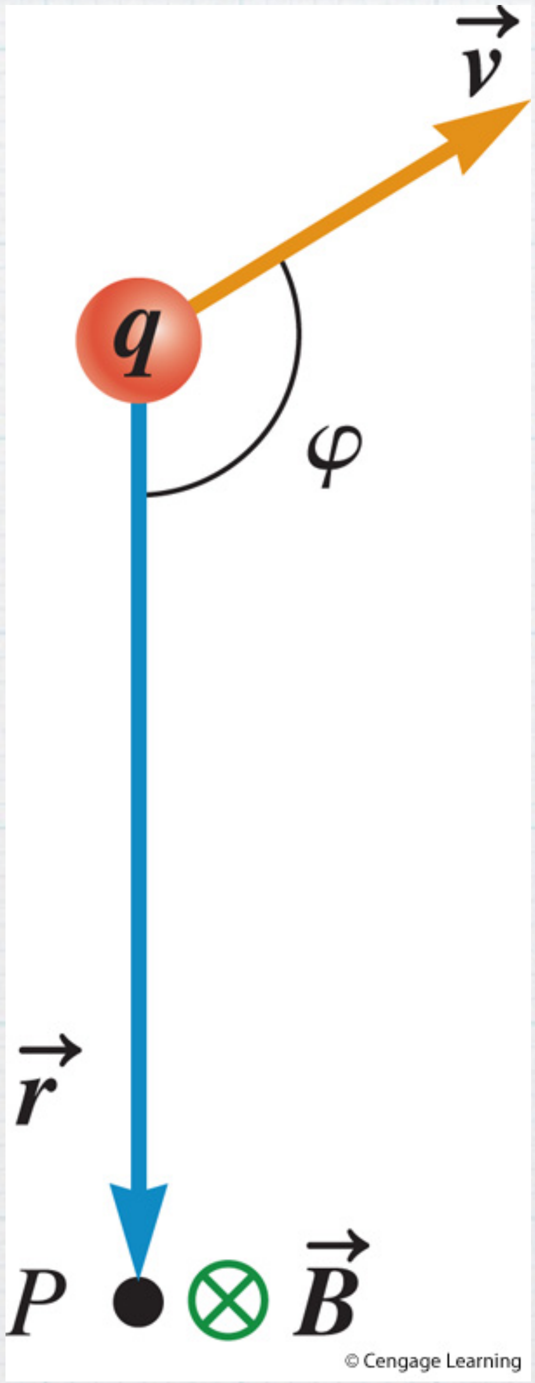
* The units of the magnetic field are Teslas
* Typical field strengths
    * Earth's magnetic field 5×10^{-5}T
    * Sun's magnetic field 2×10^{-4}T
    * Bar magnet 5×10^{-3}T
    * World's strongest magnet 45T
    * Neutron Star magnetic field 10^{8}T to 10^{9}T

Reading Question 30.5

A current moving upward along a vertical wire generates a magnetic field

a. Pointed upward
b. Pointed downwards
c. Clockwise around the wire
d. Counter-clockwise around the wire

Biot Savart Law



Field due to a moving charge

$$\vec{B} = \frac{\mu_0}{4\pi} q \frac{\vec{v} \times \vec{r}}{r^3}$$

$$|\vec{B}| = \frac{\mu_0}{4\pi} q \frac{|\vec{v}| sin\psi}{r^2}$$

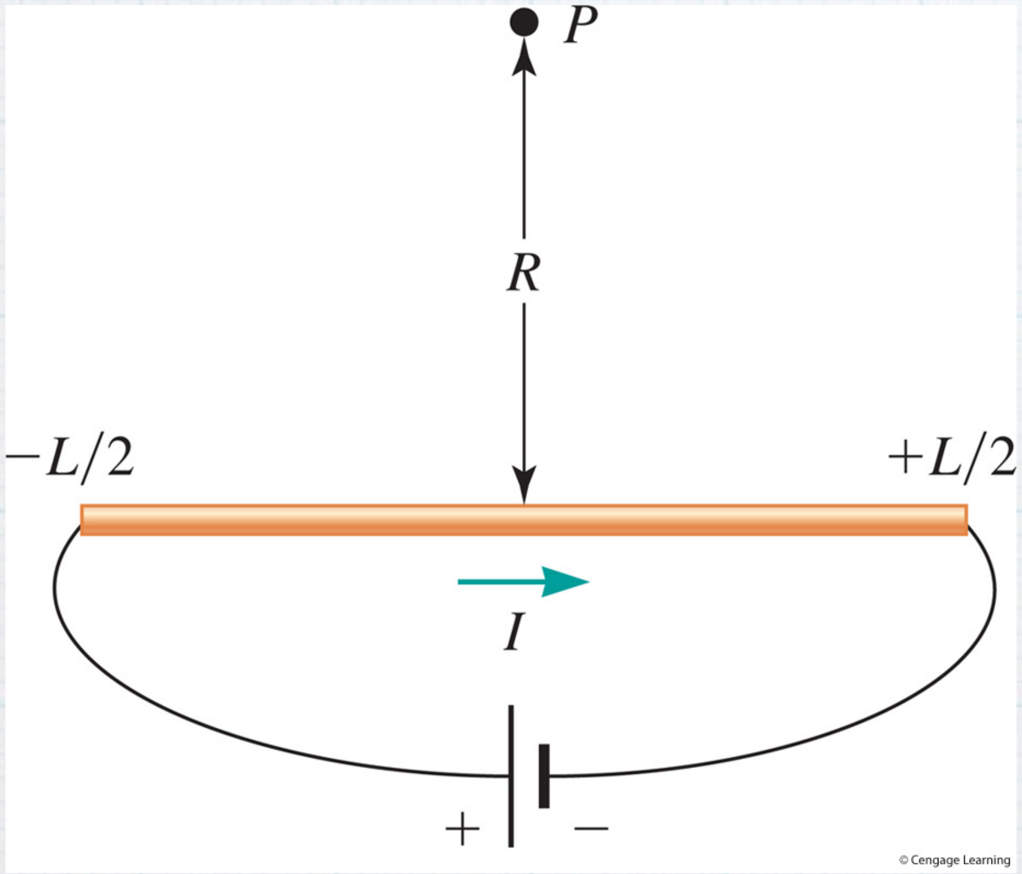
Permeability of free space

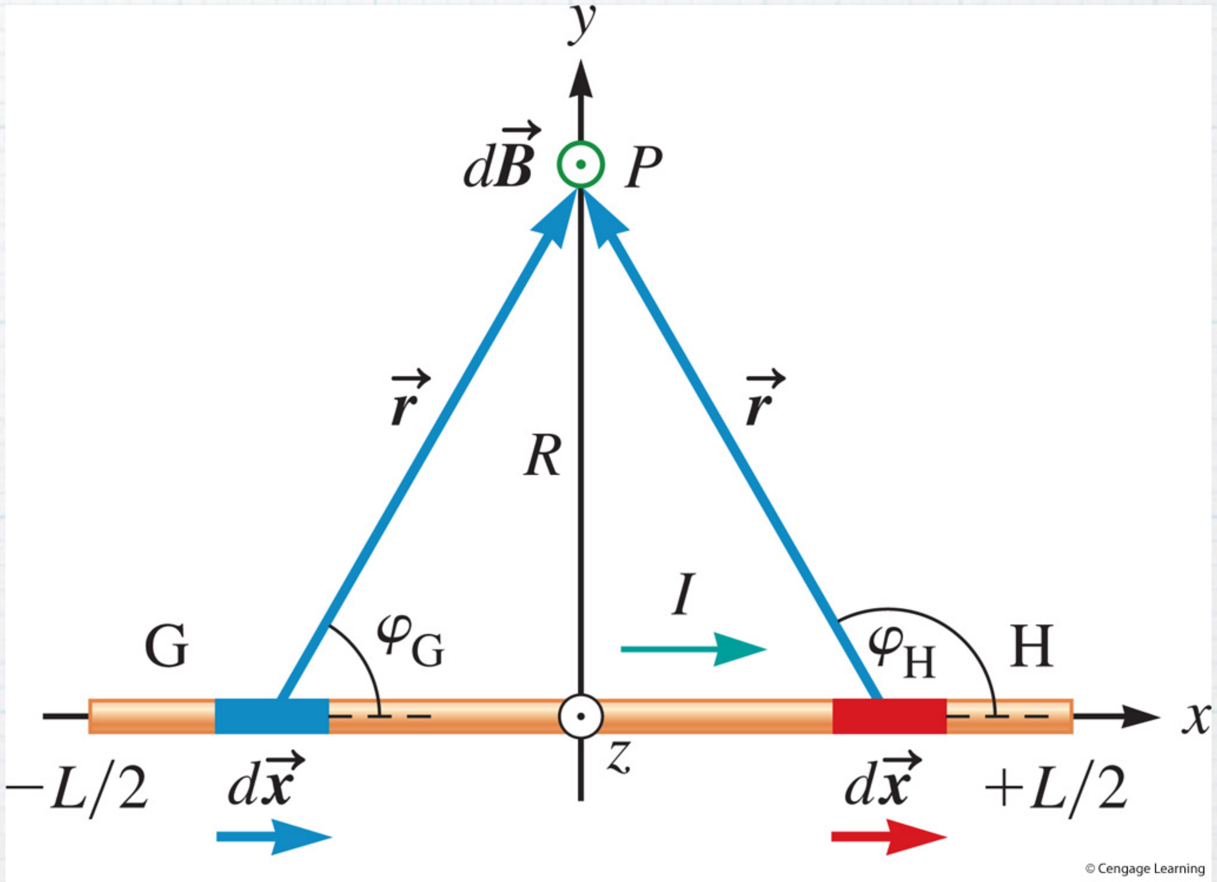
$$\mu_0 = 4\pi \times 10^{-7} \frac{T \cdot m}{A}$$

Example
field due to electron orbiting proton

Field of a long straight wire

$$d\vec{B} = \frac{\mu_0}{4\pi} I \frac{d\vec{l} \times \vec{r}}{r^3} \qquad |d\vec{B}| = \frac{\mu_0}{4\pi} I \frac{sin\psi}{r^2} dl$$

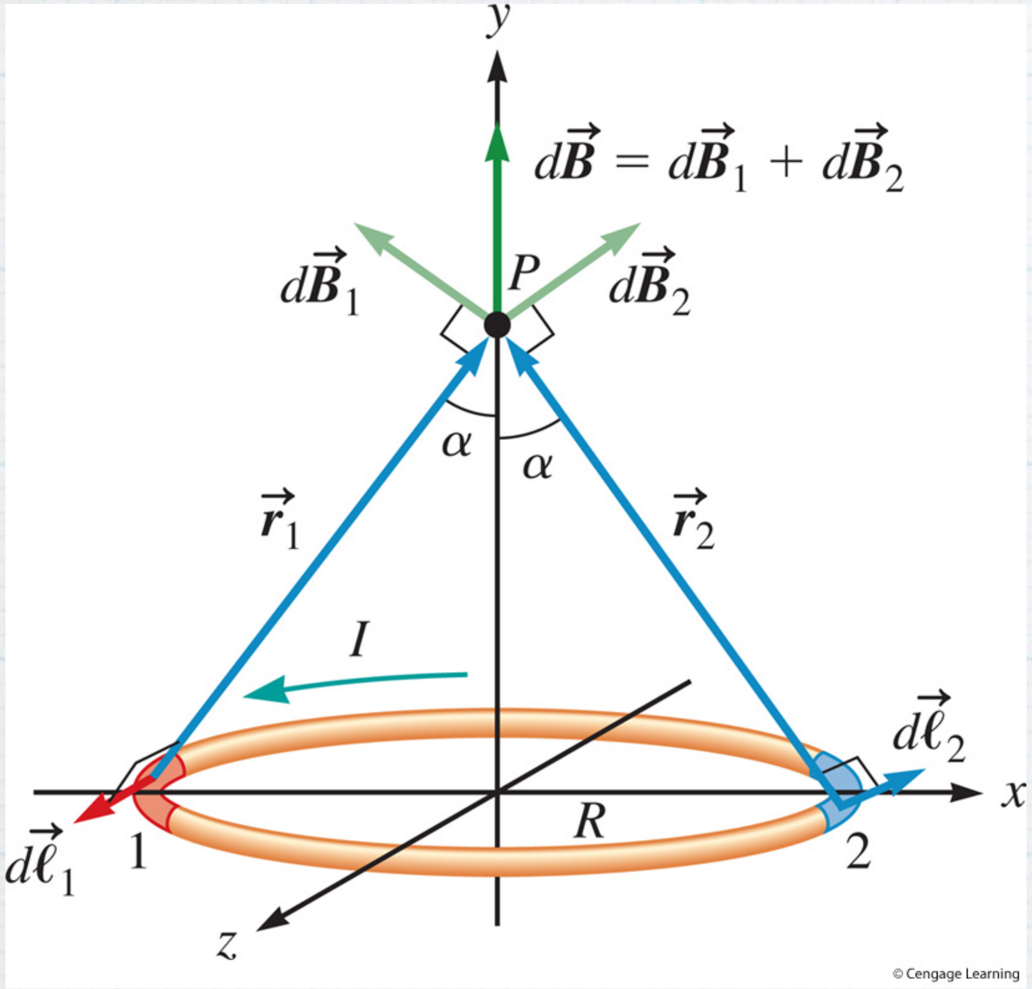




$$\vec{B} = \frac{\mu_0 I}{2\pi R}\left[\frac{L}{(L^2+4R^2)^{1/2}}\right]\hat{k}$$ For large L $$|\vec{B}| = \frac{\mu_0 I}{2\pi R}$$

Example

Magnetic field of a current loop



$$|\vec{B}| = \frac{\mu_0 I R^2}{2(R^2 + y^2)^{3/2}}\hat{j}$$

What is it at the center?

What is it 1cm and 1 m above?

What is it for Y >> R?

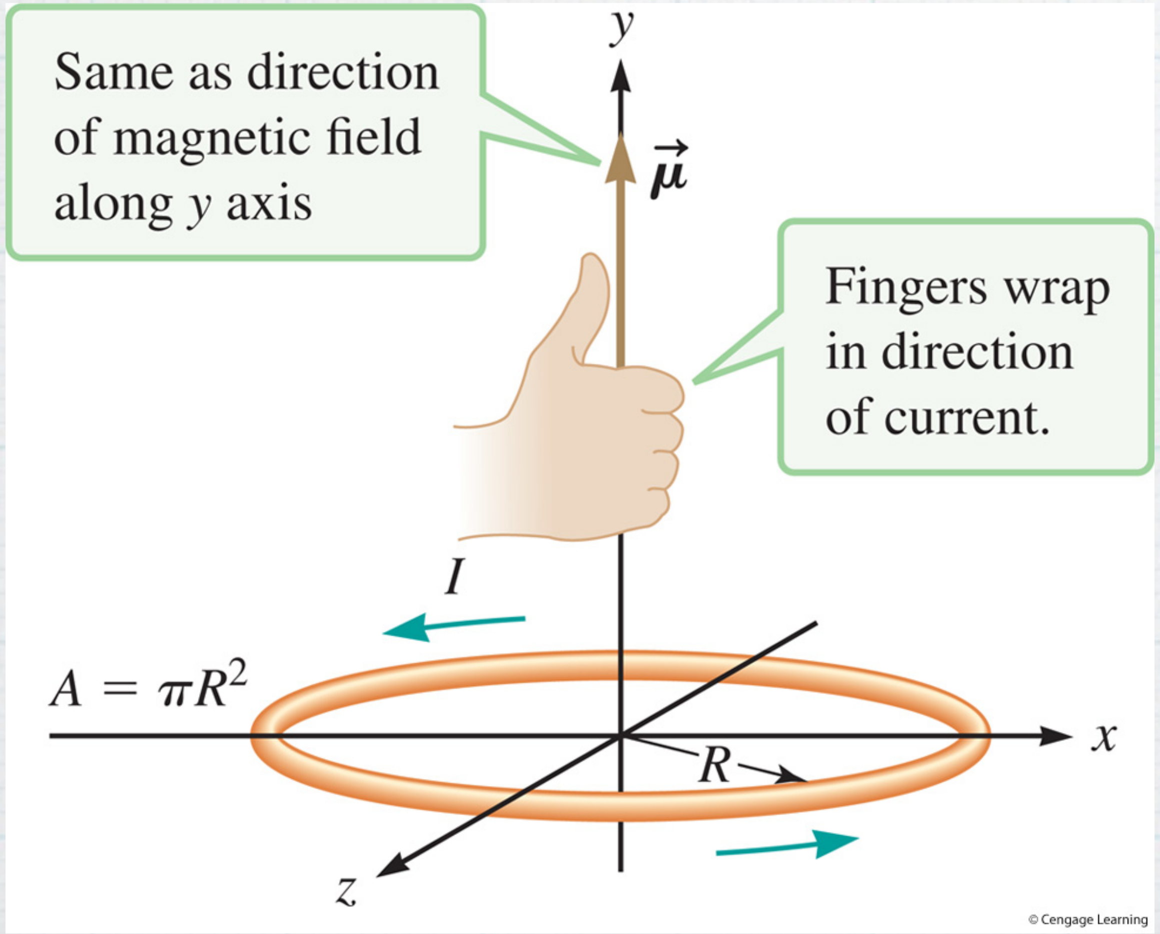
Magnetic Dipole Moment

Always

$$\mu = IA$$

For a current loop

$$y >> R \to \vec{B} = \frac{\mu_0 I R^2}{2y^3}\hat{j} \quad \text{and} \quad \mu = I\pi R^2$$

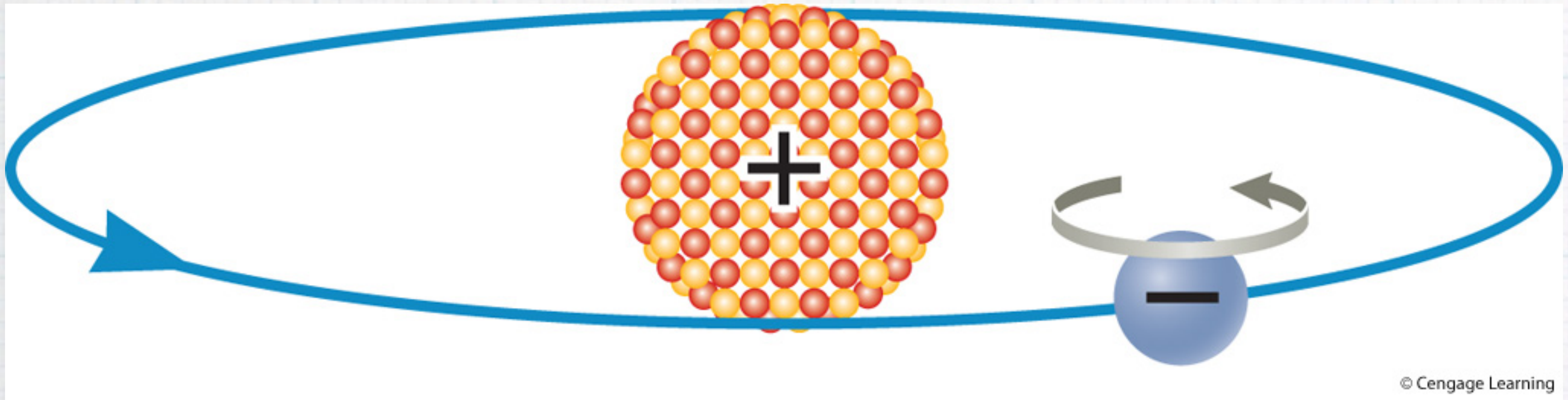


$$\vec{\mu} = I\pi R^2\hat{j}$$

$$\vec{B} = \frac{\mu_0}{2\pi}\frac{\vec{\mu}}{y^3}$$

Example

Atoms


+
−
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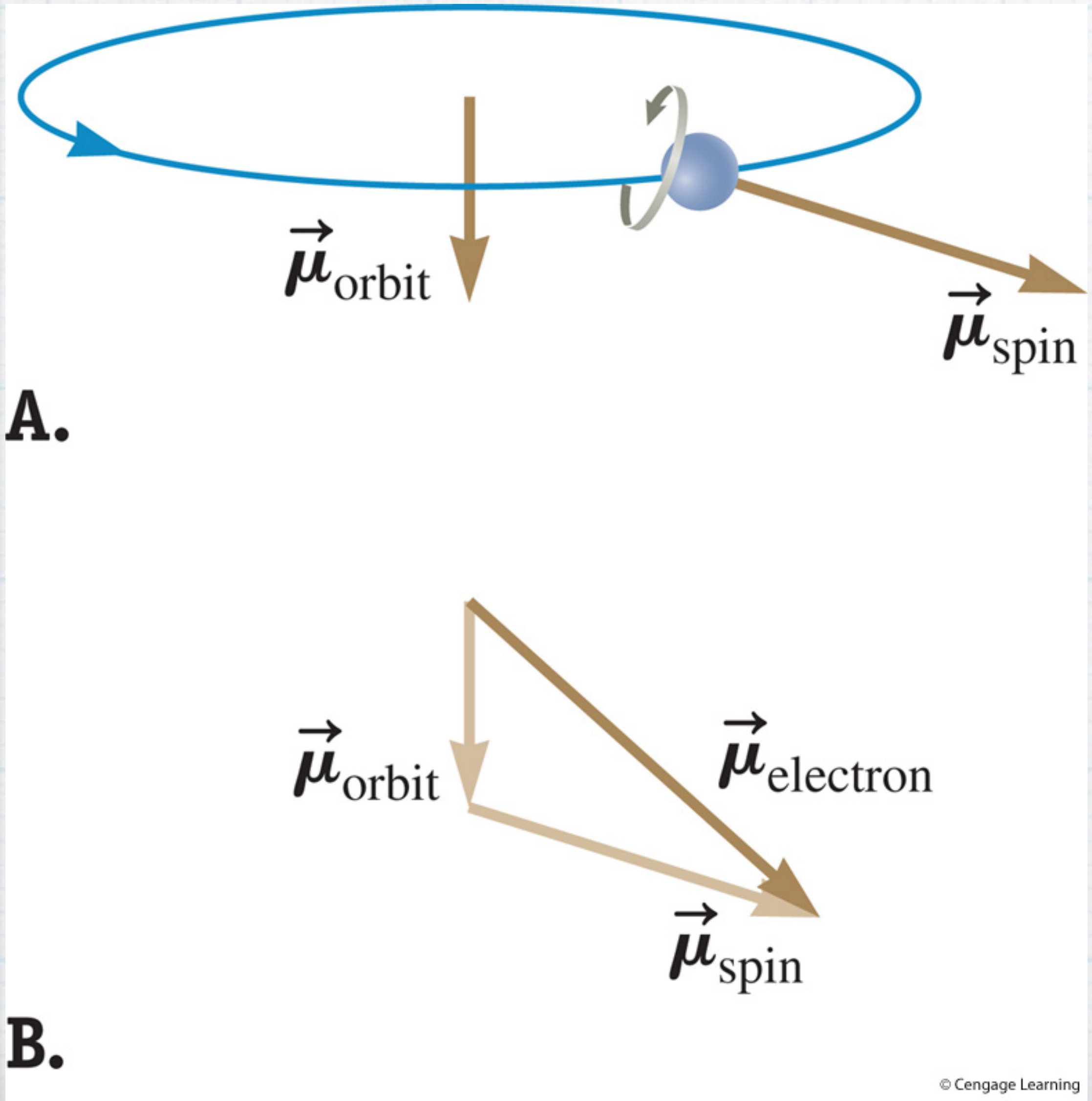
$\vec{\mu}_{orbit}$
$\vec{\mu}_{spin}$
A.
$\vec{\mu}_{orbit}$
$\vec{\mu}_{electron}$
$\vec{\mu}_{spin}$
B.
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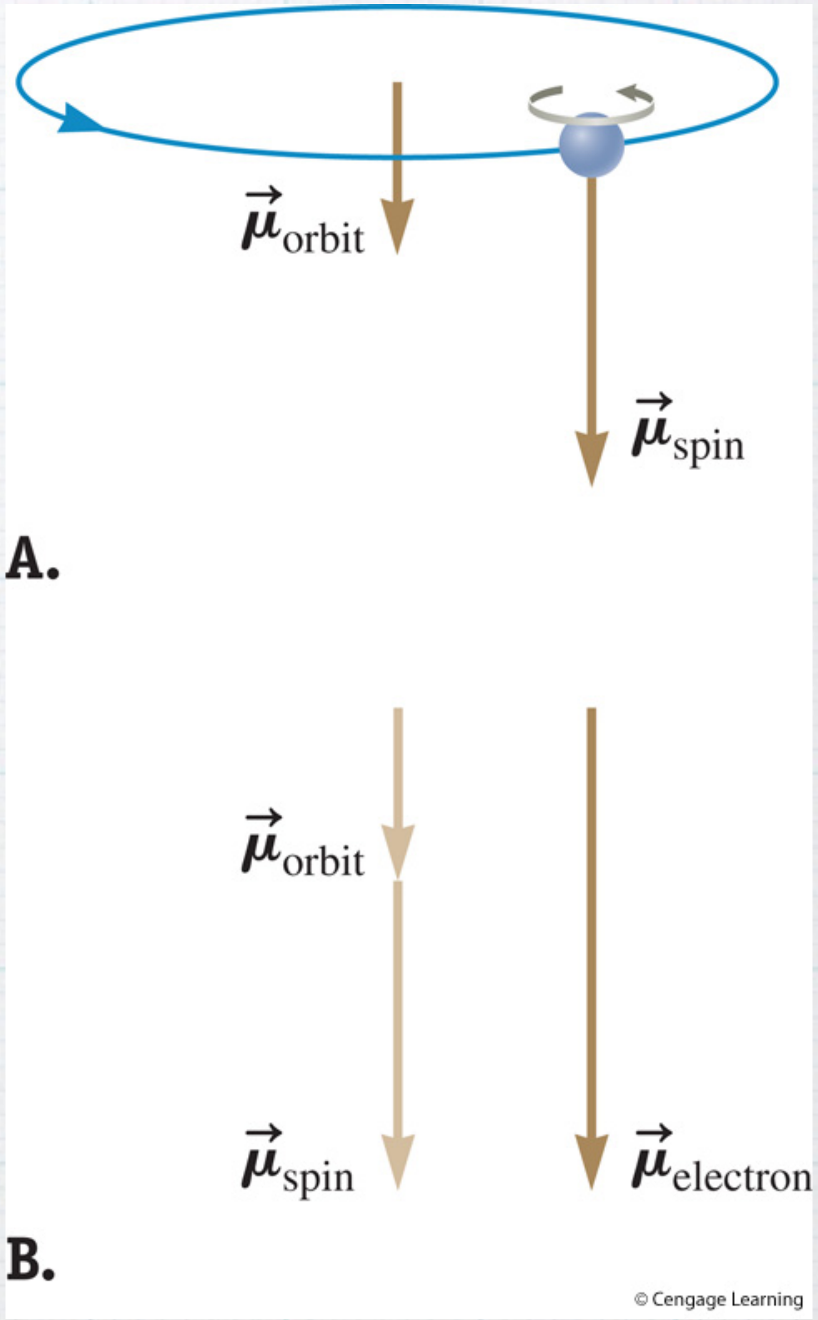
$\vec{\mu}_{orbit}$
$\vec{\mu}_{spin}$
A.
$\vec{\mu}_{orbit}$
$\vec{\mu}_{spin}$
$\vec{\mu}_{electron}$
B.
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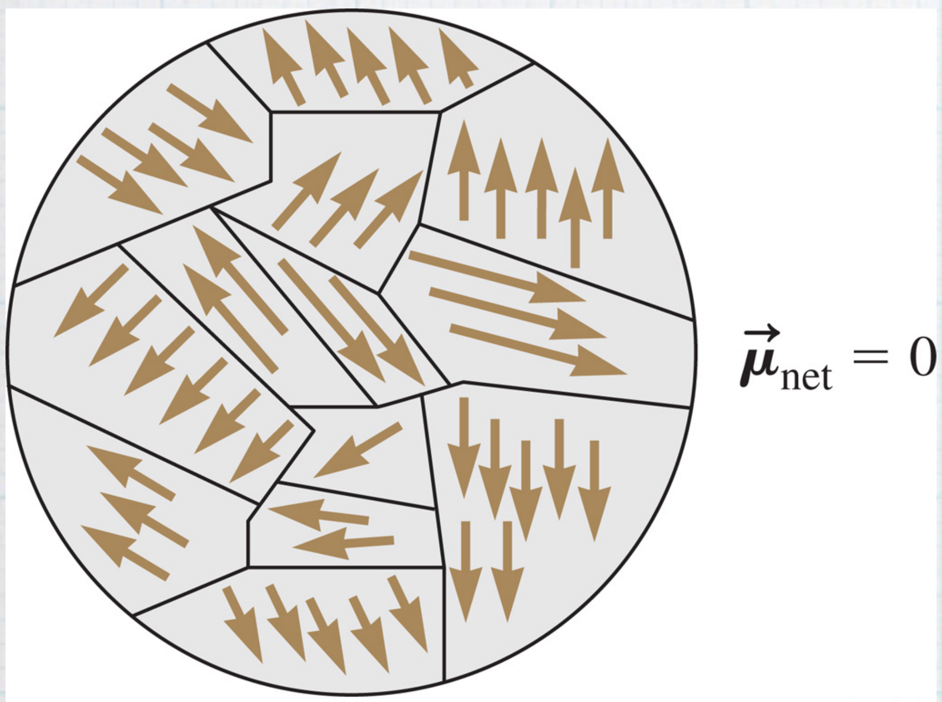
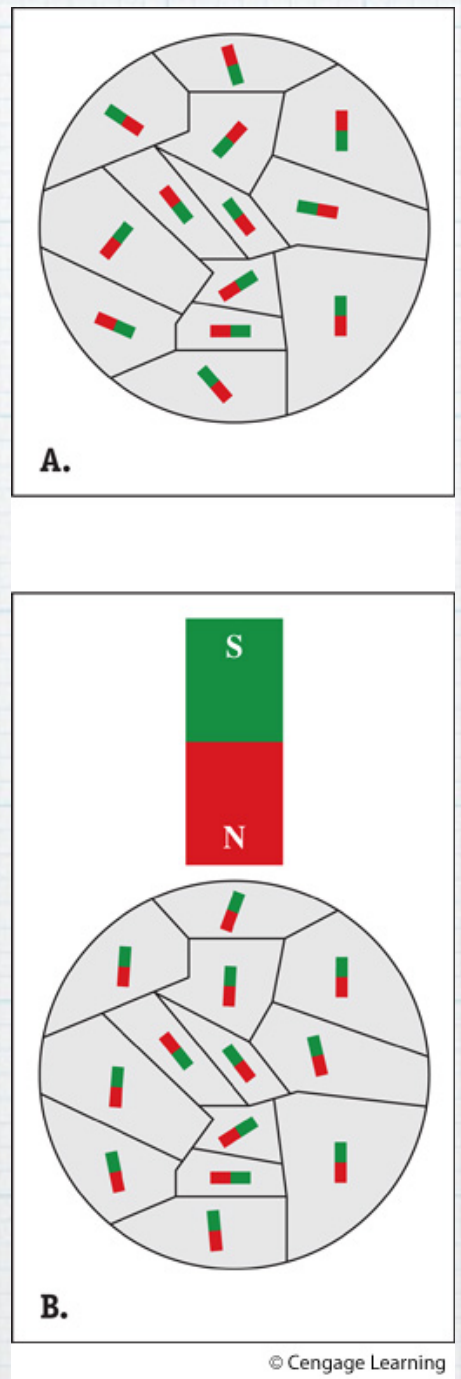
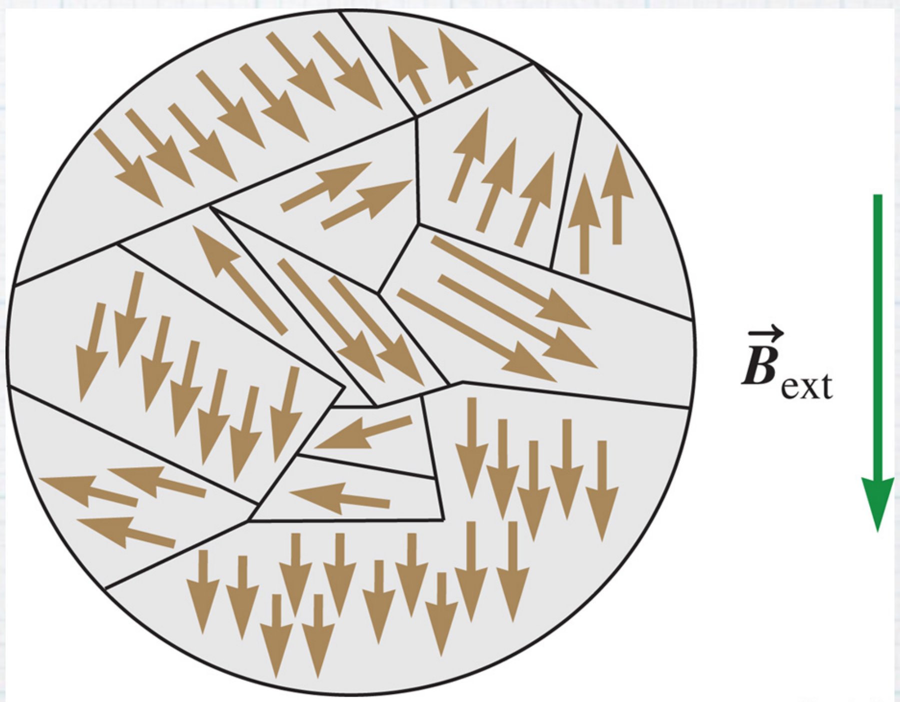
Example

Ferromagnetic material







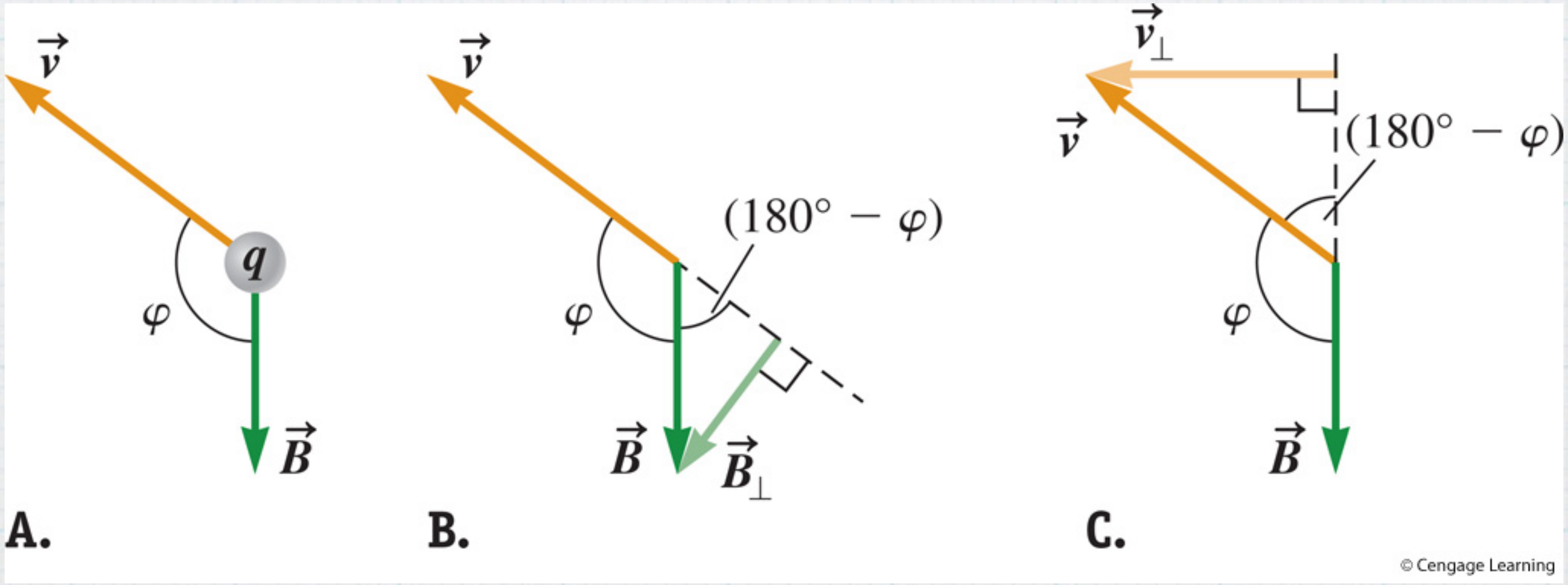
Magnetic Force on a Charged Particle

The magnetic force is a TURNING force

$$\vec{F}_B = q(\vec{v} \times \vec{B})$$

$$|\vec{F}_B| = |q|(|\vec{v}||\vec{B}|sin\psi)$$

$$|\vec{F}_B| = |q|(|\vec{v}||\vec{B}_\perp|)$$



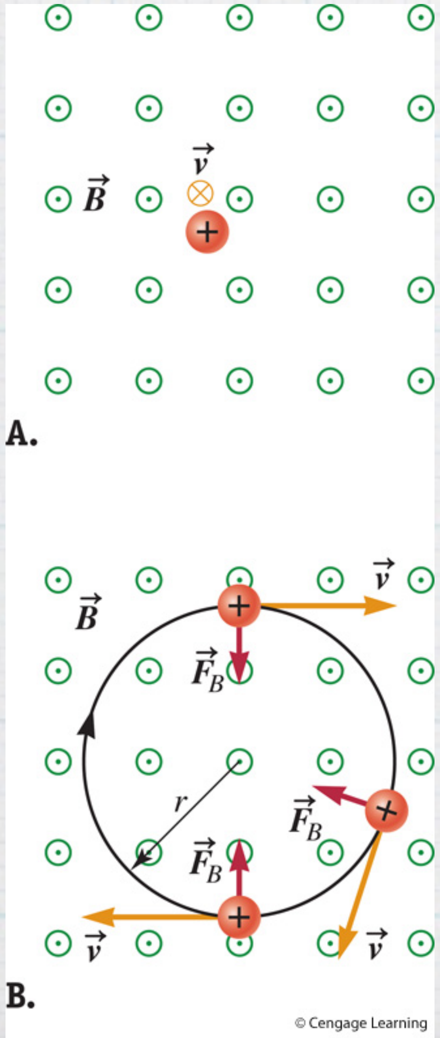
Right Hand Rule #2 and examples

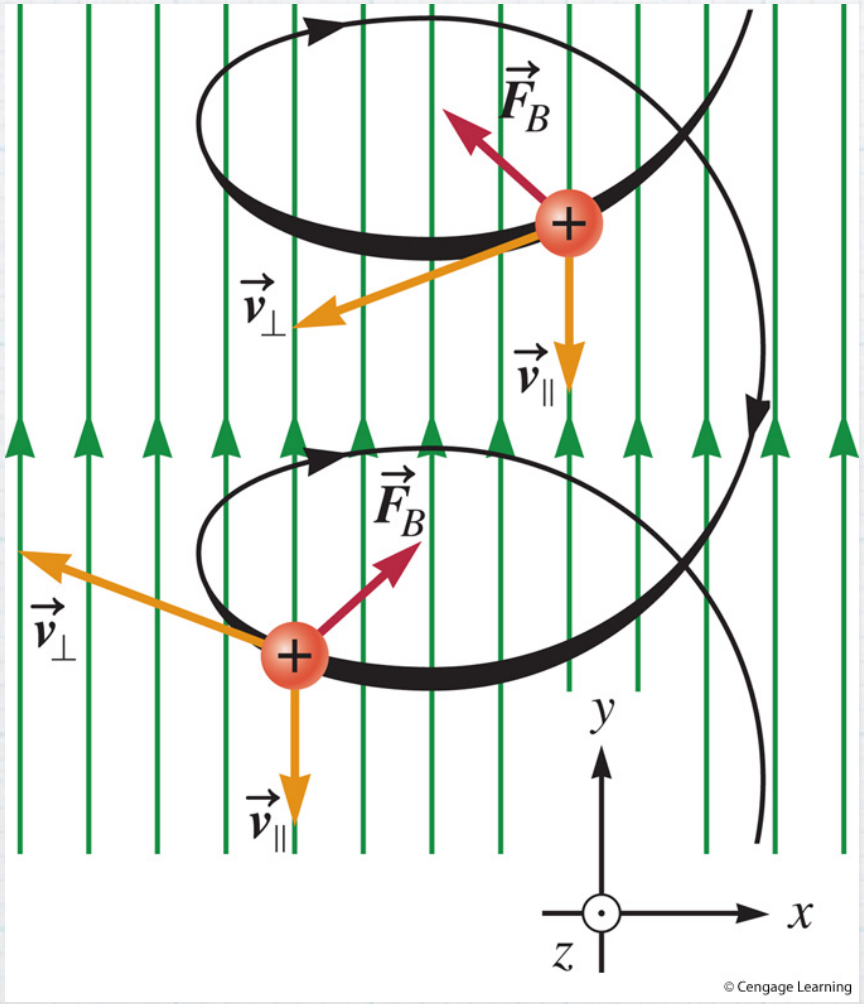
* Only the perpendicular component matters
* Let's look at a few cases
* Let's calculate a few cases

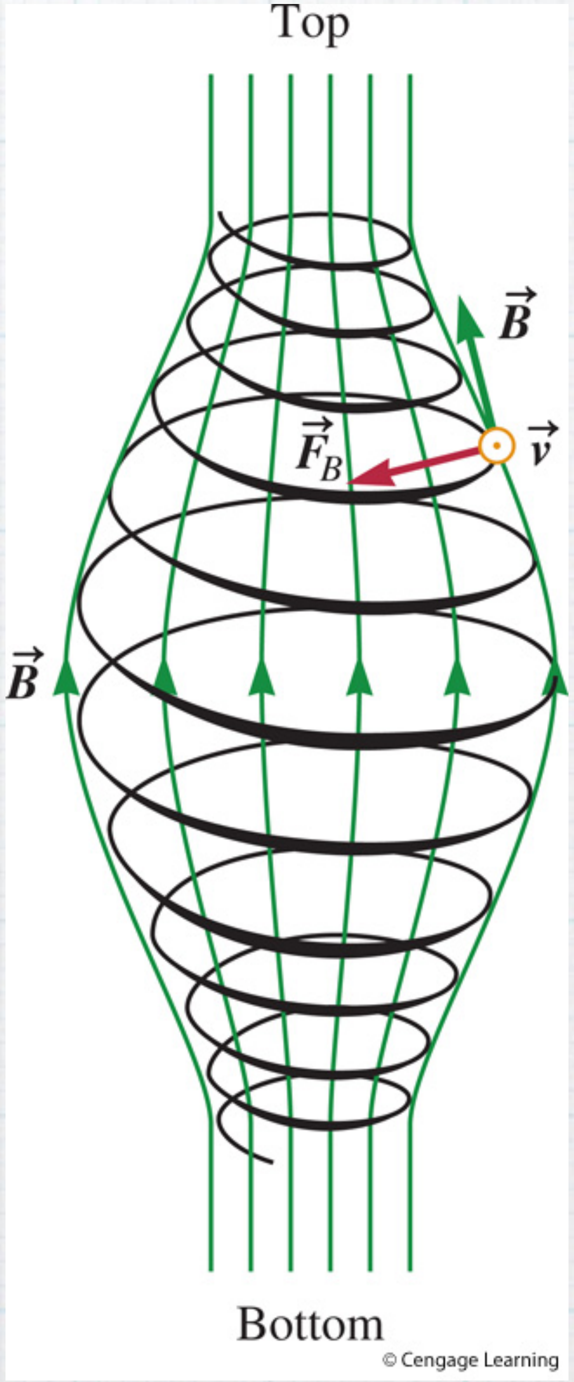
Lorentz Force

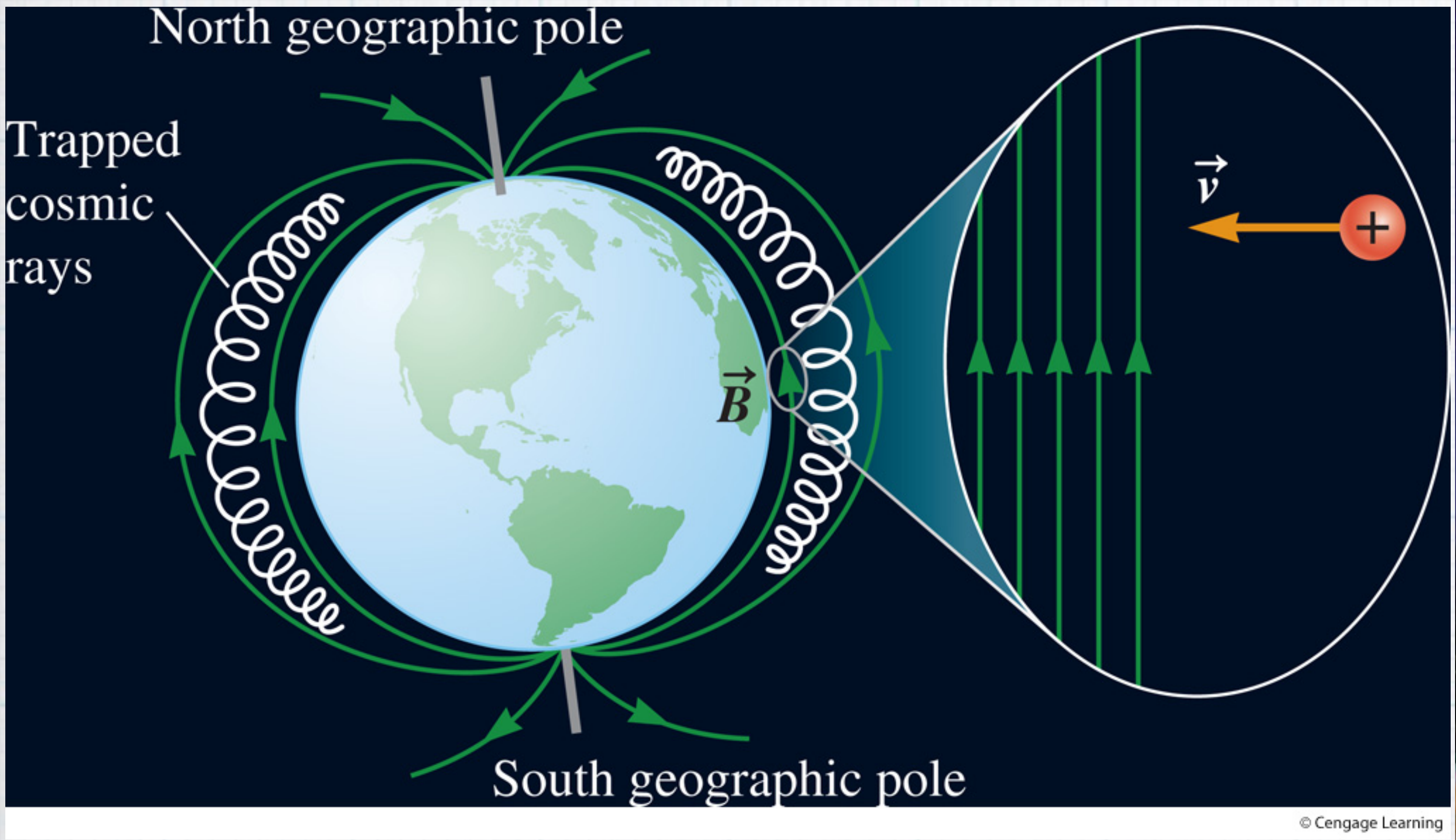
$$\vec{F}_L = \vec{F}_E + \vec{F}_B = q(\vec{E} + \vec{v} \times \vec{B})$$

* Let's do a few qualitative and quantitative examples








North geographic pole
Trapped cosmic rays
$\vec{B}$
$\vec{v}$
+
South geographic pole
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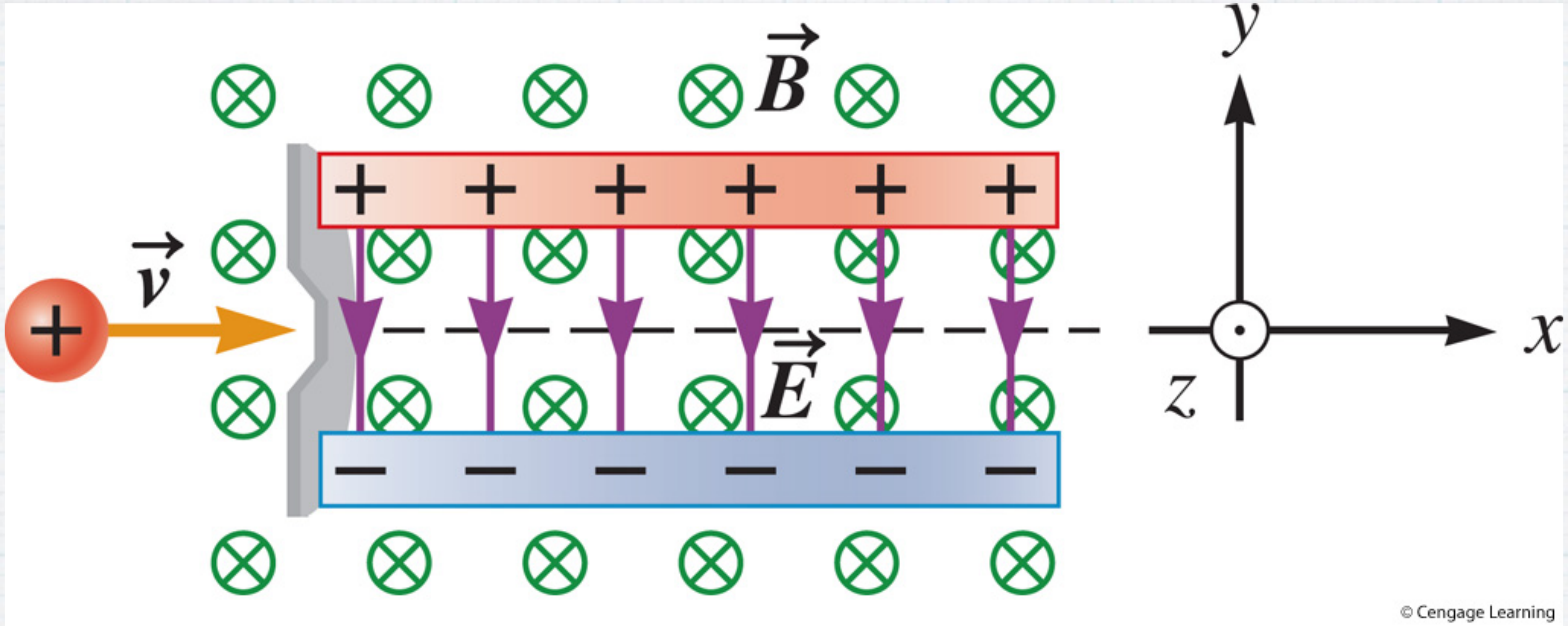
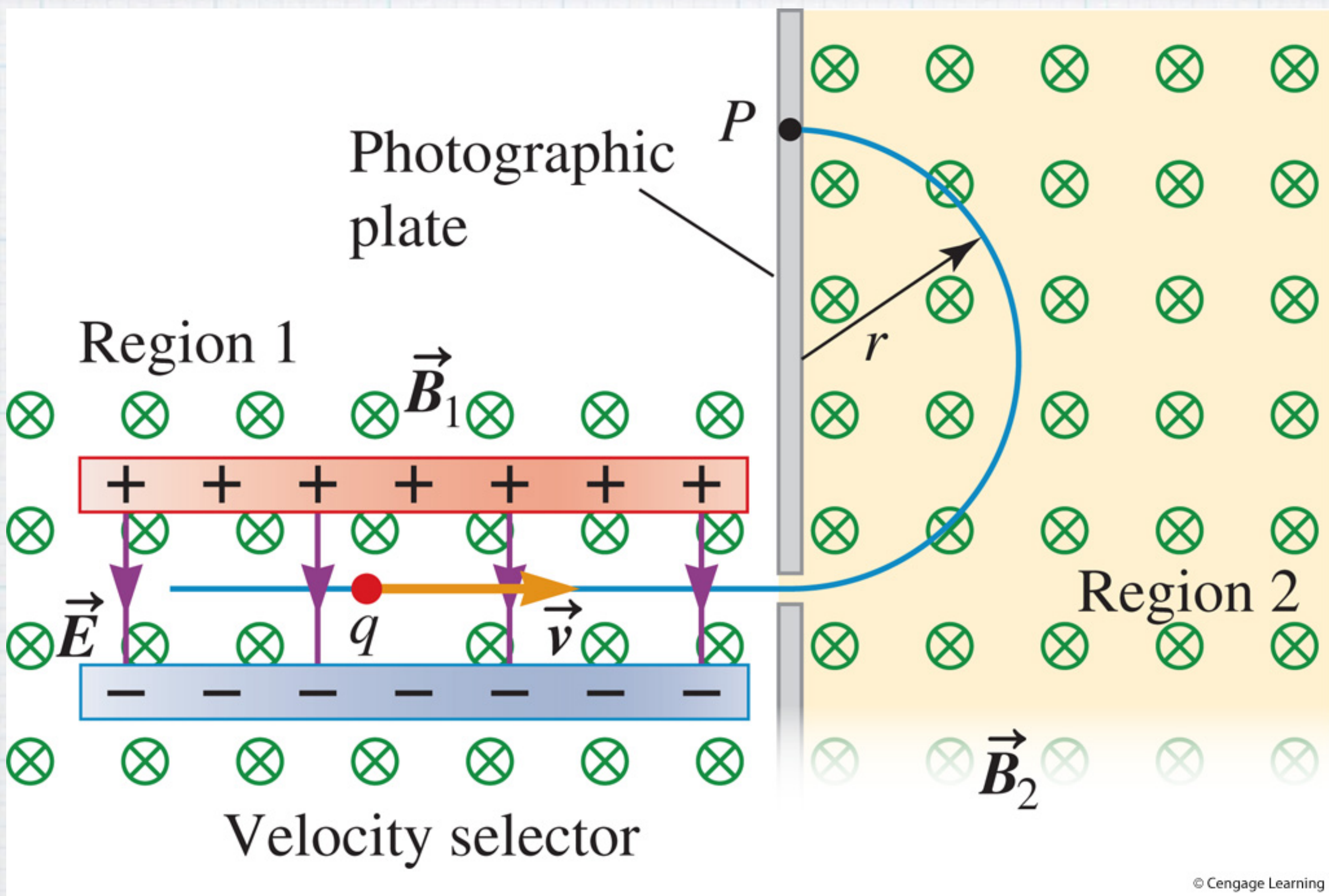




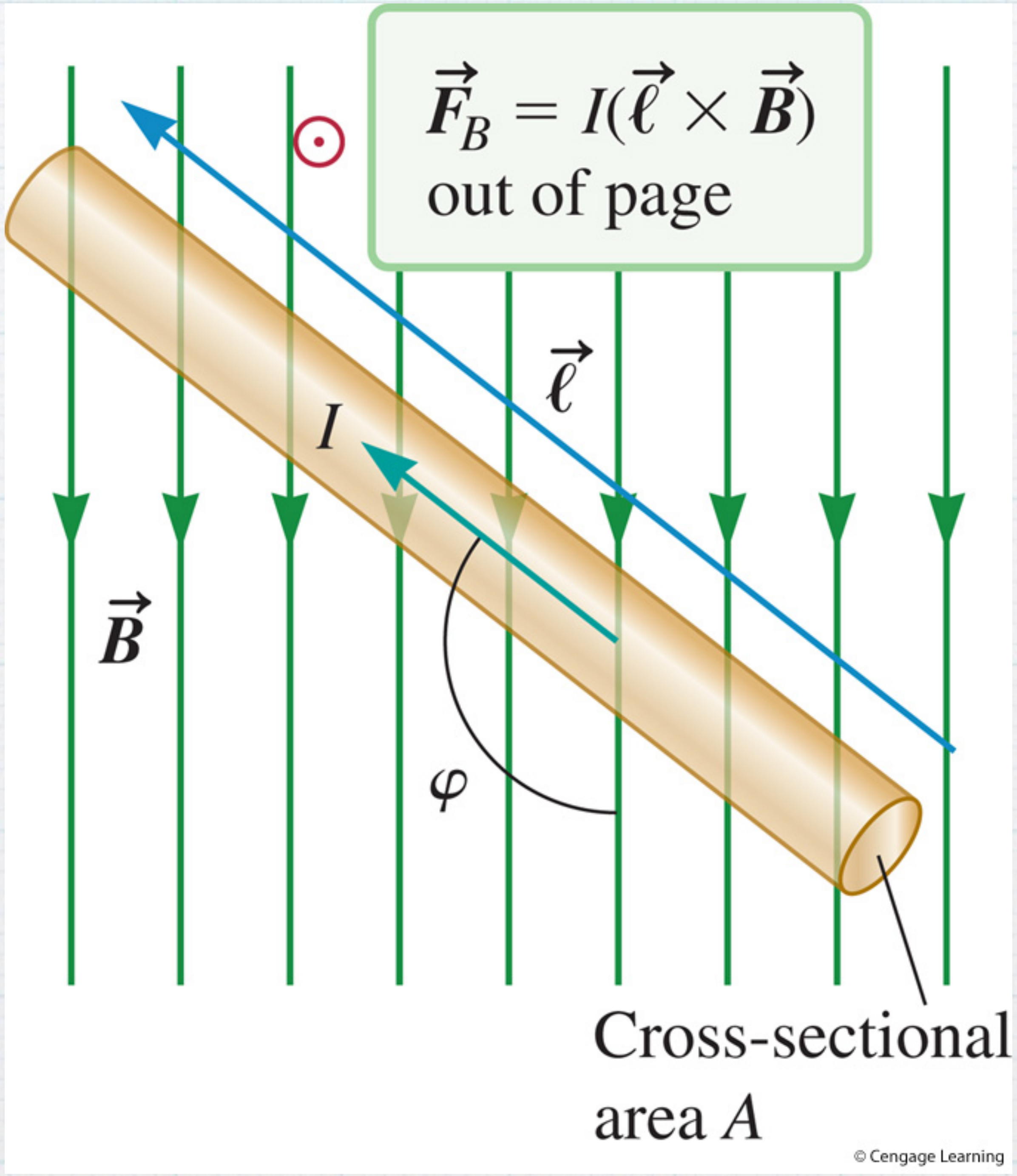
Mass Spectrometer

Reading Question 30.6

A magnetic field can only _____ the velocity of a moving charged particle. It can _____

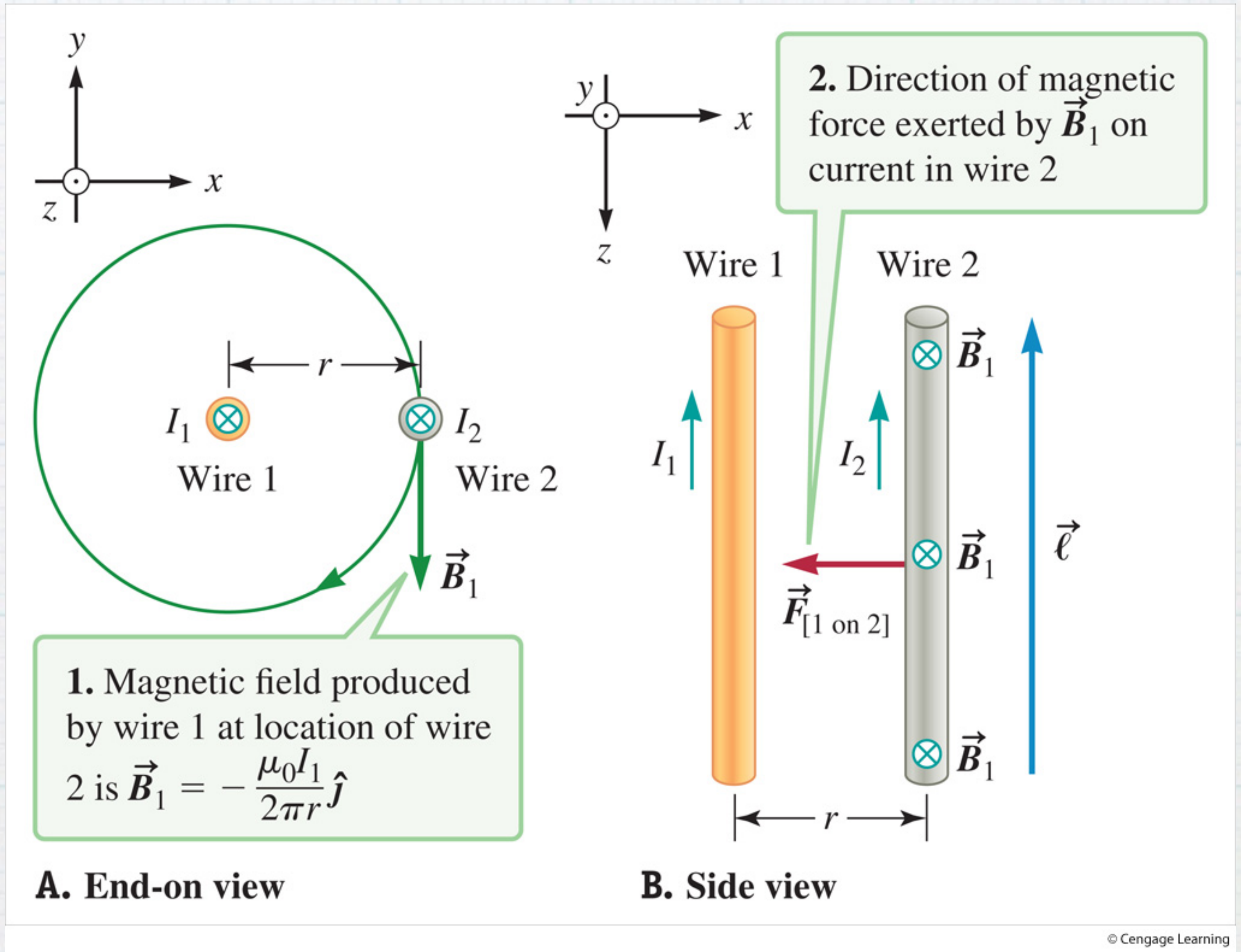
a. Accelerate, not decelerate
b. Change the direction of, change the kinetic energy
c. Accelerate, not do work
d. Change the direction of, do no work.

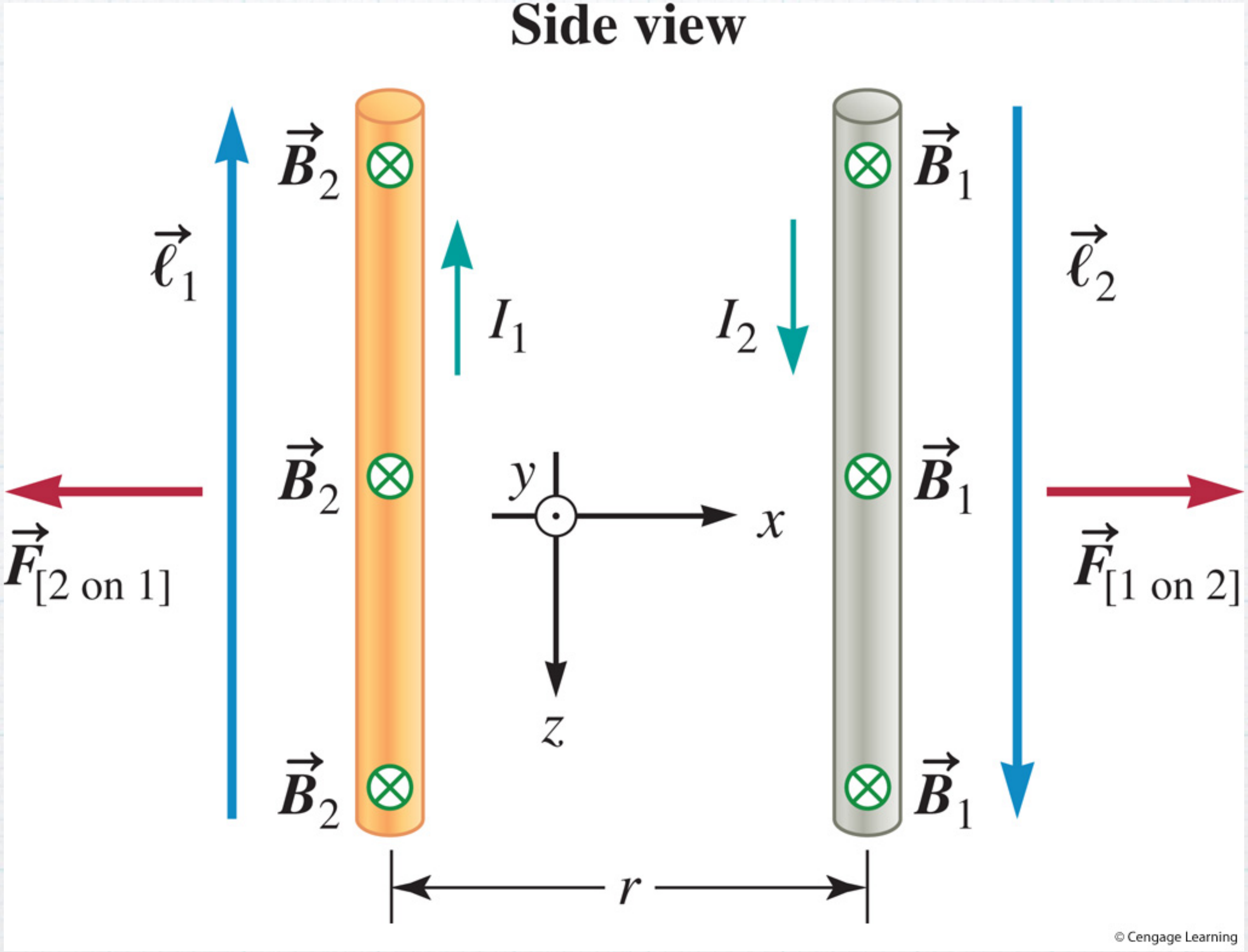
Force on a current carrying wire



Force Between Two Long, Straight Wires

* The magnitude is given by
* $$\vec{F}_{1-2} = \frac{\mu_0}{2\pi}\frac{I_1 I_2 l}{r}$$
* Let's see if we can reason out the direction




Side view
$\vec{B}_2$
$\vec{B}_2$
$\vec{B}_2$
$\vec{B}_1$
$\vec{B}_1$
$\vec{B}_1$
$\vec{\ell}_1$
$\vec{\ell}_2$
I_1
I_2
y
x
z
$\vec{F}_{[2 \text{ on } 1]}$
$\vec{F}_{[1 \text{ on } 2]}$
r
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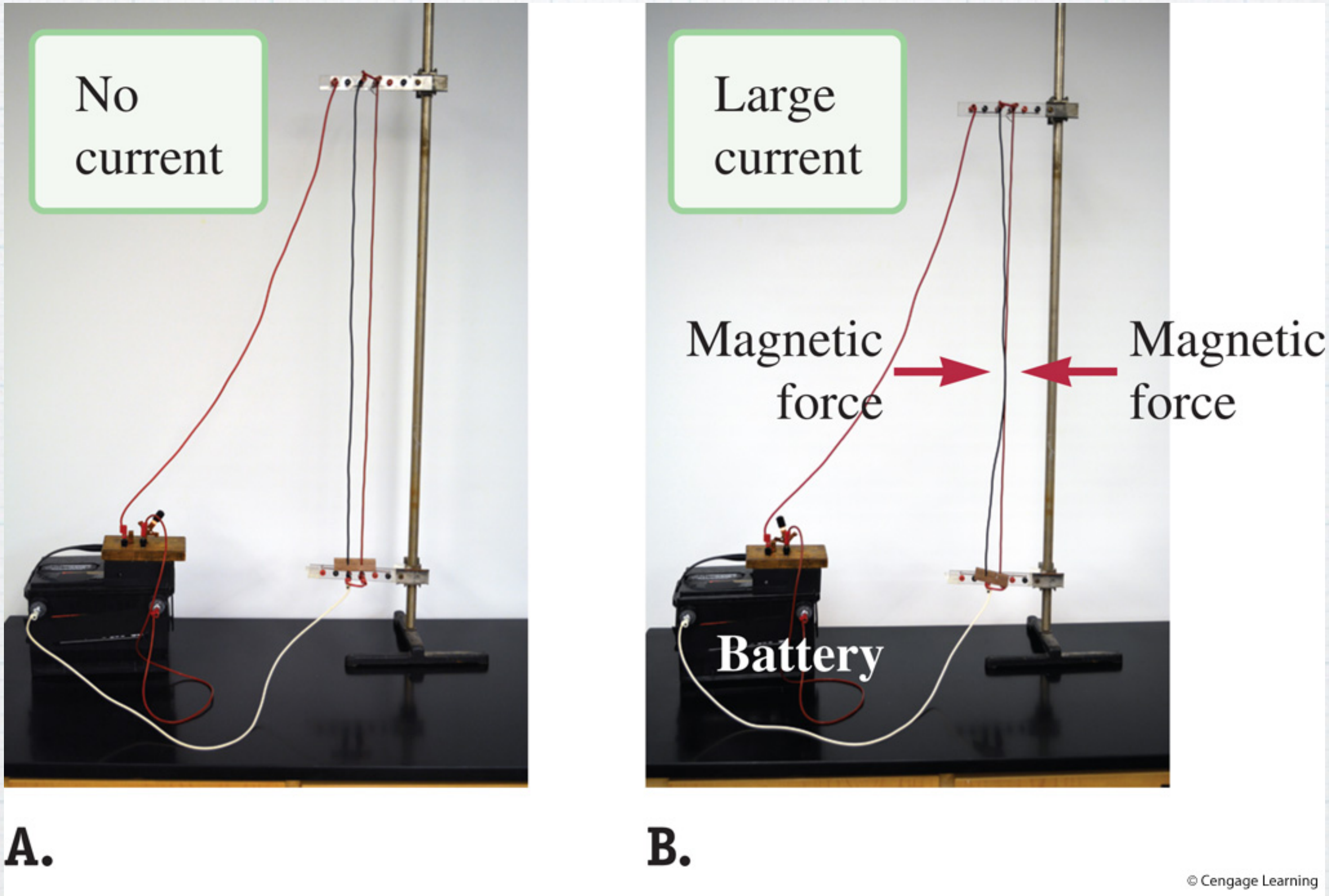
Example


No current
Large current
Magnetic force
Magnetic force
Battery
A.
B.
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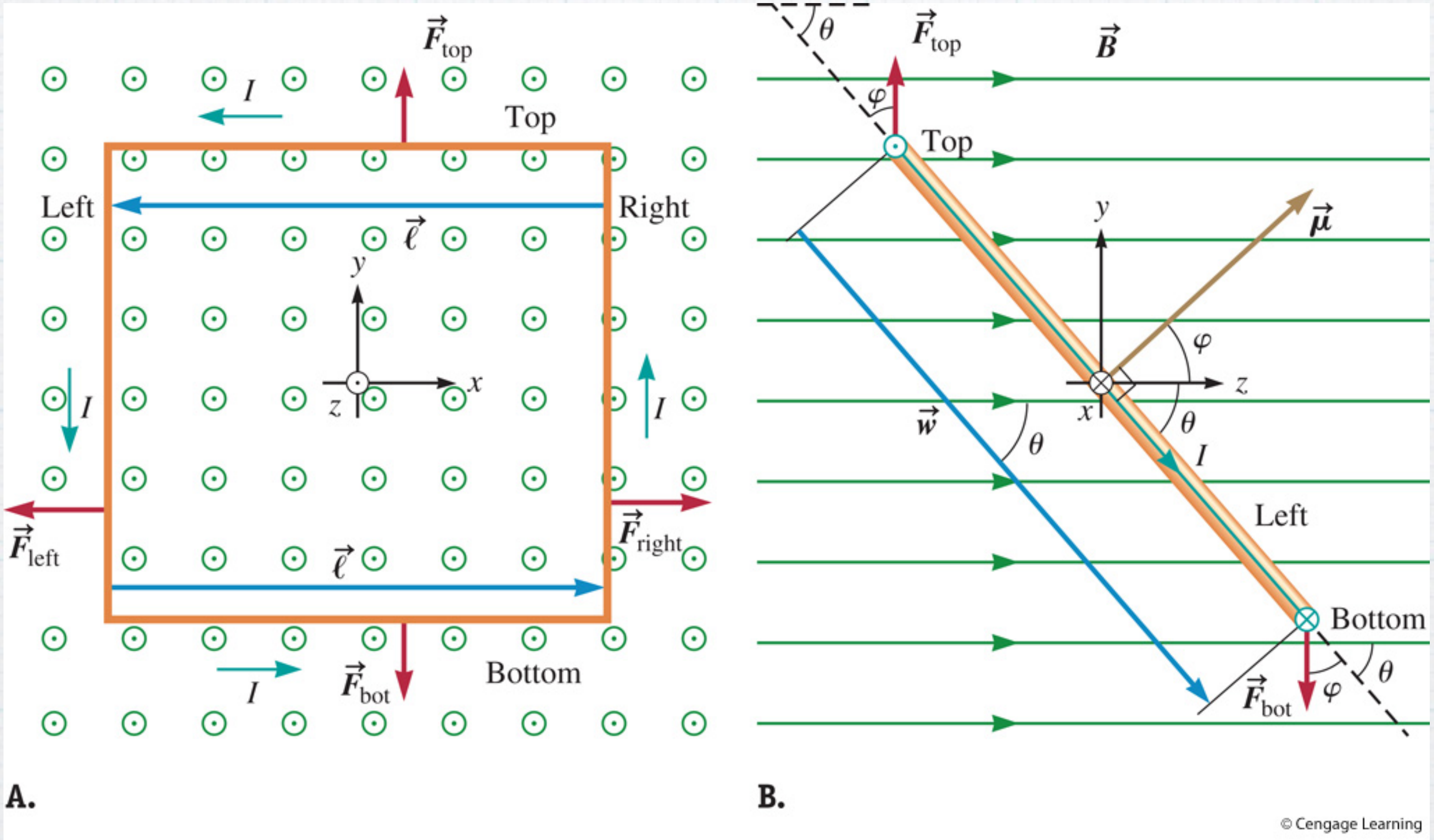
Torque on a Current Loop in a Magnetic Field



Torque

* When field is perpendicular to plane
* When field is parallel to plane
* In between?
* Torque attempts to align plane of current loop with the magnetic field
* Be careful, the angle here is NOT the same as the angle for forces
* Examples

$$\tau = NIABsin\psi$$

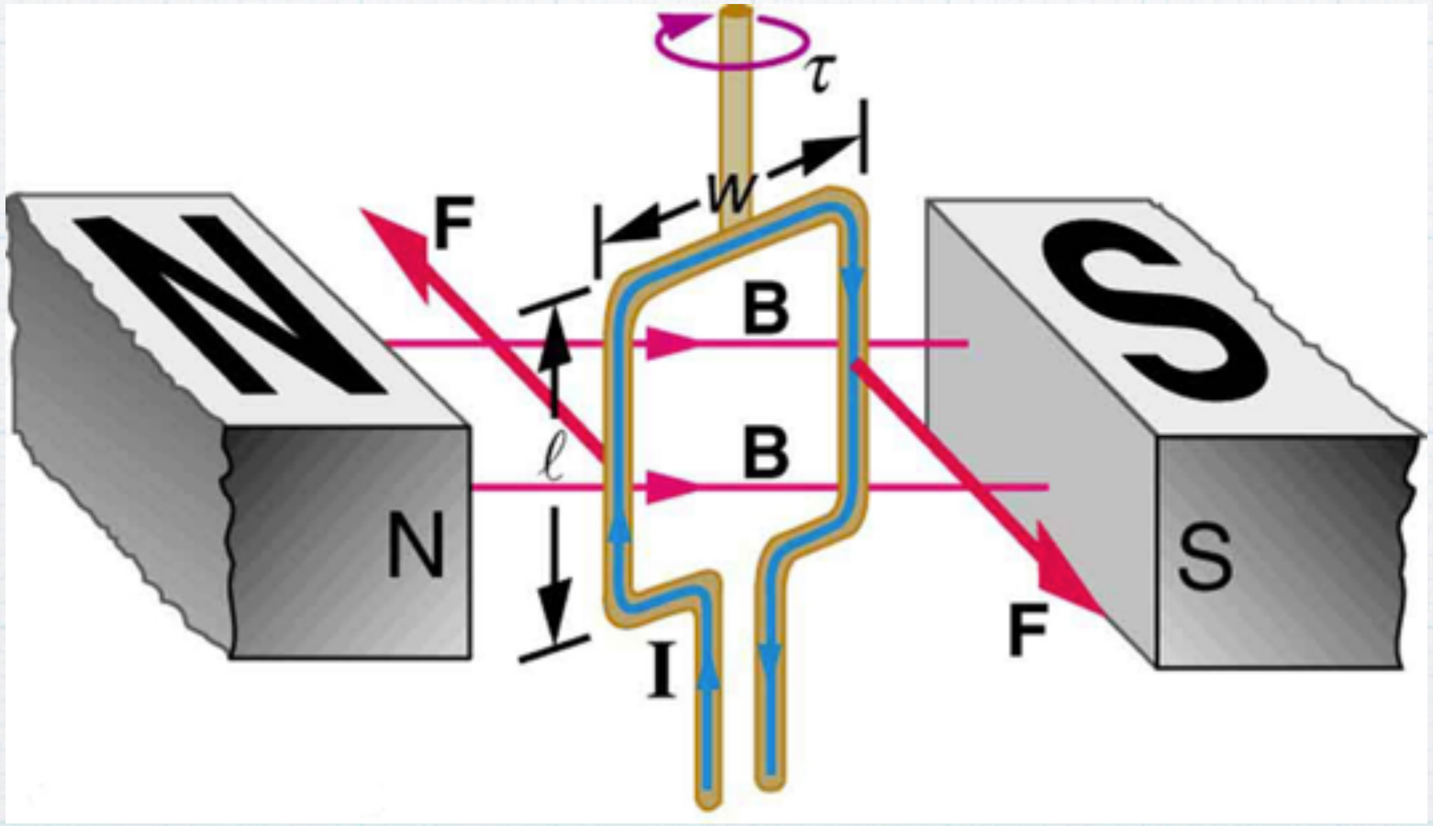
$$\tau = N\mu Bsin\psi$$

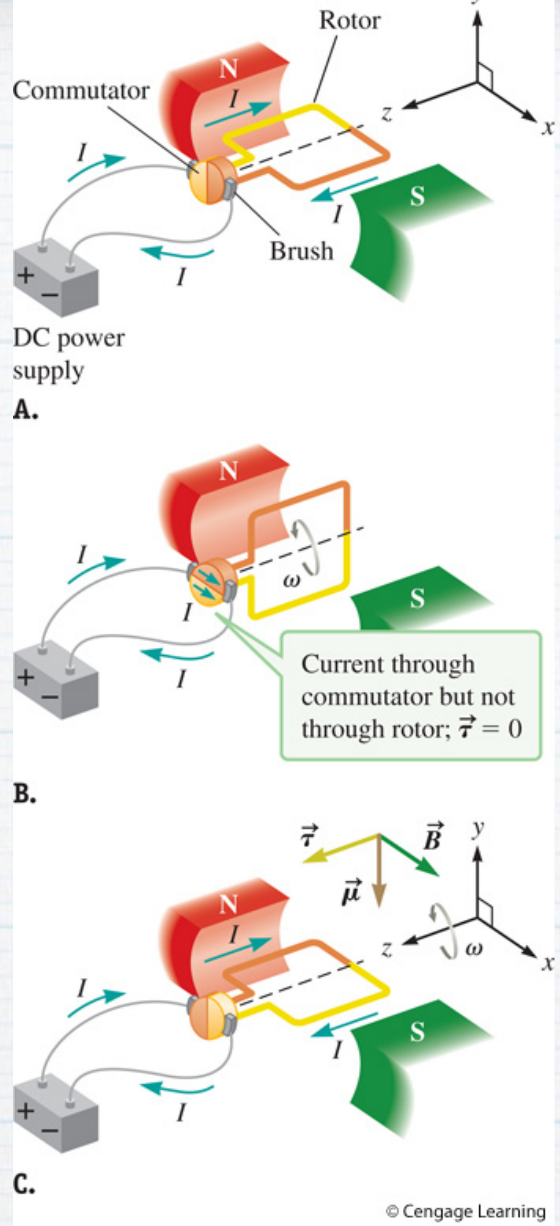
$$\vec{\tau} = n\vec{\mu} \times \vec{B}$$

If there is potential for motion, there is potential energy

$$U = -\vec{\mu} \cdot \vec{B} = -\mu Bcos\psi$$

Motors/Generators

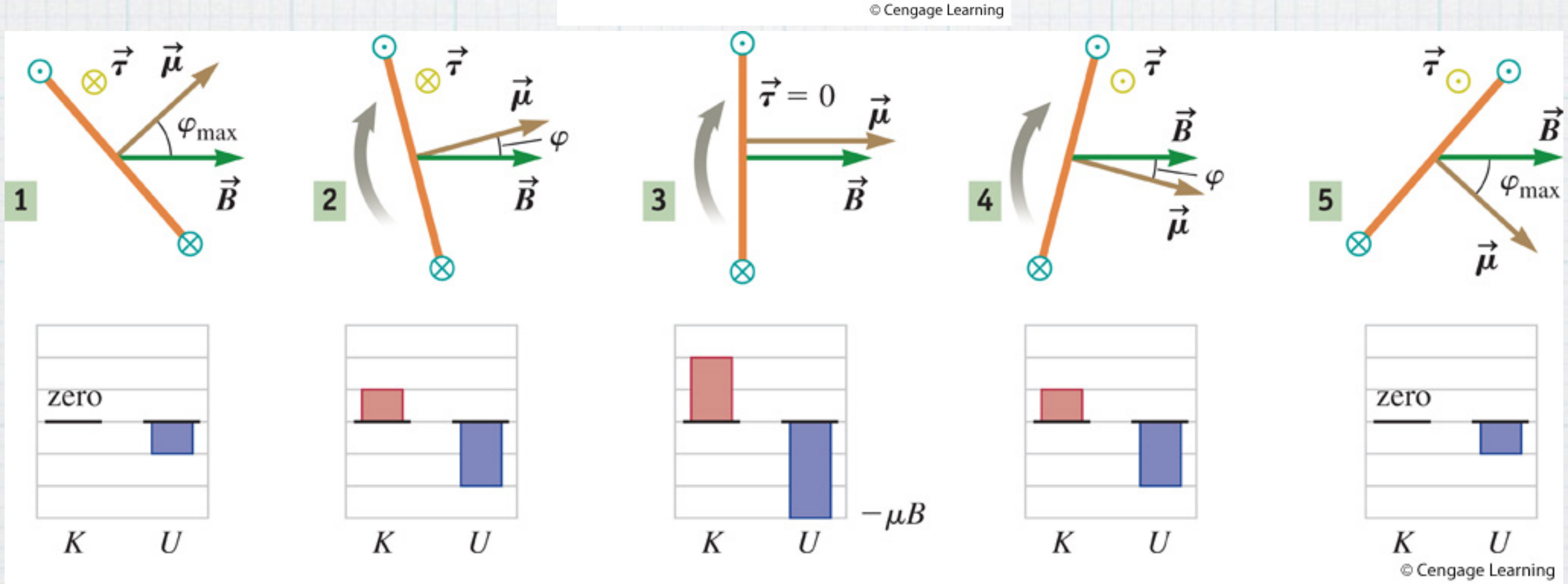




$$\vec{B} = B\hat{i}$$

$$\vec{\mu} = -\mu\hat{j}$$

$$\vec{\tau} = -\mu B(\hat{j} \times \hat{i}) = \mu B\hat{k}$$



Example