Physics 1B

Lecture 19B

"Conscience is or magnetic compass;

reason our chart"

--Joseph Cook

Magnetic Fields

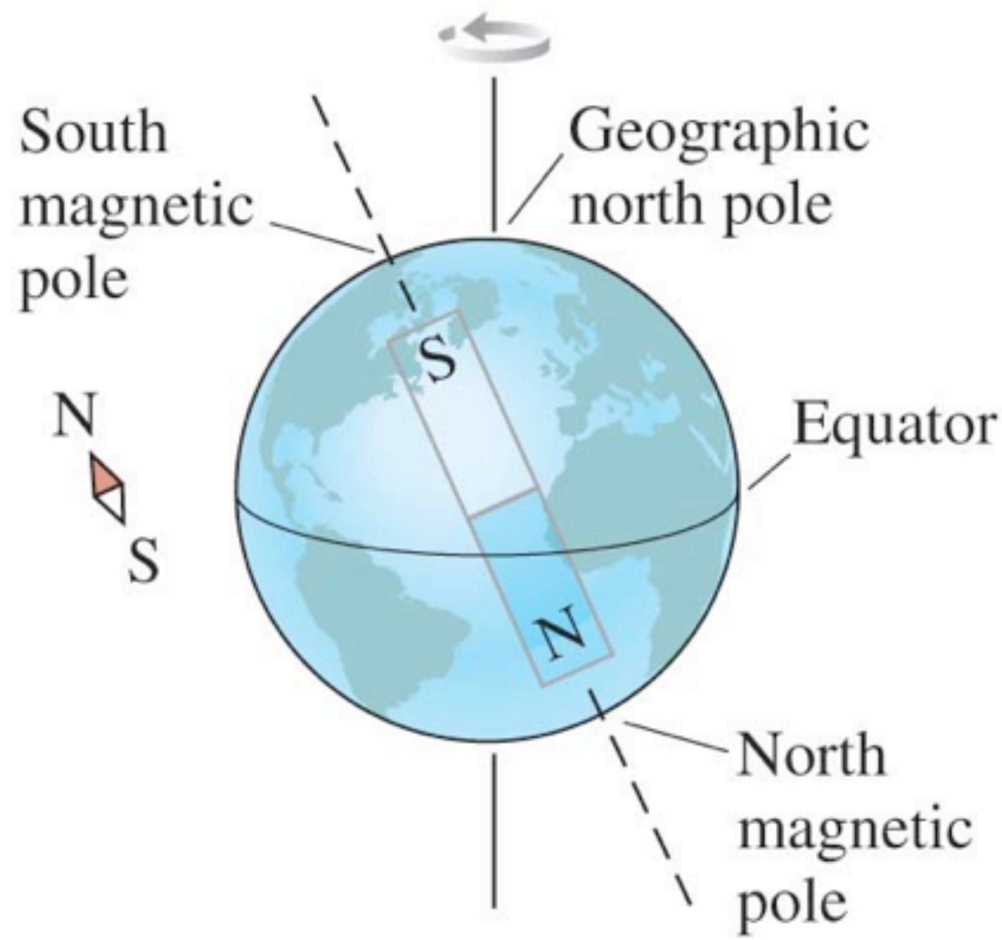
- The proper way to handle magnetic forces is to concentrate on magnetic fields.
- A magnetic field is located in a region of space surrounding a moving charge.
- This charge will also have an electric field surrounding it.
- A magnetic field is a vector quantity given by:

$$\vec{B}$$

- The SI unit of the magnetic field, B is the Tesla.
- Earth's magnetic field is: 0.5×10^{-4} Teslas.

Magnetic Fields

FIGURE 33.1 The earth is a large magnet.



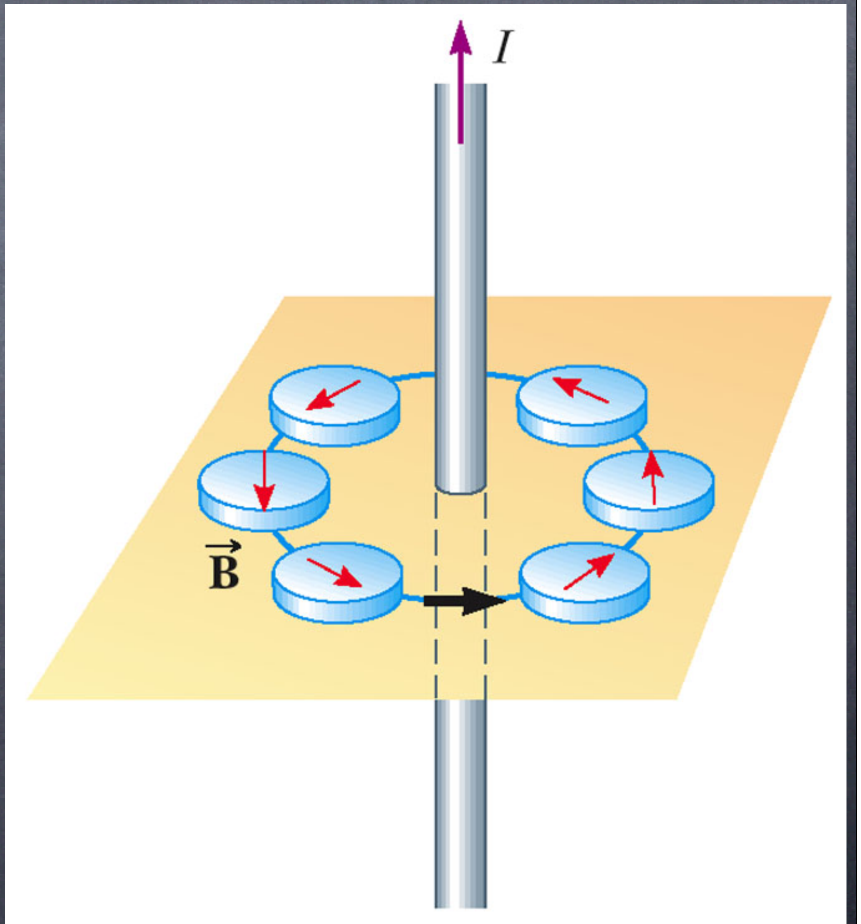
Magnetic Fields

- We will treat magnetic forces and fields how we treated electric forces and fields.
- We will use a two-step process:
- step (i): Moving charges, I, creates a B field.
- step (ii): Moving charge, q, experiences magnetic force from the field.

Moving charges (current I) [Amps] → creates → B field [Teslas] → exerts force on → other moving charges q [Coul]

Magnetic Fields

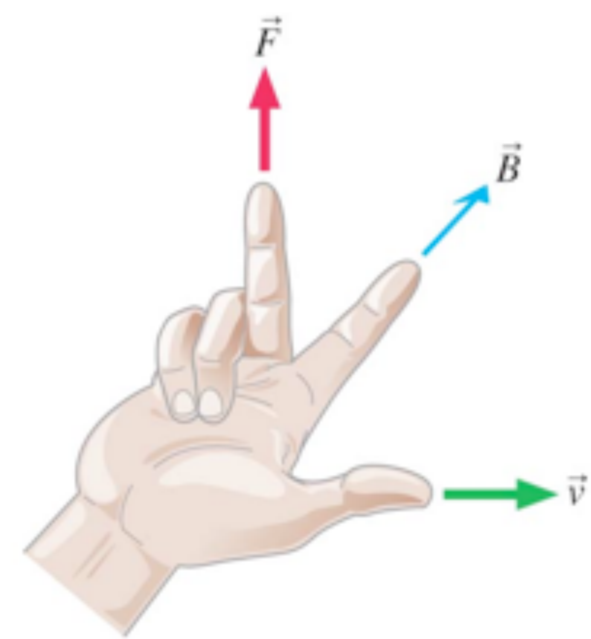
- Note that a moving charge will not create a magnetic field, B, that will exert a force on itself.
- That violates Newton's Third Law (you need two objects to have a force).
- Let's examine the simplest case of a long, straight wire with current I.
- This current will create a magnetic field, B, surrounding it.



Step 2

- To find the direction of the magnetic force on a moving charge, q, due to magnetic field, B use RHR1.
- Note: this works for a positive charge, q, only.
- To find the magnitude of the magnetic force on a moving, v, charge, q, due to magnetic field, B use:

FIGURE 33.34 The right-hand rule for magnetic forces.

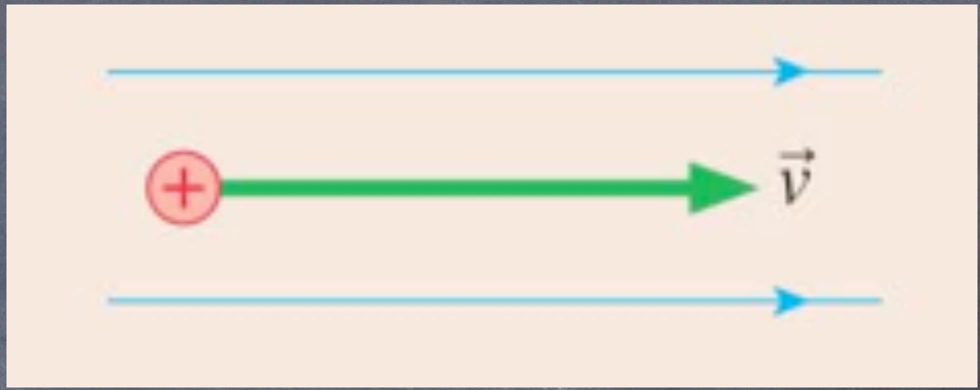


$$F = q\left|\vec{v}\right|\left|\vec{B}\right|\sin\theta$$

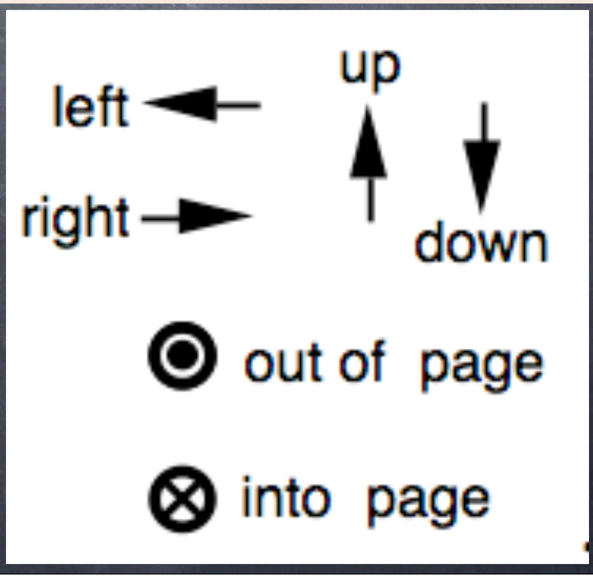
- where θ is the angle between the velocity and magnetic field vectors.

Step 2

- This means that if the velocity vector and the magnetic field vector are parallel (or anti-parallel), there is no force on a charged particle, q, due to the magnetic field.

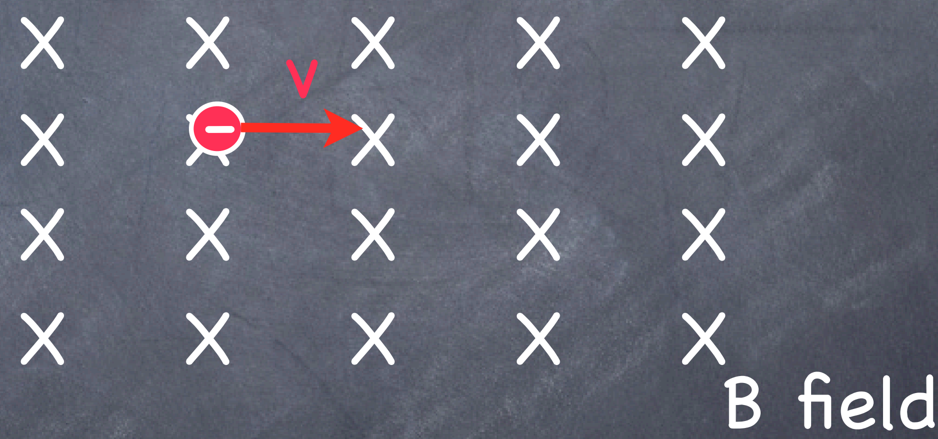


- Also, if the moving particle is neutral, there is no force.
- We define some basic directions that help us with the 3D nature of magnetic forces.
- Assume these directions are valid unless told otherwise.



Step 2

- <u>Example</u>
- An electron travels at 2.0×10^7m/s in a plane perpendicular to a 0.10T large uniform magnetic field as shown below. Describe its resulting path (both magnitude and direction).



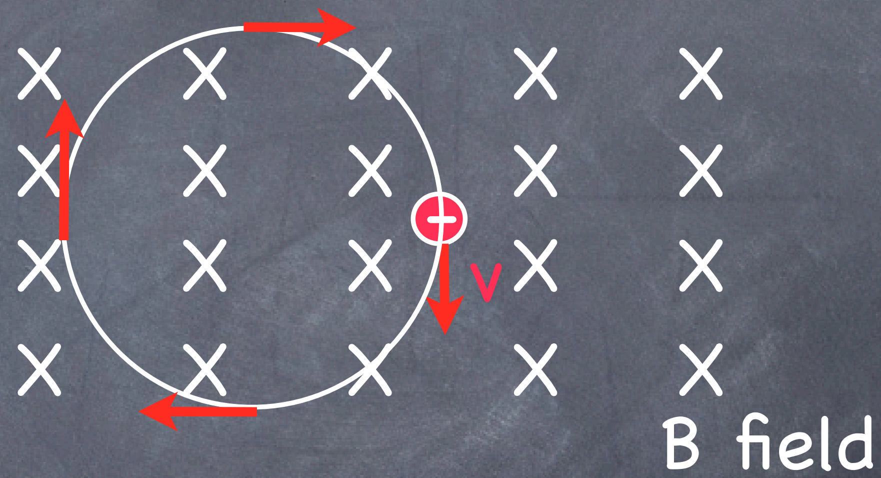
- <u>Answer</u>
- First, you must define a coordinate system.
- Let's say the original direction of motion of the electron as the positive x-direction.

Step 2

- Answer
- Originally, the electron moves to the right and the magnetic field is into the page (board).
- Apply RHR, put your thumb in direction of velocity, your forefinger in the direction of the B-field.
- The resulting magnetic force is upward. But you ask yourself one last question, is the electron positively or negatively charged?
- It is negatively charged, so you flip the magnetic force vector so that it is downward.
- So, the electron will originally feel a downward force due to the external magnetic field.

Step 2

- Answer
- This means that the electron will eventually be moving downward in the magnetic field.
- Now, which direction will it feel a force?
- Via RHR, it will feel a force to the left (don't forget to flip the vector at the end).



- This will keep on occurring until it completes one circular loop (and then it keeps repeating).
- So, the resulting path will be circular (clockwise) as the magnetic force causes centripetal acceleration.

Step 2

- <u>Answer</u>

- To find the magnitude, use Newton's 2nd Law with the magnetic field causing a centripetal acceleration.

$$\sum F = ma$$

$$F_B = ma_c$$

$$qvB\sin\theta = m\frac{v^2}{r}$$

$$qB(1) = m\frac{v}{r}$$

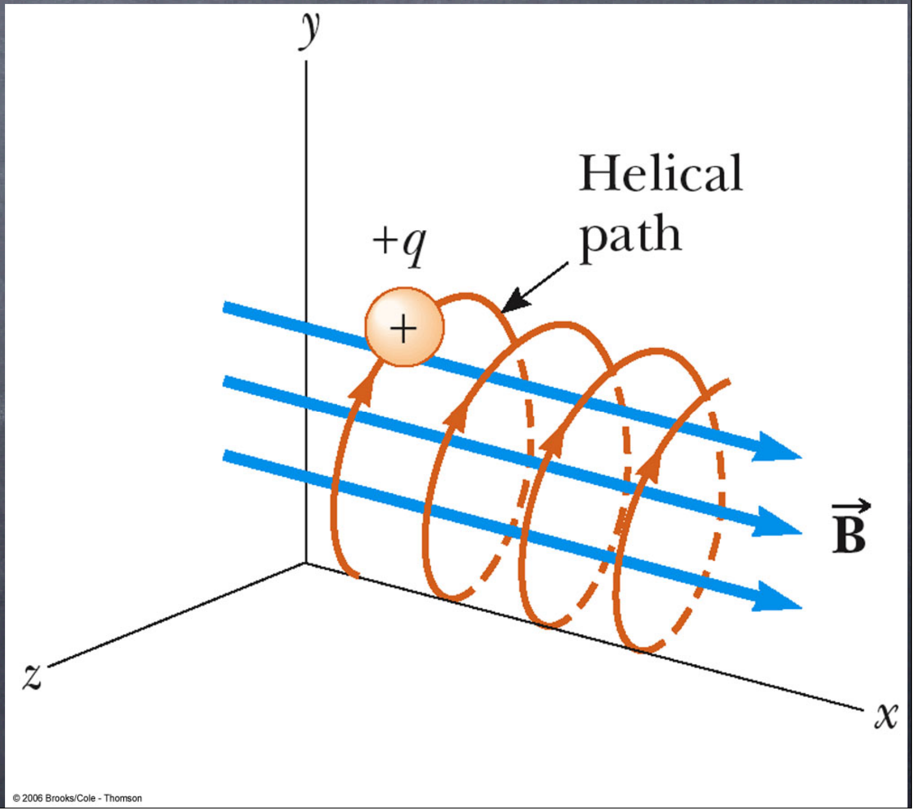
$$r = \frac{mv}{qB}$$

- We know all of the variables (e and m_e can be looked up).

$$r = \frac{\left(9.11\times10^{-31}\text{kg}\right)\left(2.0\times10^{7}\ {}^{\text{m}}\!/\!_{\text{s}}\right)}{\left(1.60\times10^{-19}\text{C}\right)\left(0.10\text{T}\right)} = 1.1\times10^{-3}\text{m}$$

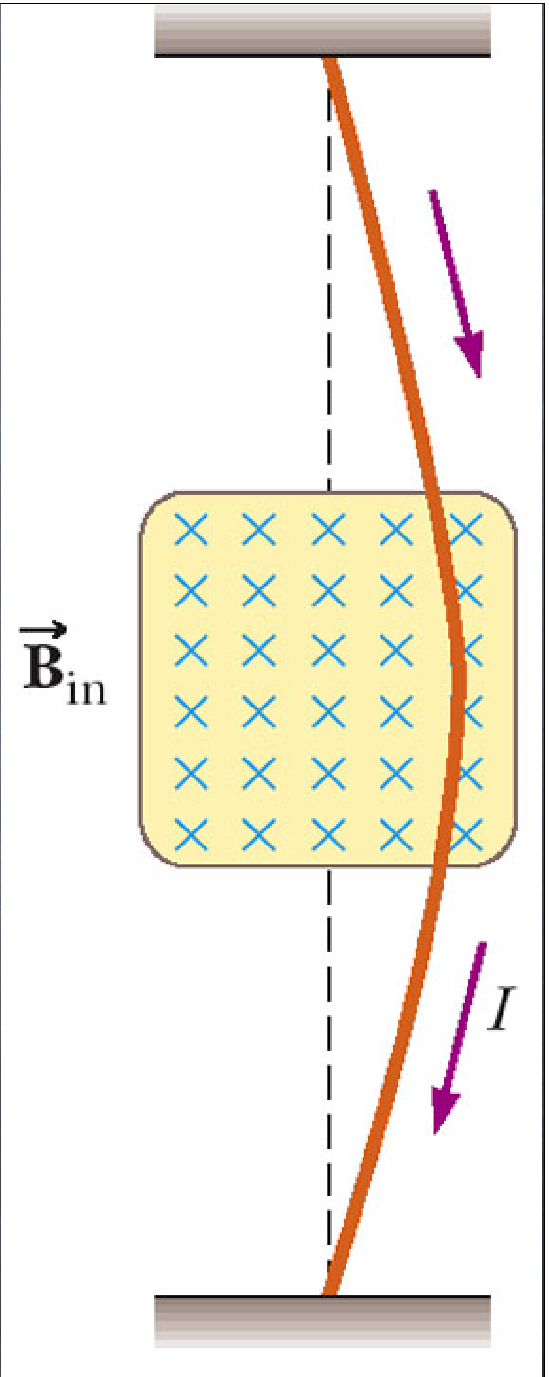
Step 2

- Note that the radius of the path followed depended on the mass and the charge of the object.
- We can use this fact to separate objects with the same charge but with different masses (Mass Spectrometer).
- In the previous example, if the electron's original velocity was not perpendicular to the magnetic field, then the resulting path with will be spiral.
- This spiral path is called a helix.



Force on a Wire

- If the current in a wire is moving downward and the magnetic field is into the board apply Right Hand Rule 1:
- Your positive current velocity points down (thumb)
- Your magnetic field points into the board (forefinger).
- Middle finger then points to the right.
- Force is to the right since current is defined as positive charge moving.



Force on a Wire

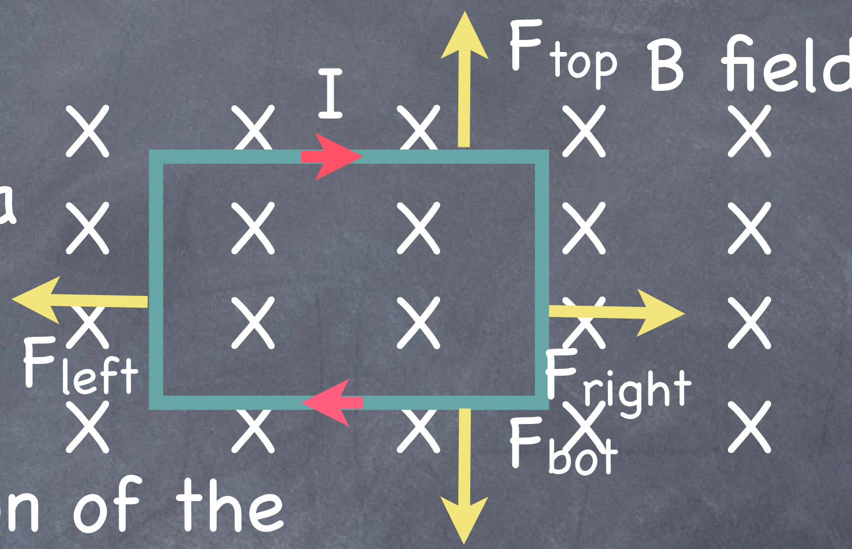
- The magnetic force is exerted on each moving charge in the wire.
- The total force is the sum of all magnetic forces on all the individual charges producing the current.

$$F = I\ell B \sin\theta$$

- where θ is the angle between B and the direction I that points along ℓ.
- As always the direction of the force is found by Right Hand Rule 1.

Torque on a Current Loop

- Let's say we have a rectangular loop of wire (of length b and width a) with a clockwise current immersed in a magnetic field.



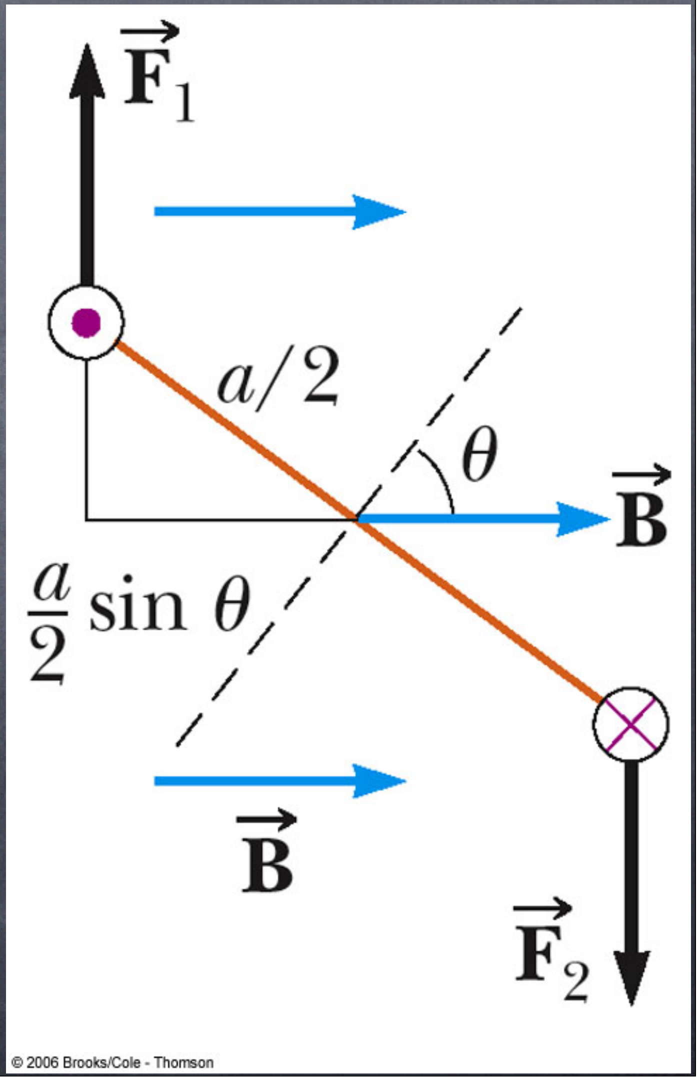
- What would be the direction of the magnetic force on this wire loop?
- Use RHR on each section of the wire.
- For the top section, the force would point upward.
- For the bottom, the force would point downward.
- For the left, the force would point to the left.
- For the right, the force would point to the right.

Torque on a Current Loop

- The forces cancel out. So nothing will happen to the loop.
- But, what if the wire loop was slightly tilted (θ) with respect to the magnetic field.
- Now, we can create a torque due to these forces about a central axis.
- The torque on the top section will be given by:

$$\tau_{top} = |\vec{r}||\vec{F}_{top}|\sin\theta$$

$$\tau_{top} = \frac{a}{2}F_{top}\sin\theta$$



Torque on a Current Loop

- The torque on the bottom section will be given by:

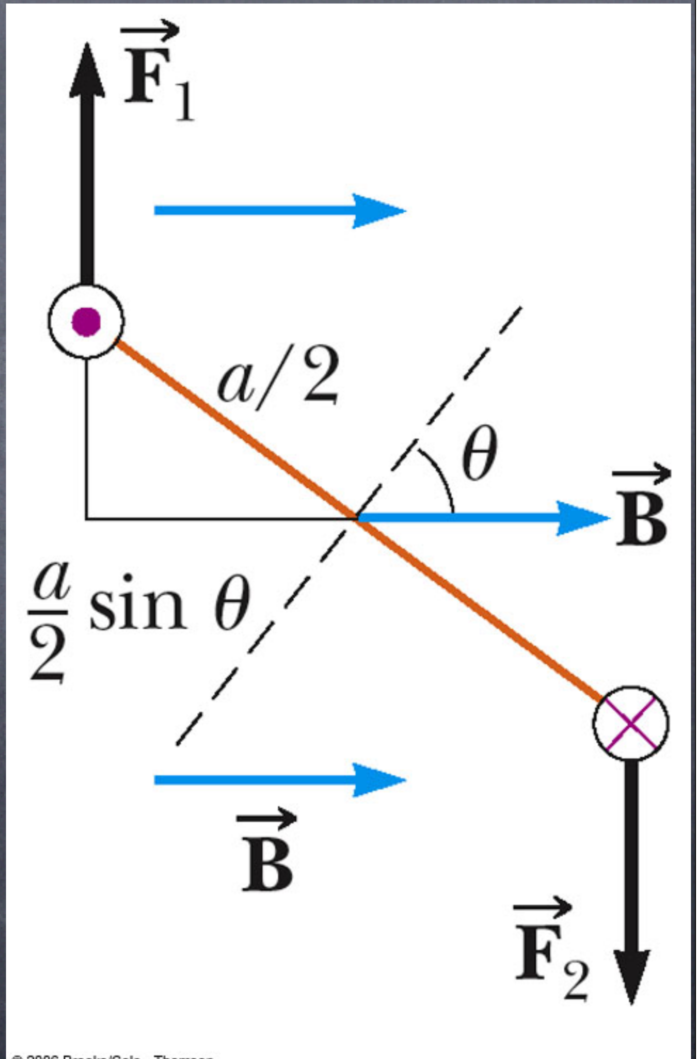
$$\tau_{bot} = |\vec{r}||\vec{F}_{bot}|\sin\theta$$

$$\tau_{bot} = \frac{a}{2}F_{bot}\sin\theta$$

- The force on the top and bottom wire will have the same magnitude given by:

$$F_{top} = F_{bot} = IbB\sin 90^\circ = IbB$$

- Also, by right hand rule, the torques will point in the same direction, such that the torque from the top and bottom add.



Torque on a Current Loop

- To find the total torque on the current loop, merely add the torques:

$$\tau_{tot} = \tau_{top} + \tau_{bot}$$

$$\tau_{tot} = \frac{a}{2} F_{top} \sin\theta + \frac{a}{2} F_{bot} \sin\theta$$

$$\tau_{tot} = aF_{top} \sin\theta = a(IbB)\sin\theta$$

$$\tau_{tot} = IAB\sin\theta$$

- where A is the area of the loop.
- If we were to make N loops of this wire then our equation would become:

$$\tau_{tot} = NIAB\sin\theta$$

Magnetic Moment

- The first part of right side of the last equation (NIA) is completely dependent on properties of the loop.
- Because of this we define the magnetic moment vector, μ, of the wire:

$$\mu = NIA$$

- The magnetic moment vector points perpendicular to the plane of the loop(s), a normal so to speak.
- The angle θ will be between μ and B such that:

$$\tau = \vec{\mu} \times \vec{B} = |\vec{\mu}||\vec{B}|\sin\theta$$

For Next Time (FNT)

- Start reading Chapter 20
- Start working on the homework for Chapter 19