# Physics 2B

## Lecture 29B

"There is a magnet in your heart that will attract true friends. That magnet is unselfishness, thinking of others first. When you learn to live for others, they will live for you."

--Paramahansa Yogananda

# Magnetic Fields

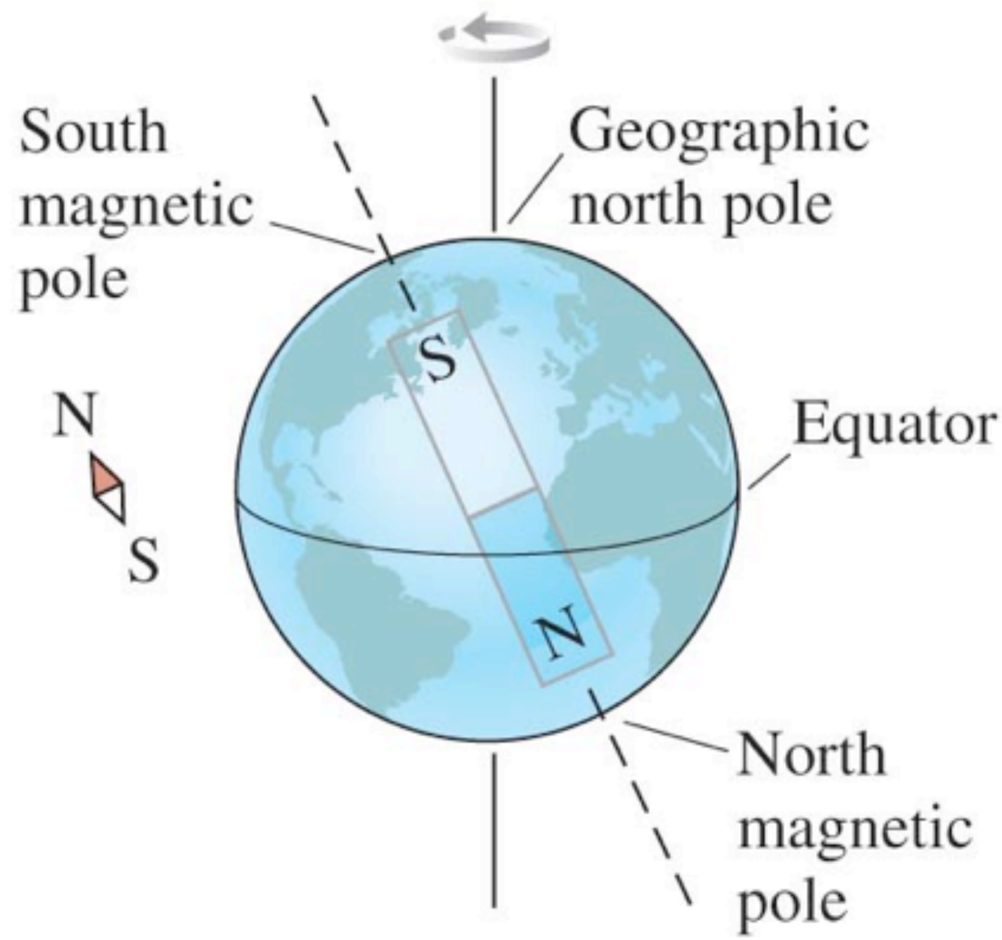
- The proper way to handle magnetic forces is to concentrate on magnetic fields.
- A magnetic field is located in a region of space surrounding a moving charge.
- This charge will also have an electric field surrounding it.
- A magnetic field is a vector quantity given by:

$$\vec{B}$$

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

# Magnetic Fields

FIGURE 33.1 The earth is a large magnet.



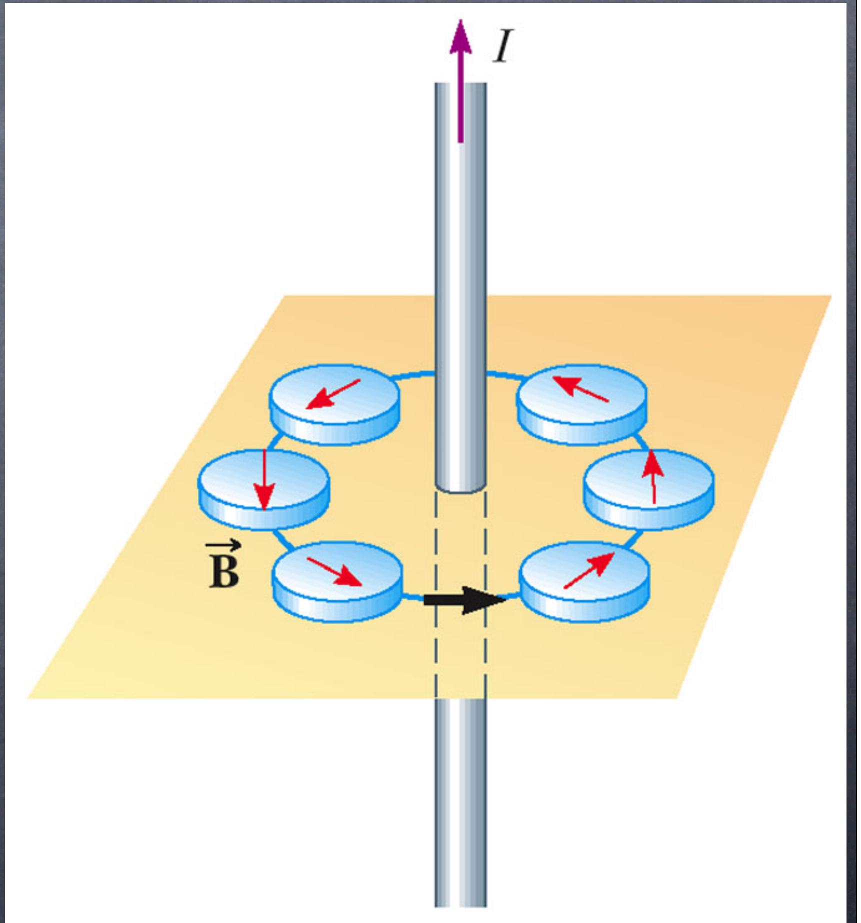
# Magnetic Fields

- 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 RHR.

$$\vec{F} = q\vec{v} \times \vec{B}$$

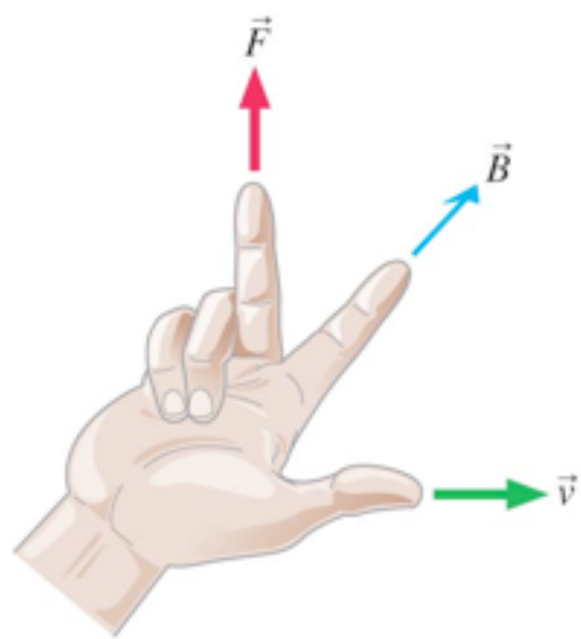



FIGURE 33.34 The right-hand rule for magnetic forces.

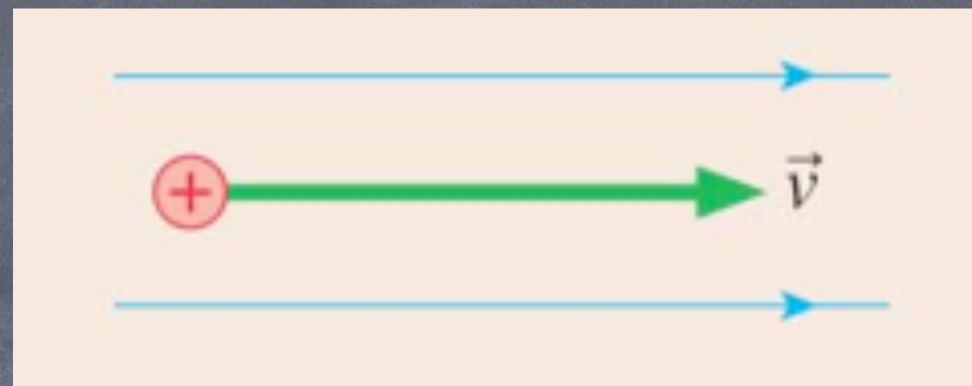
- To find the magnitude of the magnetic force on a moving, v, charge, q, due to magnetic field, B use:

$$\vec{F} = q|\vec{v}||\vec{B}|\sin\alpha$$

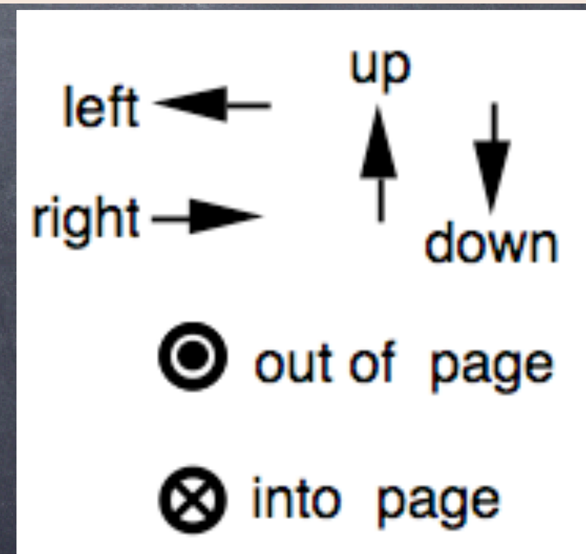
- where α is the angle between the velocity and magnetic field vectors.

# 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.

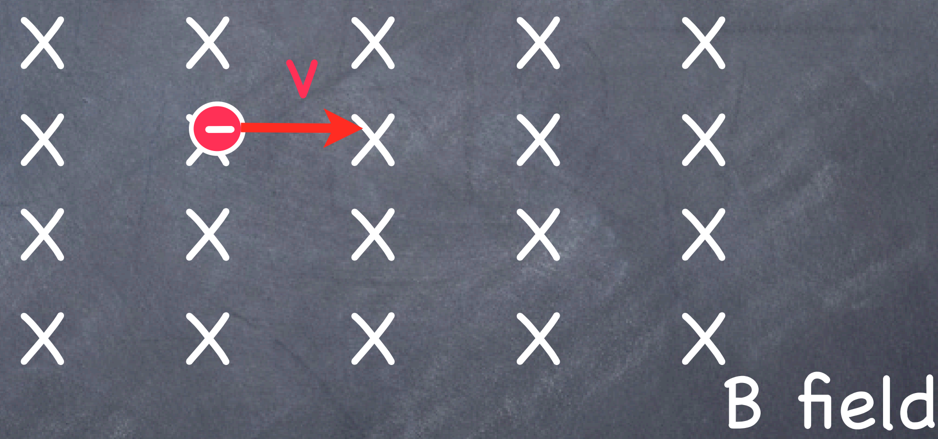



- We define some basic directions that help us with the 3D nature of magnetic forces.
- Assume these directions are valid unless told otherwise.



# Step 2

- <u>Example</u>
- An electron travels at $2.0\times10^{7}$m/s in a plane perpendicular to a 0.10T large uniform magnetic field as shown below.  Describe its resulting path (both magnitude and direction).



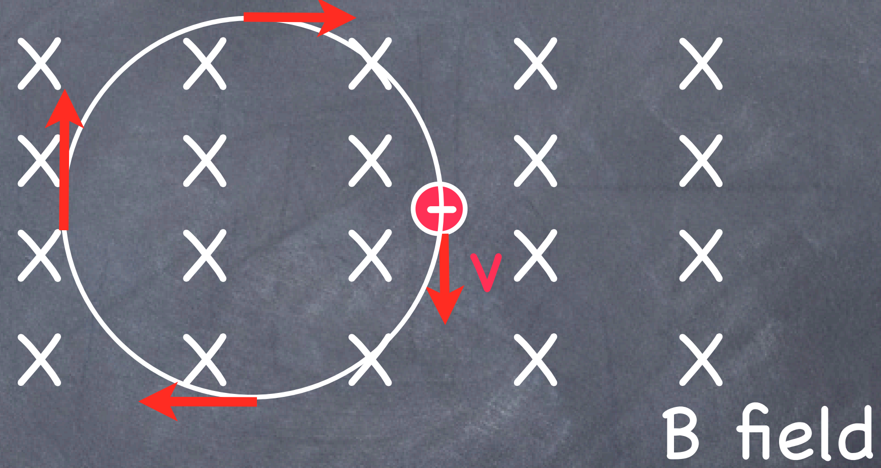

- <u>Answer</u>
- First, you must define a coordinate system.
- Let's say the original direction of motion of the electron as the positive x-direction.

# 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

- <u>Answer</u>
- 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).

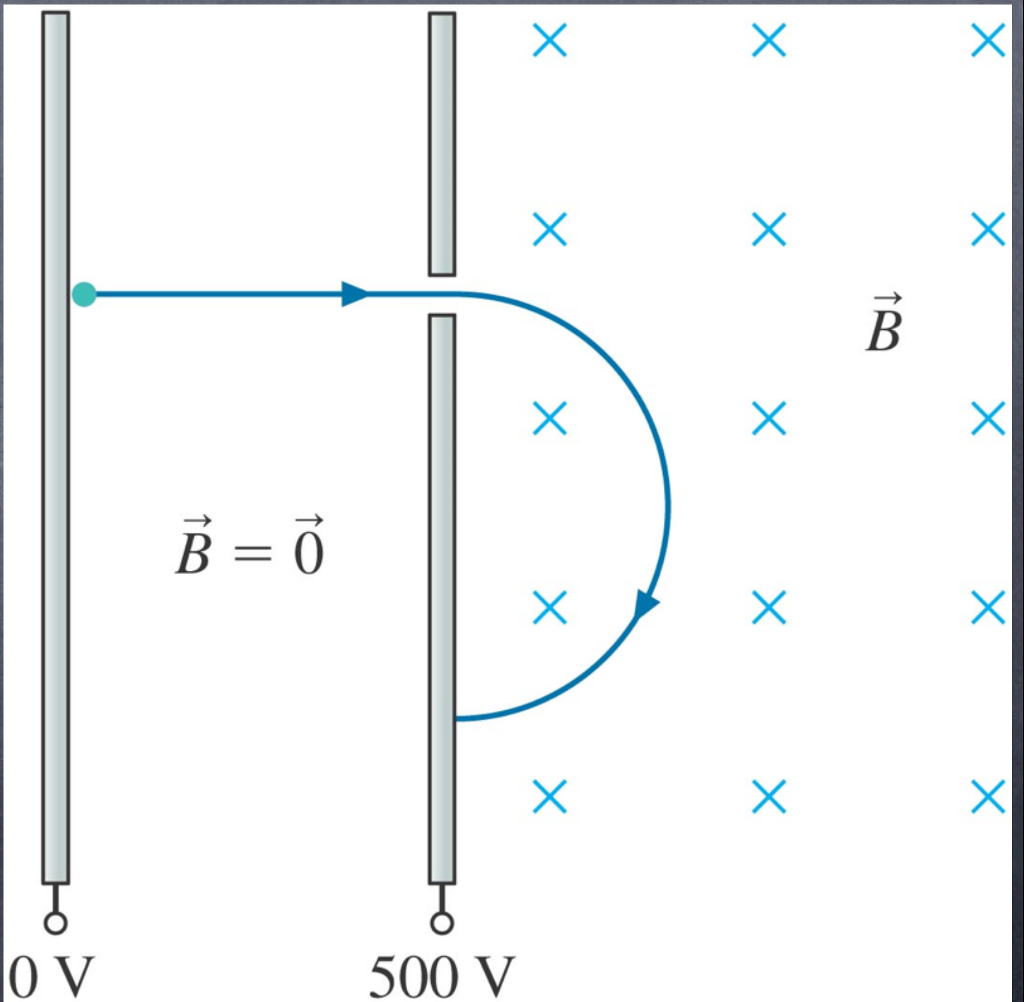
$$r = \frac{(9.11\times10^{-31}\,\mathrm{kg})(2.0\times10^{7}\,\mathrm{m/s})}{(1.60\times10^{-19}\,\mathrm{C})(0.10\,\mathrm{T})} = 1.1\times10^{-3}\,\mathrm{m}$$

# Step 2

- The equation for the radius of the circular motion becomes rather important.

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

- 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).



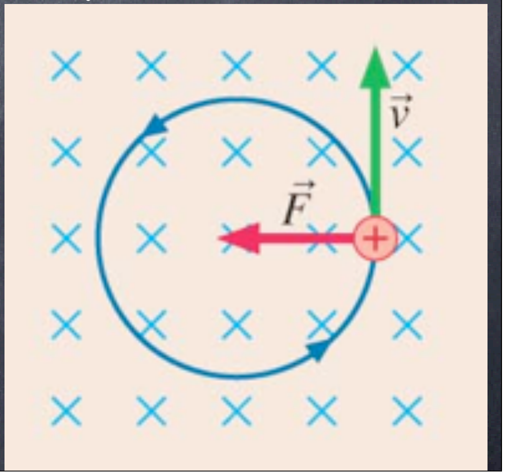
# Step 2

- The classic question usually becomes: How long does it take for a charged particle to complete one orbit?

$$T = \frac{2\pi r}{v} \qquad T = \frac{2\pi}{v}\frac{mv}{qB} \qquad T = \frac{2\pi m}{qB}$$

- It became very useful to talk about the frequency at which the charged particles came by (they were moving pretty fast).
- This turns out just to be the inverse of the period.

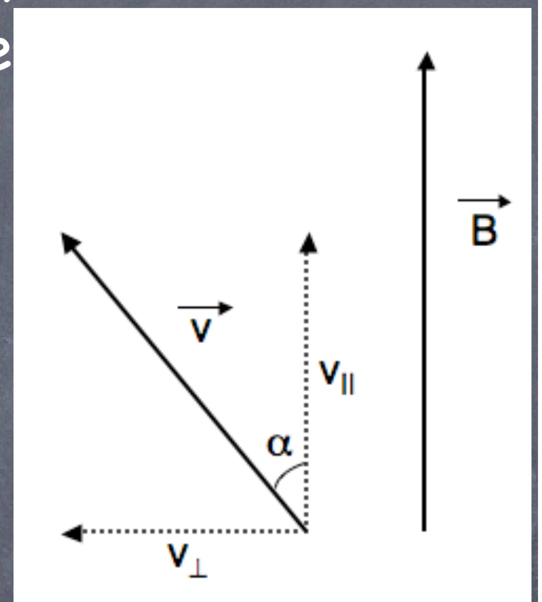
$$f = \frac{qB}{2\pi m}$$

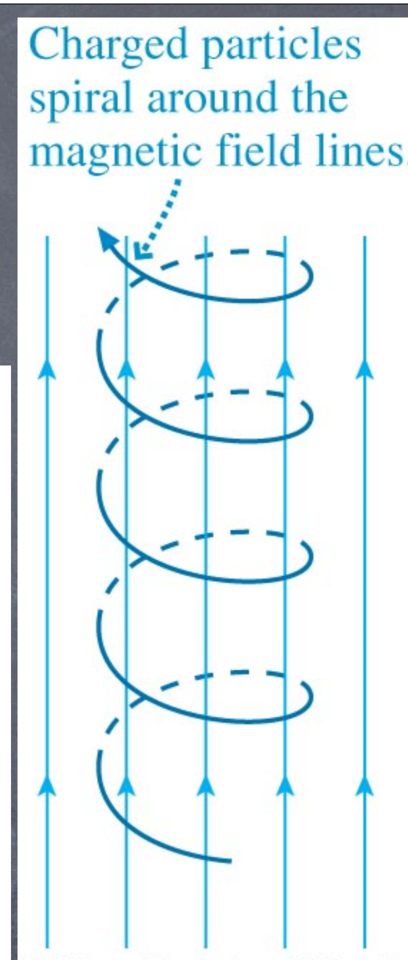



- This is known as the cyclotron frequency. It only works if B and v are perpendicular.

# Step 2

- 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.




- In this case, you can break the velocity of the charged particle into two components, one parallel to B, $v_{||}$ and another perpendicular to B, $v_{\perp}$.
- The perpendicular component, $v_{\perp}$, will be the one that determines the radius of the helix.

# Helical Path

- Example
- An electron follows a helical path in a uniform magnetic field given by:

$$\vec{B} = \left(20\hat{i} - 50\hat{j} - 30\hat{k}\right)\ \mathrm{mT}$$

- At time t = 0, the electron's velocity is given by:

$$\vec{v} = \left(20\hat{i} - 30\hat{j} + 50\hat{k}\right)\ \mathrm{m/s}$$

  - (a) What is the angle α between v and B?
  - (b) What is the radius of the helical path?

- Answer
- Fortunately a coordinate system has already been determined for us.

# Helical Path

- Answer
- To find the angle, calculate the scalar product of v and B:

$$\vec{v}\cdot\vec{B} = |\vec{v}||\vec{B}|\cos\alpha$$

$$\cos\alpha = \frac{\vec{v}\cdot\vec{B}}{|\vec{v}||\vec{B}|}$$

- To solve this, let's first calculate the scalar product between v and B (drop units for simplicity):

$$\vec{v}\cdot\vec{B} = \left(20\hat{i} - 50\hat{j} - 30\hat{k}\right)\cdot\left(20\hat{i} - 30\hat{j} + 50\hat{k}\right)$$

$$\vec{v}\cdot\vec{B} = (20\cdot 20)\hat{i}\cdot\hat{i} + (50\cdot 30)\hat{j}\cdot\hat{j} - (30\cdot 50)\hat{k}\cdot\hat{k}$$

$$\vec{v}\cdot\vec{B} = 400 + 1500 - 1500 = 400$$ mT(m/s)

- Next, calculate the magnitude of v:

$$|\vec{v}| = \sqrt{(20\cdot 20) + (50\cdot 50) + (30\cdot 30)}$$

$$|\vec{v}| = \sqrt{400 + 2500 + 900} = \sqrt{3800}$$

$$|\vec{v}| = 61.6$$ m/s

# Helical Path

- Answer
- Next, calculate the magnitude of B:

$$\left|\vec{B}\right| = \sqrt{(20\cdot 20)+(30\cdot 30)+(50\cdot 50)}$$

$$\left|\vec{B}\right| = \sqrt{400+900+2500} = \sqrt{3800}$$

$$\left|\vec{B}\right| = 61.6 \text{ mT}$$

- Finally, this gives us:

$$\cos\alpha = \frac{\vec{v}\cdot\vec{B}}{\left|\vec{v}\right|\left|\vec{B}\right|} = \frac{400}{(61.6)(61.6)} = \frac{400}{3800}$$

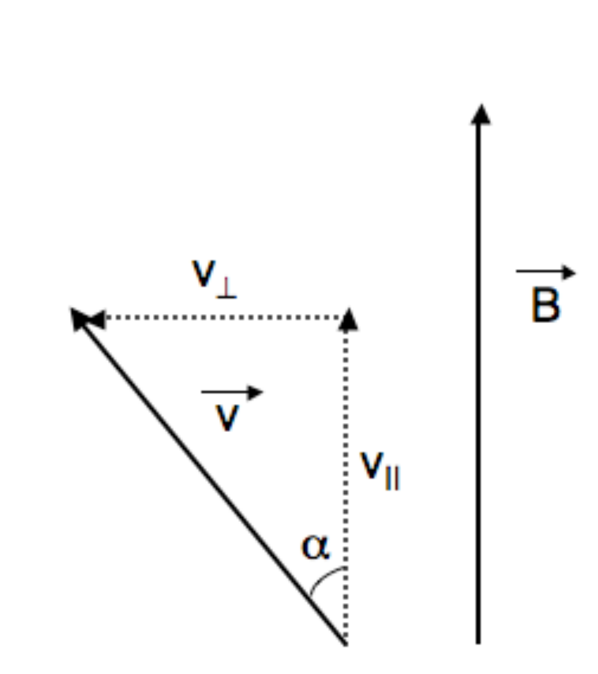
$$\alpha = \cos^{-1}\left(\frac{400}{3800}\right) \qquad \alpha = 84°$$

- This is the answer to part (a).

# Helical Path

- Answer
- For part (b), use the formula we found for circular motion.

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




But the velocity here is the perpendicular component to the magnetic field.

$$v_\perp = v \sin\alpha$$

$$v_\perp = \left(61.6\,\mathrm{m/s}\right)\sin\left(84.0°\right)$$

$$v_\perp = 61.3\,\mathrm{m/s}$$

Plugging this into the circular motion formula gives us:

$$r = \frac{\left(9.11\times10^{-31}\,\mathrm{kg}\right)\left(61.3\,\mathrm{m/s}\right)}{\left(1.60\times10^{-19}\,\mathrm{C}\right)\left(61.6\times10^{-3}\,\mathrm{T}\right)}$$

$$r = 5.7\times10^{-9}\,\mathrm{m}$$

# For Next Time (FNT)

- Keep reading Chapter 29
- Finish working on the homework for Chapter 28