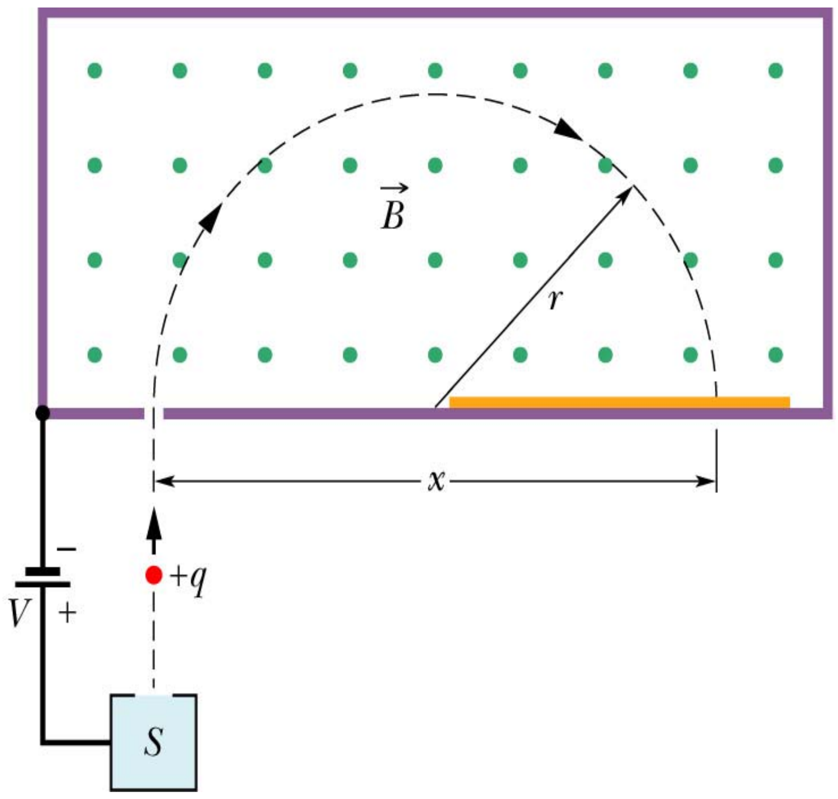
Synchrotrons

- FERMILAB (near Chicago)
  - Uses 6 synchrotrons – the largest with 4 mile circumference
  - Accelerates protons and anti-protons
  - Protons move at 99.9999% speed of light (Go around ring 50,000 times in second)
  - Beam energies of 1 TeV (1 TeV = 10^{12} eV)

Mass Spectrometer

- What do we do with the particle beams?
- Can measure a particle's mass using a mass spectrometer.
- Accelerate particle using potential difference, *V*.
- (May also use the Cyclotron to accelerate the particle.)
- Chamber with *B* field causes particle to bend, striking photographic plate (yellow).



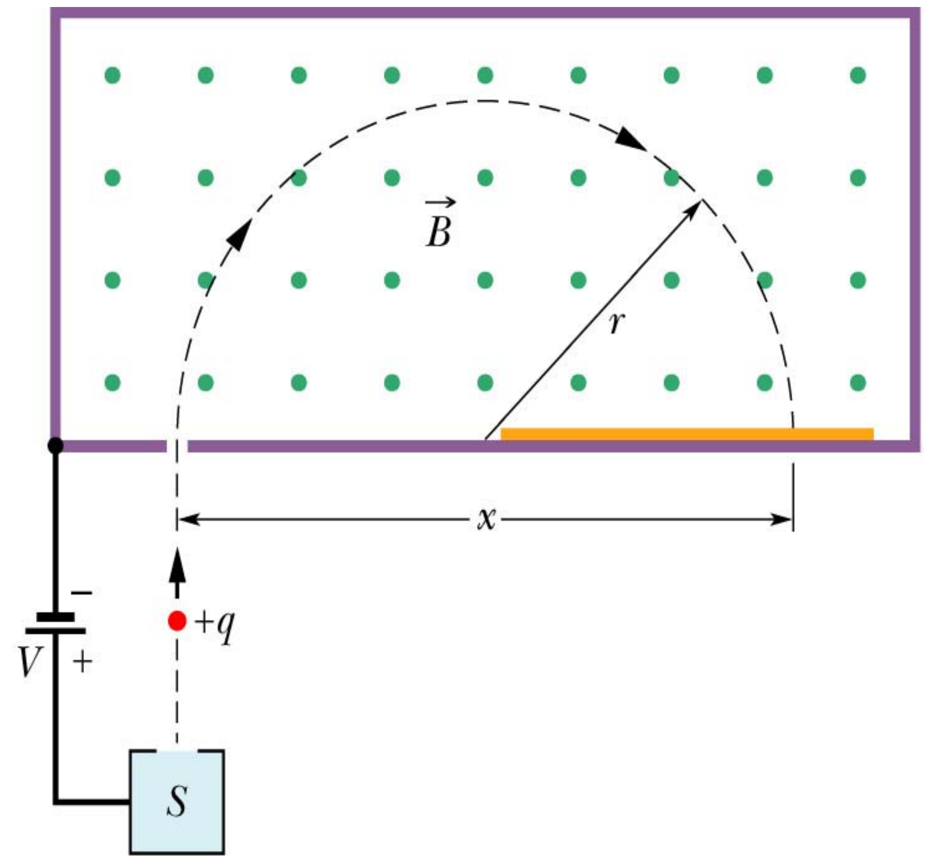
Mass Spectrometer

- Conservation of energy

$$\Delta K + \Delta U = 0$$

$$\tfrac{1}{2}mv^2 - qV = 0$$

$$v = \sqrt{\frac{2qV}{m}}$$



- Substituting v into relation for r gives

$$r = \frac{mv}{qB} = \frac{m}{qB}\sqrt{\frac{2qV}{m}} = \frac{1}{B}\sqrt{\frac{2mV}{q}}$$

Mass Spectrometer

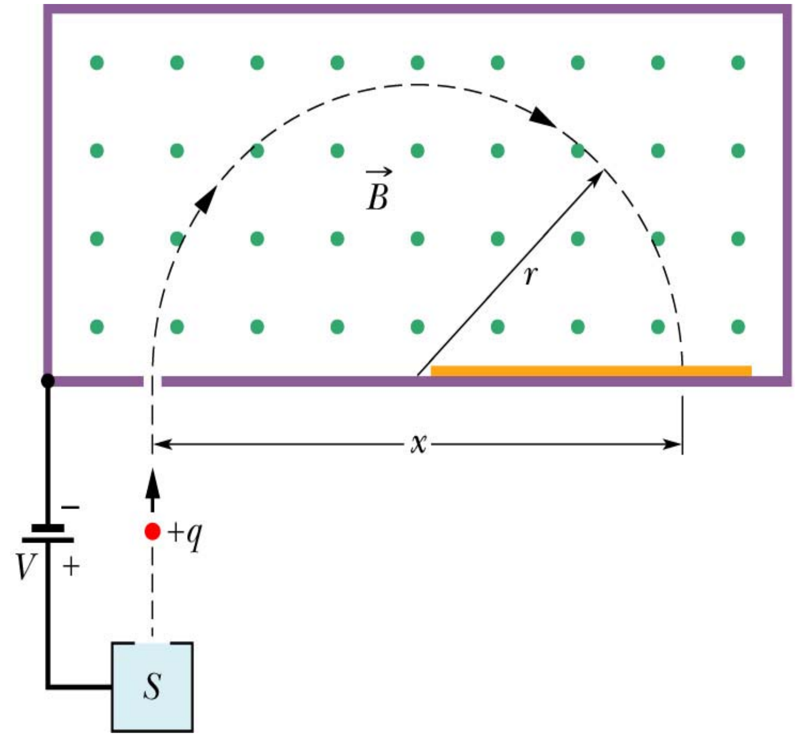
- Rearranging for *m*

$$r = \frac{1}{B}\sqrt{\frac{2mV}{q}}$$

$$m = \frac{B^2 r^2 q}{2V}$$

- Distance $x = 2r$

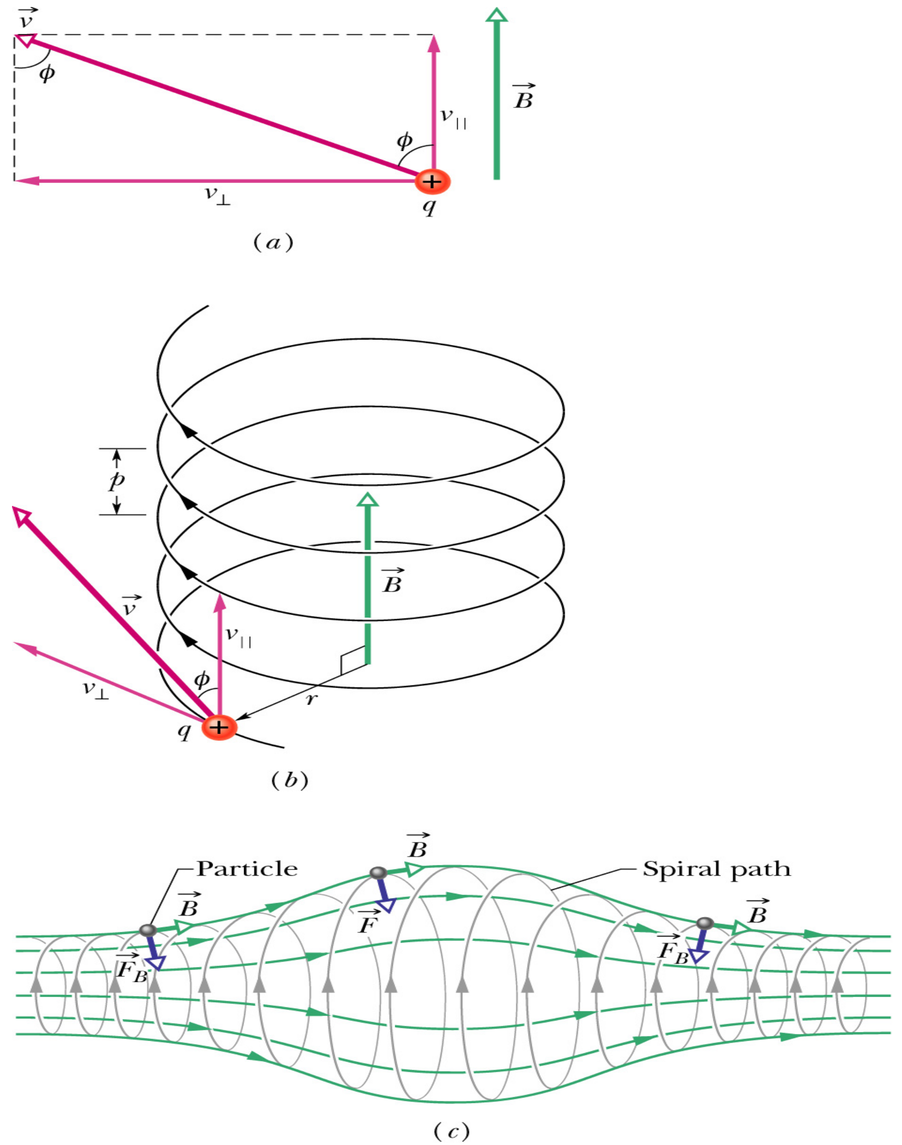
$$m = \frac{B^2 x^2 q}{8V}$$



Application: Measure masses of tiny particles (mass spectrometers)

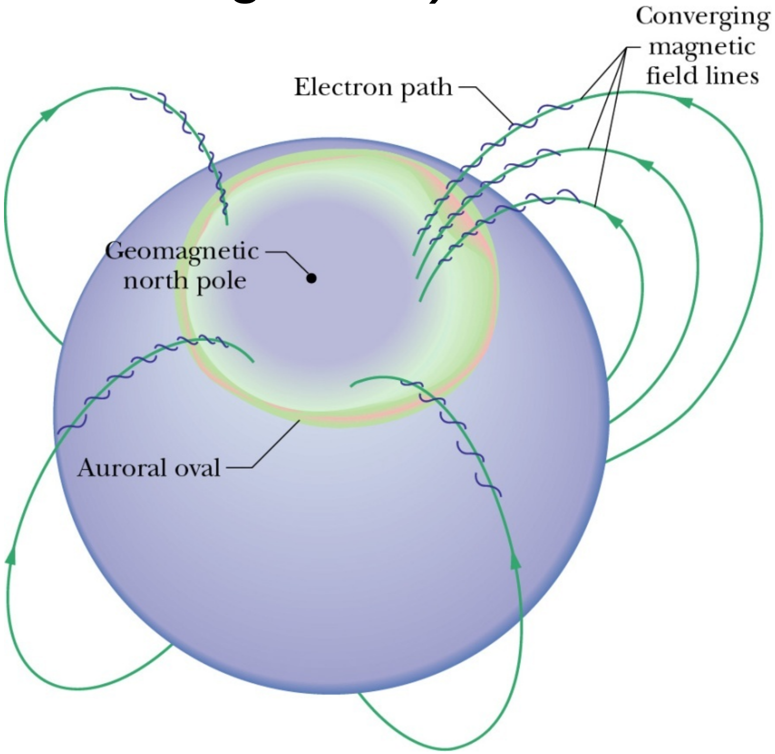
Magnetic Bottle

- So far assumed *v* and *B* were always ⊥
- If *v* has a component || to *B* then particle will have helical path
- Particles in a non-uniform field spiral faster where field is stronger.
- Magnetic bottle: particles deflect back at the strong fields end.



Earth's Magnetic Field

- Magnetic Bottle: *Van Allen* Radiation Belts, Northern lights
- Particles spiral back and forth between the strong field regions at either end
- Collisions with oxygen atoms emit green light (~ 100 km above ground)



What is F_B on a current?

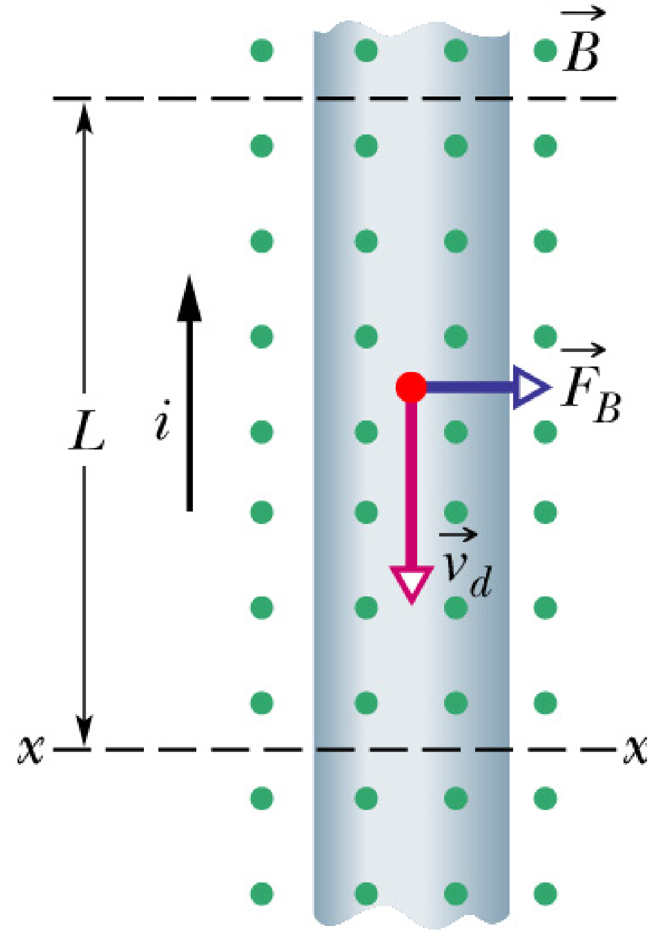
$$\vec{F}_B = q\vec{v} \times \vec{B}$$

- Want to replace q with i

$$i = \frac{dq}{dt} \quad \text{so} \quad q = it$$

- Relate time t to length of wire L and drift velocity v_d

$$v_d = \frac{L}{t} \quad \text{so} \quad t = \frac{L}{v_d}$$



F_B on a current

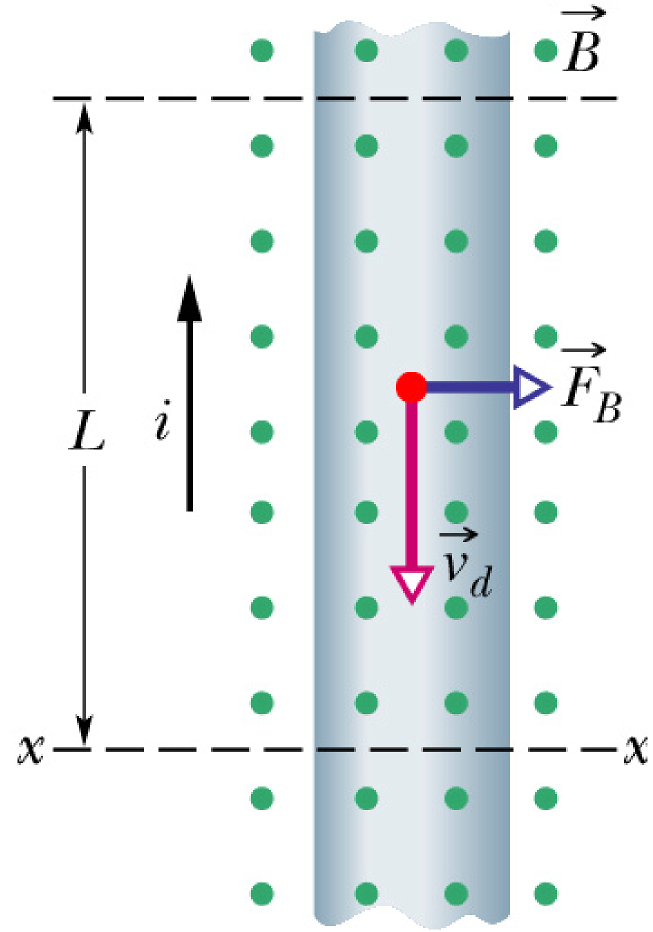
- Charge is $$q = \frac{i\,L}{v_d}$$

- Substitute this for q in

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

- Velocity is drift velocity, v_d

$$F_B = qv_d B\sin\phi = \frac{iLv_d}{v_d} B\sin\phi$$



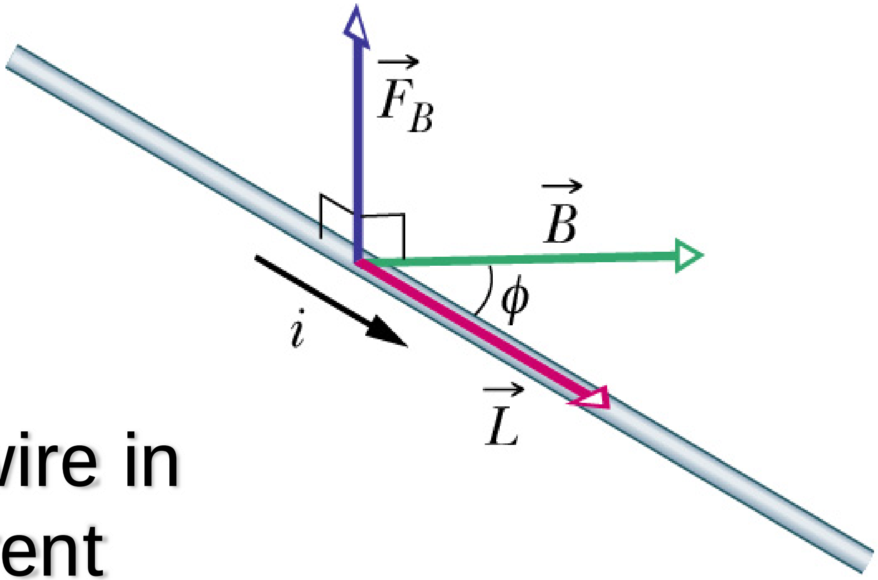
F_B on a current

$$F_B = iLB\sin\phi$$

- Force on a current is

$$\vec{F}_B = i\vec{L}\times\vec{B}$$

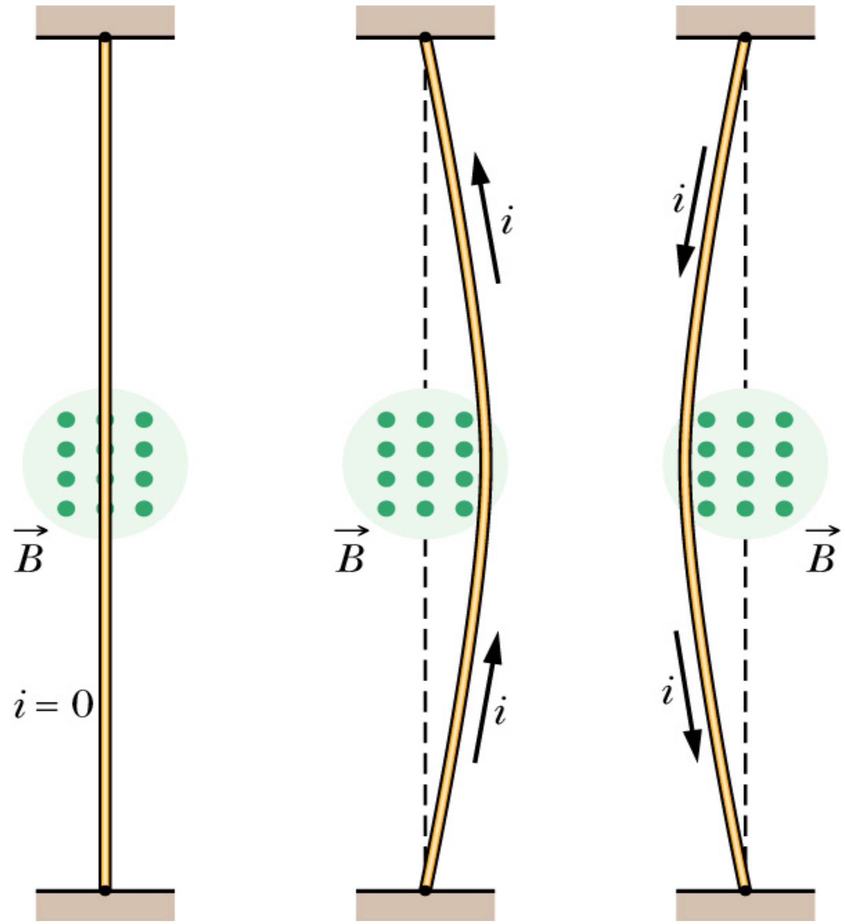
- Vector L points along wire in the direction of the current



- Force on a single charge is $\vec{F}_B = q\vec{v}\times\vec{B}$

F_B on a current

- Hall effect - *B* field exerts force on electrons moving in wire
- Electrons cannot escape wire so force is transmitted to wire itself
- Change either direction of current or *B* field, reverses force on wire



Exercise

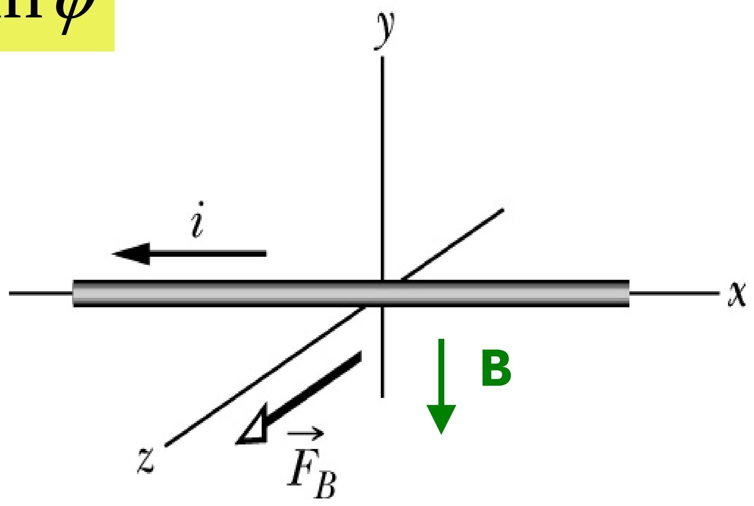
- What is the direction of the *B* field so F_B is maximum?

$$\vec{F}_B = i\vec{L} \times \vec{B} = iLB\sin\phi$$

- Where's the maximum?

$$\sin\phi = 1, \quad \phi = 90$$

- What's the direction of *B*? Use right-hand rule



B points in -y