

October 7th

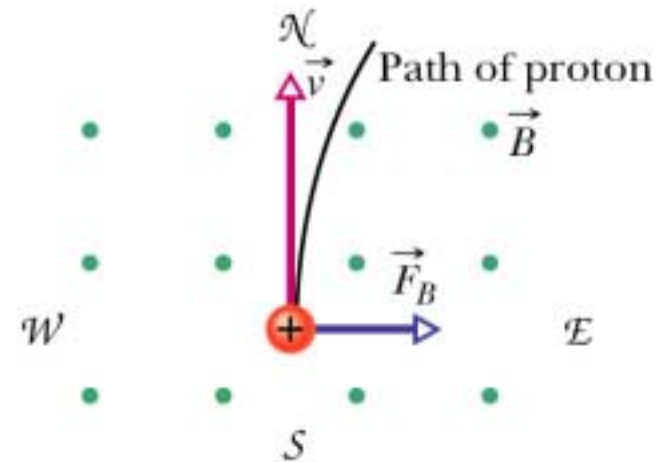
Magnetic Fields - Chapter 29

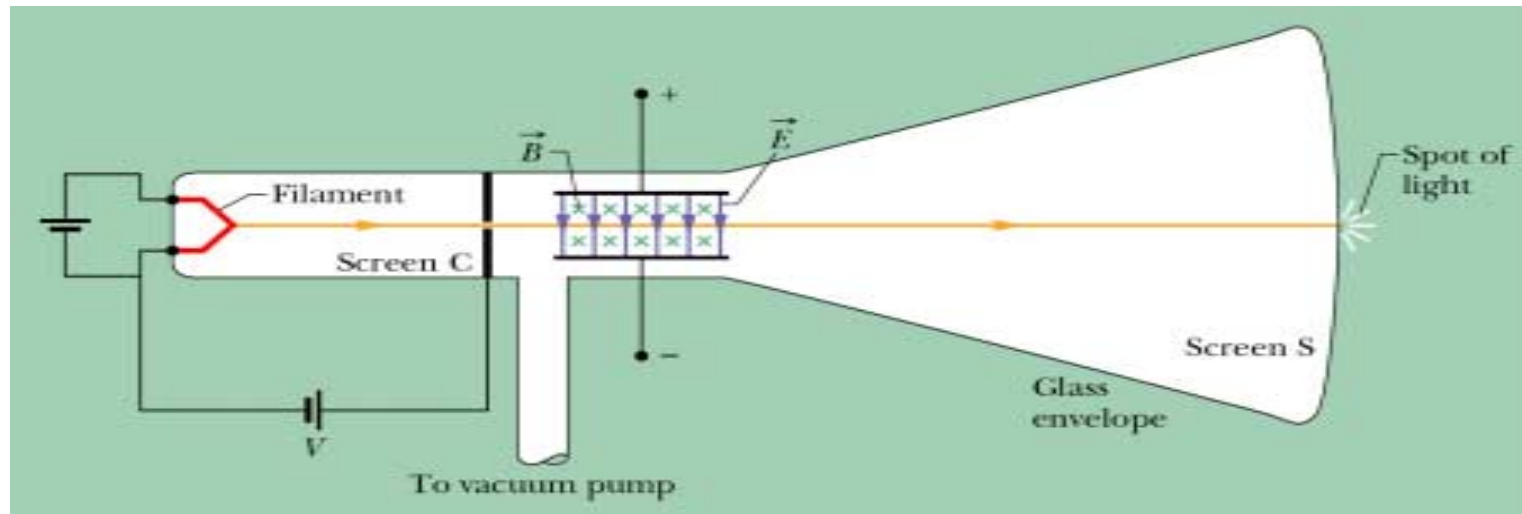
Review (Fig. 29-6)

- Force due to a magnetic field is

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

- F_B is always \perp to v and B
- F_B does not change the speed (magnitude of v) or kinetic energy of particle
- F_B only changes direction of v



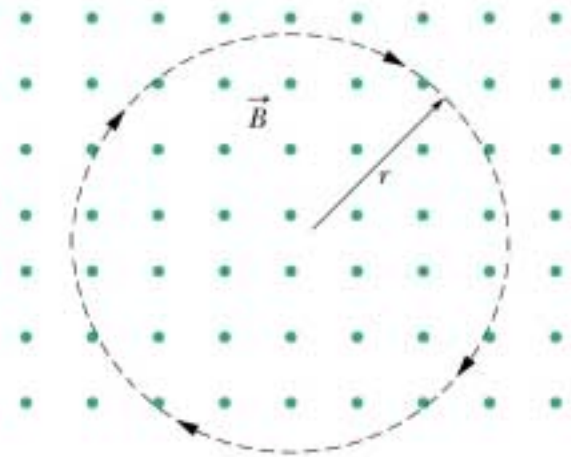


- Crossed fields (E and B are \perp)
- Can deflect a beam of electrons by
 - E field from charged parallel-plates
 - B field from magnet
- What happens if only a B field and a beam of electrons?

Magnetic Fields (Fig. 29-14)

- F_B continually deflects path of charged particles
- If v and B are \perp , F_B causes charged particles to move in a **circular path**
- If B points towards you
 - + particles move clockwise.
 - - particles move counter clockwise.

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



Magnetic Fields

- Derive radius of circular path for particle of charge, q , and mass, m , moving with velocity, v , which is \perp to B field

$$F_B = |q\vec{v} \times \vec{B}| = qvB \sin \phi = qvB$$

- Newton's second law for circular motion is

$$F = ma = m \frac{v^2}{r}$$

- Setting the forces equal and solving for r

- **Faster particles move in larger circles**

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

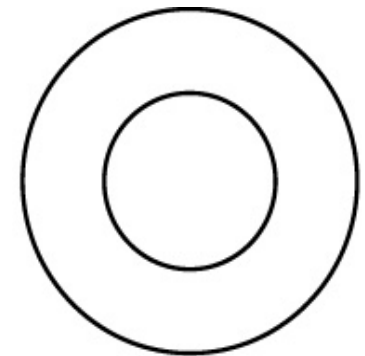
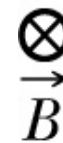
$$r = \frac{mv}{qB}$$

Checkpoint #4

- A proton and an electron travel at same v (in the plane of the page).

- There is a B field into the page.

- A) Which particle follows the smaller circle?



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

$r \propto m/q$, $|q_e| = |q_p| = e$, and $m_p > m_e$,
so the electron has the smaller circle

- B) What direction does the electron move in?

Clockwise

Magnetic Fields

- Period, T , is the time for one full revolution

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

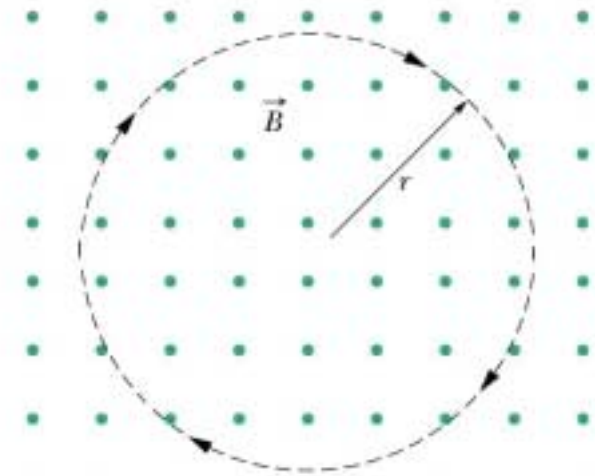
- Frequency, f , is the number revolutions per unit time

$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

- Angular frequency, ω , is

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

- Only depend on q and m but not v



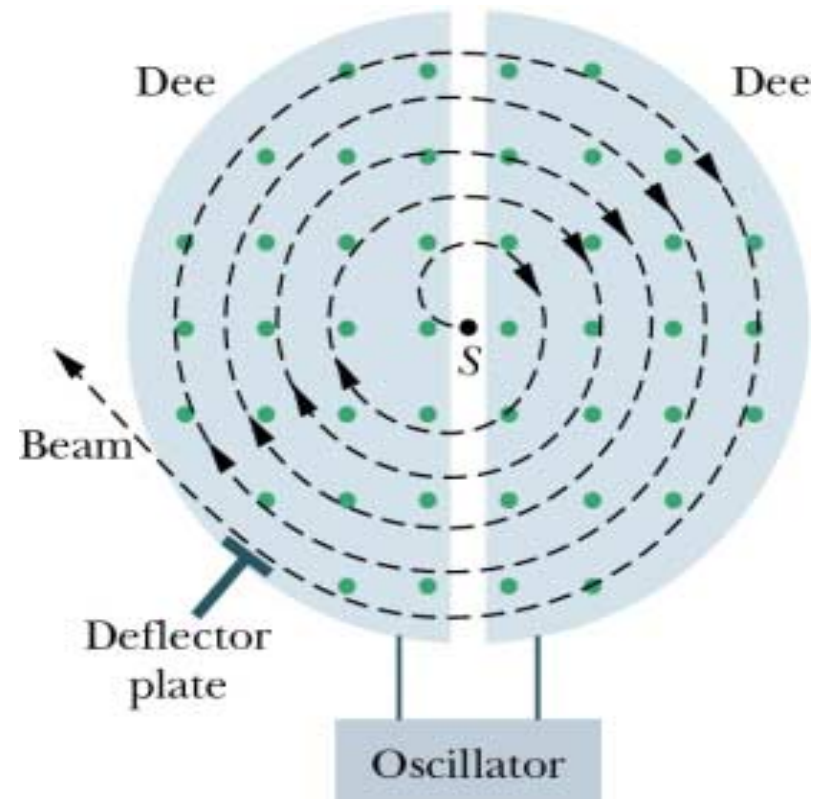
Magnetic Fields

- Nuclear and high-energy physicists probe the structure of matter by
 - Circulating charged particles in a magnetic field and applying electrical kicks to accelerate the particles.
 - After they reach the desired energy they slam into solid target or collide it with another particle head-on.
- Two devices used to accelerate particles are:
 - **Cyclotron:** National Superconducting Cyclotron Laboratory (NSCL) – MSU – **Nuclear Physics**
 - **Synchrotron:** Fermi National Accelerator Laboratory (Fermilab) – **Particle Physics**

Magnetic Fields (Fig. 29-15)

- **Cyclotron**

- Particles starts at the center.
- They circulate inside 2 hollow metal D shaped objects
- Alternate the electric sign of the Dees so V across gap alternates (the oscillator does this).
- Whole thing immersed in magnetic field B (green dots pointing out of page) \perp to v
- B approximately 1-10 T (tesla).

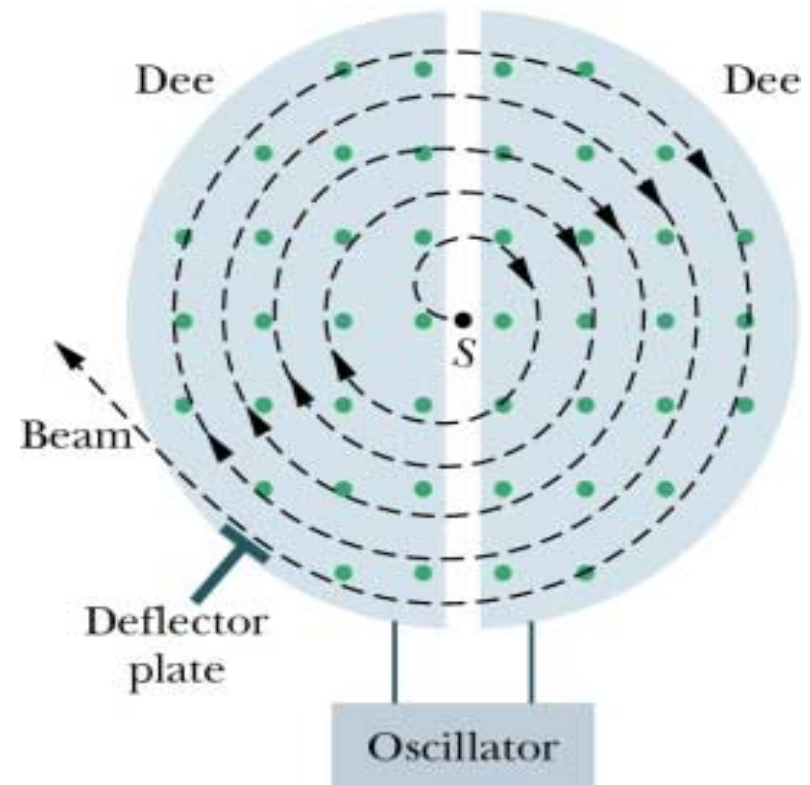


Magnetic Fields (Fig. 29-15)

- **Cyclotron**

- Proton starting in center will move toward negatively charged Dee
- Inside Dee E field = 0 (inside conductor) but B field causes proton to move in circle with radius which depends on v

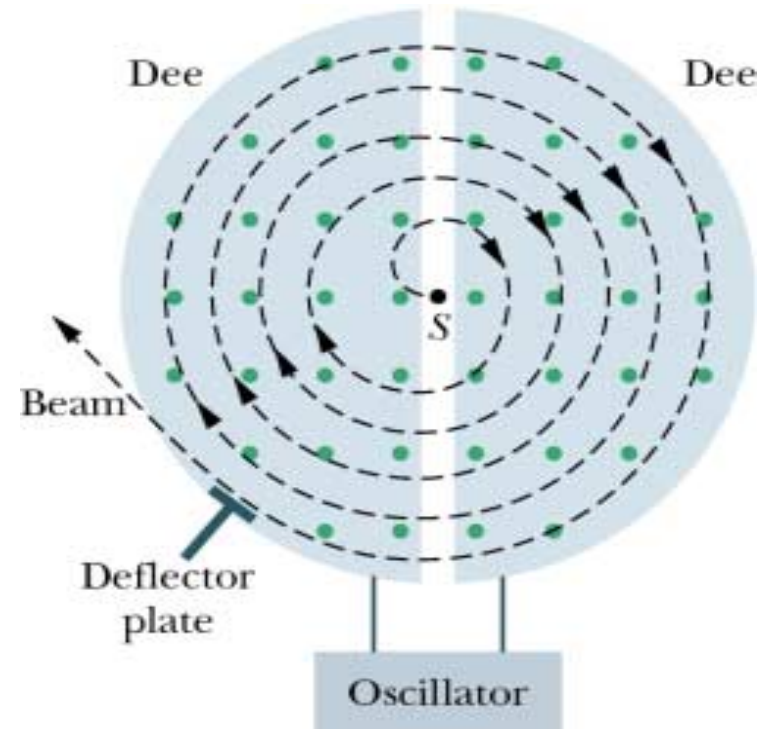
$$r = \frac{mv}{qB}$$



Magnetic Fields (Fig. 29-15)

- **Cyclotron**

- When proton enters gap between Dees E field is flipped so proton is again attracted to negatively charged Dee
- Every time proton enters gap the polarity of the Dees is changed and the proton is given another kick (accelerated)



Magnetic Fields (Fig. 29-15)

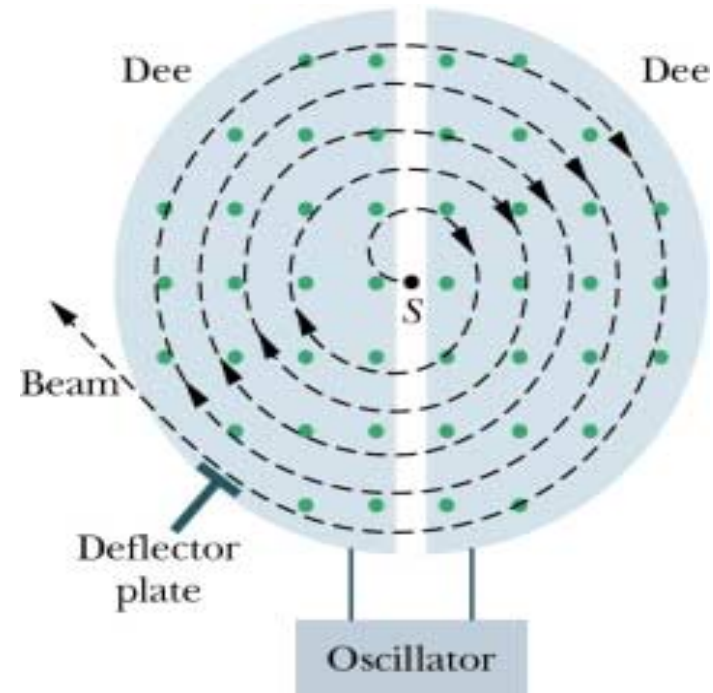
- **Cyclotron**

- Key is that the frequency, f , of the proton does not depend on v and must equal the f_{osc} of the Dees

$$f = f_{osc}$$

$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

$$qB = 2\pi m f_{osc}$$



Magnetic Fields

NSCL - MSU

- NSCL cyclotron
- National Superconducting Cyclotron Laboratory
 - Fits in building next door
 - Can accelerate many different kinds of nuclei.
 - Generates beams of nuclei with energies up to 20 GeV (1 GeV = 10^9 eV)



Machining the surface of the K500 cyclotron radio-frequency (RF) liner on a 10-foot-diameter vertical lathe. The RF liner is a thin copper shell that surrounds the magnets in the cyclotron and carries away excess power supplied by the radio frequency. Both cyclotrons currently operating at the NSCL have been designed and built in the laboratory.

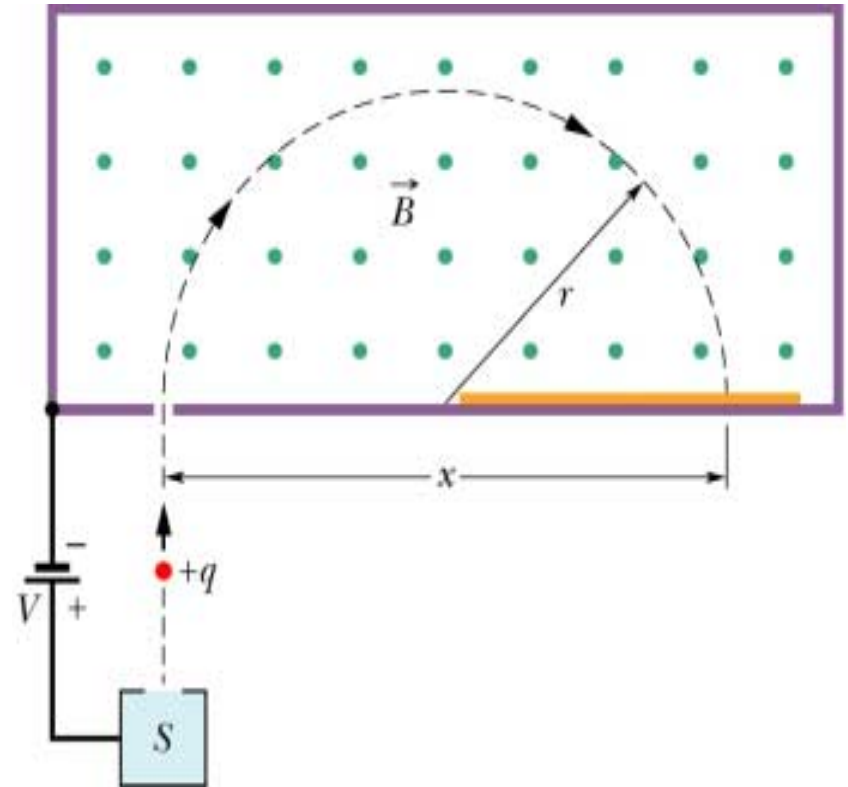
Magnetic Fields

- **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)



Magnetic Fields (Fig. 29-14)

- 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).



Magnetic Fields (Fig. 29-12)

- Conservation of energy

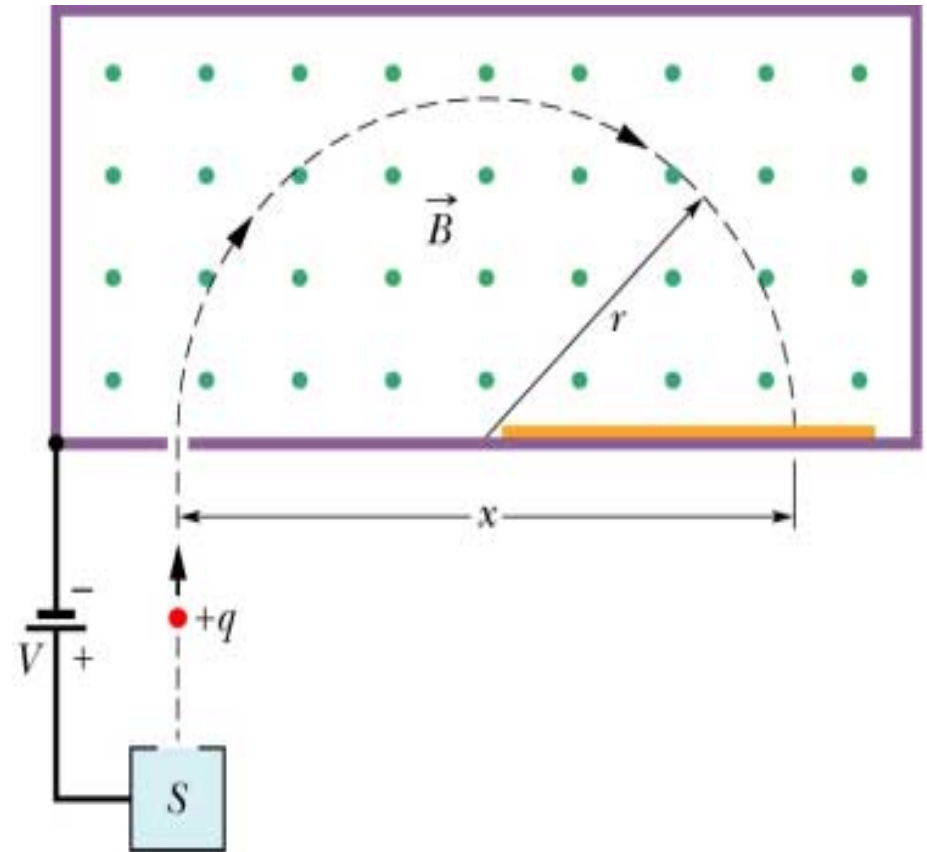
$$\Delta K + \Delta U = 0$$

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

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

- Substituting v into relation for r gives

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



Magnetic Fields (Fig. 29-12)

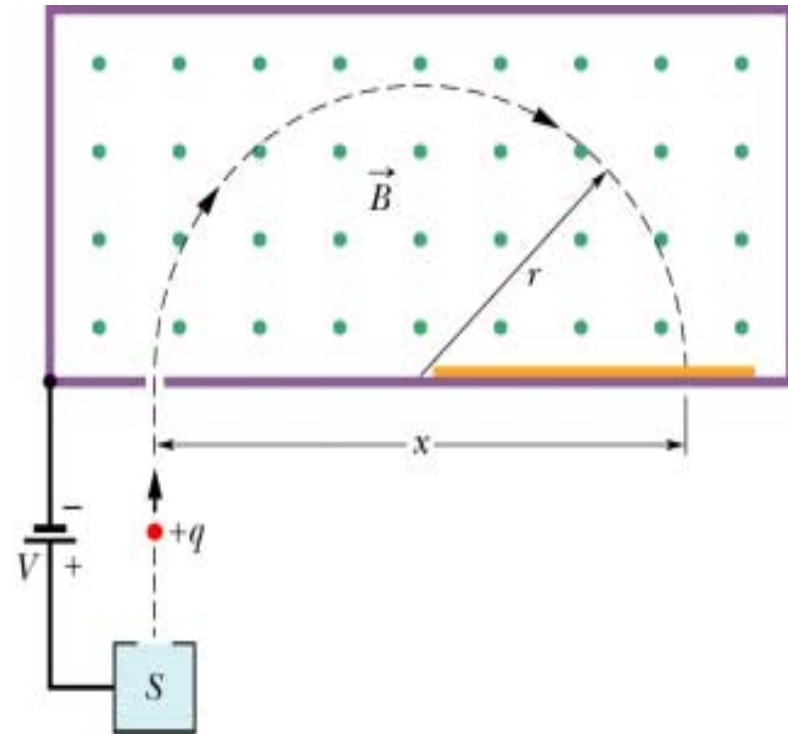
- Rearranging for m

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

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

- Distance $x = 2r$

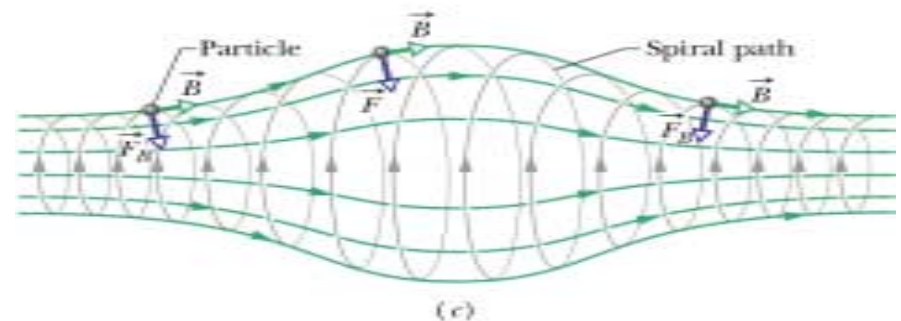
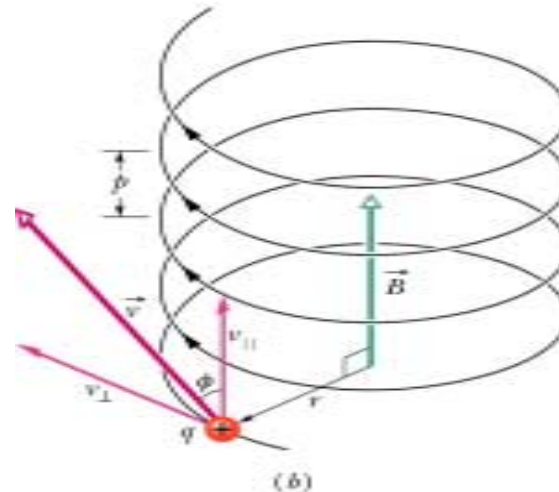
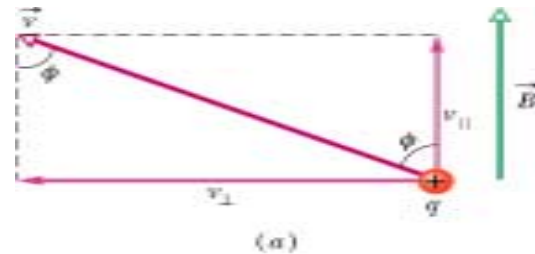
$$m = \frac{B^2 x^2 q}{8V}$$



Application: Measure masses of tiny particles (**mass spectrometers**)

Magnetic Fields (Fig. 29-11)

- So far assumed v and B were always \perp
- If v has a component \parallel 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.



Magnetic Fields (Fig. 29-12)

- **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)

