# PLC for Today
Wednesday, March 13

- I will be available at 2:00 pm in PLC.
- If the PLC is empty, I will be available in my office, Physics 122.
- If no students come, I may leave the office before 4:30 pm.
- There will be no evening PLC.

Applications of Electromagnetism
(Optional Lecture)

- **Particle Accelerators**
  - Linear Accelerators
  - Cyclotrons
- **Beamline Magnets**
  - Steering Magnets
  - Focusing Magnets
- **Velocity Selectors**
- **Detectors**
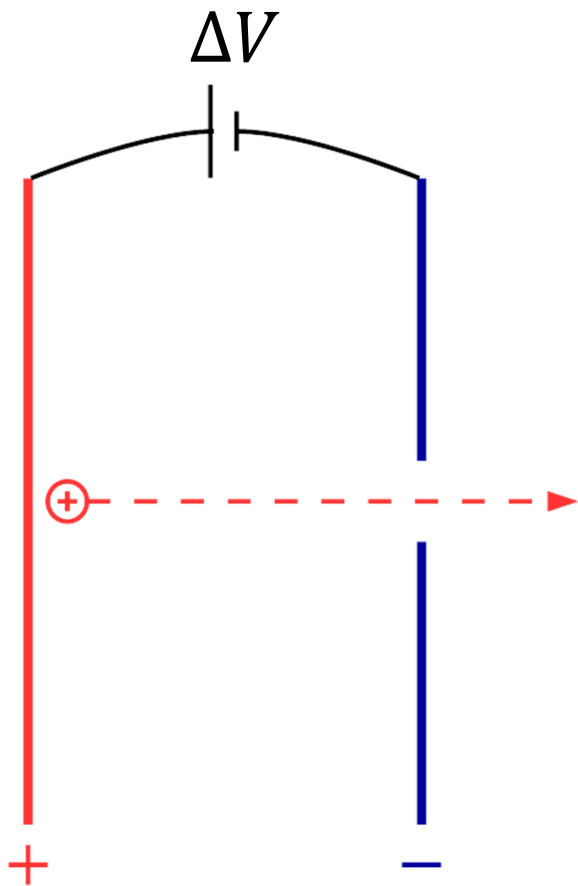 - Spectrometers
  - Drift Chambers

Linear Accelerator

Charged particles are accelerated across a potential difference.

ΔV
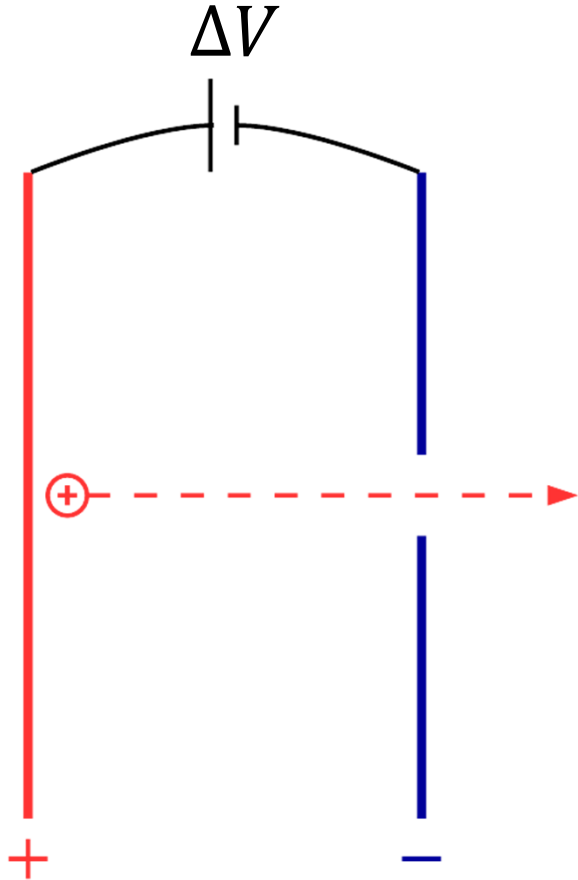
$$\vec{F} = q\vec{E}$$

Linear Accelerator

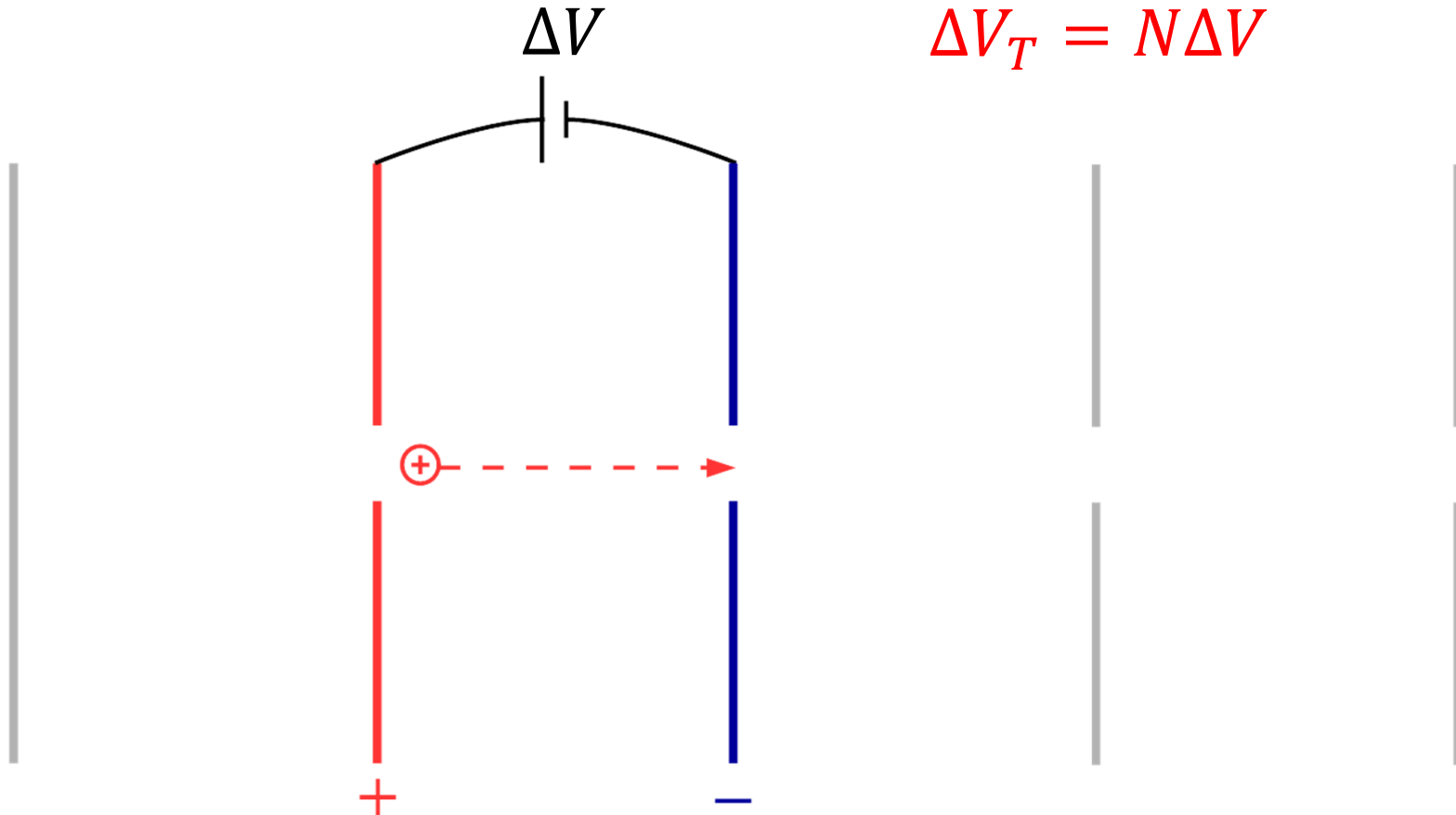Charged particles are accelerated across a potential difference.

$$U_0 + K_0 = U_f + K_f$$

$$-\Delta U = K_f$$

$$-q\Delta V = \frac{1}{2}mv_f^2$$
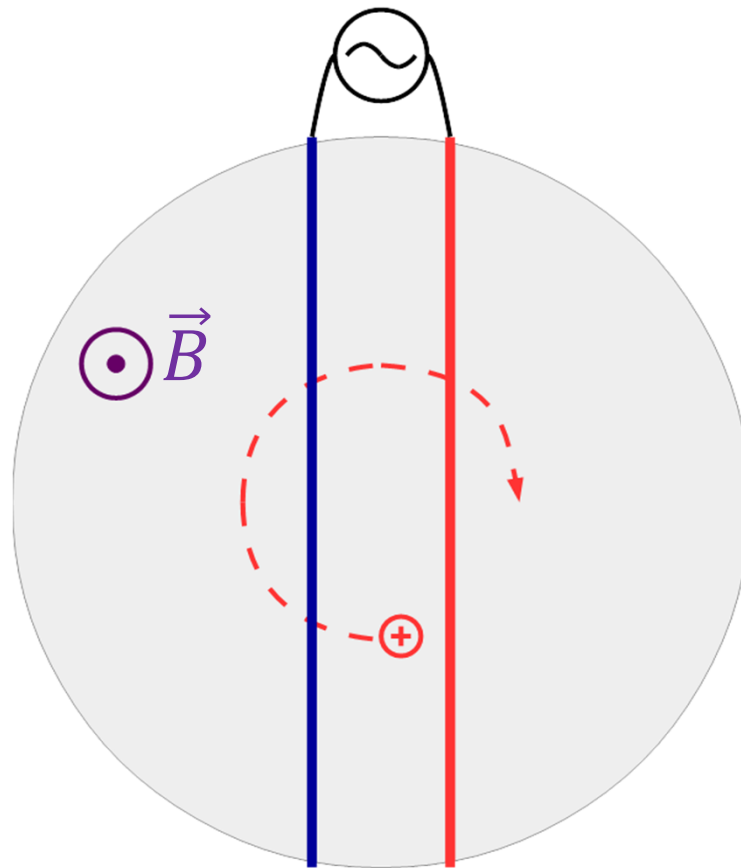
$$\sqrt{\frac{2|q\Delta V|}{m}} = v_f$$

ΔV

$+$ $-$

Linear Accelerator

Potential difference across plates when particle is between plates. (N regions between plates)

$$\Delta V$$

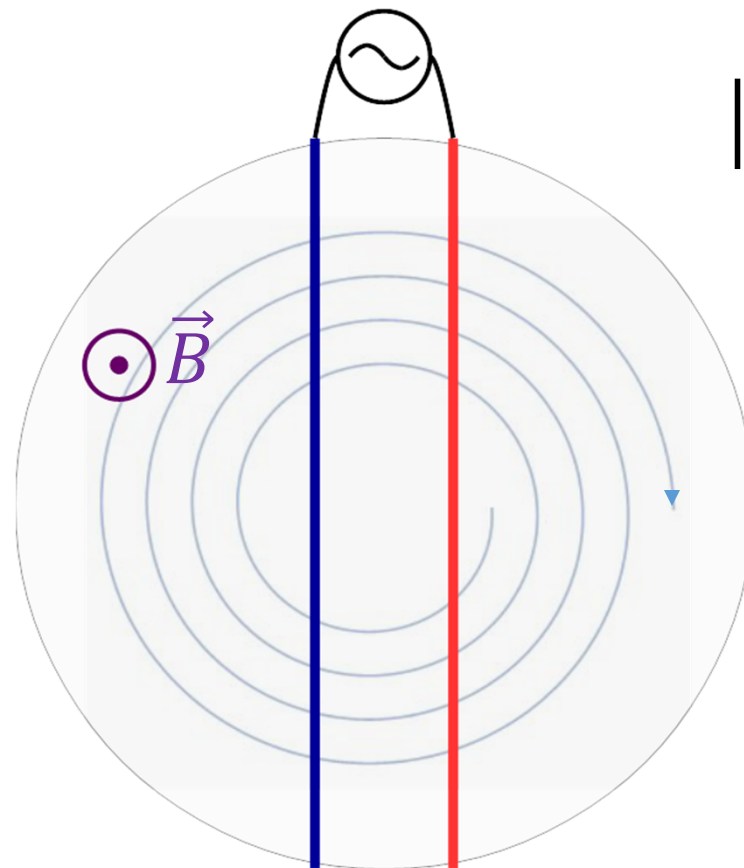$$\Delta V_T = N\Delta V$$

$+$ $\qquad$ $-$

Cyclotron

If you want to accelerate particles and are limited on space - keep sending them through the same two plates.

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

Cyclotron

Particles spiral out as they accelerate, increasing speed and radius proportionally.

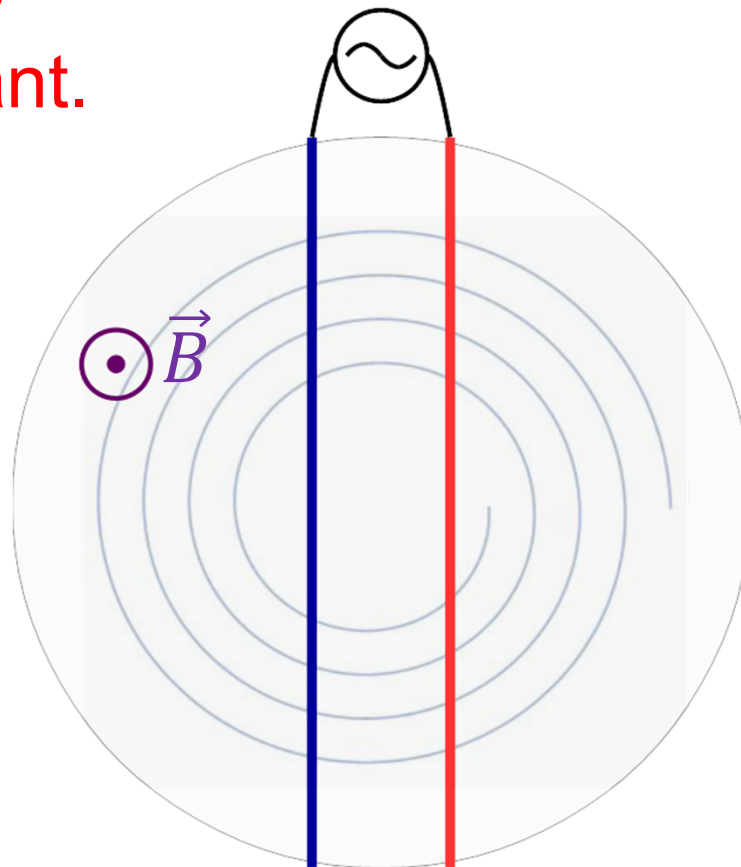$$\left|q\vec{v} \times \vec{B}\right| = \frac{mv^2}{r}$$

$$qvB = \frac{mv^2}{r}$$

$$\frac{qB}{m} = \frac{v}{r}$$

$\odot \vec{B}$

Cyclotron

Particles spiral out as they accelerate, increasing speed and radius proportionally so that the period and frequency remain constant.

$$\frac{|q|B}{m} = \frac{v}{r}$$
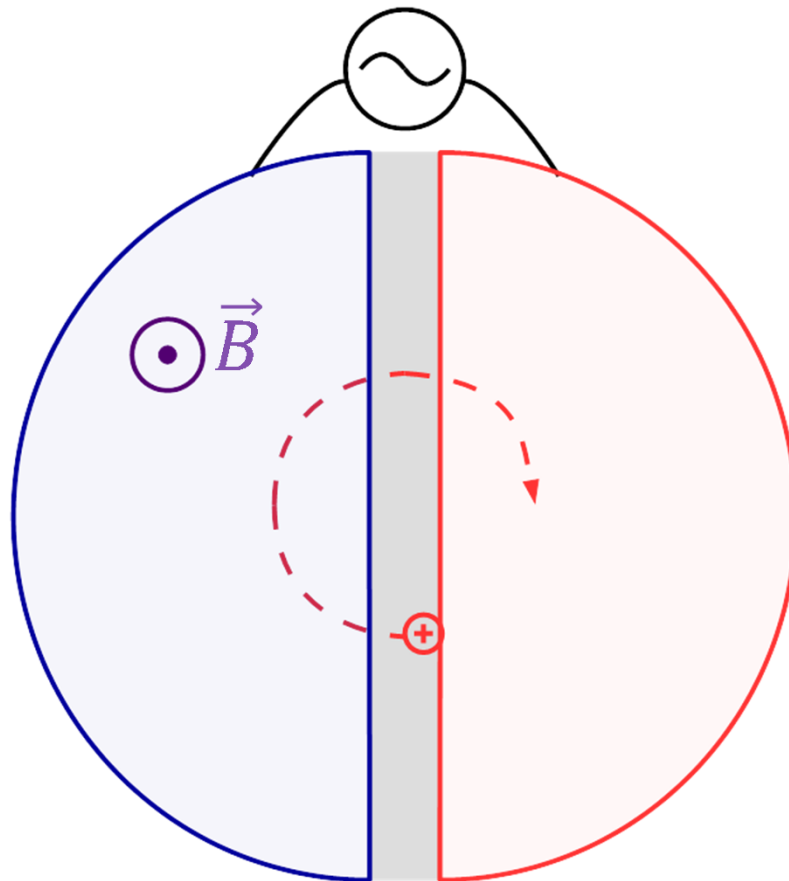

$$T = \frac{2\pi r}{v}$$

$$T = \frac{2\pi m}{|q|B}$$
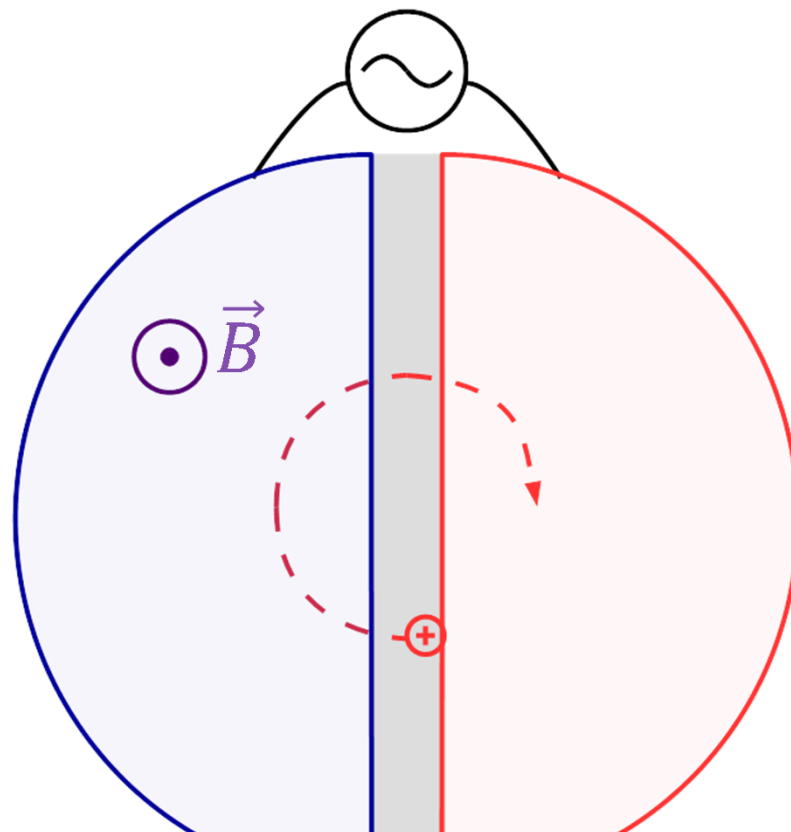
$$f = \frac{|q|B}{2\pi r}$$

Cyclotron

Instead of plates, use "*D*'s", hollow *D*-shaped conductors with a top, a bottom and an outside edge.

Cyclotron

Instead of plates, use "*D*'s", hollow *D*-shaped conductors with a top, a bottom and an outside edge.
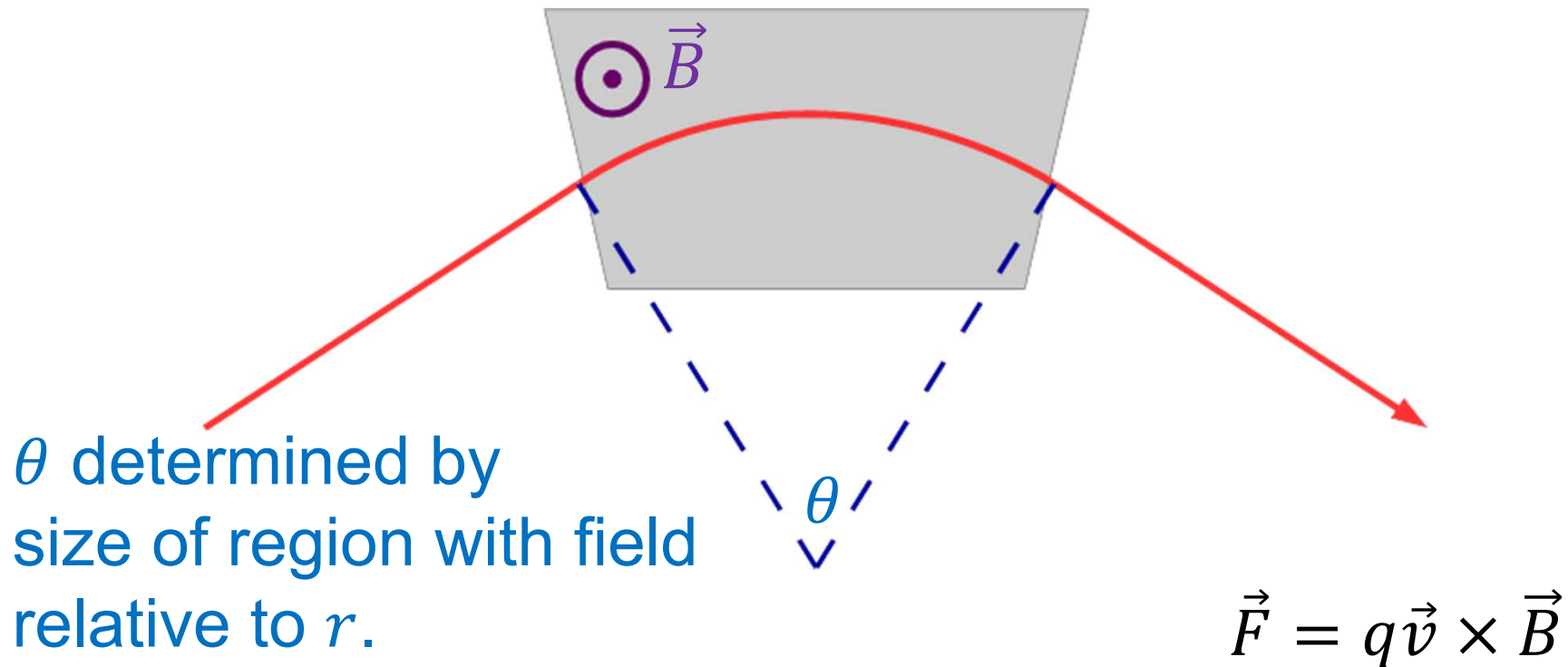
$\odot \vec{B}$

Modern cyclotrons use complex electromagnetic fields created without *D*'s.
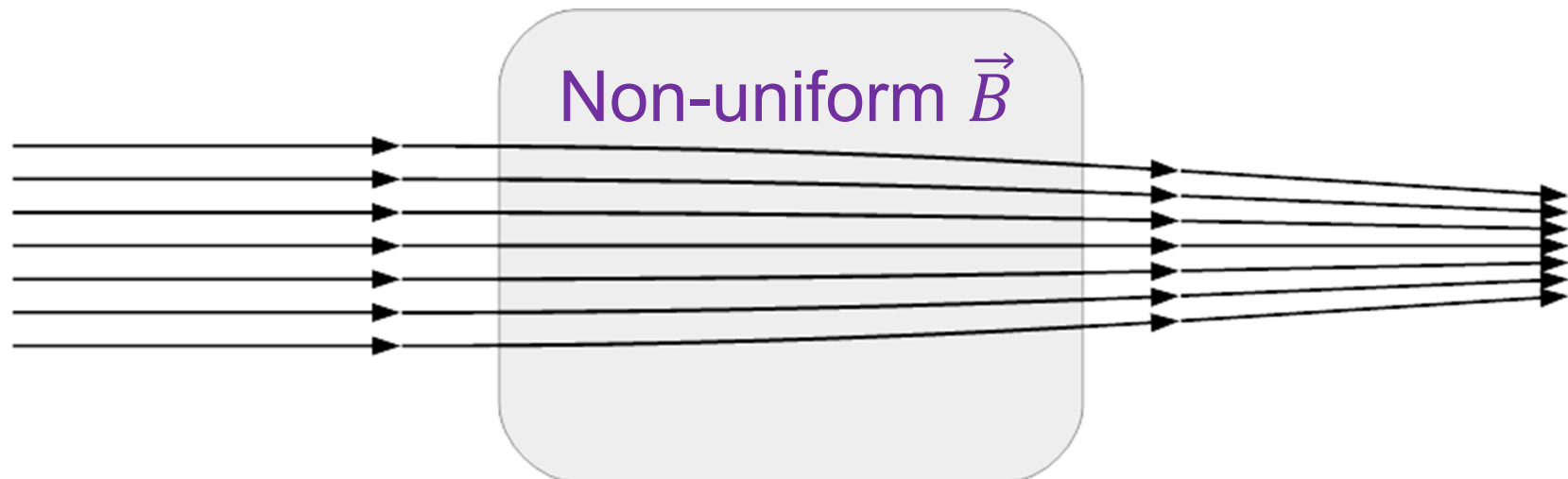
Steering Magnets

Beamlines are turned with steering magnets.

$$r = \frac{mv}{|q|B}$$

$\odot \; \vec{B}$

θ determined by size of region with field relative to r.

θ

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

Focusing Magnets

Beamlines are focused with special magnets.
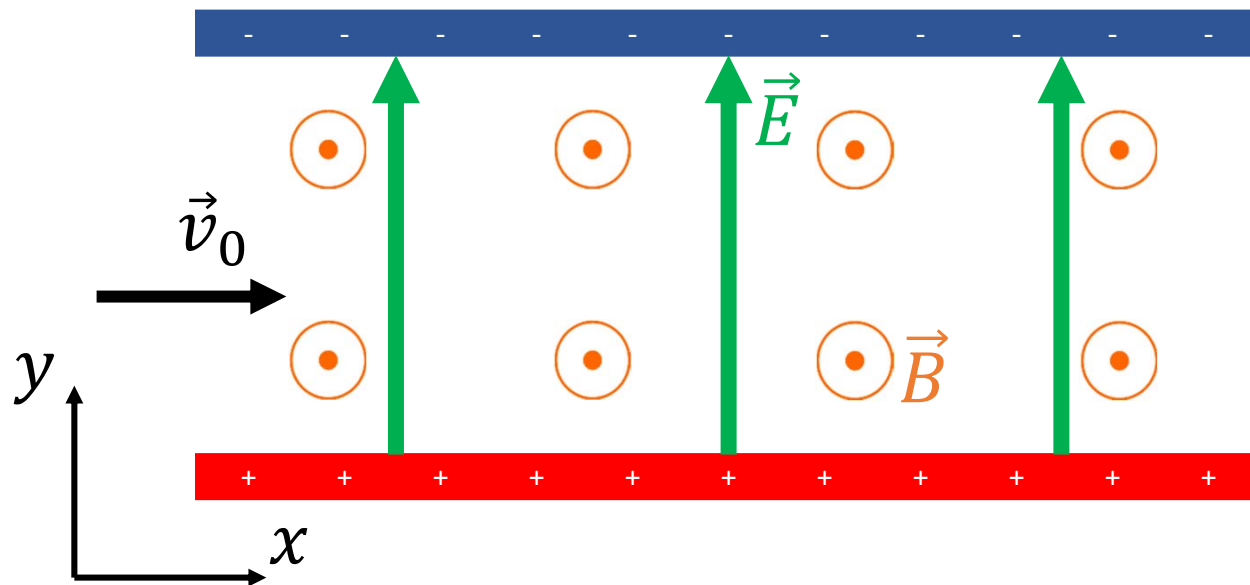
Non-uniform $\vec{B}$

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

(Unfortunately, a magnet can only focus in one transverse dimension and at one location along the beam. Beamlines may have many such focusing magnets.)

Velocity Selector
(See previous lecture.)

If $v_0 = \dfrac{E}{B}$, then $\vec{F} = 0$ and the trajectory is a straight line.
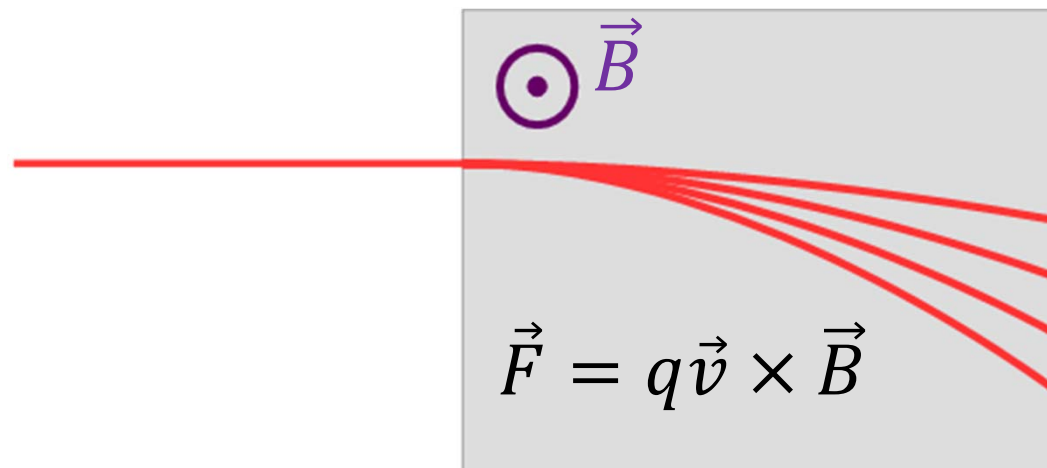
$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

Spectrometers

Consider a bending magnet with a back wall that registers interactions with charged particles. The particles will separate according to their radius of curvature.
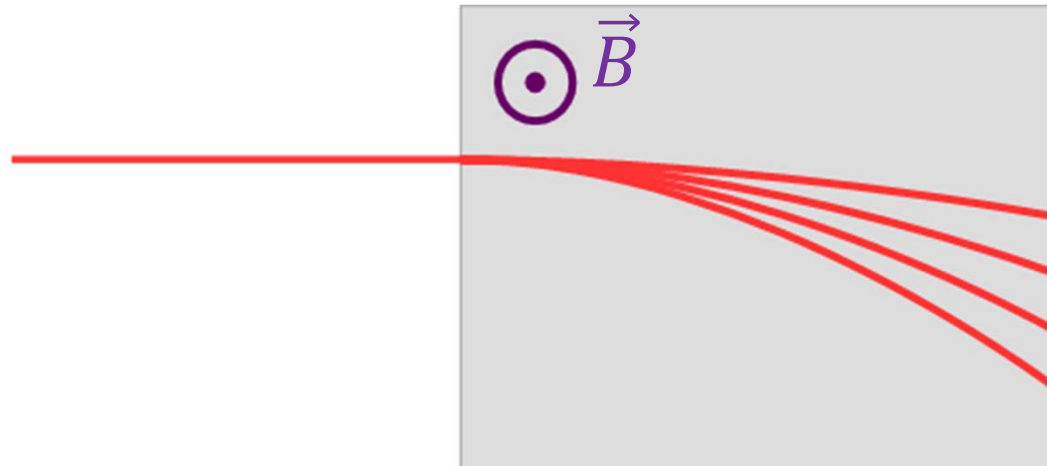
$$r = \frac{mv}{|q|B}$$

$$\vec{B}$$

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

Spectrometers

Consider nuclei that have been accelerated across a potential difference ΔV yielding a radius of curvature in the magnetic field

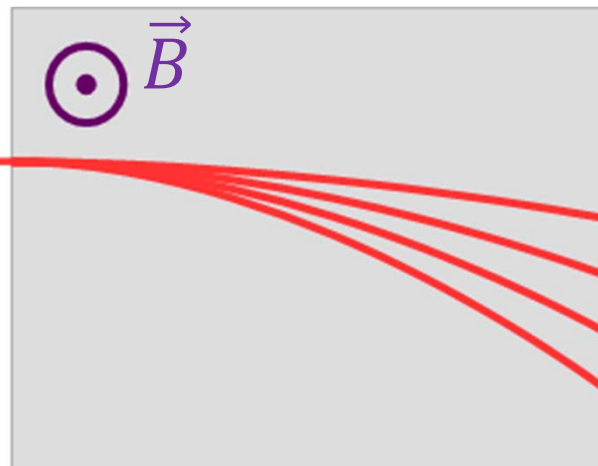$$r = \frac{1}{B}\sqrt{\frac{2m\Delta V}{q}} \sim \sqrt{\frac{m}{q}} \sim \sqrt{\frac{A}{Z}}$$

Spectrometers

Isotope	$\sqrt{A/Z}$
$^{13}_{7}\text{N}$	$\sqrt{13/7}$
$^{14}_{7}\text{N}$	$\sqrt{2}$
$^{15}_{7}\text{N}$	$\sqrt{15/7}$
$^{16}_{8}\text{O}$	$\sqrt{2}$
$^{17}_{8}\text{O}$	$\sqrt{17/8}$
$^{18}_{8}\text{O}$	$\sqrt{9/4}$

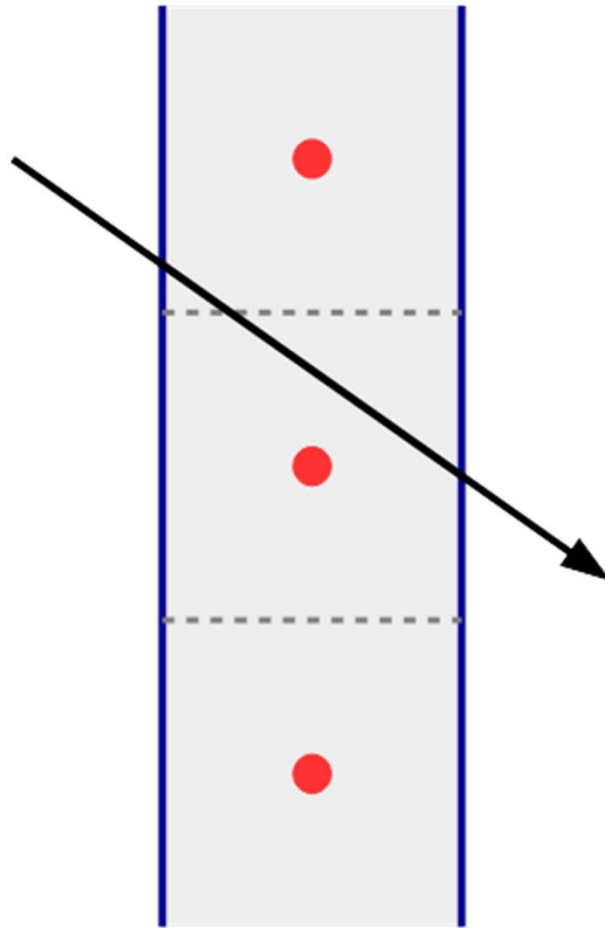Separation of fully ionized isotopes by mass to charge ratio.

$$r = \frac{1}{B}\sqrt{\frac{2m\Delta V}{q}} \sim \sqrt{\frac{m}{q}} \sim \sqrt{\frac{A}{Z}}$$
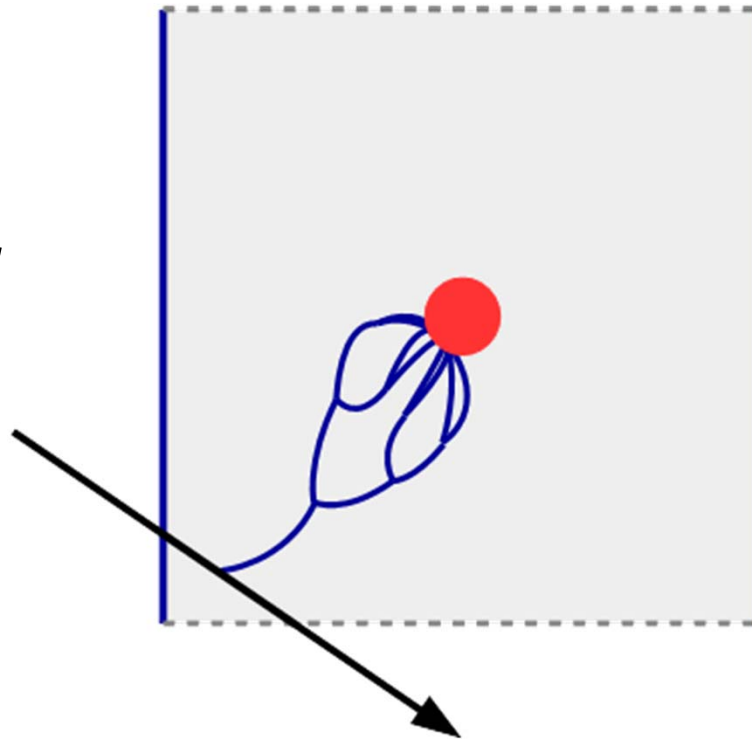
$\odot\ \vec{B}$

Drift Chambers

Drift chambers signal the passage of ionizing particles.

Drift Chambers

- Passing particle ionizes atoms in gas.
- Free electrons accelerate towards cathode.
- Electrons ionize more atoms on way to cathode.
- Momentary measureable current created.

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$$

$$\vec{F} = q\vec{E}$$

Accelerator Physics

Examples from today's lecture:
- Particles accelerated with electric fields.
- Particle beams steered with magnetic fields.
- Particle beams focused with magnetic fields.
- Particle velocities selected with crossed electric and magnetic fields.
- Particles identified with magnetic fields.
- Particle location and direction determined with electric fields.