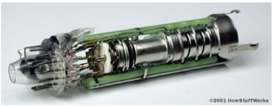
4.3 Particles in Magnetic Fields, Current Carrying Wires

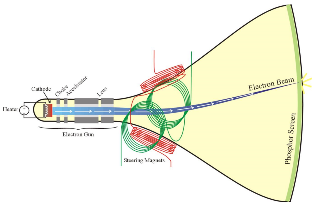
Applications

Old TV screens (Cathode Ray Tubes (CRT)) used moving electron beams to make images. (Show CRT - Anecdote)

Magnetically deflected electrons struck the inner surface of the screen at different locations.
Welding anecdote.



Electron Gun



Mass Spectrometers

Mass spectrometers analyze moving ions: comparing ion size vs. charge determines sample composition.

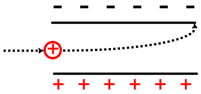
Step 1: ions with a specific velocity pass through a velocity selector.

Step 2: ions reach a detector, entering a B-field which deflects them based on mass.

Step 1: Velocity Selection

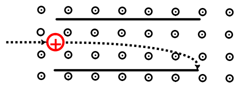
Two forces act on moving ions:

A. Electric field (voltage) pushes/pulls directly as ions move past charged plates (separated r meters):



$$F_E = qE = \frac{q\Delta V}{r}$$

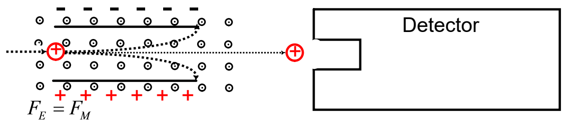
B. A perpendicular B-field uses right hand rule:



$$F_M = qvB$$

Step 1 Summary

When forces balance, ions of a particular velocity reach the detector.



$$F_E = F_M$$

$$\frac{q\Delta V}{r} = qvB$$

$v = \frac{\Delta V}{B \cdot r}$	v = velocity (m/s) V = voltage (V) B = magnetic field (T) r = plate separation (m)

Note: Charge is irrelevant!

1. Velocity Selector Example

Protons pass into a velocity selector with a B-field of 5.0 T, and an electric field of 1,500 V (r = 3.7 cm). What speed makes it through?

$$v = \frac{\Delta V}{B_1 d} = \frac{1{,}500\,V}{5.0\,T \cdot 0.037\,m} = 8{,}100\,\frac{m}{s}$$

Step 2: Detector

Particle accelerator image: why are there spirals?

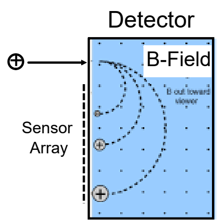
When ions enter a detector's B-field, they follow an arc.

Mass differences determine where ions are sensed.

$$F_c = F_M$$

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

$m = \frac{qBr}{v}$	m = mass (kg) q = charge (C) B = magnetic field (T) r = arc radius (m) v = velocity (m/s)



2. Detector Example

The protons pass into a detector (at 8,100 m/s) with a B-field of 0.023 T, and follow a curve with a diameter of 7.35 E -3 m.
What's a proton's mass (hint: use your resources for charge, not mass! That's cheating)?

$$m = \frac{qBr}{v} = \frac{1.6E-19C \bullet 0.023T \bullet (7.35E-3m \div 2)}{8{,}100\frac{m}{s}} = 1.7E-27kg$$

Force on Wires

Electric current is affected by B-fields.
Assume current is positive charges:

$\vec{F}_M = I\vec{\ell} \times \vec{B}$ AP Equation	F = force (N) I = current (A (C/s)) l = wire length (m) B = magnetic field (T)

At an angle:

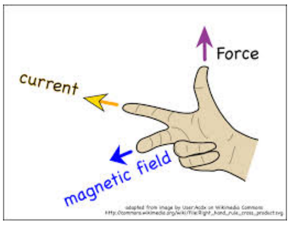
$$\left|\vec{F}_M\right| = \left|I\vec{\ell}\right|\left|\sin\theta\right|\left|\vec{B}\right|$$

AP Equation

Merge these two!

Right Hand Rule Again

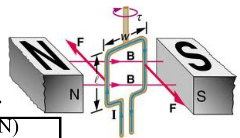
Instead of velocity, consider current direction:



Torque on Current Carrying Loops

Current in motor loops (windings) causes torque.

Loops have cross sectional area.



$\tau = NIAB\sin\theta$	τ = torque (m • N) N = loop number I = current (A (C/s)) A = loop area (m^2) B = magnetic field (T)

Demo: Cut-away motor.

3. Torque Example

An 8.0 amp motor has 312 windings, each with a 0.0020 m^2 area. What B-field produces a maximum torque of 65 m•N?

At maximum torque,
$\theta = 90°$ ($\sin 90° = 1$):

$$\tau = NIAB\sin\theta$$

$$B = \frac{\tau}{NIA} = \frac{65\,m \bullet N}{312 \bullet 8.0\,A \bullet 0.0020\,m^2}$$

$$= 13T$$

Homework 4.3

Problems 4.3 in your Booklet
Due: Next Class