Chapter 26: Magnetism, Force and Field
Tuesday October 11th

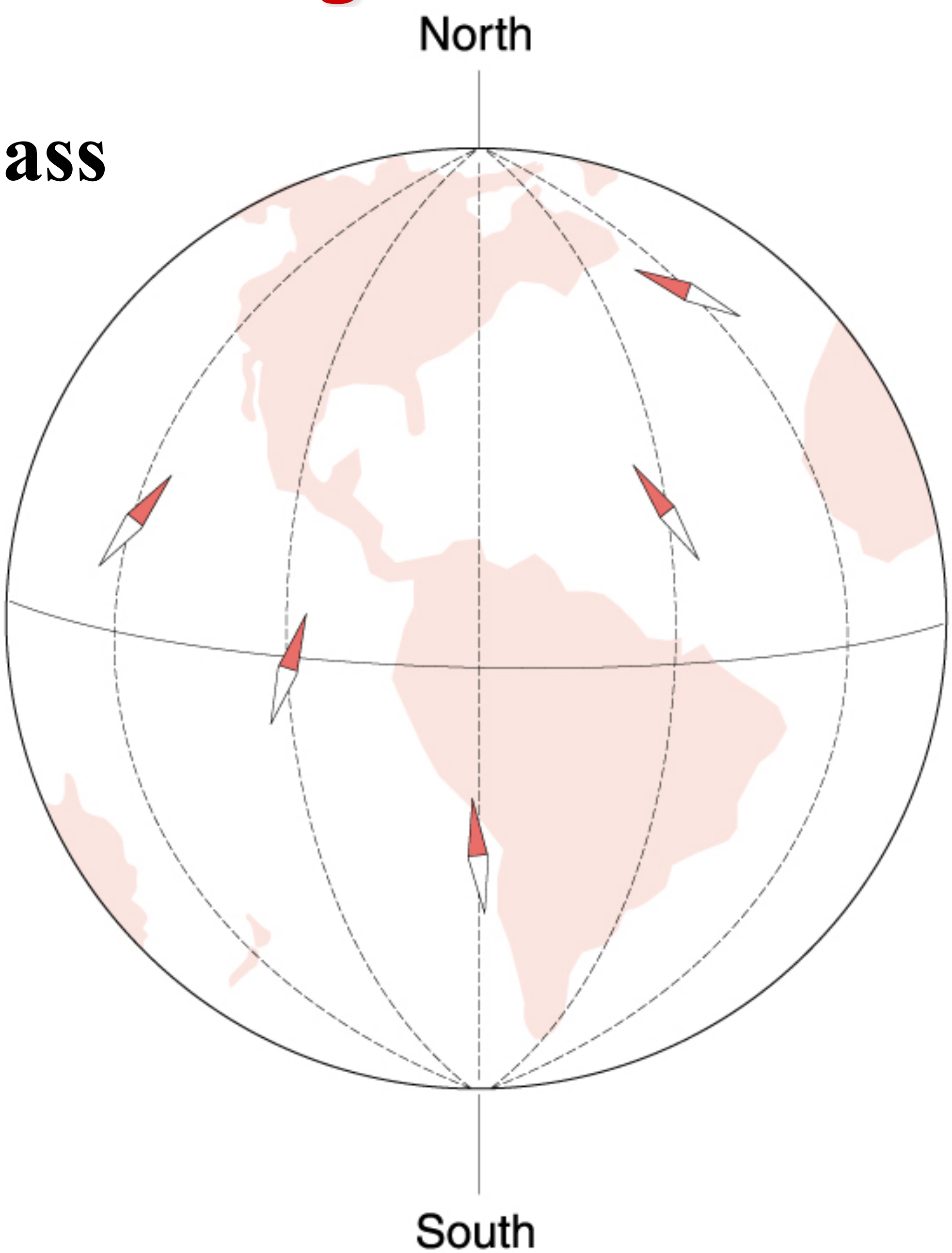
Cumulative mid-term exam next Thursday
In-class – 75 minute, written exam

- Review of Mini Exam 3
- Brief history of magnetism
- Forces on moving charges
  - The Lorentz force
  - Velocity, momentum and mass detectors
  - Cyclotron motion
- The force on a current carrying wire
  - Torque on a current loop (if time)

Reading: up to page 442 in the text book (Ch. 26)

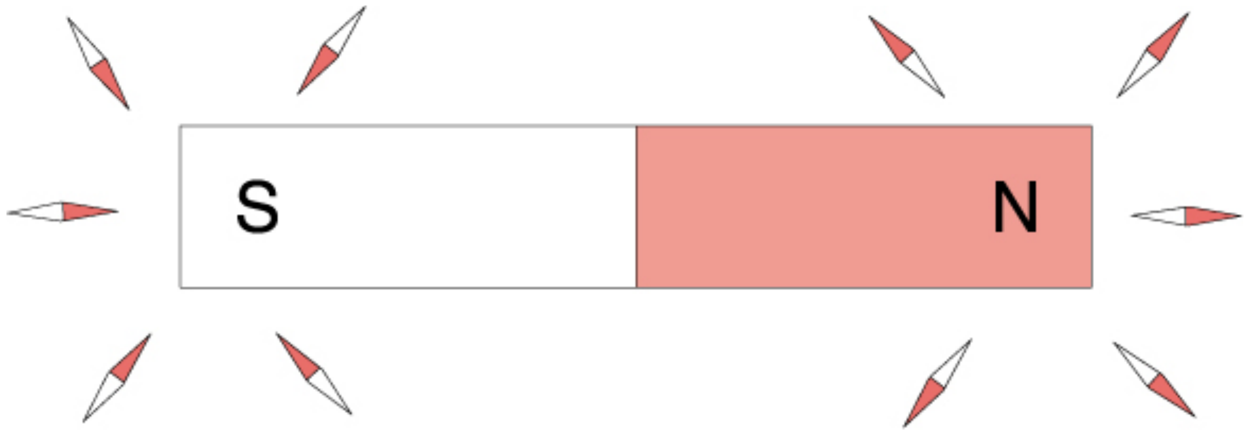
Magnetic Field

The compass
1000 AD



The Magnetic Field

The 'Gilbert Model' (William Gilbert - 1600)

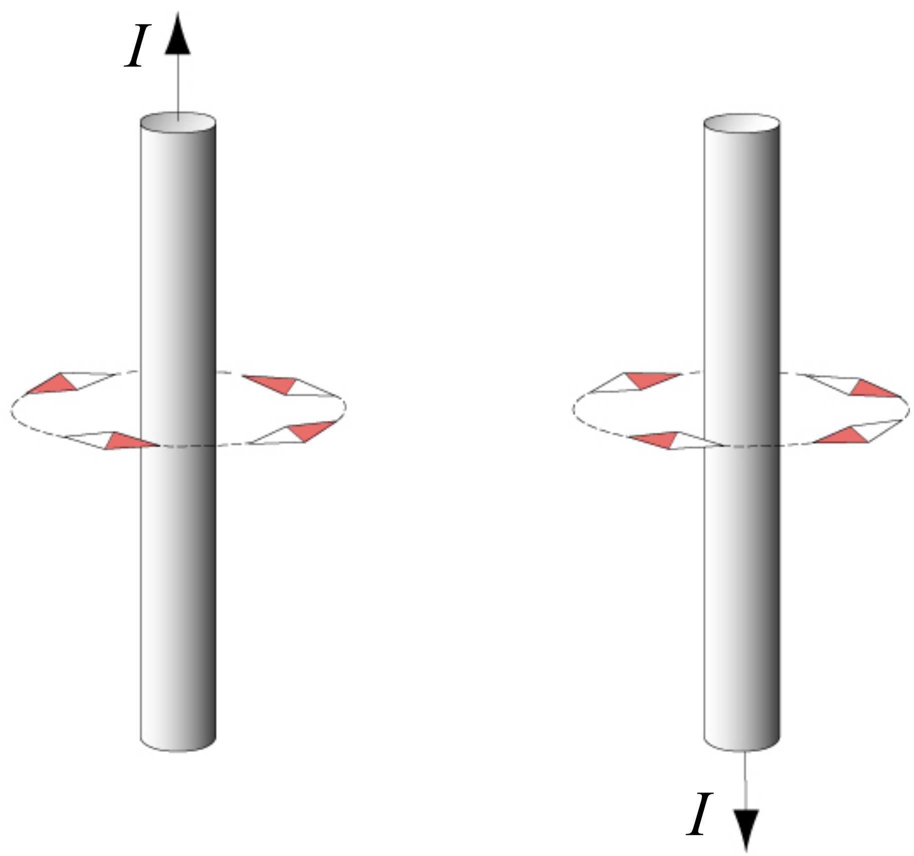


Like poles repel, and unlike poles attract.

The Magnetic Field

1820 - Electromagnetism, Current

In 1820, a physicist Hans Christian Oersted, learned that a current flowing through a wire would move a compass needle placed beside it. This showed that an electric current produced a magnetic field.



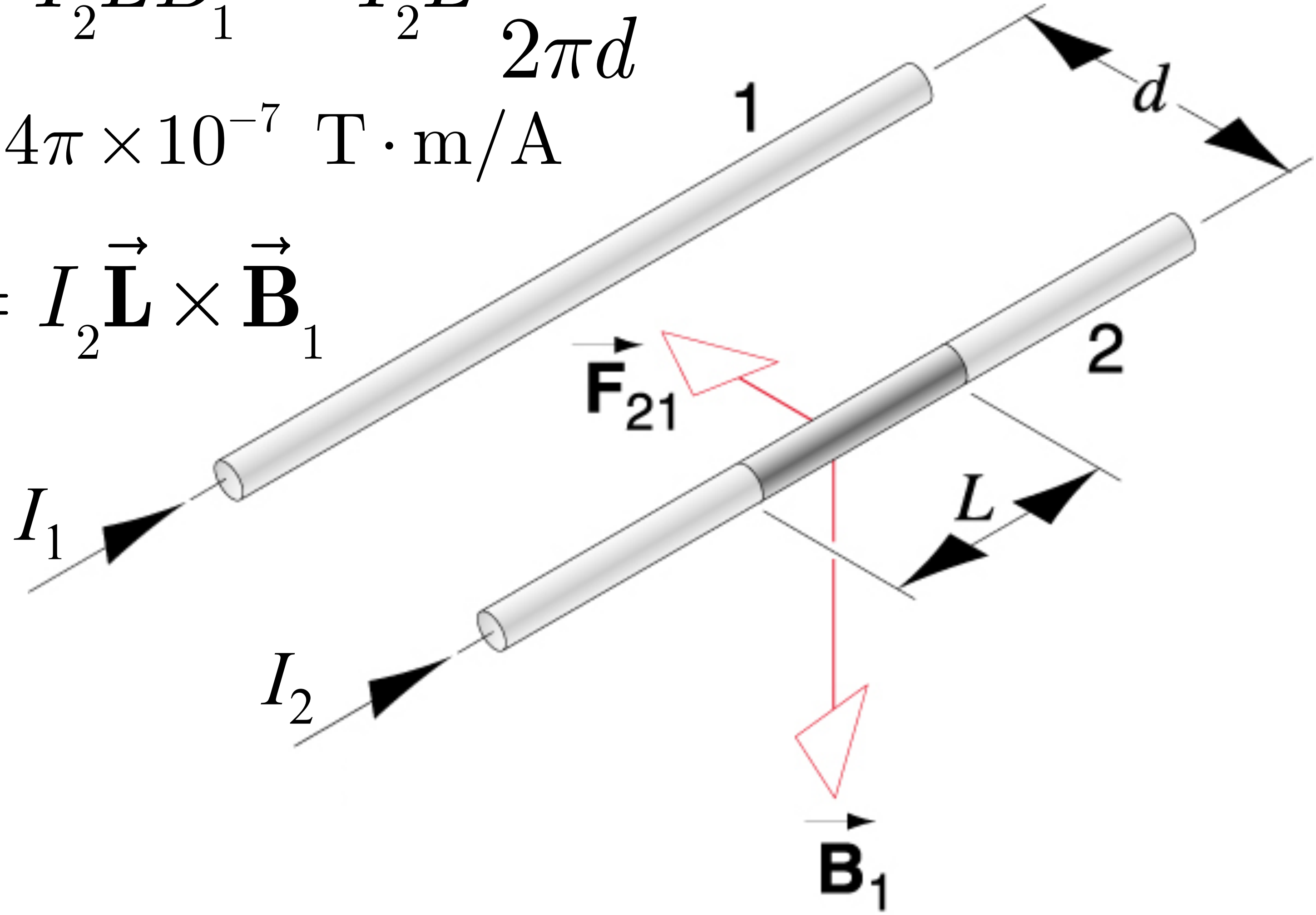
Ampere: magnetic force between two wires

Also 1820

$$F_{21} = I_2 L B_1 = I_2 L \frac{\mu_o I_1}{2\pi d}$$

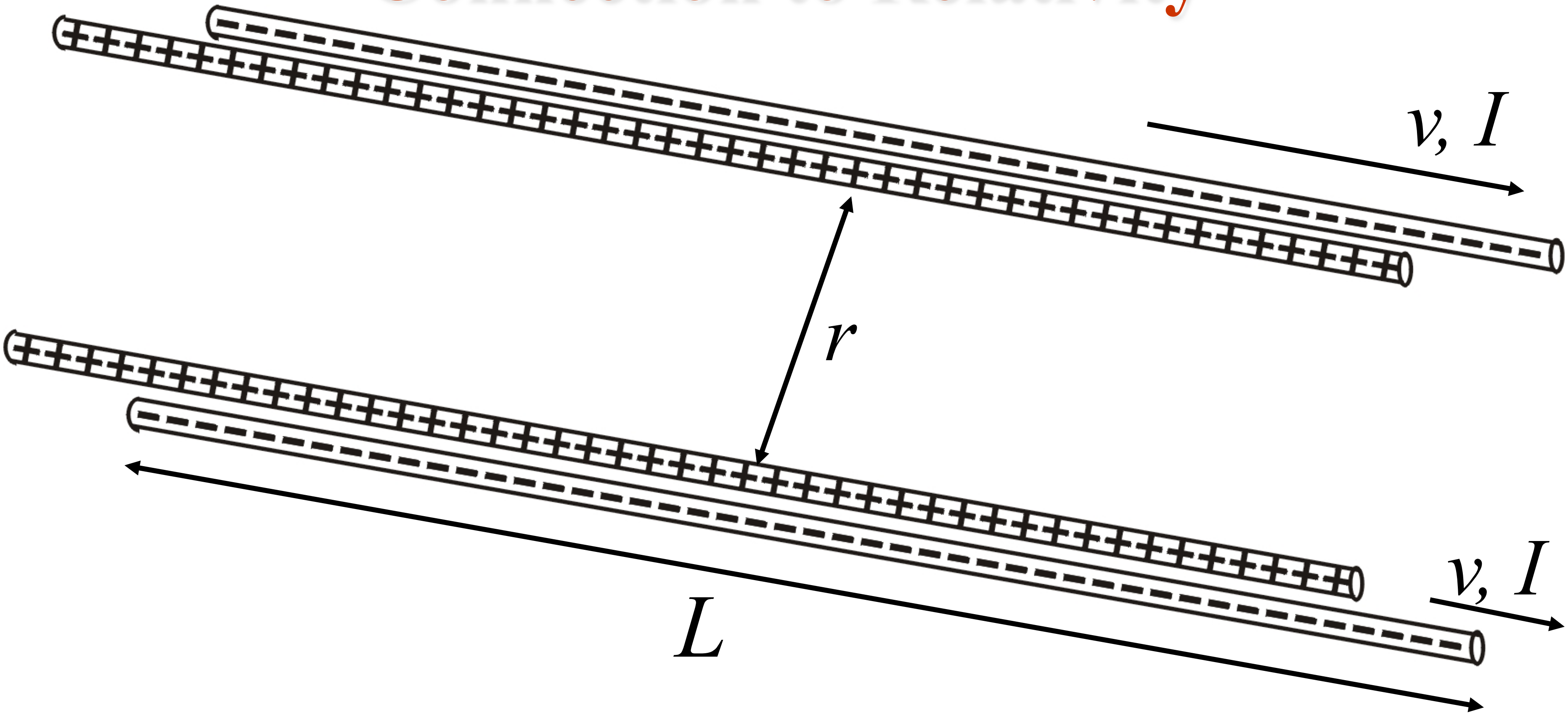
$$\mu_o = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$$

$$\vec{\mathbf{F}}_{21} = I_2 \vec{\mathbf{L}} \times \vec{\mathbf{B}}_1$$



μ_o chosen so that when $I_1 = I_2 = 1$ A, and $L = d = 1$ m, $F_{21} = 2\times10^{-7}$ N

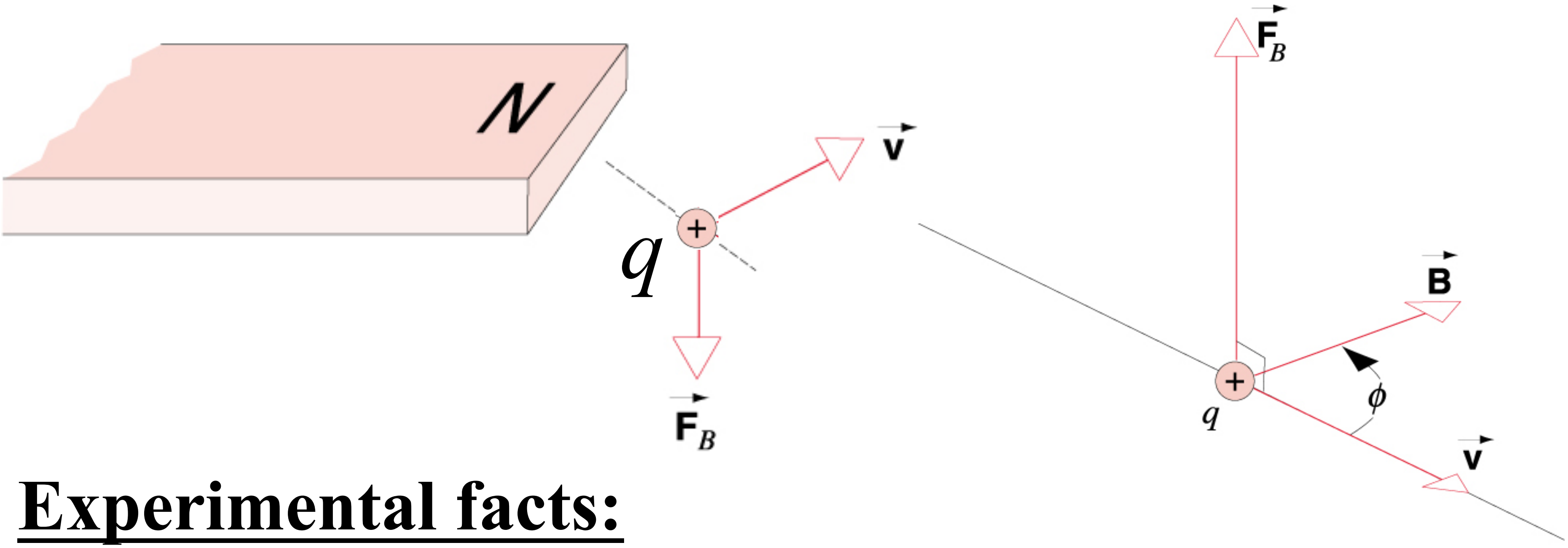
Connection to Relativity



Because + and – charges move at different speeds, the electrostatic force between them is modified by an amount v^2/c^2

$$F_{+-} = \left[\frac{\lambda}{2\pi\varepsilon_o d} \times \lambda L\right]\left(\frac{v^2}{c^2}\right) = \left(\frac{I}{2\pi\varepsilon_o c^2 d}\right) IL = BIL; \quad B = \frac{\mu_o I}{2\pi d}; \quad \frac{1}{c^2} = \mu_o \varepsilon_o$$

Magnetic Forces Act on Moving Charges



<u>**Experimental facts:**</u>

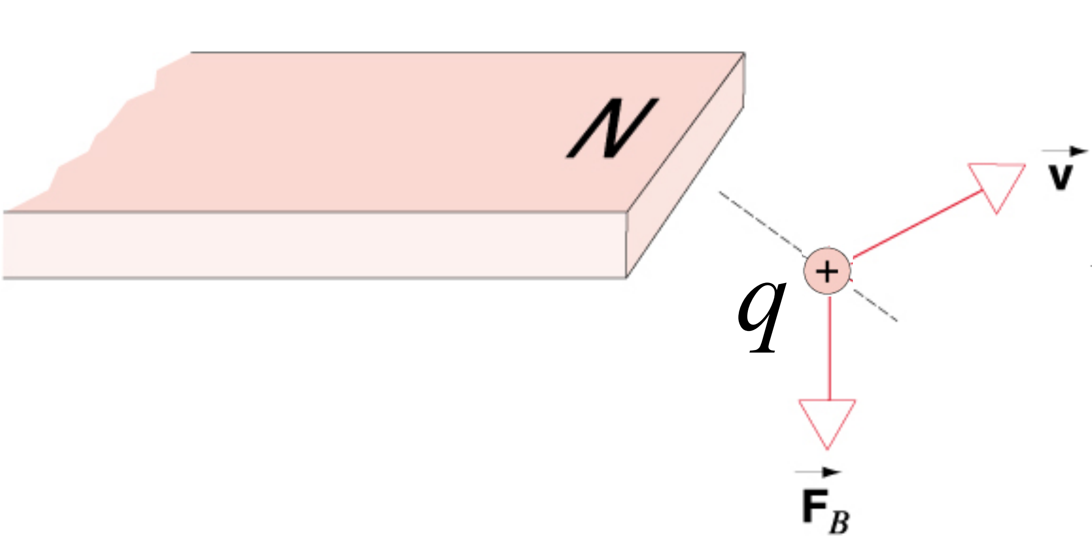
1. The magnitude of the force is proportional to the velocity.

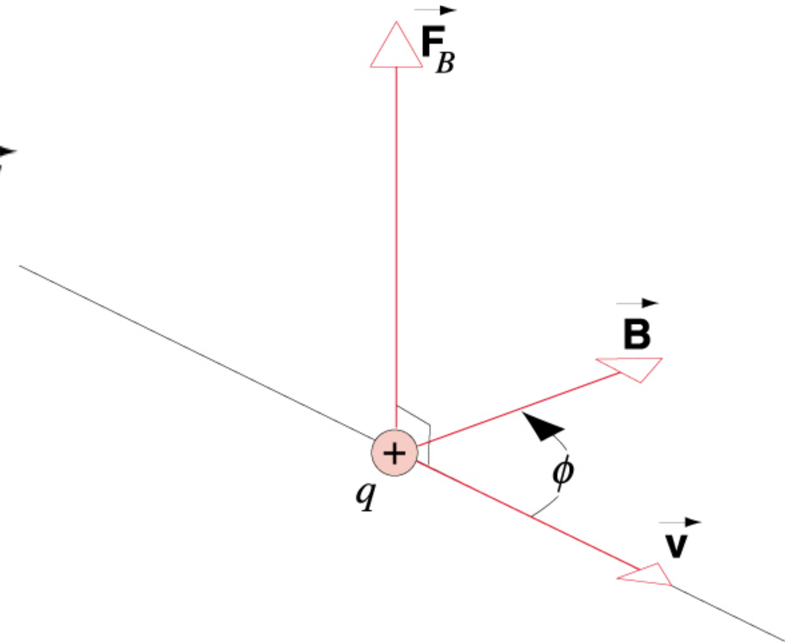
2. The magnitude of the force is proportional to the charge.

3. The magnetic force is always perpendicular to the velocity of the test charge (magnetic forces do no work!).

3. The magnetic force also depends on the direction of the velocity relative to certain fixed axes - being zero in one direction and maximum perpendicular to this direction.

Magnetic Forces Act on Moving Charges





We define the magnetic field:

$$B = \frac{F_{B,\max}}{|q|\,v}, \quad \text{or} \quad F_B = |q|\,vB\sin\phi$$

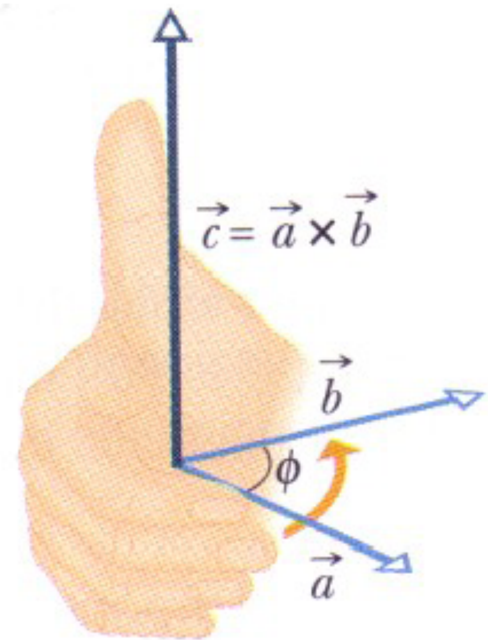
In fact:

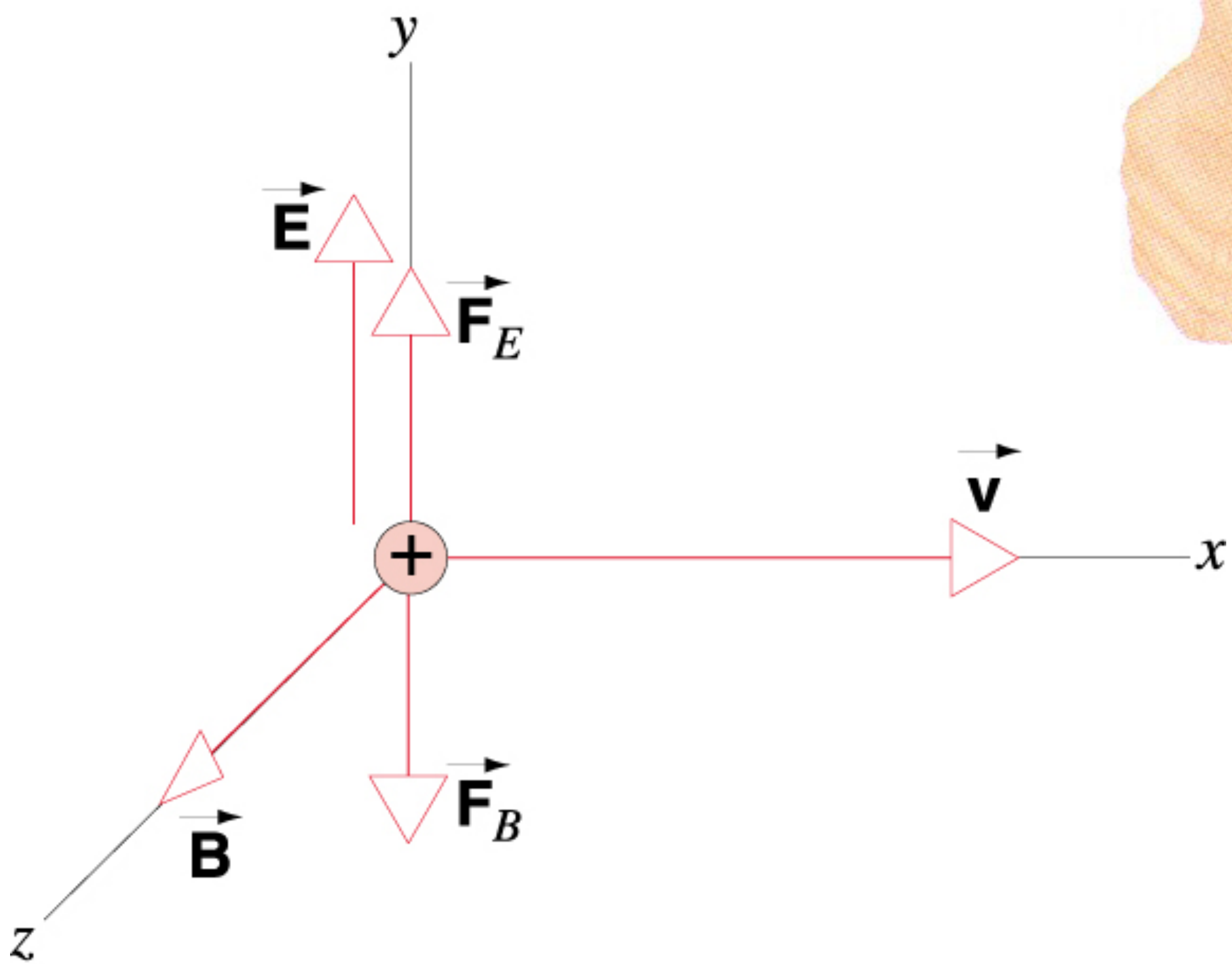
$$\vec{\mathbf{F}}_B = q\,\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

$$1\,\text{tesla} = 1\,\frac{\text{newton}}{\text{coulomb} \times \text{meter/second}} = 1\,\frac{\text{newton}}{\text{ampere} \times \text{meter}}$$

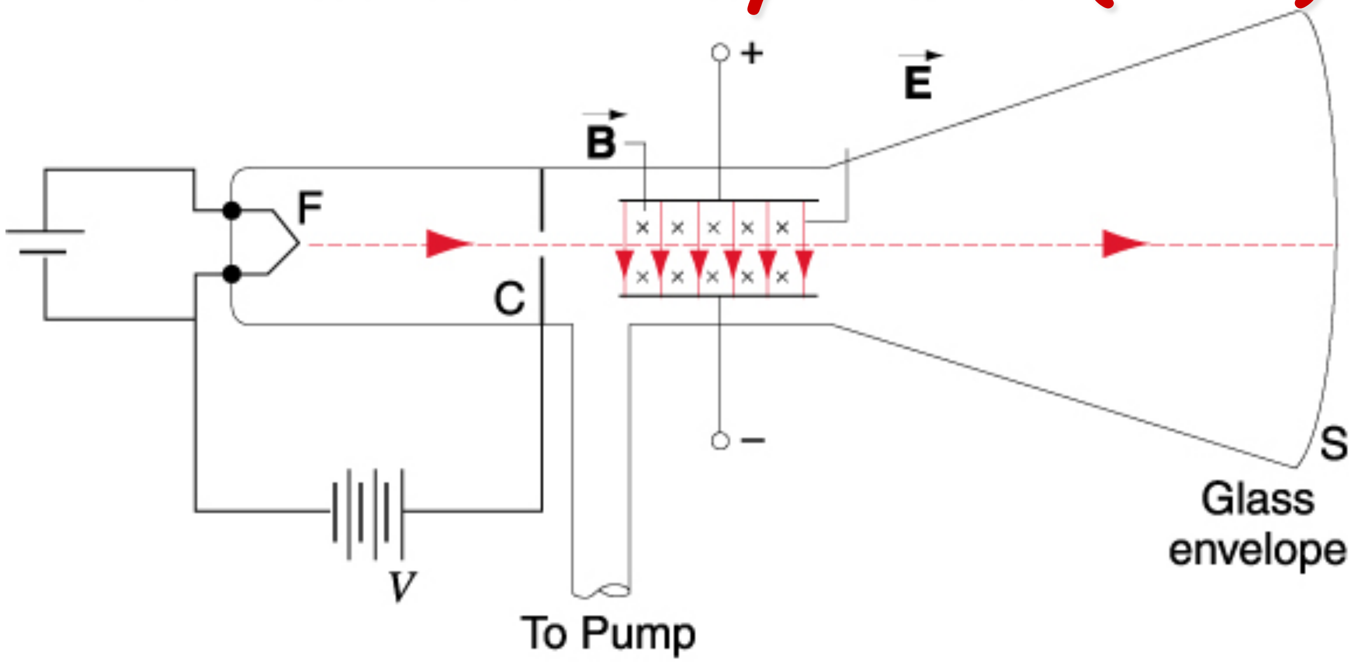
The Lorentz Force

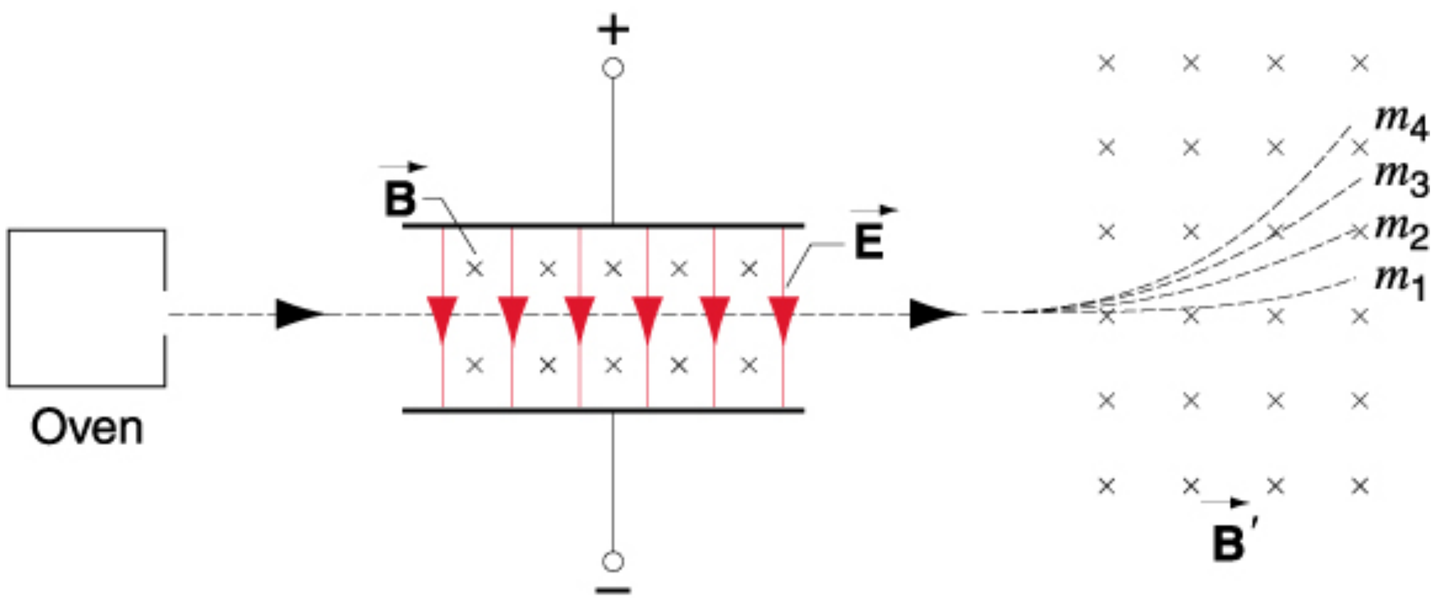
$$\vec{\mathbf{F}} = q\left[\vec{\mathbf{E}} + \left(\vec{\mathbf{v}} \times \vec{\mathbf{B}}\right)\right]$$





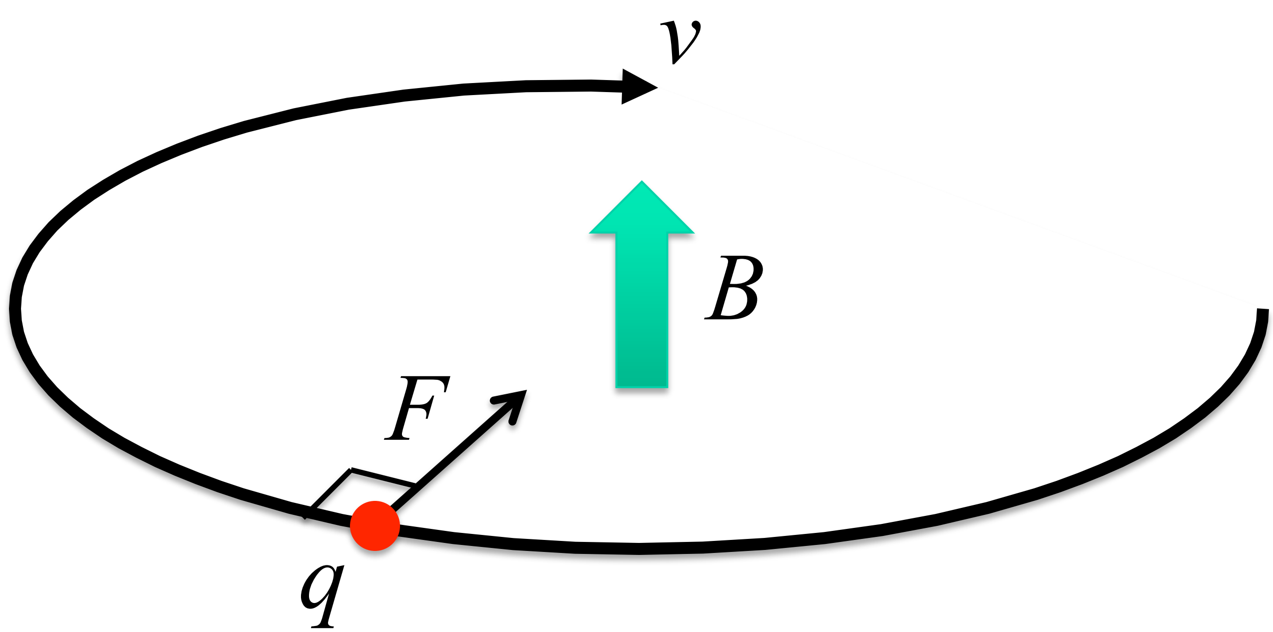
The Cathode Ray Tube (CRT)





Cyclotron Motion

Uniform magnetic field



- Force is perpendicular to v, so it can do no work
- Consequently, v is a constant of the motion
- Since q, B and v are constant, then so is F
- Consequently, trajectory is a circle in plane $\perp B$

The Lorentz Force

•The velocity filter:
(undeflected trajectories in crossed *E* and *B* fields)

$$v = \frac{E}{B}$$

•Cyclotron motion:

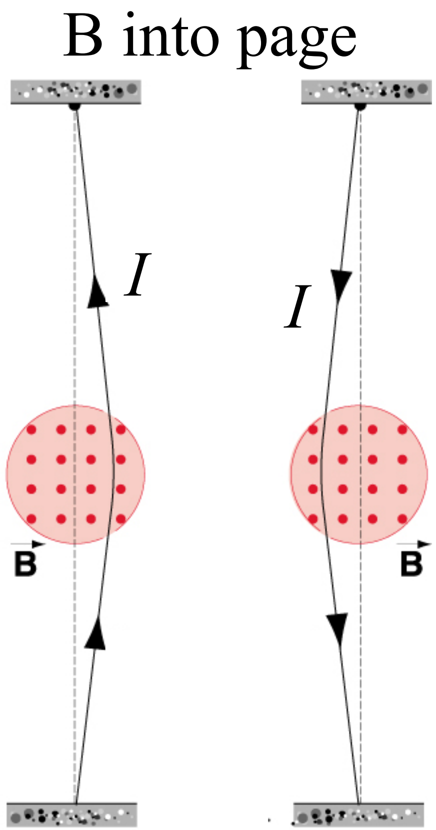
$$F_B = ma_r \qquad \Rightarrow \qquad |q| vB = m\frac{v^2}{r}$$

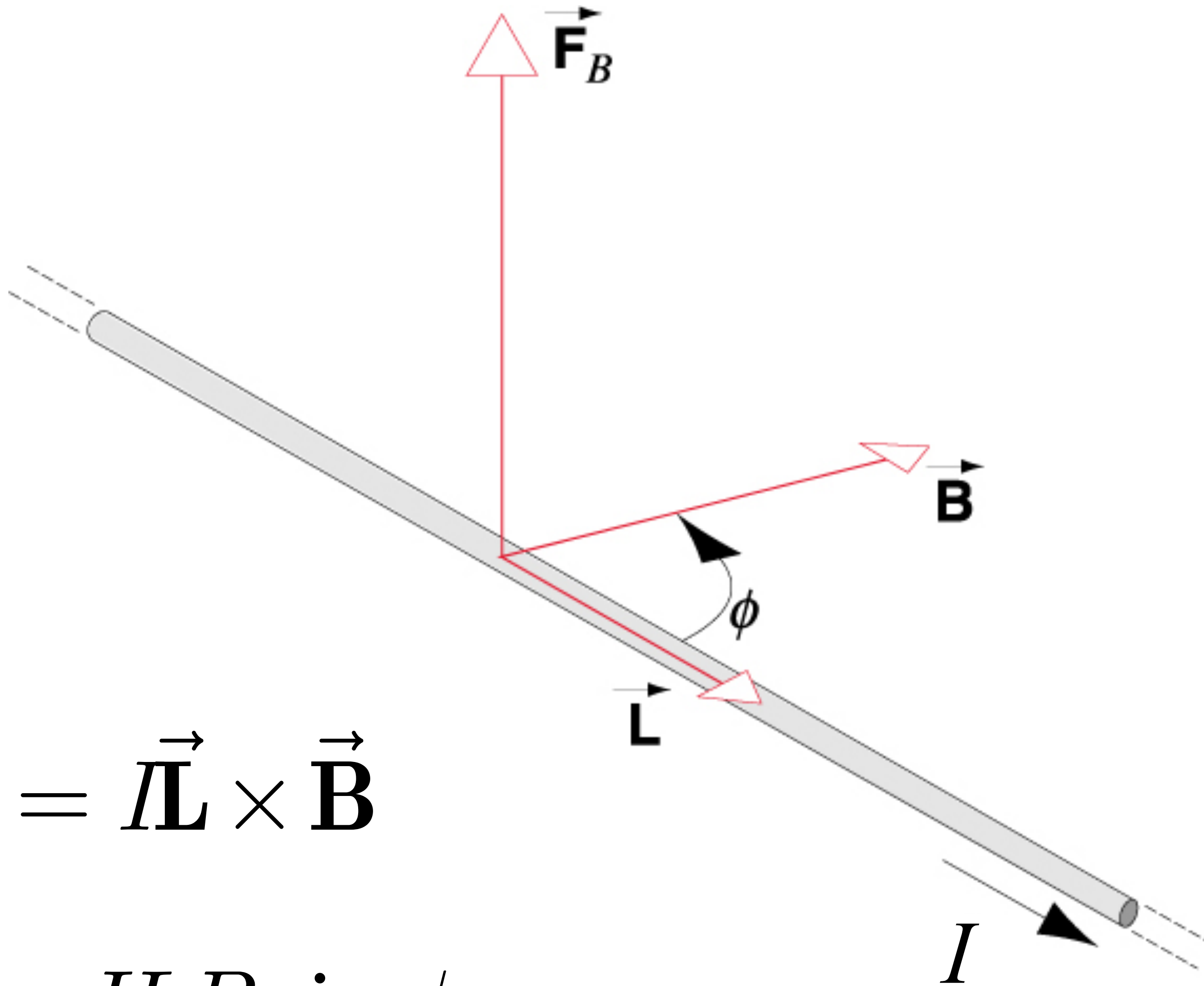
•Orbit radius: $$r = \frac{mv}{|q|B} = \frac{p}{|q|B}$$ momentum (p) filter

•Orbit frequency: $$\omega = 2\pi f = \frac{|q|B}{m}$$ mass detection

•Orbit energy: $$K = \tfrac{1}{2}mv^2 = \frac{q^2B^2R^2}{2m}$$

The Magnetic Force on a Current-Carrying Wire





$$\vec{\mathbf{F}}_B = I\vec{\mathbf{L}} \times \vec{\mathbf{B}}$$

$$= ILB \sin\phi$$