Electricity and Magnetism

- Today
  - Charged particles in B-Field
  - Sources of B-Field

Magnetism

- Magnetic Force and Magnetic Field

- How are Force and Field related?
- What is the Source of the Field?

Force on moving charge

- Charged particle in a combination of Electric and Magnetic Field:

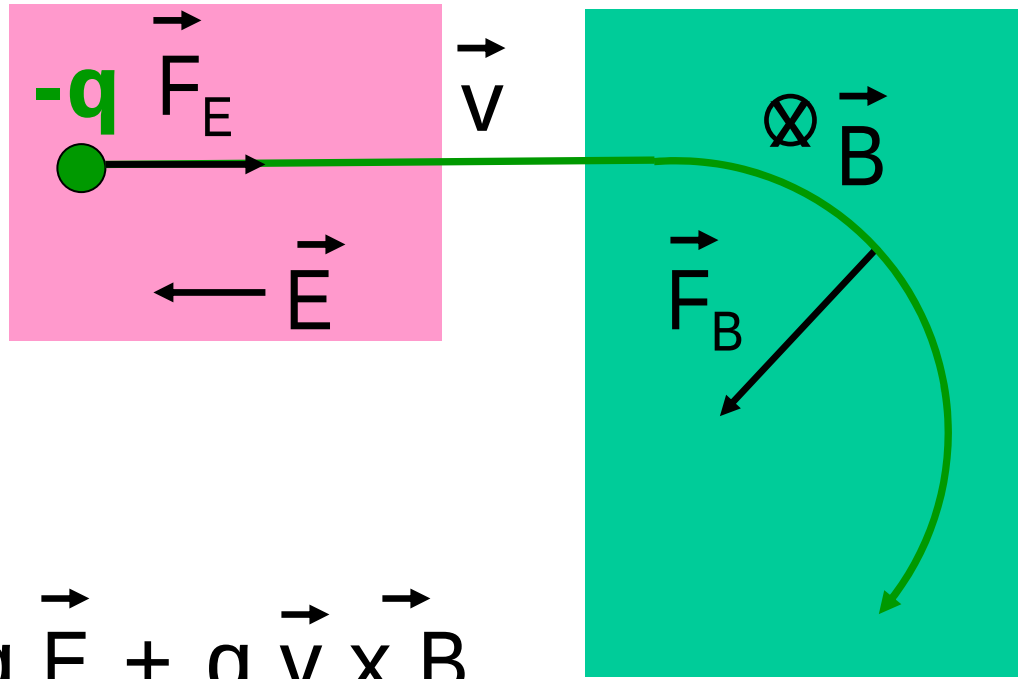
$$\vec{F}_L = q\vec{E} + q\vec{v} \times \vec{B}$$

Lorentz Force

This we know!

Direction: Right-Hand Rule

Force on moving charge



In B-Field:

$$F = m\,a$$

$$|q|\,v\,B = m\,v^2/R$$

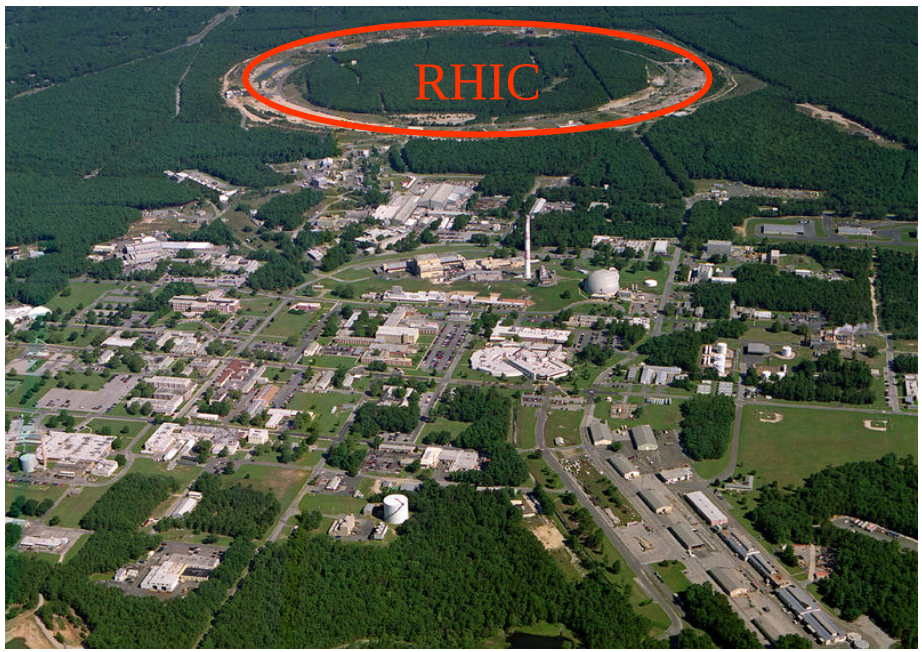
$$\rightarrow \quad R = m\,v/(q\,B)$$

Cyclotron Radius

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

Example

1 mile



- Why so big?

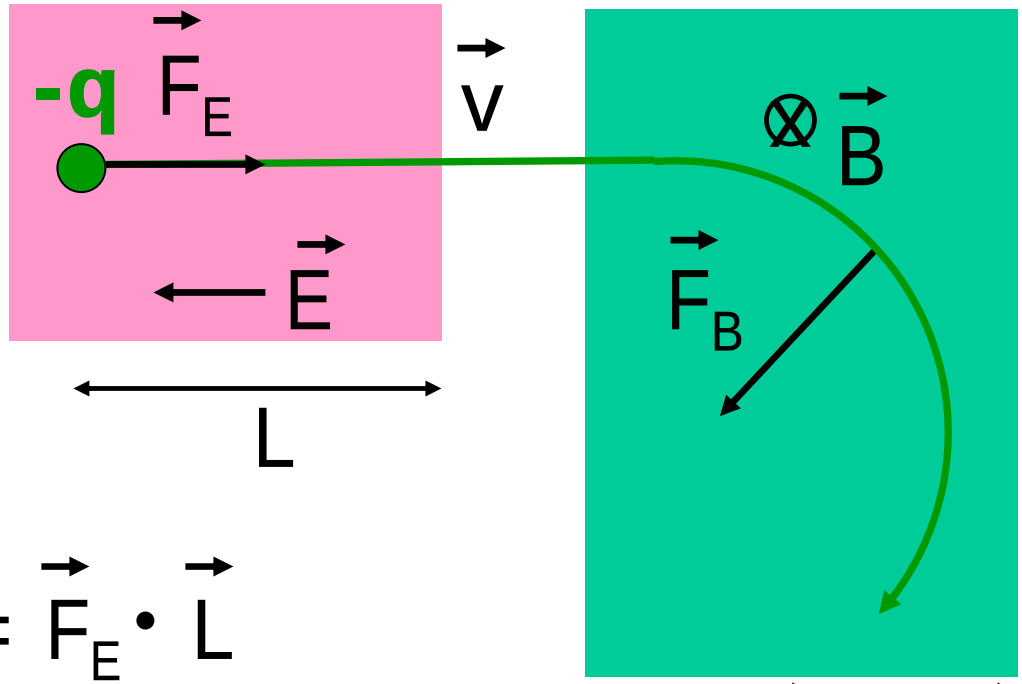
$$R = m\,v/(q\,B)$$

Momentum $\vec{p}$

- Large p -> Large R
- B ~ 10T (very big!)
- Max. B in Lab around 100 T

Relativistic Heavy Ion Collider

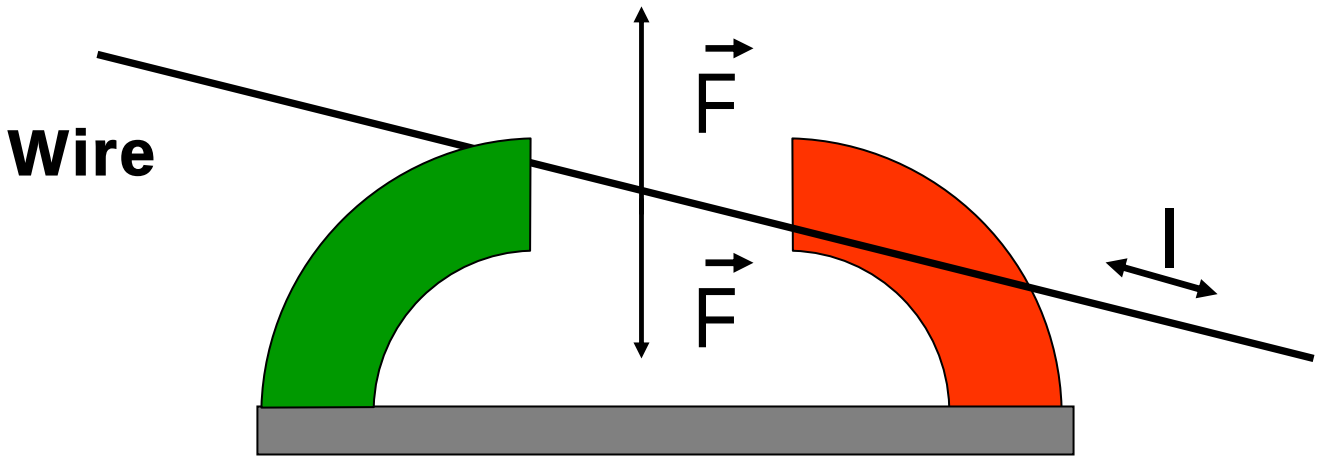
Work done on moving charge



$$W = \vec{F}_E \cdot \vec{L}$$
$$= q\,E\,L$$

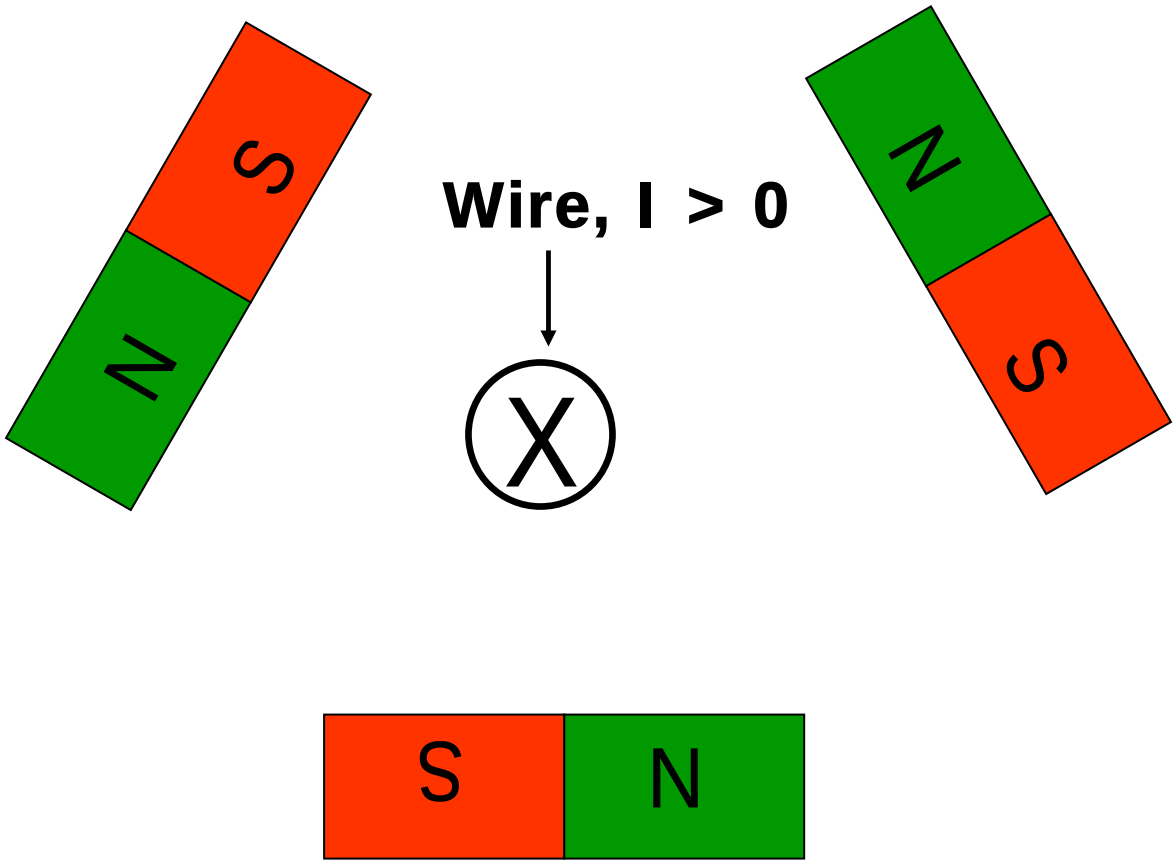
$$dW = \vec{F}_B \cdot d\vec{L} = (q\,\vec{v} \times \vec{B}) \cdot d\vec{L}$$
$$= 0$$

Magnet and Current

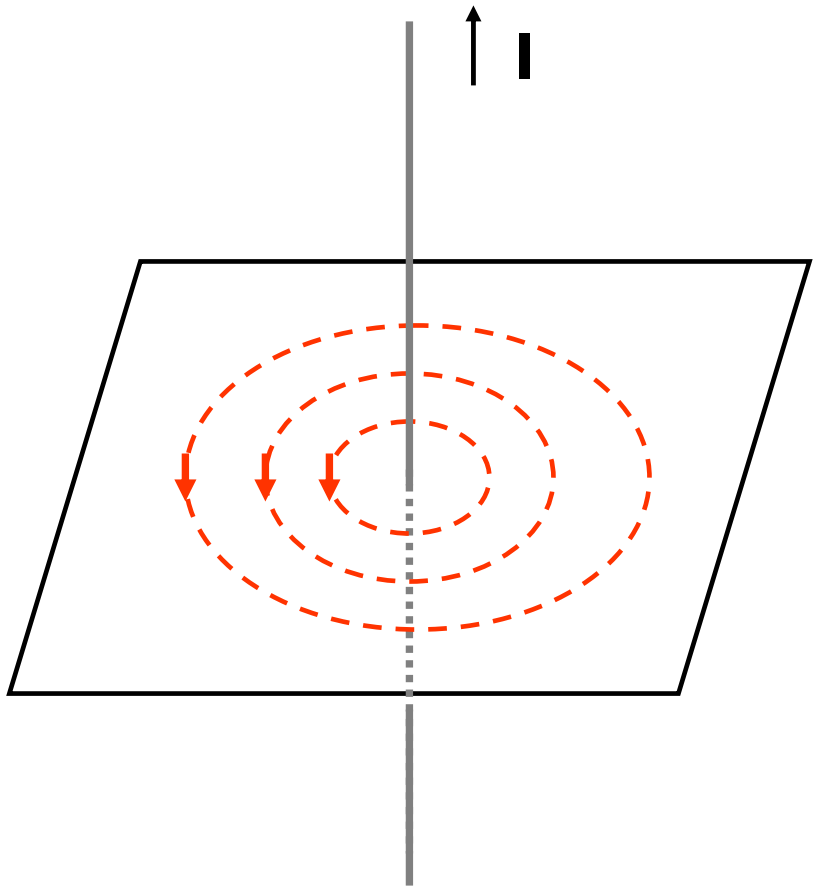


- Force on wire if I != 0
- Direction of Force depends on Sign of I
- Force perpendicular to I

Currents and Magnetic Field

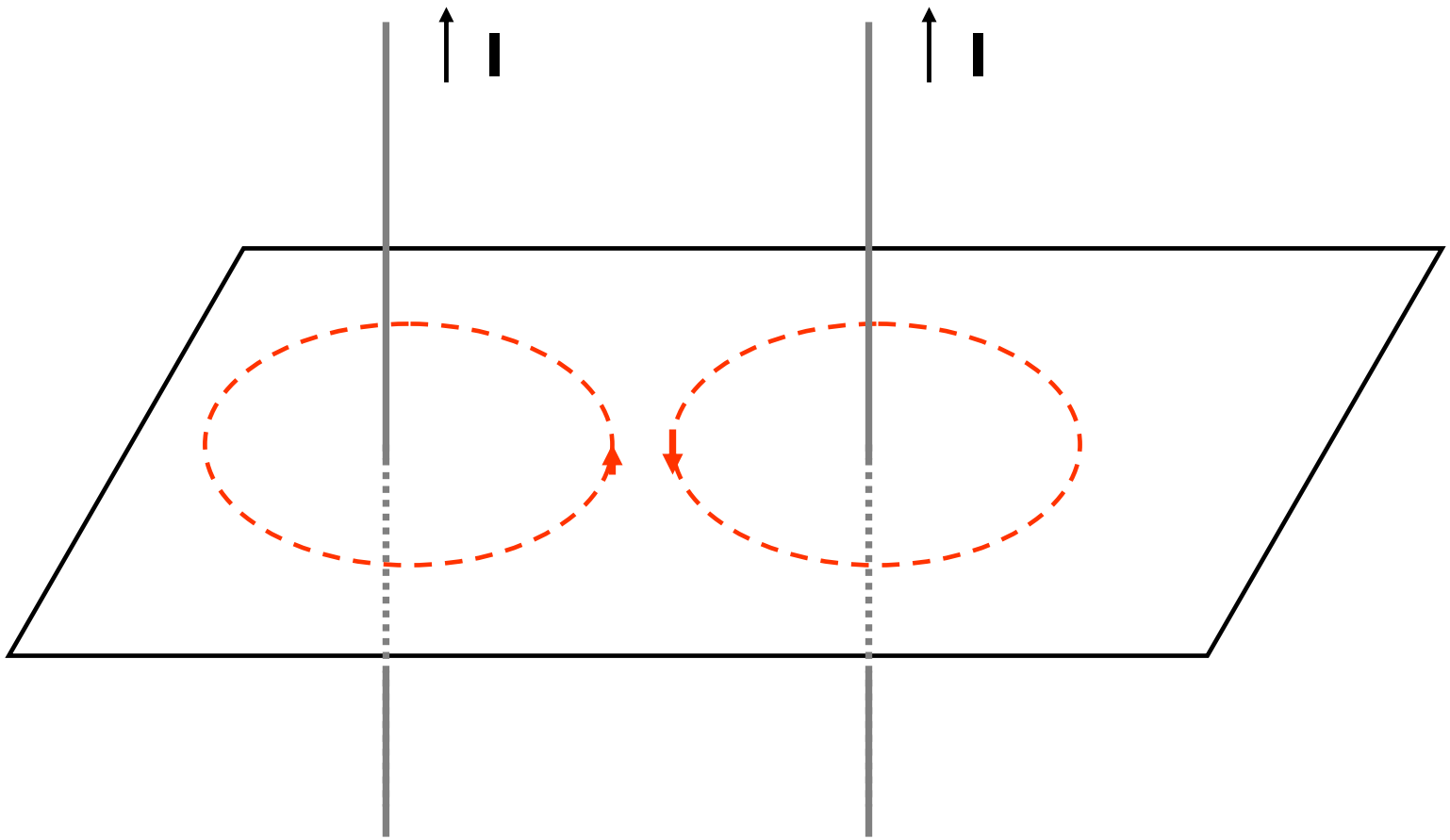


Currents and B-Field

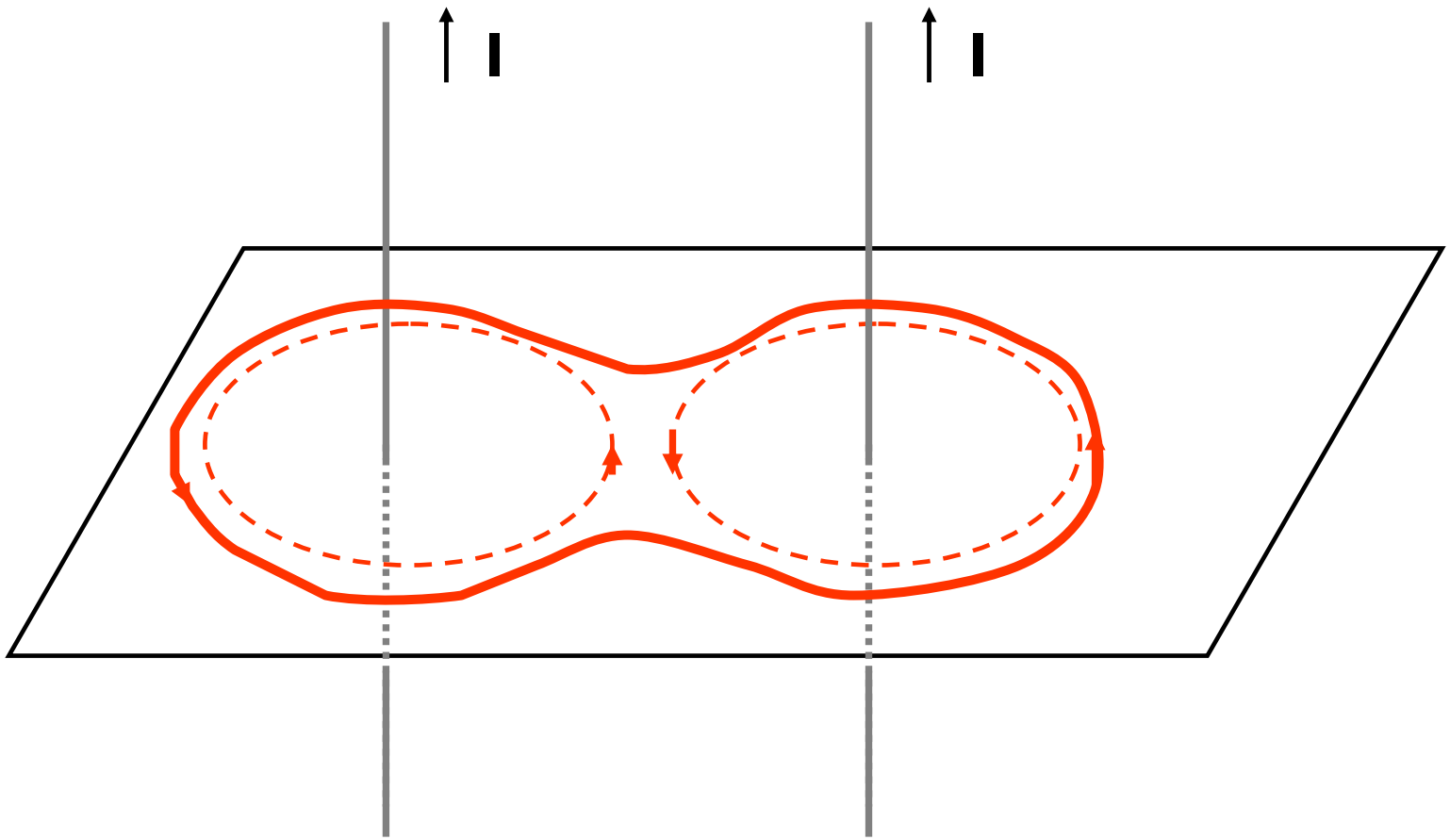


- Current as Source of B
- Magnetic Field lines are always closed
  - no Magnetic Charge (Monopole)
- Right Hand Rule

Currents and B-Field

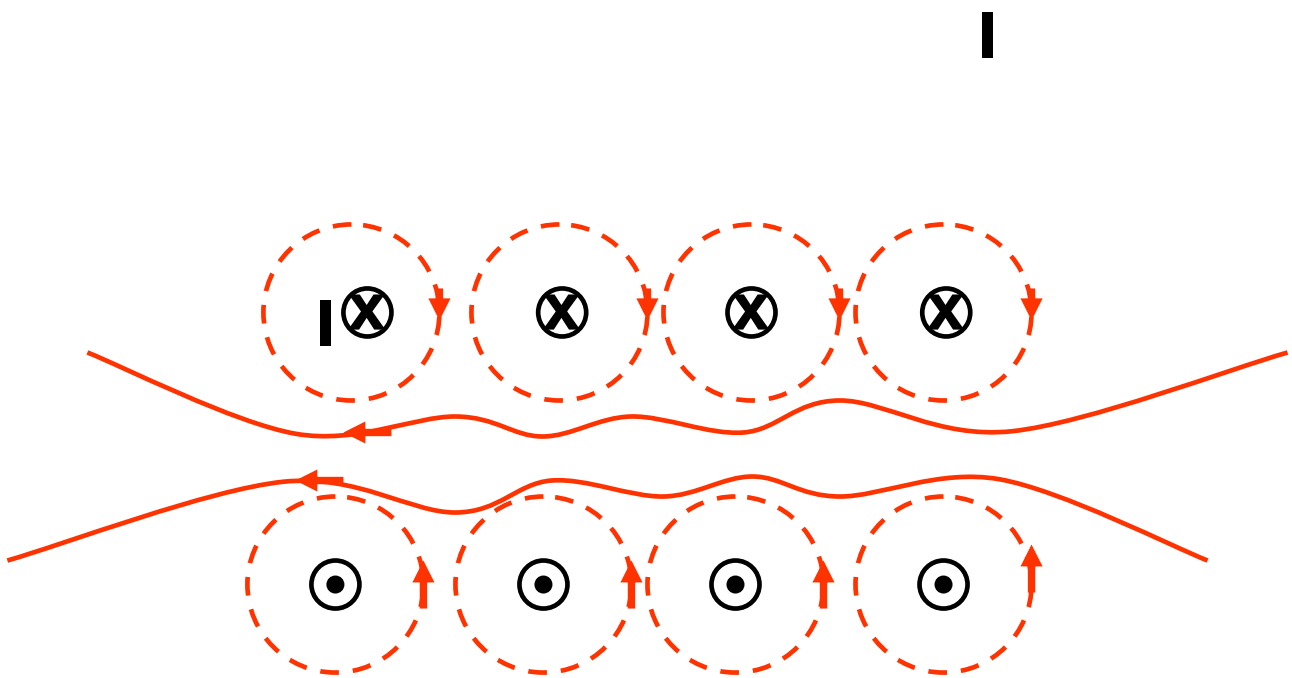


Currents and B-Field



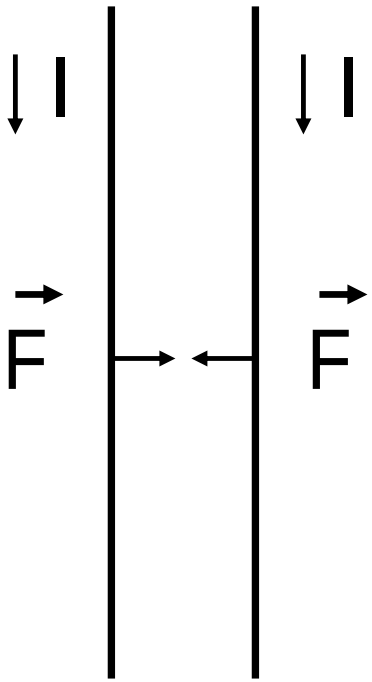
- Superposition Principle!

Currents and B-Field

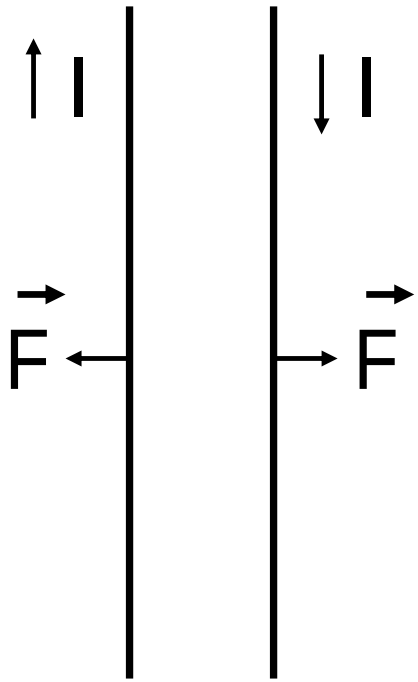


- Solenoid: Large, uniform B inside!

Current and Current

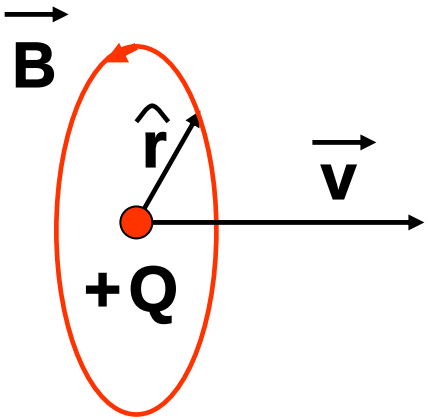


Attraction

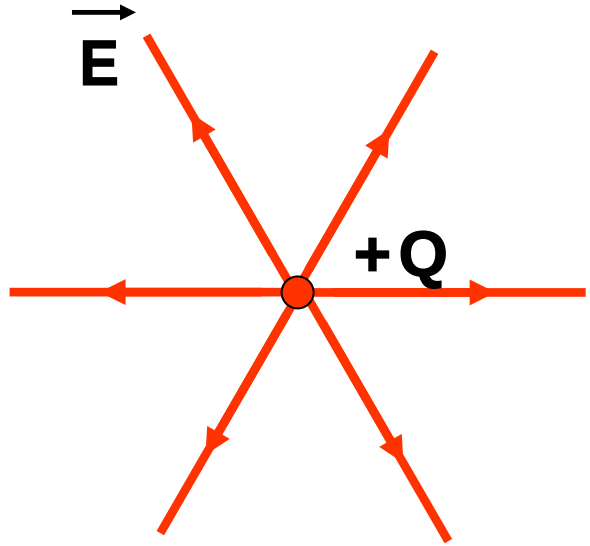


Repulsion

Magnetic Field vs Electric Field



B	E
~q	~q
~1/r²	~1/r²
~v x r	/
azimuthal	radial

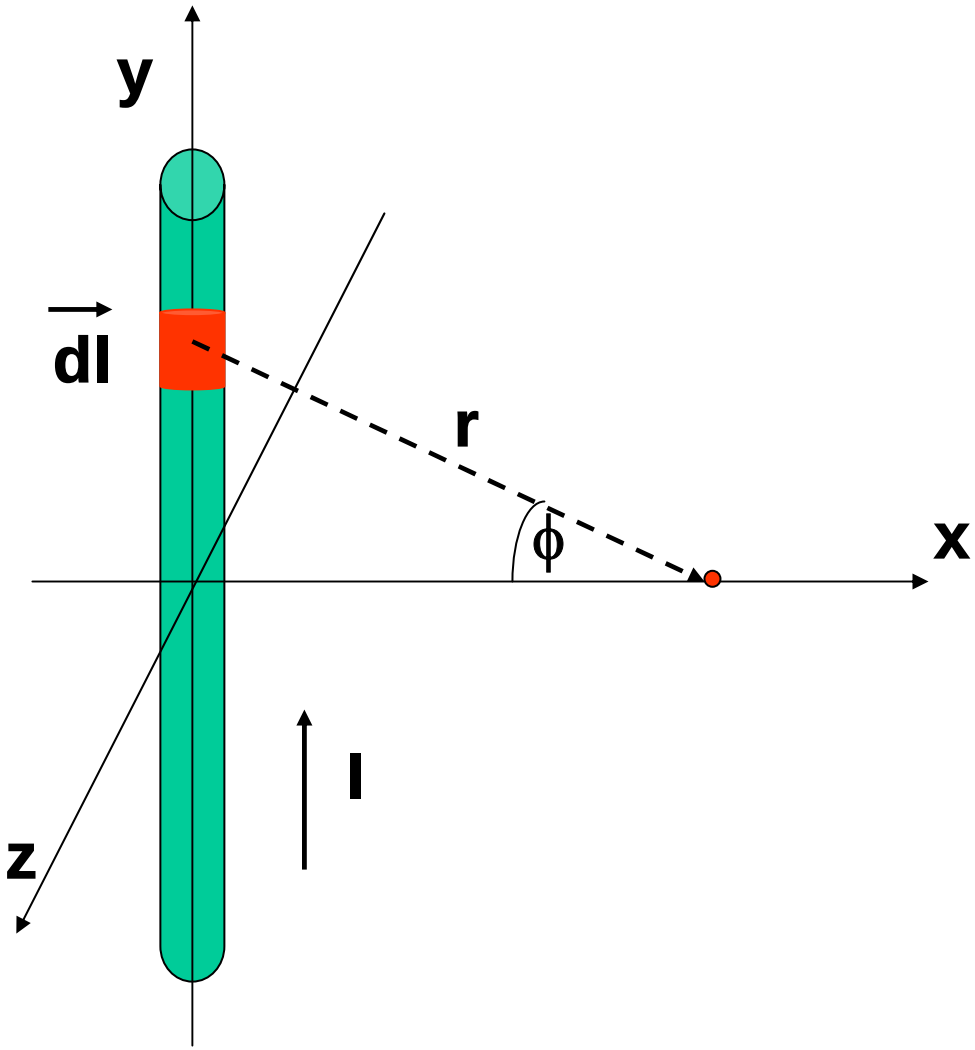


$$\vec{B} = \mu_0/(4\pi)\, Q/r^2\, \vec{v} \times \vec{r} \qquad \vec{E} = 1/(4\pi\varepsilon_0)\, Q/r^2\, \hat{r}$$

$\mu_0 = 4\pi \cdot 10^{-7}$ T m /A

$\varepsilon_0 = 8.85 \cdot 10^{-12}$ C^2/(Nm^2)

Magnetic Field for Current I



Magnetic Field for Current I

$\vec{B} = \mu_0/(4\pi)\, Q/r^2\, \vec{v} \times \hat{r}$ for single charge

$I = dQ/dt \rightarrow dQ\, \vec{v} = dQ\, \vec{dl}/dt = I\, \vec{dl}$

$$dB = \mu_0/(4\pi)\ I\ \vec{dl} \times \hat{r}/r^2$$

Law of Biot-Savart:

Magnetic Field dB for current through segment dl