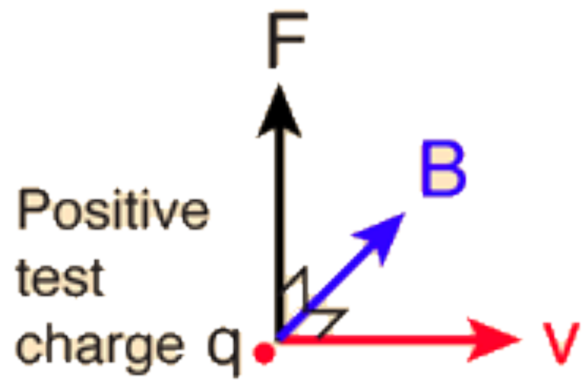
# Physics II: 1702/029:028
# Electricity and Magnetism

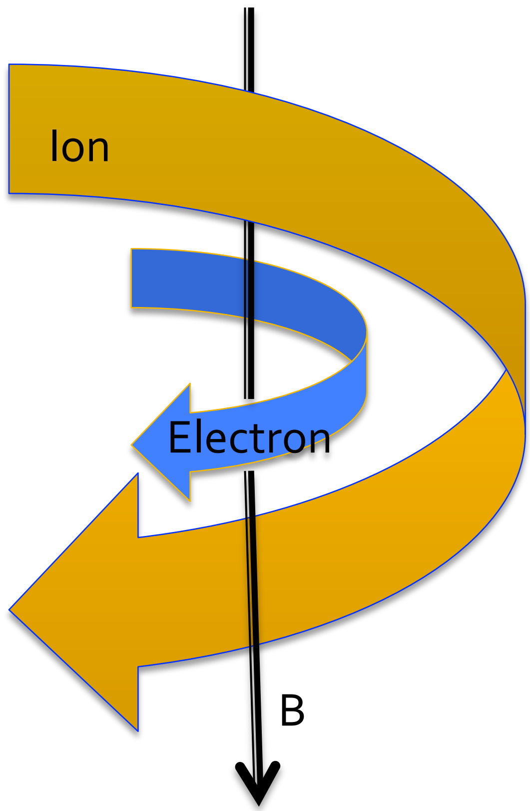
Professor Jasper Halekas
Van Allen 70 [Clicker Channel #18]
MWF 11:30-12:30 Lecture, Th 12:30-1:30 Discussion

# Magnetic Force on a Point Charge

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



# Charged Particle Gyration




Particles Move in Circle

$$qvB = mv^2/r$$

# Work Done by E and B

Electric:

$$W = \int_B^A \vec{F}.d\vec{x} = \int_B^A q\vec{E}.d\vec{x} = qE\int_B^A dx = qEd$$

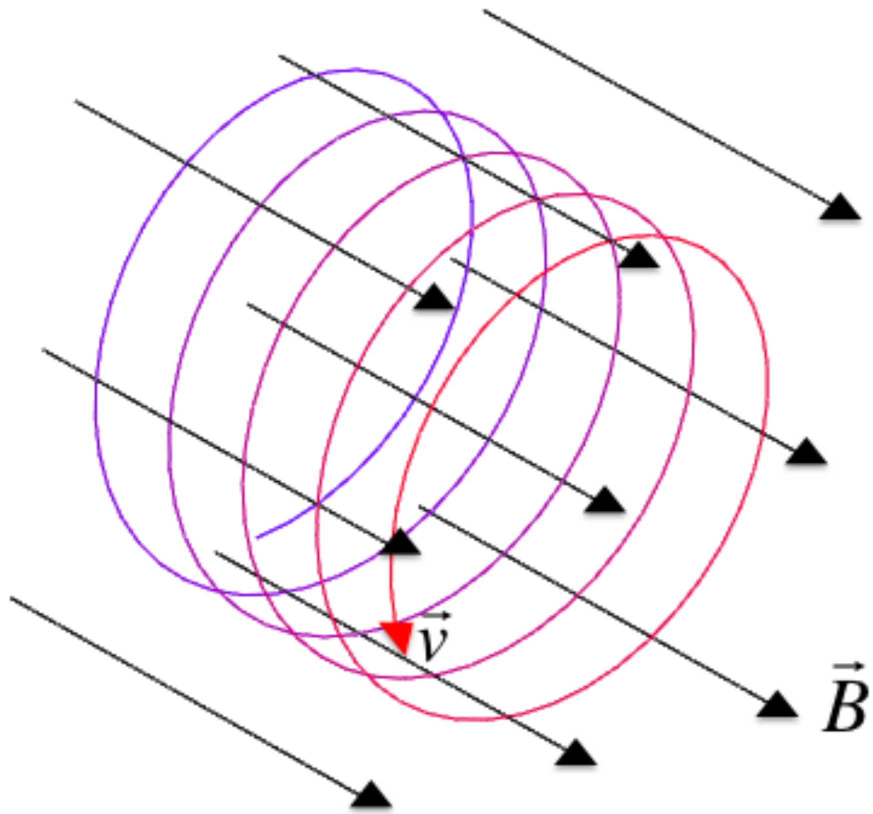
Magnetic:

$$\mathbf{F}\cdot d\,\mathbf{l} = q(\mathbf{v}\times\mathbf{B})\cdot\mathbf{v}\,dt = 0$$

Often stated as "magnetic fields do no work". Another way to think about it is that magnetic fields do not have a scalar potential associated with them.

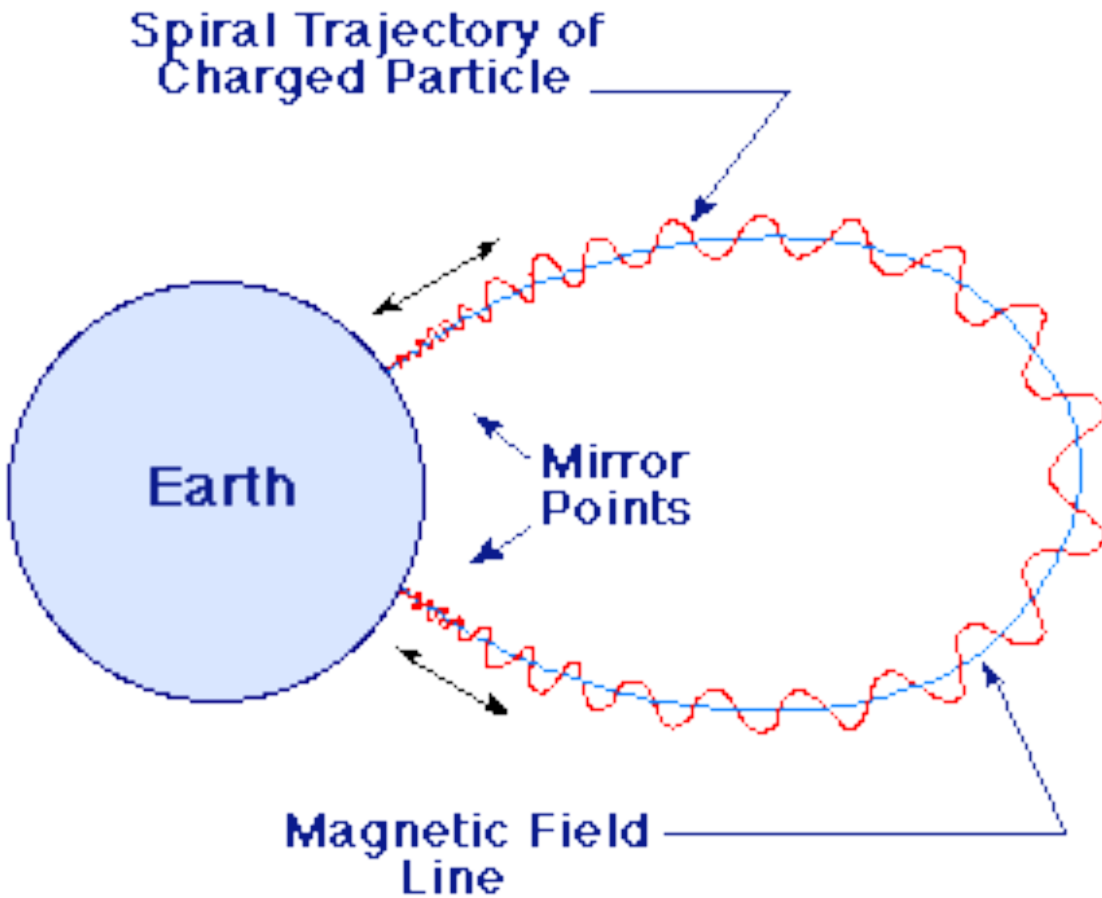
But, magnetic fields often seem to be "doing work"! Nonetheless, it always turns out to be some other part of the system that actually does the work.

# Charged Particle Helical Motion



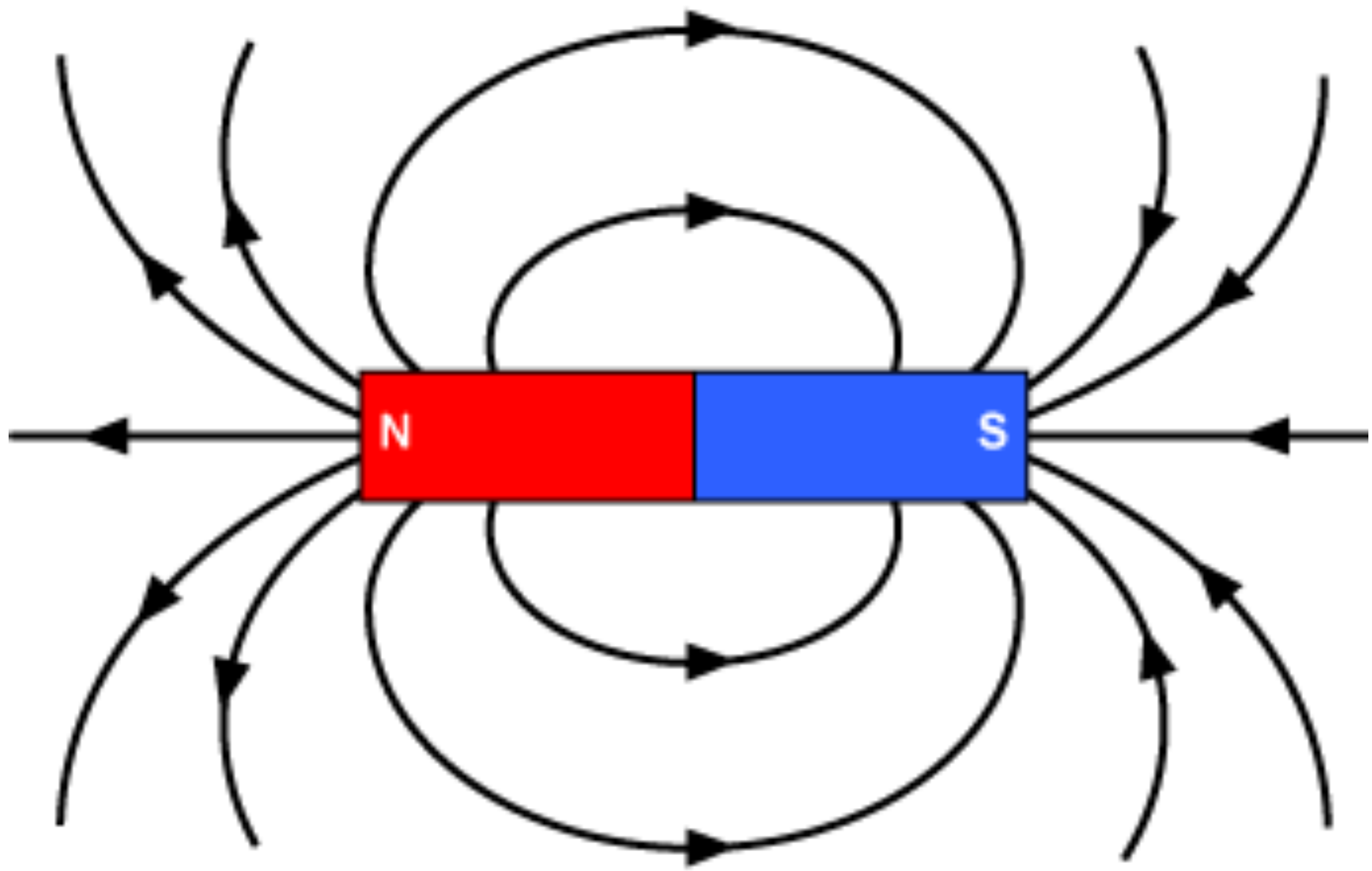

$V_{||}$ = Constant

# Charged Particle Helical Motion



# Aurora

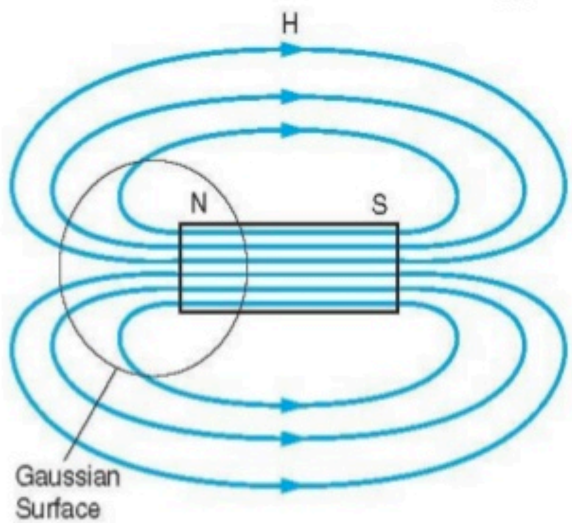
# Magnetic Dipoles



# Magnetic Monopoles

- Never Discovered!

Law of conservation
of magnetic flux




$$\oint_{s} \overline{B} \bullet d\overline{s} = 0$$

**Law of conservation of magnetic flux or Gauss's law for magnetostatic field**

# Maxwell's Equations: Integral Form

$$\oint \mathbf{E}\cdot d\mathbf{A} = \frac{q_{enc}}{\varepsilon_0}$$ ✔

$$\oint \mathbf{B}\cdot d\mathbf{A} = 0$$ ✔

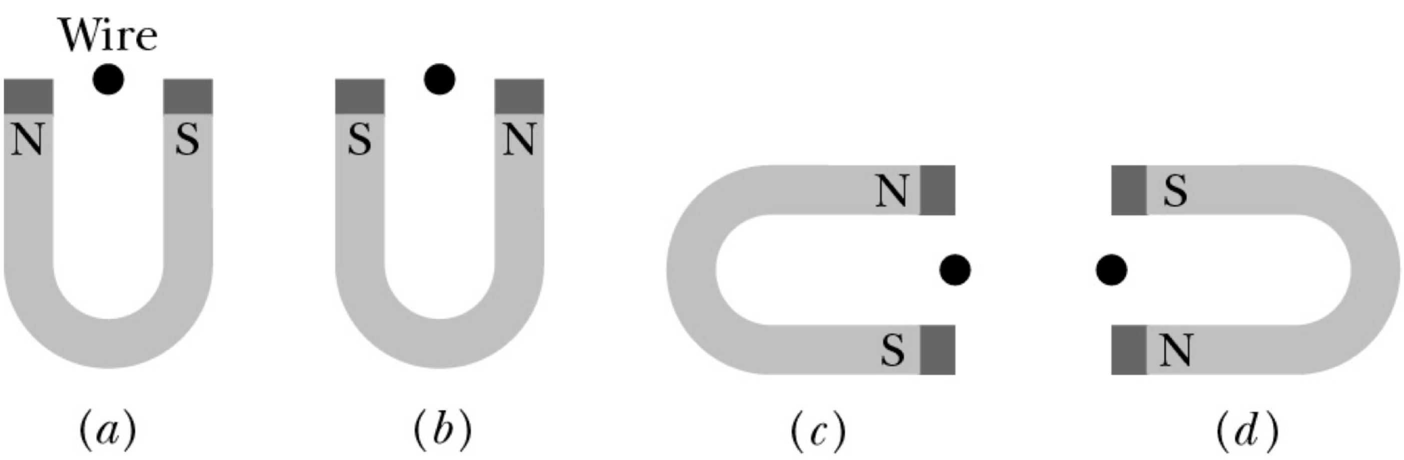
$$\oint \mathbf{E}\cdot d\mathbf{s} = -\frac{d\Phi_\mathrm{B}}{d\mathrm{t}}$$

$$\oint \mathbf{B}\cdot d\mathbf{s} = \mu_0\varepsilon_0\frac{d\Phi_\mathrm{E}}{d\mathrm{t}} + \mu_0 i_{enc}$$

# Concept Check

Q29) The figure below shows four views of a horseshoe magnet and a straight wire in which electrons are flowing out of the page, perpendicular to the plane of the magnet. In which case will the magnetic force on the wire be directed upwards?

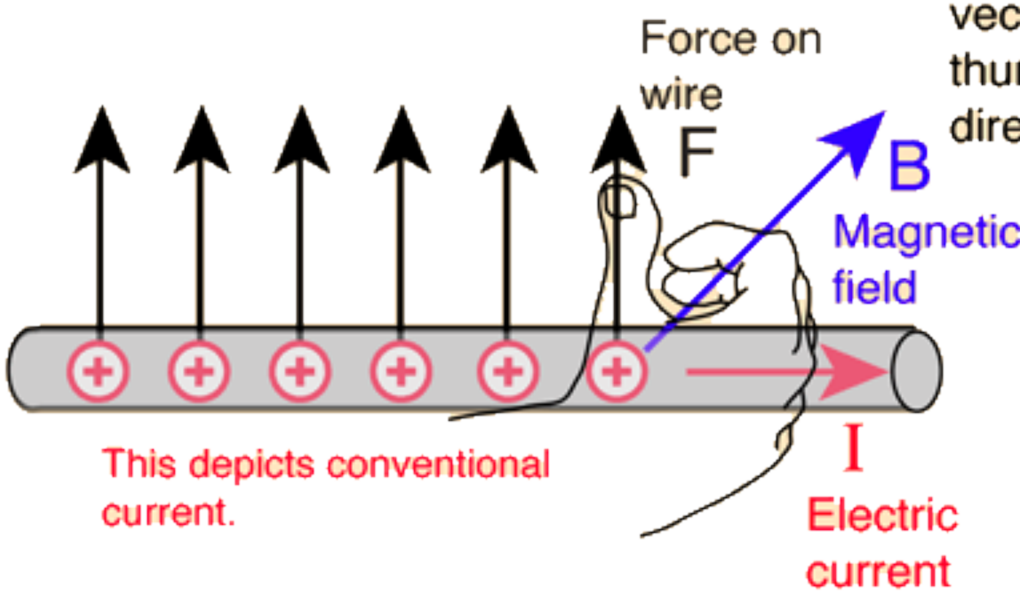
1) a
2) b
3) c
4) d



# Magnetic Force on a Current

- Current is just lots of charge carriers flowing!
- To get force on current carrying wire, just add up forces on charged particles

Curl fingers as if rotating vector I into vector B. The thumb is then in the direction of the force F

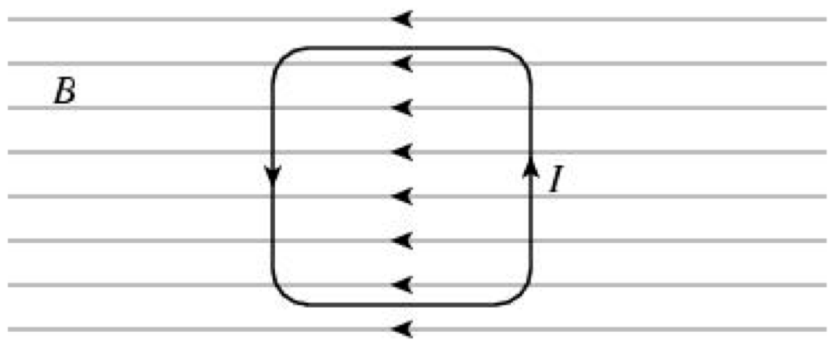



$$\vec{F} = \vec{I}L \times \vec{B}$$

Force on straight wire of length L

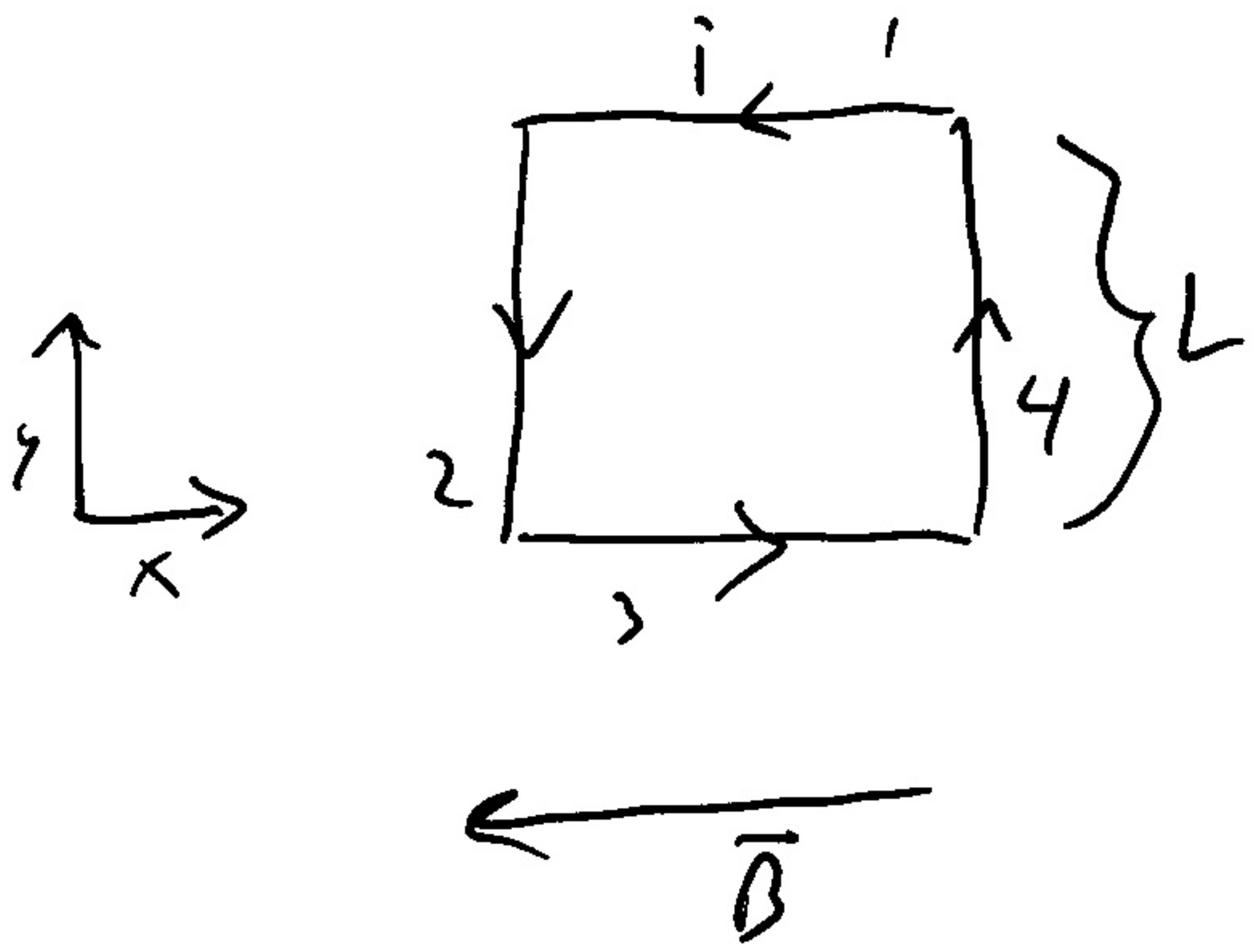
# Concept Check

Q33) A current loop is placed in a magnetic field as shown below. The loop tends to




1) rotate, left side up
2) rotate, right side up
3) rotate, bottom side up
4) rotate, top side up
5) none of the above - it stays in place

$$\vec{F} = i\vec{L} \times \vec{B}$$




$$\vec{F}_1 = 0$$

$$\vec{F}_3 = 0$$

$$\vec{F}_2 = -iLB\hat{k}$$

$$\vec{F}_3 = iLB\hat{k}$$

$$\vec{\tau} = \sum \vec{r} \times \vec{F}$$

$$= L/2\,\hat{i} \times iLB\hat{k} \;-\; L/2\,\hat{i} \times (-iLB\hat{k})$$

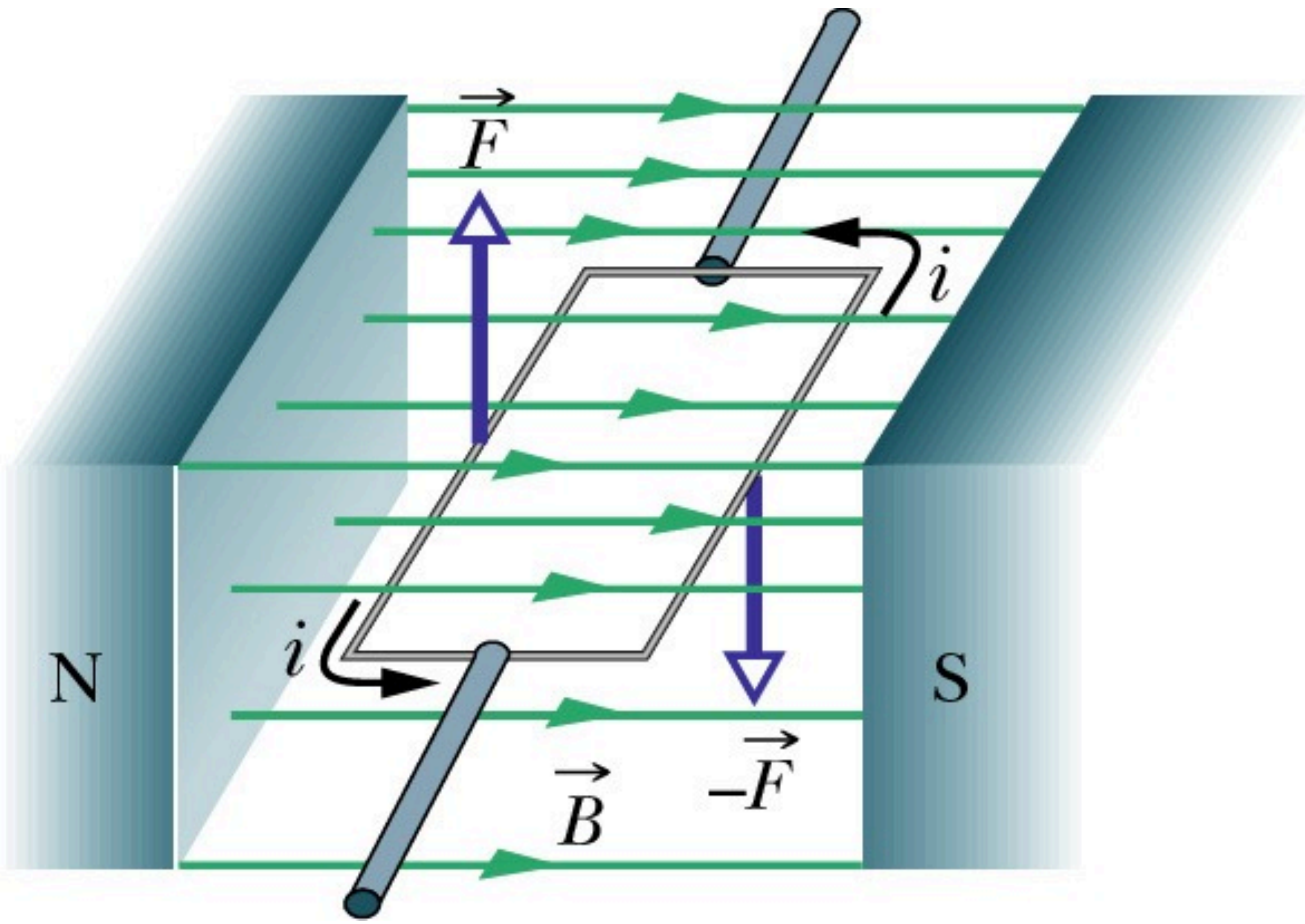
$$= iBL^2/2 \cdot -\hat{j} \;+\; iBL^2/2 \cdot -\hat{j}$$

$$= \boxed{-iBL^2\hat{j}}$$

CW around y-axis

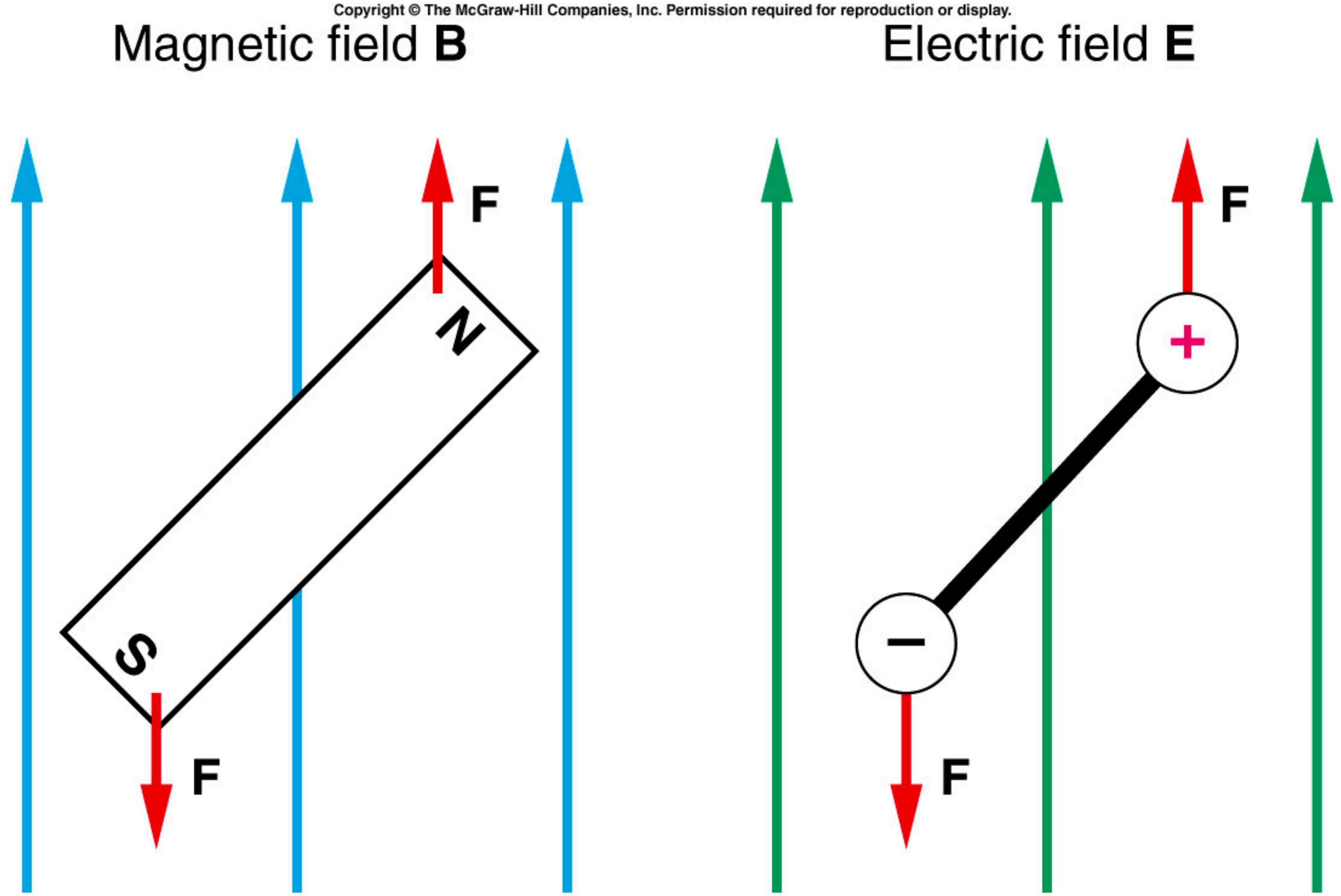
- right side up

# Magnetic Torque on a Current Loop

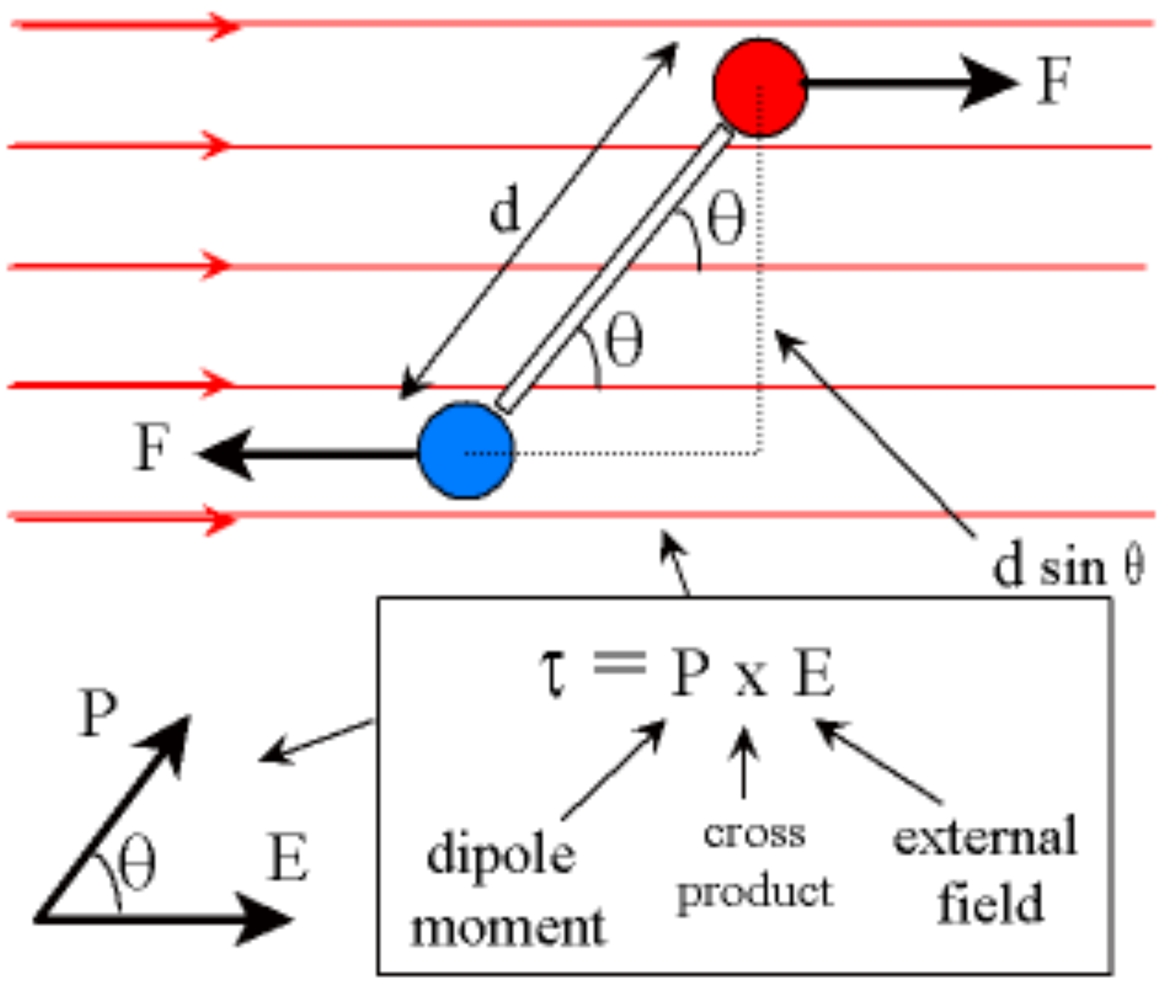


# Torques on Dipoles

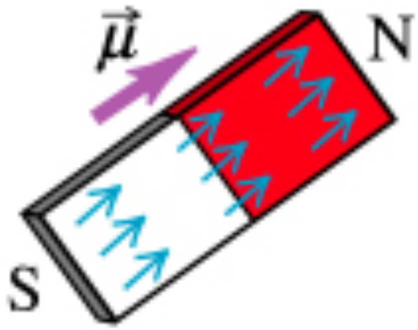




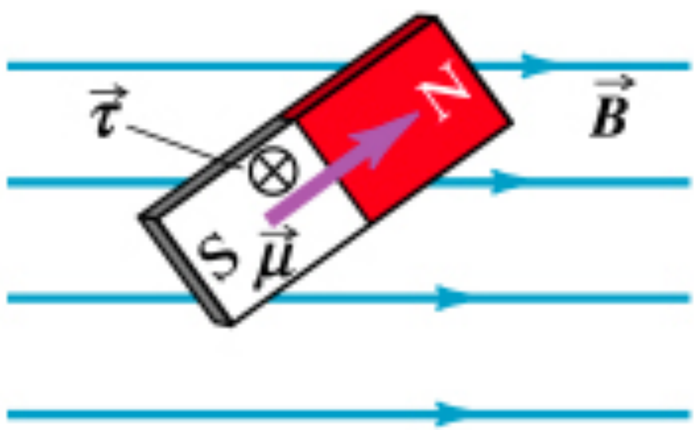
# Torque on Electric Dipole



# Torque on Magnetic Dipole




(b)

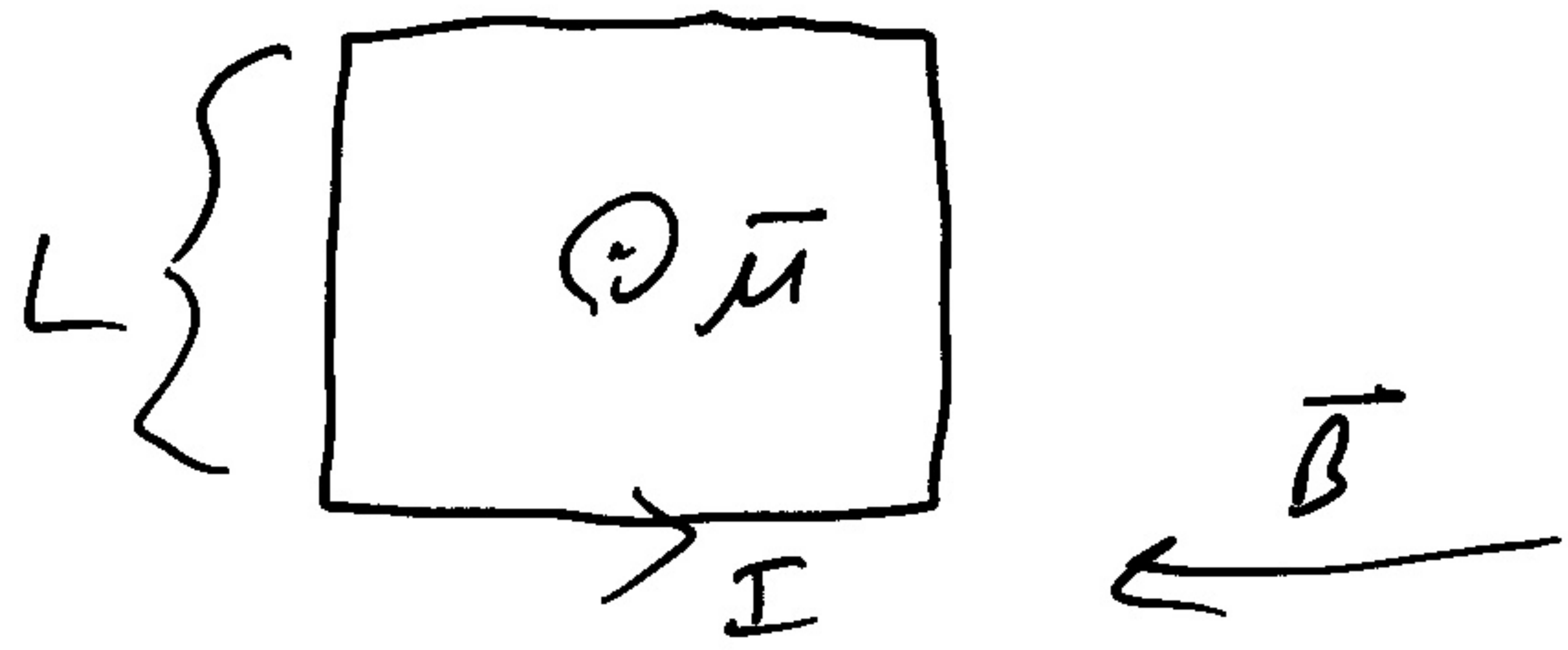



(c)

$$\tau = \mu \ x \ B$$

# Magnetic Dipole Moment


$$\mu = IA$$




$$\mu = IA\hat{k} = IL^2\hat{k}$$

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

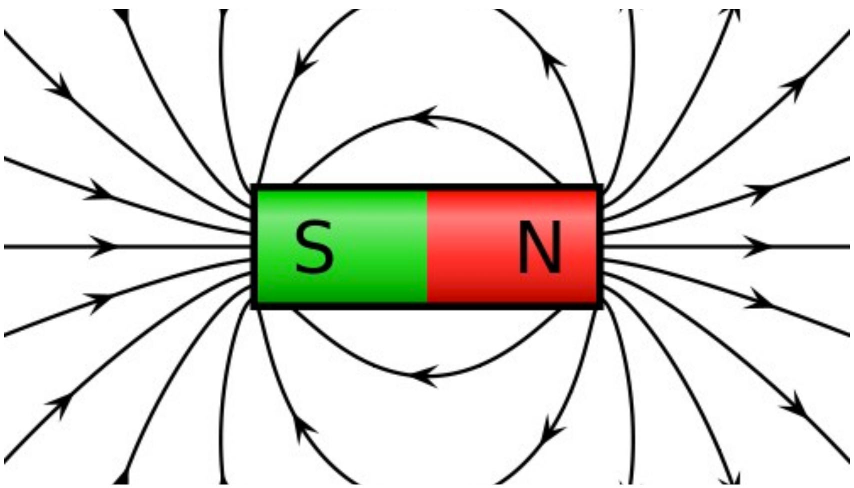
$$= IA\hat{k} \times B\hat{i}$$

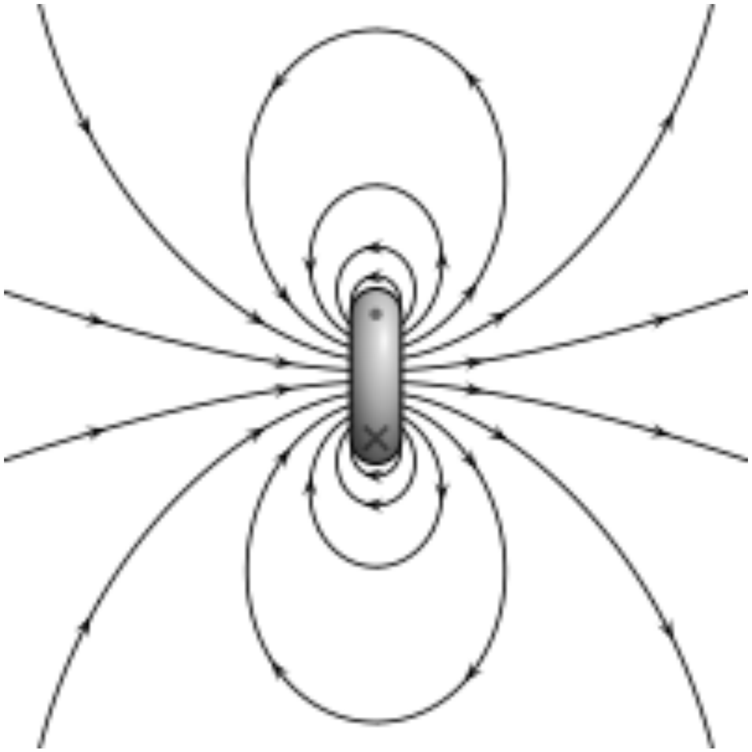
$$= -IAB\hat{j}$$

$$= \boxed{-IBL^2\hat{j}}$$

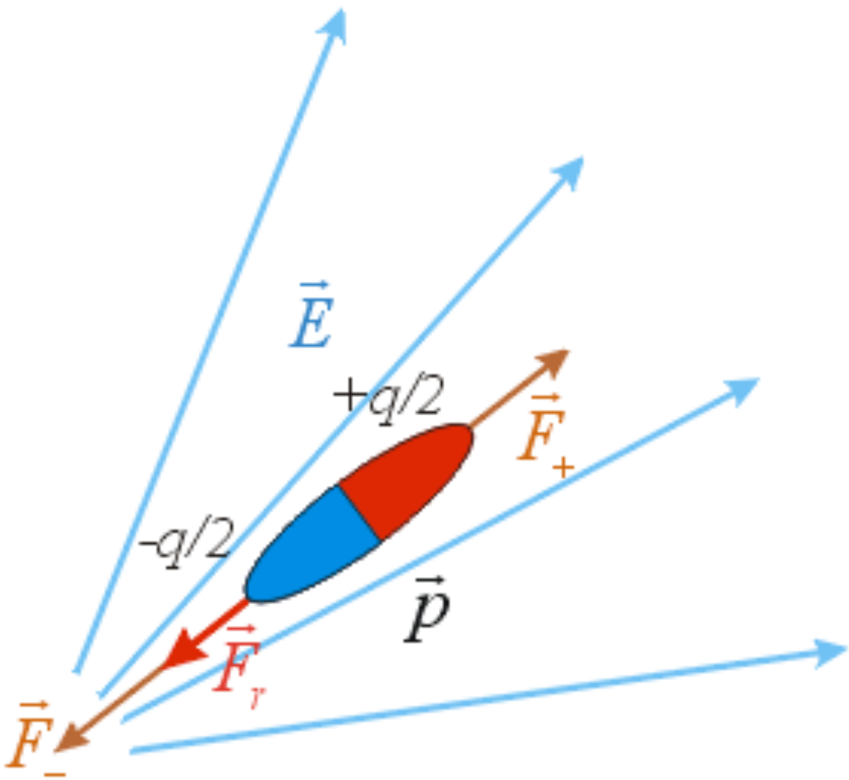
- Same answer as we got looking @ current segments

# Magnetic Dipoles:
# Bar Magnet Vs. Current Loop



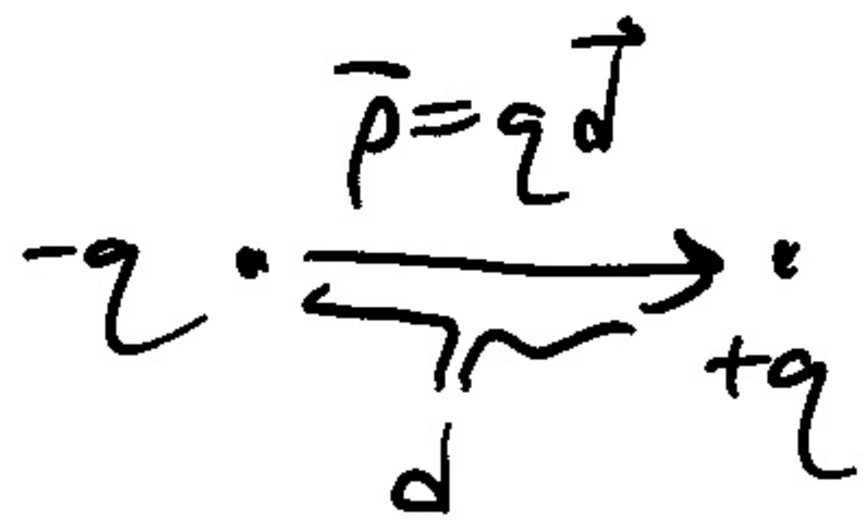
# Force on Electric Dipole




$F_- > F_+ \quad \vec{F}_r = \frac{q}{2}(\vec{E}_+ - \vec{E}_-) < 0$

$$\vec{F}_{total} = \vec{p} \bullet \nabla \vec{E}$$

# Force on electric dipole




$$\vec{F} = \vec{F}_+ + \vec{F}_-$$
$$= q\vec{E}_+ - q\vec{E}_-$$
$$= q(\vec{E}_+ - \vec{E}_-)$$
$$\sim q(\vec{E}_- + \vec{d}\cdot\nabla\vec{E} - \vec{E}_-)$$
$$= q\vec{d}\cdot\nabla\vec{E}$$
$$= (\vec{p}\cdot\nabla)\vec{E} = \nabla(\vec{p}\cdot\vec{E})$$

for constant $\vec{p}$

- In 1-d $F_x = p_x \partial/\partial x \, E_x$

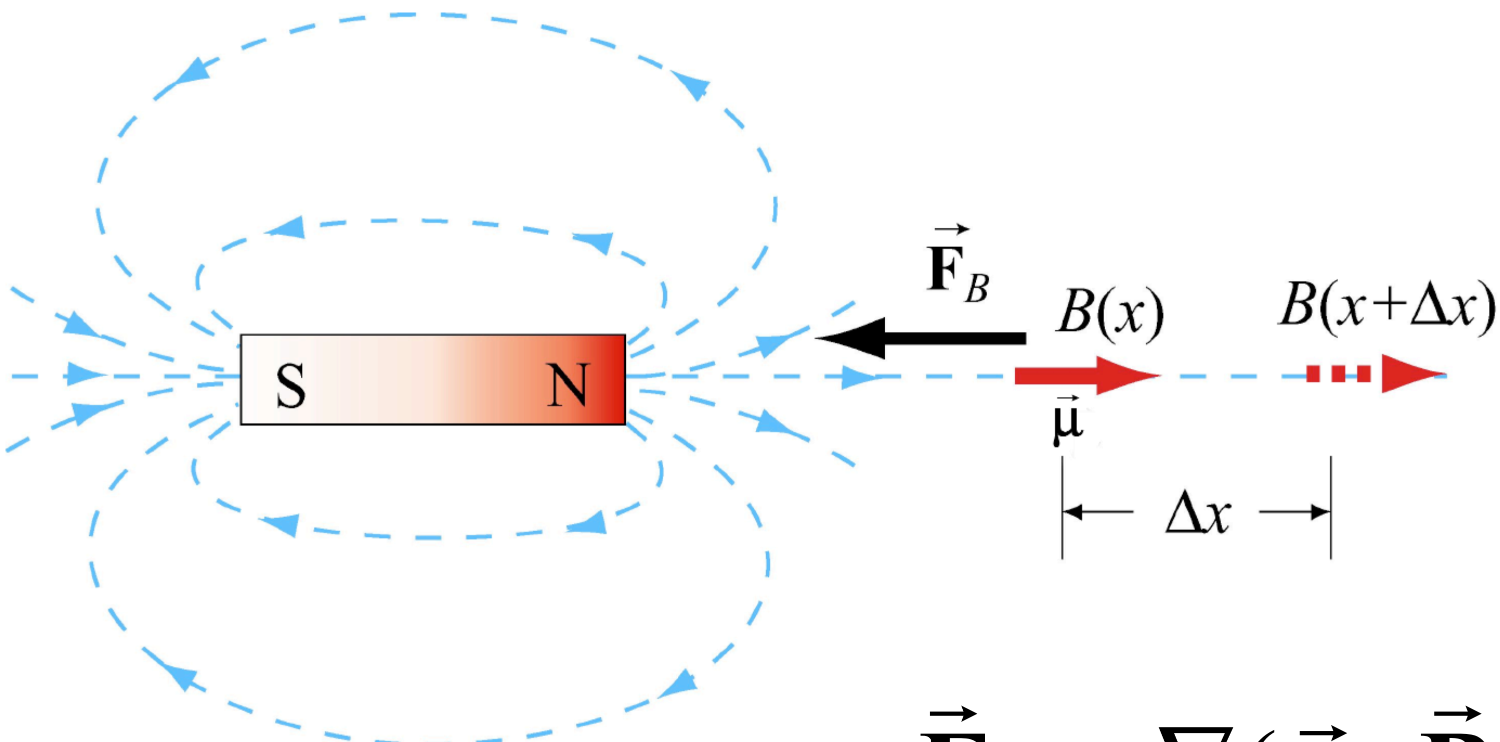

$F = p_x \partial/\partial x \, E_x < 0$

$\vec{F}$ ←

← $\vec{p}$ $F = p_x \partial/\partial x \, E_x > 0$

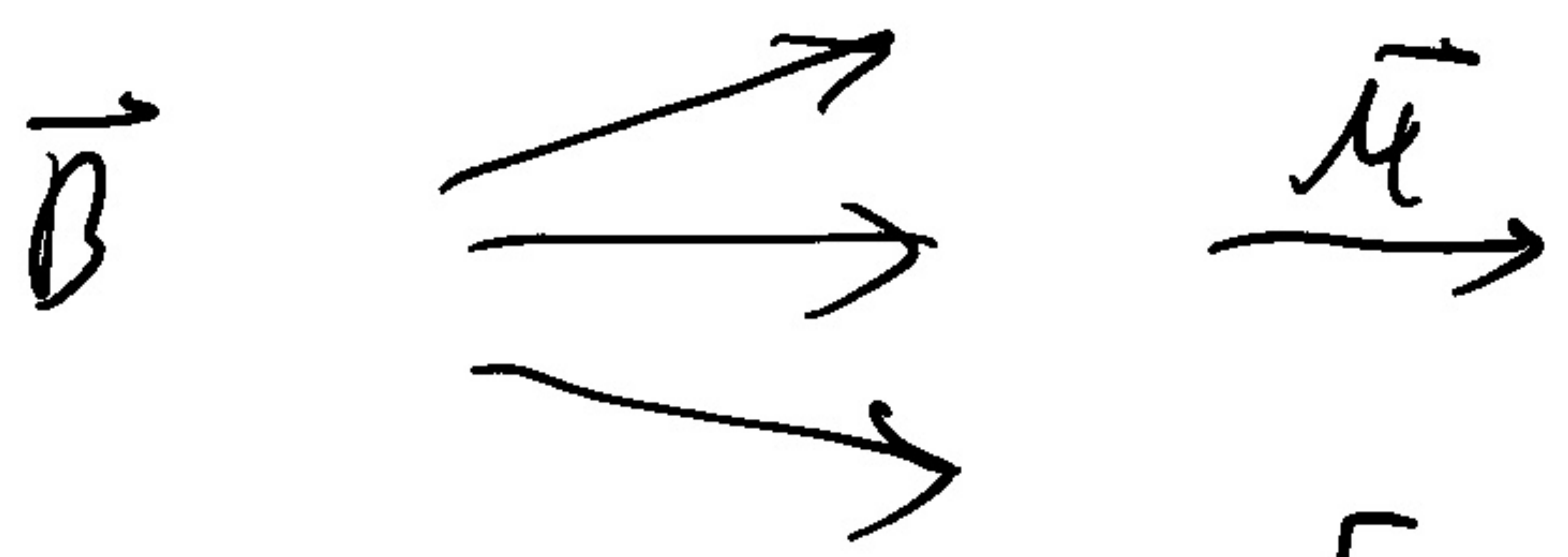
$\vec{F}$ →

# Force on Magnetic Dipole




$$\vec{\mathbf{F}}_B = \nabla(\vec{\mu} \cdot \vec{\mathbf{B}})$$

# Force on magnetic dipole




$$F_x = \mu_x \frac{\partial}{\partial x} B_x < 0$$

$\vec{F}$ $\longleftarrow$

$\vec{\mu}$ $\longleftarrow$

$$F_x = \mu_x \frac{\partial}{\partial x} B_x > 0$$

$\vec{F}$ $\longrightarrow$