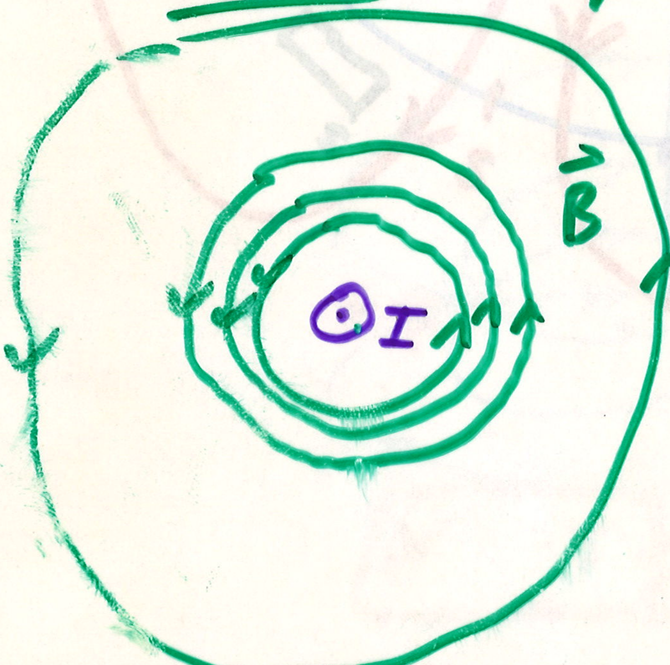
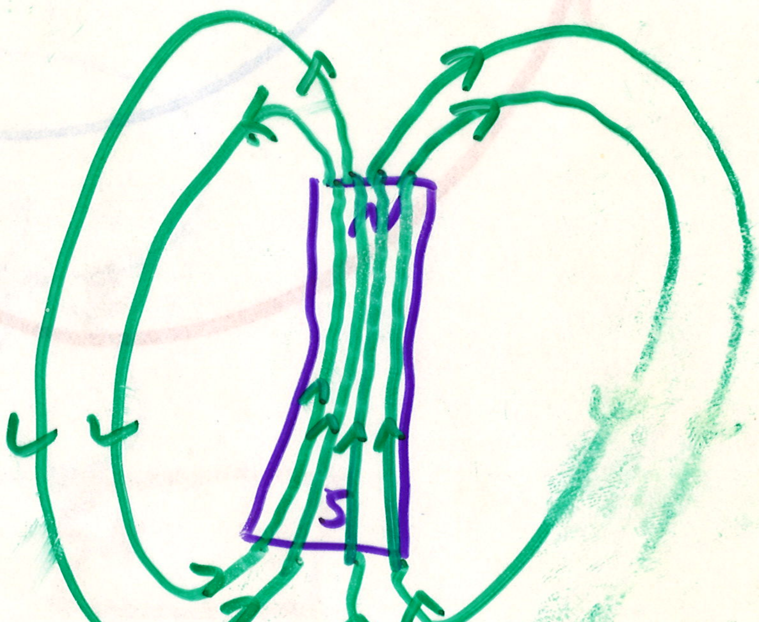
- There are no magnetic charges (monopoles) as yet.

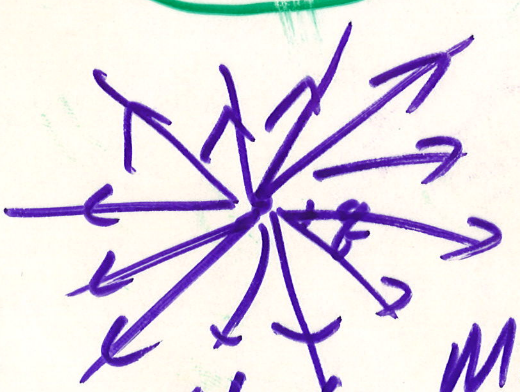
- Magnetic field lines begin and end on magnetic charges

- Magnetic field lines must form <u>closed</u> loops



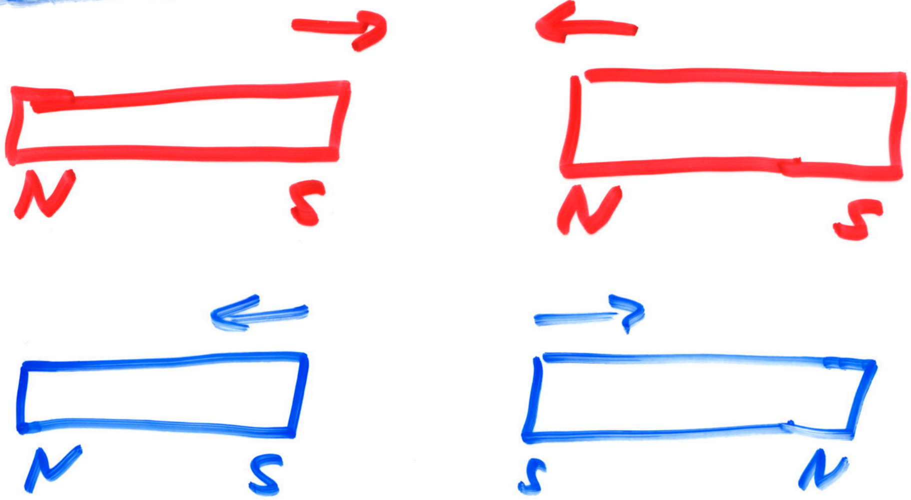



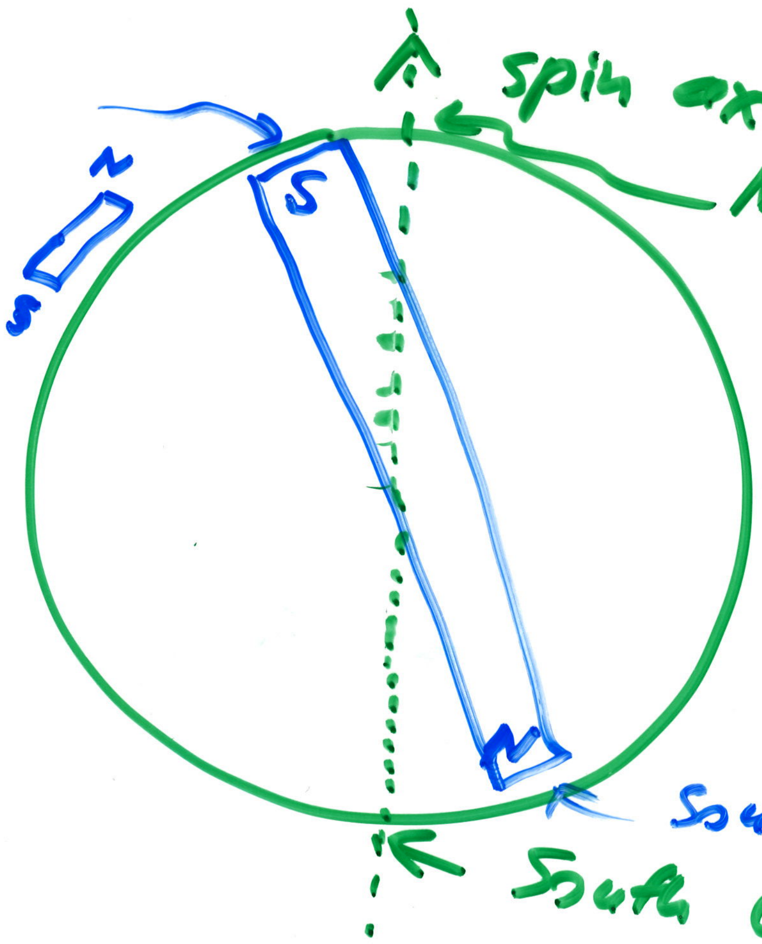

Mag. Dipole



Electric Monopole

Opposite magnetic poles <u>attract</u>; like magnetic poles <u>repel</u>.

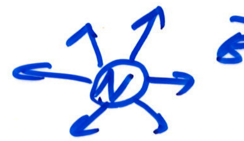



Bar magnet <u>Model</u> of Earth

# The Magnetic Field

The magnetic field is not produced by "magnetic charges" called magnetic monopoles.




Instead, electric charges in motion, that is, currents produce the magnetic field $\vec{B}$.

Recall: the electric force is

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

force on charge $q$

field produced by all charges <u>except</u> $q$.

We derived this from Coulomb's Law

$$\vec{F}_{\substack{\text{of } 1\\ \text{on } 2}} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{(r_{12})^2}\,\hat{r}_{1\to 2}$$

from experiment

---

We determine the magnetic force from experiment also:

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

force on charge $q$

velocity of charge $q$

magnetic field produced by all moving charges <u>except</u> $q$

"cross product" or "vector product"

The cross-product is <u>perpendicular</u>

to both vectors in the product.

$\vec{F}_m$ is $\perp$ to $\vec{v}$

$\vec{F}_m$ is $\perp$ to $\vec{B}$

$\vec{v}$ and $\vec{B}$ can be $\perp$ or $\parallel$ or

anything in between. $|\vec{F}_m| = q v B \sin\theta$

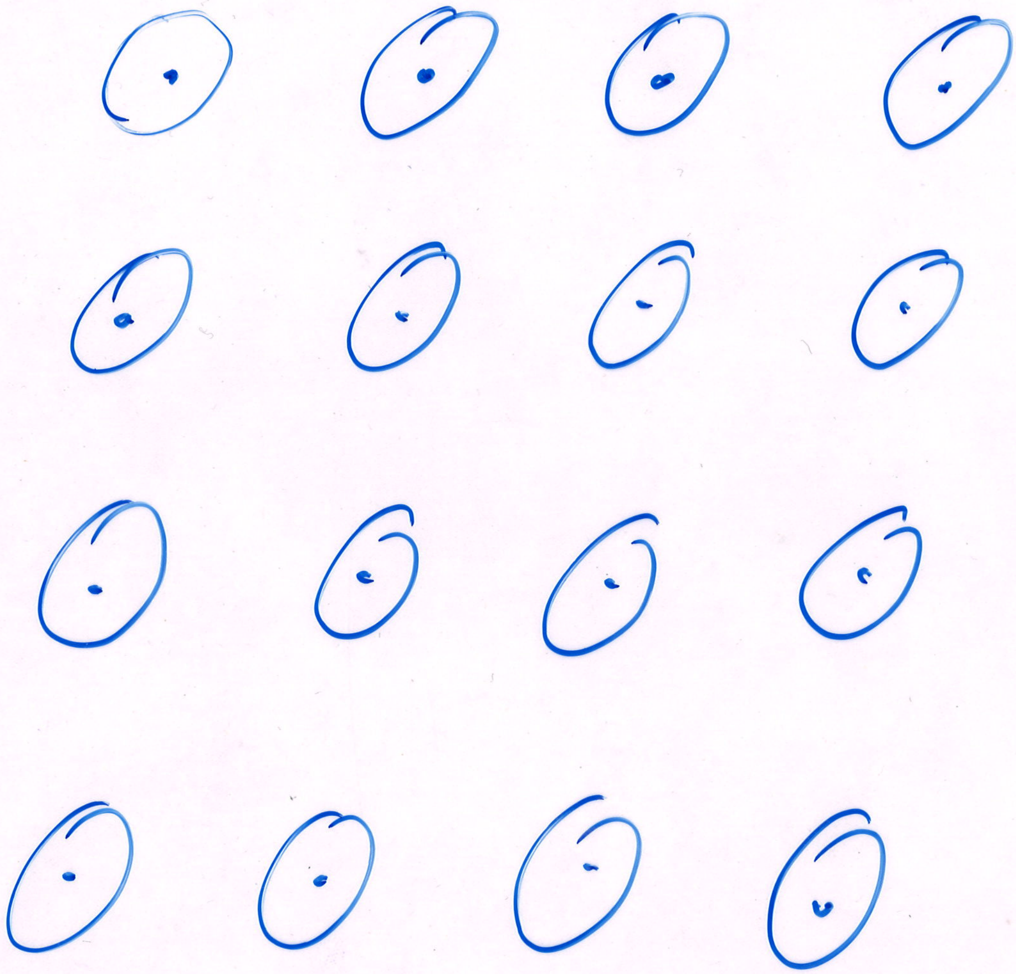
---

Consequence:

The magnetic force <u>does no work</u>.

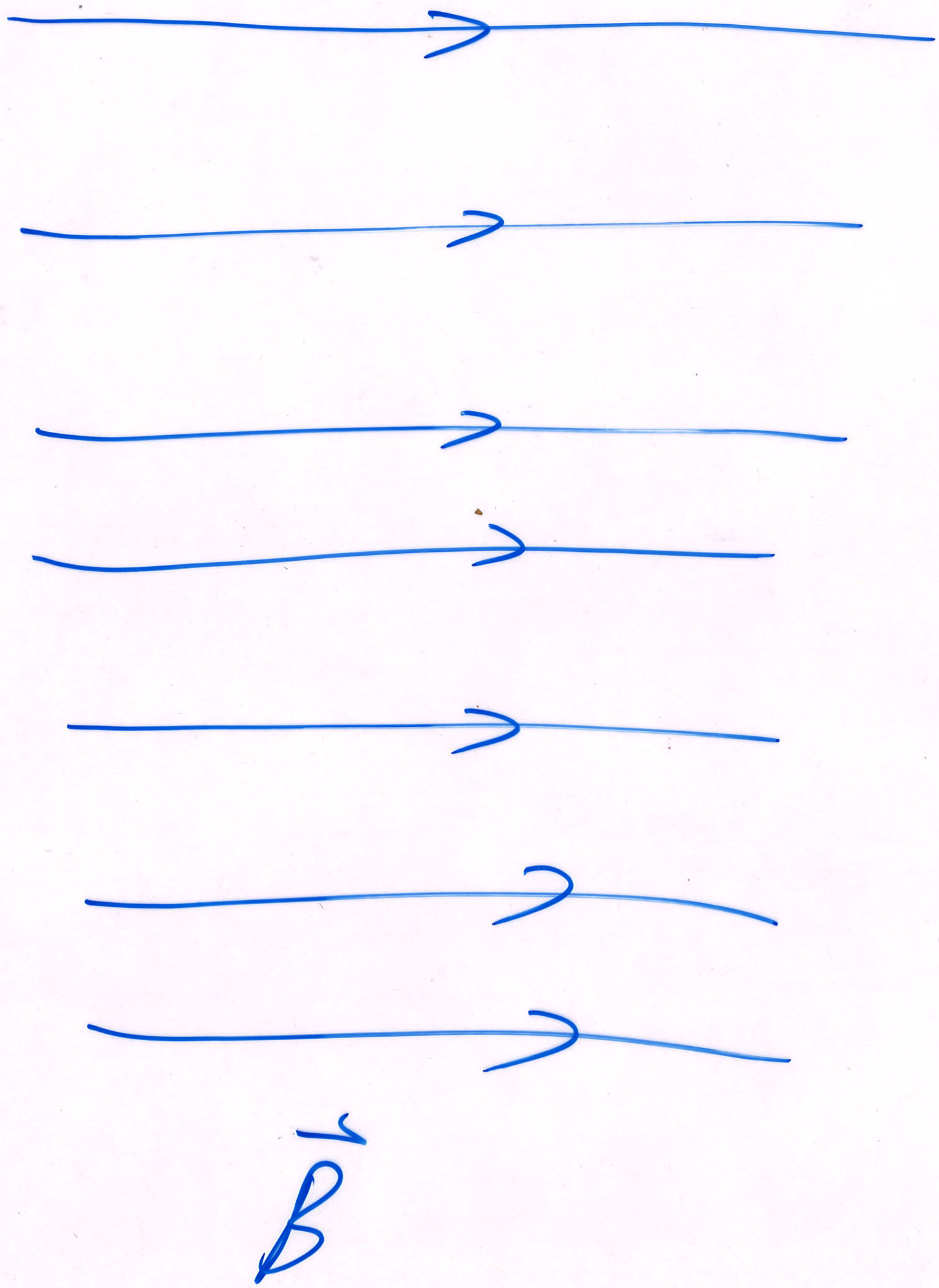
<u>Power</u> $P_{inst} = \vec{F} \cdot \vec{v} = \frac{dW}{dt}$

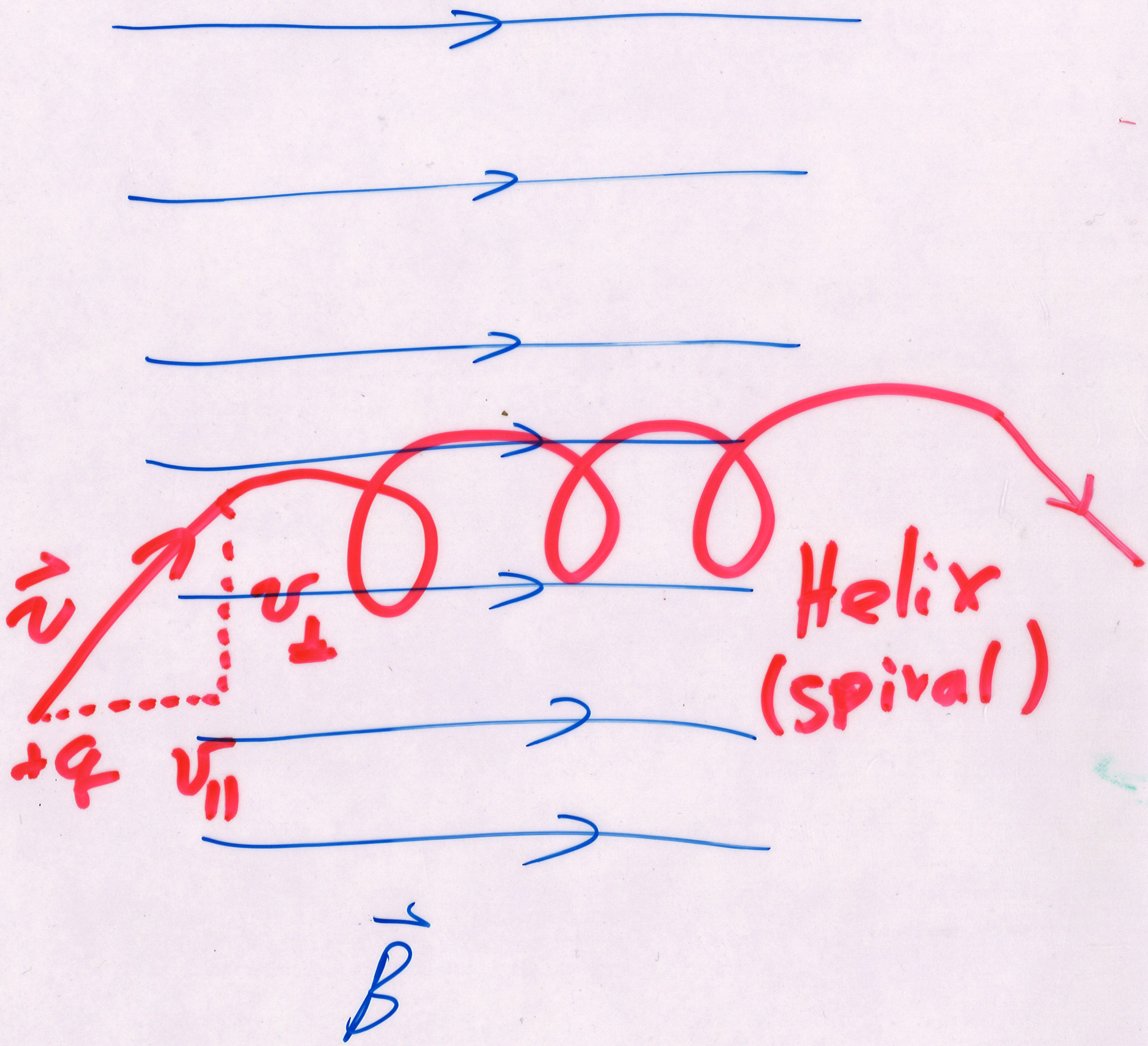
$$W_m = \int_0^T P(t)\, dt = \int_0^T \underbrace{\vec{F}_m \cdot \vec{v}}_{0} = 0$$



$\vec{B}$ out of page

$\vec{B}$ into page

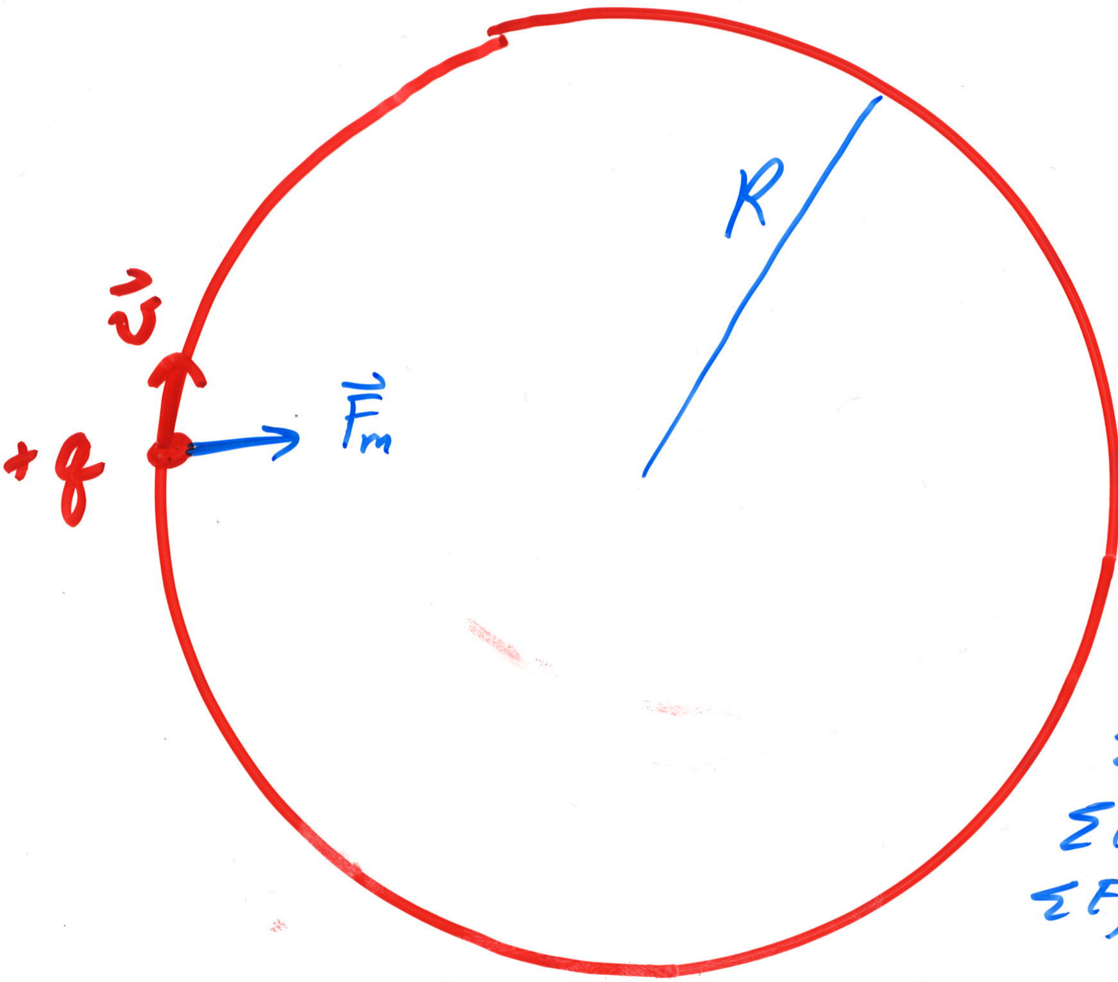

$\vec{B}$



$\vec{v}$
$v_\perp$
$+q$
$v_{\parallel}$
Helix
(spiral)
$\vec{B}$

# Radius of Orbit in a $\vec{B}$ field

$\odot \vec{B}$




$$\Sigma \vec{F} = m\vec{a}$$
$$\Sigma F_x = m a_x$$
$$\Sigma F_y = m a_y$$

$$\Sigma F_r = m a_r \qquad \vec{F}_m = q\vec{v}\times\vec{B}$$

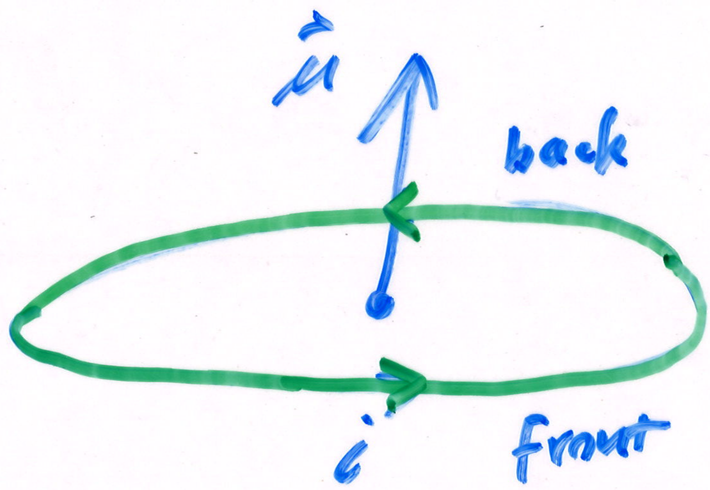
$$F_m = m\left(\frac{v^2}{R}\right) \qquad |\vec{F}_m| = q v B \sin\theta$$

$$q v B = \frac{m v^2}{R}$$

$$\boxed{R = \frac{m v}{q B \sin\theta}}$$

# Magnetic Dipole Moment

For a **flat** current loop, the magnetic dipole moment is a vector $\vec{\mu}$ with magnitude $|\vec{\mu}| = i \cdot \text{Area}$ and direction given by the right-hand rule



$$\vec{F}_m = \left(\frac{q}{\Delta t}\right) \vec{v}\,\Delta t \times \vec{B}$$

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