Chapter 19:

Review

Electric force on a charged particle placed in electric field: $\vec{F} = q\vec{E}$

Torque

$$\vec{\tau} = \vec{r} \times \vec{F}$$
$$\tau = rF \sin\theta$$

Vector notation:

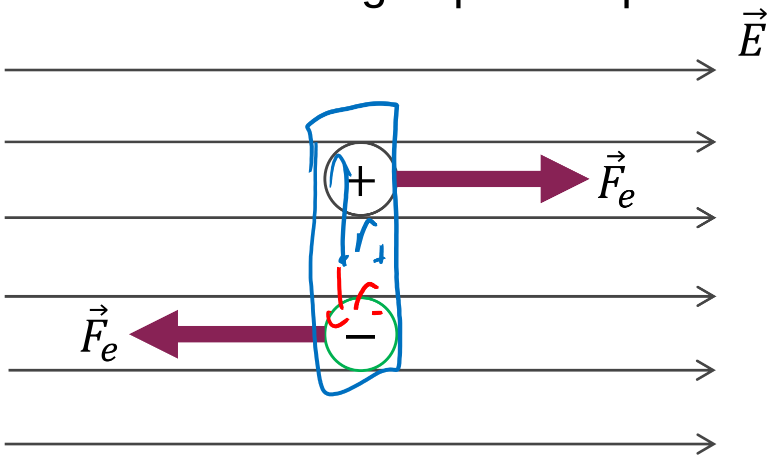
right $\rightarrow$ left $\leftarrow$

$\uparrow$ up $\downarrow$ down

$\cdot$, $\odot$ out of the page $\times$, $\otimes$ into the page

REVIEW

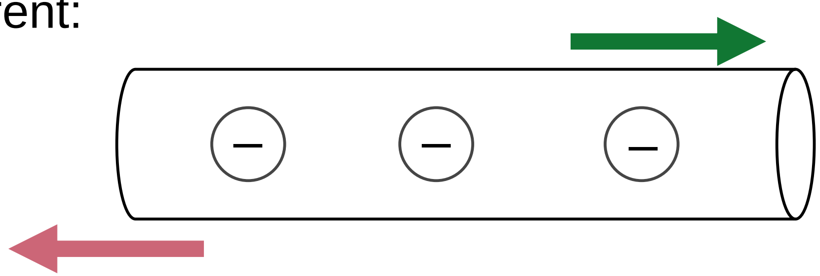
Force on a charged particle placed in the electric field:



Force on a charge in the electric field in along the electric field lines; parallel for a positive charge and antiparallel for a negative charge

Electric current:

ELECTRON CURRENT

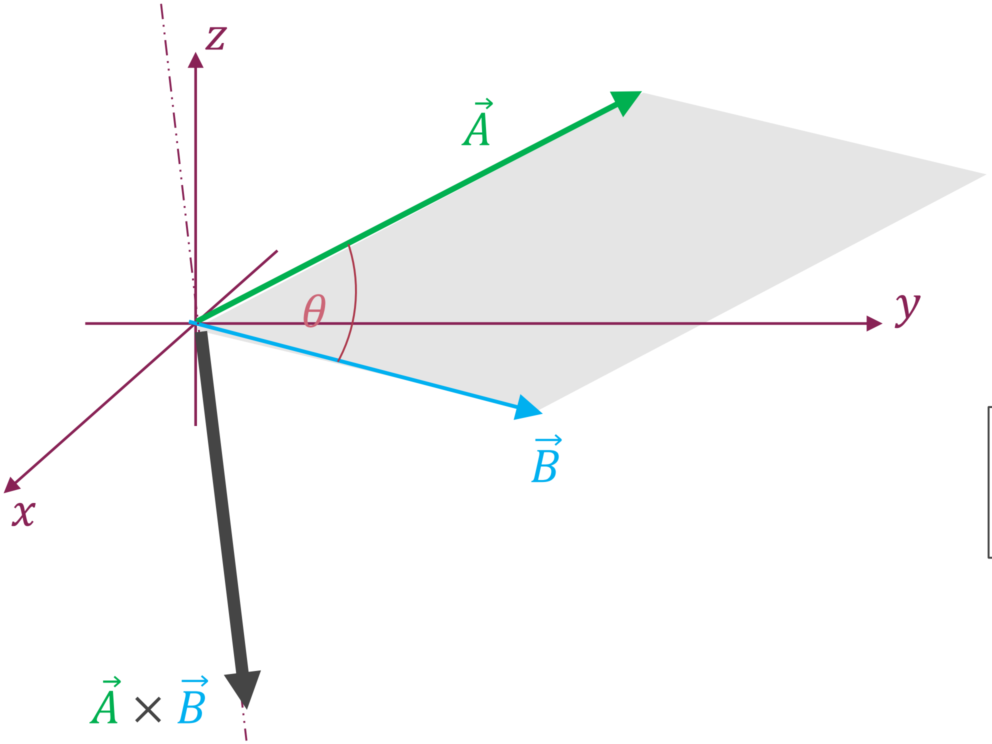


CONVENTIONAL CURRENT

$I \propto q v_d n$ Current is proportional to the charge, drift speed and number of carriers

While we know that electrons are the ones that are **really** moving, we will always consider a **conventional** current, which assumes positive charges are the ones moving in the wire.

Vector (cross) product of two vectors



$$\left|\vec{A} \times \vec{B}\right| := |A||B| \sin(\measuredangle\left(\vec{A}, \vec{B}\right))$$

The resultant vector, $\vec{A} \times \vec{B}$, is perpendicular to **both** $\vec{A}$ **and** $\vec{B}$

Magnitude:

$$\left|\vec{A} \times \vec{B}\right| = |A||B| \sin(\theta)$$

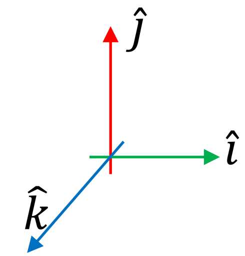
Mathematical expression:

$$\vec{A} \times \vec{B} = \hat{\imath}\left(A_y B_z - A_z B_y\right) + \hat{\jmath}(A_z B_x - A_x B_z) + \hat{k}(A_x B_y - A_y B_x)$$

Regular Cross Product

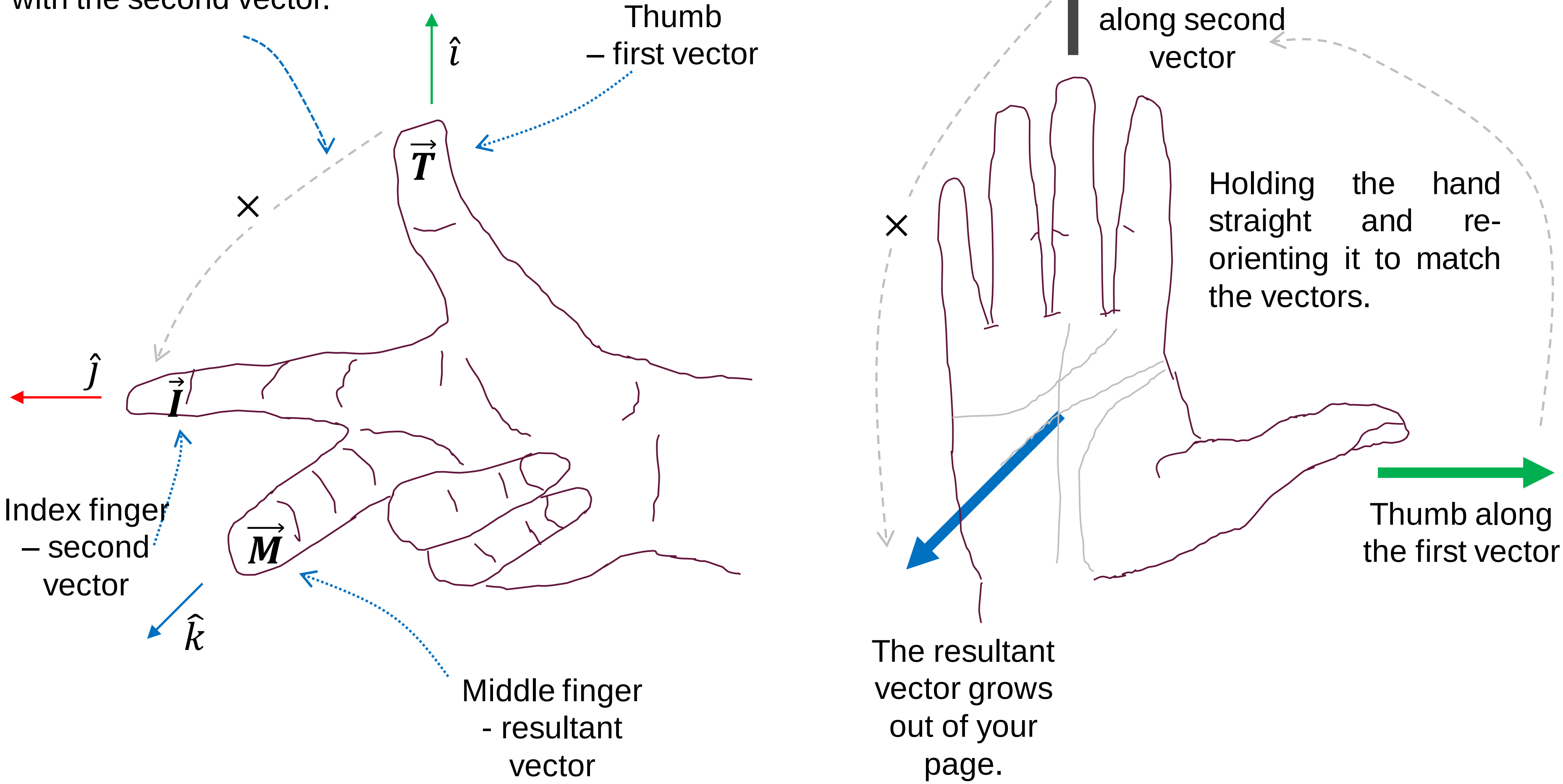
$(\mathbf{t}_{\text{thumb}} - \mathbf{i}_{\text{index}} - \mathbf{m}_{\text{middle}})$

$$\vec{T} \times \vec{I} = \vec{M}$$



$$\hat{k} = \hat{\imath} \times \hat{\jmath}$$

First vector is crossed with the second vector.

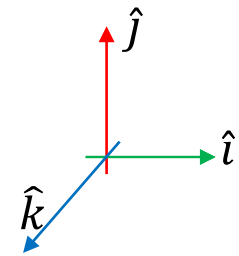


ABC (IMT) RULE

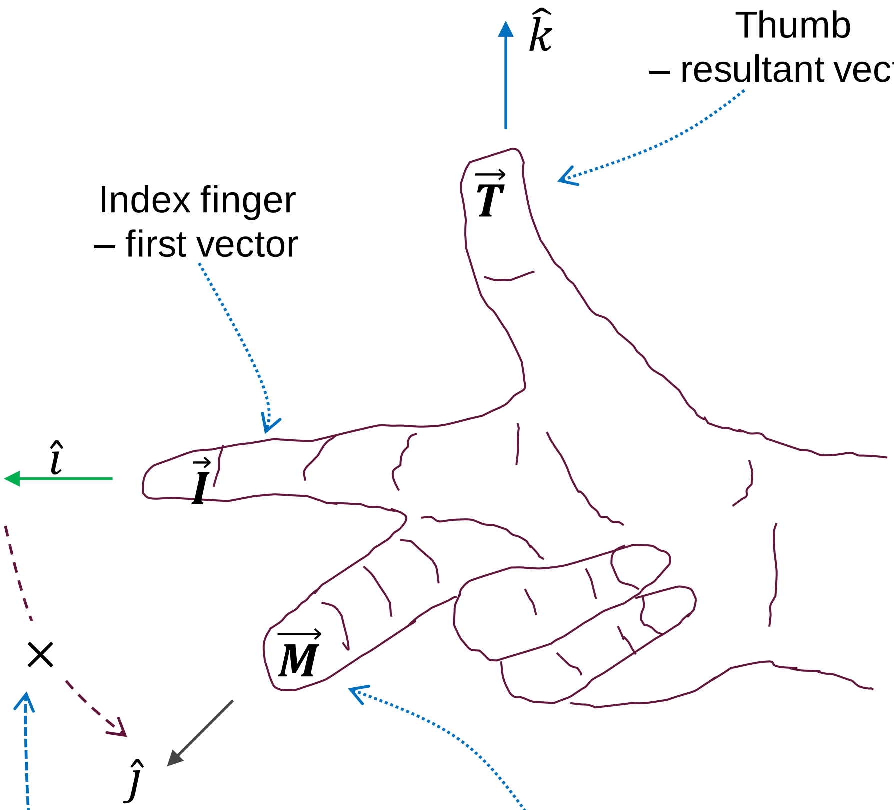
Regular Cross Product

($\mathbf{i}_{\text{index}}$ – $\mathbf{m}_{\text{middle}}$ – $\mathbf{t}_{\text{thumb}}$)

$$\vec{I} \times \vec{M} = \vec{T}$$



$$\hat{k} = \hat{\imath} \times \hat{\jmath}$$

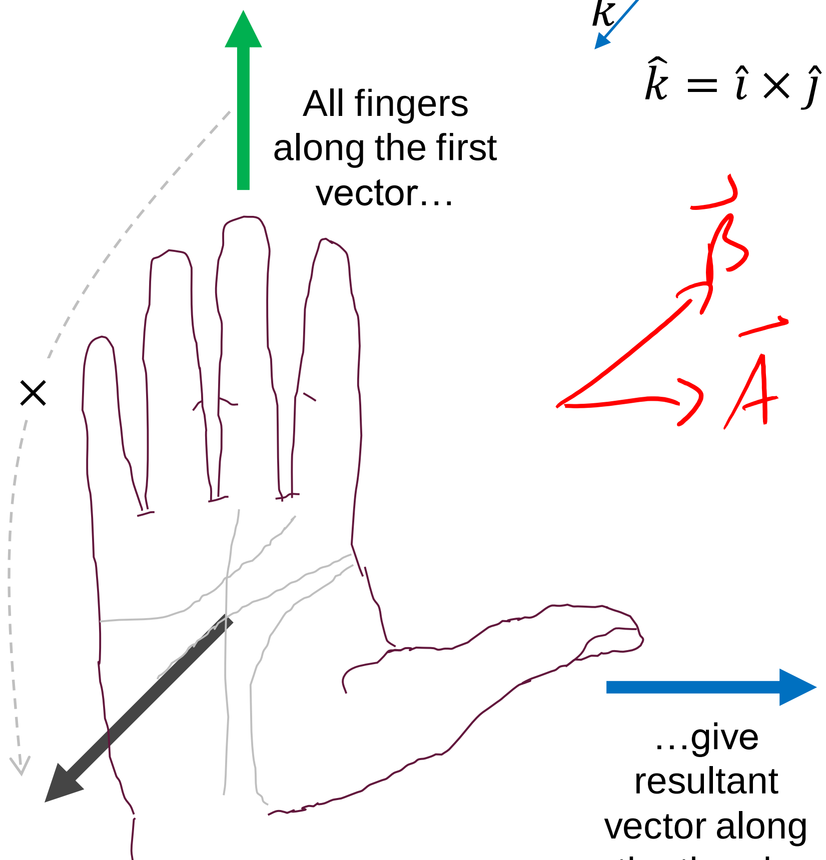


Thumb
– resultant vector

Index finger
– first vector

Middle finger
– second vector

First vector is crossed with the second vector.



All fingers along the first vector…

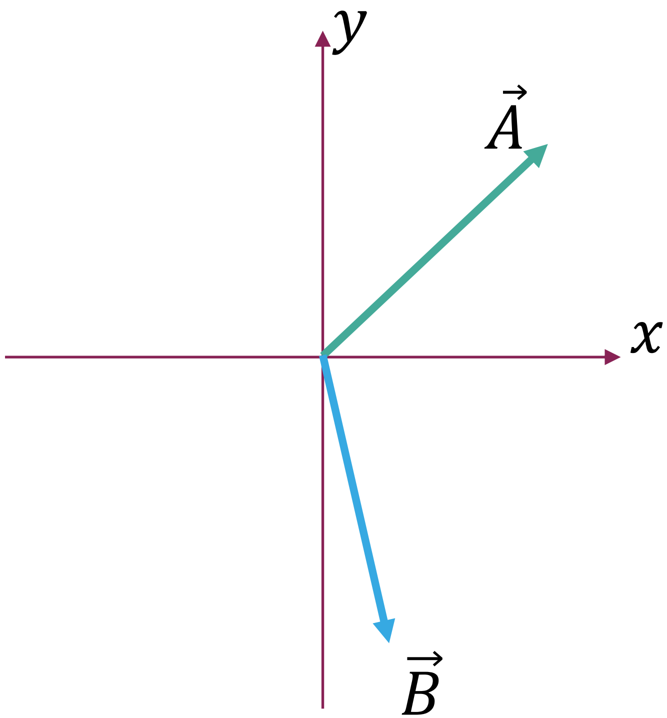
,,, folded towards the palm, where second vector is growing out of…

…give resultant vector along the thumb.

USE

Up × South = East

Consider a cross product of vectors $\vec{A}$ and $\vec{B}$ $\vec{A} \times \vec{B}$.



What is the direction of the resulting vector?

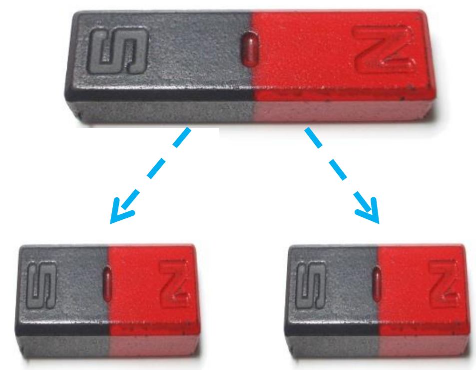
a) INTO THE PAGE ($-z$ direction)

b) OUT OF THE PAGE ($+z$ direction)

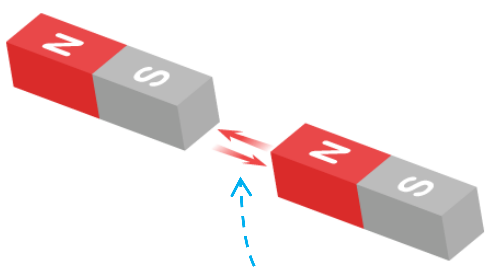
MAGNETISM

A bar magnet that is allowed to rotate freely will always turn to align itself in an approximate north-south direction.

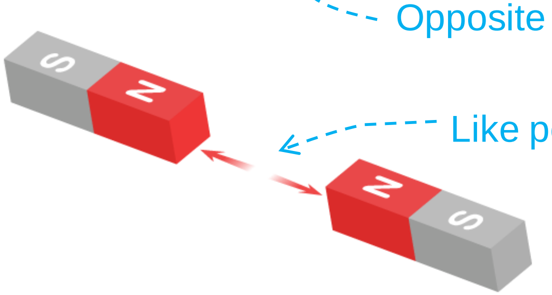
North seeking pole (**north pole).**



When a magnet is cut in half, two weaker, but complete magnets are produced.



Opposite poles attract



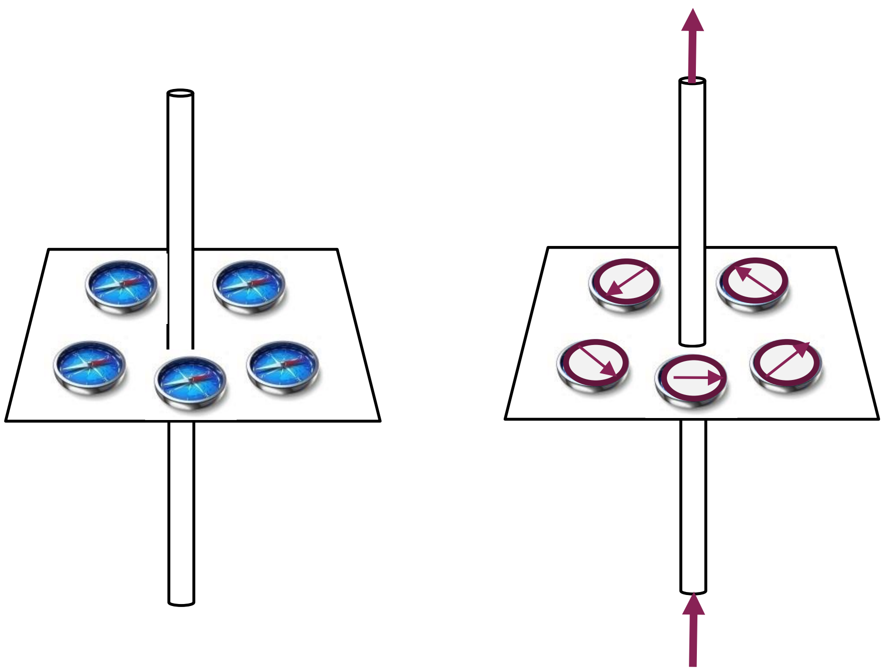
Like poles repel.

South pole of a magnet attracts the "north seeking" end of compass needle. Needle itself is a magnet.

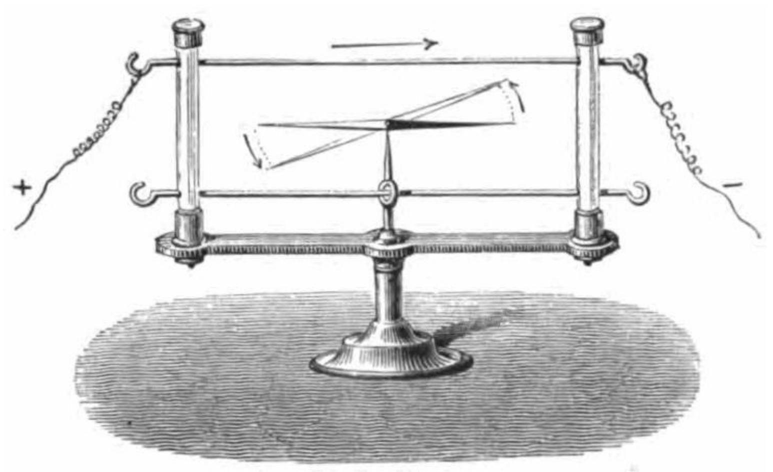
THE DISCOVERY OF THE MAGNETIC FIELD

Oersted:

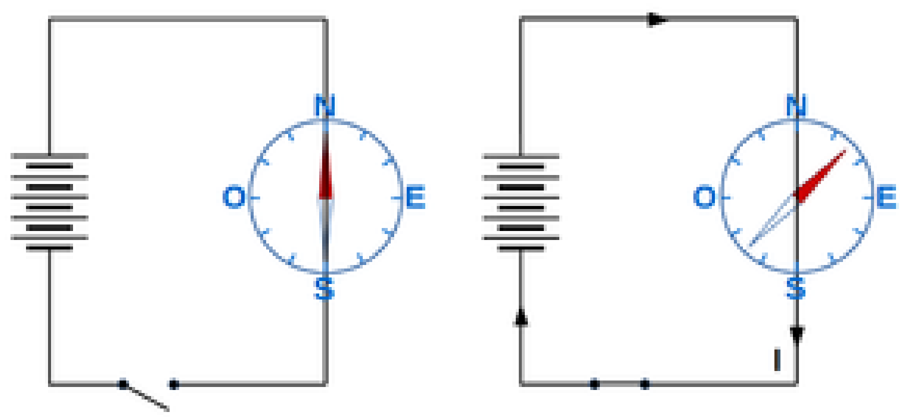
Magnetism is caused by an electric current.



Conventional current



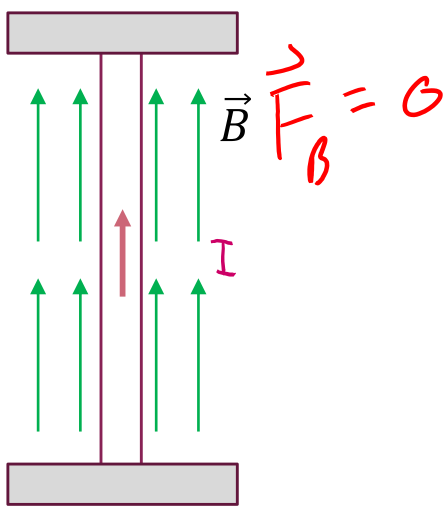
Oersted's classroom demonstration (demonstrating the new invention of a battery).

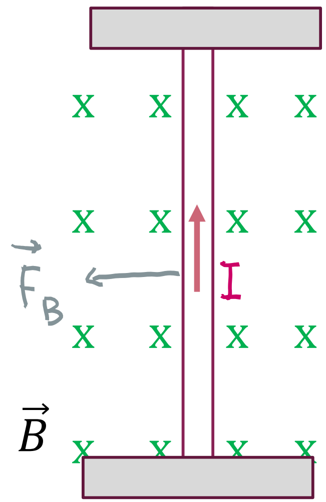


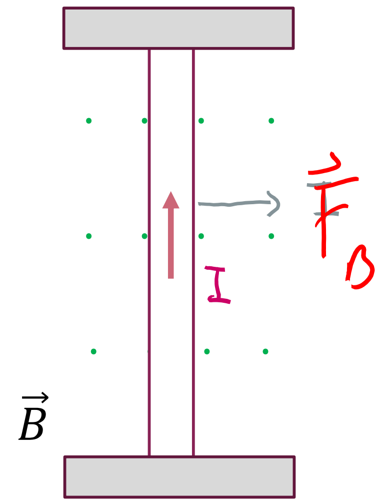
We will first consider how moving charges behave
when they are placed in the magnetic field.

20.3 Magnetic Forces on Current-Carrying Wires

Consider a current carrying a conventional current I placed in an external magnetic field $\vec{B}$.







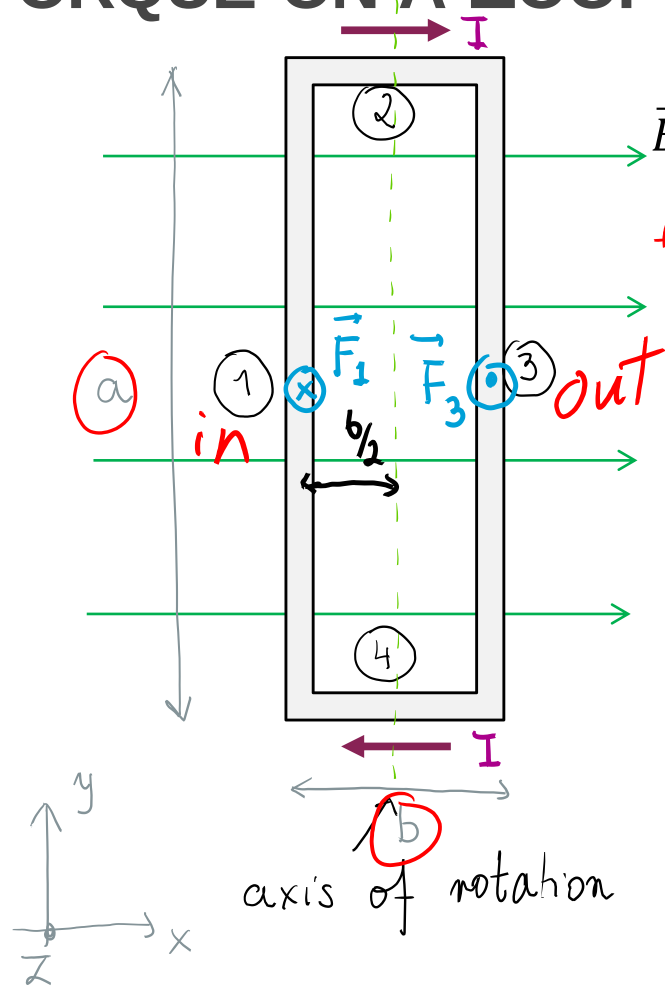
When the current is along the direction of the field, there is no force on the wire

When magnetic field is perpendicular to the current, the wire experiences a force.
The direction of that force can be determined using right-hand-rule.

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

$$\left|\vec{F}_B\right| = ILB$$

Torque on a Loop in a Magnetic Field



FORCE ON SIDE #1

near $F_1 = IaB$ into the page

far $F_2 = 0$ I is parallel to $\vec{B}$

$F_3 = IaB$ out of the page

$F_4 = 0$ I is antiparallel to $\vec{B}$

Two forces in opposite directions not acting on the same spot → torque!

TORQUE $\tau_1 = F_1 \frac{b}{2}$ (− y direction)

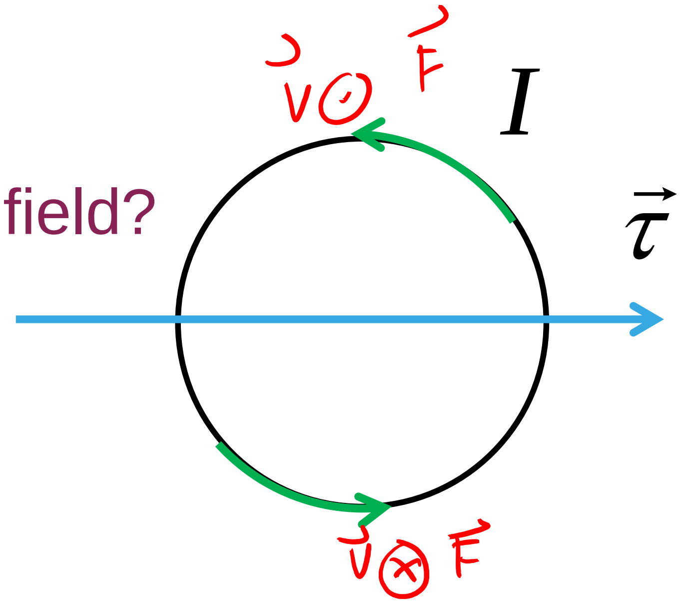
$\tau_3 = F_3 \frac{b}{2}$ (− y direction)

Total: $\tau_1 + \tau_2 = \underbrace{F_1 \frac{b}{2} + F_3 \frac{b}{2}}_{-y \text{ dir}} = IaB\frac{b}{2} + IaB\frac{b}{2}$

$\tau = I\underbrace{ab}_{\text{area}}B = IAB$

- This question forces you to think a bit backward, but let's try.
- Consider a circular loop shown in the picture. There is a counter-clockwise current in the loop, I.
- When you look at the loop it is rotating around the direction shown by $\vec{\tau}$.
- To figure out the rotation of the loop, take your right hand and put the thumb in the direction of the torque.
- Your fingers (curled) will tell you which way the loop is rotating.

What is the direction of the magnetic field?



20.4 A Particle Moving in Magnetic Field

When a charged particle is moving, it creates magnetic field.

It also responds to external magnetic field, by experiencing a **magnetic force** $\vec{F}_B$.

$= I\vec{l} \times \vec{B}$

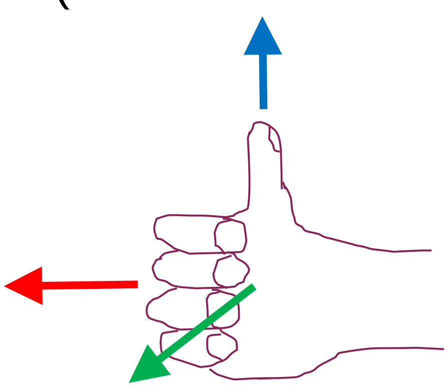
Magnetic Force: $\vec{F}_B = q\vec{v} \times \vec{B}$

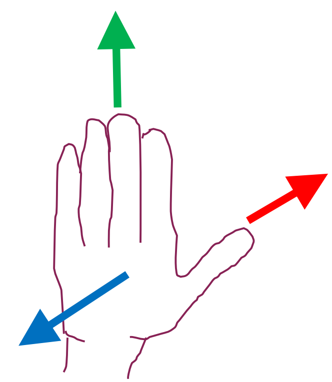
Magnitude of the magnetic force:

$F_B = |q|vBsin\phi$

Direction: **Determined by right hand rule [RHR]**

Two rules (word of advice: pick one and stick to it)





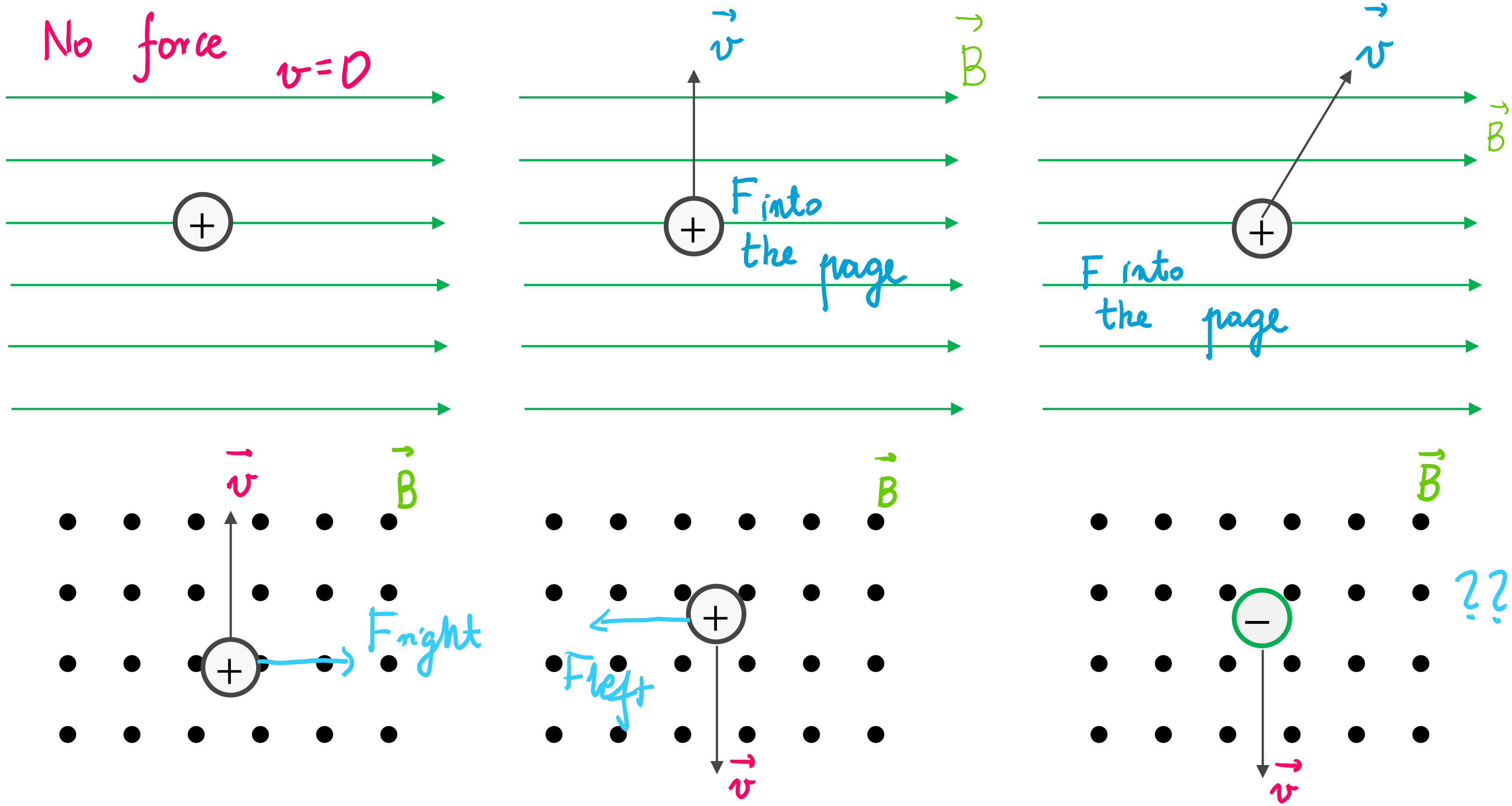
"very bad" rule *©Dr. Rick Goulding*

Fingers along $\boldsymbol{\vec{v}}$, *palm facing* $\boldsymbol{\vec{B}}$, *force* $\overrightarrow{\boldsymbol{F_B}}$ *on positive charge in the direction of the thumb.* IMT

fingers as field lines

Fingers along $\boldsymbol{\vec{B}}$, *thumb pointing in direction of* $\boldsymbol{\vec{v}}$, *force* $\overrightarrow{\boldsymbol{F_B}}$ *on the positive charge extends outward the palm* TIM

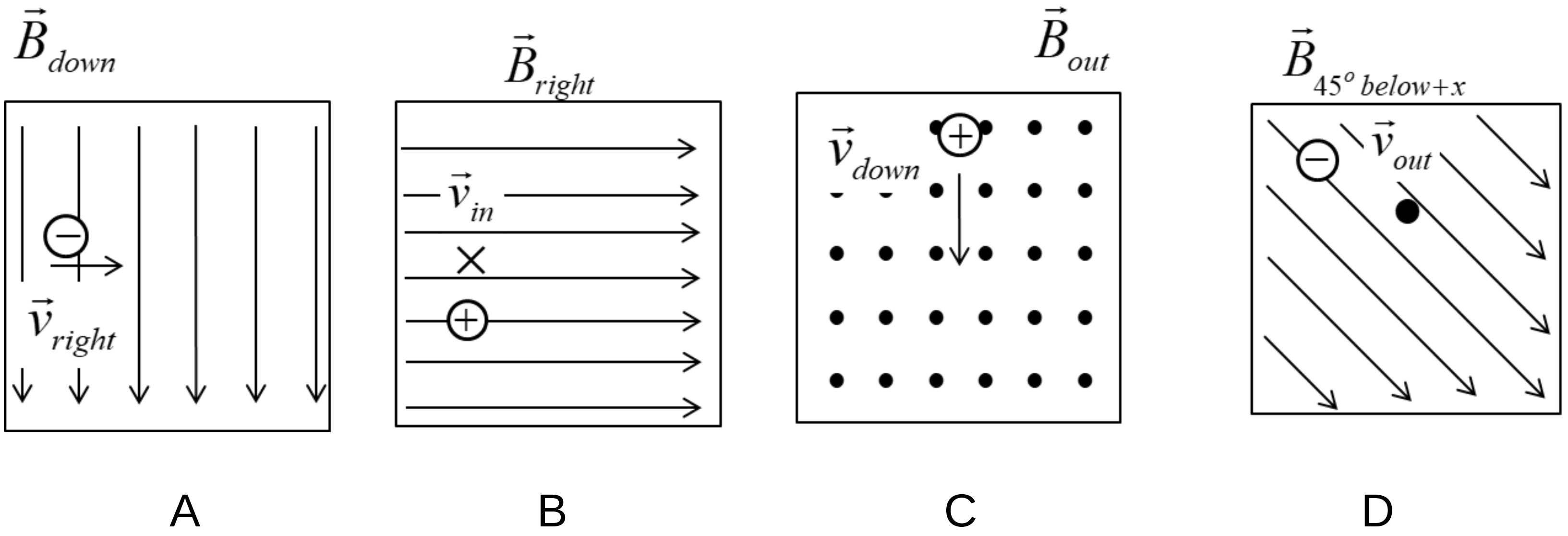
MAGNETIC FORCE ON A MOVING CHARGE



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

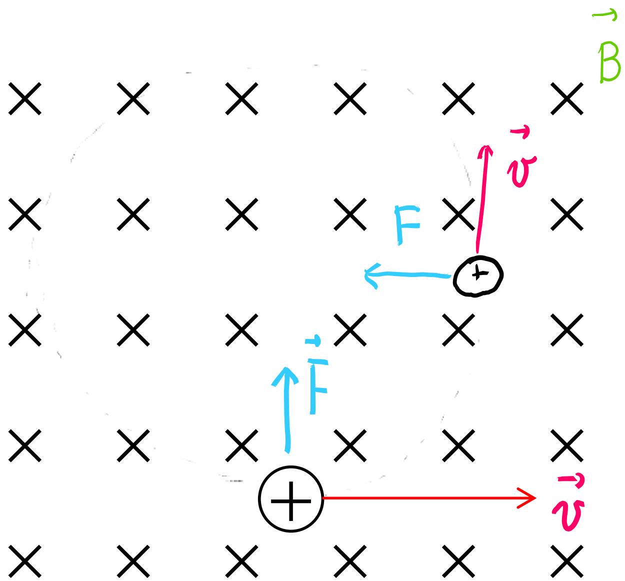
$$F_B = qvB sin\phi$$

In the series of settings, determine the direction of missing vector.



left

20.6 A CIRCULATING CHARGED PARTICLE



Newton's 2ND law

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

$$\boxed{R = \frac{mv}{qB}}$$

Time to make one loop $T = \frac{2\pi R}{v} = \frac{2\pi\, mv}{qBv} = 2\pi \frac{m}{qB}$

INDEPENDENT ON v & R