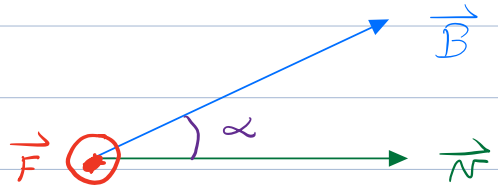
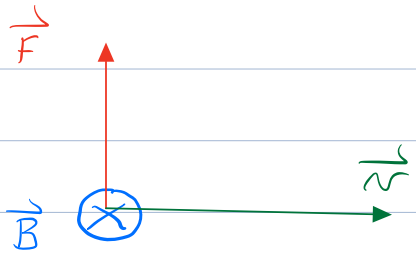
24.5: Magnetic Fields Exert Forces on Moving Charges

Consider a charge q moving with velocity $\vec{v}$ in an applied magnetic field $\vec{B}$. ($\vec{B}$ might be due to some other coils or magnets.)

Top View



Side View



$\vec{F}$ is $\perp$ to the page, coming out of the paper.

$\odot$ ⇒ out of the page

$\otimes$ ⇒ into the page

$|\vec{F}| = q v B \sin\alpha$

direction of $\vec{F}$: $\perp$ to $(\vec{v}, \vec{B})$ plane, given by a right hand rule

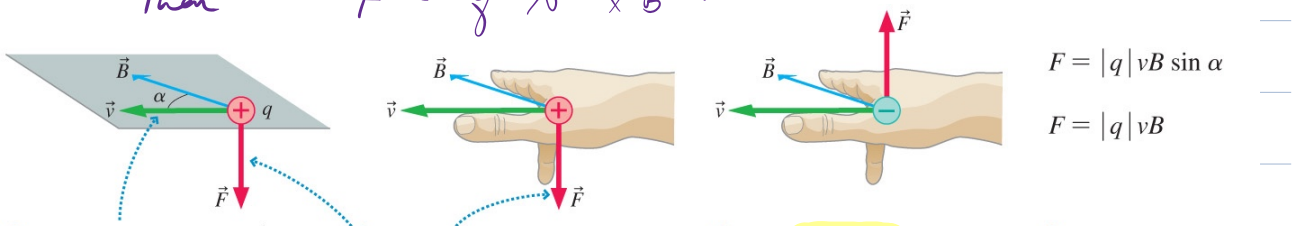
Write $\vec{F} = q\vec{v} \times \vec{B}$ (cross product)

Right hand: 1) place fingers along $\vec{v}$

2) curl them to point along $\vec{B}$

3) Thumb points in direction of $\vec{v} \times \vec{B}$

Then $\vec{F} = q\vec{v} \times \vec{B}$.



❶ Note the direction of $\vec{v}$ and $\vec{B}$, and find the angle α between them.

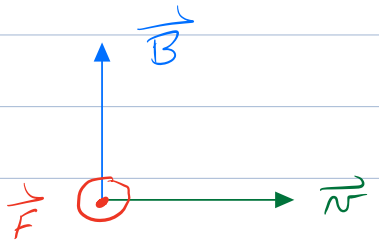
❷ The force is perpendicular to the plane containing $\vec{v}$ and $\vec{B}$. The direction of $\vec{F}$ is given by the right-hand rule.

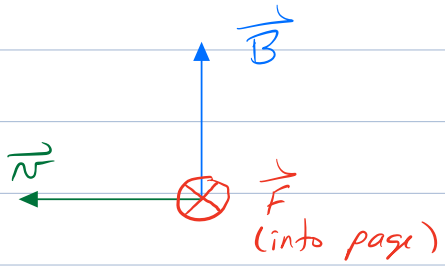
❸ For a negative charge, the force is in the direction opposite to that predicted by the right-hand rule.

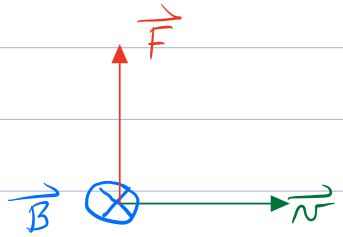
❹ The magnitude of the force is given by Equation 24.5 or Equation 24.6.

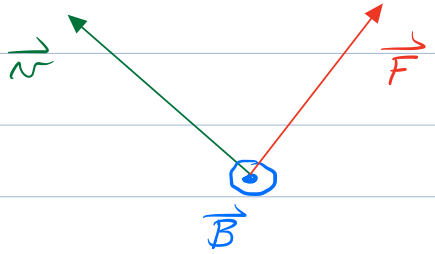
$$\vec{F} = q\vec{v} \times \vec{B}$$

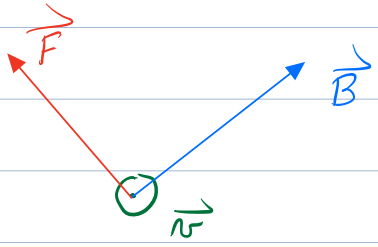
examples: (all assuming a positive charge q)

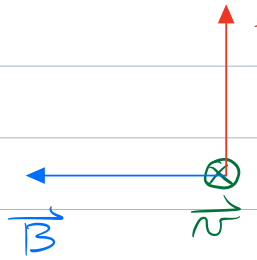






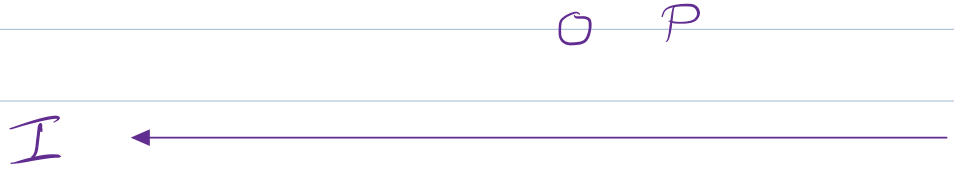




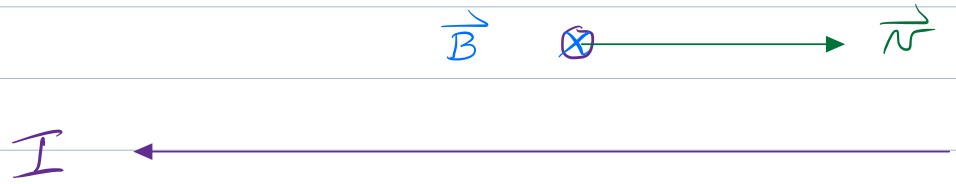


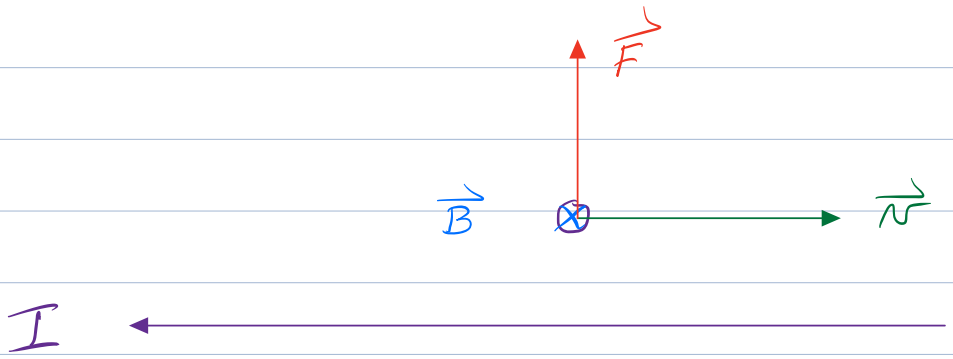
What if q is negative? Then $\vec{F}$ points in the other direction.

Example: The long straight wire carries a current I to the left. ① What is the direction of the magnetic field due to the wire at point P?

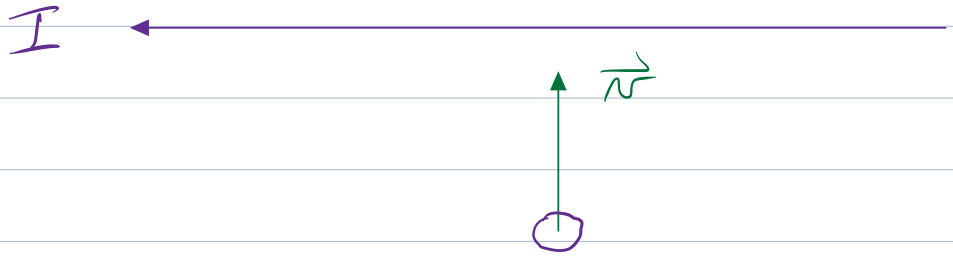


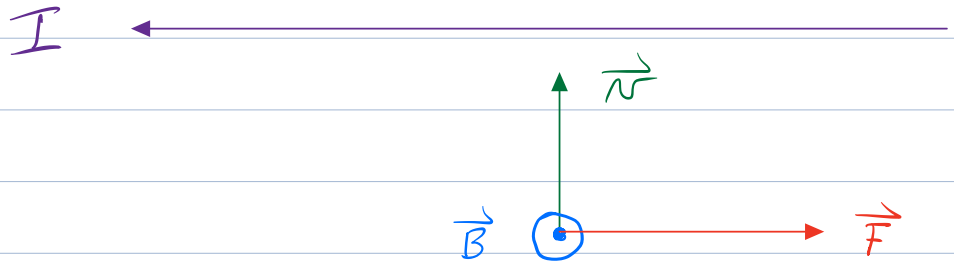
Next, a positive charge q is moving to the right with velocity $\vec{v}$ at point P. ② What is the direction of the force on the moving charge?





Lastly, what is the direction of the force on a positive charge moving towards the wire from below?

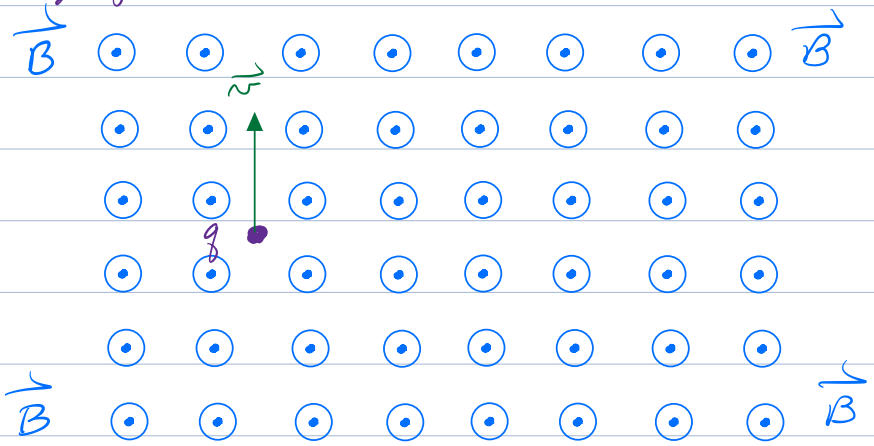




(More with numbers later.)

Return to 24.5 – forces on individual charges

Suppose $\vec{B}$ = uniform, and out of the page. Assume a positive charge q.



Poll: direction of $\vec{F}$?

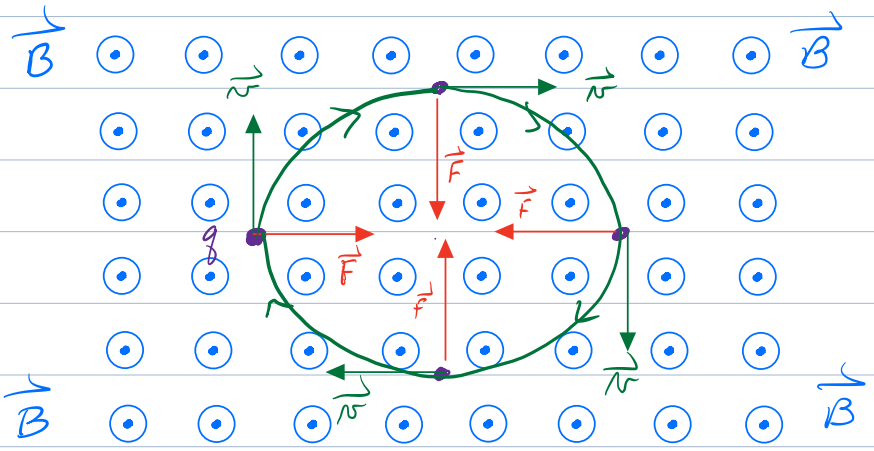
(repeat)

Recall $\vec{F} = q\vec{v} \times \vec{B}$: Right Hand Rule

① Fingers along $\vec{v}$

② curl fingers to point to $\vec{B}$

③ Thumb points along $\vec{F}$.



Result: particle goes in a circle of radius r.

Use $\Sigma F = ma$

$$qvB\sin 90^\circ = \frac{mv^2}{r}$$

or:

$$r = \frac{mv}{qB}$$

Application: measuring m/q for a charged particle

→ electron: Lab

→ charged ion: Mass spectrometer

Cyclotron: Sometimes ask how long does it take to complete one orbit, or what is the orbit frequency?

$$T = \frac{2\pi r}{v} = \frac{2\pi\left(\frac{mv}{qB}\right)}{v} = \frac{2\pi m}{qB}$$

$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

e.g. an electron in Earth's magnetic field (the aurora)

$m = 9.11 \times 10^{-31}\ kg$

$q = -e = -1.602 \times 10^{-19}\ C$

$B = 5 \times 10^{-5}\ T$

$$|f| = \left|\frac{qB}{2\pi m}\right| = \frac{(1.602\times10^{-19}\,C)(5\times10^{-5}\,T)}{2\pi(9.11\times10^{-31}\,kg)} = 1.4\times10^{6}\,Hz$$

What does the − sign mean? The direction is opposite

Related application: velocity selector. (See example.)