PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 21900

General Physics II

Electricity, Magnetism and Optics

Lecture 11 – Chapter 17.3

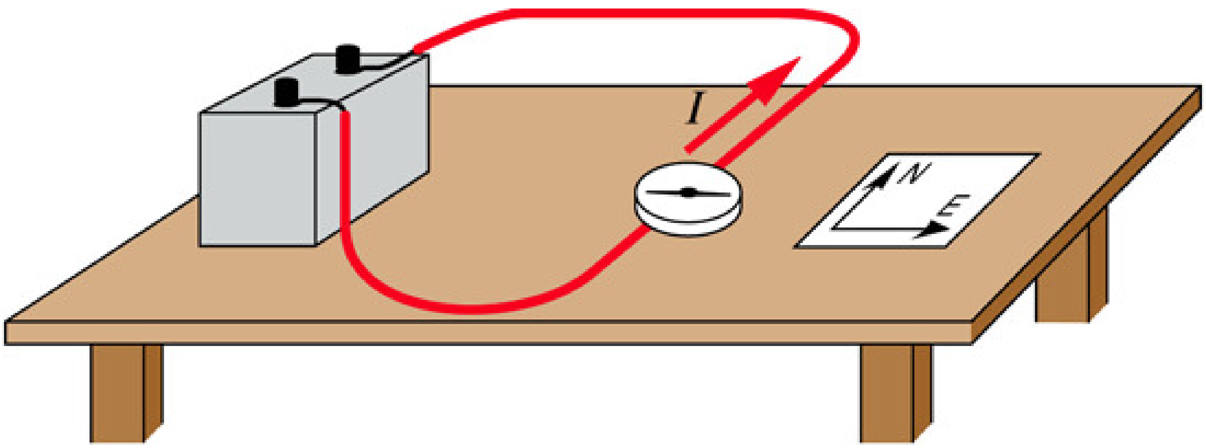
The Lorentz Force

Fall 2015 Semester

Prof. Matthew Jones

Magnetic Forces

- A connection between electricity and magnetism was first observed in about 1820 by Hans Christian Ørsted:



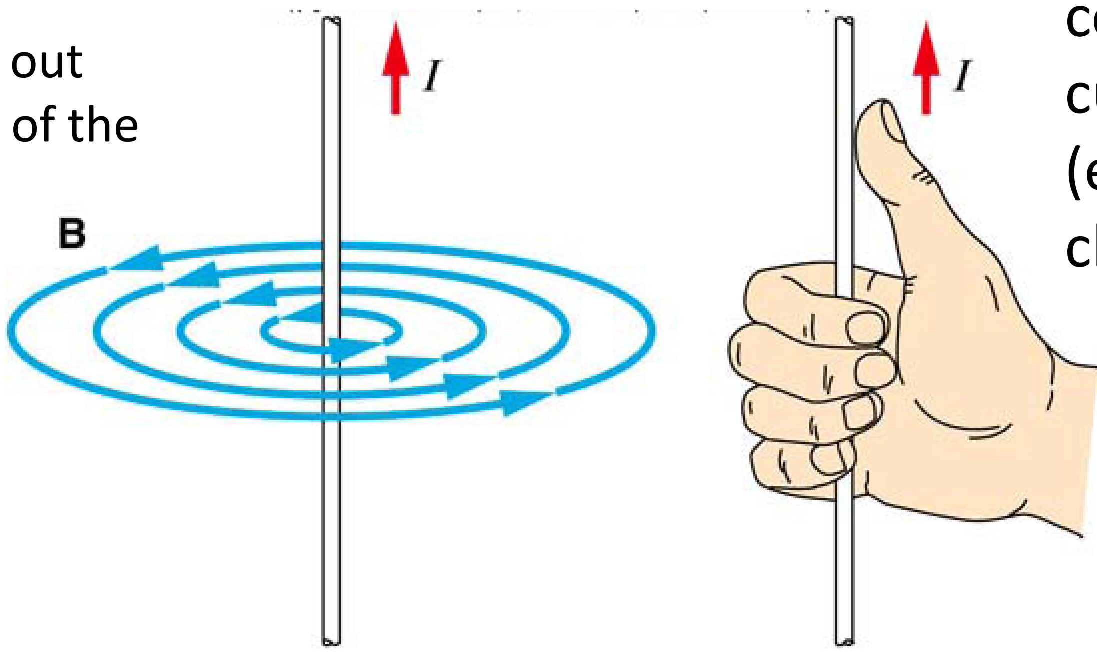
The orientation of the wire with respect to the compass is important!

- The current through the wire caused a deflection in the nearby compass needle.

Magnetic Forces

- Conclusion: the current must generate a magnetic field

The deflection of the compass needle maps out the direction of the $\vec{B}$-field lines.

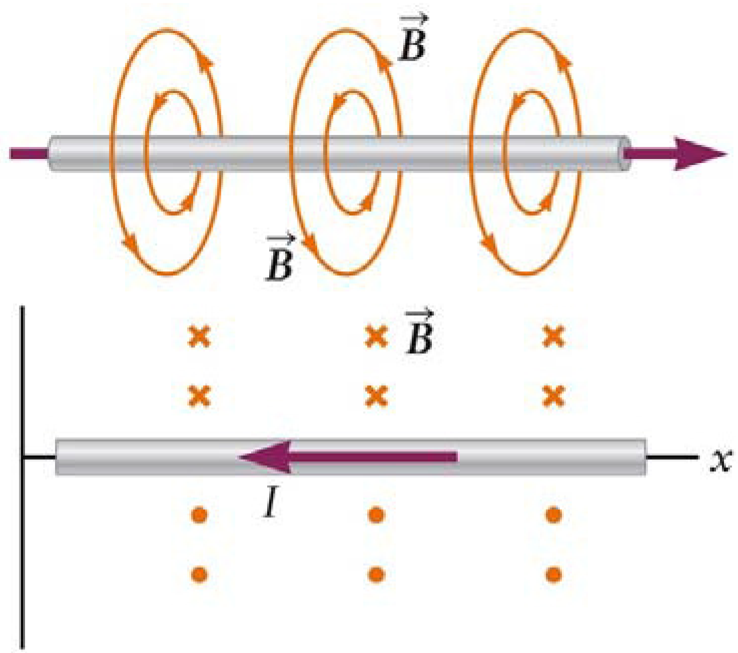


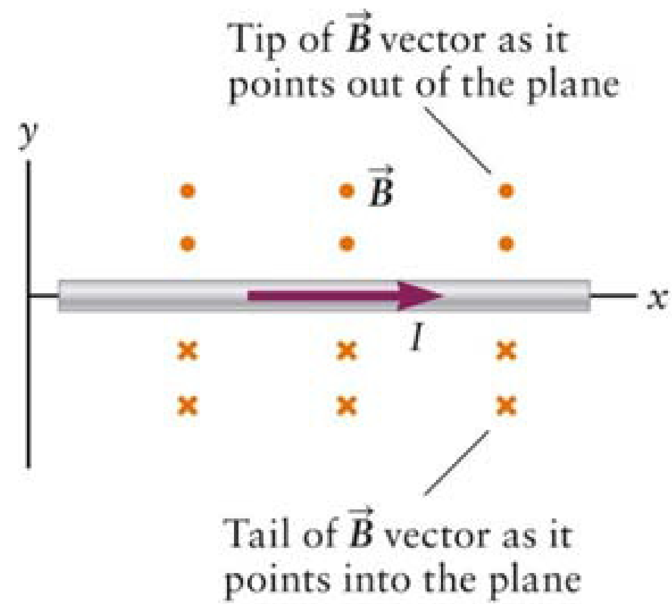
Direction of conventional current flow (eg. positive charge carriers)

This particular version of “the right-hand rule” shows how to get the direction of the magnetic field right.

Magnetic Field Lines

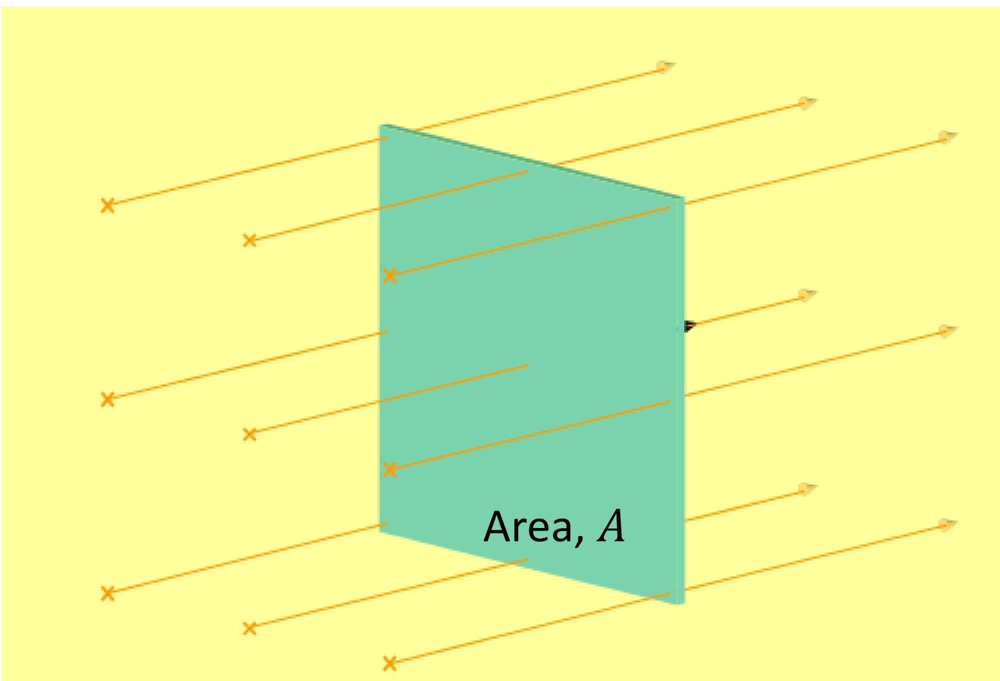
- With electric fields, we could describe them using projections onto a 2-dimensional plane.
- Magnetic fields involve 3-dimensional geometries.
- We need some new notation to explain these ideas:





Magnetic Flux

- Another term for the "magnetic field" is ***magnetic flux density***
- Magnetic flux is the "number" of magnetic field lines intersecting a surface:



Uniform magnetic field $\vec{B}$, surface area A produces magnetic flux

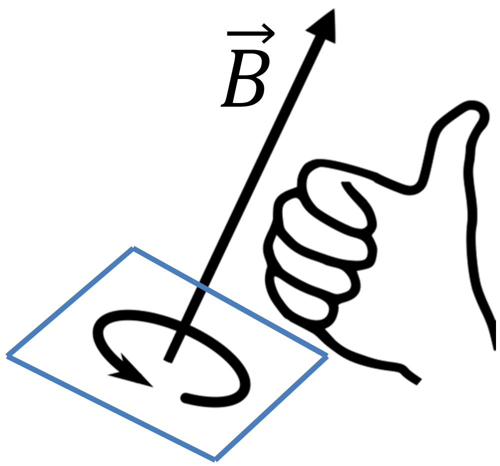
$$\Phi_B = B \cdot A$$

MKS units for magnetic flux is the Weber (Wb)

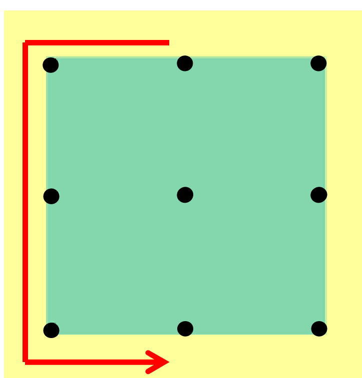
Magnetic Flux

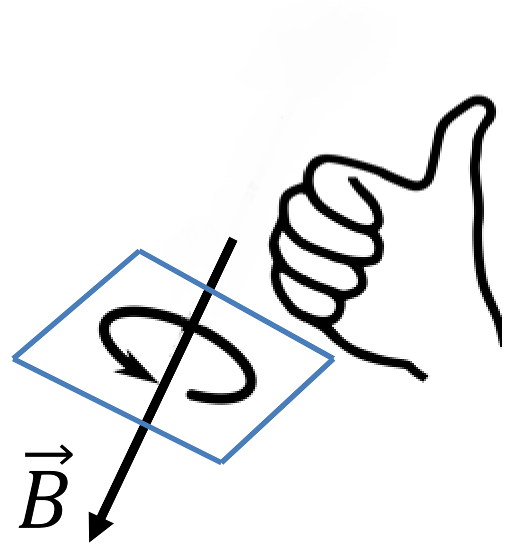
- The orientation of the surface is important!
- Surfaces have two sides…
  - Draw a loop around the boundary
  - Use the right-hand rule to see what direction your thumb is pointing
  - If your thumb points in the same direction as $\vec{B}$ then the flux is positive
  - If your thumb points in the direction opposite $\vec{B}$ then the flux is negative

Magnetic Flux

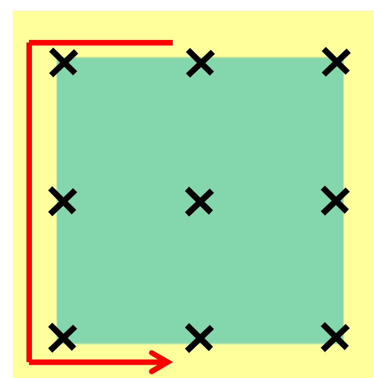


$$\Phi_B > 0$$



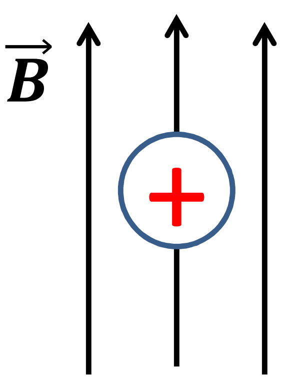


$$\Phi_B < 0$$

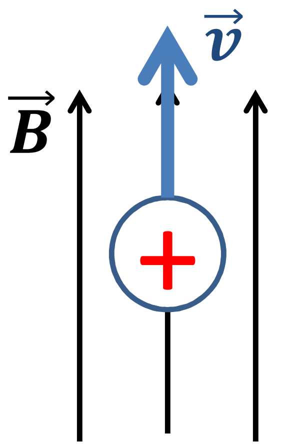


Lorentz Force

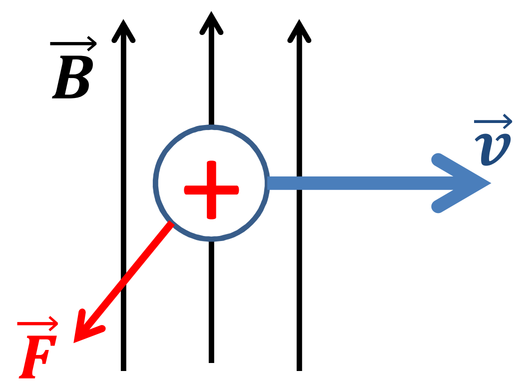
- A magnetic field exerts a force on a *moving* charge
- The magnitude of the force is depends on:
  - The magnetic field, $\vec{B}$
  - The charge, Q
  - The velocity, $\vec{v}$
  - *The direction of $\vec{v}$ relative to $\vec{B}$*



$\vec{v} = 0$
No force

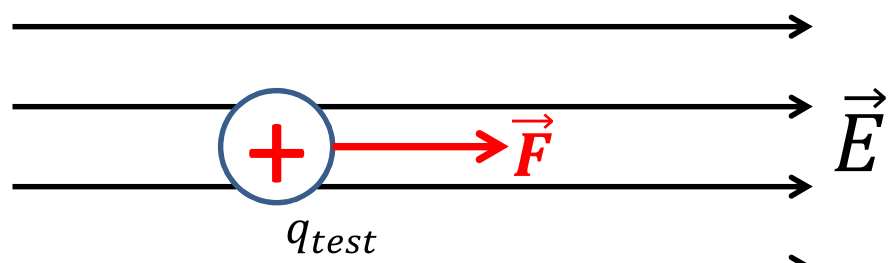


$\vec{v}$ parallel to $\vec{B}$
No force



$\vec{v}$ perpendicular to $\vec{B}$
Maximum force!
Perpendicular to both $\vec{B}$ and $\vec{v}$

Comparison with Electric Field



$$\vec{F} = q_{test}\,\vec{E}$$

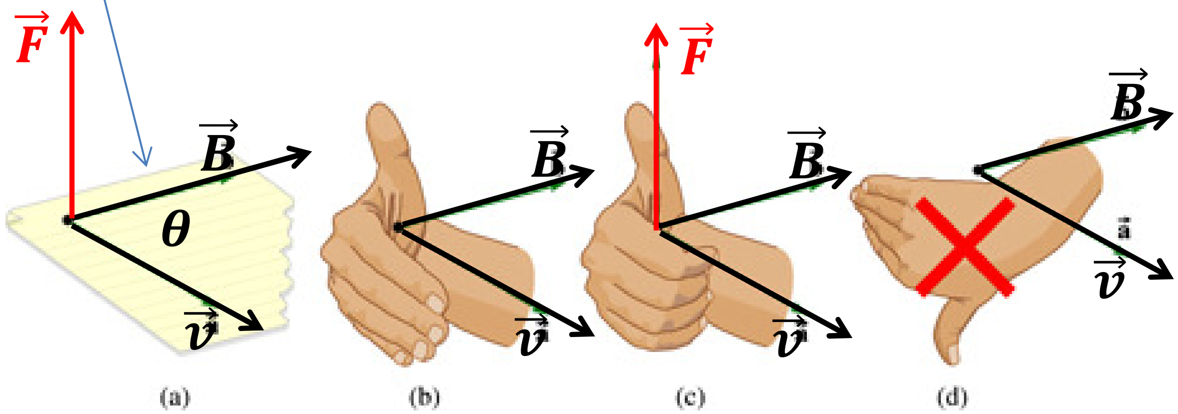
- The force on a test charge is in the same direction as the field, $\vec{E}$.
- The force on a moving charge in a magnetic field is perpendicular to both $\vec{v}$ and $\vec{B}$…

The Lorentz Force (1892)

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

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

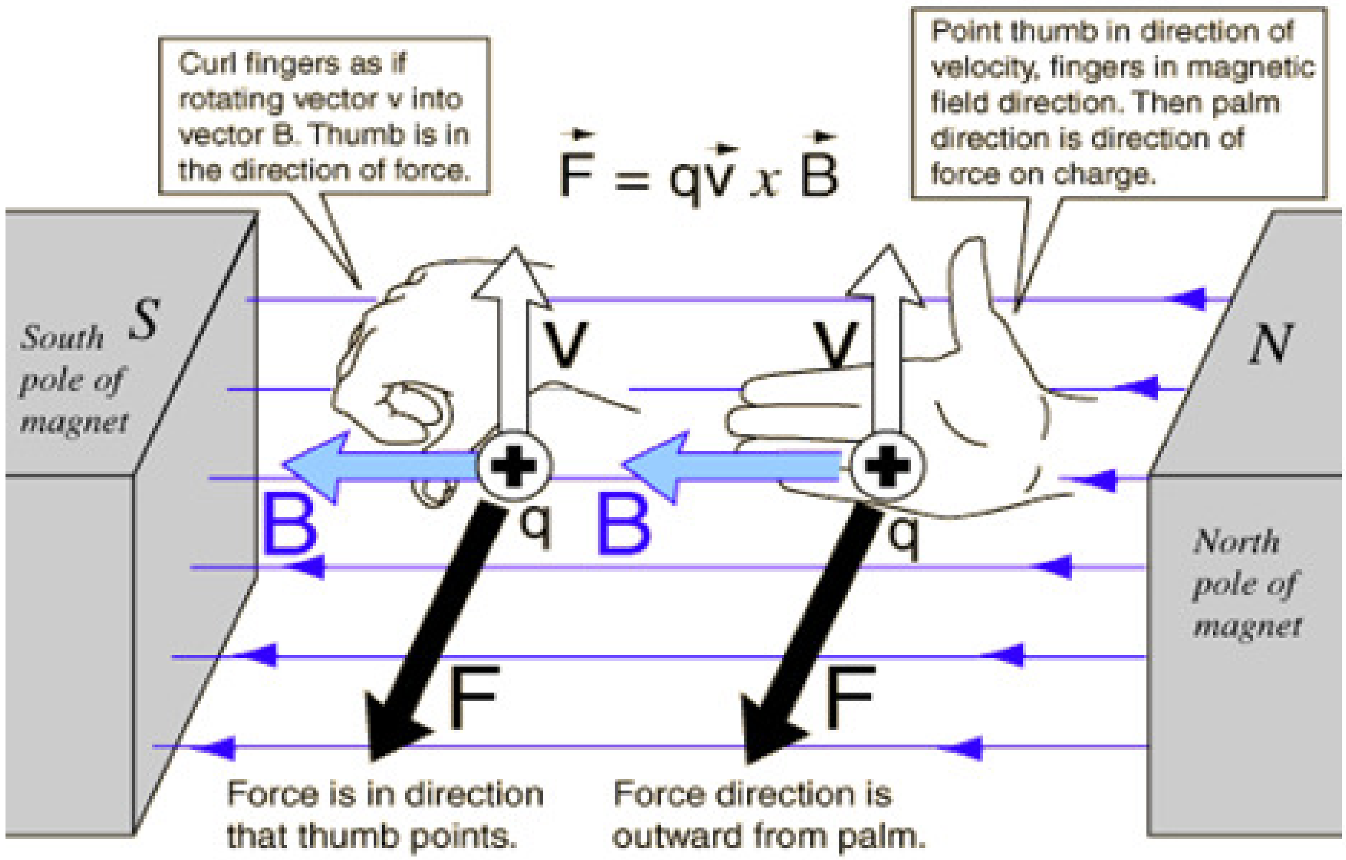
Always choose the smallest angle between $\vec{v}$ and $\vec{B}$.



Focus on the plane containing $\vec{v}$ and $\vec{B}$

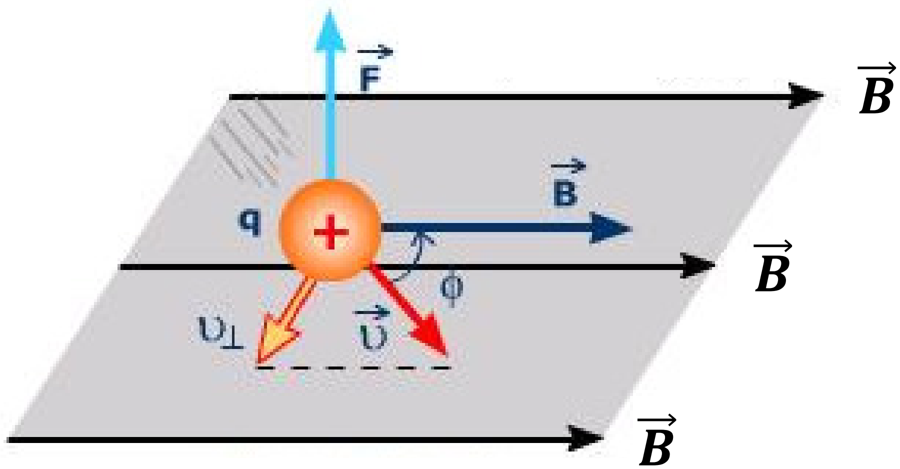
The force on a charge of $\mathbf{1}\ \boldsymbol{C}$ moving with a velocity of $\mathbf{1}\ \boldsymbol{m/s}$ in a field of $\mathbf{1}\ \boldsymbol{T}$ will be $\mathbf{1}\ \boldsymbol{N}$.

Direction of Magnetic Force on a Charged Particle in a Uniform B Field



There are actually lots of “right-hand rules”… the important thing is to always use your right hand!

Understanding the Lorentz Force



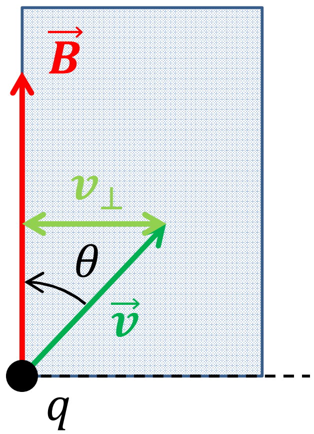
$$\left|\vec{F}\right| = |q| v B \sin\theta$$

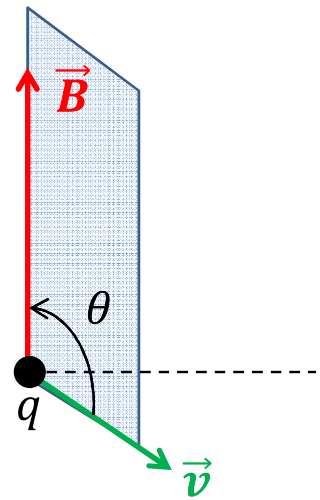
But $v_{\perp} = v \ \sin\theta$

$$\left|\vec{F}\right| = |q| v_{\perp} B$$

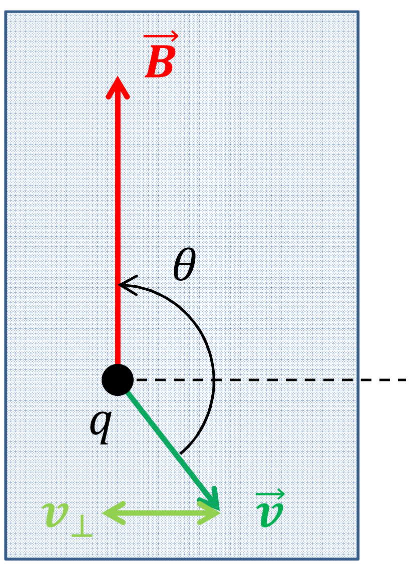
Only the component of $\vec{v}$ that is **perpendicular** to $\vec{B}$ is important!

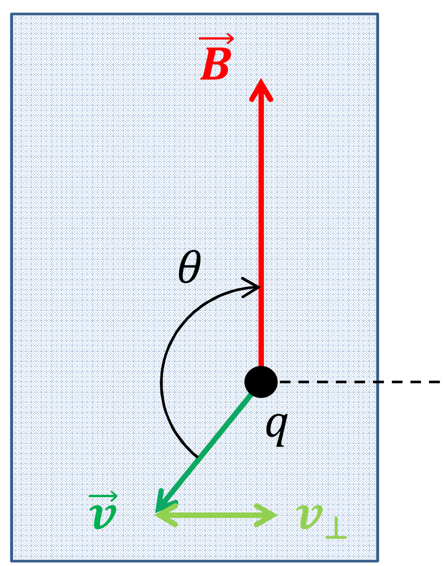
Examples



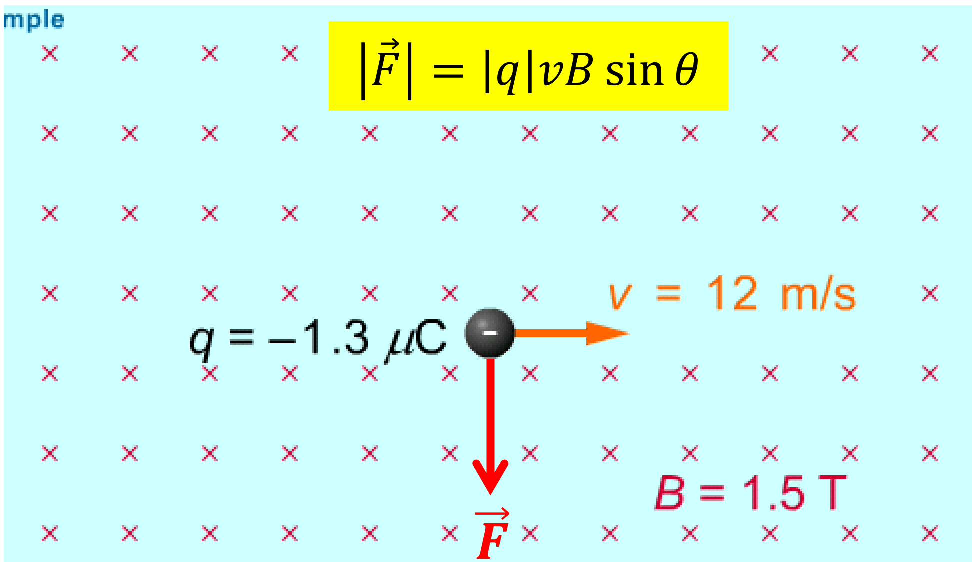


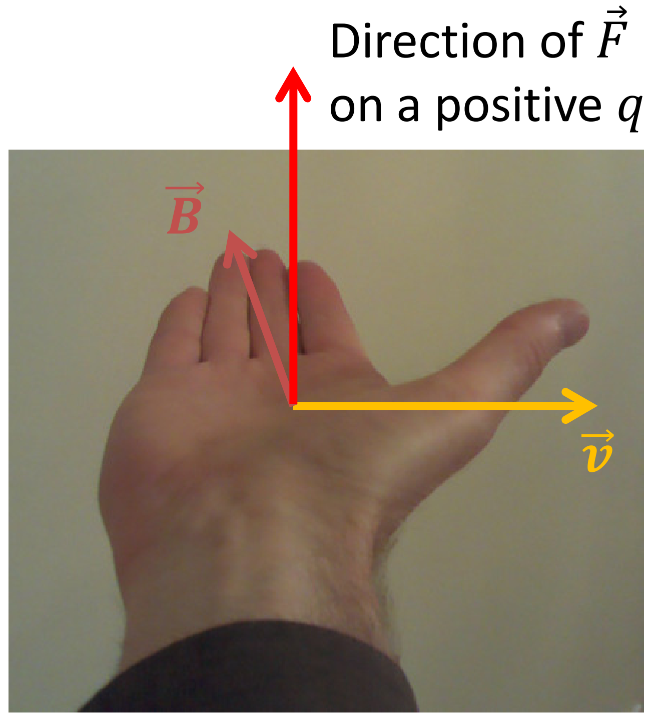
Note: Use the right-hand rule to determine the ***direction*** of the force on a positive charge $+\boldsymbol{q}$. If the charge is negative, just reverse the direction.





What is the magnetic force on the charged particle?



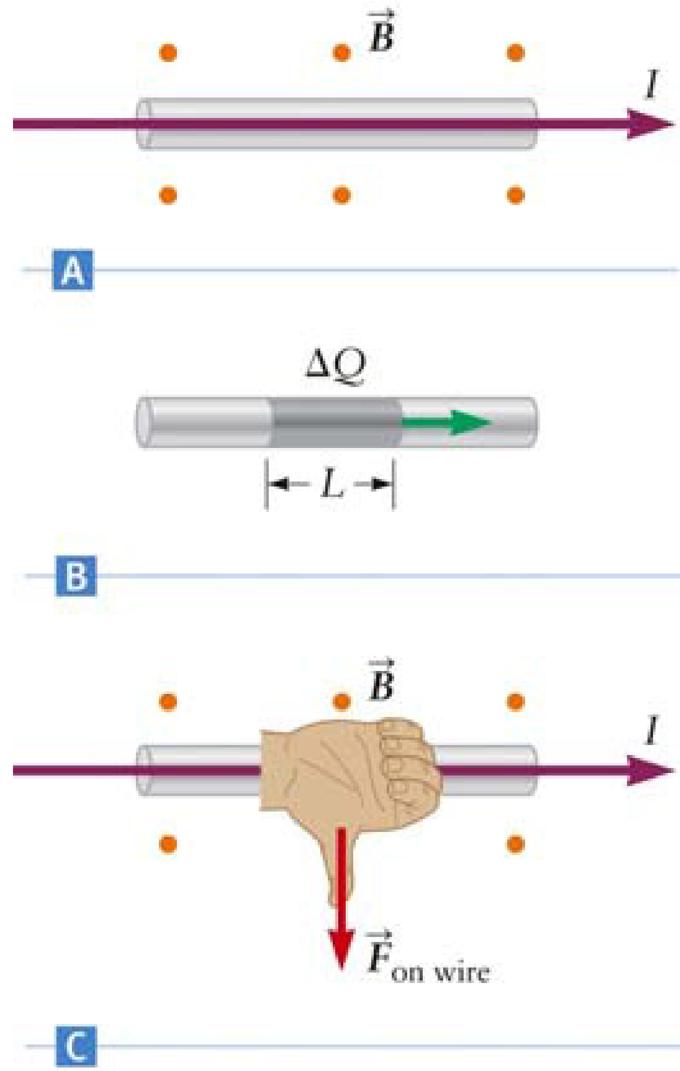


$$|\vec{F}| = |q|vB\sin\theta$$
$$= |-1.3\times10^{-6}\,C|\cdot(12\,m/s)\cdot(1.5\,T)\cdot\sin 90°$$
$$= 2.34\times10^{-5}\,N$$

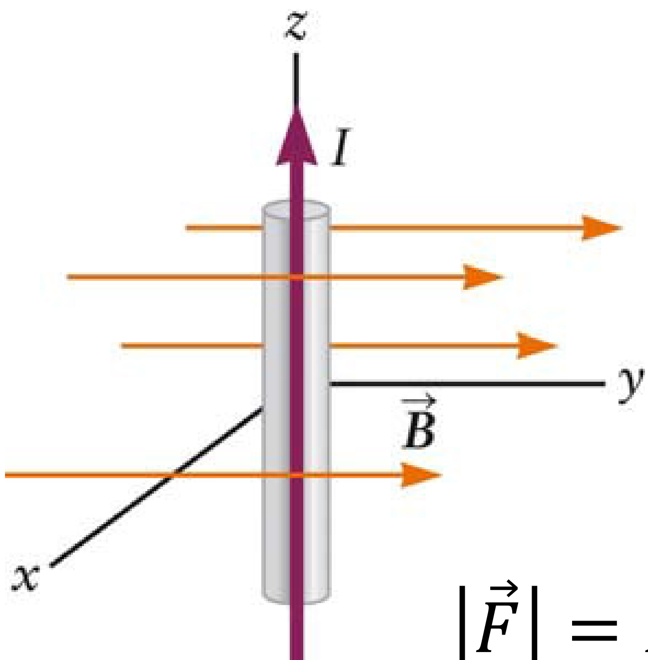
Direction??? Use the right-hand rule… but q is negative, so reverse the direction of $\vec{F}$… It points down.

Force on a current carrying wire in a B field

1. An electric current is a collection of moving charges:
$$I = \Delta Q/\Delta t$$
2. Lorentz force:
$$F = qvB\sin\theta$$
$$\theta = \angle(\vec{v}, \vec{B})$$
Let $q = \Delta Q$ and $v = L/\Delta t$.
3. Force on the wire carrying current $I = \Delta Q/\Delta t$ should be:
$$F = I\,B\,L\,\sin\theta$$
4. Direction of the force is given by the right-hand rule.



Example

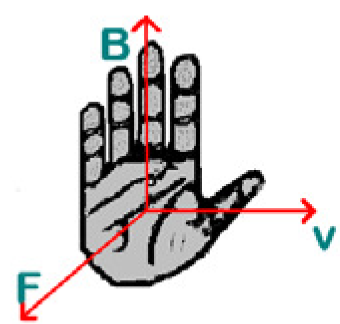


A 1.5 m long piece of wire is in a uniform magnetic field of 2 T. If the wire is carrying a current of 1.3 A, what force will it feel?

$$\left|\vec{F}\right| = I\ L\ B\ \sin\theta$$
$$= (1.3\ C/s) \cdot (1.5\ \text{m}) \cdot (2.0\ T) \cdot \sin 90°$$
$$= 3.9\ N$$

Direction?

-x direction.



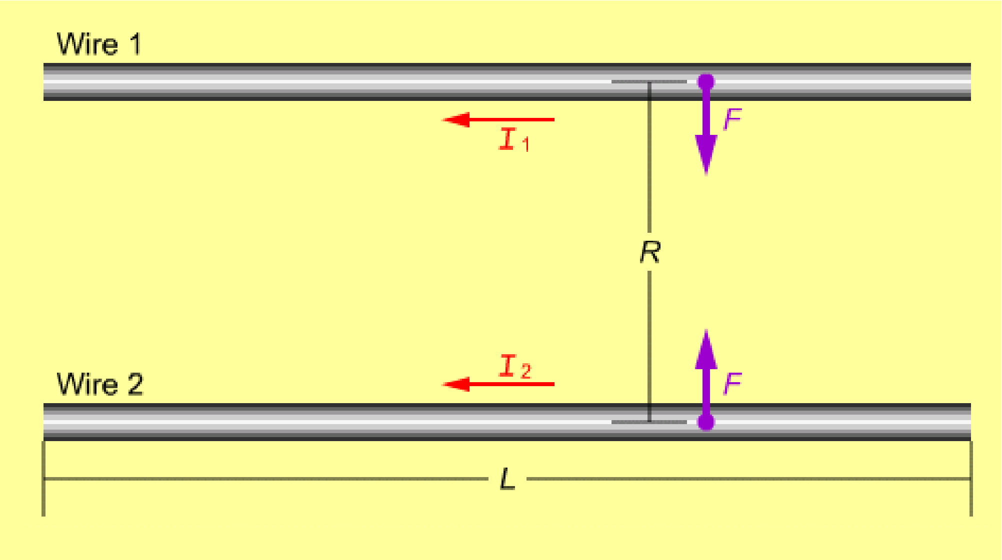
Force on Two Current Carrying Wires

- A current carrying wire creates a magnetic field
- Another current carrying wire in a magnetic field experiences a force

$$F \propto \frac{I_1 I_2}{R} L$$

$$\boldsymbol{F = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{R} L}$$

$$\mu_0 = 4\pi \times 10^{-7} N/A^2$$



Parallel currents attract, anti-parallel currents repel.