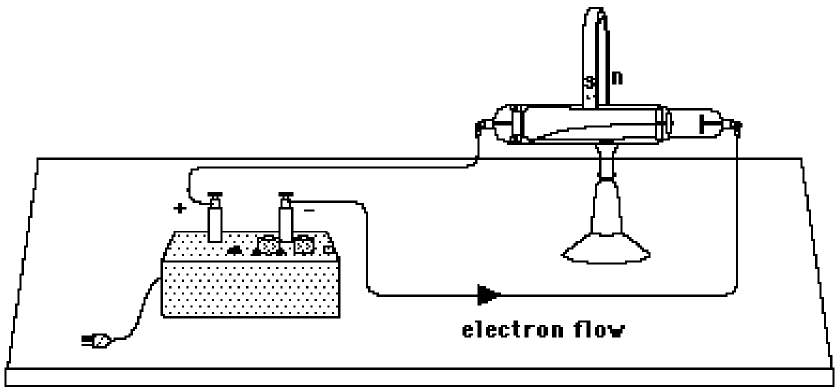
Magnetic Field Effects on Charged Moving Particles.

We know that a current of charged particles causes a magnetic field force in a certain direction. In fact, this statement is also true for any stream of charged particles (for example, a cathode ray, which is a stream of electrons).

Consider now the situation where a permanent magnet is placed in close proximity with a stream of charged particles. In this case, there are two magnetic fields which create a *net* force on the charged stream: the field of the permanent magnet, and the field caused by the stream of charged particles.

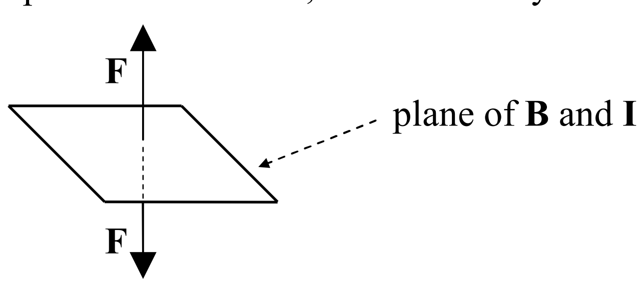
Consider a simple CRT that only accelerates electrons, as shown in the diagram below:



- A magnet brought close to the tube will deflect the stream, but not in the direction of the magnetic field of the magnet.
- The direction will instead be *perpendicular* to the magnetic field, due not only to the field effects of the magnet, but also the magnetic field created by the moving charges.
- This resultant force can also cause a current-carrying wire to move (more on this later).

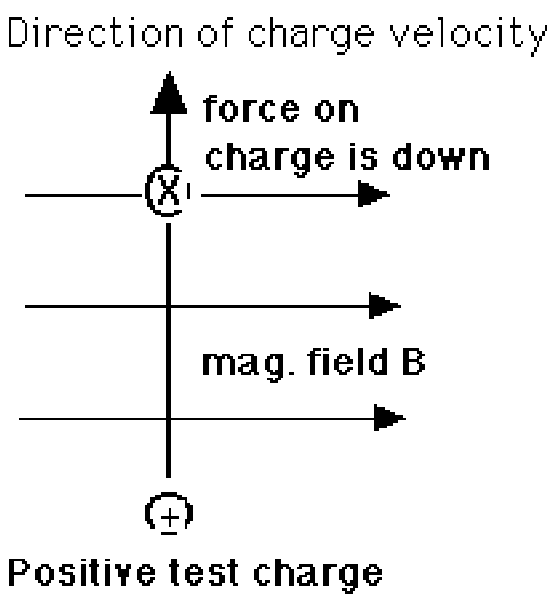
From experimental data, it has been found that the direction of the net magnetic force that acts on a current of charge '**I**' is *always* perpendicular to the direction of current and perpendicular to the direction of the magnetic field '**B**' of the magnet brought close to the current flow.

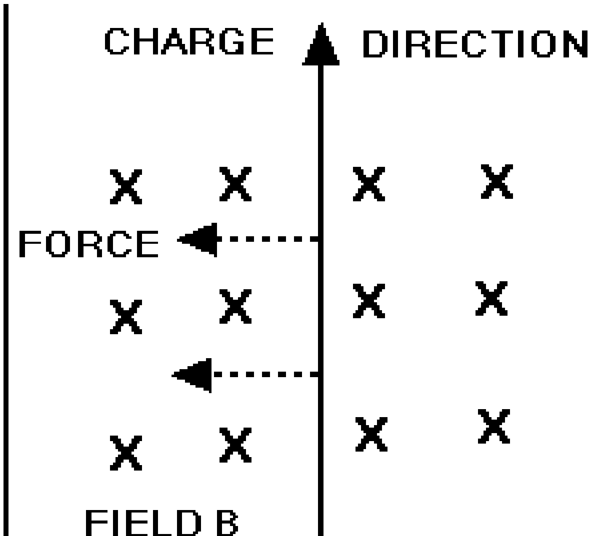
- In fact, **B** and **I** are at right angles to each other, existing in the same plane
- The force **F** created from these two entities can therefore be perpendicular to both, only in *two* possible directions, as indicated by the arrows below:



- To choose the *correct* direction, use a different form of the **Right-Hand-Rule**; start by holding your right hand *flat*, with fingers together and thumb spread apart:
  - ➢ thumb points in the direction of *conventional* current;
  - ➢ fingers point in the direction of the magnetic field lines for the nearby magnet;
  - ➢ the **palm** faces in the direction of the resultant $\mathbf{F_{mag}}$.
- if you are dealing with *electric* current, or cathode rays or other negative charges, use the **Left-Hand-Rule** (same method, south paw)

Examine the two diagrams below; use the **RHR** in each case to confirm the direction of force on the *positive* test charge. Note that in the right diagram, the **x**'s represent mag. field lines *into* the page.





Expressions for the Magnitude of Magnetic Field Force & Strength

The deflecting force on a moving charge varies directly with:

- the *size* of the charge **q**, in coulombs (C);
- the *velocity* of the charge **v**, in m/s; and
- the magnitude of the external magnetic field strength **B**, in tesla (T).

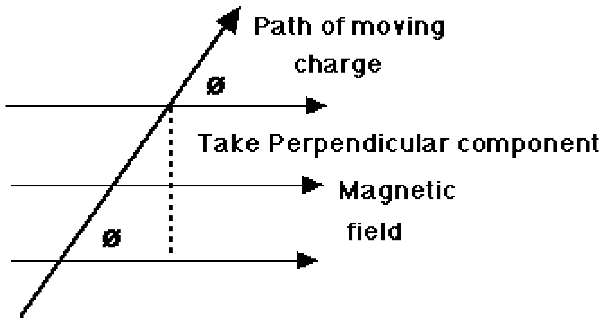
From these statements, an equation has been developed to calculate $\mathbf{F_{mag}}$, based on these quantities:

$$\boxed{\mathbf{F_{mag} = qvB}}$$

Note that this formula is used to determine the *maximum* magnitude of the magnetic force on a moving charge, where '**v**' and '**B**' are perpendicular to each other. If the path of moving charges is *parallel* to the field lines, no force will be exerted on the charges.

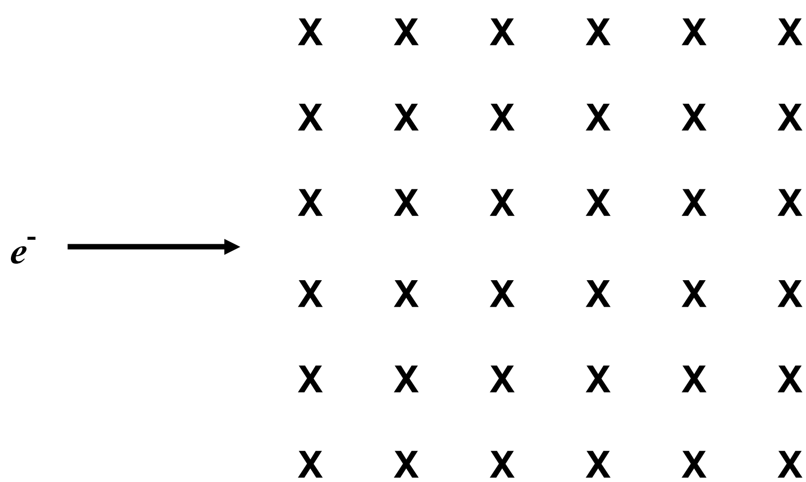
(Aside: Because the velocity (i.e. motion) of the charged particle is not always perpendicular to the magnetic field, the perpendicular component of the velocity must be determined in order to calculate the force; that is,

$$\mathbf{F = qvB \sin \theta}$$



This formula is not used in Physics 12, but *is* used in college level physics courses.)

Example #4: An electron travelling at 2.5 x 10^7 m/s enters a magnetic field of strength 4.1 x 10^{-3} T as shown below. Note that the field lines, represented by 'X', are into the page, and are perpendicular to the electron's path.

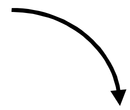


a) **What is the magnetic force that acts on the electron once it enters the field?**
b) **Use the left-hand rule (remember, this is a negative charge) to sketch the path of the electron in the field.**

(see Electromagnetism Ex 4 for answer)

Now let's consider what will happen to the direction of the electron as a result of $\mathbf{F_{mag}}$ in Example 4.

- First, the electron will deflect to the right of its original path.



- However, $\mathbf{F_{mag}}$ will *always* be ⊥ to the path of the electron, due to the presence of **B**.
- As a result,
  - the magnitude of **v** will not change for the electron.
  - the force $\mathbf{F_{mag}}$ can be described as *centripetal*.
  - the electron travels in a circular path for the duration of its time within field **B**.

We can develop an expression that relates the magnetic field to the circular motion of any charged particle moving at right angles within that field.

If: $\mathbf{F_{mag} = qvB}$ and $\mathbf{F_c = ma_c = m\frac{v^2}{r}}$

Then: $\mathbf{qvB = m\frac{v^2}{r}}$ which becomes $\mathbf{qB = \frac{mv}{r}}$

This is a simple but important derivation; practice it!

Example #5: Using the information from example 4, what is the radius of the circular path taken by the electron once it enters the field?

(see Electromagnetism Ex 5 for answer)

Finally, look at the following equation again: $\mathbf{qB = \frac{mv}{r}}$

By simple algebraic re-arranging, we see that the radius of the circular path taken by *any* charged particle in a magnetic field depends on the following:

$\mathbf{r \;\alpha\; mv}$ and $\mathbf{r \;\alpha\; 1/qB}$

In other words, radius depends directly on the momentum (**p = mv**) of the charged particle!