There are two types of magnets: permanent magnets and electromagnets.

Permanent magnets
- Maintain magnetic field without an external current applied
- Hard vs Soft
  - Hard: Very difficult to magnetize, but maintains field for a long time. (Ni-Co, Nd magnets)
  - Soft: Easy to magnetize, but loses field quickly. (i.e. Iron)
- Domains - A permanent magnet is made up of areas, called “domains,” where the electron spins of the atoms are lined up in a particular direction. When most of the domains of a magnet are aligned, the magnet will have a field in that direction.

Overall Magnetic Field

Field in each domain

South

North
Earth Magnetic Field - Created by molten iron

Note that technically, the Earth's magnetic North is in Antarctica!!

Magnetic Fields

Attract

Repel

B lines parallel in between
Force on a Moving Charged Object

If moving charged objects, such as electrons accelerated by a cathode ray tube (CRT) are subjected to a magnetic field \( \vec{B} \) perpendicular to the direction of motion, they will be accelerated by a force \( \vec{F} \) perpendicular to both \( \vec{B} \) and \( \vec{v} \):

\[
\vec{F} = q\vec{v}\vec{B}\sin\theta
\]

\( \vec{F} \) = Force on particle (N)
\( q \) = Charge of object (C)
\( \vec{B} \) = Magnetic field (Tesla = T)

\[
1 \ T = \frac{1 \ \text{Weber}}{m^2} = 1 \ \frac{N}{C \cdot m/s} = 1 \ \frac{N}{A \cdot m}
\]

\( \theta \) = Angle between \( \vec{v} \) and \( \vec{B} \)

* Note that \( F \) is zero if:

\( q = 0 \)
- or -
\( \vec{v} = 0 \)
- or -
\( B = 0 \)
- or - if \( \vec{v} \) is in same direction as \( \vec{B} \) !!!!
We can figure out the direction of \( \vec{F} \) by using the right hand rule:

\[
\begin{align*}
\vec{B} & \rightarrow \vec{v} \\
\text{Palm faces in the direction of } \vec{F} & \end{align*}
\]

*Note that for magnetism, we have to be able to indicate direction in 3 dimensions:

<table>
<thead>
<tr>
<th>Arrow Direction</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>up</td>
<td>( \uparrow )</td>
</tr>
<tr>
<td>down</td>
<td>( \downarrow )</td>
</tr>
<tr>
<td>right</td>
<td>( \rightarrow )</td>
</tr>
<tr>
<td>left</td>
<td>( \leftarrow )</td>
</tr>
<tr>
<td>into page</td>
<td>( \otimes )</td>
</tr>
<tr>
<td>out of page</td>
<td>( \odot )</td>
</tr>
</tbody>
</table>

\[\text{An arrow from behind}\]
\[\text{An arrow from head-on}\]
Example - Force on an Electron in a $\vec{B}$ Field

Cathode Ray Tubes (CRTs - aka. "tube" televisions) use a beam of high-speed electrons to produce images on a TV screen. This beam must be bent in order to make more than just a single dot on the screen. Find the direction of deflection (Force) on a beam traveling through a $\vec{B}$ field as shown:

![Diagram of electron source and $\vec{B}$ field]

By right hand rule, $\vec{F}$ (and the direction of deflection) is into the paper.

Force on a Current-Carrying Wire

A wire is just an object through which charges can move. We call charges moving in a wire current. We can modify the basic equation $F = qv\vec{B}\sin\theta$ for wires, as follows:

\[
F = qvB\sin\theta \\
F = qIB\sin\theta \\
F = ILB\sin\theta
\]
**F = BIL \sin \theta**

- \( F \) = Force on wire (N)
- \( B \) = Strength of \( \vec{B} \) field (T)
- \( I \) = Current through wire (A)
- \( l \) = Length of wire in \( \vec{B} \) field (m)

**Example - A wire in a field**

If we have a \( \vec{B} \) field facing into the page, and current flowing up through a wire:

When current flows through wire, it will be forced to move to the left.