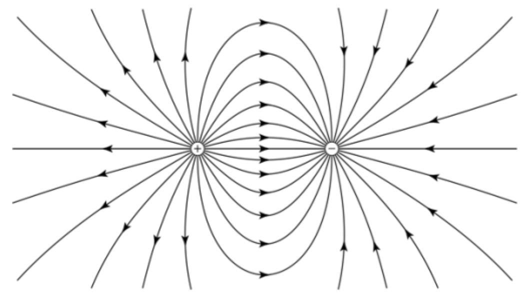
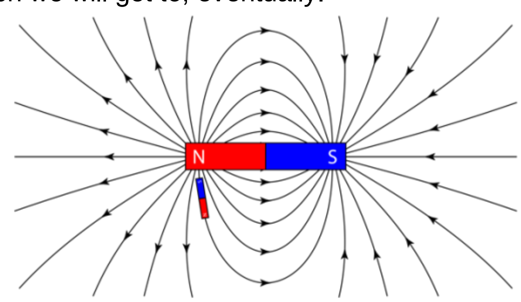
Flipping Physics Lecture Notes:
Magnetic Fields and Magnetic Forces on Moving Charges
[http://www.flippingphysics.com/magnetic-field-force.html](http://www.flippingphysics.com/magnetic-field-force.html)

Magnetic fields (or "B" fields) are be created by magnetic dipoles:

- Just like electric charges are described as positive and negative charges, magnetic poles are described as north and south poles.
    - A magnetic monopole has never been found.
        - This does not mean magnetic monopoles do not exist.
            - We cannot prove magnetic monopoles do not exist.
                - We can only say we have no evidence that they exist.
    - If a magnetic dipole is broken in half, it becomes two new magnetic dipoles.
- Like poles repel and unlike poles attract.
    - Just like the Law of Charges



- The magnetic field caused by a magnetic dipole looks remarkably like the electric field caused by an electric dipole.
    - B field lines external to the magnet, point from north pole to south pole.
        - Just like E field points from positive charge to negative charge.
    - Magnetic field lines must be closed loops.
        - Due to Gauss' law for magnetism which we will get to, eventually.
        - This means B fields inside the magnet point from the south pole to the north pole, to complete the closed loop.
    - A magnetic dipole placed in a magnetic field will align itself with the magnetic field.
        - Think *compass!*




- For planet Earth:
    - The location of the geographic north pole is close to that of the magnetic south pole.
    - The location of the geographic south pole is close to that of the magnetic north pole.
        - The north pole of a compass points north because it is attracted to the magnetic south pole of the Earth.
            - (unlike poles attract)
    - The magnetic field of the Earth can be approximated as a magnetic dipole.

Magnetic dipoles are the result of electric charges moving in circles.

- We will cover electric charges moving in circles creating magnetic fields extensively later. At this point, just know that electric charges moving in circles create magnetic fields.
- The magnetism of magnets is most often the motion of electrons moving in circles inside them.
- Permanent magnetic dipoles and induced (temporary) magnetic dipoles are a property of the object which results from the alignment of magnetic dipoles within the object.

The material composition of a magnet affects its magnetic behavior when it is placed in an external magnetic field:

- *Ferromagnetic* materials can be *permanently* magnetized by an external magnetic field.
    - The alignment of the magnetic domains or atomic magnetic dipoles is *permanent*.
    - Example materials: nickel, iron, cobalt
- *Paramagnetic* materials are only *temporarily* magnetized by an external magnetic field.
    - The alignment of the magnetic domains or atomic magnetic dipoles is *temporary*.
    - Example materials: aluminum, magnesium, titanium

Just like materials have an electric permittivity, ε, materials also have a magnetic permeability, μ:

- Magnetic permeability: the measurement of the amount of magnetization a material has in response to an external magnetic field.
    - Ferromagnetic materials have high magnetic permeabilities that increase in the presence of an external magnetic field.
    - Paramagnetic materials have low magnetic permeabilities.
    - The magnetic permeability of materials is not constant. It changes depending on various factors such as temperature, orientation, and the strength of the external magnetic field.
- The magnetic permeability of free space has a constant value, $\mu_0$: $\mu_0 = 4\pi \times 10^{-7} \frac{T \cdot m}{A}$

A magnetic field is defined by the fact that a moving electric charge in a B field can experience a magnetic force, $F_B$.

- $\vec{F}_B = q\vec{v} \times \vec{B} \Rightarrow \|F_B\| = qvB \sin\theta$
    - This equation is an experimentally determined equation. In other words, there is no way to mathematically derive it! We know it is true because we have repeatedly measured it.
    - Notice the similarities to the torque equations: $\vec{\tau} = \vec{r} \times \vec{F} \Rightarrow \|\tau\| = rF \sin\theta$
- $\Rightarrow B = \frac{F_B}{qv \sin\theta} \Rightarrow \frac{N}{C\left(\frac{m}{s}\right)} = \frac{N}{\left(\frac{C}{s}\right)m} = \frac{N}{A \cdot m} = \text{tesla, } T$
    - $1 \text{ tesla, } T = 10{,}000 \text{ gauss, } G$