We live in a magnetic field.

The earth behaves almost as if a bar magnet were located near its center. The earth’s axis of rotation and Magnetic axis are not the same—they’re about 11.5° apart.

A compass is a magnet w/a north and south end which orients itself in the earth’s magnetic field.

The north end of the compass needle points to the north magnetic pole of the earth, which is magnetically south! i.e., The geographic north pole is the magnetic south pole!
Magnets exert forces on each other.

- Like poles repel each other (likes repel)...and
- Unlike poles attract. (Opposites attract)
- The big difference between magnetic poles and electric charges is that magnetic poles cannot be isolated (electric charges can). i.e., You will not find a north pole without a south pole. Break a magnet, you get two small magnets w/N&S.
Magnetic Domains

Not Magnetized
- In a material that is not magnetized, the magnetic domains point in random directions.

Magnetized
- In a magnetized material, all or most of the magnetic domains are arranged in the same direction.
Magnetic Fields

- Just like an electric charge produces an electric field surrounding that charge, a magnet produces a magnetic field surrounding that magnet.

- We can determine the strength and direction of this magnetic field.

- Direction: the direction of the magnetic field is determined by the force on the north end of a compass.

- The magnetic field *always* points away from the north end of the magnet and toward the south end.
At any location in the vicinity of the magnet, the north pole (the arrowhead of Fig. 21.3) of a small compass needle points in the direction of the magnetic field at that location. These small arrowheads can be drawn as lines... Magnetic Field Lines.

The magnetic field *always* points away from the north end of the magnet and toward the south end.

Fig. 21.3

Fig. 21.4a

Fig. 21.4c
Magnetic Force on a moving charge:

► When a charge is placed in an electric field, it experiences an electric force.

► When a charge is placed in a magnetic field, it experiences a magnetic force if the following two conditions are met:

1) The charge must be moving (no magnetic force acts on a stationary charge).

2) The velocity of the moving charge must have a component perpendicular to the direction of the magnetic field.
A positive test charge, \( +q \), is moving with velocity, \( v \), through a magnetic field. The magnetic field, \( B \), is produced by an arrangement of magnets not shown in the drawing and is assumed to be constant in both magnitude and direction.

- Charge moving parallel to the field = no magnetic force. (a)
- Charge moving perpendicular to the field = max. magnetic Force. (b)
- Charge moving at an angle \( \theta \) with respect to the field, only the velocity component \( v \sin \theta \), which is perpendicular to the field, gives rise to a magnetic force. (c)

\[ (b) \& (c) \rightarrow \text{The charge experiences a maximum force when the charge moves perpendicular to the field.} \]
Right Hand Rule #1 (pg 790)

- This RHR is used to find FORCE...
- The direction of the force ($\mathbf{F}$) is perpendicular to both the magnetic field ($\mathbf{B}$) and velocity ($\mathbf{v}$), and can be remembered with the right hand rule.
- Point fingers in direction of $\mathbf{B}$ and thumb in direction of $\mathbf{v}$, and palm of hand points to $\mathbf{F}$ for a positive charge.
- If a moving charge is negative, then force is opposite to that predicted by right hand rule.
Measuring the Magnetic Field Strength, B:

- Recall that the electric field at any point in space is the force per unit charge that acts on a test charge \( q \) placed at that point. Or, \( E = \frac{F}{q} \) or \( F = Eq \).

- In the magnetic case, the test charge is moving, and the force depends not only on charge \( q \), but also on the velocity component, \( v \sin \theta \), that is perpendicular to the magnetic field, \( B \).

\[
F = B q \, (v \sin \theta)
\]

- Or \( B = \frac{F}{q \, (v \sin \theta)} \)

- \( F \) = the magnitude of the magnetic force on a positive test charge, \( q \) (Units: N)
- \( B \) = the magnitude of the magnetic field at any point in space [Units: \( \text{N} \cdot \text{s}/\text{C} \cdot \text{m} = \text{T} = \text{Tesla} \)]
- \( q \) = magnitude of the positive test charge (Units: Coulombs)
- \( v \) = velocity of the positive test charge and makes an angle \( \theta \) with the direction of the magnetic field. (Units: m/s)
More about Teslas...

- Since current = charge/time or \( q/t = I \) then with units: \( C/s = \text{Amps} \),
- \( \therefore C/s = A, \text{ or } s/C = 1/A \) so,
- \( (N \cdot s)/(C \cdot m) = N / (A \cdot m) = T \)
- The average Magnetic Field Strength on the surface of the earth is \( 10^{-4} \, T \), and
- \( 10^{-4} \, T = 1 \, \text{gauss} \)
A charge moving through a magnetic field can experience a magnetic force.

Since electric current is a collection of moving charges...

A current in the presence of a magnetic field can also experience a magnetic force.
The wire carries a current $I$, and the bottom segment of the wire is oriented perpendicular to a magnetic field $B$. A magnetic force *deflects* the wire to the right.

- The right hand rule works here too: replace velocity with current, $I$.
- The magnetic force is the net force acting on the total charge $q$ moving through the wire.
Recall: $F = q \nu B (\sin \theta)$

And current $= I = \frac{q}{t}$

Multiply the right side of the above equation by $\frac{t}{t}$:

$F = \left(\frac{t}{t}\right) q \nu B (\sin \theta)$

$F = \left(\frac{q}{t}\right)(\nu t) B (\sin \theta)$ and $\nu t = \text{distance or } L \text{ for length}$

$F = (I)(L) B (\sin \theta)$

$F = I L B \sin \theta$

$F =$ magnetic force on a current-carrying wire of length, $L$

$\theta =$ the wire is oriented at an angle $\theta$ with respect to the magnetic field, $B$

:. when $\theta = 90^\circ$, and the wire is perpendicular to the magnetic field, the magnetic force is at a maximum,

and when the current carrying wire is parallel to the field, the magnetic force does not exist, $F = 0$. 
The current $I$ in the wire, oriented at an angle $\theta$ with respect to a magnetic field $B$, is acted upon by a magnetic Force, $F$.

$F = ILB\sin \theta$
Magnetic Fields produced by Currents

- A current carrying wire produces a magnetic field of its own. (Oersted in 1820.)

- When there is a current in the wire (Fig. a), the compasses align w/ the magnetic field being produced by the current-carrying-wire.

**A moving charge produces a magnetic field.**

- The magnetic field forms concentric circles about the wire.

- Reverse the current & the magnetic field is reversed.

RHR#2: (pg 783) thumb points in direction of current & the curled fingers point in direction of magnetic field.
Right Hand Rule #2 (pg 783)

- This RHR used to determine direction of B
- Curl the fingers of the right hand into the shape of a half-circle.
- Point the thumb in the direction of the conventional current, I, and the tips of the fingers will point in the direction of the magnetic field, B.
For a long, straight wire having current run through it...

- Experimentally, it is found that the magnetic field, $B$, produced is directly proportional to the current, $I$, and inversely proportional to the radial distance, $r$, from the wire.

- $B \propto \frac{I}{r}$

- An equation relating these variables and a proportionality constant $(\mu_0/2\pi)$ is as follows:

$$B = \left(\frac{\mu_0}{2\pi}\right)\frac{I}{r} = \frac{I\mu_0}{(2\pi r)}$$

$\mu_0$ = a constant called the permeability of free space = 

$4\pi \times 10^{-7}$ Tm/A = $\mu_0$. 
A current carrying wire produces a magnetic field which acts upon charges in nearby conductors.

- The magnetic field that surrounds a current carrying wire can exert a force on a moving charge.
- The moving positive charge, \( q \), experiences a magnetic force \( F \) because of the magnetic field \( B \) produced by the current in the wire.
- Use *Right Hand Rule #1* to determine direction of force on \( q \).
Current carrying wire bent into a loop will have magnetic field lines patterned like figure (a).

\[ B = \frac{N I \mu_0}{2R} \]

- \( B \) = the magnetic field at the center of the loops
- \( N \) = number of loops
- \( R \) = radius from center (inside) of loop

\( \mu_0 \) = a constant called the permeability of free space = \( 4\pi \times 10^{-7} \) Tm/A
(a) The field lines around the bar magnet resemble those around the loop in Fig 21.30a.
(b) The current loop can be imagined to be a phantom bar magnet w/a north pole and a south pole.
(a) The two current loops attract each other if the directions of the currents are the same and (b) repel each other if the directions are opposite. The “phantom” magnets help explain the attraction and repulsion.
If the wire is wound so the turns are packed close to each other and the solenoid is long compared to its diameter, the magnetic field lines have the appearance shown in the drawing.

The magnitude of the magnetic field in the interior of a long solenoid is

\[ B = nI \mu_0 \]

\( n = \text{the number of turns per unit length} \)
\( n = \frac{N}{L} \)
Calculating force between current carrying parallel runs of wire:

\[ F = \frac{\mu_0 I_1 I_2 L}{2\pi d} \]

- \( L \) = the length of wire that is parallel
- \( d \) = the distance between wires
Current carrying wires exert magnetic forces on one another.

► (a) Two long, parallel wires carrying currents $I_1$ and $I_2$ in opposite directions repel each other.

► (b) The wires attract each other when the currents are in the same direction.
(a) Currents in the same direction attract.

Force of magnetic field $\vec{B}_2$ on current $I_1$

Magnetic field $\vec{B}_2$ created by current $I_2$

$\vec{F}_2$ on 1

$\vec{F}_2$ on 1

$d$

$\vec{F}_1$ on 2

$\vec{F}_1$ on 2

Force of magnetic field $\vec{B}_1$ on current $I_2$

Magnetic field $\vec{B}_1$ created by current $I_1$

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(b) Currents in opposite directions repel.
Torque on a magnetic dipole

- Torque = \( \mathbf{F} \cdot \mathbf{l} \) or force perpendicular to the lever arm. Torque produces rotation.

- For a rotating current carrying loop in a magnetic field a torque is applied.

- If we insert \( F = (I)(L)\mathbf{B}\sin\theta \) into the above equation we get:
Magnetic dipole moment

- $T = I l | B$ or $I A B (\sin \theta)$
- The quantity $I A$ is called the magnetic dipole moment because the torque depends on these two properties of the loop.
- The torque also depends on the angle this moment makes with the field; max at $90^\circ$ and min at $0^\circ$. 

![Diagram](image)
Magnetic dipole moment

Here are some examples of magnetic dipole moments.

The magnetic dipole moment is represented as a vector that points in the direction of the dipole’s field. A longer vector means a stronger field.