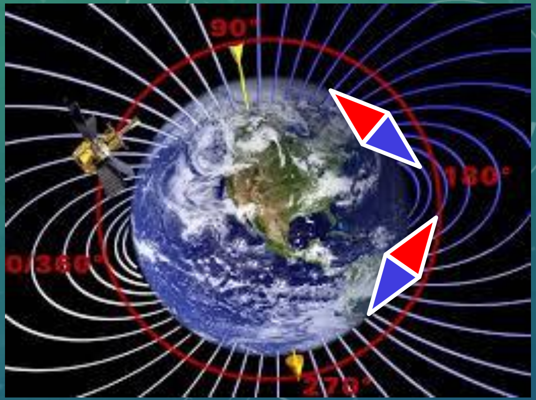
MAGNETIC FIELD: EFFECTS, SOURCES, AND FORCES

PES 1000 – PHYSICS IN EVERYDAY LIFE

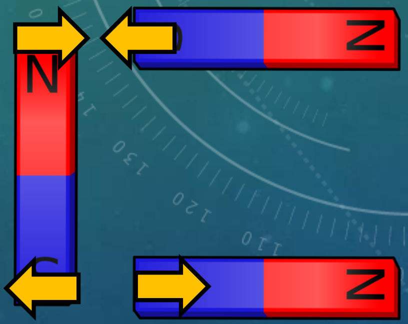
TWO 'FLAVORS' OF MAGNETISM

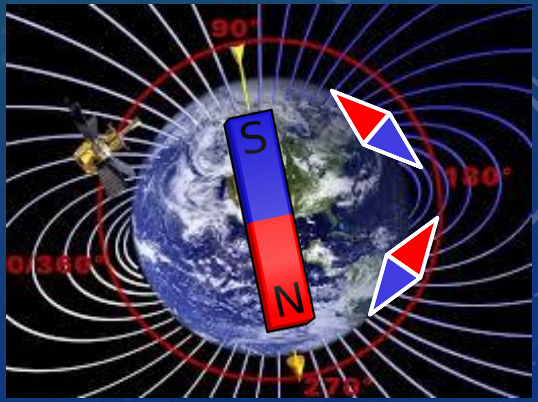


- Magnetism was discovered in antiquity.
- Naturally occurring magnets, lodestones, had two ends that would attract or repel other lodestones.
- Lodestones (if friction is eliminated) naturally orient themselves toward Earth's poles.
  - The ends of the lodestone are traditionally called North and South, depending on which geographic pole it pointed toward.
  - You could paint the north-pointing end red and label it *N*. Likewise, you could label the south-pointing end *S*.
  - The ends of the magnets are called 'poles', and they have 'polarity'. You can test this with a compass.

TWO 'FLAVORS' OF MAGNETISM

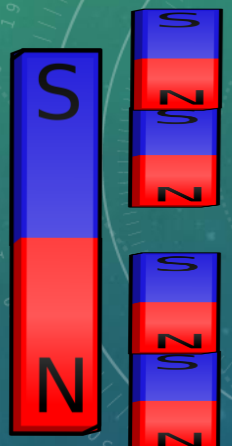
- Experiments show that two like poles (North-North or South-South) repel, while North and South attract.
- A North-magnetic pole is South-seeking, and vice versa.
- Consequence: The Earth's North geographic pole is actually a South magnetic pole, because the end of magnet labeled 'North' points toward it.
    - Also, the magnetic poles of the Earth are not stationary, nor are they exactly coincident with the geographic poles (which are fixed and clearly defined by the Earth's spin axis), and the magnetic poles have actually swapped in the past!

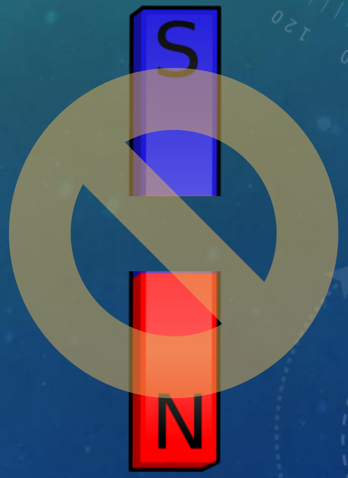


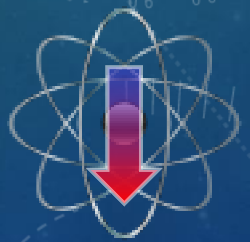
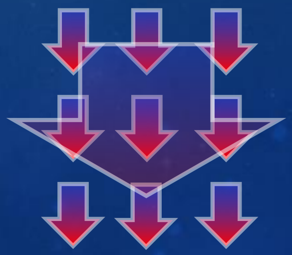
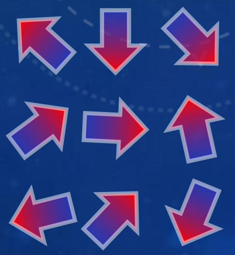


BREAKING A BAR MAGNET INTO PIECES

- If we break a bar magnet in half in order to have isolated North and South poles (monopoles)…
  - …we find we can't do this! We get two smaller magnets, each with its own N and S poles.
- If we keep going, breaking each of these magnets in half and so on…
  - …we find that even at the atomic level each iron atom has a N and S pole.
  - There are no monopoles, only dipoles!
- In a permanent iron (ferrous) magnet, these atomic dipoles are aligned, so that the overall piece of iron has a net magnetic field.
  - This is called *ferro-magnetism*.
- In a regular (non-magnetized) piece of iron, the dipoles point in random directions, and the net magnetic field is zero.





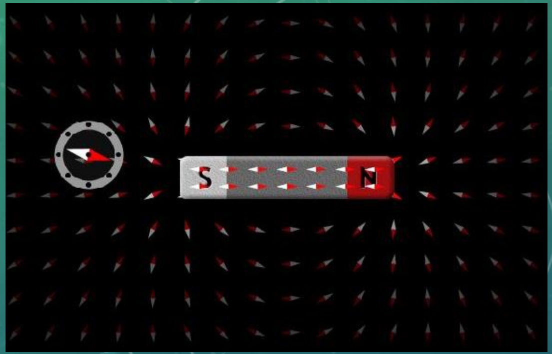




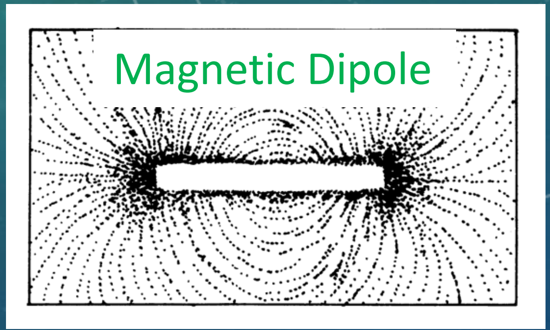
MAGNETIZING IRON & MAGNETIC DOMAINS

- A microscopic view of a normal piece of iron shows that there are many tiny regions (domains) where the atomic magnets are aligned.
  - The magnetic domains point in random directions, resulting in no net magnetic field in the iron.
- If an external magnetic field is applied, however, it forces the domains to slightly align with itself (temporarily), causing a net magnetic field in the iron and a resulting attraction.
  - This is how a permanent magnet sticks to a non-magnetic refrigerator, for example.

- How to form a permanent magnet:
  - Apply a very strong external field, leaving a residual magnetic field in the iron once the external field is removed. (Example: magnetic information storage)
  - Allow the molten iron to cool in the presences of an external field. The domains will 'freeze' in an aligned configuration. (Example: natural lodestone cooled within the Earth's magnetic field.)
- How to remove a permanent magnetic field: apply heat or physical vibration (also 'degaussing', which is the application of an oscillating field with decreasing magnitude).

MAGNETIC FIELDS



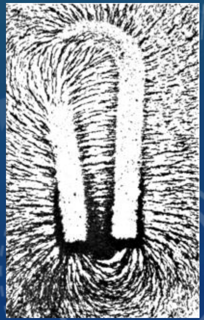


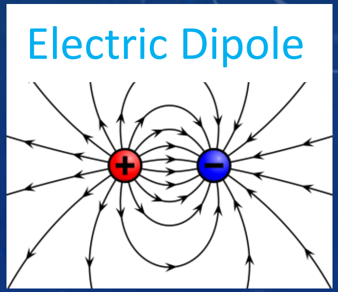
Magnetic fields, like electric fields, have a size and direction. They are vectors.

- The variable used is usually $\vec{B}$.
- The SI unit for magnetic field strength is the Tesla (T).

The magnetic di-polar field can be visualized much like we did for electric fields.

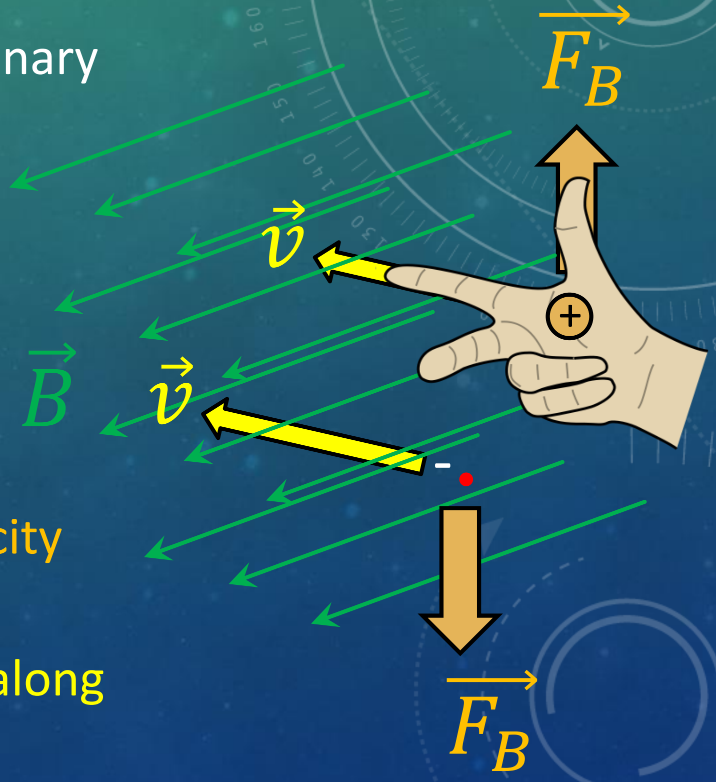
- We could make a grid around the magnet, place a compass at each point, and show the direction with an arrow and the strength with the brightness of the arrow.
- Another method is to connect all the arrows into field lines.
  - Field lines always form closed loops. The loop may extend to infinity. They run through the magnet itself.
  - The lines run from North to South.
  - Lines are close together in regions of a strong magnetic field.
  - Iron filings will align with the magnetic field lines, providing a visualization of them.
- Note the similarity of the electric and magnetic dipole fields.





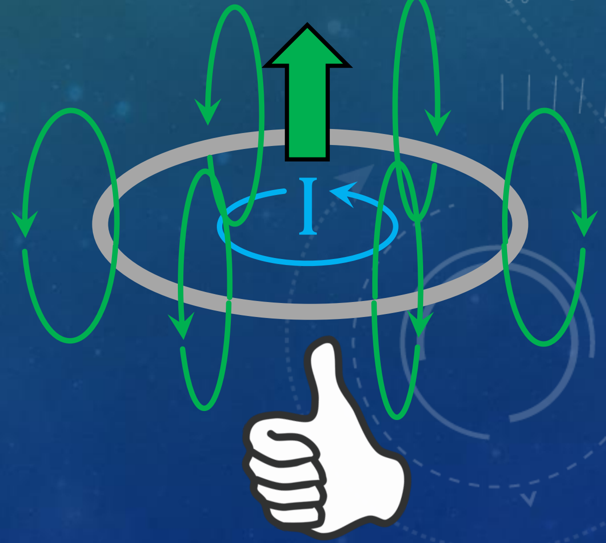
MAGNETIC FORCE

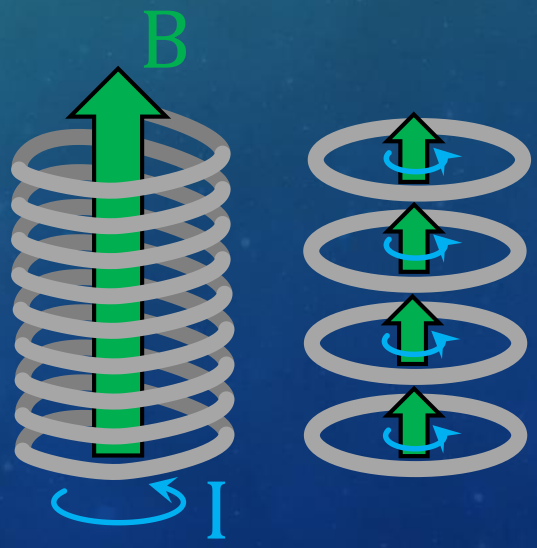
- Only moving charge experiences a force due to a magnetic field. A stationary charge is unaffected by a magnetic field.
- The force on the moving charge depends on:
  - The size and sign of the charge
  - The speed and direction the charge is moving relative to the field
  - Magnetic field strength
- The direction of the force is perpendicular to both the field and the velocity of the moving charge.
  - For positive charge, it follows the right-hand-rule, with index finger along the velocity, middle finger along the field, and thumb indicating the direction of the force.
  - If the charge is negative, the force is in the opposite direction.
- Static charge generates (and experiences force from) only an electric field.
- Moving charge generates (and experiences force from) both magnetic and electric fields.



MAGNETIC FIELD DUE TO A CURRENT-CARRYING WIRE

- Imagine a long, straight current-carrying wire.
  - Closed magnetic loops form around the wire.
  - Right-hand-rule: Thumb is in direction of current, fingers curl in direction of magnetic field.
- Bend the wire into a loop of current-carrying wire.
  - Magnetic loops join in the middle.
  - Right-hand-rule: Fingers curl in direction of current, Thumb is in direction of magnetic field.
- Make a series of loops – magnetic fields join.
- Form a coil of wire (solenoid)
- This is an electro-magnet which can be switched on and off, and easily reversed.

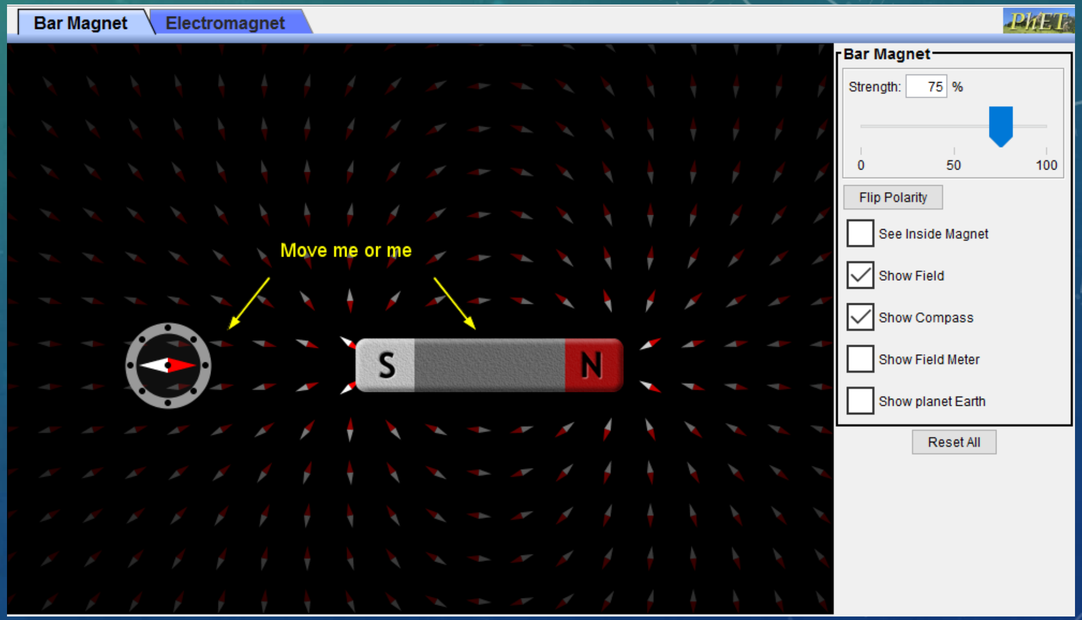




MAGNET SIMULATION

- Link to simulation: https://phet.colorado.edu/en/simulation/legacy/magnets-and-electromagnets

- Things to do:
  - On the 'Bar Magnet' tab:
    - Observe how the compass North is attracted to magnet's South, and vice versa.
    - Click the 'See Inside Magnet' to see the magnetic loops passing through the bar magnet.
    - Click the 'See planet Earth' to see the similarity of the Earth's magnetic field to a bar magnet.
  - On the 'Electromagnet' tab
    - You can turn off the magnetic field, and you can reverse it.
    - See how similar the electromagnet is to a bar magnet.



CONCLUSION

- Magnetism has two types of poles: a North and a South. North poles seek South poles and vice versa. Poles of the same type will repel each other.
  - SI unit of magnetic field is Tesla (T). Gauss (G) is another unit that is sometimes used.
- Di-pole magnetism is present in a magnet all the way down to the atomic level. There are no monopoles.
- In a ferrous (iron-like) material, tiny regions (domains) of atomic magnets will be aligned.
  - Different domains may point different directions (no net magnetic field).
  - If enough domains align, the iron may become temporarily or permanently magnetized.
- Magnetic forces on a moving charge follow the right-hand-rule.
- Moving charge forms a magnetic field around itself. Current carrying wires may be used to form a powerful magnetic field.