

Magnetism

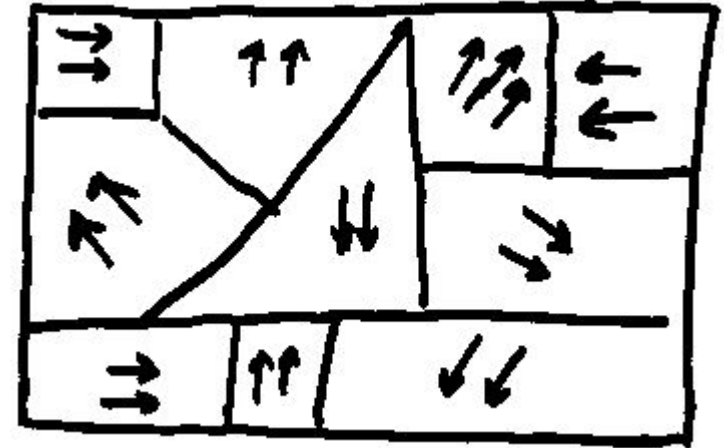
- At first blush: some similarity with electrostatic forces:
 - Can be attractive and repulsive
 - Falls off with distance
 - Different magnets have different strength
- Maybe the same thing? NO, because
 - Charged objects aren't necessarily attracted to magnets
 - Permanent magnets seem all to be made of iron and a few other metals
 - Biggest difference: Magnets never come alone - every positive (North) pole always is attached to a negative (South) pole. Even cutting a magnet in pieces doesn't change this
- New phenomenon
 - Due to “magnetic charges” (monopoles)? NO! (we haven't found one yet)
 - Actually due to MOVING electric charges (see later)
- Has its own field!

Dipole Magnets

- North and South pole
- Equal poles repel, opposite poles attract
- Force “transmitted” by magnetic field \mathbf{B} (similar to \mathbf{E})
 - exit from North Pole and enter through South pole of magnet, but continue throughout the interior
- In a homogeneous external magnetic field, dipoles experience no net force but they DO experience TORQUE!
- Example: Compass in Earth’s magnetic field
 - Earth itself is a magnet
 - South pole somewhere in Canada (NOT at typo)
 - North pole somewhere south of Australia
 - Compass aligns itself with field so **its** North pole points north

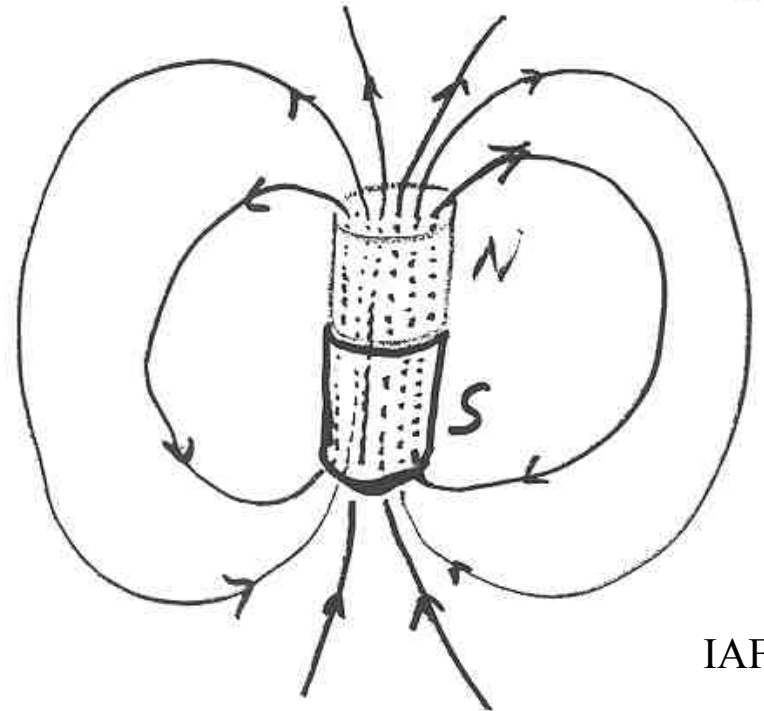
Magnetic materials

- Permanent magnets (*Ferromagnetism*)
 - Domains
 - Examples: Iron, Nickel, Cobalt, ...
- Induced magnets (*Paramagnetism*)
 - Polarization along external field
 - Attracted towards magnets; e.g. liquid oxygen)
- Non-magnetic material (doesn't really exist)
- Anti-magnetic material (*Diamagnetism*)
 - Practically ALL materials; most extreme: superconductor
 - repelled away from magnets (levitation)
- Quiz: How to distinguish a bar magnet from a piece of non-magnetic iron if you have no other materials around?
Answer: Saw it in half, making 2 dipoles - the two opposite ends attract and the same poles repel; or hang it up on a thin thread and see whether it keeps orienting itself in the same direction again and again (presumably along Earth's magnetic field).



Rules for field lines

- Just like electric field lines:
 - Direction shows direction of field
 - Density shows strength of field
- Very different:
 - Field lines can NEVER begin or end
 - They can go on forever, or
 - They can form closed loops!
- Example: dipole magnet



Magnetic fields due to currents

- Any moving charge produces a magnetic field!
- Simple straight wire: Magnetic field lines circle the wire; field falls off like $1/\text{distance}$ from the wire
- Simple loop of wire: Field similar to a very short dipole *)
- Solenoid: Field similar to a very long dipole *)
- Electromagnet: Field can be enhanced and shaped by magnetic materials, like iron. Example: C-magnet
- Superconducting electromagnet
Example: CLAS at Jefferson Lab

*) This similarity is NOT accidental - in permanent magnets, all the spinning electrons combine to create a circumferential current



Magnetic force on moving charges

- The weirdest force law yet:
If a charge q moves to the left and the magnetic field points up, then the charge will be deflected away from you *)
(unless q is negative - then the deflection is in the opposite direction)
- This (Lorentz-)Force is proportional to q , \mathbf{B} and \mathbf{v} !!!
 - ONLY the part of \mathbf{B} that is perpendicular to \mathbf{v} counts!
 - Because force is perpendicular to \mathbf{v} , charged particles neither speed up nor slow down in magnetic fields - kinetic energy is conserved!
- Interesting applications: CRT screens, accelerators,...
- Typical motion: Circle (for a homogeneous magnetic field)

*) “right hand rule”: thumb in direction of motion, index finger in direction of \mathbf{B} , middle finger in the direction of force

Magnetic force on current-carrying wires

- Equally weird:
If a current flows to the right and the magnetic field points away from you, then the wire will be pushed UP (right hand rule again)
- This (Lorentz-)Force is proportional to I , L and \mathbf{B} !
- Interesting applications:
 - Electric Meters
 - Electric Motors, relays,...
- To close the circle: Two parallel wires exert a force on each other! If both carry 1 A and are 1 m apart, the force will be $2 \cdot 10^{-7} \text{N}$
=> Definition of Ampere!

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