Unit 5: Magnetism and Electromagnetic Induction

5.1 - Magnetic Systems

- current causes magnetic fields
  - orbital motion of electrons create a north and south pole of the magnet
    - all of the magnets will point their north poles in the same direction when they are grouped together
    - when the magnet is split in half, there will still be north and south poles
- magnetic domains cause materials to become magnetized
- the geographic north pole is the magnetic south pole

📢 - This unit is going to be about magnetism and will heavily relate back to the previous two units

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5.2 - Magnetic Permeability and Magnetic Dipole Moment

- if all of the magnetic dipole moments are aligned into magnetic domains, and then those are aligned, then we've created a magnet
- putting iron through the center of a solenoid makes things react to it quicker
- **magnetic permeability:** $\mu_0 = 4\pi \times 10^{-7}$, is the measure of how easily a magnetic dipole can cause a magnetic field through free space
  - different materials can have different magnetic permeabilities

📢 - **Magnetic permeability:** a constant value denoted as $\mu_0 = 4\pi \times 10^{-7}$

5.3 - Vector and Scalar Fields in Magnetism

- moving charges creates a magnetic field, which is a vector
- the magnetic field from a wire flows in a circle
- using your right hand, point your thumb in the direction the charge is flowing through the wire
  - curl your fingers in, and they should point away from you or towards you — that's the direction that the magnetic field is moving
  - for example: the charge is moving to the left of the wire (conventional current) and your fingers are curled outwards — the magnetic field points away from you
- x's represent magnetic field into the page, while dots represent magnetic field out of the page
- **magnitude of a magnetic field of a wire:** represented by B, measured in Teslas, and calculated by $B = \frac{\mu_0 I}{2\pi r}$, is the magnitude of magnetic field emitting from a wire

📢 - **Magnitude of a magnetic field around a wire (T):** represented by B and calculated by $B = \frac{\mu_0 I}{2\pi r}$
- Magnetic field is a vector quantity and you have to find the vector sum when there is more than one field present

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5.4 - Monopole and Dipole Fields

- gravitational fields:
  - caused by one mass (monopole field)
  - denoted by field lines, where it's denser (stronger force) near the object
  - attractive force in the direction of the field
- electric fields:
  - caused by a single charge (monopole field)
    - denser and stronger the closer to the charged object
  - can also be caused by two charges (dipole field)
    - the strongest field is where the lines are closest together
    - can experience attractive or repulsive forces
- magnetic fields:
  - caused by a permanent magnet (dipole field)
    - denser and stronger the closer to the magnetic field
    - field points away from the south pole and towards the north pole
  - can also be caused by moving charges, or current
    - strongest at where the field lines are closest
    - causes moving objects with charge to experience a force
    - use the right-hand rule to determin the direction of the field for the current

📢 - Compare and contrast gravitational, electric, and magnetic fields

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5.5 - Magnetic Fields and Forces

- **right hand rule:** hold your hand in an L shape — your thumb represents v, fingers represent B, and your open palm represents the direction of the magnetic force F
  - represents 3D relationship between magnetic force F, magnetic field B, and velocity of the particle v
  - use your *right hand* because it applies to positively charged particles
    - you can use your left hand for negatively charged particles
- the right hand rule ONLY applies to perpendicular relationships
  - if velocity and field are parallel, there is no force
  - if the velocity and field are not perpendicular, there is force but only on the perpendicular component of the velocity
- **magnetic force:** represented by F_M, measured in Newtons, and calculated by $F_M = qv \cdot B \cdot \sin\theta$, is the force experienced by a charge in a magnetic field
  - to get the magnitude of magnetic force, use the equation $|F_M| = |qv||B||\sin\theta|$
- the magnetic field around a wire forms in concentric circles
  - field is caused by current flowing through the wire, so current is proportional to magnetic field strength
  - direction of current affects direction of the field
- an external magnet can cause magnetic domains to align and create a magnet

📢 - The right hand rule is useful for figuring out the relationship between magnetic force, magnetic field, and the velocity of the particle
- The right hand rule ONLY applies to positive charges and perpendicular relationships
- **Magnetic force (N):** represented by F_M and calculated by $F_M = qv \cdot B \cdot \sin\theta$, is the force experienced by a charge in a magnetic field

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5.6 - Magnetic Forces

- for wires, magnetic force is calculated by $F_M = I \cdot l \cdot B \cdot \sin\theta$ where I is the current and l is the length of the wire
- the motion of a particle can tell us about the direction of flow of charge in a wire
  - if a charged particle is moving one way but gets deflected to move another (F_M) then we can figure out the direction of the magnetic field using the right hand rule
- an electric force can be added to a magnetic force or field and influence the charge
- magnetic force between two wires:
  - there are two wires A and B
  - find the magnetic field of wire A using the equation $B_A = \frac{\mu_0 I_A}{2\pi r}$
  - find the force that wire B experiences using the equation $F_{M,B} = I_B \cdot l_B \cdot B_A \cdot \sin\theta$
- a current-carrying wire can't experience its own magnetic field
  - if two wires have currents that both point in the same direction then their forces will pull the other wire closer
  - if two wires have currents that point in opposite directions then their forces will repel each other

📢 - Magnetic force of a wire: $F_M = I \cdot l \cdot B \cdot \sin\theta$ where B has to be the field of another charge or wire, because the wire can't experience its own field
- The movement of two wires depends on whether they are pointed in the same or opposite direction

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5.7 - Forces Review

- a particle in a magnetic field will move in a circle because the velocity and force are constantly changing but always perpendicular to each other
  - use the equation $m\frac{v}{r} = qB$ for a particle experiencing centripetal motion
  - magnetic force does not do work on the charged particle

- gravitational fields and forces
  - field: $g = \frac{GM}{r^2}$
  - force: $F_g = mg = \frac{GMm}{r^2}$
- electric fields and forces
  - field: $E = \frac{kQ}{r^2}$
  - force: $F_e = qE = \frac{kQq}{r^2}$
- magnetic fields and forces
  - field: $B = \frac{\mu_0 I_1}{2\pi r}$
  - force: $F_M = I_2 l B \sin\theta = \frac{\mu_0 I_1 I_2 l}{2\pi r}$

- magnetic and electric fields can combine to influence particles
  - magnetic force points down, electric force points up, so the particle moves in a straight line
  - when $F_M = F_e$, then $vB = E$
- velocity doesn't affect electric force, but it does affect magnetic force — if velocity is decreased, then the particle will move in the direction of the electric field because the magnetic field force is weaker
  - slow protons experience net downwards force, fast protons experience net upwards force
  - work is being done by the electric field

📢 - Charged particles in a magnetic field will move in a circle
- Magnetic and electric forces can combine to influence charged particles
- If a charged particle doesn't move linearly in a combined magnetic and electric field, it's because one of the forces (magnetic or electric) is stronger than the other

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5.8 - Magnetic Flux

- ferromagnetic
  - have magnetic domains which can be aligned by external magnetic fields
  - can be permanently magnetized by external fields
- paramagnetic
  - can be temporarily aligned by external fields
  - magnetic dipoles do not remain aligned when the external field is removed
- diamagnetic
  - the dipole moments weakly align opposite the magnetic field
  - alignment stops after the field is removed

- **emf:** represented by ϵ, measured in Volts, and calculated by $\epsilon = Blv$, is the measure of potential difference between two ends of a rod
  - place a rod in a magnetic field, and there are no forces present when the rod is stationary
  - but when the rod starts moving, the electrons will move (because of the right hand rule) and gather at one end of the rod
  - the two ends are now charged
- **magnetic flux:** represented by Φ, measured in Webers, and calculated by $\Phi_B = B \cdot A \cdot \cos\theta$, is the strength of the field flowing through a section of the field
  - if the area of the loop A is parallel to the field, then there is no flux
  - the loop should be perpendicular to the loop for maximum flux
- **Lenz's Law:** when a loop of wire experiences a changing magnetic flux, a current will be induced in the loop that flows in such a way as to create a *new* flux to oppose the *change in flux*
  1. determine direction of existing magnetic flux through the loop
  2. determine if the flux is increasing, decreasing, or constant
     1. if it's increasing, the direction will be opposite
     2. if it's decreasing, the direction will be the same
  3. determine the direction of the new magnetic flux opposing the changing in flux
  4. use the right-hand rule for current in a loop to determin direction of the current
- **Faraday's Law:** $\epsilon = -\frac{\Delta\Phi_B}{\Delta t}$ calculates the magnitude of induced emf when flux is changing
- rotate the magnet around the y axis opposed to a loop to induce current

📢 - **Magnetic flux (Wb):** represented by Φ and calculated by $\Phi_B = B \cdot A \cdot \cos\theta$, is the strength of he field flowing through a loop
- **Lenz's Law:** when a loop of wire experiences a changing magnetic flux, a current will be induced in the loop that flows in such a way as to create a *new* flux to oppose the *change in flux*
- **Faraday's Law:** $\epsilon = -\frac{\Delta\Phi_B}{\Delta t}$ which calculates the magnitude of induced emf when flux is changing
- **emf (V):** represented by ϵ and calculated by $\epsilon = Blv$, is the measure of potential difference between two ends of a charged rod