Unit 3: Electric Force, Field, and Potential

3.1 - Electric Systems

- Bohr model generally represents an atom
  - electrons don't move on tracks as represented in the Bohr model
  - *protons* are positively charged and represented by p^+
  - *neutrons* are neutral and are represented by n^0
  - *electrons* are negatively charged and represented by e^-
    - located outside of the nucleus and are highly mobile
  - *conductors* allow electrons to freely move through the material
    - microscopic properties show that the electrons surrounding the atoms that make up the material are allowed to move around
- *insulators* do not allow free motion of electrons

> 📢 - Protons are positive, neutrons are neutral, and electrons are negative.
> - Conductors allow electrons to move throughout the material

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3.2 - Electric Charge

- **charge:** represented by Q and measured in Coulombs
  - **coulomb:** SI unit of charge, represented by C, equivalent to $I \cdot s$ where s is seconds
  - comes from protons and electrons, which are called "charge carriers"
    - when an object is neutral, it has an equal amount of protons and electrons
    - negatively charged: more electrons
    - positively charged: more protons
  - electrons and protons carry the same amount of charge, called the *elementary charge*
    - $e = 1.60 \times 10^{-19}\ \text{C}$
    - all charges must be multiples of the elementary charge
  - like charges repel, opposite charges attract
  - charge cannot be created or destroyed
- **electric current:** represented by I and measured in Amperes, calculated by $I = \frac{\Delta Q}{\Delta t}$, is the quantity of charge flow per unit of time
  - **ampere:** SI unit of current, represented by A, equivalent to $\frac{C}{s}$ where s is seconds

> 📢 **Charge (C):** represented by Q
> **Current (I):** represented by A

3.3 - Conservation of Electric Charge

- the net charge in an isolated system remains constant
  - objects can exchange electrons through contant
    - electrons move around to create a positive or negative charge, but the system is still neutral
    - protons do not move
  - electrons will spread out from high concentration to low concentration to maintain equilibrium

> 📢 - Charge is conserved in a closed system
> - Electrons move to maintain equilibrium, but not protons

3.4 - Charge Distribution - Friction, Conduction, and Induction

- when observing charges of two objects
  - repulsion: both objects are charged
  - no reaction: both objects are neutral
  - attraction: both objects are charged or one object is charged and the other is neutral
- neutral objects can be attracted to charged objects
  - electrons are still capable of moving within neutral objects
  - a charged object can push like electrons away, creating a polarized object
    - if the object is grounded during polarization, the object becomes charged
  - induction is when an object picks up a charge without being touched
    - the quantity of charge on the polarized object is the same quantity of charge from the object used to induce the charge
- when materials slide past each other, electrons travel between them
  - dissimilar materials have different electronegativities, which prompt some materials to "steal" electrons
  - conduction is when two objects start out charged and balance their charges through physical contact
    - electrons shift from high concentration to low concentration
  - friction is when two objects start out neutral and charge each other through physical contact
    - end up with same magnitude of charge
- when charge is added to insulators, the charge stays at where it was added because the electrons aren't allowed to move around
  - net charge stays in one place
- when charge is added to conductors, the electrons spread out through the material away from other electrons
  - net charge moves towards outside of the object
- polarization is when electrons shift in a neutral object

- in conductors, electrons are allowed to move and can shift towards one side of the object, making polarization comparatively strong
- in insulators, electrons shift only towards one side of the atom, and polarization is comparatively weak

> 📢 - Charging by induction means that the object is not being touched, but instead wired to ground and polarized
> - Charging by conduction means two already-charged objects balance through contact
> - Charging by friction means two neutral objects charge each other through contact
> - Charge added to insulators stay in one place, while charge added to conductors tend to move around
> - Polarization in insulators are weak because electrons only shift on the atom, while polarization in conductors are strong because electrons shift in the object

3.5 - Electric Permittivity

- **electric permittivity:** represented by ϵ and measured in $\frac{C^2}{N \cdot m^2}$, calculated by $\epsilon = \kappa\epsilon_0$ is the measure of resistance to the propagation of electric field
    - κ is the dielectric constant of a material
    - **vacuum permittivity:** $\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{N \cdot m^2}$, is the resistance of a vacuum to the travel of an electric field
- electric permittivity refers to the measure of matter's resistance, while vacuum permittivity refers to free space

> 📢 **Electric Permittivity ($\frac{C^2}{N \cdot m^2}$):** represented by ϵ and calculated by $\epsilon = \kappa\epsilon_0$, is how resistant a material is to an electric field passing through it
> **Vacuum Permittivity:** a constant value denoted as $\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{N \cdot m^2}$

3.6 - Introduction to Electric Forces

- Newton's Second Law: $a = \frac{\Sigma F}{m}$
    - for the same amount of force, bigger objects have more inertia and less acceleration
    - electrons are more likely to move because they are less massive and experience more acceleration despite experiencing the same force as a proton
- Newton's Third Law: all actions have an equal and opposite reaction
    - forces experienced in an interaction are equal in magnitude and opposite in direction
- positive objects aren't attracted to neutral objects but could polarize them, creating a small charge

> 📢 - For the same net force, smaller objects have a higher acceleration than larger objects
> - All forces in an interaction are equal in magnitude and opposite in direction
> - Neutrons can't be polarized, but neutral objects can be

3.7 - Electric Forces and Free Body Diagrams

- draw diagrams that accurately communicate forces
  - draw the object as a single dot
  - draw forces as arrows pointing away from the dot with the length of the arrow corresponding to force magnitude
  - forces that don't cancel out in opposing directions represent acceleration
- direction of force between two objects depends on their charge

📢 - Simplify the system to draw free body diagrams
- Opposite forces attract and like forces repel

3.8 - Describing Electric Force

- Inverse-Square Law: phenomena that spread out radially, in a sphere shape, from a point source
- **Coulomb's Law:** $F_E = k\frac{q_1 q_2}{r^2}$, calculates the magnitude of force between two charges
  - k is Coulomb's constant, equal to $9 \times 10^9 \frac{N \cdot m^2}{C^2}$
  - because Coulomb's constant uses meters, all other values must be converted to meters
- to take ratio of a new value compared to an old value, divide the new equation by the old equation with their respective multiplied values
- determine net forces of charges in one dimension
  1. draw a free body diagram
  2. set up a net force equation
  3. substitute equations for forces into the net force equation
  4. simplify and solve
- determine net forces of charges in two dimensions
  1. draw a free body diagram
  2. determine size of individual forces on point
  3. break forces into x and y components using $\sin\theta$ and $\cos\theta$
  4. vector addition

📢 - **Coulomb's Law:** $F_E = k\frac{q_1 q_2}{r^2}$, calculates the magnitude of force between two charges

3.9 - Gravitational and Electromagnetic Forces

- electric force is for microscopic, gravitational force is for macroscopic
  - electric force is much greater than gravitational force when calculating forces between protons and electrons, enough for gravity to be negligible
- **Law of Universal Gravitation:** $F_g = G\frac{m_1 m_2}{r^2}$, calculates the magnitude of gravitational attraction between two objects
  - G is the gravitational constant, equal to $6.67 \times 10^{-11} \frac{m^2 N}{kg^2}$

- Gravitational force is negligible at microscopic levels
- **Law of Universal Gravitation:** $F_g = G\frac{m_1 m_2}{r^2}$, calculates the magnitude of gravitational attraction between two objects

3.10 - Vector and Scalar Fields in Electricity

- fields show the effect that an object has on the space around it
- electric field diagrams show the size and direction of force that a positive charge would experience if placed in that location
    - if vectors point inwards, the charge is negative, because the vectors always reference a positive charge
- **electric potential:** represented by V and measured in Volts, calculated by $V = k\frac{q}{r}$, is the energy per unit of charge at a specific point
    - **volt:** SI unit of electric potential, equal to $\frac{J}{C}$ where J is in joules and C is in Coulombs
    - scalar quantity with no direction
- **electric field:** represented by E and measured in $\frac{N}{C}$, calculated by $E = k\frac{q}{r^2}$, is the force per unit of charge at a specific point
    - vector quantity with positive and negative directions

- **Electric Potential (V):** calculated by $V = k\frac{q}{r}$, is the amount of energy per unit of charge at a specific point
- **Electric Field ($\frac{N}{C}$):** calculated by $E = k\frac{q}{r^2}$ or $E = k\frac{F_E}{q}$, is the amount of force per unit of charge at a specific point

3.11 - Electric Charges and Fields

- use $E = k\frac{q}{r^2}$ when describing a field by the charge creating that field
- use $E = k\frac{F_E}{q}$ when describing a field by the charge experiencing the field, where F_E is the force felt by the charge
- when calculating net electric field between vectors, break them down into components to calculate final vector
    - electric field also exists whether a charge is present or not
- electric field inside a conductor is always zero
- parallel plate capacitor is a pair of large, conducting plates at different electric potentials
    - creates a uniform electric field facing towards the negative plate
    - isolines are evenly spaced lines between two plates

- Parallel plate capacitors are a pair of plates with opposite electric charges and the electric potential is constantly decreasing from the positive to negative plate

3.12 - Isolines and Electric Fields

- isolines represent distortion of space due to a charge

- all electric potential charges on an isoline are equal and are drawn in equal intervals
- electric fields are perpendicular to isolines and point towards the negative charge
- potential difference is calculated by subtracting two potential values
  - negative value is like losing potential and "going downhill
- magnitude of electric field is the sum of the electric fields divided by the distance
- electric fields are uniform between parallel plate capacitors or when a sphere is big enough to seem flat

> 📢 - All points on an isoline are equal
> - The vector perpendicular to an isoline is the motion towards or away from the charge

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3.13 - Conservation of Electric Energy

- **electric potential energy**: measured in Joules, calculated by $U_E = qV$ and $U_E = qEr$, is energy stored in the arrangement of charged objects
  - $U_E = qV$ is for energy per charge
  - $U_E = qEr$ is for between two locations or at a specific location
- work must be done to move a charge against the direction it would naturally go

> 📢 - **Electric Potential Energy (J):** calculated by $U_E = qV$, $U_E = qEr$, or $U_E = q(\frac{kQ}{r_2} - \frac{kQ}{r_1})$, is the amount of energy stored in a system