Chapter 25 – Electric Charges and Forces

25.1 Developing a Charge Model

- Understanding electric charge without using electrons or protons, model developed long before we knew about parts of atoms.
- Experiments to help develop understanding
    - Two plastic rods – nothing happens
    - Two plastic rods rubbed by wool repel
    - Two glass rods rubbed by silk repel
    - A glass rod with silk and a plastic rod with wool will attract.
    - The more the wool or silk has been rubbed the stronger the forces will be
    - The strength of forces decreases as distance increases
- This is an example of long-range forces (think gravity / non-contact forces)
    - First time seeing a repulsive force
    - A charged rod will pick up small pieces of paper, but a neutral rod will not
    - Both a plastic and glass rod will be attracted to a neutral rod
    - A plastic rod that has been charged will be attracted to the material it was charged by and repelled by the material that charges the opposite type rod.
    - Other objects charged will be attracted to one rod and repel the other type, but not attract both
    - There is no charged rod that can pick up paper and attract both types of rods
- One way to test if a charged object is charged and not neutral is to put it near small pieces of paper.

Charge Model

- Frictional forces can add or remove "charge". The more something is rubbed the more charged it becomes.
- There are two kinds of charge and only two kinds of charge. (Plastic charge and Glass charge)
- Two like charges repel, two opposite charges attract.
- Neutral objects have an equal amounts of plastic and glass charges and rubbing them somehow separates the charges
    - Charge plastic rod touch a neutral metal sphere, the metal sphere will then have plastic charge after the plastic rod is removed.
    - Charge a plastic rod then run your finger along it and will no longer act like it is charged.

- Two metal spheres connected by a plastic rod, if you charge one sphere the other sphere does not pick up the charge on the first sphere.
- If on the other hand the metal spheres are connected by a metal rod then both spheres will act as if they have been charged.

Model update

- Charge can be transferred if things touch. (Discharging)
- Two different types of materials conductors and insulators
  - Conductors allow charges to easily move
  - Insulators are materials in which charges remain fixed in place.

25.2 Charge

- Benjamin Franklin coined the terms positive charge and negative charge
  - He found charges add like positive and negative numbers
- A Glass rod rubbed by silk is said to be positively charged
- A Plastic rod rubbed by wool is said to be negatively charged
- Since this is the definition, by convention electrons are negative and protons are a positive charge
- Charge like mass is an inherent property of matter.
- Electrons and Protons have the same amount of charge but opposite signs. This is called the fundamental unit of charge (e) but charge is represented by the symbol q or Q
  - $q = (N_p - N_e)\, e$
  - Most things have an equal number of protons (N_p) and electrons (N_e)
  - If you are electrically neutral then $q = 0$
  - Neutral does not mean “no charge” it means No net charge.
- Charge is quantized, it always occurs in integer multiple of e.
- Objects acquire charges by picking up electrons (protons do not transfer).
- Removing an electron is called ionization.
  - An atom missing an electron is called a positive ion the net charge $q = +e$.
  - An atom acquiring an electron is called a negative ion the net charge $q = -e$.
- **Law of Conservation of Charge** – Charge cannot be created or destroyed. Charges can be transferred from one object to another as electrons or ions move about, but the total amount of charge remains the constant. If the plastic rod acquires a charge from the wool $q_{wool} = -q_{plastic}$.

- Use diagrams, keep track of the net number of plusses and minuses they should not change as the problem is worked.

25.3 Insulators and Conductors

- Electrons in an insulator are tightly bound and not free to move around
    - Charging an insulator by friction leaves patches of molecular ions on the surface but they are not free to move around
- In metals the outer (valence) electrons are only weakly bounded, in a solid the electrons become detached and are free to wander about. The solid is still electrically neutral though. The motion of the charges is called a current.
- Charges that physically move are called charge carriers.
- Insulators are charged by rubbing, the charges do not move around but stay in the localized area.
- Metals cannot be charged by friction. The electrons that are added will shove the sea of electrons a little to the side. This happens basically instantaneously.
- Charges in an isolated conductor are in static equilibrium called electrostatic equilibrium. The charges are at rest with no net force acting on it.
- In an isolated conductor, any excess charge is located on the surface of the conductor.
- Any object that is connected by a conductor to the earth is said to be grounded because the Earth is a conductor.
- Grounding an object will prevent the build up of excess charges on the object.
- Charge Polarization help explains how a charged object exerts a force on a neutral object.
    - Moving a charged rod close to but not touching an electroscope will cause the metal leaves to move apart and stay apart as long as the charge rod in near by.
    - The electroscope is still overall electrically neutral but has a region of localized positive charge and a region of localized negative charge.
    - This slight separation of charges caused by the charged rod attracting or repelling electrons on the electroscope causes the leaves to move apart.
    - The sea of electrons is slightly disrupted by the charge rod but once it is disrupted the positive region will exert a restoring force so that not all of the electrons will shift.
    - A net force caused by this charge polarization is called a polarization force. This is caused by the charges on the metal being separated not because the two objects are oppositely charged.
- The Electric Dipole – Bringing a charge near an atom will cause a slight disruption of the electron cloud this causes an slight net force towards the charge.

- A polarizing force will act on each atom in an insulator like paper, this generates a net force towards the charged object.
- Charging by Induction – Hold a positive charge rod near an electroscope near but not touching it. This will shift electrons close to the side the rod is near, creating a localized negative region and the leaves will be a localized positive region. When a person then touches the electroscope the person will have electrons transfer to the electroscope towards the charged rod. This leaves the person with an electron deficiency and the electroscope with an excess of electrons. When charged rod is removed the leaves will collapse from the polarization going away but then separate further as the excess of electrons spread out.

25.4 Coulomb's Law

- This is the force law that describes electric forces. Electric forces obey an *inverse-square law*, this is similar to Newton's Law of Gravity. This is also related to Newton's 3rd Law.

$$F_{1\,on\,2} = F_{2\,on\,1} = \frac{K|q_1||q_2|}{r^2} \quad Equation\ 25.2\ page\ 732$$

- K is the electrostatic constant, $K = \frac{1}{4\pi\varepsilon_o} = 9.0 \text{ x } 10^9 \frac{\text{N*m}^2}{\text{C}^2}$. Actual value is $8.99 \text{ x } 10^9 \frac{\text{N*m}^2}{\text{C}^2}$
- q is the charge of the two objects.
- This force can be attractive for opposite charges or repulsive for like charges.
- This force is equal and opposite on the two charges, called point charges.
- q can be positive or negative but Coulomb's law will only give magnitude because of the absolute values signs in the equation.
- Units of charge is a Coulomb (C), it is a derived unit of charge from the SI unit for current.
- *e* the fundamental unit of charge has been measured to have a value of $e = 1.60 \text{ x } 10^{-19}$ C, in chemistry this is treated as a -1 or + 1. Silly chemist!
- The amount of charge produced by rubbing a glass or plastic rod is 1 nC (10^{-9} C) to 100 nC (10^{-7} C). This means there is an excess or deficit of 10^{10} to 10^{12} electrons.
- The permittivity constant, $\varepsilon_o = \frac{1}{4\pi K} = 8.85 \ x\ 10^{-12} \ \frac{C^2}{N\,m^2}$,
- Rearrange Coulomb's Law using ε_o gives

$$F = \frac{1}{4\pi\varepsilon_o}\frac{|q_1||q_2|}{r^2}$$

- **Using Coulomb's Law**

- Coulomb's Law applies to only point charges.
- Electric Forces can be superimposed. (Add up or subtract the forces present.)

25.5 The Field Model

- Coulomb's Law and Newton's Law of Gravity imply that if a charged particle moves then another charged particle must react instantaneously. Both Coulomb and Newton's Laws do not depend on time.
- Michael Faraday came up with the idea of a field.
- Faraday's idea is that A influences the space around it then B reacts to that space. The Newtonian's view is that A and B interact directly.
- The alteration of space is the agent by which A and B interact. The action of A disturbs the space which then travels to B and B then interacts with the space. This is a localized interaction much like a contact force.
- Faraday's idea is now called a Field. A charge will make an alteration to everywhere in space.
  - The alteration of the space around a mass is called a gravitational field.
  - The alteration of the space around a charge is called an electric field.
- Newton's laws deals with how something effects a particle (one spot in space), Faraday's idea deals with how every spot in space is affected.
- James Clerk Maxwell was able to provide the mathematical foundations to Faraday's field in 1865.

- **Electric Field Model**
  - Source charges alter the space around them by creating an *electric field,* $\vec{E}$.
  - A separate charge in the field will experience a force $\vec{F}$ **exerted by the field**.
  - $\vec{E}_{(x,y,z)} \stackrel{\text{def}}{=} \dfrac{\vec{F}_{on\ q}\ at\ (x,y,z)}{q}$ $\quad Equation\ 25.5\ page\ 738$
- Electric Field Strength, $\vec{E}$, is in N/C.
- Charges only exert forces on other charges not on themselves.
- The field is the agent that exerts an electric force on a charged particle.
- The electric field is a vector field.
- If q is positive then the electric field points in the same direction as the electric force on that charge.
- Equation 25.5 can be rearranged to find the Force exerted on a charge q by a known electric field.
  - $\vec{F}_{on\ q} = q\vec{E}$

- The force on a negative charge is opposite the direction of the electric field. If you use Coulomb's Law and the electric field formula together you get equation 25.8
    - $\vec{E} = \frac{1}{4\pi\epsilon_o}\frac{q}{r^2}$
- The electric field always points **AWAY** from a **positive charge** and **towards** a **negative charge**.
- The size of an arrow in the electric field indicates the size (strength) and direction of the electric field. The further you move away the smaller the field becomes because of the inverse squared relationship between electric force and distance between the charges.
- Each vector ONLY represents the field at that point in space it does not stretch across the space to other points.