21.01

What is Physics?

- **Physics** = the study of physical phenomenon and the mechanisms that cause them
  - This class is focused on **electromagnetism**
- Physics first discovered by the Greek philosophers
  - Rub piece of amber and it "pulls" straw near it
- **Hans Christian Oersted** = physicist who discovered the *unity* of electricity and magnetism(~1820)
  - Prior to this, the two phenomenon were assumed to be independent of one another
- **Michael Faraday** = physicist that pioneered much of the properties of electromagnetism
  - Didn't break these laws down into concrete formulas
    - Physicists *love* them some formulas
- **James Clerk Maxwell** = physicist who made Faraday's discoveries more conrete
  - Created **Maxwell's Equations**
    - **Gauss's Law**

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

    - **Gauss's Law for Magnetism**

$$\nabla \cdot \mathbf{B} = 0$$

    - **Faraday's Law of Induction**

$$\nabla \times \mathbf{E} = -\frac{\delta \mathbf{B}}{\delta t}$$

    - **Ampere's Circuital Law**

$$\nabla \times \mathbf{B} = \mu_0 \big(\mathbf{J} + \epsilon_0 \frac{\delta \mathbf{E}}{\delta t}\big)$$

- **Benjamin Franklin** = American scientist
  - Credited with describing the two electric charges as "positive" and "negative"
  - Also introduced the idea of **excess charge**
    - **Excess charge** = an imbalance in positive and negative charge

Conductors and Insulators

- **Conductor** = a material that permits electrons to move relatively freely
  - **Superconductors** = a material that acts as a *perfect* conductor
    - Offers no resistance to electric flow
  - Generally, conductors have electrons on the outer shells whose ionization energy is small
- **Insulators** = a material that blocks electrons from moving freely
  - Also called **nonconductors**
- **Semiconductor** = a material whose capacity to permit electrons to move freely is in between **insulators** and **conductors**
- **Induced charge** = a phenomenon in which an object's internal electric field will orient itself to align with an external electric field and create a **dipole**
  - **Dipole** = an object that is positively charged on one side and negatively charged on the other

Coulomb's Law

- **Electrostatic force** = the force that charged particles exert on one another
  - Vector quantity–the direction always points towards or away from the particle in question
- **Coulomb's Law** = an equation that describes the magnitude of the **electrostatic force**
  - Named after Charles-Augustin de Coulomb
  - Discovered in 1785

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$$

$$\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$$

$$k = \frac{1}{4\pi\epsilon_0} = 9.99 \times 10^9 \frac{Nm^2}{C^2}$$

$$\epsilon_0 = 8.85 \times 10^{-12}\frac{C^2}{Nm^2}$$

  - ϵ_0 is called the **permittivity constant**
    - Mostly used for historical reasons, as it made simplifying other equations easier
  - Very similar to equation for Newtonian gravity

$$\vec{F_g} = G\frac{m_1 m_2}{r^2}\hat{r}$$

Electric Charge and Current

- SI unit for charge is **Coulomb(C)**
  - For practical reasons, the **Coulomb** is defined using the **Ampere**
- **Ampere** = SI unit for current
  - Current is defined as the following, where i is current and q is charge

$$i = \frac{dq}{dt}$$

    - Rearranging, we can see where the units come from

$$i \times dt = dq$$

$$(A) \times (sec) = (C)$$

    - So 1 Ampere is equal to $1\frac{C}{sec}$, and 1 Coulomb is equal to $1A \times sec$
- Electrically charged objects(which we treat as particles for simplicity) exhibit many of the same characteristics as do particles in newtonian physics
  - **Force** vectors add together to create a **net force**($\sum \mathbf{F}$)
    - **Net force** is also called **resultant force**

Shell Theories

- **Shell theories** = models that are used to simplify problems by assuming that bodies can be treated as particles
- Shell Theory 1
  - a charged particle placed *outside* of a **shell** that is uniformly charged about its surface will experience an electrostatic force equal to the circumstance in which the shell is a particle located at the center of the shell with the same charge
- Shell Theory 2
  - a charged particle placed *inside* of a shell that is uniformly charged about its surface will experience no electrostatic force from the shell
    - Why would that be the case???
- **Spherical conductors**
  - in a spherical conductor with an excess charge, particles seek to maximize the distance between all other similarly charged particles

21.02

Charge Is Quantized

- Originally, scientists thought that electric charge was a continuous phenomenon
  - But, because matter is a discrete phenomenon, charge is as well
- **Elementary charge** = the essential "stepping size" that the net charge of an object or particle can increment or decrement by
  - *All* charges can be represented as

$$n\mathbf{e}, n \in \mathbb{Z}$$

  - where

$$\mathbf{e} = 1.602 \times 10^{-19} C$$

- **Quantized** = a word that is meant to convey the discrete nature of a phenomenon
  - things come in "packets" rather than continuously flowing like a substance

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21.03

Charge Is Conserved

- In physics, almost *everything* is conserved
  - the same holds true for **charge**
- Charge acts like mass in classical Newtonian physics
- **Conservation of Charge** = a hypothesis put forth by Benjamin Franklin that asserts the prior is the case
- Examples
  - Nuclear decay
    - Whenever a decay event occurs, the newly created particles always have an overall charge that is equal to that of the parent particle
      - $^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{Th} + {}^{4}\mathrm{He}$
    - **Annihilation** = two particles colliding and destroying each other
      - Charge is perserved
    - **Pair Production** = the spontaneous creation of particles from existing energy
      - $\gamma \rightarrow \mathrm{e}^{-} + \mathrm{e}^{+}$