Phy 213: General Physics III

Chapter 21: Electric Charge
Lecture Notes

Electric Charge

- An intrinsic property of fundamental matter, i.e. protons & electrons
- The SI unit of charge is the coulomb (C): *derived from the base SI unit of electric current the ampere:*

$$q = \int dq = \int_{t_i}^{t_f} i \cdot dt \Rightarrow [\text{units: } 1\text{ C} = 1\text{A}\cdot\text{s}]$$

- There are 2 types (polarities) of charge:
  - Positive (+): e.g. protons ($q_{proton} = +1.602\text{x}10^{-19}$ C)
  - Negative (-): e.g. electrons ($q_{electron} = -1.602\text{x}10^{-19}$ C)
- Atoms & molecules have no net charge
  - Equal # of protons & electrons
  - Protons & electrons have the same magnitude but opposite charge
- Properties of charge:
  - Like charges repel each other
  - Unlike charges attract each other

Conductors & Insulators

Conductors: materials that allow the movement of electric charge through them

1. Excess charge will repel itself pushing all excess charge to the surface of the conductor
2. Under equilibrium conditions, all excess charge resides along the surface of the conductor
3. When electric charge flows along a conductor (i.e. electricity) it flows along the surface *(think about the implications!)*
4. The electric field inside a conductor is zero

Insulators: materials that do not allow the flow of electric charge through them

1. Excess charge will remain fixed (or static)
2. Excess charge can be inside an insulator or along its surface and does not have to be uniformly distributed
3. Electric charge inside insulator depends on orientation and quantity of excess charge

Charge Quantization & Conservation

1. Electric charge is <u>quantized</u>
   a. The elementary unit of charge: $e = 1.602 \times 10^{-19}$ C
   b. The magnitude of net charge for any matter is

$$|q_{net}| = Ne$$

   where N is the number of elementary charges

2. Electric charge is <u>conserved</u>
   a. There is no known process that can change the charge of something, *in any process the total net charge must remain constant*

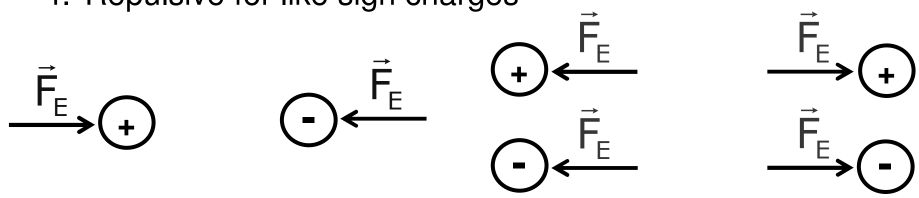
<u>Example:</u> *During "beta" decay, a neutron splits into a proton & an electron:*

$$^{14}_{6}C \rightarrow \, ^{14}_{7}N^{+} + e^{-}$$

$$^{3}_{1}H \rightarrow \, ^{3}_{2}He^{+} + e^{-}$$

Electric Force

- The interaction between electric charge pairs is referred to as electric force (F_E)
- Characteristics of the electric force:
    1. Proportional to the magnitude of each charge in the pair
    2. Inversely proportional to the square of the separation distance
    3. Attractive for opposite sign charges
    4. Repulsive for like sign charges



Coulomb's Law

1. The attractive/repulsive force between charges is called <u>electric force</u> (remember forces are vectors!)
2. The magnitude of the electric force between 2 point charges can be determined by Coulomb's Law:

$$\left|\vec{F}_E\right| = k\frac{|q_1||q_2|}{r^2} = \frac{1}{4\pi\varepsilon_o}\frac{|q_1||q_2|}{r^2}$$

← *The most common form of the eqn.*

where:

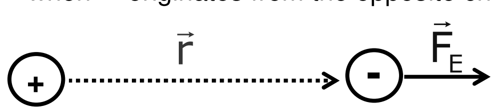
$k = 8.99 \times 10^9\ N{\cdot}m^2/C^2$ {Coulomb's constant}

$\varepsilon_o = 8.85 \times 10^{-12}\ C^2/N{\cdot}m^2$ {called the "permittivity" constant}

r is the separation distance between charges

q_1 & q_2 are the magnitudes of the point charges

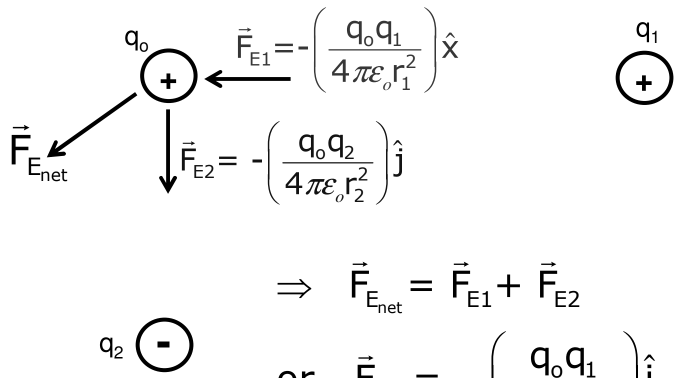
3. The direction of F_E exerted on a charge is along the line of separation between the charges ($\hat{r}$) and is determined by the sign of the charges when $\vec{r}$ originates from the opposite charge



$$\vec{F}_E = \left(\frac{q_1 q_2}{4\pi\varepsilon_o r^2}\right)\hat{r}$$

The Vector Nature of Electric Force

When an electric charge interacts with multiple charges, the electric force vector between each charge adds independently as vectors:



$$\Rightarrow \quad \vec{F}_{E_{net}} = \vec{F}_{E1} + \vec{F}_{E2}$$

$$\text{or} \quad \vec{F}_{E_{net}} = -\left(\frac{q_o q_1}{4\pi\varepsilon_o r_1^2}\right)\hat{i} - \left(\frac{q_o q_2}{4\pi\varepsilon_o r_2^2}\right)\hat{j}$$

Work Performed by Electric Forces

Consider a proton and electron separated by $1.0\text{x}10^{-10}$ m

1. What is the electric force exerted on the electron by the proton? $\vec{F}_E = \left(\frac{q_p q_e}{4\pi\varepsilon_o r^2}\right)\hat{i}$ = ______?

   $q_p = +1.60\times10^{-19}$C

   $q_e = -1.60\times10^{-19}$C

2. How much work would it take to move the electron halfway to the proton? Assume the proton is fixed.

$$dW = \vec{F}_E \cdot d\vec{r} \Longrightarrow W = \int dW = \int_{r_i}^{r_f} \vec{F}_E \cdot d\vec{r} = \int_{r_i}^{r_f} \left(\frac{q_p q_e}{4\pi\varepsilon_o r^2}\right) \cdot dr \cdot \cos 0^o$$

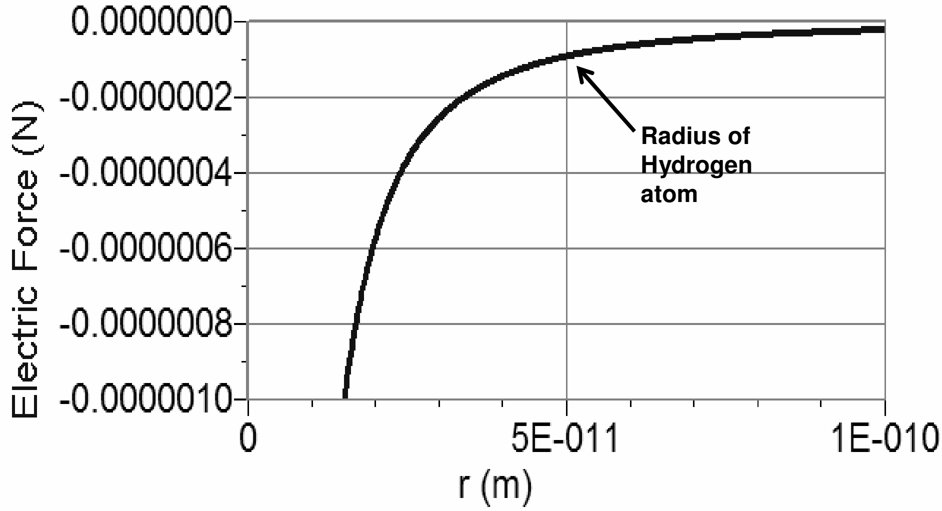
$$W = \left(\frac{q_p q_e}{4\pi\varepsilon_o}\right)\int_{r_i}^{r_f} \frac{dr}{r^2} = -\left.\frac{q_p q_e}{4\pi\varepsilon_o r}\right|_{r_i}^{r_f} = \text{\_\_\_\_\_\_?}$$

3. Where does the energy go?

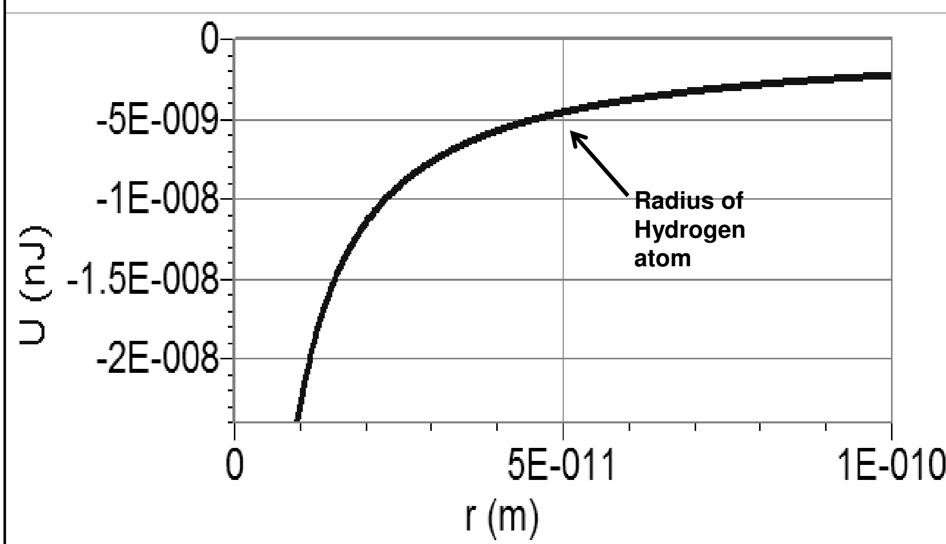
   Since F_E is a conservative force, W performed at the expense of the electric potential energy, U_E: $W = -\Delta U$

Electric Force vs Distance

(exerted on an electron due to a single proton)



Potential Energy vs Distance *(for 1 proton & 1 electron)*

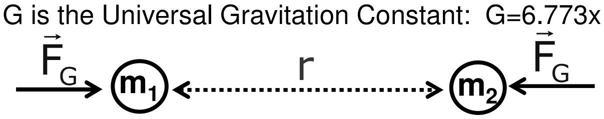


A Tale of 2 Forces

1. Coulomb's Law is structurally similar to another familiar force law, Newton's Law of Gravitation *(what a coincidence… eh?)*

$$\vec{F}_E = k\frac{q_1 q_2}{r^2}\,\hat{i}_r \qquad \vec{F}_G = G\frac{m_1 m_2}{r^2}\,\hat{i}_r$$

2. *Characteristics of Newton's Universal Law of Gravitation:*
   a. F_G is always attractive between 2 masses
   b. F_G is proportional to the magnitude of each mass in the pair
   c. F_G is inversely proportional to the square of the separation distance
   d. G is the Universal Gravitation Constant: $G=6.773\times10^{-11}\,N\cdot m^2/kg^2$



3. *Note: Newton's Universal Law of Gravitation pre-dates Coulomb's Law by several decades…*

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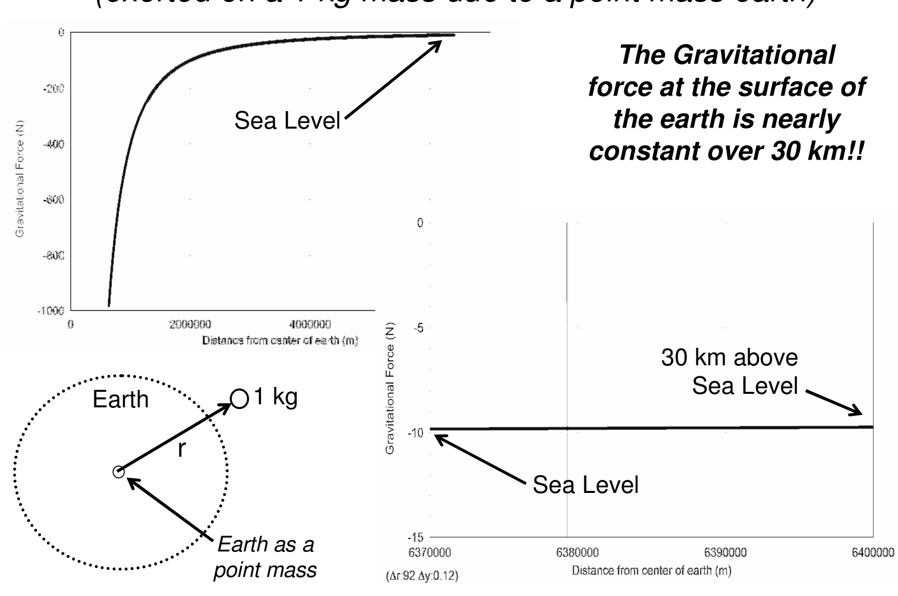
Gravitational Force vs Distance

(exerted on a 1 kg mass due to a point mass earth)

The Gravitational force at the surface of the earth is nearly constant over 30 km!!



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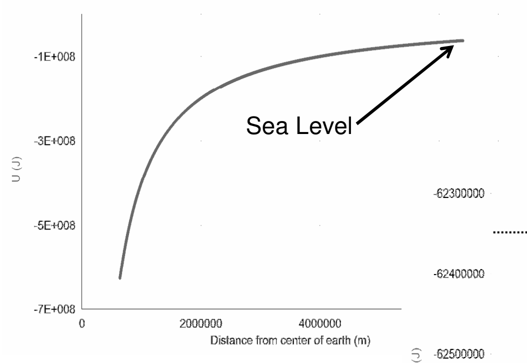
Gravitational Potential Energy vs Distance

(exerted on a 1 kg mass due to a point mass earth)



The Gravitational Potential Energy is nearly linear from the surface of the earth to over 30 km!!