PHYS 1444 – Section 501
Lecture #2

Monday, Jan. 23, 2006
Dr. Jaehoon Yu

- Brief history of physics
- Some basics …
- Chapter 21
  - Static Electricity and Charge Conservation
  - Charges in Atom, Insulators and Conductors & Induced Charge
  - Coulomb's Law

Announcements

- Your five extra credit points for e-mail subscription is till midnight Wednesday, Jan. 25. Please take a full advantage of the opportunity.
  - Eleven of you have subscribed so far. Thank you!!!
- Twenty of you have registered in the homework system.
  - I am TOTALLY impresssed!!! GOOOOOOOD Job!!
  - But many of you forgot to download and submit homework. Please do so to get a free full credit homework!!
- Remember the quiz next Monday, Jan. 30, early in the class
  - Covers Appendix A and CH21

Brief History of Physics

- AD 18th century:
  - Newton's Classical Mechanics: A theory of mechanics based on observations and measurements
- AD 19th Century:
  - Electricity, Magnetism, and Thermodynamics
- Late AD 19th and early 20th century (Modern Physics Era)
  - Einstein's theory of relativity: Generalized theory of space, time, and energy (mechanics)
  - Quantum Mechanics: Theory of atomic phenomena
- Physics has come very far, very fast, and is still progressing, yet we've got a long way to go
  - What is matter made of?
  - How do matters get mass?
  - How and why do matters interact with each other?
  - How is universe created?

Needs for Standards and Units

- Three basic quantities for physical measurements
  - Length, Mass, and Time
- Need a language that everyone can understand each other
  - Consistency is crucial for physical measurements
  - The same quantity measured by one must be comprehendible and reproducible by others
  - Practical matters contribute
- A system of unit called SI (*System International*) established in 1960
  - Length in meters (*m*)
  - Mass in kilo-grams (*kg*)
  - Time in seconds (*s*)

SI Base Quantities and Units

Quantity	Unit	Unit Abbrevation
Length	Meter	m
Time	Second	s
Mass	Kilogram	kg
Electric current	Ampere	A
Temperature	Kelvin	k
Amount of substance	Mole	mol
Luminous Intensity	Candela	cd

• *There are prefixes that scales the units larger or smaller for convenience (see pg. 7)*

Prefixes, expressions and their meanings

- deca (da): 10^{1}
- hecto (h): 10^{2}
- kilo (k): 10^{3}
- mega (M): 10^{6}
- giga (G): 10^{9}
- tera (T): 10^{12}
- peta (P): 10^{15}
- exa (E): 10^{18}

- deci (d): 10^{-1}
- centi (c): 10^{-2}
- milli (m): 10^{-3}
- micro (μ): 10^{-6}
- nano (n): 10^{-9}
- pico (p): 10^{-12}
- femto (f): 10^{-15}
- atto (a): 10^{-18}

How do we convert quantities from one unit to another?

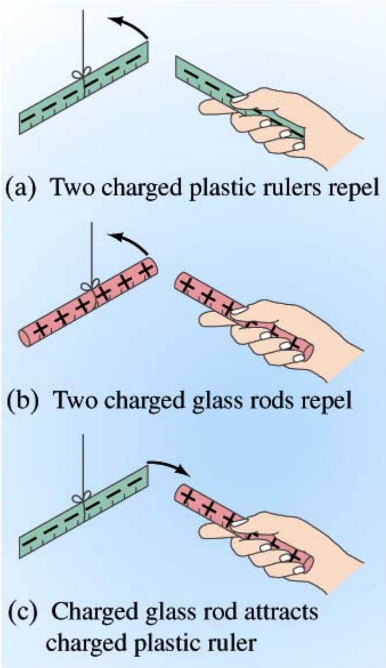
Unit 1 = Conversion factor X Unit 2

1 inch	2.54	cm
1 inch	0.0254	m
1 inch	2.54×10^{-5}	km
1 ft	30.3	cm
1 ft	0.303	M
1 ft	3.03×10^{-4}	km
1 hr	60	minutes
1 hr	3600	seconds
And many	More	Here….

Static Electricity; Electric Charge and Its Conservation

- Electricity is from Greek word *elecktron*=amber, a petrified tree resin that attracts matter if rubbed

- Static Electricity: an amber effect
  - An object becomes charged or "posses a net electric charge" due to rubbing
  - Can you give some examples?
- Two types of electric charge
  - Like charges repel while unlike charges attract
  - Benjamin Franklin referred the charge on glass rod as the positive, arbitrarily. Thus the charge that attracts glass rod is negative. ➔ This convention is still used.



(a) Two charged plastic rulers repel

(b) Two charged glass rods repel

(c) Charged glass rod attracts charged plastic ruler

Static Electricity; Electric Charge and Its Conservation

- Franklin argued that when a certain amount of charge is produced on one body in a process, an equal amount of opposite type of charge is produced on another body.
  - The positive and negative are treated algebraically so that during any process the net change in the amount of produced charge is 0.
    - When you comb your hair with a plastic comb, the comb acquires a negative charge and the hair an equal amount of positive charge.
- This is the law of conservation of electric charge.
  - The net amount of electric charge produced in any process is ZERO!!
    - If one object or one region of space acquires a positive charge, then an equal amount of negative charge will be found in neighboring areas or objects.
    - No violations have ever been observed.
    - This conservation law is as firmly established as that of energy or momentum.

Electric Charge in the Atom

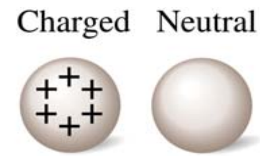
- It has been understood through the past century that an atom consists of
  - A positively charged heavy core ← What is the name?
    - This core is nucleus and consists of neutrons and protons.
  - Many negatively charged light particles surround the core ← What is the name of these light particles?
    - These are called electrons
    - How many of these?

As many as the number of protons!!

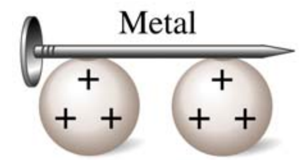
- So what is the net electrical charge of an atom?
  - Zero!!! Electrically neutral!!!
- Can you explain what happens when a comb is rubbed on a towel?
  - Electrons from towel get transferred to the comb, making the comb negatively charged while leaving positive ions on the towel.
  - These charges eventually get neutralized primarily by water molecules in the air.

Insulators and Conductors

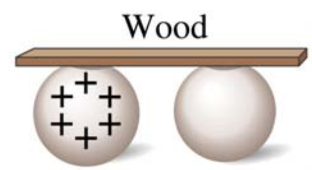
- Let's imagine two metal balls of which one is charged



- What will happen if they are connected by
  - A metallic object?
    - Some charge is transferred.
    - These objects are called conductors of electricity.
  - A wooden object?
    - No charge is transferred
    - These objects are called nonconductors or insulators.



(b) Conductor

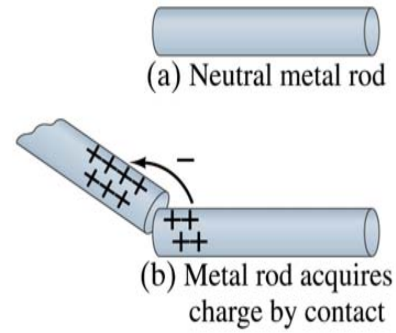


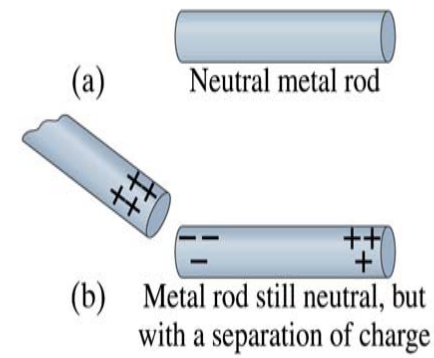
(c) Insulator

- Metals are generally good conductors whereas most other materials are insulators.
  - There are third kind of materials called, semi-conductors, like silicon or germanium ➔ conduct only in certain conditions
- Atomically, conductors have loosely bound electrons while insulators have them tightly bound!

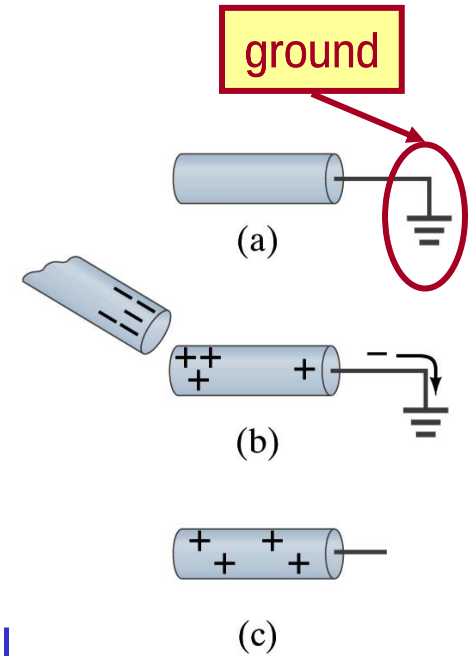
Induced Charge

- When a positively charged metal object is brought close to an uncharged metal object
  - If the objects touch each other, the free electrons in the neutral ones are attracted to the positively charged object and some will pass over to it, leaving the neutral object positively charged.
  - If the objects get close, the free electrons in the neutral ones still move within the metal toward the charged object leaving the opposite of the object positively charged.
    - The charges have been “induced” in the opposite ends of the object.

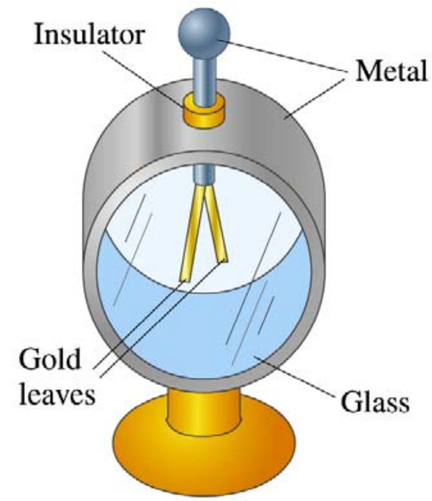




Induced Charge



- We can induce a net charge on a metal object by connecting a wire to the ground.
  - The object is "grounded" or "earthed".
- Since it is so large and conducts, the Earth can give or accept charge.
  - The Earth acts as a reservoir for charge.
- If the negative charge is brought close to a neutral metal
  - The positive charges will be induced toward the negatively charged metal.
  - The negative charges in the neutral metal will be gathered on the opposite side, transferring through the wire to the Earth.
  - If the wire is cut, the metal bar has net positive charge.
- An electroscope is a device that can be used for detecting charge and signs.
  - How does this work?



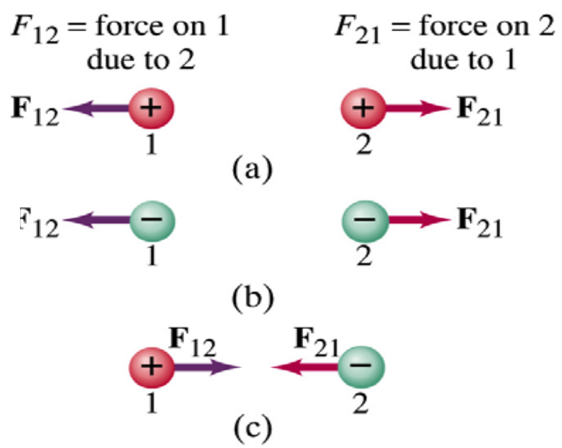
Coulomb's Law

- Charges exert force to each other. What factors affect the magnitude of this force?
  - Any guesses?
- Charles Coulomb figured this out in 1780's.
- Coulomb found that the electrical force is
  - Proportional to the multiplication of the two charges
    - If one of the charges doubles, the force doubles.
    - If both the charges double, the force quadruples.
  - Inversely proportional to the square of the distances between them.
  - Electric charge is a fundamental property of matter, just like mass.
- How would you put the above into a formula?

Coulomb's Law – The Formula

$$F \propto \frac{Q_1 \times Q_2}{r^2} \quad \xrightarrow{\text{Formula}} \quad F = k\frac{Q_1 Q_2}{r^2}$$

- Is Coulomb force a scalar quantity or a vector quantity? Unit?
  - A vector quantity. Newtons
- Direction of electric (Coulomb) force is always along the line joining the two objects.
  - If the two charges are the same: forces are directed away from each other.
  - If the two charges are opposite: forces are directed toward each other.
- Coulomb force is precise to 1 part in 10^{16}.
- Unit of charge is called Coulomb, C, in SI.
- The value of the proportionality constant, k, in SI unit is $k = 8.988 \times 10^9 \;\; \mathrm{N \cdot m^2}/C^2$
- Thus, 1C is the charge that gives F~9x10^{9}N of force when placed 1m apart from each other.



Electric Force and Gravitational Force

$$F = k\frac{Q_1 Q_2}{r^2} \Leftrightarrow F = G\frac{M_1 M_2}{r^2}$$

Extremely Similar

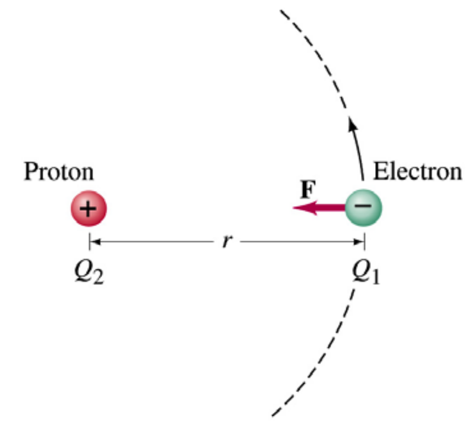
- Does the electric force look similar to another force? What is it?
  - Gravitational Force
- What are the sources of the forces?
  - Electric Force: Charges, fundamental properties of matter
  - Gravitational Force: Masses, fundamental properties of matter
- What else is similar?
  - Inversely proportional to the square of the distance between the sources of the force ➔ What is this kind law called?
    - Inverse Square Law
- What is the difference?
  - Gravitational force is always attractive.
  - Electric force depends on the type of the two charges.

The Elementary Charge and Permittivity

- Elementary charge, the smallest charge, is that of an electron: $e = 1.602 \times 10^{-19} C$
  - Since electron is a negatively charged particle, its charge is $-e$.
- Object cannot gain or lose fraction of an electron.
  - Electric charge is quantized.
    - It changes always in integer multiples of e.
- The proportionality constant k is often written in terms of another constant, ε_0, the permittivity of free space. They are related $k = 1/4\pi\varepsilon_0$ and $\varepsilon_0 = 1/4\pi k = 8.85 \times 10^{-12} C^2/N \cdot m^2$.
- Thus the electric force can be written: $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$
- Note that this force is for “point” charges at rest.

Example 21 – 1

- **Electric force on electron by proton.** Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by the single proton (Q_2=+e) that is its nucleus. Assume the electron "orbits" the proton at its average distance of r=0.53x10^{-10}m.



Using Coulomb's law $$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2} = k\frac{Q_1Q_2}{r^2}$$

Each charge is $Q_1 = -e = -1.602\times10^{-19}C$ and $Q_2 = +e = 1.602\times10^{-19}C$

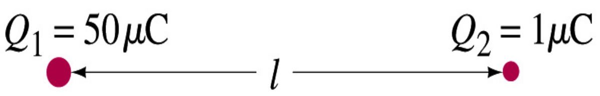
So the magnitude of the force is

$$F = \left|k\frac{Q_1Q_2}{r^2}\right| = 9.0\times10^9\ N\cdot m^2/C^2\ \frac{\left(1.6\times10^{-19}C\right)\left(1.6\times10^{-19}C\right)}{\left(0.53\times10^{-10}m\right)^2}$$
$$= 8.2\times10^{-8}N$$

Which direction? Toward each other…

Example 21 – 2

- **Which charge exerts greater force?** Two positive point charges, Q_1=50μC and Q_2=1μC, are separated by a distance L. Which is larger in magnitude, the force that Q_1 exerts on Q_2 or the force that Q_2 exerts on Q_1?



What is the force that Q_1 exerts on Q_2? $$F_{12} = k\frac{Q_1 Q_2}{L^2}$$

What is the force that Q_2 exerts on Q_1? $$F_{21} = k\frac{Q_2 Q_1}{L^2}$$

Therefore the magnitudes of the two forces are identical!!

Well then what is different? The direction.

Which direction? Opposite to each other!

What is this law? Newton's third law, the law of action and reaction!!