PHYS 1441 – Section 001
Lecture #2

Tuesday, June 9, 2020

Dr. Jaehoon Yu

- Brief history of physics
- Standards and units and other basics
- CH21
  - Static Electricity and Charge Conservation
  - Charges in Atom
  - Insulators and Conductors & Induced Charge
  - Coulomb's Law

Announcements

- 38/51 of you have registered in the homework system.
  - 22/38 submitted the homework!
  - Fantastic job!!
  - You need my enrollment approval… So move quickly…
  - Remember, the deadline for the first homework is 11pm, Thursday, June 11
  - You **MUST submit** the homework to obtain **100% credit**!
  - Also please be sure to make the payment in time otherwise your access as well as my access to the site for grading is cut.
- Reading assignments: CH21 – 7
- Quiz at the beginning of the class tomorrow, Wed. June 10
  - Appendix A1 – A7 and what we've learned today (CH21 – 5 or 6?)!
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of handwritten formulae and values of constants for the exam
  - No derivations, word definitions or setups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
  - Must send me the photos of front and back of the formula sheet, including the blank!

Extra Credit Special Project #1

- Compare the Coulomb force to the Gravitational force in the following cases by expressing Coulomb force (F_C) in terms of the gravitational force (F_G)
  - Between the two protons separated by 1m
  - Between the two protons separated by an arbitrary distance R
  - Between the two electrons separated by 1m
  - Between the two electrons separated by an arbitrary distance R
- Five points each, totaling 20 points
- BE SURE to show all the details of your own work, including all formulae, proper references to them and explanations
- Must be handwritten and submit all pages in a single PDF file
  - File name must be: SP1-First-Last-summer20.pdf
- Due at the beginning of the class Monday, June 15

Why do Physics?

Exp. {
- To understand nature through experimental observations and measurements (**Research**)

Theory {
- Establish limited number of fundamental laws, usually with mathematical expressions
- Predict the nature's course

⇒Theory and Experiment work hand-in-hand

⇒Discrepancies between experimental measurements and theory are good for improvements

⇒The general principles formulated through theory is used to improve our everyday lives, even though some laws can take a while till we see them amongst us

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 does matter get mass?
  - How and why do matters interact with each other?
  - How is the universe created?

Terminology: Models, Theories and Laws

- Models: An analogy or a mental image of a phenomena in terms of something we are familiar with
  - Thinking light as waves that behave just like water waves
  - Often provide insights for new experiments and ideas
- Theories: More systematically improved version of models
  - Can provide quantitative predictions that are testable and more precise
- Laws: Certain concise but general statements about how nature behaves
  - Energy & momentum conservations, charge conservation, etc
  - The statement must be found experimentally valid to become a law
- Principles: Less general statements of how nature behaves
  - Has some level of arbitrariness

Uncertainties

- Physical measurements have limited precision, however good they are, due to:
  - Stat.{ – Number of measurements (Normally scales by $1/\sqrt{N}$)
  - Syst.{ – Quality of the instruments (meter stick vs micro-meter)
  - – Experience of the person doing measurements
  - – Etc
- In many cases, uncertainties are more important and difficult to estimate than the central (or mean) values

Significant Figures

- Denote the precision of the measured values
  - The number 80 implies precision of +/- 1, between 79 and 81
    - If you are sure to +/-0.1, the number should be written 80.0
  - Significant figures: non-zero numbers or zeros that are not place-holders
    - 34, 34.2, 0.001, 34.100
      - 34 has two significant digits
      - 34.2 has 3
      - 0.001 has one because the 0's before 1 are place holders to position "."
      - 34.100 has 5, because the 0's after 1 indicate that the numbers in these digits are indeed 0's.
    - When there are many 0's, use scientific notation for simplicity:
      - $31400000=3.14\times10^{7}$ (on Quest 3.14E7 format is used)
      - $0.00012=1.2\times10^{-4}$

Significant Figures

- Operational rules:
  - Addition or subtraction: Keep the **smallest number of decimal place** in the result, independent of the number of significant digits: 12.001+ 3333.1= 3345.1
  - Multiplication or Division: Keep the **smallest number of significant digits** in the result: 12.001 x 3.1 = 37, because the smallest significant figures is ?.

What does this mean? **The worst precision ditermines the precision the overall operation!!**

In English? **Can't get any better than the worst of the measurements!**

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

Larger

- 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}
- zetta (Z): 10^{21}
- yotta (Y): 10^{24}

Smaller

- 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}
- zepto (z): 10^{-21}
- yocto (y): 10^{-24}

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	$2.54x10^{-5}$	km
1 ft	30.3	cm
1 ft	0.303	m
1 ft	$3.03x10^{-4}$	km
1 hr	60	minutes
1 hr	3600	seconds
And many	More	Here….

What does the Electric Force do?

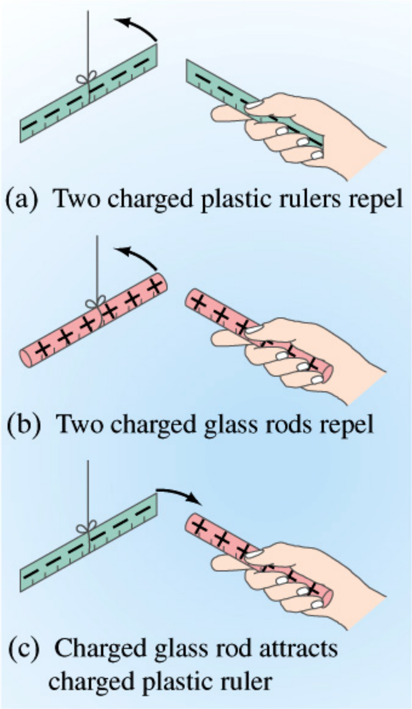
- Electric force is the bases of modern technology
  - Virtually everything we use every day uses the electric force
    - Can you give a few examples?

- But this force also affects many others
  - Making up materials with atoms and molecules
  - Biological metabolic processes
    - Nerve signals, heart pumping, etc
- Virtually all the forces we have learned in Physics I:
  - Friction, normal force, elastic force and other contact forces are the results of electric forces acting at the atomic level

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, positive/negative
  - 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.



Static Electricity; Electric Charge and Its Conservation

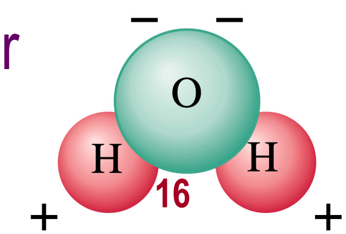
- Franklin argued that when a certain amount of charge is produced on one body in a process, an equal amount of opposite type of charge is produced on another body.
  - The positive and negative are treated algebraically so that during any process the net change in the amount of produced charge is 0.
    - When you comb your hair with a plastic comb, it acquires the 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 an 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 an Atom

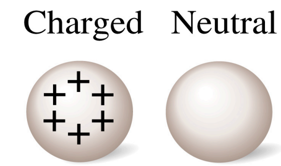
- It has been understood through the past century that an atom consists of
  - A positively charged heavy core ← What is the name?
    - This core is called the nucleus and consists of neutrons and protons.
  - Many negatively charged particles with small mass surround the core ← What is the name of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

As many as the number of protons in the nucleus!!

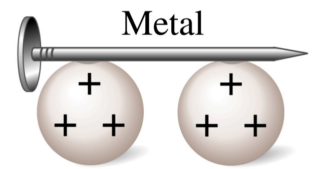
- So what is the net electrical charge of an atom?
  - Zero!!! Electrically neutral!!!
- Can you explain what happens when a comb is rubbed on a towel?
  - The electrons from the towel get transferred to the comb, making the comb negatively charged while leaving positive ions on the towel.
  - These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



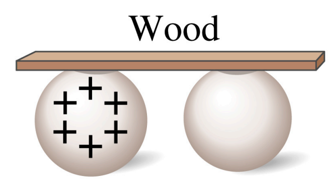
Insulators and Conductors



- 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 through this object.
    - These objects are called the **conductors of electricity**.
  - An wooden object?
    - No charge is transferred
    - These objects are called the **nonconductors or insulators**.



(b) Conductor

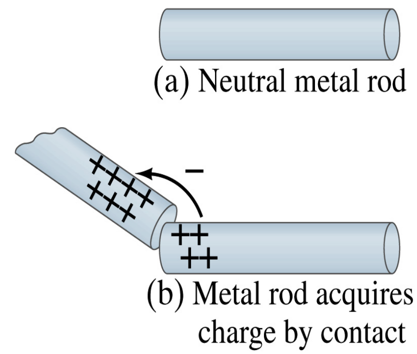


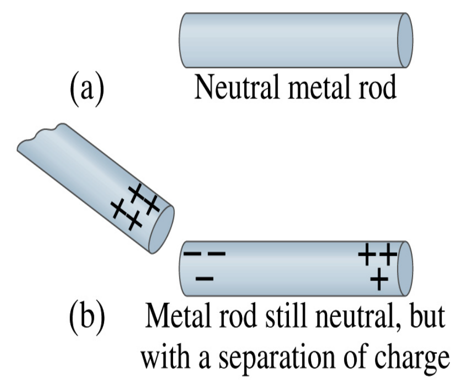
(c) Insulator

- Metals are generally a good conductor 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

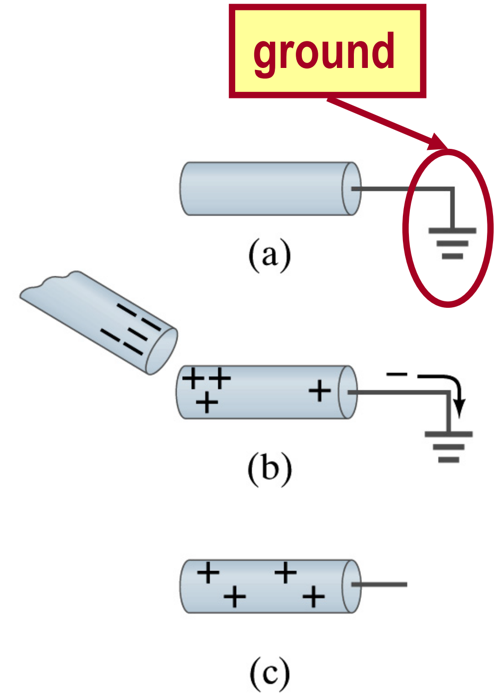
- When a positively charged metallic object is brought close to an uncharged metal object
  - If two objects touch each other, the free electrons in the neutral one are attracted to the positively charged object and some will pass over to it, leaving the neutral object positively charged ➔ Charging by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

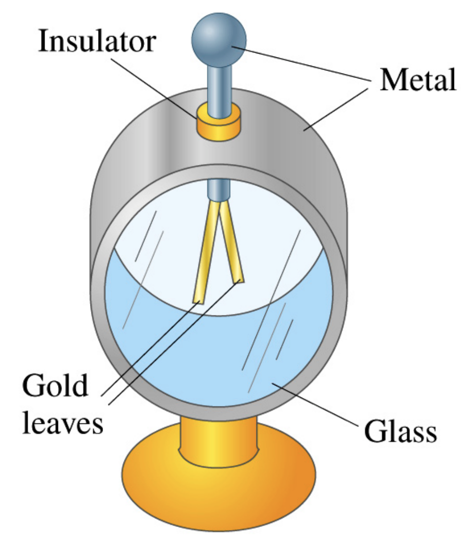




Induced Charge

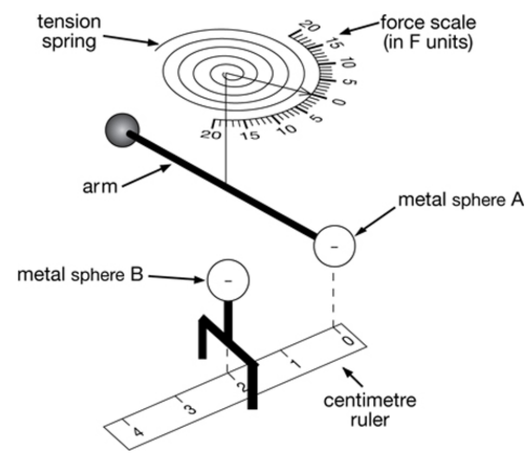
- We can induce a net charge on a metal object by connecting a wire to the ground.
  - The object is "grounded" or "earthed".
- Since the Earth is so large and conducts, it can give or accept charge.
  - The Earth acts as a reservoir of electric charge.
- If negative charge is brought close to a neutral metal
  - Positive charge 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 through an experiment using a torsion balance



- Coulomb found that the electric 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 the 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. The unit is Newtons (N)!
- The direction of electric (Coulomb) force is always along the straight line joining the two objects.
  - If the two charges are the same: forces are directed away from each other.
  - If the two charges are the 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 $k = 8.988 \times 10^9 \ \mathrm{N} \cdot \mathrm{m}^2 / C^2$
- Thus, 1C is the charge that gives **$F \sim 9 \times 10^9 N$** of force when placed 1m apart from each other.

Electric Force and Gravitational Force

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

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: Electric 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. (must pay good attention to the signs due to the sign of the charge and the vector force directions!!)

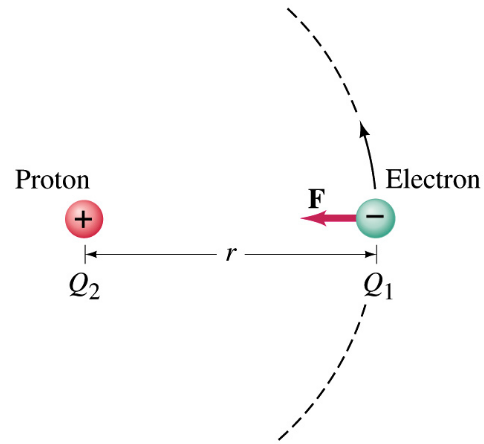
The Elementary Charge and Permittivity

- The elementary charge, the smallest unit 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.
    - Charge of an object changes always in an integer multiples of e.
    - What kind of quantity is the electric charge? **Scalar!!**
- 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 also be written as: $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$
- Note that this force is for "point" charges at rest.

***Mirriam-Webster, Permittivity: The ability of a material to store electric potential energy under the influence of an electric field**

Example on the Coulomb Force

- **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. What is the orbital speed of the electron (m_e=9.12x10^{-31}kg)?



Using Coulomb's law $$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2} = k\frac{Q_1 Q_2}{r^2}$$

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

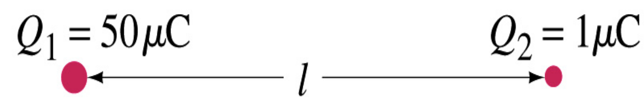
So the magnitude of the force is

$$F = \left|k\frac{Q_1 Q_2}{r^2}\right| = 9.0\times10^{9}\ N\cdot m^2/C^2\,\frac{\left(1.6\times10^{-19}C\right)\left(1.6\times10^{-19}C\right)}{\left(0.53\times10^{-10}m\right)^2}$$
$$= 8.2\times10^{-8}N$$

Which direction? Toward each other… Orbital speed of the election?

Example 21 – 1

- **Which charge exerts a 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!!