P132 Introduction

I) Review assignment sheet
   Office hours M,W 2-3 in Smith 4192
   Email kass.1@osu.edu
   Website: www.physics.ohio-state.edu/~kass/P132
   Need help: Tutor room Smith 1101 A

II) What will we study this quarter?
   Electricity and Magnetism
   forces between electric charges
   electric field from static electric charges
   magnetic field due to electric current
   basic electric circuits (capacitors, resistors, inductors)
   induction (time varying magnetic fields)

   Unification of E&M was one of the greatest scientific feats!
   (first unification: celestial and terrestrial gravity)
   Leads to special relativity (A. Einstein)
   Quantum Mechanics applied to E&M
      is our most successful theory!

III) Key (s) to success in this class
   Read material before coming to class!
   Do the homework (all of it).
   ASK questions if/when you do not understand material

IV) What do YOU need to know for this class….
   Physics: some of P131 (force, energy, work, torque…)
   Math: algebra, trig, vectors, and some calculus
      => vector calculus
   Everything is in appendix E of your textbook!
      Multiplying vectors (dot and cross products)
      Trig functions (CSC? =1/sin)
      Derivatives: anyone know how d/dx CSC(x)?
      Integrals: integral (x)…what about x^2e^{-ax}?
      Look them up in appendix E!!

Remember:
Physics is an experimental science!
Math is its language.
Electric Charge Basics

From EXPERIMENTS we have learned that:

1) there are two kinds of electric charges in nature: “positive” and “negative”
   note: For gravity there is only one type of “charge” (mass).
   For magnetism there are no magnetic charges (magnetic monopoles)
2) Like charges repel each other and unlike charges attract each other.
   “opposites attract”
   note: For gravity the charges always attract each other.

3) Electric charge is quantized!
   smallest unit of charge = charge on electron or proton
   \(|e|=1.6\times10^{-19} \text{ Coulombs}\)
4) Electric charge is conserved.
   decay of neutron: \(n\rightarrow\text{proton} + \text{electron} + \text{anti-neutrino} [0\rightarrow(+)(-)(0)]\)
Types of Materials

Classify materials based on their ability to conduct electrical charge.

**Conductors**
- These are materials in which electric charge (electrons) move freely.
- Metals are good conductors: copper, gold, aluminum
- Charge on a conductor distributes itself over entire surface.
  (more on this later)

**Insulators**
- These are materials in which electric charge *cannot* move freely.
- Examples: rubber, glass, wood
- The excess charge on an insulator stays fixed in place.

**Semiconductors**
- Electrical properties modified by adding other material + electric field
- Examples: silicon, germanium, diamond
- Transistors!

**Superconductors**
- Materials where there is no resistance to the flow of current
Charging a Material

We can transfer electric charge by rubbing together certain types of material..Materials are typically electrically neutral:

atoms have same number of + and – charges.

By rubbing certain materials we can transfer a small amount of electric charge:

Take electrons away from material: becomes positively charged
Add electrons to material: becomes negatively charged

It is easy to demonstrate this phenomena:
Rub a piece of plastic with fur.

Electrons are removed from fur and added to plastic
→ plastic is now negatively charged
→ fur is now positively charged

Can demonstrate that plastic is electrically charged by bringing a metal rod next to it.
metal rod will be attracted to the plastic!
the plastic will induce a charge on the conductor.
free charges in conductor will re-arrange themselves

move conductor close to charged insulator and the free charges in conductor re-arrange themselves.
Electric Forces on a Charge

Through a series of experiment Charles August de Coulomb discovers that the force between two objects with electric charge has the following properties:

a) the force is proportional to the charge on each object
b) the force varies as the inverse of the square of the distance between the charges
c) force is attractive for opposite charges (+,-), repulsive for same charges (++,--) 

The magnitude of the force (in Newtons, N) between two point charges is given by:

\[ F = k \frac{q_1 q_2}{r^2} \]

\( q_i \) is the electric charge on particle i (i=1 or 2). The unit of charge is the Coulomb (!). By definition a Coulomb is the amount of charge that pass through a cross section of a wire in 1 second when there is 1 ampere (Ampere was another famous physicist) of current.

the charge on an electron (or proton) is: \( q=1.6 \times 10^{-19} \) C

1 Coulomb = 6.25x10^{18} electrons (or protons)

\( k \) is a fundamental constant of nature.

\[ k = \frac{1}{4\pi \varepsilon_0} = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2 \]

\( \varepsilon_0 \) is the permittivity constant

\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{m}^{-2} \]

\( r \) is the distance in meters (m) between the charges.
The Vector Nature of the Electric Force

Force is a vector, so to completely describe a force we need to specify its magnitude and direction.

EXAMPLE: Two point charges $q_1$ and $q_2$ are separated by a distance $r$.

The magnitude of the force on charge $1$ exerted by charge $2$ is:

$$F_{12} = k\frac{q_1 q_2}{r^2}$$

The magnitude of the force on charge $2$ exerted by charge $1$ is:

$$F_{21} = k\frac{q_2 q_1}{r^2}$$

The directions of the force (given by the arrow) depend on the sign of the charges:

The magnitudes of these forces are equal! $F_{21} = F_{12}$

Newton's 3rd Law applies here.

The forces are directed towards or away from the point particles.

Like charges repel

Opposite charges attract
Coulomb’s Laws Vs Newton’s Law of Gravity

Both laws have the same form:

\[ F_{electric} = k \frac{q_1 q_2}{r^2} \quad F_{gravity} = G \frac{m_1 m_2}{r^2} \]

Both laws are strictly true for point-like objects.

Just like for gravity the following shell theorems are true:

1) A shell of uniform charge acts as a point charge at points outside of the shell.

![Shell Diagram](shell-diagram.png)

shell with charge \( q \) uniformly distributed over it

2) The force on a charge inside a uniformly charged spherical shell due to the shell charge is zero.

![Shell Diagram](shell-diagram.png)

There is no force on \( Q \)!

To get the force on a charge due to multiple other charges we use the superposition principle.

\[ \overrightarrow{F}_1 = \overrightarrow{F}_{12} + \overrightarrow{F}_{13} + + + \overrightarrow{F}_{1n} \]
Electrostatic Force Vs Gravitational Force

Consider two protons inside the nucleus of an atom. The gravitational force is attractive while the electrostatic force is repulsive. Which of these forces is greater??

\[ F_{\text{electric}} = k \frac{q_1 q_2}{r^2} \quad F_{\text{gravity}} = G \frac{m_1 m_2}{r^2} \]

\[ \frac{F_{\text{electric}}}{F_{\text{gravity}}} = \frac{k \frac{q_p^2}{r^2}}{G \frac{m_p^2}{r^2}} = \frac{k q_p^2}{G m_p^2} = \frac{(8.99 \times 10^9 \text{Nm}^2 / \text{C}^2)(1.6 \times 10^{-19} \text{C}^2)^2}{(6.67 \times 10^{-11} \text{Nm}^2 / \text{kg}^2)(1.67 \times 10^{-27} \text{kg}^2)^2} = 1.3 \times 10^{36} \]

The electric force is 36 orders of magnitude larger than gravity!!
So, what holds the nucleus together?? Why doesn’t it blow apart?
answer: The \textit{strong force} (\textit{nuclear force}) holds the nucleus together.
Example

Three identical conducting spheres have the (excess) charges shown:

A, -2Q

B, -4Q

C, 8Q

What happens if:

a) A and B are connected by a thin wire for a short time?
   The total charge of -2Q + (-4Q) will be distributed equally between the two spheres (since they are identical). After the wire is disconnected they will both have: -3Q

b) A wire is now attached to B and ground (the earth)?
   The excess charge on B will drain off and go to the ground. As a result B will now have 0 charge.

c) B and C are connected by a wire for a short time.
   The charge on C will be equally shared by B and C. As a result both B and C will now have 4Q of excess charge.

In the above diagram what is the electrostatic force on A?

We need to use the principle of superposition to solve this problem!

\[
\begin{align*}
F_A &= F_{AB} + F_{AC} \\
F_{Ax} &= F_{ABx} + F_{ACx} = |F_{AB}| \cos 60^\circ + |F_{AC}| \cos 300^\circ \\
F_{Ay} &= F_{ABy} + F_{ACy} = |F_{AB}| \sin 60^\circ + |F_{AC}| \sin 300^\circ
\end{align*}
\]

\[
|F_A| = \sqrt{F_{Ax}^2 + F_{Ay}^2}
\]

\[
\theta = \tan^{-1}\left(\frac{F_{Ay}}{F_{Ax}}\right)
\]
A few words about charge sharing and *grounding*

An interesting property of conductors is that any excess charge will reside on its outer surface. Consider two identically sized spherical conductors.

One of the conductors has an excess of charge \( Q \), the other is uncharged.

If we connect the spheres together and then move them apart the charge will be equally shared and now each will have excess charge \( Q/2 \). (ok, we already knew this.)

Consider two conducting spheres that are not identical in size. One has radius \( r_1 \), the other \( r_2 \).

The conductor with \( r_1 \) has excess charge \( = Q \), the conductor with \( r_2 \) is initially uncharged.

If we now connect the spheres the charge will divide according their radius.

\[
Q_1 = Q \frac{r_1}{r_1 + r_2} \quad \text{and} \quad Q_2 = Q \frac{r_2}{r_1 + r_2}
\]

In order to derive these equations we need material in Ch25. In this chapter we learn that conductors are always equipotentials.

Now, let’s assume \( r_1 = 1 \text{ m} \) and \( r_2 \) is a sphere the size of the earth \( (r_2 = 6 \times 10^6 \text{ m}) \).

How much charge will be left on sphere 1 if it contacts sphere 2 and then move it far away from sphere 2?

\[
Q_1 = Q \frac{r_1}{r_1 + r_2} = Q \frac{1 \text{ m}}{(1 \text{ m}) + (6 \times 10^6 \text{ m})} \approx 1.6 \times 10^{-7} Q
\]

Therefore, to a very good approximation all of the excess charge will go to sphere 2 (the “earth”). Since for all practical purposes, the earth is by far the largest conducting sphere possible this explains why when we *ground* something by connecting to the earth all excess charge gets absorbed by the earth.