Electrostatics
Useful Information

- [http://lonc apa. msu. edu/](http://lonc apa. msu. edu/)
  - From this link you can enter LON-CAPA

- All information about this course is online

- 6 in-class exams (usual lecture time and room):
  - Every other Tuesday (see syllabus for detailed dates)
  - Each exam has a correction set,
    earn back 30% of points you missed
  - Cheat sheet: one 5” by 8” index card

- Homework due every Monday at 10:00 p.m.
Clickers

- We will give in-class quizzes using the iClicker system
- You need to purchase a clicker from the Book Store
- We will have our first clicker quiz next Monday
- The quizzes will count 5% grade (3 points for the correct answer, 1 point for an incorrect answer)
- It is up to you to have your clicker and to make sure that it is working
- We will take a dim view of anyone in class using more than one clicker
- 90% of clicker score will give you the full 5% extra credit
  - No makeup for clicker quizzes
- Clickers only work in the section for which you registered
Clickers

- Register your clicker on lon-capa
- If I don’t have your clicker number, you cannot get clicker credit
Homework

- Homework set 0 is open
  - Due Monday evening, 1/13
  - A few basic questions to get you prepared for this class
  - Mostly math and calculator gymnastics

- Homework set 1 is open
  - First actual physics homework set
  - Due next Monday evening 1/20

- First exam is Tuesday, 1/28
  - Covers the first three weeks, HW sets 1 and 2, chapters 21 and 22
Problem solving strategy

- Use this approach to solve problems, in particular if at first you have no clue.

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**Step 1**

**Think**

**Recognize the problem**

What’s going on?

Think

**Describe the problem in terms of the field**

What does this have to do with…?

Sketch

**Plan a solution**

How do I get out of this?

Research

**Execute the plan**

Let’s get an answer!

Simplify, Calculate, Round

**Evaluate the solution**

Can this be true?

Double-check

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**Step 2**

**Sketch**

- Draw a picture
- Phrase the question in your own words
- Relate the question to something you just learned
- Identify physics quantities, forces, fields, potentials,…

**Step 3**

**Research**

- Find a physics principle (symmetry, conservation, …)
- Write down the equations
- Solve equations, starting with intermediate steps
- Check units, order-of-magnitude, insert into original question, …

**Step 4**

**Execute**

- Let’s get an answer!

**Step 5**

**Double-check**
Electricity and Magnetism

- Electricity and magnetism: known for thousands of years
  - The ancient Greeks knew that a piece of amber rubbed with fur would attract small, light objects
    - The word for electron and electricity derived from the Greek word for amber, ἥλεκτρον
  - Naturally occurring magnetic materials called lodestones were used as early as 300 BC to construct compasses

- The relationship between electricity and magnetism was not known until the middle of the 19th century
The Fundamental Forces

Range:

**Gravity**

Range: $\infty$

**Electromagnetic**

Range: $\infty$

**Weak**

Range: $10^{-18} \text{ m}$
0.1% of the diameter of a proton

**Strong**

Range: $10^{-15} \text{ m}$
diameter of medium-sized nucleus
Fundamental Forces of Nature

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Forces of Nature

- Electricity
- Magnetism
- Electromagnetic force
- Weak force
- Strong force
- Electroweak force

~1850
~1970
present?

January 9, 2014
Chapter 21
Gravitational and Electric Forces

- For gravity we defined a gravitational force

\[ F(r) = G \frac{m_1 m_2}{r^2} \]

- and a gravitational potential

\[ U(r) = -G \frac{m_1 m_2}{r} \]

- We will do the same for the electric force and the electric potential
- We will introduce the concept of an electric field to help us understand the electromagnetic force
Electric Charge

- Everyday example: When walking on a carpet on a dry winter’s day and then touching a door knob, one often experiences a spark
  - This process is called **charging**
    - Charging: negatively charged electrons move from the atoms and molecules of the carpet to the soles of our shoes, to the body
  - A spark occurs when the built-up charge discharges through the metal of the door knob.

- Similar phenomenon involving wind, rain and ice produces lightning
**Electric Charge**

- Normally objects around us do not seem to carry a net charge
- They have equal amounts of positive and negative charge and thus are **electrically neutral**
  - Negative charge means an excess of electrons
  - Positive charge means a deficit of electrons

- **Demo:**
  - If we rub a plastic rod with fur, the rod will become charged
    - If we bring two charged plastic rods together, they will repel each other
  - If we rub a glass rod with silk, the rod will become charged
    - If we bring together a charged plastic rod and a charged glass rod, they will attract each other
Law of Charges

- This result leads to the Law of Charges
  - Like charges repel and opposite charges attract

- Note that this behavior is different than gravitation in which the force is always attractive
Law of Electric Charges

- This result leads to the Law of Electric Charges
  Like charges repel and opposite charges attract.

- The unit of charge is the Coulomb, abbreviated C
  • named after Charles-Augustin de Coulomb (1736 – 1806)

- The Coulomb is defined in terms of the SI unit for electric current, the ampere, abbreviated A
  • named after Andre-Marie Ampere (1775 – 1836)

- The ampere is a basic SI unit like the meter, the second, and the kilogram.

- The unit of charge is defined as

  \[ 1 \text{ C} = 1 \text{ A s} \]
Charge of an Electron

- We can define the unit of charge in terms of the charge of one electron
- An electron is an elementary particle with charge $q = -e$
  
  - $e = 1.602 \times 10^{-19}$ C
  - A proton is a particle with $q = +e$
- A Coulomb is a large amount of charge
- Typically we deal with smaller amounts of charge
  
  - 1 microCoulomb = 1 $\mu$C = $1.0 \times 10^{-6}$ C
  - 1 nanoCoulomb = 1 nC = $1.0 \times 10^{-9}$ C
  - 1 picoCoulomb = 1 pC = $1.0 \times 10^{-12}$ C
- The number of electrons required to make a Coulomb is
  
  - $N_e = 1$ C per electron/$1.602 \times 10^{-19}$ C = $6.242 \times 10^{18}$ electrons
Charge Conservation

- Benjamin Franklin (1706 - 1790) is credited with establishing the convention of which electric charge is positive and which is negative
- Franklin also proposed that electric charge is conserved
- For example, when a plastic rod is charged by rubbing it with a fur, *charge is neither created nor destroyed*, but instead electrons are transferred to the rod leaving a net positive charge on the fur

**Law of charge conservation**

- The total charge of an isolated system is strictly conserved
- This law adds to our list of conservation laws: conservation of energy, conservation of momentum, and conservation of angular momentum
Elementary Charge Quantum

- Electric charge is quantized
- The smallest charge observable is the charge of an electron
- Established by Robert Millikan (1868 – 1953)

possible charges: 1e, 2e, 3e …
3.67e or 0.5e is not possible
Structure of Atoms

- Atoms are electrically neutral.
- Atoms are composed of a positively charged atomic nucleus surrounded by negative electrons.
- The atomic nucleus is composed of positively charged protons and electrically neutral neutrons.
- The number of protons is the same as the number of electrons.
Description of Atoms

Atomic number = \( Z \)
Mass number = \( A \)
\# electrons = \( Z \) (charge = \(-Ze\))
\# protons = \( Z \) (charge = \(+Ze\))
\# neutrons = \( N = A - Z \)
For example, \(^{12}\text{C}\) has
- 6 protons
- 6 neutrons
- 6 electrons

Atomic mass = \( ZM_p + NM_n \)
\( ZM_e \) – binding energy/\( c^2 \)
Atomic mass \( \approx AM_p \)
Insulators and Conductors

- The electronic structure of materials determines their ability to conduct electricity
  - “Conducting electricity” means the transport of electrons
- Materials that conduct electricity well are called conductors
  - Electrons can move freely (some of the electrons)
    - Metals
    - Water with dissolved materials
- Materials that conduct electricity poorly are called insulators
  - Electrons cannot move freely
    - Glass
    - Plastic
    - Cloth
    - Pure water
Semiconductors and Superconductors

- **Superconductor:**
  - Some materials conduct electricity with no resistance
  - Mainly metals at very low temperatures (liquid helium)
  - Persistent currents

- **Semiconductor**
  - Semiconductors are materials that can be switched between being an insulator and being a conductor.
  - Backbone of modern electronics and computers.

Replica of first transistor in 1947
Electrostatic Charging

- Giving a static charge to an object is called electrostatic charging
- We will approach our study of electrostatic charging through a series of simple experiments
- A power supply or a battery can provide positive and negative charge
- Insulating paddles can be positively or negatively charged
- We will make a conducting connection to the Earth
  - We call this connection grounding
  - The Earth is a nearly infinite reservoir of charge and neutralizes electrically charged objects connected to it
Electroscope

- An electroscope gives an observable response when it is charged.
- This electroscope has two conductors that are initially vertical and touching when the electroscope is uncharged.
- When the electroscope is charged, the hinged conductor will move away from the fixed conductor.
- Note that we cannot tell the sign of the charge.
Charging by Contact

- If the negatively charged paddle touches the electroscope, electrons will flow from the paddle to the conductors, producing a net negative charge
Inducing a Negative Charge

- If we bring a negatively charged paddle near an electroscope, the electrons are repelled from the ball, inducing a negative charge on the conductors.
Positive Charging by Induction

- We can create a positive charge
  - Starting with an uncharged electroscope
  - Bringing a negatively charged paddle close to the electroscope
  - Connecting a ground to the electroscope
  - Removing the ground
  - Taking the paddle away
Electrostatic Force – Coulomb’s Law

- The law of electric charges is evidence of a force between any two charges at rest.

- Experiments show that for the electrostatic force exerted by charge 2 \((q_2)\) on charge 1 \((q_1)\), the force on \(q_1\) points toward \(q_2\) if the charges have opposite signs and away from \(q_2\) if the charges have like signs.

\[
\begin{align*}
\text{Same sign} \\
\begin{array}{c}
\bullet q_2 \\
\rightarrow F_{2\rightarrow 1} \\
\bullet q_1
\end{array}
\end{align*}
\]

\[
\begin{align*}
\text{Opposite sign} \\
\begin{array}{c}
\bullet q_2 \\
\leftarrow F_{2\rightarrow 1} \\
\bullet q_1
\end{array}
\end{align*}
\]