### Chapters 22-25: Electromagnetism!

**Electric Force vs. Gravitational Force**

- What properties does the gravitational force depend on?
- What properties does the electric force depend on?

\[ F_{\text{grav}} = \frac{Gm_1m_2}{d^2} \quad F_{\text{elec}} = \frac{kq_1q_2}{d^2} \]

### Some basic similarities:

- Both forces obey Newton’s Third Law (action-reaction pairs)
- Both forces are inverse-square laws
- Both forces depend on amount of charge/mass in both objects

### Some differences:

- Gravity is MUCH WEAKER!
  - \( G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2 \)
  - \( k = 9.0 \times 10^9 \text{ N m}^2/\text{C}^2 \)
- The electric force can be attractive or repulsive, but the gravitational force is always attractive
  - Like charges repel, opposite charges attract

### Charges

- Electric force depends on the amount of electric charge in the two objects
- Positive charge usually comes from having more protons than electrons, negative charge from having more electrons than protons
- The amount of charge is very nearly balanced in most everyday materials

### Electrons vs. Protons

- Charge is measured in units of coulombs (C), and can be positive or negative
- Charge of one electron (-e): \(-1.6 \times 10^{-9} \text{ C}\)
- Charge of one proton (+e): \(+1.6 \times 10^{-9} \text{ C}\)
- Most atoms have equal numbers of protons and electrons
Conservation of Charge
• When we charge an object, we're not creating or destroying electrons: we're just moving them from somewhere else
• This is the case EVERY TIME: scientists have NEVER seen an event that created or destroyed any charge!

Conductors and Insulators
• Similar to conductors/insulators of heat
• The motion of charges (current) is related to how loosely or tightly connected electrons are to atoms
• Good Conductors (poor insulators): electrons can exchange energy more easily
• Good Insulators (poor conductors): electrons are more tightly bound

So how do you move charges?
• Charging by friction/contact: ever brushed/combed your hair on a very dry day?
• Charging by induction: you can get charges to move within an object because they're reacting to NEARBY charges!

Demo time!

Conceptual Check: Which pair feels an attractive force?

Conceptual Check: Which pair feels a repulsive force?
Conceptual Check: Which pair feels the weakest force?

Conceptual Check: Which pair feels the strongest force?

Conceptual Check: Consider just situation B. Which feels a stronger force: the charge on the right or the charge on the left?

Summary so far:

- Charge: carried by protons and electrons, is conserved, is measured in coulombs (C), source of electric forces
- Coulomb’s Law: describes electric forces due to charges
- Charging: the act of moving some charges to another object, can be done by contact/friction or by induction (induction produces electrically polarized substances)

More Charging by Induction

- Charging by induction can occur in good conductors or in poor conductors
- Even if electrons are not free to move to the edges of the object, the atoms they are bound to can realign themselves
- When this happens, the atom is “electrically polarized”

Electric Fields

- Fields are a physicist’s way of explaining “action at a distance”
- The gravitational field of Earth interacts with a dropped rock, causing it to fall
- The electric field of a charged piece of metal interacts with an electron, causing them to be pulled towards one another
Electric Field

• $E = \frac{F}{q}$
• The electric field at any given location points in the same direction as the electric force at that location (on a small positive “test charge”)

Drawing Electric Field Lines

• Electric Field lines always point away from positive charges and towards negative charges
• Represent the direction in which a small positive “test charge” would feel pushed due to Coulomb’s Law

Electric Shielding

• Imagine you have a conducting sphere, and you put some extra electrons on it: new electric field strength!
• The electrons will then move in response to this E-field, until there is no more E-field.

⇒ The electric field inside a conductor is zero

More Shielding

• If the object isn’t a sphere, the charges won’t be evenly spread out, but they’ll still arrange themselves in such a way that $E=0$ inside
• The “pointier” the conducting object, the more concentrated the charge will be at the points:

Energy Fields

• We often think of the gravitational field and electric field as “force fields”, but a better description would be “energy fields”!
• Electric potential refers to the stored energy in the E-field

Conceptual Check: If you want to move an electron closer to a proton, what would you have to do?

A. Push on the electron harder than the repulsion due to the electric force
B. Nothing: The attraction due to the electric force will pull the electron and proton closer together automatically.
Conceptual Check: If you want to move an electron closer to another electron, what would you have to do?

A. Push on the electron harder than the repulsion due to the electric force
B. Nothing: The attraction due to the electric force will pull the electrons closer together automatically.

Electric Potential

- Electric potential is the potential energy per unit charge (which is usually more convenient to work with than straight electric potential energy)
- \[ V = \frac{PE}{q} \]
- Electric potential is also called voltage, and measured in units of Volts (V)
- 1 Volt = 1 Joule / 1 Coulomb

Example:

- A charge of 20 microcoulombs is placed in a location where the electric potential is 200 V. What is the potential energy of this charge?
- What if, instead, we had a charge of 20 C?
- Should she be worried about the voltage of a charged balloon?

Capacitors

- Capacitors are devices used to store electric energy
- Usually made of two plates separated from each other, not touching
- A battery pulls electrons from one plate to another, so that the two plates have equal positive and negative charges.

Main Points from Ch 22:

- Charges
- Conductors and Insulators
- Electric Force (Coulomb’s Law)
- Electric Field
- Electric Potential Energy and Electric Potential
- Capacitors

Chapter 23: Electric Current
Moving Charges

- We can think of the flow of charges along a conducting wire as similar to the flow of water through a pipe.
- How many charges? How fast? → Current

- Charge flows (and we have some electric current) whenever there is a difference in electric potential, or voltage.

Current

- Measured in units of amperes, or “amps”
- 1 A = 1 C/sec
- Remember: current is the flow of charge, so we’re measuring how many coulombs of charge move per second.
- In water analogy, electric current is like water current, the rate of flow.

Voltage

- Measured in volts (V)
- Voltage is what “drives” or “pushes” the current
- Due to electric potential!

- In water analogy, voltage or potential difference is similar to a pump moving water through a pipe.

Resistance

- Measured in ohms, (Ω)
- In the water flow analogy: resistance would be like the size or length of the pipe.

- Typical resistances:
  - 0.03 Ω (1 km of overhead power line)
  - 200 Ω (Light bulb)
  - 1000 Ω (Human body, wet)
  - 100,000 Ω (Human body, dry)

Ohm’s Law

- Current ~ voltage
- Current ~ 1/resistance

- Using the right units, we get Ohm’s Law: Current = voltage / resistance

- In equation form: I = V/R or V = IR

Example: Ohm’s Law

Imagine you plug a light bulb with a resistance of 144 Ω up to a 120-V potential (such as that coming from your wall power socket). How much current is there in the light bulb?