Chapter 20: Electric Fields and Forces

20.1: Charges and Forces

How Do We Know Charge Exists?

- You cannot observe the individual charges, but you can see their effects on each other
- Charges can be transferred from one object to another
- Charges come in two types: positive and negative

What effects can you see?

- Socks stick to sweatshirts in the dryer: static electricity
- You get a shock when you pet the cat (on a dry day)
- Your hair stands up when you comb it

Couldn't It Just Be Gravity?

- No
- You can observe attraction and repulsion; gravity does not repel!

Insulators and Conductors

- A material through which charge can move freely is a conductor
- Metals are typically very good conductors (not all equally good)
- In conducting fluids, ions can move freely

Charge Polarization: No Contact Required

- Like repels like: you can push electrons away without making contact
- You are not pulling protons out of the nucleus!
- You are not adding/subtracting, you are simply manipulating what is already there

20.2: Charges, Atoms, and Molecules

Charge Is a Particle? No Way!

- 1897: JJ Thomson discovers the electron
- Long story short: cathode rays turn out to be particles that are far smaller than anyone had imagined
- These particles (electrons) have both charge and mass that can be measured accurately (thanks, Millikan!)
- Another victory for the scientific method!

Charge is Quantized

- Every e^- has the same charge as every other e^-: $q = -1.6 \times 10^{-19}\text{C}$
- Every proton has the same charge as every other p^+: $q = -1.6 \times 10^{-19}\text{C}$
- Quantization: You cannot have half an electron! Can't have half a proton!

Charge Is Conserved

- Since charge is inherent to the particle (electron or proton), it is conserved
- You cannot create/destroy matter means you cannot create/destroy charge, either
- Conservation of mass is conservation of charge!

Ionization

- When we observe electrostatic charging, it's all about moving the e– around (not the protons!)
- A positive ion is missing one or more e–
- A negative ion possesses one or more extra e–

Electric Dipoles

- An atom can be electrically neutral and still be manipulated
- Charges 'off balance:' the arrangement of the (+) and (–) charges is not symmetric
- Positive at one end (pole), negative at the other end (pole) = two poles = dipole!

Hydrogen Bonding

- Ever wonder why water is such a good conductor? It's definitely not a metal!
- Molecular dipole: each hydrogen atom donates its electron to the oxygen
- This fills the oxygen's valence shell, and makes the oxygen side of the molecule (+)
- Leaves the hydrogen side of the molecule (–)

It's In Your DNA

- You probably know more about the biology than I do
- Hydrogen bonding is why C+G or A+T are allowed
- If you want to know how your DNA with all that H, C, N, O is related to stellar evolution, I can tell you that

20.3: Coulomb's Law

Coulomb Was A Clever Man

- It's the 1780s! The electron hasn't been discovered yet!
- Coulomb could not measure absolute charge, but he could measure relative charge!
- Relative is all you need to be able to make comparisons (the constant of proportionality will work itself out with the units)

Coulomb's Law

- $\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$
- Direct proportionality to charge
- Inverse square law with distance
- Likes repel, opposites attract
- This is a vector equation!

Compare Electrostatic to Gravitational Force

- It's not even a contest
- Same objects at same separation: Coulomb force is 10^{18} times larger
- Basically, gravity is completely ignorable; Coulomb wins every time

I Don't Want to Alarm You, But...

- Electrostatic repulsions are pretty much all around you, making your everyday life not just easier, but possible
- All those forces from CP I? Tension, friction, normal—those are all Coulomb repulsions

20.4: The Concept of the Electric Field

Action-At-A-Distance

- How can Object A affect Object B if they are not literally touching?
- Well, it's clearly possible: Both gravitational and and electrostatic forces are demonstrable
- Still leaves you with a giant shoulder-shrug over how it actually works

What Is A Field?

- Start with the concrete and work up to the abstraction
- Question: What happens to Object A because of Object B? (Could be A and B have mass, or maybe they have charge--either way)
- Answer: Object A gets pushed/pulled by the force exerted on it by Object B (duh, right?)
- You can describe the outcome qualitatively or quantitatively

Qualitatively, Then: What Is a Field?

- A description: It answers the question "What happens…"
- You do not need to test gravity with every tennis ball you see; you know that every tennis ball will behave the same way
- It doesn't even need to be a tennis ball, does it? It does not have to be a real thing at all, it can be the idea of a thing
- Gravity pulls your real tennis ball and your imaginary tennis ball exactly the same way: straight down to the ground

Quantitatively: What Is a Field?

- Draw the answer to the question "What happens…", and for gravity you've got a straight line pointing at the center of the Earth
- If you were standing on Mars, your tennis ball would behave precisely the same way: it would fall toward the center of Mars
- How do you distinguish between them? Mars' gravity is 3.7 m/s^2, and Earth's is 9.8 m/s^2
- So, you can say the shape of each field is the same, but the field strengths are different

Gravitational Field Due to a Single Object With Mass

- Let's get beyond the $g = 9.8\text{m/s}^2$ at or near the surface of the Earth
- Drop that tennis ball from higher and higher above the surface, and it still falls straight "down"
- But when you get far enough away, you can't use $F = mg$ anymore, you have to use $F = G\frac{mM}{r^2}$, and the acceleration is no longer 9.8m/s^2
- $F = m\left[G\frac{M}{r^2}\right]$, and now the acceleration is $\left[G\frac{M}{r^2}\right]$, which represents the effect on m due to M (call it the field strength!)

Electric Field Due to a Single Point Charge

- You are "dropping" charges instead of masses, but they are behaving exactly the same way
- Qualitatively: Electric field lines are radial, exactly like the gravitational field lines
- Fixed $+Q$: Field lines are radially directed outward ($+q$ pushed away from $+Q$)
- Fixed $-Q$: Field lines are radially directed inward ($+q$ pulled towards $-Q$)

Electric Field Due to a Point Charge: Quantitatively

- $F = q\left[k\frac{Q}{r^2}\right] = qE$ (This is a vector equation!)
- Q: Fixed charge that creates the field (may be + or -)
- q: Test charge used to "see" the field (default is always positive!)

20.5: The Electric Field of Multiple Charges

Superposition of Charges

- What if you have more than one fixed charge (a distribution of charges)?
- Add them up: $E = E_1 + E_2 + \ldots + E_n$
- This is vector addition!

Infinite Sheet of Charge = Uniform E Field

- Distribute total charge $+Q$ over some area A (not literally infinite)
- E is constant, perpendicular away form plane
- If you used charge $-Q$, direction would be toward plane
- A uniform field which is not distance-dependent is a useful thing to have in your back pocket

Electric Field Lines

- Field line = tangent to the field vector (and $\vec{E}$ is parallel to $\vec{F}$), directed from (+) to (–)
- Use superposition when there is more than a single charge
- Graphically indicate field strength with line density: More lines means a stronger field

20.6: Conductors and Electric Fields

E Field of a Thin Spherical Conducting Shell

- Apply excess (–) charge to a thin, hollow, metal sphere
- Like repels like: Charge will distribute evenly over the surface of the shell
- Outside the sphere: Effectively a point charge!
- Inside the sphere: $\vec{E} = \mathbf{0}$ ($E = \frac{F}{q}$: add up all those vector forces and $\sum F = \mathbf{0}$!)

Faraday Cage

- Take an uncharged, hollow, conducting container (any shape is good, as long as it's hollow)
- Put it in an external $\vec{E}$ field (you choose how to come up with this)
- Why aren't you getting electrocuted?!?!?!
- Surprise! Net $\vec{E}$ field inside the uncharged container (Faraday cage) is exactly zero

20.7: Forces and Torques in Electric Fields

The Force is Easy

- $\vec{F} = q\vec{E}$

The Dipole Moment

- Put a polar molecule in a uniform E field: what happens?
- One end is pushed, the other end is pulled: creates a torque
- Torque creates rotation, so molecule will rotate
- When does it stop? When the dipole moment aligned with the field