Review for first midterm

Some of these ideas are definitions or assumptions of the model – those are the basic ideas we use as starting points for reasoning. Other ideas are reasoned results – when it’s a reasoned result, you should be able to explain where it came from, how it arises from the definitions and assumptions of the model, and you should be able to respond to conflicting lines of reasoning. I’m not going to list all the results, just a few core examples. You should be familiar enough with the basic ideas to remember and understand them well – you should know them “by heart.” But you don’t have reasoned results.

Don’t study by memorizing! Study by re-explaining the ideas to yourself, in terms an eighth grader could understand. And don’t do lots and lots of problems! Do a small number of problems (maybe six?) lots of different ways. Practice seeing the connections between different ideas, especially from the basic ideas to reasoned results. And try to find and reconcile possible confusions! When you feel you understand a problem, ask yourself “What might confuse me about this, if I were looking at it again for the first time? What questions might I have later?” Test yourself by changing the problem a little bit and then solving it again. (That’s a lot of how I write exams – I look at problems we’ve done and I change them.)

Electric Charge

- **Basic idea**: There are two kinds of charge throughout matter, in huge numbers, that are never created or destroyed—positive (protons) and negative (electrons). They’re equal and opposite in charge, so matter is generally neutral, but when an object has an excess of one or the other measured in Coulombs.
- **Basic idea**: The force between two charges is given by Coulomb’s law \( F = k \frac{q_1 q_2}{r^2} \), where \( k = 9 \times 10^9 \text{N} \cdot \text{m}^2/\text{C}^2 \). That expresses not only that opposites attract and likes repel, but also how the force depends on distance and is proportional to each of \( q \) and \( q \). (As with gravity, this is “action at a distance” – an influence of one charge on another across a distance in space.)
- **Reasoned result**: This is a force like any other force! So if we want to know the force on any one charge, we add up the forces by any other charges around. And, like any forces, they add as vectors.

Different materials: flow of charge, acquisition of charge

- **Basic idea**: Some materials let charge flow within them easily; we call them conductors. Some materials don’t let charges flow easily within them; we call them insulators. In between these two extremes, many materials let charge flow, but not easily; we call them resistors (or resistive materials).
- **Any type of material can get an excess charge, since to be charged, some charge simply needs to go on or off the object. It needn’t flow, just go on or off!**
- **Basic idea**: You can separate charge by rubbing different materials together — one comes away with more negative charge and the other with more positive. Batteries put different materials into chemical contact with each other, and the difference in tendency to take on or give up electrons makes for the potential difference across the terminals.
Dipoles

- **Definition:** A dipole is opposite charges separated by a distance. Many materials are made up of dipoles, e.g., water (each molecule is a dipole).
- **Reasoned result:** You can make or induce a dipole in a conductor by putting it near a charge. Since charges are free to move in the conductor, the like charges can move away and the unlikes can attract.
- **Reasoned result:** A dipole, or a material made up of many dipoles, can feel and exert a force on a charge, because the dipoles rotate. That puts one side of the dipole a little closer to the charge than the other, and by Coulomb’s Law that means its interaction with the charge is a little stronger.

Potential, current, circuits

- **Definition:** Electric potential, or voltage, is the potential energy per unit charge, measured in Volts = Joules/Coulomb. This potential energy results from the electric repulsions and attractions between charges. Potential is analogous to pressure, and we often describe it that way, as electrical pressure; it’s also analogous to height. We’re almost always interested in the potential difference from one place to another.
- **Definition:** Current is the rate of flow of charge, that is the amount of charge per unit of time, measured in Amperes = Coulombs/second. In a circuit there’s the stuff (charge), the flow of stuff (current), and the pressure (the voltage). Also there are wires (things that allow current to flow easily), resistors (which restrict flow), and batteries (which try to maintain pressure differences.) Batteries maintain a potential difference between the two terminals – that’s a difference in electrical pressure, not current, not amount of charge! — unless the current is so high that the battery can’t separate charge fast enough.
- **Basic idea:** Ohm’s Law says that the current through a resistor is proportional to the potential difference across the resistor: \( \Delta V = IR \), where \( R \) is the resistance measured in Ohms (1 \( \Omega \) = 1 volt/ampere), \( \Delta V \) is the potential difference from one side of the resistor to the other, and I is the current through the resistor. Many materials have this property, of satisfying Ohm’s Law; materials that don’t we still speak of as having a resistance, but we say the resistance varies with the voltage.
- **Reasoned result:** Charge loses electrical potential energy as it passes through a resistance, an amount of energy equal to \( Q \Delta V \), where \( Q \) is the amount of charge and \( \Delta V \) is the voltage drop. A current through a resistance loses electric potential energy at a rate of \( I \Delta V \), because \( I \) is the amount of charge that drops \( \Delta V \) in potential per second.
- **Definition:** Power is energy per time, measured in Watts = Joules/second. Reasoned result: So \( P = \text{power} = I \Delta V \).
- **Reasoned results:** The brightness of a bulb depends on the power, the electric energy it uses (and turns into light and heat) per unit of time. For a given bulb, the current is determined by the voltage across it, and a higher voltage means a higher current means more power means brighter bulb. A bulb with lower resistance but the same voltage (e.g. in a parallel circuit) has more current going through it, which means more power and a brighter bulb. A bulb with lower resistance but the same current (e.g. in a series circuit) has less of a potential difference & dimmer bulb.
- **Reasoned result:** Kirchoff’s loop rule. If you sum all these pressure drops and increases around any loop in a circuit, they must sum to zero: You end at the same potential where you started. When you follow a loop in the direction of the current, you see a pressure\footnote{\[ \Delta V = V_1 - V_2 = IR \]}
drop across a resistor (you’re moving from high to low) and a pressure increase across a battery (in the “right” battery direction – you’re going from low to high.)

• **Reasoned result:** Kirchoff’s junction rule – current in = current out to any point in a circuit, as long as there’s no build up or draining of charge at that point. This follows from the foothold that charge is never created or destroyed.

• **Reasoned result:** Since conductors have very low resistance, under ordinary circumstances (no short circuits!) there’s no change in potential along a wire.

### Capacitors

• **Definition:** Capacitance $C=Q/\Delta V$, where $\Delta V$ is the potential difference, $Q$ (and $-Q$) are the charges on the plates of the capacitor. 1 Farad = 1 Coulomb/1 Volt

• **Reasoned result:** A parallel plate capacitor with area $A$ of plates and spacing $d$ has a capacitance proportional to the area of a plate and inversely proportional to the distance between them: $C=\varepsilon_0 A/d$. ($\varepsilon_0$= constant)

• **Measured value:** $\varepsilon_0=9 \times 10^{-12}$ Farads/meter.

• **Reasoned result:** Time constant for discharging or charging for a circuit with a resistor in series with a capacitor: $\tau=RC$.

### Electric fields

• **Definition:** The electric field is the force per unit charge: $E=F/q$.

• **Reasoned result:** If the electric field is constant in some region of space, the potential difference between two points would be $\Delta V = E \cdot d$, where $d$ is the distance you moved along the electric field. This is just an application of Work = Force x distance, but thinking of the work and force per unit of charge.

• **Reasoned result:** Electric forces are perpendicular to lines of constant potential; electric forces point toward decreasing potential. The analogy between potential and height is useful, and we spent time looking at topographical maps to help think about it. The elevation corresponds to the potential; the steepness corresponds to the strength of the electric field.

• **Definition:** A material that lets charge move more easily when there is an electric field has a lower resistivity ($\rho$), and we found we could model resistance as caused by obstacles – more obstacles means higher resistance.

• **Reasoned result:** The resistance of a resistor depends on the resistivity $\rho$ of the material: $R=\rho l/A$. Longer resistor, more resistance, wider, less resistance.