Electrostatic equations - what they mean and why we need to know about them!

Are electric motors useful in your life? We use them in drills, computers, gasoline powered cars, elevators, air conditioners, refrigerators, DVD players, washers and dryers and many more items you use every day for a modern lifestyle. Like everything else in the universe we know of, what these items can do is determined by the laws of physics. To make something move takes a force, so we learn Coulomb's law to find how much force electrically charged particles can exert. To make a computer disk spin or lift you up in an elevator takes work, a force applied over a distance. To understand the limitations and abilities of this ultimately requires stretching Coulomb's law a bit, by applying it over a distance to find how much work can be done.

Understanding why voltage and electrical field strength are important is a little bit more of a stretch, so let me give you an analogous example. Let's say you were concerned with disease control and wanted to know about mosquito populations. If Connecticut is 4 times bigger than Rhode Island, it probably has 4 times more mosquitoes than Rhode Island. But, is the total amount of mosquitoes a more useful statistic to know than mosquitoes per square mile? Personally, I would want to know how "crowded with mosquitoes" each place is and take size out of the equation. This is called "normalizing" a statistic and makes comparisons more apples vs. apples than apples vs. oranges. It's like looking at the average income per person rather than the total income for an entire country. You learn a lot more about poverty by normalizing income data rather than giving totals.

In the same way, voltage is a useful quantity for physicists and engineers to use. Voltage is the energy per charge. So, if you take the work that can be done by an electrical circuit and divide it by the amount of charge that moves through a circuit, you get voltage. If you ever see those big D cell batteries and the tiny AAA batteries, they both provide 1.5 V. The only difference between them is that a D cell battery is bigger and so it will last longer before running out of the chemicals needed to provide the voltage. Electrical field strength is to force (Coulomb's law) as voltage is to work (or energy).

Sometimes, normalized quantities are more useful than total amounts. Think of that next time you look at the voltage of a 1.5 volt battery!

Summary of Electrostatic Equations for "point charges"

Force - Coulomb's law (N) $F = k\frac{q_1q_2}{r^2}$ • A single charge can't create a force (what would it push on...see Newton's 3 law!), so you have two q's for a force • Forces are vectors • r is the distance between charges • Negative values mean attraction and positive values mean repulsion	Electric Field Strength (Normalized Force, N/C, V/m) Force per charge $E = \frac{F}{q} = \frac{kq}{r^2}$ • r is the distance between charges • Electric fields are vectors, there is a direction associated with electric fields • There is only q, because a single charge sets up an electric field, just like a single mass sets up a gravitation field (like earth has a gravitational field surrounding it) • See the charge, be the charge - just like you should have a <u>positive</u> attitude while studying this, you need to pretend you are a <u>positive</u> charge to figure the correct direction!
Work/Electrical Potential Energy (Force x Distance, J) Work = F x r, since r is the distance $W \text{ or } EPE = k\frac{q_1q_2}{r}$ • This is the work done to bring a charge q_2 from ∞ to a distance r away from q1 • If q_2 and q_1 are like charges, they repel each other and <u>you do positive work</u> to bring them together (like pushing a spring inward, the force you have to apply means you are storing energy in the spring and doing work) • If q_2 and q_1 are opposite charges, they attract each other and <u>you do negative work</u> by allowing them together (like you released a previously compressed spring - you are getting rid of the energy stored in the spring) • You can do positive and negative work, but work and energy are scalars - positive and negative are useful for keeping track of conservation of energy • We say there is electrical potential energy associated with charges when they are close enough to interact	Voltage (Normalized Work/Energy, J/C ≡ Volts) Work per charge, known as "Electrical Potential" $\Delta V = \frac{W}{q} = \frac{kq}{r}$ • Since voltage is normalized, a single charge sets up a voltage (moving another charge into its "field" <u>would</u> require work per charge and change the energy per charge...see the connection with electric field strength?) • Voltage is a scalar, like work, there are positive and negative voltages, so be careful with you accounting for complex systems using multiple charges (keep + and - signs for charges!) • Voltage and electrical potential are synonyms; you often hear voltage called electrical potential, so: a) know the term b) distinguish it from electrical potential energy • You can think of something with high voltage as having a lot of energy or "push" for any charge residing in such a location

<u>Other handy stuff:</u> $e = 1.60 \times 10^{-19}$ C $k = 9.0 \times 10^{9}$ Nm^2/C^2 Q = ne

e is the fundamental charge, the magnitude of charge on a proton or electron, k is Coulomb's constant and Q = ne shows charges come in integer multiple of e. You can't have half and electron, or 0.37 of a proton, etc.

<u>Capacitors or "uniform electric fields":</u> W or EPE = -qEd, $\Delta V = -Ed$