Electric Charge: Crash Course Physics #25

Crash Course: Physics
https://youtube.com/watch?v=TFlVWf8JX4A
https://nerdfighteria.info/v/TFlVWf8JX4A

The shock you get from a doorknob. That trick you used to do with a balloon to make your hair stick up. Or, of course, a lightning strike. They're all governed by the same principle--static electricity. Static electricity occurs when an object obtains a net amount of positive or negative electric charge, creating an imbalance that wants to be returned to equilibrium. Its effects aren't always as dramatic as lightning, though.

Let's take two pieces of tape that are both stuck to a table. If you rip them both off the table and tried to stick them together, that should be easy enough, right? But it turns out that they repel one another. But try this. Stick one on top of the other, rip the pair off the table, then separate the pieces. They're no longer repelled; now they're attracted to one another.

In the first scenario, both pieces of tape stole negative charges from the table, and since like charges repel, the pieces moved away from one another. In the second scenario, one piece of tape stole negative charges from the other, leaving the pieces with opposite overall charges, making them attract. Our study of electricity begins here, with basic observations about electric charges that hundreds of years ago sparked the imagination and innovation that changed our world forever.

To understand electricity, you should start with an atom. Atoms contains charged particles, positive protons and negative electrons, and generally there's an equal number of each, meaning the net electric charge of the atom is zero. It's electrically neutral. In solid materials, protons stay fixed but some electrons are free to move around.

These moving electrons are called free electrons. They reside in the atom's outer shell as valance electrons, and they're easily plucked off and carried around when acted upon by an outside force. How easy it is for electrons to move around depends on the material, and we describe the materials in the same manner that we do for heat transfer, with conductors and insulators. Materials that are conductors, like copper, let free electrons move freely throughout the solid, while insulators, like wood, hold onto them tightly, limiting their flow.

So, we've got insulators and conductors with free electrons moving around in them. But what causes these charged particles to move in the first place? The answer is, an imbalance of electrical charge, when some part of an object has a different number of free electrons then another part. When we talk about an object having an overall negative charge, we mean that it has too many electrons. And when we talk about an object having an overall positive charge, we mean it's missing free electrons.

This imbalance can be created and resolved in lots of different ways. Say you have a glass rod that's electrically neutral and you rub it with a cloth. That physical interaction causes electrons to hop on to the cloth, leaving the rod with an overall positive charge. This is called charging be friction. Both the cloth and the rod began with a neutral charge, but after friction the rod has a net positive charge. But whether the rod ends up with a net positive or net negative charge depends on the materials that you use.

The Ancient Greeks actually rubbed fur against amber and discovered that the amber would then attract hair and feathers. Today, we understand that the fur stole electrons during the process, giving the amber an overall positive charge, just like the glass rod.

Now it's important to note that no new charges were created during this process. The overall charge between the two objects is still zero. This is known as the Law of Conservation of Electric Charge. It says that you can never create a net electric charge. Instead, charge can only move from one place to another. Now, if we bring our positively charged glass rod in contact with another neutral rod, some of the negative charge--that is, some electrons--would jump from the neutral rod to the positive one until both objects have the same distribution of charge. So now we have two rods that are both slightly positive. This is called charging by contact. When the two objects touched, charges moved between them.

Okay, so charges can move when different materials touch each other, either through friction or simple contact. But materials don't actually have to touch in order for their electrons to get all rearranged. Say you bring a positively charged rod close to a metal conductor rod. Then the electrons in part of the metal rod will be drawn towards the positive rod.

Now the side with more electrons has a negative charge, leaving the other side of the rod with fewer electrons and a positive charge. You know what we've done here? We've polarized the metal rod, we've redistributed the charge in order to create an imbalance of charge, within an object, an object that's still electrically neutral.

Now imagine that we slice the metal rod right down the center. It still hasn't touched the positive rod, but since we split it while an imbalance was present, we're left with one positive side and one negative side. This process is known as charging by induction, creating a net charge without contacting another object. Now if a charged object is connected to a much larger, neutral conducting object, then the net charge gets redistributed so that the smaller object loses most of its net charge. How large an object are we talking about, exactly? Well, how about Earth?

The earth's surface is a fairly good conductor in most places and for all purposes, it can be considered neutral. So connecting a charged object to the ground creates a way for the charge to leak into the earth, rendering the object electrically neutral. This is known as grounding. So let's say we repeat the previous experiment, but we bring a negatively charged rod close to our neutral one.

The neutral rod becomes polarized, with a net positive charge close to the charged rod, and a negative charge on the opposite side. But if we ground the metal rod, the negative charges repelled by the charged rod now have a place to go--the earth. The negative charges scurry away, leaving the metal rod with an overall positive charge. Now, if we sever the connection to the ground, our rod remains positively charged.

This process required no contact between the rods, only a connection to the ground. Okay, so we've talked about how opposite charges attract, and like charges repel, but how do we quantify those interactions in terms of equations and units? Well, we'll want to find the force on charged particles in Newtons. But to calculate the number of Newtons, we'll first need to measure the charge, denoted by q, in units called Coulombs.

Since objects can positive or negatively charged, q can have both positive and negative values. For example, one electron has a charge of negative $1.6*10^{-19}$ Coulombs. That means there are $6.24*10^{18}$ electrons for every negative Coulomb. This value, the charge of a single electron in Coulombs, is known as the elementary charge and is denoted with a lowercase 'e'. We'll use this notation a lot when talking about protons and electrons, since protons have a charge or positive e (+e) and electron of negative e (-e). Now that we have a way to measure the charge we can calculate the force between particles.

And the equation we use is very similar to the one we use with gravitation. It's just instead of using kilograms to find Newtons, here we're using Coulombs to find Newtons. Our equation here states

that the force between two charged particles is equal to the product of the two charges divided by the distance between them squared. And the distance is squared because just like gravitation, when the distance between objects doubles, the force between them reduces to a quarter of the original value.

And also, as with gravitation, this force has its own proportionality constant. It's labeled lowercase 'k' and its value depends on the medium that surrounds the charges. The vast majority of the time, the medium you'll be working with will just be air, or possibly a vacuum. And in both cases, the constant is $9*10^{9}$ Coulombs. So when you multiply the expression by k, that gives you the result in terms of Newtons.

This whole expression is known as Coulomb's Law, and k is often known as the Coulomb's Law Constant. Now gravitation and electrostatic forces work in totally different ways of course, so we have to express them differently too. The force of gravity, after all, is always attractive. But the electrostatic forces can either be attractive or repulsive, depending on the sign of the charges. So the product of the two charges can be negative or positive, with the resulting sign of F being plus or minus, corresponding to either attraction or repulsion.

Now, let's put Coulomb's Law to the test. Let's say there are two electrons that are one nanometer apart--that's $1*10^{-9}$ meters. You can calculate the force between them by multiplying their charges, which are both negative $1.6*10^{-19}$ Coulombs, divided by the distance between them squared. You then multiply that by k and the resulting force is positive $2.3*10^{-10}$ Newtons. Now, notice that the answer is positive. That means the electrons repel one another.

If we used a proton and an electron the same distance apart, we'd get negative $2.3*10^{-10}$ Newtons, meaning they'd attract one another. And just like other forces, vector addition also applies here too. This means we can solve for the net force on a charge by using Coulomb's Law on each pair of charges in any situation. From Coulomb's Law, we can calculate the magnitude of the force and find the direction based on the sign of the result. So from a simple trick with tape and the help of a couple of animated rods, we've already covered the basics of electrostatic forces.

Next time, we'll learn about electric fields and how to visualize their effect on neighboring objects. Today, we learned about electrostatic forces and how electrical charge can be altered and rearranged. We also discussed Coulomb's Law and how the force between charged particles is calculated using vectors. Crash Course Physics is produced in association with PBS Digital Studios. You can head over to their channel and check out a playlist of the latest episodes, from shows like PBS Idea Channel, Braincraft and ShanksFX. This episode of Crash Course is filmed in the Dr. Cheryl C. Kinney Crash Course studio with the help of these amazing people and our equally amazing graphics team is Though Cafe.