MITOCW | electric_potential

Air is normally an insulator, but under certain conditions, it can suddenly and temporarily change into a conductor, and we end up with a spark. In this video, we'll use the related concepts of electric fields and electric potential to explain how insulators can suddenly, dramatically and temporarily become conductors. This video is part of the Derivatives and Integrals video series. Hello. My name is John McGreevy. I am a professor in the physics department at MIT, and today I'll be talking with you about the electric field and electrical potential. To get the most out of this video you should already have some exposure to the electric field and electric potential. You should be able to take a mathematical expression for the field and obtain the potential, and vice versa. You should also know how to draw equipotential surfaces and electric field vectors. Throughout this video our goal is to help you gain a clearer picture of the electric field and the electric potential. By the end of the video you should also be able to describe the process of electrical breakdown by using either the field or the potential. Let's start with a review of electric field and electric potential. First we'll describe them conceptually. Then we'll show the mathematical relationship between them, and show some of their typical visual representations. First, let's see what you remember. Take out a piece of paper and write down everything you remember about the electric field and the electric potential. Try to concentrate on their similarities and differences. Pause the video to do this. Now you can compare the list you made to our list. The electric field is generated by electric charges, and extends an infinite distance from them. If you bring a second electric charge into a region of electric field, there will be a force exerted on it. Like all forces, that force has magnitude and direction. The stronger the charge is, the more force will be applied to it. The electric field is a vector quantity. It has a vector value at every point in space, measured in Newtons per Coulomb or Volts per Meter. Much like the electric field, electric potentials are created by charges and extend an infinite distance from them. If you bring a second charge into a region of electrical potential, that second charge will gain or lose potential energy. The stronger that charge, the more its potential energy will change. Unlike the electric field, the electric potential is a scalar quantity, which means that everywhere you look you can find a number that represents the potential, measured in Joules per Coulomb. Let's look at two ways to envision an electric potential for a positively charged line near the origin. We're going to look at this in two dimensions to make things easier to see. We can also draw the level curves for the electric potential function. These are called "equipotential lines," because the value of the potential is equal at every point on a given line. For instance, we might draw lines every ten volts. If we plot the potential on the vertical axis, we end up with this mountain-like shape. We can imagine positive charges rolling down the mountain as they are pushed away from our line charge. We can also sketch the electric field around a line charge. If we pick regularly spaced points at which to draw our electric field vectors, we end up with a picture like this one. Each vector shows the direction and strength of the electric field at that point. The longer the arrow, the stronger the field is. Here you might imagine the arrows pushing a positive charge away from our line Displaying both the equipotential lines and the field vectors at once, we get this picture. You can see that the equipotential lines are always perpendicular to the field. Since charges create both fields and potentials, both will be present all the time, though we might only draw one or the other. The field and the potential are related mathematically through the gradient operator. As a vector operator, the gradient turns the scalar potential into a vector field. To go in the other direction, a line integral of the electric field turns that vector field into the scalar electric potential. The negative sign that appears in both equations is importantâ€"the electric field points in the opposite direction from any changes in the potential. If the electric potential increases in a particular direction, the electric field points in the opposite direction. We're going to use something called "electrical breakdown" to illustrate our concepts today. We'll start with an example, give a definition, then go into an explanation of the phenomenon. Here is a clip from the Boston Museum of Science to demonstrate the phenomenon. Quite a dramatic demonstration! Let's look at this in a little more depth. Electrical breakdown is defined as the process by which an insulating material in a strong electric field becomes electrically conductive. The material actually changes from being an insulator to being a conductor. In the clip you saw, this happened in the air near the Van de Graaff generator, and a large electric spark resulted. You may sometimes hear this referred to as breakdown potential, or breakdown voltage, which is the same thing. The exact value of the electric field needed depends on many factors, including distance, humidity, temperature, and the material itself. Here is a simplified explanation of how electrical breakdown works in air. Consider this house in a thunderstorm. If we zoom in on the air above the house, we can see the molecules of gas in the air. Thunderstorms involve strong electric fields and high electric potential differences. We can represent those on our diagram. Imagine that one electron is pulled from its atom by the strong electric field. Because the electron is negatively charged, it will accelerate against the electric field, and will eventually collide with another atom. That collision might knock another electron loose. Now there will be two electrons accelerating. A single electron can thus create a chain reaction, where many atoms lose their electrons. This creates a region of ionized air. Air is normally a good insulator, but the presence of ions allows it to conduct electricity. ...resulting in a lightning bolt! Let's use the electric field and electric potential to investigate this situation further. Here are the Van de Graaff generators from the video, charged up, with a metal ball as a target. Let's take a simplified version of the situation shown. Draw the equipotential surfaces around these two objects, and then draw in the electric field arrows as well. You can ignore the presence of the support pillars. Here are two hints. First, the small metal ball is grounded, or "earthed," with an electrical potential of zero. Second, the electrical charge on the generator will spread itself equally over the surface of the conducting spheres. Pause the video here to draw the equipotential lines and the field vectors. Here's another picture of the generator with the target ball nearby. This picture is too complex. Let's create a simpler version of the picture. That's Now we can draw in the lines. Our equipotential lines will "hug" the surface of the conductors when they are nearby. Because the charge is spread evenly across the surface of the conductor, the whole surface will be at the same electric potential. The equipotential lines will tend to be smoother when farther away from the conductors. Because the electric potential of the Van de Graaff generator gets up to about one million volts (or 1000 kilovolts), and we have drawn eight lines in the picture, each line must represent a difference of about 125 kilovolts. In this view we have colored in the regions where the equipotential lines are more closely packed, or less closely packed. In the blue area, with the close-packed lines, the gradient of the potential is larger. Because the electric field is proportional to the gradient of the potential, the places where our lines are more closely packed will have a stronger electric field. In the red areas, where equipotential lines are far apart, the gradient of the potential is smaller. Therefore, the electric field will be weaker. We can use this as a guide when drawing our field vectors. Let's draw in those electric field vectors now. We have assumed here that the generator becomes positively charged, but if it were negatively charged, we could simply reverse the direction of our arrows. Look carefully: our field arrows are perpendicular to the equipotential surfaces at all points. Check your own diagram - is this true on yours as well? Our field arrows are longer where the equipotential lines are more closely packedâ€"is this true on your diagram? If you need to revise your diagram or draw a new one, do so now. If you have questions for your teacher, here is a chance to ask them. Pause the video here. Some of you may be confused by the terminology that is used for this phenomenon. Many people refer to the "breakdown potential" required to create a spark. However, but you may have noticed that the sparks in the video were produced where the electric field was the strongest, not where the electric potential was the highest. Turn to a friend and discuss why this is the case. Pause the video here to discuss. If we return to the equations that relate the field and the potential, we can improve our understanding. You can see that we have a gradient termâ€"a derivative with respect to distance. If our potential changes slowly over distance, the field is weak, and no spark is generated. On the other hand, if the potential changes quickly over distance, the field is strong. A stronger field is more likely to remove an electron from an atom. In fact, when numerical values are given for the breakdown potential, they are most often given in "volts per meter," which is a measurement of the electric field. The term "breakdown potential" is a little misleading, but it is still the standard terminology. To review, the gradient connects the electric field to the electric potential. A steeper change in the potential results in a stronger electric field. We also saw that electrical breakdowns happen in areas of strong electric field, or of steep change in electrical potential. We hope you enjoyed this clip from the Theatre of Electricity at the Boston Museum of Science. Good luck in your future studies of electricity.