

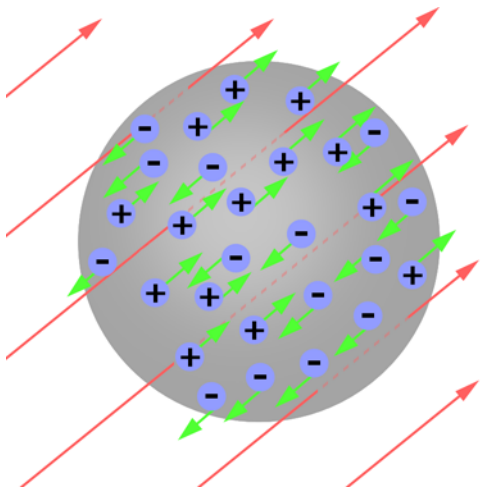
## On the fields generated by circuits

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The force created between any two bodies at any distance great or small is inversely proportional to the square of the distance between them and directly proportional to the product of the magnitude of the two charges. The so called “Electric Field” refers to a set of imaginary curves used to visualize the effects of the charge(s). The field at a certain point is equal to the force per charge of a small, positive test charge that lies on the point of interest. The electric field lines will curve such that the electric field on any point on the line lies on the tangent line of the curve. Do note, however, that the electric field lines do not represent the *path* of a positive test charge. It is simply a group of curves whose tangent lines represent the direction of the electric field at that point. In the following paragraphs I will consider not only the fields generated by static point charges, but I will investigate the fields driving a circuit in a general circuit.

A conductor is a substance in which electrons can flow freely. In an ideal conductor, any build up of charge would be canceled instantaneously. In a realistic conductor of nonzero resistance, there would be more of a “charge gradient” such that the electric field at any point in the conductor is enough to push the electron occupying that area forward. In fact, even before we connect the wire to the battery there will be build-ups of charge throughout the wire as the charges move under the influence of the electric field from the battery. In the following paragraph I will only consider a wire *close* to a battery before it is connected. The electrons will continue moving until the net electric field at every point on the interior of the conductor is zero. However, this does not mean that the electrons are distributed evenly throughout the wire! If this were so then the electric field due to the battery must be zero, and this is a trivial situation that we will not deal with. In other words the electric field due to charge build up in the wire plus the electric field due to the battery must be zero. This must be the case since the electrons eventually reach equilibrium, and if there were an electric field then the electrons would move further. Because the electrons always move in the opposite direction as the field lines, they will get nearer to the positive terminal of the battery. They will continue doing so until the electric fields cancel.



This image illustrates how the many positive and negative particles in an ideal conductor move in the presence of an electric field. The red arrows represent the lines of force of the electric field. The green arrows represent the electric force on each particle. Due to this motion, there will be an excess of negative charges on the left side and an excess of positive charges on the right side. This creates a new electric field which points in the opposite direction as the original electric field. This

process will continue until all field in the conductor has been canceled. As the electric field lines approach the conductor they are unaffected, but upon passing through the surface of the conductor they disappear. As soon as we bring the ends of the wire close to the battery terminals, the build-up of electrons near the end of the conductor close to the positive terminal and the absence of electrons near the end of the conductor close to the negative terminal will increase due to the increasing electric field. When the conductor touches the terminal the excess of electrons will be drained and the absence of electrons will be filled. The excess of charges in the wire may move about in waves or some such path until the equilibrium has been reached. This excess of charge that builds up should generally move to the surface of the wire and thereby be called a surface charge. My guess is that most surface charges for low voltage applications are minimal due to the small potential difference. For high voltage situations, however, this is not the case. Along the lines of the thoughts about the movement of the charges in the wire where the wire is not touching the battery, a similar process is used in radio transmission. A changing electric field can cause a small change in electric field somewhere else. This can cause electrons to move back and forth in a wire great distances away. This small current can be measured and amplified to be turned into useful information.

We can observe the charge equilibrium in a circuit by strewing grass seeds upon a glass plate on which the circuit has been created with India ink. A perfect conductor will not produce an electric field because the initial field would be canceled immediately. A resistor will produce an electric field as the opposite ends of the resistive section build up with charge. Although the electric field will construct it self very quickly, there is still a small interval of time when the field is not static. However, by the time the grass seeds are dropped on the glass plate the charges in the wire have already spread out to their appropriate places. It may be interesting to consider how the charges move through the wire. It has been shown that the motion of electrons in a wire can be represented by Brownian motion, but from a macroscopic point of view the field production may be very interesting. Consider a resistor circuit where the entire wire is made of one resistive wire with constant resistance density. Before the wire is connected to the battery the charges will move to either side of the wire due to the presence of the electric field from the DC power source. Again, eventually the charges will reach equilibrium in the process explained earlier. The negative electrons will flee away from the direction of the electric field and produce a charge gradient.



Notice how the charges are more close together when nearer to the poles of the battery (The larger charges outside of the resistor). This effect is called induction. The point of my explanation is that when the voltage is turned on there suddenly appears an electric field and the charges in the wire move to cancel it out. Even in a resistor in equilibrium placed within a constant electric field there exists no electric field on the interior of the resistor. This is different in a conductor where the charges are not free to move, but my point is that the charges go to where they are most comfortable. A simple explanation goes as follows:

Consider the notion that there exists an electric field in the conductor. If there was then there would be motion of charged particles in the conductor contradicting the initial condition that the conductor was in equilibrium.

The positive charges pull toward the negative pole of the battery and the negative charges pull toward the positive pole of the battery. In essence it is the field that drives the electrons in the circuit, but this is only virtually instantaneous. If you suddenly applied a voltage where the battery *wasn't even connected to the wire* there would still be current running through the wire for a very short period of time. However, as I said earlier, this field is very rapidly canceled out by the build up of charge on either side of the wire.

However, once you touch the wire to the battery, the excess of charges can drain and so the electric field can continually drive the electrons in the wire without counter-productive excess build up of charge on either end of the wire. These surface charges can be better understood if we consider water running through a hose. Consider, for example a hose running from a higher gravitational potential to a lower gravitational potential. Water could be inserted into the top and it would run down the hose. But what if the hose was looped so that it went down, and then came back up again a bit, and then went down farther. Any water that entered the hose would just get stuck in the downward loop. But in an electric circuit the electricity would flow continuously no matter how the wire is configured. But if you think about allowing water to continue flowing through the wire, once the loop filled up with water, the water is allowed to flow through the rest of the hose. Although this is not exactly what happens in an electric circuit, it can help one to understand what happens in a circuit.

Conclusion: The electric voltage in a circuit is not just some number without meaning. The amount of current through any part of the wire depends upon not only the direction of the initial electric field but it is also due to the position of the charges in the wire. Each charge produces a field of its own and can create more complex electric fields. Second it is important to note that there is no push that exists *only at the battery terminals*. Instead, there is an electric field throughout the entirety of the wire that determines the total voltage. It is easy to think that one end of the battery pushes and the other end pulls like water moving through a pipe. This, however, is not the way it works. All nonzero charges in the wire have electric forces acting on them. It is better to consider a field surrounding the wire from the battery terminals that push the electrons through the wire. The build-up of charge within the wire also affects the field. If charges with same sign did not repel then electricity going around bends would be difficult. The charges would get stuck in the bends due to the influence of the electric field. Because they affect each other, electricity will follow the wire in any direction. Electricity is too important an invention to the world for it to be misunderstood or forgotten. Electricity lights up homes practically everywhere in the world.