May 10

How Does Electricity Work?

Science, Technology, Astrophysics & Cosmology, Material Science

Visualizing Electricity

Electricity is a common phenomenon that we encounter continually throughout the day. Almost everyone is acquainted with electrical technology. We have also experienced sparks from arc'ed static electricity after walking across a carpeted room and grounding to metal, perhaps a doorknob. We have taken in the incredible power of lightning during a thunderstorm. And yet, when we go to find out what is actually happening during these events, we are generally met with one of two somewhat obtuse visualizations: The water pressure model or the electron-bead model. Both are analogies by degree. In in the former, electric potential (voltage) is comparable to pressure in a pipe where current is flow of water. In the latter, electricity results from little beads called electrons that travel down a wire.

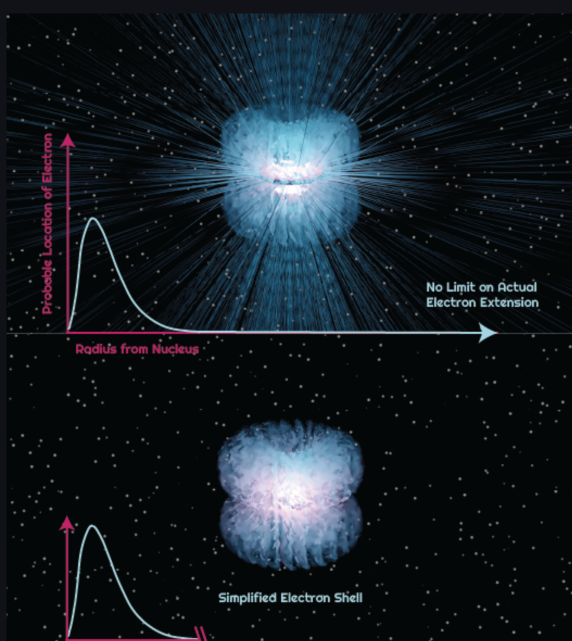
Both of these visualizations have their merits. The water-pressure model helps us conceive of abstract concepts like potential and resistance — and yet clearly the wires, capacitors, and resistors of electrical circuitry bear little resemblance to the structures of dams, pipes, and constricting conduits. The electron-bead model is highly accurate in terms of quantitative accounting, but it stretches the imagination as to how a moving bead actually produces motive pressure, other than the self-referential concept of "charge," which itself lacks visualization. To address these shortcomings, we propose the following animation: Electricity as surface-to-surface rotational gearing between electron-shells on atoms (see **movie** below). This is not the end-all-be-all visualization, but hopefully a few steps in the right direction.

This video is an updated way to visualize electricity. We hope to improve upon the old text-book style "electron-bead-flow" and "hydrodynamic" analogies.

Electricity Begins with Atoms

Any physical concept is best first understood under the simplest conditions imaginable. Later, after we gain access to the basic inner workings of a phenomenon, we can extend these principles to other situations of greater and greater complexity. For this reason, explanation of inter-atomic phenomena, including electricity, need to begin with the simplest atom: hydrogen. Hydrogen constitutes the majority of the material in existence, and in its ionized form is capable of hosting gargantuan currents throughout the interstellar cosmos.

Hydrogen has one electron, which exists predominantly within certain radial distances of the nucleus. This electron, often referred to as the electron cloud, is synonymous with the location of the surface of the atom. While 99.999% of the electron exists within 430 pm of the nucleus, there is a small chance of finding the surface extended to incredible distances. In fact, under Quantum Mechanics, the radial distribution function for the electron has no limit on distance. For our model, we represent these extensions of the electron shell as incredibly thin filaments, radially organized about the atom, as shown below in **Figure 1**:



Our visualization of electricity uses hydrogen atoms based on the radial distribution function of Quantum. Though the extension of the electron from the nucleus is unlimited, we ignore the small 0.001% of the radial distribution. These tiny filaments of the atomic surface will come in to play in more complex phenomena.

In the Lab...

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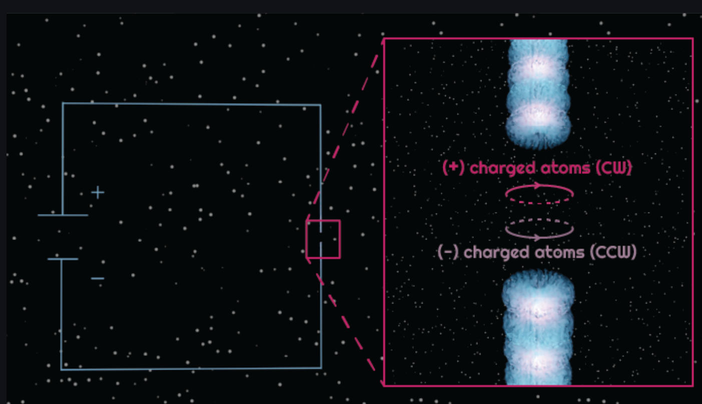
A Highly Simplified DC Circuit

The circuit shown below (**Fig 2**) is composed of single-file hydrogens. We can consider the hydrogens ionized and illustrate this as enmeshed electron shells. This is another way of showing shared electrons between atoms. We see that the electron columns at either terminal rotate opposite. This rotation illustrates cohesive directionality of angular momentum. Cohesive angular momentum of the electron shell explains the concept of "charge," where in this example clockwise (CCW) rotation represents positive (+) charge and counter-clockwise (CW) is negative (-) charge. The arbitrary assignment of sign to CW or CCW rotation is unimportant, as the conventions concerning directionality of charge have wandered throughout history. The essential feature is that, on average, the direction of cohesive rotation is in opposition between (+) and (-) charged terminals in a circuit.

Charge is also a scaled quantity. In the illustrated circuit, electrons rotate faster at the (-) terminal than the (+). This is not a general feature concerning (+) and (-) charged terminals but is rather particular to illustration of the concept of electric potential. Fast rotating shells represent greater electron momentum, and hence electrically more productive shells, than those depicted with slower rotation. Under quantum mechanics it is not possible to precisely separate the contribution of speed and directionality to electron momentum, so our visualization simplifies momentum to speed of rotation. Together, the difference in electron momentum (speed, directionality) between electrons at each terminal signifies the concept of voltage, or electric potential.

The greater the voltage drop between terminals, the greater the current produced once the two make contact. Therefore, current is the process where greater momentum electron shells (faster, more cohesive) incite weaker (slower, less cohesive) shells into motion. When the two terminals make contact, the momentum transfer between the newly engaged columns occurs rapidly, at near light speeds. The atoms stay put, however, and their electrons continue to rotate at much less ferocious speeds. This is the concept of drift velocity.



Charge is represented by direction of electron shell rotation (Clockwise, CW; Counter-Clockwise (CCW). The electric potential, or voltage, is illustrated with the differential momentum of electron shells between each terminal. Current results from fast, cohesive shells at one terminal driving the motion of less active shells at the other.

Extrapolation of the Hydrogen Circuit to Actual Wires

It's important to recognize this visualization is a highly simplified model of electricity. We simplify the differences in charge constituting voltage with directional rotation speed. In reality, while charge *is* quantized since an object can only rotate one way or the other with respect to some arbitrary axis, electron angular momentum is a continuous concept. For instance, electron momentum could deconstruct to cohesion of surface rotation and/or it could reflect rotational speed, but these are indistinguishable to the theorist and experimenter alike. In any event, it is apparent that the actual electron shells are, in fact, rotating.

Also, if we look at more complex ato[illegible] we find additio[illegible]trons. We w[illegible] visualize these additional electrons as additio[illegible] with neighboring atoms. The conducting metals in real wires, for instance, have multiple polar lobes constituting their electron shells. These complex electron shapes are mathematically described by the concept of orbitals. The unique multi-lobed structure of p- and d-type orbitals on a metal atom is perhaps why they are such effective conductors. Each pair of polar surfaces within an orbital is able to productively contact neighboring atoms. Also, actual wiring in modern technology often utilizes alternating, rather than the illustrated direct-type, current. Our visualization is easily extended to alternating current by having the atoms move back and forth instead of unidirectionally — a motion which is equally capable of providing motive force at a distance through a circuit.

This visualization is just a starting point for the imagination. It is not perfect, but it moves things in the right direction. For example, it has some serious advantages over the traditional visualizations like the "electron bead flow" and "water-pressure analogy." Unlike these traditional models, we are invoking real structural understanding of the atom to sum up the phenomenon of electricity. The bead-model of the electron, also called the Bohr model of the atom, has been seriously disregarded for several decades in favor of valence shells, which we reference exclusively. The water-model illustrates potential and current well, but the analogy also fails to join what is structurally clear about the atom from quantum theory. Here we hope to have included these oversights into a cohesive visualization by providing for the concepts of charge, voltage, and current with simple hydrogen atoms moving one another through basic surface-to-surface contact.

Note: While the above model for electricity presented here was inspired in part by the ideas of Bill Gaede, the fiber-based atomics we use throughout this blog should not be conflated with Bill's atomic model.

electricity

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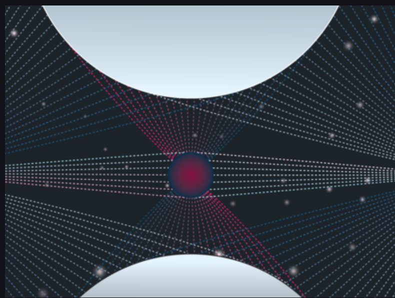

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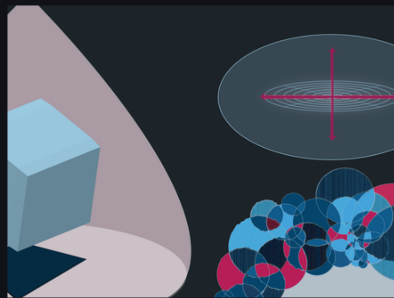

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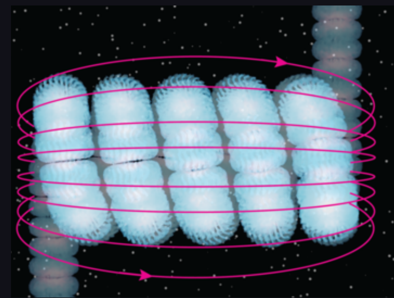

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