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About This Book

After seeing the movie "Star Wars," Kenn Amdahl realized that his young sons suddenly knew everything about Wookies and the Force, effortlessly, without study. Their minds were alert and engaged by all the fun in the movie, and therefore receptive to learning anything. Yoda could have taught them chemistry. On the other hand, if Han Solo and Luke Skywalker were described in the style of some traditional text books, they would seem dull as Victorian pinochle players. Darth Vader would be as hard to remember as the fourth President of the United States, whoever that was.

Kenn wondered if one could write engaging books on dull subjects that would make learning as effortless as watching a movie. To test his idea, he wrote this book about electricity, careful to keep the pace lively and the reading easy, entertaining, and irreverent. One would have to say it worked rather well.

But the concept was new and therefore seemed risky to publishers. The book was rejected by 89 different publishers and agents before Kenn decided all of them were simply wrong. He formed Clearwater Publishing and released it himself. Since then, it has been in print continuously, sold well, and generated an army of fans around the world. You are about to become one of them. Besides teaching thousands of people about electricity, this book helped inspire all the books for dummies and idiots, as well as helping to light the path for small publishers everywhere. Today, small companies publish more than half the titles released each year.

You'll enjoy this book even if you have no special desire to learn about electricity, just as you can enjoy Star Wars without a desire to understand light swords. The learning is a bonus: You won't be able to prevent it.

This book has been typeset in a more efficient style than the earlier printings. Despite fewer pages, it contains the complete text of the original. Some old, minor mistakes and typos have been replaced with new typos and mistakes.

Introduction

Some people honestly believe they understand electricity, just as alchemists once thought they understood how to transform lead into gold. Don't despise or ridicule these poor souls. They should be tolerated and gently educated until they are ready to rejoin society.

No one really understands electricity.

But no one wants to admit it.

Once I realized that truth, it became easy to learn *about* electricity.

Whatever it is (the accepted theory changes every fifty years or so), the stuff has been observed and studied for several hundred years. We can predict its behavior, just as an ancient witch-doctor could predict an eclipse. And we can use it, as a cook uses yeast, even though he doesn't know or care what all those microscopic critters are doing in his dough. We can learn plenty about electricity, and we use it every day.

Yet some people prefer to stay ignorant of the workings of electricity, because of a fear similar to the common fear of automobile engines. We know there's a monster lurking under the hood (or in those wires...). We know that it feeds upon gasoline and magic (or that it dwells in nuclear power plants and lightning...) and if we disturb it, it will strand us at the worst possible time (or electrocute us). Perhaps if we ignore it, it will leave us alone.

I am here to tell you that electricity is a trained elephant. It is big and strong, yes. We avoid the tusks and try not to let it step on us, of course. But it is a friendly giant, with a very simple mind, and it always responds to the commands it knows. A child can lead it like a puppy.

Electricity has less than a dozen observable characteristics; we seldom are concerned with more than half of these. Electricity is comparable in complexity to a facial tissue. A facial tissue may have length, width, thickness, weight, color, fragrance, texture, some number of plies or layers, strength, absorbency, a brand name and a price. Add to that the fact that it may be either mine or yours, or of unknown origin, and that it may be either new or used, fresh and smooth or mashed together after months in last winter's coat pocket, or that it may have gone through the washing machine a time or two, and you can see that a facial tissue is a lot more complicated than electricity.

There are six ways to produce electricity; you need to understand two of them.

Of the six ways to get useful work out of electricity, only three are important.

And most of our manipulation of electricity is accomplished with a dozen or fewer devices in various combinations.

That's it.

When you understand two dozen concepts you'll feel comfortable with electricity. I have eaten coleslaw that had more ingredients. Electricity is simple.

But this beautiful and powerful mystery is hardly ordinary or boring. If there is magic in the universe, the evidence must surely be electricity and life itself. Just as we know enough about life to perform crude biological parlor tricks (grow hybrid corn, treat a simple disease), so we are children in the sorcerer's work-room playing with electrical spells we don't really understand. We can no more explain the inner workings of the electrical phenomenon than we can breathe life into a crescent wrench. Yet we have seen its power, and the few tricks we can perform make us feel wise indeed.

Shall we study this wonder the same way we study geography or algebra (subjects that really *are* boring)?

No. Like any magical thing, it should be studied by flashlight, under the covers, late at night so mom and dad won't know. Keep this book hidden in your own secret place. As you learn the magic words, the potions, the hexes and spells, you will unlock a remarkable force from another dimension. Your fear will slowly change to an eerie curiosity. You will find yourself wanting to know more, no matter the price.

Finally, you will call out in the stillness of your darkened room, "Show yourself! I am not afraid!"

You will force yourself to sit still, but your hands will be trembling. You will hear a sound somewhere in the darkness. And when that awesome grinning genie finally swells into the room, with blood red eyes and flashes of lightning showing through his ghostly mass, then you will wonder at your own brave foolishness and ache to run to some bright and safe place... but it will be too late. He will lean low until you feel his hot ozone breath on your cheek. His voice will crackle and hum like a high voltage power line as he whispers in your ear:

"You have summoned me, master. What is your command?"

There will be no time to check your notes. You will hold your breath, fight down your terror, and make a wish.

Telling yourself, over and over again, that you don't believe in magic.

The Author

Eugene Amdahl is probably a genius. For years he designed computers for IBM, then he started Amdahl Corporation (which is now a multi-million-dollar-a-year super-computer company) and began working on even more complicated and wonderful electronic ideas. His name is always spoken reverently by electrically inclined people.

I've never met Eugene Amdahl, but somebody told me he's my father's third cousin, once or twice removed. Or something like that.

My father, Bernhard Amdahl, worked for the telephone company for years, solving difficult electronic problems, teaching classes, doing telephone company stuff. One of my uncles, Vincent Backlund, repairs televisions for a hobby. My uncle John Amdahl taught electronics for the Navy. My uncle Lowell Amdahl repaired computers for IBM. Many of my relatives have been deeply involved with electronics.

So, you see, I acquired my electronics expertise not in the traditional way, through education. I got mine genetically.

Unfortunately, I was unaware of this gift. I thought I was a guitarist. I became more convinced that electronics was not a part of my destiny when I tried to read books that claimed they would teach me the subject. Immediately I noticed an interesting phenomenon. After about three pages, my eyelids began to droop and I felt a tremendous urge to go mow the lawn.

I nearly killed that lawn trying to learn electronics, but I persisted. I read 18 pounds of beginning electronics books, stole information from friends and relatives, and performed countless boring and unsuccessful experiments. The one rule I learned is the one that says beginning books must be dull and they must be written by guys who forgot years ago how confusing the language and culture can be when you are a foreigner in the land of electronics.

This book may be the exception. I consider my lack of a Ph.D. in electrical engineering to be one of my soundest qualifications for writing it. If you are completely ignorant about electronics, I am the guy for you. I can speak to you as an equal.

The Creative Use of Jargon

Nearly every area of human activity, from sports to medicine, has its own specialized vocabulary, its own "little language." These words and phrases are the "jargon" of the activity. When you learn to play golf, you learn about hooks, slices, chip-shots, eagles and birdies. When cooking, you baste, saute, marinate, reserve liquids and clarify your onions. And, by the time you finish this book, you'll be swapping voltage jokes with electrical engineers, gossiping about push-pull amplifiers with the TV repairman, and saying words like "resistance," "capacitance," and "frequency modulation" confidently, as if you understood them. Remember that most education is based on the premise that speaking the language is more important than having something to say. Learning the vocabulary of a hobby is part of the fun.

More than that, it's powerful. Jargon is the weapon of choice at cocktail parties and among people who "take lunches" with each other.

The creation of jargon is the primary activity of educators, sportscasters, politicians and street-gangs. Jargon provides the clearest distinctions between generations. ("Isn't that groovy? Isn't it boss?"/ "I don't understand, Dad. I thought it was totally phat.") Our various jargons are the dialects of American culture, our class distinctions, and the uniforms of our jobs and interests. Without them we would all seem pretty much the same. Jargon is diversity and freedom and democracy. Eliminating jargon is the first step on the road to communism.

As a practical matter, jargon serves two rather wonderful purposes. First, it's a short-hand for the people who understand it. A sportscaster couldn't possibly describe the individual movements of twenty-two football players racing around the field. Because of the language of "football-talk," he doesn't have to. He says, "The quarterback goes to the shotgun, both receivers split wide to the left. Single set-back. Eighty runs a post pattern, clearing the zone. Number Seven reads the safety blitz, dumps it off to the tight end on a quick comeback up the middle. He's hit immediately, but he got about five on it. Second down." Who needs television when you've got a guy who can describe the action like that? It's poetry.

Unless, of course, you don't understand the vocabulary. Which brings up the other wonderful thing about jargon: It can be used to confuse and exclude people who are not members of the club. I call this "the Pig-Latin Principal." Remember the gleeful feeling you got as a child, talking to your buddies in gibberish that your sister couldn't understand? Well, that's the same feeling that lawyers get when they say "caveat emptor," or "corpus delicti," or "ipso-facto." You'll notice, however, that when they truly wish to communicate they talk like this: "You owe me eight-hundred dollars. Pay now." No jargon there.

Suppose you want to fool someone into believing that you understand something. No problem; use jargon:

"Daddy, why does the TV picture go goofy when I touch the screen with my magnet?"

"That's easy, son. The magnetic lines of force deflect the stream of electrons in the cathode ray tube, causing a distortion in the raster."

"Wow, you sure are smart, Daddy!"

"Thanks, son."

Perhaps eighty-five per cent of the task of learning electronics is simply remembering about two dozen neat words. And they are, indeed, wonderful words, masterpieces of jargon. Magnificent phrases like "inductive reactance" flow effortlessly from the lips of guys who can't cook hot dogs or find the flashing blue light in a K-Mart store. That's important to keep in mind. It doesn't take a lot of brains to learn a few words. Parakeets and myna birds do it all the time. You can, too. It's not work, it's just a game.

Say we want to build a radio using only items we can find around the house. First, of course, we give the project itself an important-sounding title, like "Electronics Survival Drill" or "Self-Sufficiency Experiment." (Incidentally, this is the same process that is used in writing grant proposals.) We might be able to build the Vacuum Tube Diode Rectifier out of a big bottle, like the kind that gourmet lemonade comes in. Of course, you wouldn't want to use some old used bottle would you? No sir, this is Science. You're just going to have to go out and buy a new bottle and empty it yourself.

Of course, we could build a battery out of many different things, but I really prefer the batteries I make out of the liquid from those big, juicy pickles with a lot of garlic you get in the refrigerated section of the grocery store. Sure they cost a little more, but then you want to be careful around electricity. Cut corners when you're studying geography or Latin. Then we're going to need some resistors. Haven't you ever wondered how much resistance was in a half-pound roast beef sandwich? Me too. How about paper to use as the dielectric in your capacitors? I have found that the paper they use in a particular fishing magazine works especially well. For an antenna, I bet the aluminum tubing in one of those folding patio lounge chairs would be perfect. Or a long fishing pole might work. A True Scientist and Earnest Student would have both available and experiment to see which one works best.

I'm sure you are beginning to get the hang of it. I often sacrifice my weekends to the pursuit of scientific knowledge. My wife is understanding and supportive when I explain how I have to buy materials to make a vacuum tube diode, some capacitors, resistors and a battery. She gives me the money. Then, when I say that I want to conduct comparative antenna experiments somewhere far from all the electromagnetic interference of the city, she makes me drive all the way out to Giant Trout Lake. I protest, of course, but finally my sense of responsibility wins out. After all, I have a strong commitment to education. I drive out to the lake with my lounge chair, fishing pole and other electrical components, and spend the weekend studying.

And that's the way we use jargon.

Static Electricity:
A Cat's Nightmare

When you rub your shoes on the carpet and then touch your unsuspecting cat's nose, you are experimenting with static electricity. The satisfying little snap and the quick flash of light that proves to the world that you are not a "cat person" is not, technically speaking, static electricity, however. Static means un-moving, or stationary, and something zapped from your finger to the cat, obviously in motion. An electrical engineer would refer to it as a "spark." This is probably as good a time as any for us to begin learning technical terms like that. Whatever it is, if electricity isn't moving, we call it static electricity. A spark is electricity moving through air. Static electricity can cause sparks, but once it's moving, it's not static any more.

Static electricity is what filled your body when you shuffled your feet on the carpet. As you stood there grinning, saying, "Here kitty-kitty..." in your sweetest voice, you were loaded with the stuff. Except that your hair tended to stick out, you couldn't feel it, or smell it, or sense it in any way. The friction of your feet gathered something from the carpet, something invisible to all of your senses. Whatever it is, it can't be observed directly. The only evidence of its existence is the effect it has on things that we can observe. Things like cats, and sleeping grandparents.

In a similar way, droplets of water in a windy cloud gather static electricity through friction with the air. The billions of droplets in a single cloud can gather an awful lot of static electricity. The sparks formed this way are called lightning. Thunder heads are often brimming with incredible amounts of static electricity as they cruise the suburbs in search of die-hard golfers.

The study of electricity began in ancient Greece when shepherds discovered that they could gather static electricity by petting their sheep with pieces of amber (petrified tree sap). It is hard to imagine why that first shepherd decided to try the experiment. It is also hard to imagine why they continued the practice long enough to make it into the history books, since there isn't a lot you can do with static electricity. I suppose it's evidence that they also had cats.

These unwashed illiterate sheep herders, camping for months with their flocks, rubbing the ones they could catch with amber, are the fathers of modern electronics. They discovered that the piece of amber became temporarily changed by this rubbing, and would now attract little bits of dried leaves, just like a magnet attracts iron. Wonderful trick though that is, the Greeks did not spend a lot of time developing it, and electricity remained a harmless novelty for about 18 centuries. Interestingly enough, the Greek word for amber is "electron."

During the 18th century (1700-1799) guys in tight pants and powdered wigs performed what were known as parlor tricks. After dinner, they would retire to the living room, (known back then as the parlor) and amuse the young ladies with gadgets and magic tricks involving things like magnets, mirrors and primitive household chemistry. This era is fondly referred to as "the Age of Enlightenment" and these parlor tricks evolved into what is now known as science. Because of one parlor trick, these fellows figured out that there are two different kinds of static electricity.

Our dapper heroes took a bar of hard rubber and rubbed it on some wool. This was called charging it.

A small, lightweight ball, made of the spongy material found inside dead weeds (pith) was suspended from a string.

Now, if they held the rubber bar close to the hanging pith ball, the ball would swing toward it. The charged rubber bar attracted the pith ball. However, if they let the two actually touch each other, after clinging together for a second or two, the ball would swing away from the bar. No longer attracted, it was actually repelled by the bar. By touching it, the bar had transferred some of its charge to the ball.

The experiment worked just as well if they charged a glass rod by rubbing it on silk. It would attract the pith ball for a long time, unless the two actually touched each other. If they touched, they would cling together for a minute, and then the ball would swing away from the rod and do its best to avoid the rod however it was chased.

Here's the interesting part: A pith ball that has been in contact with a charged rubber bar, while now repelled by that rubber bar (or any other charged rubber bar) is still attracted to a charged glass rod. And a pith ball charged by contact with a glass rod, will try to swing away from any charged glass rod, but will be attracted to a charged rubber bar. Kind of like some innocent puppy that chases both skunks and porcupines. If it catches a skunk, it learns its lesson and runs away from all future skunks, but it still chases porcupines.

Obviously, there are two kinds of static electricity. There's the kind you get by charging bars of hard rubber and the kind you get by rubbing glass and silk together. This parlor trick, and this deduction, are important only because all the rest of the science of electricity is based upon them. Otherwise I wouldn't even mention it. They could have named the two kinds of charge "Glass-Type Charge" and "Rubber-Type Charge." They could have named them "Bartholomew" and "Alfred." As it turns out, they named them "positive" and "negative."

By repeating the old pith ball trick dozens of times for the bored young ladies of the day, these fellows came to be pretty good at it and could predict what was going to happen. Each and every time, a charged object would attract an uncharged ("neutral") object. And two objects, one charged with positive static electricity and the other with negative, would be attracted to each other.

But two objects, both charged with positive static electricity, would repel each other. Two objects, both charged with negative static electricity, would also repel each other.

There have been many complicated theories over the years to explain why this is so. Most people are happy with the current explanation, a few aren't so sure. The experiment itself can be performed in dozens of variations by a child, and the results are consistent. Something magical happens when things are occupied by static electricity, and we remember it by the simple slogan:

"Like charges repel each other. Opposites attract."

A Brief Digression

It occurs to me that the world would be different, in subtle ways, if they had actually named the two types of charges Bartholomew and Alfred.

When we jump-start a car, we'd have to remember to connect Bartholomew to Bartholomew and Alfred to Alfred. We'd have to remember that electricity always flows from Alfred to Bartholomew and never from Bartholomew to Alfred.

A transistor has three sections; We'd have to label the two types of transistors as either Bartholomew-Alfred-Bartholomew transistors or Alfred-Bartholomew-Alfred transistors. Parts would have to be made larger to accommodate printing the names, and therefore heavier. With these larger, heavier parts, space flight would probably have been impossible.

In some ways, on the other hand, we would have been better off with Alfred and Bartholomew. The words "positive" and "negative" have caused us many problems. Back in the pith ball days, no one knew for sure if electricity moved, or if it was alive, or what. Ben Franklin was pretty sure it moved, only it moved so darned fast he couldn't tell which direction. In trying to organize the thinking about this infant science, he took a calculated mental gamble and suggested that it always moved in one direction, from one type of charge to the other. So far, he was correct. Pushing his luck, he guessed that it always moved from things with a positive charge toward things with a negative charge. After all the parlor experiments, those terms were established. This time old Ben bet on the wrong horse, however. Much later, with more modern instruments, we learned that electricity always moves from things that have a negative charge and toward things that have a positive charge.

This was embarrassing. Everyone loves Ben Franklin. After all, wasn't he the man who invented Daylight Savings Time as a joke, never thinking for a minute anyone would actually try the silly thing? Wasn't he a founder of our country? Now our scientists would have to say he was dead wrong. Worse than that, years and years had gone by, with textbooks written, devices invented and patented, final exams prepared and graded, all based on diagrams that had arrows pointing the wrong direction.

We had to change the textbooks, of course. We had to set the record straight. But, to be polite to old Ben, we created some jargon to make him look a little less foolish. The truth is that electricity always moves from negatively charged things toward positively charged things. But, if you're looking at an old diagram with arrows going backward, you don't say it's written wrong. You say that it is written in "conventional current." In conventional current, electricity goes from positive to negative, like Ben thought it did. "Conventional" is a great electrical jargon word which means "backward from what's really going on."

So now you've got two important things to remember. In static electricity, things with the same kind of charge ("like charges") will repel each other, while things with opposite charges (a positive and a negative) will attract each other. And when electricity, whatever it is, moves, it always moves from negative things toward positive things.

It would be a good rule for all of us to follow in our lives.

The Electron Theory: Scientific Models and Watermelons

Man thinks in analogies, in fables, in parables. That is, he compares things he doesn't understand to things he does ("It's like bees pollinating flowers, son.") This makes facts understandable and easy to remember. We take subtle, confusing or complicated phenomena and translate them into simple little picture stories. ("The universe is like a watermelon, and the stars are its seeds.")

These "scientific models" are useful teaching tools and handy communications aids, but they are also dangerous, because no model is perfect. When we use an analogy or model too much, we risk losing sight of the reality the model tries to represent. In the worst case, we teach school children that our model itself is reality. Scientific thought has always been limited by the imperfections of its various analogies.

In most ways, electricity is not much like the models used to describe it. "It's like water flowing through a pipe;" "Radio waves are like ocean waves;" "Resistance is like friction." Although each of these may help you understand some aspect of electricity, you have to be constantly aware that they are all just little picture-stories, little teaching tools, and nothing else. It's not like bees pollinating flowers, really, son. It's better than that.

The electron theory is nothing more than one more rather elaborate scientific model which may or may not be perfectly accurate. Your teachers will tell you it is perfect, that it is truth. Then, next year, when it must be modified a bit to accommodate some new information, they'll tell you once again that it's perfect, it's truth, it's reality. It won't occur to them to apologize for lying to you last year.

On the other hand, humans do think in analogies. The electron theory, bizarre and outlandish as it seems to me, works for most people. Models should not be thrown out with the bath water. They are not dangerous as long as you remember Amdahl's First Law:

"Don't mistake your watermelon for the universe."

The Electron Theory: The Easter Bunny of Science

For a long time, static electricity was the only show in town. In the early 1800's, if you said you were an electrical engineer, that pretty much meant you liked to zap cat noses. Many more parlor tricks were devised, most of them based on the same attraction-repulsion concept. In order to create even neater tricks, people wanted to understand what was actually going on inside that pith ball.

Why does friction create static electricity?

Why do objects charged with static electricity attract things like pith balls and paper?

Why do opposite charges attract each other, and like charges repel each other?

The truth is, nobody knows for sure. In the last couple hundred years several theories have become popular, then faded and been replaced. Each one, in its time, was taught as truth. People have devised some marvelous parlor tricks (television, satellite communications and computers spring to mind) despite these changing theories. Ben Franklin, Thomas Edison and Albert Einstein each made contributions, even though they subscribed to different theories.

As I write this, the vast majority of people believe that the electron theory is truth. When I say "the vast majority" I mean "every single person who thinks about electricity except me." Given the history of man's theories, that doesn't bother me. In 1450 they called you a goofball and you flunked geography class if you didn't believe the world was flat. In 1900 you flunked physics if your calculations indicated it was possible for man to fly in machines. In 1980 you'd lose your tenure for suggesting that superconductors were possible at temperatures as warm as liquid nitrogen, though now we know they are. Today science teachers will think you're more than just a bit odd if you don't believe in the electron theory. They certainly won't accept you into graduate school, let alone allow you to repair their TV set.

Therefore, you need to know enough about the electron theory to pass for one of Them – should you ever get surrounded by a mob of high school science teachers, for example. Your life may depend on it. If you find some irritating inconsistencies in the electron theory, don't worry. That only means that your brain is still alive. Just remember, it's called a theory because it has never been proven. True believers will insist that anyone with a pure heart will accept it on faith, this collection of bizarre, supposedly self-evident truths. Of course, that's also what they said during the Spanish Inquisition, and the Salem witch trials.

The electron theory maintains that everything in the universe is made of tiny particles called molecules, most of which are too small to be distinguished even when using the best microscopes in the world.

You will know you're dealing with a molecule, and not something larger, this way: If you try to break it into smaller pieces you'll change the nature of the material. For example, if you took a single molecule of salt, and broke off even a little of it, it would no longer be salt. It wouldn't taste like salt or act like salt. Some of it would look and act like sodium, while some of it would look and act like chlorine. Chlorine is a poisonous gas, by the way, so if you decide to split up some salt molecules, don't sprinkle any on your tomato sandwich. The smallest amount of salt you can have is one molecule.

But molecules are not the smallest critters in the zoo. Salt molecules are built out of sodium molecules and chlorine molecules. Water molecules are built out of hydrogen molecules and oxygen molecules. These, again, can't be broken down any further without changing the nature of the stuff. Chip away at a hydrogen molecule and you get something that is no longer hydrogen. At one point in history, someone decided that the substances that couldn't be broken down at all (by the methods available to them) were the smallest, simplest things that could be known. They were the building blocks, or elements, of every other substance. Scientists made a systematic list of these elements and started writing chemistry books.

Then someone figured out that elements must be made of even smaller parts. It was the only way to explain the results of their experiments. Different models were tried. The one that stuck says that molecules are built out of atoms.

Atoms are visualized as tiny solar systems. They have a massive central part, called a "nucleus," with little bitty satellites called "electrons" spinning around them. These electrons are so tiny that some early books said they have no weight.

The nucleus is made of relatively large and heavy components. There are two types of items that might be found in a nucleus. One kind is a proton, which always has a positive charge. Picture a proton as a big yellow pumpkin. A nucleus always has at least one proton. It may have several clustered together, like a mass of pumpkins glued together into a big ball. A nucleus may also have one or more neutrons. Picture a neutron as a big green watermelon. Neutrons are just as massive as protons, but they have no charge.

So, you have a mass of pumpkins and watermelons glued together into a bulky decoration to hang in your living room. Since protons always have a positive charge, and neutrons have no charge at all, the whole affair has a positive charge. The more protons, the more charge. Adding neutrons (watermelons) increases the weight of the nucleus, but doesn't affect the charge.

Picture the electrons that are buzzing around this huge vegetable sculpture as mosquitoes. Each mosquito (electron) has a negative charge. In fact, each one has exactly the same amount of negative charge as one pumpkin (proton) has positive charge. Since opposites attract, each pumpkin will attract exactly one mosquito. If there are five pumpkins hanging there, there will probably be five mosquitoes in frenzied orbit. Those nasty little bugs are moving so fast that even in our model we can't see them. All we see is a blurry haze, like a cloud surrounding the nucleus.

The electrons organize themselves around the nucleus in very specific flight patterns. According to the theory, they form layers around the nucleus, like the layers in an onion. Each layer can accommodate only a certain number of electrons. When the layer closest to the nucleus is filled, the next layer starts filling up, and so on. The electrons in the layers closest to the nucleus feel its attraction the most, and are the most difficult to disturb. They paid a lot of money to get front-row seats, and they don't care if it rains. They're going to stay.

Electrons that can't be disturbed easily are called "bound" electrons.

The outermost layer or "level" of electrons is the most interesting. In the atoms of some materials, the electrons in the outer layer are held relatively loosely. It doesn't take much effort to dislodge them. These are called "free" electrons. Once an electron is knocked away from the atom, it goes bouncing around through the material and will probably knock other electrons loose.

The electron theory, in a nutshell, says that electricity is this movement of free electrons. Static electricity occurs when there is not an equal number of protons (with their positive charges) and electrons (with their negative charges). The nucleus is massive, like the pumpkin and watermelon decoration which you have forgotten to remove from your living room. The electrons, like mosquitoes, are highly mobile. So, if anything is going to move, it's going to be the electrons. Electrons are repelled by other electrons. (All electrons have a negative charge. Like charges…) Electrons are attracted to positive charges (opposites…) An atom which for some reason has more protons than electrons will have positive charges which are not off-set by negative charges. It will have vacancies in its outer shell. Electrons will be attracted to it.

How does the electron theory explain the pith ball trick? When we shuffle our feet on the carpet, it says, we somehow accumulate extra electrons in our body. Our body is, therefore, negatively charged. These electrons tend to repel each other. They move as far away from each other as they can, and wind up being concentrated on our skin. The electrons on the skin of our finger repel electrons in the pith ball. Electrons flee from its charge. Pretty soon we have chased enough electrons away from our finger that they are concentrated on the far side of the ball. That means that the near side has too many protons; it has a positive charge. The negative charge on our finger, and the positive charge on the near side of the ball will attract each other. One of two things will happen. The electrons will leap across the gap, and we will see a spark. Or the protons, locked together in the pith ball, will move as a group toward our finger. They will pull the rest of the ball with them.

If we touch the ball, electrons stream from our body onto the ball until it has many more than usual. It has as many as it can hold. We have given it a negative charge. Now the ball is repelled by our still-negative finger.

It's a slick explanation. Oh, sure, it doesn't answer the questions: Why do like charges repel each other? Why do opposites attract? What does a proton have that an electron wants? And what is a charge, anyway? How did protons and electrons get them? And why don't neutrons have any? If you get more deeply curious, you will find people willing to tell you that an electron has no weight, yet it is subject to centrifugal force. But your science teacher says only things with weight are subject to centrifugal force. A few people will suggest that it does have weight yet it moves at speeds approaching the speed of light. Einstein proclaimed that to be illegal. Why are some electrons happily bound, while others with the same background are free?

The electron theory doesn't answer these questions. Your science teacher will say, who cares? And who cares that electrons have never been directly observed? We have seen streaks of light in cloud chambers that we think are the footprints of electrons. We have seen dots on photographic film that we believe were caused by electrons. True, we set up those experiments believing ahead of time that we would see evidence to support the electron theory, but that shouldn't matter, should it? It is widely accepted as truth. It works. That's why it's not called the electron hypothesis. On the other hand, it has never been conclusively proven. That's why it's not called the Electron Law.

Books have been written on the electron theory, courses have been taught, degrees granted. If you want to pass this course, (you will hear) stop making trouble.

Now comes the hard part. You must learn to smile and agree with them. Don't confront them, not yet. We are dangerously outnumbered. Imagine yourself transported in time back to old Salem, where they burned people suspected of conspiring with the Devil. Now imagine that it's bonfire season, and you realize you have somehow brought a television set and DVD player with you. Do you invite the neighbors in to watch your collection of Star Trek re-runs?

Another example: Imagine yourself as a single Oklahoma Sooners fan in Lincoln, Nebraska, in the wrong bleachers at the annual Football Game and Bone Crunching Ceremony. The biggest game of the year, the Grudge Match, The Hate Bowl. You are surrounded by 50,000 fans, all dressed in red, foam dribbling from their rabid lips, hate and anger in their eyes. Whose fight song are you going to sing?

"Of course there are electrons! I believe! I believe!"

Shout it out loud a few times. Then pull the covers back up over your head, turn on your flashlight and continue reading. There are no electrons. It's not like that at all.

The Ultimate Rubber Band Gun

Wait a minute, I hear you saying. Let me get this straight. Things that have the same charge repel each other, push each other away. Yet protons, those massive particles which have a positive charge, cluster together with each other and with neutrons to form the nucleus of atoms. Why don't they repel each other? What holds them together?

The answer is that they are held together by rubber bands. The protons want to repel each other. They push at each other just as hard as they can, but those little rubber bands are tough. They rarely break.

Of course, when they do break, the nucleus explodes. Protons and neutrons fly in every direction, releasing all their stored-up energy. Some of the energy escapes as heat, some as light, some as other forms of radiation. We're talking about a lot of energy here. If the movement of mosquito-electrons can do lightning-sized damage, imagine what happens when you start throwing pumpkins and watermelons around.

When one of those protons or neutrons, careening free like a crazy bowling ball, happens to slam into another nucleus, it's likely to break that nucleus' rubber bands, too. More protons and neutrons will be freed. This is called a "chain-reaction." If there are enough protons and neutrons bouncing around, the reaction will be self-sustaining. The material is radioactive. You might be able to see it glow.

If the material is dense, that is, there are many massive nuclei close to each other, and you've got enough chain reactions, a lot of heat, light and other radiation will be produced. The limiting factor becomes the physical size of your chunk of radioactive stuff. If it's small, the whole process is controlled; a lot of those wild and free nuclear particles won't run into another nucleus before they escape into the air. The heat produced in this situation can be captured and used.

If your chunk of radioactive stuff is bigger, the odds increase that each proton will bang into another nucleus before it flies free. More chain reactions will be started than are fizzling out. This point is called the "critical mass." When you exceed the critical mass, your atomic bomb explodes.

Scientists who try to picture everything as some variety of wave or field or force call the rubber bands "the strong force." Scientists who try to picture everything as some sort of particle call the rubber bands "gluons." This is because they glue the nucleus together. No one knows what really holds protons together in a nucleus. No one knows if there really are protons. They certainly don't know if there are electrons. But they know that if you break your rubber bands, you will blow a huge piece of real estate to smithereens.

You don't need to know any of this to study electricity. I just thought it was interesting.

A New Age Dawns:
Who's Moving Around Inside That Wire?

It's Little Greenies.

That's right. Little Greenies. It's not electrons at all. Electrons are a myth, a superstition. They don't make sense, they're boring, and they've never been proved. Shoot, I've never seen an electron, have you? Of course not. No one has. Sure, the electron theory seems to work a lot of the time, but so did the Flat Earth Theory. The theories of Aristotle, Newton and Euclid appeared to work pretty well, too, for a few hundred years. Now they seem childish. All because bold and adventurous thinkers like you and me were willing to consider alternatives.

Elegant and innovative alternatives, like The Greenie Theory.

I developed The Greenie Theory while fishing at a lake in Utah. It was one of those rare and special times when you have a whole city's water supply all to yourself. One of those days when the fish won't bite, but the sun is hot, the water is cool and clear, and you don't care. Cynics will try to convince you that the beer I was drinking provided most of my inspiration. I'm sure they said that about Einstein, too.

Anyway, as I started to work on that second six-pack, I experienced a vision, a revelation. Electricity suddenly made sense. All I had to do was forget the nonsense I had been trying to understand about charges and protons and neutrons, examine the evidence with an open mind, and it became obvious. There were little guys inside those wires. Little green guys. Once I had that much, the rest fell into place. By the end of the day, not only had I filled in the details of The Theory, but I had proof positive that it was truth.

Like electrons, Little Greenies are too small to be seen. Even if you had a microscope that was infinitely powerful, you couldn't see them, because they're invisible. And, even if you had a tool that allowed you to see invisible things, you'd probably never corner one to study, because they're imaginary.

That may be the key to my whole theory, and why it will ultimately replace the electron theory. A big flaw of the electron theory is that scientists give electrons a whole truckload of outrageous characteristics and then ask us to believe that the little rascals are real. That is confusing. Real things can usually be proven. Real things don't have contradictory characteristics. Real things can be visualized. Scientists will tell you for example, that no matter how sophisticated our instruments get, it will always be impossible to know exactly where any one electron is at any certain time. It's part of the theory. Does that sound like a real thing?

On the other hand, people don't have any difficulty in accepting and believing in imaginary things (like a balanced federal budget, or UFOs, or lucky fishing shoes. Even now I hear you say, "Wait a minute! That's not fair! Those shoes really are lucky!") As long as we understand that something is imaginary, we don't have to justify it. We simply don't walk under the ladder, or sleep on the 13th floor. I bet the electron theory guys wish they had thought of it first. This little twist makes the Greenie Theory a near-perfect scientific model. It works in every case, it's easy to believe, and it's impossible to disprove. It would be like trying to disprove the existence of Santa Claus. Maybe you can't prove he exists, but it's even tougher to prove that he doesn't. And, as long as you believe, it doesn't really matter, does it?

But, as I said before, I have proof. I was working out some of the finer details of the theory, fishing pole in one hand, beer can in the other, sunburn spreading across my neck and shoulders, when I realized I wasn't alone.

"Psst!" The sound startled me and I dropped my fishing pole. It clattered on the rocky ground as I tightened my grip around the beer can in my other hand. At first I thought it was a snake, then I realized someone was trying to get my attention. Yet I knew I was the only human within 50 miles. I would have seen the dust if someone had driven up to the lake, and no one could have hiked in. Hesitantly I stood up and peered around the boulders. Someone was talking to me.

"Like, man, it's a bummer, can you dig it? Like, my foot, see, it's stuck in these rocks. Not cool, man, not in the program. Do you read me?"

It was a young man, very thin, in an a white T-shirt and cut-off jeans. His hair was light brown and hung down to his shoulders. He wore a red head-band. His features were pleasant enough, in fact, he would probably have been considered good-looking on a college campus, except for one slight irregularity. From his face to his bare feet, his skin was as green as spinach.

"What?" I said. The surprise of seeing anyone, let alone someone who looked like they had been dyed green at Woodstock, disoriented me a bit.

"My foot's stuck," he repeated, tugging at his leg as if to prove it. Finally I came to my senses and helped him move one of the boulders enough for him to slip free. The stones were big; I didn't see how anyone could have gotten a foot between them in the first place unless they simply materialized there.

"Like, thanks, bro'," he said, rubbing his ankle. He reached out to shake my hand. "The name's Mike." I shook his hand.

"My name..."

"Yeah, I know. You're Kenn. I know all about you, man. You were picked." He started rubbing his foot again. "Just like me."

He flexed his ankle while I stood there speechless, watching him. This had to be someone's idea of a bizarre joke.

"No damage done," he said, putting some weight on his foot. "We've never tried that before. Could have been worse. I could have come together inside a rock or something."

"Who are you?" I was too surprised to be tactful. He laughed. It was an easy, confident laugh.

"You mean what am I, don't you? I'm a Greenie. 'Little Greenies,' I think you call us. We're the guys in electricity, the brothers boogyin' down those wires, lighting your bulbs, frying your burgers. Your brain was scrambling trying to picture an electron and you said the magic word. So, here I am."

"Aren't you a little...big?" He laughed again.

"Like, this probably seems a little off-the-wall to you, doesn't it? Like, I'm probably weirding you out. Usually I'm real small. This is a first. I don't know exactly how, but they changed me so I'd be more like you. 'Anthropomorphosizing,' I think they called it. It's supposed to be temporary." He grinned with very white teeth and crossed his fingers.

I sat down on a rock and reached for another beer. Just to be friendly, I offered him one too, even though I was pretty sure I was in the middle of some sort of heat-induced hallucination.

"No can do, bro', wrong dimension. But it's a good idea. The first communication between man and Greenie. That's like history. We ought to have a brew together. Slop some suds."

He reached behind the boulder and pulled out his own six-pack, opened a can, and drained it down. "Right on!" he said, wiping his green mouth with the back of his green hand. "Sock it to me!"

I just stared out at the glassy lake and wondered what I had eaten that might have been bad. Mike was happy just to sit there not saying much, drinking his beer and watching the birds. He seemed very real.

There was no easy way to start this conversation. "If electricity is really you little Greenies, why haven't you made contact before?" I asked.

"Hey, why haven't you guys tried to contact us? Anyway, we just found out that humans exist. We managed to pick up a couple of your television programs, and finally figured out how to de-code them."

"So that's how you learned English?"

"Right on, man! We learned everything about you humans from just three TV shows. First, of course, there was "Dobie Gillis," with that smooth cat Maynard G. Krebbs. Then we picked up on "Laugh-In" and "Saturday Night Live." It's all we needed, if you can dig it.

Totally. Now we're working on de-coding some musical show about a gong which ought to help even more."

"You learned English by watching "Dobie Gillis" and "Laugh-In?"

He smiled and nodded, proud of that accomplishment.

"A lot of Greenies still don't believe in you humans, though. That's part of the reason I was sent. I'm supposed to get evidence. Do you have any ideas?"

"If they don't believe in humans," I asked, "What do the rest of the Greenies believe in?" In unison, like spectators at a tennis match, we turned to watch a bird gliding low over the water looking for fish.

"It's weird, man," he said. "They've got this fairy tale to explain all the strange things you folks do. They call it the electron theory.

I just nodded, and we didn't talk any more. Didn't need to. We understood each other. The sun sank below the horizon and we watched the twilight uncover all the colors that had been hiding in the clouds. The sky faded from blue, to orange, to gray, and finally to deep velvet black. Mike the Greenie and me, the human, fell asleep without noticing that we were sleepy, like little boys at summer camp.

If I had dreams that night, of any kind, I've forgotten them.

Birth of a Prophet

"Why do you call yourselves Greenies?" The sun had risen, and I was frying a couple of fresh trout over the campfire.

"Actually," Mike said slowly, "You were the one to call us Greenies. The name we call ourselves does not translate well. But our scientists could tell, somehow, that you were on the right track. Anyway," he said, pulling his T-shirt up to expose a flat green belly, "We're green."

"But, in my theory, you were invisible."

"That makes it tougher, of course," he said, "But hey, I believe you also said we're imaginary. I don't feel imaginary, but I guess it's possible. If you're imaginary, man, you can be whatever color you want. And I want to be green."

"Maybe I just don't understand. You're green, and you're invisible. You exist, and yet you're imaginary?"

"Hey, man," he said, "If you can't handle the truth, you can always go back to the electron theory."

I just nodded and we ate the trout in silence. Contradictions had never stopped any other scientific theory, I thought. And, after all, he was right there beside me, a green hippie who appeared out of nowhere from another dimension. It was a pretty compelling argument. I did find it curious that he could eat my trout, but he couldn't drink my beer. I decided it was a minor philosophical annoyance. We talked all morning.

I learned that Mike was a messenger and pioneer of sorts. His mission was to explain to me what electricity really is, and why it does the things it does. I had been chosen to receive this message, to be a sort of prophet who would teach this truth to the world.

I told him I'd rather just fish. He shrugged.

"It's up to you man. I'll lay it out for you, you do what you want. But it's a pretty low-key gig. Nobody'll believe you anyway."

"Then why bother?"

"Oh, sooner or later they'll dig it. It's a human tradition, as far as we can tell. One guy figures things out, he gets ridiculed and usually killed. They sock it to him. After a while, everyone says, 'Hmm… old dead what's-his-name had a good idea, didn't he? Maybe we ought to try that.' Then they use his idea, make a lot of money, and name a wing of the library after him."

"You make it sound like a lot of fun."

"Hey, we don't figure they'll kill you. They'll be cool. We figure they'll call you crazy, say you're not a totally hep cat. Then they'll put you on the late night talk shows and let you drift into oblivion. You'll be small potatoes. It's not like you'll be suggesting nationalizing the utility companies, or cutting the tobacco subsidy."

"I don't know…"

"Look, no robes or anything. Keep the sneakers. You don't even have to talk. Just write it down somewhere, like in a diary or something. Fifty years from now, who knows? Maybe you'll be famous. Anyway, I got to tell you what I know before I split. Otherwise, I can't

get back. And I got this chick back there…" His eyes rolled upward and his smile told the rest. How could I resist? I couldn't keep him from his Little Greenie sweetie.

"Okay, Okay, no promises. But I'll listen."

Mike pulled a trout out of the pan and grinned. "Dreamsville, daddy-o! Too much!"

I didn't have the heart to tell him that no one talks like that anymore.

Voltage and Motivation: Greenies Do Things For Reasons

"Greenies like to party," Mike said. "It's what we live for. And a party means girls, beer, and rock 'n roll. If there's a bunch of Greenies cruising down a wire, you can bet we're headed for a party."

"Am I supposed to be writing this down?" I asked.This was a new role for me. Mike and I were sitting by the lake fishing. He had somehow come up with the neatest fishing pole I'd ever seen. It was long, glossy black, and made a low whirring sound whenever he cast.

"Nah," said Mike. "You can't write and fish at the same time. Let's just mellow out and get on the same wavelength. Let the heavy stuff slide for a while."

"Right," I said, suppressing an urge to either say, "Like right," or "Right on."

"Anyway," he continued, "When Greenies party, it works like this: the chicks buy kegs of beer and turn up their radios. The brothers hear that rock 'n roll, get in their little green cars and motovate toward the music. Works every time."

"Don't the girls ever drive toward the guys?"

"No, man, that's not the way it works. The chicks buy the beer and we chase 'em. We hear that music and the urge comes over us. We call it the "need-to-party." Suddenly he put down his pole, went over to the boulder he had appeared behind, and came back with a book. "It's a Greenie-English dictionary," he said. "You know, for translating.

Let's see, need-to-party...Oh, yeah, here it is: 'voltage.' We call it the need-to-party, you call it voltage. Does that make sense to you?"

"Well, sort of," I said slowly. "Voltage is supposed to be electrical pressure. Electromotive force, they sometimes call it. If you have a lot of electrons in one place, they'll repel each other. That's because they all have a negative charge. They'll be attracted to a positive charge. The amount of attraction is called voltage. If you have a lot of electrons in one place and very few in another there's a lot of voltage between the two places. Voltage is also called 'potential,' because whenever you have that situation you have the potential of electrons moving to equalize their numbers in the two spots. Basically, voltage is electrical pressure."

Mike just stared at me.

"That's what they teach you?"

I nodded, and he shook his head.

"That's heavy, man. You got to can all that stuff. Voltage is like..." He paused, searching for a word. His face brightened. "Desire. That's pretty good. Or motive. It's the reason we move. Whether we can get to the party or not, voltage is how much we want to go." He shook his head in disbelief. "Electromotive force! What do they think, we're like water in a pipe, and voltage is the water pressure that forces us through?"

"Well," I said, "Actually I have heard that analogy used before..."

"This may be harder than I thought." Mike stared into the distance. The sun was reflecting off all the tiny wind-waves on the surface of the lake, the birds and insects were settling into their mid-day song routines. I thought I saw his fishing line twitch just a little.

"Electricity is Greenie dudes making tracks for those Greenie babes. And voltage is the reason we go. It's our need-to-party. It's our thirst for brew. It's the big itch that must be scratched. It's a lot more like hunger than it is like water pressure."

"I've never heard it explained quite like that before."

"I can dig it, man, but I got to tell it like it is. Say you got a flashlight battery. On the positive side of that battery you got a bunch of Greenie chicks. And, I mean, some of those chicks are *very* positive. On the negative side, you got some Greenie dudes. Those chicks, they buy a couple kegs and turn up their little boom boxes. Us guys, we hear the music, and right away we feel that need-to-party. The more chicks there are, the more little boom boxes they got, which makes that music loud. That means more dudes hear it and feel that need-to-party. If there's a way for us to get there, we're gonna cruise. If all the bridges are down and the roads are closed, maybe we can't get there. But we're still gonna feel that urge. That's what voltage is: It's boy Greenies feeling that need-to-party and girl Greenies playing rock 'n roll. Voltage is that hunger to be movin' on down the road."

That all seemed pretty far-fetched to me. "Gosh, Mike," I said, trying to be diplomatic. "Most of the books I've read say that the negative side of a battery has excess electrons, giving it a negative charge. The positive side of the battery hasn't got as many electrons as it has protons, so it has a positive charge. The excess electrons are attracted to the positive side of the battery. Given a route, they'll travel toward it. Voltage is supposed to be the difference in those charges that causes the attraction."

Mike just laughed. At that moment, the tip of his pole jerked toward the lake. He yelled out some expression I'd never heard before and began playing a fat rainbow trout. Obviously, my education would have to wait.

The Woodstock of Voltage

The first dream didn't make me nervous. It was natural, even pleasant. I was floating effortlessly through a dense swirling fog. Somehow I knew that I was a great distance above the ground, and the fog around me was really a cloud. The wind lifted me like a feather, but I felt no sense of danger, no urgency or unease. I could have been a drop of water, comfortable in familiar surroundings.

Gradually I became aware that someone else was also floating in the cloud, but I couldn't see them clearly. I tried to shout a greeting, but, in my peaceful, sleepy condition, that required more effort than I could muster. I closed my mouth again and waited. The wind tossed me more vigorously, but it didn't frighten me. It was fun. I found myself laughing like a trusting baby being tossed around by his mother. The other figure moved closer as the wind tossed him, too, and I could see that it was Nick Scott, my best friend in first grade. I can't remember now if he looked grown up or not, and it didn't seem to matter at the time. It was Nick, all right, and though we hadn't seen each other for years, he recognized me at once and grinned. A happy warmth filled me. There was a lot of catching up to do, a lot of questions I wanted to ask old Nick, and I didn't know where to start. Nick nodded, as if he understood, and neither of us spoke. It was enough just to be together again.

Now I could see that there were other boys and men floating in the cloud, too. As they drifted close, I recognized old friends I hadn't seen in a long time. Each one smiled and nodded when they saw me. They kept appearing out of nowhere until there were thousands of us, floating together, riding crazy up-drafts and sliding down invisible thermal hills like children at some bizarre amusement park.

Then I heard a familiar throbbing sound somewhere in the distance, too faint to be sure of. The men around me stopped moving and became alert, cocking their heads, straining to hear it, too. It grew louder and I could distinguish drums, then an electric guitar, and finally a familiar voice singing. It was Chuck Berry doing *Johnny B. Goode*.

Now, *Johnny B. Goode* is one of those songs I can't resist. My foot starts tapping at the thought of it. It affects me like a drug, or magic. When I hear it, I want to be on the dance floor, right next to the biggest speaker, flailing around like an octopus on a fish hook. Of course, when I heard it now, I moved toward the sound and so did all the guys around me. The sound came from somewhere below the cloud.

The bottom edge of the cloud was flat and abrupt, like a floor, and as far as my eyes could see it was covered with men and boys, floating and staring eagerly at the ground far below. There was a huge green meadow down there, with a stage in the middle of it. Chuck Berry Himself was playing with an all-star band, and he was really smokin'. He was burning up that stage as if he were 19 years old again and still had something to prove. He sang like he owned the world and all the good things in it, and rock 'n roll was the part of his kingdom he loved the best.

A huge crowd had gathered. With a start I realized that there were no men in that audience. Only beautiful women, dancing and clapping in time to the music, shaking their hair and laughing with each other. I'd never seen so many people having such a good time.

Suddenly a powerful feeling swept over me. I had to be down there. I had to be dancing. Nothing else in the world mattered, nothing else was real. There was only a burning hunger to be part of that crowd, part of the music. But it was much too far below me. There was no way to get there. My mouth went dry and I started to sweat. I ached to join the celebration.

From out of nowhere a green figure appeared beside me.

"Can you feel it?" Mike asked. I could only nod. "It's cool, man. That's what I was telling you about. That's the need-to-party. You call it voltage. All these guys are feeling it. When there's enough voltage, they'll jump. You will too. Watch this!"

Mike put his arms up in the air, crouched and dived toward the ground. I was terrified, as I watched him plunge almost in slow-motion. But when he finally hit the ground, instead of being smashed to bits, he bounced as if he'd landed on some huge trampoline and started coming back up. When he was nearly back to the cloud, someone else jumped, and the two of them fell together to the meadow only to bounce back once more. This time a dozen guys jumped with them. Pretty soon, thousands of men were diving from the cloud and bouncing off the meadow like a column of tennis balls. It didn't seem to hurt them, and I couldn't wait any longer. I leaped for the meadow.

Somehow Mike was there again, falling right with me.

"Lightning, man," he said. "You're doing lightning. You just can't hold back that much need-to-party."

"This is a weird dream," I muttered, and woke up just before I hit the ground.

Voltage: The Short Version

Voltage is the force that pushes electricity, the reason it moves, or wants to move. The word "voltage" hasn't got any special Latin meaning or anything. It simply honors an early scientist named Volta. Voltage is measured in units called volts. A flashlight battery might have a volt or two. Lightning might have a million volts.

Voltage is sometimes called "potential" because whenever there is voltage there is the potential for electricity to move. If you say something has a lot of electrical potential, that is the same as saying it has a lot of voltage. There does not have to be any electricity actually moving to have voltage. There need only be the potential for movement.

Voltage is also sometimes referred to as "electromotive-force" which is abbreviated "emf." Same stuff, new phrase. In formulas, voltage is usually represented by a capital "E."

Of course, you and I know that voltage is really "a group of Greenies' need-to-party" or their "Enthusiasm." This is also abbreviated "E" which is a handy coincidence.

If you refuse to believe in Greenies (or if you're captured and interrogated) say that voltage is the difference in the number of electrons between two points.

Current:
There Are Millions of Greenies Pounding on the Gates, Sir, and They Want to Hold an Election

"Weird dream," I said again as I woke up and rubbed my eyes. Mike was studying his little dictionary, and I could smell trout frying over the campfire. Mike was muttering to himself, and as soon as he realized I was awake, he began talking to me.

"Current!" he said in disgust. "Another dumb word! What do they think we are, drops of water or something?"

"Well..." I began.

"Don't answer, man. I don't think I want to know."

"Give me a better word," I said. "Better than that, give me a cup of coffee." I sat up as he handed me a cup of boiled coffee. I ignored the floating grounds and he ignored my sleepiness.

"Traffic, that's a better word. Little Greenies in their little green cars cruising toward the party. If there's lots of little cars, you say there's lots of current, we say there's lots of traffic."

"And that's different from voltage?"

"Oh yeah, man. Remember, voltage is the need-to-party, the desire, the motivation. It's the reason you get into your car. Current is how much traffic is actually moving down the road. You'd never confuse your thirst for a beer with the number of cars on the road, would you? Well, that's the difference between voltage and current. Different birds, man, different birds. If you had a bunch of cars parked on a steep hill, they'd all want to be moving down that hill. That steep hill is like voltage. It's the thing that pushes the cars. If a driver takes his foot off the brake, his car is going to roll down that hill. It becomes current. If there's lots of cars rolling, there's lots of current."

"I don't know, Mike," I said, sipping the coffee through my teeth to strain the grounds. "I was taught that current is the movement of electrons. If a lot of electrons are moving, we say there's a lot of current."

"Whatever works for you, man. I can dig it. I bet they count these imaginary electrons, too, and have another goofy jargon word for how much current there is, right?"

He had me again.

"They don't actually count each electron, of course, " I said, a little defensively. "But they do measure current. They can tell how much electricity is flowing through a wire. The unit of measurement is the ampere."

"Am-peer, eh?" Mike sort of grinned as he exaggerated the pronunciation. "Am-peer, am-peer; I kind of like that. I knew a girl once named Ampere. Greenest skin you ever saw. Everyone called her Amp, for short. Did they name the thing after some human girl?"

"Well, no. Ampere is not a common girl's name. Actually it was named after a man."

"A man! Wow, I bet he got teased in school!"

"It was a long time ago. Anyway, I think it was his last name. Current is measured in amperes, but sometimes we shorten that down to amps, just like the girl you knew did. You might say 'There's 10 amps of current flowing through that wire,' or 'The fuse will blow if two amps of current go through it.'"

"And do you have ampere jams when everyone gets off work at the same time and clog up the highways?"

"No, we call them traffic jams. We reserve the word ampere for electricity."

"Hmm," he said.

I took a deep breath and sorted the words in my head. Voltage is the force behind electrical movement. Current is the movement of electrons, or Greenies, or whatever, through something. Electricity can have both voltage and current at the same time, and usually does. We measure voltage in volts and current in amperes or amps. So, we might say something has 10 volts of potential and five amps of current flowing and everyone would know what we were talking about.

Even Mike would know. I could tell he thought our expressions were a little funny, and that kind of irritated me. I hadn't made fun of all his absurd attempts to talk like an American. Anyway, he was teaching me about electricity, and electricity is supposed to be a serious subject isn't it?

Yes. It certainly is.

Lake Dubious

High on a mountain sits a vast, cold and foggy lake. Two rivers leave Lake Dubious and wander down the mountainside to the ocean far below. One of the rivers is mighty, like the Nile, or the Mississippi. It is deep and wide, filled with huge, silent fish, and is used by water-skiers and houseboats. The other river is tiny, only a few inches deep and only a few feet wide. It's really just a creek. You can see the rocks you step on when you wade across it.

Lake Dubious is exactly one mile higher than sea level. Regardless of the twists and turns either river takes, they each transport water one

vertical mile over the course of their journey to the sea. The one mile difference in elevation between the lake and the sea is the reason the water flows down either river. Any drop of water in that lake has a potential fall of one mile in its future. This difference in elevation is the liquid equivalent of voltage.

Both rivers have the same voltage. They each have that same one mile difference in elevation from beginning to end. They are not identical rivers, however. One has a lot more water in it. The big river has more amperes of current. Because of this, the big river can do more work than the small river. It can carry larger ships, move large boulders that happen to fall into it, and turn a much larger water-wheel. Current is the muscles of electricity.

If you're looking for an electrical river to be your body-guard, choose one with many amperes.

Either river can move sand to the ocean. If moving sand is the job at hand, you have to know how much voltage is available, and also how much current. If you have more voltage, you'll move more sand. If you increase the current flow, you'll also move more sand. Since both the Lake Dubious rivers have the same voltage or potential, other variables account for their differences. Things like the size of their channels, whether they meander or plunge, or if either one is obstructed.

The work that electricity does is measured in "watts." Watts is simply voltage times current. If 10 amps of current are flowing, and you know you're using a 12-volt battery to push that current, then you are using 120 watts.

The power company charges you for the work their electricity does. They charge you for however many watts you use each month. Their meters measure the actual work done by electricity in your home. Your bill is based on how much sand you moved, and how far you moved it.

"Resistance, now that's a pretty good word. Opposition to current flow. Anything that makes it harder to boogy on down the road." Mike was studying his little dictionary again as I returned to camp. He hadn't even looked up, but just started talking. I was in a good mood because I'd caught several real beauties. I had always thought of 'resistance' as a political word, so I was a little confused again, but Mike just went on talking while I cleaned the fish. They really were nice fish, I thought.

"Remember," he said, "that current is like traffic. Greenies feel the need-to-party, jump in their little green cars and cruise. But there's all kinds of roads, man. Some are smooth, straight and easy to drive. They don't offer much resistance to traffic. Other roads are rotten. If it's tougher to drive, there's more resistance."

"Like a dirt road?"

"Right on! A dirt road has more resistance than a super-highway. Takes more work to go down it. A road covered with four feet of snow has a lot of resistance. If you don't have a desperate need-to-party, you won't even try to start the car."

"So resistance is green snow on the highway of life?"

"Well, yeah, I guess it is. But there's different kinds of resistance. Different materials are easier to travel through than others. Things that are easy to move through are called conductors. Metals are usually good conductors. They have very little resistance. If something has a lot of resistance, we call it an insulator. Wood is a bad conductor, a good insulator. Lots of resistance. Very tough to boogy through wood."

"I've found that to be true, myself," I said. "But you know, Mike, all the books say that a good conductor is something that has a lot of free electrons, while a good insulator doesn't."

"Well, shoot, I guess you better believe it then," Mike said with a serious face. "I didn't realize it had actually been written down in a book. It must be true. I know several million little Greenies that are going to be very disappointed, though. They'll be sitting in their little green cars looking for a highway and only finding a jumble of free electrons."

"I didn't mean to say..."

Mike interrupted my apology with a wave of his hand and a smile.

"Doesn't matter. I know you've got to tolerate all these mythologies. The important thing to remember is that electricity travels pretty easily through a conductor but, unless it has an awful lot of voltage, it won't go through an insulator. The less resistance a material has, the easier it is for electricity to go through it.

"But there's other ways to create resistance," he went on. "For example, which has more resistance, a big wire or a small wire?"

"Well," I said, "The big wire has more metal for the current to go through, so I guess it has more resistance."

"Wrong!" Mike was gleeful. "If you have a thousand cars to move from one city to another, will it be easier to go down a six lane interstate highway, or a one lane road?"

"That's obvious."

"Same with electricity. A small path is tougher to move a lot of Greenies through, so it has more resistance than a big path. Resistance can be a physical bottleneck, a very thin wire, something like that. Here's another one: Which has more resistance, a long wire or a short wire?"

I thought for a moment, not wanting to look foolish again, but knowing that logic alone wasn't going to explain Greenies any better than it explained electrons.

"I guess," I said slowly, "If you've got a thousand cars to move down a road, it would be harder to go a hundred miles than a hundred feet. You'd use up more gas, your drivers would get tired; pretty much in every way it would be harder. If current is like traffic, I'd say a long wire has more resistance than a short wire."

"Now you're catching on. A long wire does have more resistance than a short wire, and a skinny wire has more resistance than a fat one. Not much to it, bro'. A thing's resistance to current is determined by its size and shape and by what it's made of."

"And the more resistance there is, the fewer Greenies will go through it?"

"Basically, yeah. The amount of need-to-party affects the traffic, and the road conditions also affect the traffic."

"What you're saying is, if voltage increases, current also increases; but if resistance increases, the current decreases?"

Mike sat there thinking for a minute.

"Gosh, Kenn," he said at last. "I never thought of it that way before. But I think you're right." He started leafing through his little dictionary again.

"And the unit of measurement...let's see here...Oh yeah. Resistance is measured in 'ohms.' Ten ohms isn't much resistance. A million ohms is a lot."

"Hmm," I said.

"No man, not 'hmm'. It's 'ohm'. Resistance is measured in ohms."

"Oh," I began, but he misunderstood again.

"No man, pay attention. Ohms! Ohms! Resistance is measured in ohms!"

This time I just nodded.

Oh, Give Me a Home...

In the dream I was a buffalo, in the middle of a vast herd of buffaloes, and all of us were green. Several of us stood on a road near a sign that said, "This Way To Party." For as far as I could see, the prairie was dotted with green buffaloes standing around in the sunshine, chewing grass, making up poetry, doing buffalo stuff. I tried to do whatever they did and hoped they couldn't tell I was not a life-long bison.

Suddenly I heard faint music. It came from far down the road. Oh, no, I thought. Not *Johnny B. Goode*! I couldn't help myself; I immediately began walking toward it, trying to look casual. A few of the other shaggy creatures could also hear the music and began walking with me.

As the music got louder, many more of my bovine companions heard it and joined the procession. Shoulder to green furry shoulder, an army of these instinctive party animals moved toward that music like a huge rolling shag carpet.

Then the road ended at a steep canyon. We couldn't get across, but we could still hear the music, louder than ever. I discovered that buffaloes have a very intense need-to-party, and can get rather single-minded when it is aroused. They were peeved that they could not get past that canyon. It became obvious that things would not be pleasant if a solution was not found. I did not want to be handy if their playful mood turned nasty. When I suggested we all just go munch on some sagebrush and play Twenty Questions, a number of them turned toward me with suspicion in their beady little eyes.

Luckily, someone discovered a foot bridge before things got out of hand. The bridge was only wide enough for a single-file line, so one by one we began to cross. I didn't like the bridge. The canyon was deep, the bridge swayed. The vast army of snorting, hairy animals behind me pawed at the dust in their impatience and waited their turns. Deep down I knew that I wasn't like them, and that also made me nervous. The music was loud, the need-to-party was so strong you could smell it in the air. At least, I think that's what I could smell. The bridge allowed a few buffalo to make it past the canyon, but it restricted traffic greatly. Where hundreds of buffalo could travel down the road, only a single line could travel across the foot bridge. That one bottle-neck reduced all the party traffic for miles. Of course, if they turned down the music, I sensed that some of the buffaloes would lose interest pretty fast, and traffic would be even further reduced. The fellows farthest from the party wouldn't hear it. It seemed odd that both the volume of the music and the size of the footbridge could affect how many buffalo went to a party.

As I made my way across the bridge, (as carefully as is possible for a buffalo) I kept thinking that something was missing, like someone was trying to tell me something but my furry ears couldn't understand.

I woke up before I reached the party. For some reason, I couldn't get a phrase out of my head: When voltage increases, so does current. But, as resistance increases, current decreases.

It didn't seem to have much to do with buffalo.

Body Heat

Every time electricity fights its way through something that has resistance, heat is produced. The more current, the more heat. Also, the more resistance, the more heat. Since everything electricity goes through has some resistance, everything heats up, at least a little. A copper wire has less resistance than an iron nail, so if the same amount of current is flowing through them both, the nail will get hotter. A thin nail has more resistance than a thick one, so it will produce more heat. Air has a lot of resistance, but if you can provide enough voltage, electricity will even go through air. When it does, it creates a tremendous amount of heat. That's part of the fun of lightning, and why it can fry telephone poles so quickly. Much heat, produced by much current going through much resistance.

The fact that electricity always produces heat when it moves through resistance is extremely handy. The devices that heat our waterbeds, broil our steaks, toast our bread and zap insects on our patios all rely on the heat produced by electricity going through resistance to do their jobs. In the case of the unfortunate flying insect, its own body provides the necessary resistance. If an electrical device is producing heat, some current is probably moving through some resistance.

Heat produced by resistance is one of the most common and valuable products of electricity. Unwanted heat is also one of the principal causes of equipment failure. The heat created by electrical devices as an unavoidable by-product routinely melts and fries critical components. When heat is not the desired product (in a motor or computer, for example) the energy that is converted to heat is wasted and contributes to the inefficiency of the device. In many cases, enough heat is produced incidentally that equipment must be designed with a provision for cooling.

We all agree on this: Electricity produces heat as it travels through resistance. Why it does so is more of a mystery. It could be that electrons give up energy as they are forced to move from their normal nuclear orbits. More likely it's that Greenies get angry when road conditions make it difficult to get to a party and their temperatures (and blood pressures) rise. The more Greenies there are, and the more difficult the road conditions, the more heat.

Believe whatever mythology makes you comfortable, but remember this: Add more resistance, you'll get more heat. Add more current, and you're also going to get more heat. Of course, by adding more resistance you're going to reduce the amount of current, so the total amount of heat might not change. However, you can concentrate its location. If you've got a long stretch of super-highway interrupted by a cliff and foot bridge, it's easy to see where most of the buffalo cursing and swearing is going to be. Right on that footbridge, where the pressure from the rear causes a lot of painful horn wounds on your sensitive buffalo caboose at the same time that the herd ahead of you seems to be purposely trying to keep you from the party.

There are many angry phrases that don't translate well from buffalo-Greenie to English, but their general meaning is pretty universal. You will understand these phrases and learn to appreciate the heat produced by resistance the next time you try to change a light bulb with your bare hand without letting it cool down first.

Circuits, Switches, Ants, Lizards and Pigs

This has always bothered me: If the negative terminals of batteries have excess electrons (a negative charge) and the positive terminals of batteries have too few electrons (a positive charge) and opposites attract, why can't I hook a wire between the negative side of one battery and the positive side of a different battery and get any current?

The truth is it won't work. No current will flow. Had someone been able to explain that to me, I probably would never have written this book. I would have accepted the electron theory into my life with gratitude and respect for its inventors. If you like to watch people squirm, ask a science teacher to explain this to you. See if they can satisfy you without mentioning Greenies. Give them a time limit so they don't try to wear you down with jargon.

To get current to flow, there has to be a return path, a closed loop, a "circuit." A wire between the negative and positive sides of the same battery creates a "complete circuit," and current will flow through it like crazy until the battery is worn out. The word "circuit" means a path that finally returns to the spot it started from without any interruptions. If you ever want to do more than zap cat noses, you've got to fool with circuits.

A circuit requires a source of voltage like a battery. Current leaves the negative side of the battery, makes its way through a conductor and perhaps through other items like a light or a toaster, and then returns to the positive side of the battery. A device for interrupting this loop is called a "switch." The circuit is the pathway that electricity takes, including excursions through switches and other devices, until it finally returns to the voltage source.

If electricity can't flow through the circuit because the path is incomplete or broken, we call it an "open" circuit. If the loop is complete, we say it is a "closed" circuit. Remember, it only takes one break in the pathway, one "open," to stop current from moving through all parts of the circuit. That's why a switch works. By interrupting current in a one-inch section of a circuit, a single switch can control whether or not current flows through a thousand Christmas tree lights. In addition to open circuits and closed circuits, you will also hear the phrase "short circuit." A more reasonable phrase would have been "short cut." That's what it is. If there is an opportunity for Greenies to take a short cut to the party without fooling with whatever work you have planned for them later in the circuit, they will "short out" or short circuit. They'll take the easy path, the short path, the path of least resistance, even if no work whatsoever gets done.

The words "open" and "closed" confuse people. Current will flow through a closed switch but not an open one. Perhaps a complicated mathematical formula and a few words in Latin would make it more memorable.

Just kidding. How about a cute little picture story?

You are an ant, walking along the top of a wire fence.
The fence encloses a square field, and has one gate.
If the gate is closed, you walk right over it,
Around the field, returning to your starting place.

Greenies walk inside the wire beneath your feet,
You can hear them whispering to each other.
If the gate is closed, the Greenies will also walk around the field,
Over the closed gate and back to their starting place.

If the gate is open, the farmer's pig will escape.
Being an ant, you don't care about that,
But now you can't get around the field.
You stand on that last fence post, crying little ant-tears,
Until a lizard crawls up the fence post and eats you.

If the gate is open, Greenies can't get across, either.
But lizards don't care for Greenies, so they leave them alone.
The fence is a circuit, the gate is a switch
The farmer and the pig are imaginary,
The lizard teaches the electron theory at a local college.

Magnetism

Guys who believe in the electron theory don't like to talk about magnetism. It is a major source of their personal insecurity. We have known for a long time that electrical current is always surrounded by a magnetic field. We also know that whenever a magnetic field moves past a conductor it creates an electric current, but that's about all we know. Einstein spent the last thirty years of his life trying to come up with a "Unified Field Theory" which would have explained why this