RUDOLF F. GRAF

SAFE AND SIMPLE ELECTRICAL EXPERIMENTS

Here, in 101 entertaining experiments and projects, is a fast and reliable way of learning the basic principles of electricity. For maximum exposure to the fundamentals, three major categories—static electricity (38 experiments), magnetism (32) and current electricity and electromagnetism (31)—are treated separately. Each experiment, beginning with a list of the safe and inexpensive materials required and some introductory remarks, is presented with detailed step-by-step instructions and illustrations and a brief discussion of the frequently astonishing results that should be expected. From cleaning phonograph records with saran wrap and telling time with a compass to making a transformer or a telegraph sounder, the reader-experimenter learns, not only where to get electricity (from such unlikely sources as lemons or candle flames), but how to store it and use it in a number of creative ways.

At no point are special or expensive materials required. Nor does the slightest possibility exist of harming anyone—there is no call for high voltages, for dangerous acids or even for connection to the house current. Although these careful provisions make it ideal for children, this book is actually enthralling enough for young and old alike who want to know about electricity but have little or no scientific experience.

Rudolf F. Graf is singularly qualified as the author of this book. His is a familiar name to the many electronics engineers, technicians, amateur radio enthusiasts and electronics hobbyists who have read his numerous books and articles in dozens of popular magazines. He is the author of *Modern Dictionary of Electronics, Practical Electricity and Magnetism, ABC's of Electronic Test Probes, Electronic Design Data Book* and other books, and co-author (with George J. Whalen) of *Automotive Electronics, 25 Solid State Projects,* and *The Manual of Car Electronics.* A consultant on numerous projects, he has had a varied twenty-five year career in the electronics field. He is a senior member of the IEEE and holds a first class radio telephone operator's license.

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Safe and Simple Electrical Experiments

by

DOLF F. GRAF

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To my children Jeffrey and Debbie
Whose imagination and interest encouraged me to write this book
And to my wife Bettina
For her understanding and invaluable assistance

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PREFACE

The fastest and most reliable way of gaining a thorough understanding of electricity is by working with it and performing experiments rather than by just reading about it. With that thought in mind, I have prepared this book for the young and old alike who want to know about electricity but have little or no scientific experience.

This is not a reading book, nor a study book, yet it tells many interesting facts about electricity. It is not a picture book either, though it is full of illustrations. Rather this is a *doing* book! Every experiment has been tested numerous times so that if you follow the simple directions, you can count on spending many enjoyable hours successfully performing each of them. At the same time you will be learning many of the basic principles of electricity.

The book's uniform format makes it easy to follow. All experiments begin with a listing of the materials needed and a few introductory remarks. Detailed, step-by-step instructions allow you to set up most experiments in just a few minutes. These are followed by a brief discussion of the results you should expect.

In preparing this volume, I have avoided any experiments that require special or expensive materials which cannot be found in the average home or readily and cheaply obtained elsewhere. Furthermore, neither high voltages nor dangerous acids are needed for any of the experiments, nor do any require connections to the house current. All of them may be performed by even the most inexperienced or careless individual without the slightest possibility of doing harm to anyone. No special tools are needed, and the sizes of the wires, nails, and the like, that are used are not at all critical. Any size will do.

You will no doubt enjoy reading about the experiments, but you will not get the greatest pleasure nor reap the full benefit that this book can offer unless you actually do them. Since your success will depend to a large extent on the knowledge gained from previous experiments, it is best to perform them in the order in which they are presented.

Some of the experiments in this book, I must confess, have been adapted from the works of great scientists, but many are quite new and appear here for the first time. A number produce such astonishing results that they may even be used as stunts at the dinner table or at a party.

If it adds to your knowledge and understanding of electricity, this book will have served its intended purpose. As you progress, you will soon realize that no experiment is ever completely finished. Instead, the answers it provides you should only whet your appetite for embarking upon new and inviting explorations. Before long, you will discover the value of learning-by-doing. In time you should come to a thorough understanding of some of the basic forces of nature that affect you in a hundred different ways every day of your life.

As you venture forth into this new world of science, I wish you luck! With continuing interest in what is presented to you and with eagerness for what lies beyond, you may perhaps someday be the Volta of the future.

RUDOLF F. GRAF

P.S. If you should originate or know of an unusual experiment that might be included in this book, please be so kind as to drop me a note about it in care of the publisher. It might make a welcome addition to a future edition.

A Brief Chronological History of Great Discoveries in Electricity

2637 B.C.

Hoang-ti, founder of the Chinese empire, uses a magnetic chariot (legend).

600 B.C.

Thales of Miletus (640-546), Greek scientist and philosopher, discovers attractive power of charged amber.

1269 A.D.

Petrus Peregrinus discovers properties of magnetism and shows that like poles (his own term) repel and unlike poles attract.

1492

Christopher Columbus (1451-1506) shows that the declination of a compass needle varies for different parts of the world.

1600

William Gilbert (1540-1603), English physician and physicist, publishes *De Magnete,* six volumes describing the earth as having the properties of a huge magnet (and thereby explaining the behavior of the compass needle). Gilbert also coined the word "electricity" from "electron," the Greek word for amber.

1650

Otto van Guericke (1602-1686), German physicist, builds the first static machine. Consisting of a large sulphur ball mounted on a shaft, this machine produced static electricity when a pad was rubbed against the ball as it rotated.

1729

Stephen Gray (1696-1736), English electrical experimenter, evolves the concept of conductors and nonconductors. His theory led to the discovery of electrical insulation.

1733

Charles François de Cisternay Du Fay (1698-1739) of Paris discovers that there are only two kinds of electricity — vitreous (positive) and resinous (negative) — and announces that like charges repel and unlike charges attract.

1745

Pieter van Musschenbroek (1692-1761), Dutch mathematician, discovers principle of the Leyden jar, wherein charges of static electricity can be built up and stored.

1747

Benjamin Franklin (1706-1790), American statesman and philosopher, advances single fluid theory of electricity, originates "plus" and "minus" designations, and invents the lightning rod.

1771

Luigi Galvani (1737-1798), Italian physiologist, discovers that a frog's legs contract when touched at different points by two dissimilar metals which also touch. Galvani advanced theory of "animal electricity" in 1786.

1785

Charles Augustin de Coulomb (1736-1806), French physicist, proves the law of inverse squares, which states that the force exerted between two charged spheres is directly proportional to the product of their charges and is inversely proportional to the square of the distance between them. Coulomb also proved that the internal surface of a body cannot be charged with static electricity.

1800

Allesandro Volta (1745-1827), Italian physicist, discovers the first practical method of generating electricity. The voltaic pile (named in his honor) consists of a stack of silver and zinc plates separated from each other by cloth or paper saturated with a salt solution.

1819

Hans Christian Oersted (1777-1851), Danish physicist, discovers that a magnetic field is caused by electric current, thus proving that electricity and magnetism are related.

1820

André Marie Ampère (1775-1836), French physicist, shows that the forces between currents and magnets and also between two currents can be determined by assuming that each element of the circuit exerts a force on a magnetic pole and on every other current element in the circuit. This discovery established the relationship between electricity and magnetism. Ampère also developed the solenoid.

1820

Dominique François Jean Arago (1786-1853), French physicist, discovers that a magnet can be made from an iron or steel bar placed inside a solenoid through which current is flowing.

1821

Michael Faraday (1791-1867), English chemist and physicist, shows that the flow of current in a wire can cause a magnet to revolve around the wire and that a current-carrying wire tends to revolve around a fixed magnet.

1823

Thomas Johann Seebeck (1770-1831), German physicist, discovers that an electric current is produced when two dissimilar metals are joined and their junction point is heated.

1827

Georg Simon Ohm (1787-1854), German physicist, discovers the relation between current, voltage, and resistance in an electric circuit, now known as Ohm's law, which states that the electromotive force divided by the rate of current flow through a conductor represents the resistance of the conductor.

1831

Joseph Henry (1797-1878), professor of physics in Albany, N. Y., and Michael Faraday make numerous electromagnetic discoveries, such as the principle of self-inductance, the transformer, the generation of electricity by magnetism, the disk dynamo, and many others.

1833

Karl Friedrich Gauss (1777-1855), German physicist and mathematician, develops an exact mathematical formula for the magnetic field.

1834

Heinrich Friedrich Emil Lenz (1804-1865), German-Russian physicist, establishes a method of determining the directions of an induced current in a circuit, now known as Lenz's law.

1840

Samuel F. B. Morse (1791-1872), American artist and inventor, invents the telegraph.

1859

Gaston Planté (1834-1899), French inventor, makes first lead-acid storage cell to store electrical energy.

1865

James Clerk Maxwell (1831-1879), Scottish physicist, explains in mathematical terms the transmission of electric and magnetic fields through a medium.

1875

Alexander Graham Bell (1847-1922), American inventor, develops the electric telephone.

1879

Thomas Alva Edison (1847-1931), American inventor, develops a dynamo and the incandescent lamp. Edison also invented the phonograph, an improved telegraph system, talking pictures, the alkaline storage battery, and many other electrical devices.

1887

Heinrich Rudolph Hertz (1857-1894), German physicist, discovers that certain metals give off electric energy when struck by light. Herz also discovered in 1888 that electricity may be transmitted by electromagnetic waves.

1888

Nicola Tesla (1856-1943), American engineer and inventor, announces discovery of the principle of the rotating magnetic field, on which the induction motor is based.

1895

Guglielmo Marconi (1874-1937), Italian inventor, begins experiments in wireless telegraphy.

A word of explanation: The reason we stop our chronology at this point is that by the time of the invention of wireless telegraphy, the basic principles of electricity had been formulated. Beyond them lies the field of electronics, a subject outside the scope of this book.

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static electricity

Early History of Static Electricity

Thousands of years ago pine trees grew along the shores of the Baltic Sea. Although they slowly disappeared and are now long extinct, the gum from their bark became petrified and still exists. It is called amber. The ancient Greeks used amber to make necklaces and other forms of jewelry.

The Greek philosopher Thales of Miletus, reckoned to be among the Seven Wise Men of Greece, is credited with having been the first to record that a piece of amber rubbed against fur or clothing will sparkle and also attract dried leaves, feathers, pith, lint, and the like. We don't know whether this curious phenomenon was ever noticed before his time, but Thales was the first to mark it down for posterity. That was about 2,500 years ago (between 640 and 546 B.C.). It was an interesting discovery, but nobody was then able to explain exactly what was happening, and for hundreds of years the "magic" power of attraction was regarded simply as an interesting natural event.

For a long time this curious effect was associated only with amber, but later on rubbed glass was found to have similar if somewhat opposite properties. Thus there were said to be two kinds of electricity. The kind exhibited by rubbed glass was called "vitreous" and the kind exhibited by rubbed amber was called "resinous." In the Middle Ages it was discovered that many other substances showed similar properties when rubbed. These were collectively called "electrics." Those substances which could not be given this property by rubbing were then called "nonelectrics." "Electrics" are actually insulators or nonconductors, whereas "nonelectrics" are conductors. To avoid confusion, both of these terms were dropped at a later date.

Little more was discovered about this mysterious attraction until Sir William Gilbert of England, at the turn of the seventeenth century, continued where Thales left off. He published a book in which he described his work and is credited with having coined the word "electricity" from "electron" (the Greek word for amber.) Other scientists became interested, and by careful and painstaking investigation they slowly were able to unlock nature's secrets to help us arrive at a better understanding of electricity.

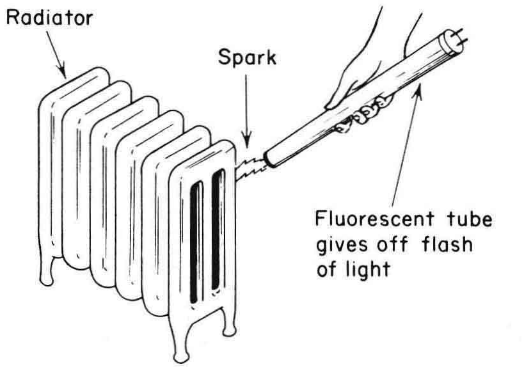
Electricity as we now know it is of two basic kinds: static electricity and current electricity. Static electricity is the kind that Thales discovered by rubbing amber and that others discovered by rubbing glass. Its name comes from the Greek word meaning "standing," because it is normally at rest. It passes from one body to another only in sudden, momentary movements. Of limited usefulness, it is often a nuisance and a hazard that can cause fires and take lives. Nonetheless, when controlled, we can have some fun with it and learn a great deal about electricity at the same time.

Static electricity experiments work best when the weather is cool and dry. Cold winter days, when the air inside is dry and warm, are ideal. On damp summer days the electrons are likely to flow away instead of staying where you can study them. Therefore if you have difficulty with any of the experiments in this section on static electricity, try it again on a day when there is less moisture in the air. On the other hand, on a very dry day, the static electricity you yourself produce by rubbing your shoes on a wool or nylon rug can also interfere with your experiment. On such days spread newspaper under your feet. Remember again, all of these experiments have been performed many times, and if you have followed directions carefully and any of them fail to work, you can most assuredly blame it on the weather.

1

Charge Yourself

> **Materials you will need:**
> *1. Woolen rug on the floor*
> *2. Fluorescent tube*



IF you ever got a shock on a cool winter day when you reached for a door knob or shook somebody's hand, you may have wondered what happened. In a darkened room you may have seen a spark. If your radio was turned on, you may even have heard the static you broadcast when the spark jumped. This is the same kind of interference you get from lightning. As a matter of fact the little spark and lightning have a lot in common.

No one knows exactly what static electricity is, and no one knows all the reasons why charged objects behave the way they do, but scientists have developed a theory that explains most of these actions. All substances are said to be made of positive electrical particles called *protons* and negative electrical particles called *electrons*. When an object is left undisturbed for a period of time the protons and electrons balance each other. That object has no charge and is said to be *neutral*. When some objects are rubbed they pick up electrons from the material doing the rubbing, whereas others give electrons to the material rubbed against them. The objects are then said to be negatively or positively charged. More on this later.

Now for our first experiment. Rub your shoes on the rug to pick up and accumulate electrons on your body. Then touch something, especially something made of metal. These excess electrons will now leave you and jump to the metal. That is what you feel, and that is the spark you see. Once this spark has jumped, you no longer have any electrical charge. To prove this, touch the object again. You will feel no more shock because all the electrical charge (electrons) you had is no longer there. Shuffle your feet again to pick up more charges and you can repeat the process.

Now try this: While holding a fluorescent tube, charge yourself well by rubbing your shoes on the rug. To make the tube give off a brief flash of light, touch the metal end to a radiator or the screw of a light switch plate while holding the tube in your hand. The tube will flash briefly as *your* charge passes through it to the radiator.

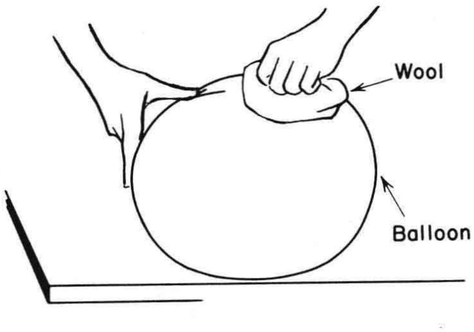
If you cannot produce a charge on a cool dry day, it is probably due to the fact that your rug has been treated with some antistatic material.

2

Charge a Balloon

> **Materials you will need:**
> *1. Rubber balloon*
> *2. Piece of wool or fur*

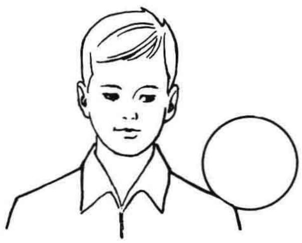
BLOW up a balloon, tie its neck securely, and rub it quickly and vigorously against a piece of wool. A sweater or a jacket is ideal for this purpose. Now hold the balloon up



against the wall. It will stick to it. It will also stick to your hand, a table, or even the ceiling if you can throw it up so that it just reaches the ceiling and does not bounce back too vigorously.

The explanation of this reaction is that rubbing removed some of the free electrons from the wool and moved them onto the balloon. This gave the balloon a negative charge. When this charged balloon was brought next to an uncharged object, such as the wall, it repelled the electrons away from the wall nearest the balloon, since like charges repel. Now there was an attraction between the balloon and the positive charges left on the wall nearest the balloon.

Once the balloons are charged, they will stick to any uncharged body and will also stick to any person anywhere on his body. Some rather amusing sights can thus be produced.

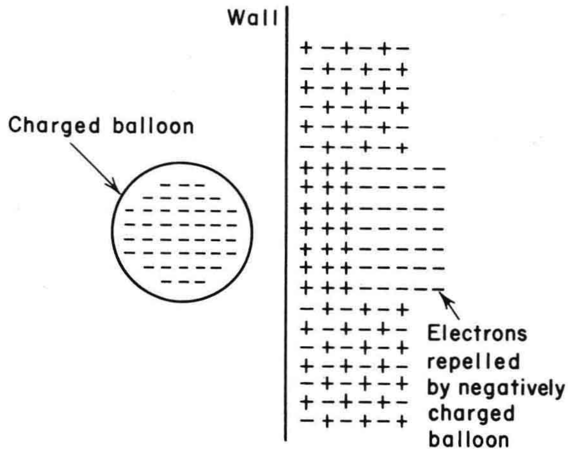


Charge a number of balloons, and you can actually walk around with the balloons clinging to you.

After a while, depending on the humidity in the air, the charge on the balloon will leak off by itself. If you want to be sure at any time that a balloon is completely discharged, put it under running water and then hang it up to dry. The water will wash away all the charges.

Blow up another balloon, charge it the same way, and try to stick it right next to the balloon on the wall. You will see that the two balloons will repel each other, and though they both will stick to the wall, they will be separated by some distance and never touch each other.

Here is something else you can try. Put a good charge on your balloon, and hold it close to your ear. You will hear crackling noises that sound very much like static on a radio receiver. This noise is caused by very tiny sparks that jump between your body and the charged balloon.



3 Charge a Piece of Paper

Materials you will need:

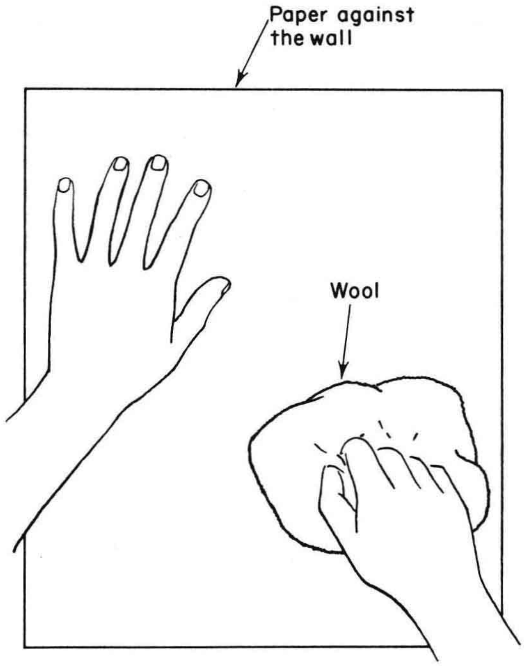
1. *Sheet of paper*
2. *Wool, nylon, Saran wrap*

BY simply rubbing a piece of paper on a dry day, it can be charged with static electricity. Hold a piece of dry paper against a wall with one hand, and rub it briskly with the other hand for a few seconds. The friction will charge the paper and make it stick to the wall. It is held there by the attraction between the charged paper and the neutral wall, as explained before. On a dry day, the paper will stick to the wall for several hours. Lift one corner of the paper slightly, and let it go. It will snap back into place, being again attracted to the wall.

Pull the paper completely away from the wall, and you will hear a crackling sound caused by the sparks which fly from the charged paper to the wall. The paper is still charged, and if you place it against another spot on the wall, a door, or a window pane, it will once more be held in place. Hold the charged paper near your face, and it will produce a tickling sensation.

A greater charge can be placed on the paper if you rub it with some of the following materials rather than with your hand. Try fur, wool, nylon, and Saran wrap, and see which gives you the greatest charge.

As a further experiment, place some celluloid or Saran wrap against the wall, and rub it with nylon or wool. You will build up some very great charges with these materials, and the results will be quite interesting.



Tricks with a Comb

4

Materials you will need:

1. *Plastic comb*
2. *Piece of wool or nylon*
3. *Tiny bits of paper and/or a cup full of puffed rice*
4. *Some cigarette ashes*

TEAR some very tiny bits of paper, and place them on a table. Now rub the comb vigorously with a piece of wool or nylon (as shown in Figure A), and bring the comb close to the tiny pieces of paper. You will see that the paper will be attracted by the comb, but watch what happens after a while. A few of the pieces of paper will suddenly shoot off the comb. First one and then another and then another. For a really interesting effect, plunge the charged comb into the puffed rice, and quickly pull it out. A lot of the puffed rice will cling to the comb, but in an instant, the grains will begin to pop off as if shot from a gun. What happened there? Why were these objects first attracted and then repelled?

What we have done by rubbing the comb is to give it a strong negative charge. Being charged, the comb attracts the uncharged bits