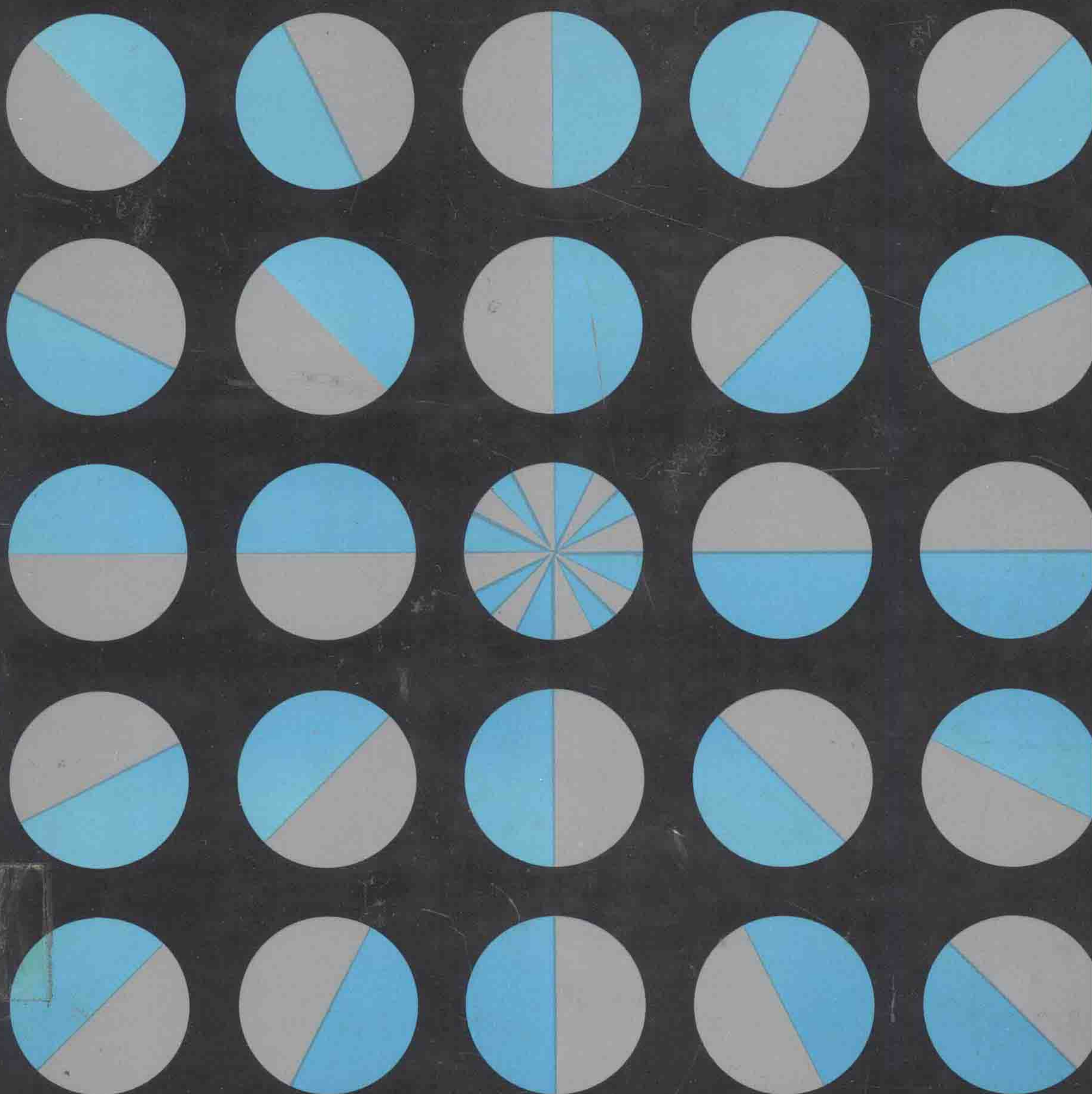
CLYDE N. HERRICK

SURVEY OF ELECTRONICS



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The Macmillan Company, New York / Collier-Macmillan Limited, London

Printed in the United States of America

The Macmillan Company
866 Third Avenue, New York, New York 10022

Collier-Macmillan Canada, Ltd., Toronto, Ontario

Library of Congress catalog card number: 72-80916

Printing: 1 2 3 4 5 6 7 8 Year: 3 4 5 6 7 8 9

Preface

With the dramatic progress of electronic science and technology in recent years, the need for a relevant survey text has become evident. Few areas of human endeavor have remained unchanged by the new science, and many are dominated by this seemingly mysterious domain of the infinitesimally small. Every boy has shared in the excitement of outer-space exploration and the moon landings as he accompanied the new breed of pioneers through the near magic of color television. He occasionally has an opportunity to see an electronic computer, silently operating at fantastic speed and solving problems millions of times faster than a skilled mathematician. His parents speak of the new industrial revolution occasioned by the techniques of automation with its electronic mediating and control processes.

Thus a real need exists for a survey of electronics within the grasp of students with a minimum technical background. This book provides a relevant perspective of the entire basic-electronics field and reviews both professional and vocational opportunities. Although not a mathematically oriented text, a central chapter on the usefulness of mathematics in electronics will lead the exceptional student to the threshold of his own mind. Similarly, circuit concepts are introduced on balance, in a functional context that contributes to a valid total view. Academic disciplines have deep historical roots, and it is appropriate to provide a brief history of electronics as our point of entry.

The student is also introduced to the scientific method, electronics in the physical sciences, outer space and moon landings, medical electronics, mathematics in electronics, economic aspects of electronics, computers, crime prevention and law enforcement, and electronics in warfare; this material is supplemented by a comprehensive glossary. The book is profusely illustrated with carefully chosen photographs and diagrams that reflect the state of electronics. Questions are provided at the end of each chapter to check the student's comprehension and achievement. Numerical problems are not included, inasmuch as the quantitative aspect of the subject is treated to better advantage in specialized electronics courses.

The author is greatly indebted to the sources credited in the text for their cooperation and provision of photographs, diagrams, and technical data. Acknowledgement is also made to the faculty of San Jose City College for their contributions, suggestions, and constructive criticism. It is appropriate that this textbook be dedicated as a teaching tool to the instructors and students of our technical schools and junior colleges.

San Jose, California *Clyde N. Herrick*

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"While we read history, we make history. . . ."
George William Curtis

Chapter 1 History of Electronics

1.1 INTRODUCTION

Electronics is a branch of physics that deals with the behavior of electrons in a vacuum, in crystals, in gases, and in liquids. An *electron* is an extremely small particle of electricity. We shall find that *electricity* is a fundamental entity of nature; it is neither matter nor energy, although it may be associated with either or both. Electricity cannot be observed directly, as illustrated in Figure 1-1. It is known only in terms of its effects, such as an electric shock, the electrification of hair when combed in dry weather, and the sparks that are produced when a pair of wires conducting electricity touch each other. Electricity can kill without warning (see Figure 1-2).

1.2 THE HISTORICAL RECORD

The science of electronics is based upon observations and discoveries that were first recorded during the Greek Enlightenment over 2,000 years ago.[1]* Although lightning, the aurora borealis, and the aurora australis have surely been observed since the advent of man, our first historical record of an electrical phenomenon was made in 600 B.C. Thales of Miletus, a mathematician and a philosopher, wrote of the

*Supra numbers refer to the "Notes" section at the end of each chapter.

attraction that amber exerts upon dust, chaff, or other particles of matter after the amber has been rubbed. Amber was named *elektron* by the Greeks; it is a yellow translucent fossil resin found on certain seashores. Today amber is known best in the form of pipestems and costume jewelry. The English word *electron* was coined by George Stoney in 1881.

Figure 1-1 *Electricity flowing through a wire.* (a) *The electricity cannot be seen.* (b) *The electricity cannot be weighed.* (c) *The electricity cannot be heard.*

(a) (b) (c)

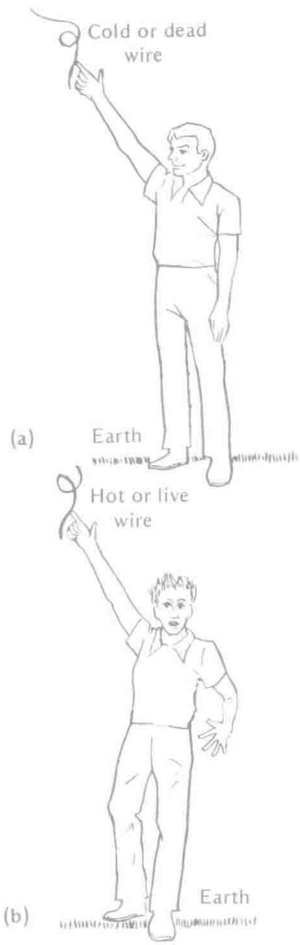
Thales wrote also of the force that is exerted by a lodestone upon iron objects, thereby placing the phenomenon of magnetism on historical record. The ancients called lodestones *magnets* because they were obtained from the Magnetes who inhabited Magnesia in Thessaly. Plato and Pliny wrote of the ability of a magnet to support a number of iron rings in the form of a chain.[2] Figure 1-3 shows how iron tacks are attracted to a lodestone. The first practical application of lodestones was in navigational compasses: Since a freely suspended lodestone points toward the lodestar by which a navigator directs his course, a lodestone is historically a guiding or leading stone. Today we call these shiny black stones *magnetite* (Figure 1-4).

Following Thales, Democritus of Abdera set forth an atomic theory of matter in 460 B.C. He speculated that all substances are formed from ultimate solid particles that were termed *atomon*. According to this classical theory, the ultimate particles were indivisible because of their absolute smallness in size. The *atomon* were stipulated to differ in shapes, arrangements, positions, and magnitudes. That is, absolute smallnesses were classified by orders of magnitudes—a concept that troubled mathematicians until comparatively recent times. Democritus denied the existence of any purpose or humanly ordered plan in the workings of nature and has been characterized as the greatest of the Greek physical philosophers.

No accurate date has been determined for the discovery of the magnetic or navigational compass. However, we know that the compass was in wide use by A.D. 1000. A modern magnetic compass is illustrated in Figure 1-5. A compass depends upon the earth's magnetic field to obtain its directive force. By the fifteenth century, it was recognized that a compass needle does not point in the exact direction of the geographical pole but makes an angle with the true meridian. (The discovery of this fact by sailors during the voyage of Columbus convinced them that they were accursed.) This angle is called the *variation* by navigators and the *declination* by physicists. Records of the variation value have been kept since 1580. At that time there was an easterly variation in London of 11°15′. This variation decreased to zero in 1657 and then became a westerly variation that reached a maximum of 24°38′ in 1818. At present the variation is decreasing at the rate of about 5′ a year.

In 1544, a German scientist named Heinrich Hartmann observed that a compass needle that was balanced horizontally when nonmagnetized dipped with its north pole downward when magnetized. A *dipping needle* is illustrated in Figure 1-6. The angle made by the needle is called the *dip*, or *inclination*. In the Northern Hemisphere, the north pole of the needle dips downward; in the Southern Hemisphere, the south pole of the needle dips downward. The line of zero dip that encircles the earth near the equator is called the *magnetic equator*. With the magnetic compass and the dipping needle, the earth's magnetic field can be mapped, as shown in Figure 1-7. A magnetic field exists in any region of space in which magnetic forces are observable.

Figure 1-2 *Electricity can kill without warning.* **(a)** *An electric wire can be safely touched if it is not electrified.* **(b)** *An electrified wire can shock or kill a person who touches it.*



1.3 ELECTRICAL MACHINES

The next invention of major importance was the *electrostatic machine*, or *static generator*, shown in Figure 1-8. This device was demonstrated by Otto von Guericke in 1671. It was of enormous value to scientists because it permitted experiments with voltages up to 20,000 volts. This electric potential will produce a spark approximately three quarters of an inch in length. Controversy arose concerning whether the electric spark was in fact man-made lightning. However, a definitive experiment to answer the question was not devised for nearly a century. In the meantime, research and experiments lead to the development of other important electrical devices.

In this era the nature of electricity was poorly understood; however, this ignorance did not prevent progress in the science. It was generally believed that electricity was some kind of subtle fluid, or possibly two fluids.[3] This erroneous conception led Pieter van Musschenbroek to devise various types of containers in which the electric fluid could conceivably be stored, as water is stored in bottles. In 1746 he unexpectedly succeeded. After running a wire from an electrostatic machine to water in a glass flask, he rotated the machine to determine whether the electric fluid might go into the water solution. Next, when he touched the wire to re-

Figure 1-3 *The attraction of iron tacks by a lodestone.*

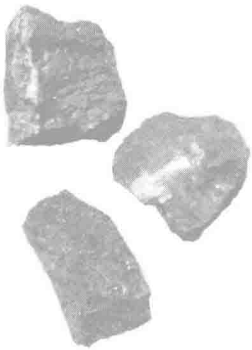


Figure 1-4 *Samples of magnetite.*

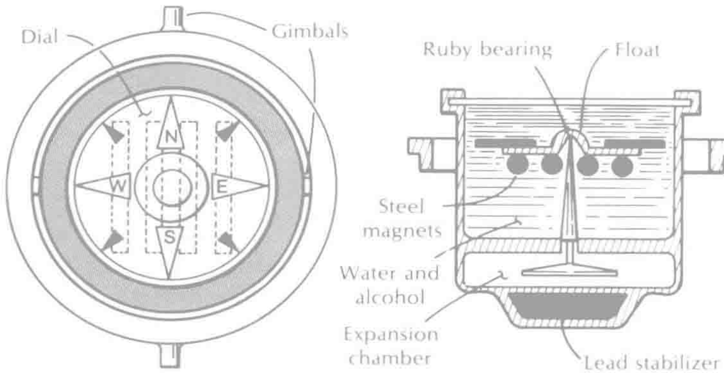
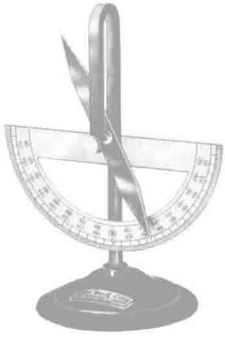


Figure 1-5 *A mariner's compass.*

move it from the water, he received a severe shock (Figure 1-9). Musschenbroek had demonstrated that electricity could be stored, and his new device was called the *Leyden jar.*

A Leyden jar is illustrated in Figure 1-10. It was soon recognized that the water employed in the original experiment was serving merely as a conductor of electricity and not as a solvent for the electrical fluid. It was also evident that Musschenbroek's hand had served as another electrical conductor on the outer surface of the glass jar. Accordingly, the commercial form of the Leyden jar was designed with tin-foil coatings on the inner and outer surfaces of the jar. A hard-rubber stopper, which served as an electrical insulator, also supported a metal rod-and-chain arrangement that made electrical contact with the inner foil coating. The Leyden jar was the first electrical capacitor. It was of basic importance because it permitted the comparatively small charge flow from an electrostatic machine to be concentrated and thereby provide an electric spark of great intensity.

Figure 1-6 *A dipping needle. (Courtesy Sargent-Welch Scientific Co., Skokie, Ill.)*



1.4 LIGHTNING AND ELECTRICITY

When a Leyden jar is charged to a high voltage, considerable electrical energy is changed into light, heat, and sound in the subsequent discharge across a spark gap. The sound that is produced is analogous to thunder that accompanies a lightning stroke. Scientists had been unable to prove, however, that a Leyden-jar discharge was in fact a lightning stroke on a small scale. Finally, in 1951 Benjamin Franklin

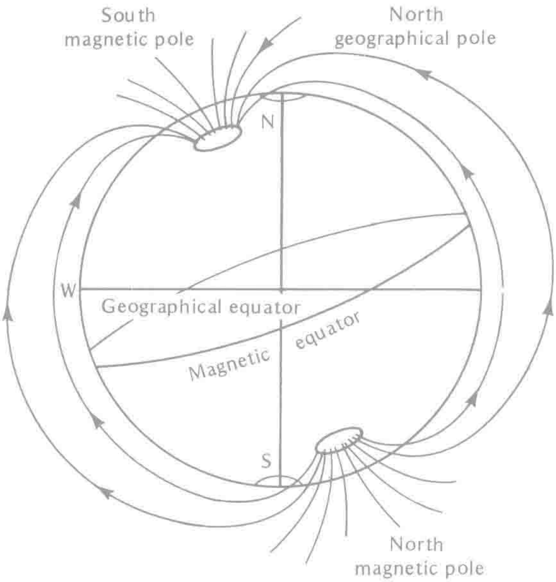


Figure 1-7 *The earth's magnetic field is represented by imaginary lines.*

provided this proof in his famous kite experiment.[4] His procedure was to fly a kite into a thundercloud and to conduct a small portion of its electric charge down the moist kite string to himself (Figure 1-11). Since iron is a good

Figure 1-8 *An electrostatic generator. (Courtesy Sargent-Welch Scientific Co., Skokie, Ill.)*

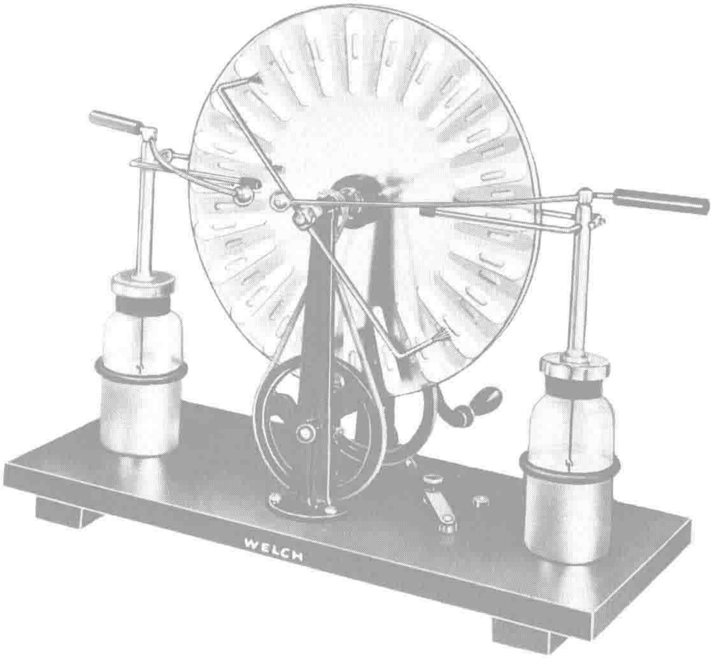


Figure 1-9 *Discovery of the Leyden jar.*

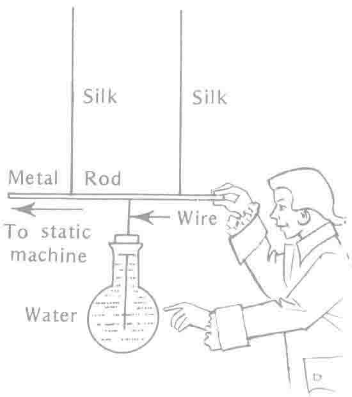
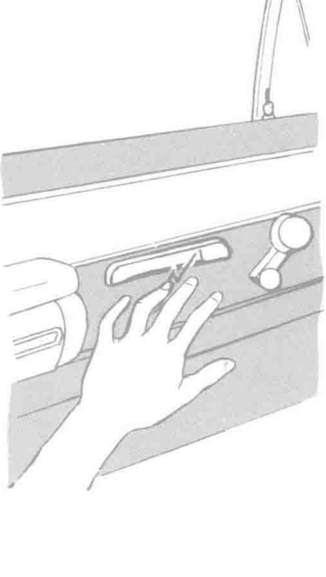


Figure 1-10 *A Leyden jar. (Courtesy Sargent-Welsh Scientific Co., Skokie, Ill.)*

Figure 1-11 *Franklin's kite experiment.*

conductor of electricity (better than moist string), Franklin passed the string through a key; when he brought his knuckles near the key, a spark was drawn occasionally that was the same as that produced by the discharge of a Leyden jar. It was a basically dangerous experiment, and other scientists in Europe were killed while making the demonstration.

Figure 1-12 *Static electricity is occasionally generated when a person slides across a plastic seat cover.*



Prior to the nineteenth century, knowledge of electricity was limited to high-voltage phenomena. That is, the electricity produced by rubbed amber or other insulators, the electricity generated by electrostatic machines, and lightning discharges provide high-voltage sources of electricity. The amount of available charge (quantity of electricity) was very small when generated by friction; however, a substantial charge could be built up by charging a Leyden jar from an electrostatic machine. Most of us are familiar with the static electricity that is produced as we slide across a plastic seat cover (Figure 1-12).

In the meantime, in 1787 an important electrical instrument called the *electroscope* was devised by Abraham Bennet.[5] It was known that substances could be charged with different kinds of electricity; the ancients had been aware that rubbed amber would attract bits of chaff under some circumstances but would repel them under other conditions. Systematic investigations had established that there were only two kinds of electricity; they were called *positive* and *negative.* Bennet, like other scientists, knew that positive charges repelled each other, that negative charges repelled each other, and that positive and negative charges attracted each other. He exploited this understanding in designing the electroscope, shown in Figure 1-13.

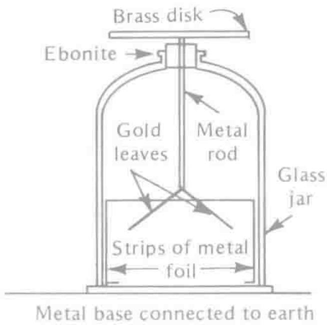


Figure 1-13 *An electroscope.*

The electroscope indicates the presence of electricity when a charged body or an electric wire is touched to its top disk. Thereupon, electricity flows from the disk down the metal rod, and charges the thin gold leaves. Since like charges repel, the gold leaves diverge and indicate the presence of electricity. Not only is the electroscope an indicator of electricity, but it is also a measuring instrument. That is, the angle by which the gold leaves diverge is proportional to the voltage that is present. Thus, an electroscope can be calibrated to indicate electrical pressure in volt units. Prior to the electroscope, scientists could measure voltages only by the distance that they caused sparks to jump across an air gap.

1.5 THE VOLTAIC CELL

The area of low-voltage electrical phenomena was opened in 1799 by the physicist Alessandro Volta, who invented the first electric battery. Luigi Galvani, a physiologist, had previously discovered that a frog's leg would twitch under certain conditions, although the leg was dead from a physiological standpoint. Galvani noted that the leg would twitch when contacted at two separated points by a pair of dissecting needles in a particular situation: The needles had to be fabricated from different metals, and the top ends of the needles had to be brought into contact with each other. This experiment aroused considerable controversy.

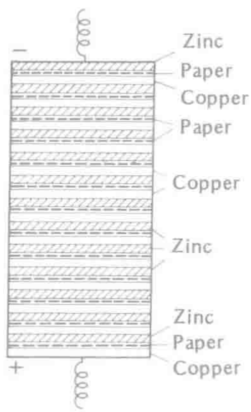
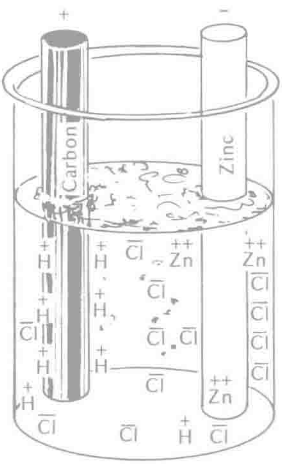


Figure 1-14 *The voltaic pile.*

Galvani believed that electricity was involved in the frog experiment, but he surmised that the electricity was being produced by physiological action inside the frog's leg. Volta, on the other hand, believed that electricity was being generated by the contact of dissimilar metals. He sought to arrange a physical device that would exploit this hitherto unknown phenomenon. His researches led to the development of the *voltaic pile*, shown in Figure 1-14. It consisted of alternate plates of copper and zinc, separated by moistened

Figure 1-15 *The basic voltaic cell.*



sheets of paper. Each pair of plates is termed a *cell* and the combination of cells is called a *battery*. By means of a large voltaic pile, it was demonstrated that a battery could generate sufficient voltage to operate an electroscope. A single voltaic cell produces approximately 1 volt. The chief disadvantage of the voltaic pile was its limitation to comparatively small electric currents. That is, although it was possible to generate a voltage as low as 1 volt, it remained to devise an electric cell that could supply a large current.

Volta's demonstration of the electric cell and battery initiated intensive research in many science centers. It was discovered that a voltaic pile would provide a greater rate of charge flow (more current) if the sheets of paper were acidulated. Next, a dilute solution of acid was utilized in a glass jar, with carbon and zinc electrodes, as shown in Figure 1-15. Although this simple arrangement is short-lived and inefficient, it provided scientists with a source of comparatively high current at low voltage. Cells and batteries were gradually improved, and they have been of great historical significance. Dramatic discoveries and inventions followed rapidly in the wake of the voltaic cell.

1.6 THE ELECTROMAGNET

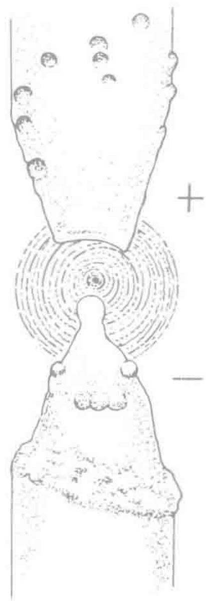
With a source of steady electric current available, a physicist named Hans Oersted made a demonstration of basic importance in 1820. He showed that if a magnetic compass is placed near a wire, the compass needle will deflect when a current flows in the wire. Since a compass needle responds only to a magnetic field, Oersted had established the fact that a current-carrying wire is surrounded by a magnetic field.[6] This was the beginning of recognition of the fact that any electric current must invariably be associated with a magnetic field. Another physicist, André Ampère, perceived that the magnetic field surrounding a current-carrying wire would be concentrated if the wire were wound in the form of a helix. This was the invention of the *solenoid*. Ampère also showed that the magnetic field of a solenoid is greatly intensified if an iron bar (core) is inserted into the helix.

When a coil of wire is wound on an iron core, the device is termed an *electromagnet*. It becomes equivalent to a permanent magnet, such as a lodestone, during the time that current flows through the winding. However, the magnetic field disappears when the current stops flowing. In other words, Ampère showed how to produce controlled magnetism. This was to be the key device in various outstanding inventions. Although Ampère suggested that electromagnets could be used to devise an electric telegraph system, he did not reduce his theory to practice. Nearly a quarter of a century was to pass before a working telegraph system was demonstrated.

1.7 THE ELECTRIC LIGHT

Contrary to general opinion, the first electric light was not invented by Thomas A. Edison but by Sir Humphry Davy and Charles De la Rive in 1801.[7] These innovators employed a pair of carbon rods and several hundred voltaic cells to develop a sustained electric *arc.* An arc discharge is shown in Figure 1-16. It is an intense source of visible light, ultraviolet light, and heat. Because of its extensive radiation of ultraviolet light, an arc will damage the retina of the eye if observed directly. Therefore, the arc must be enclosed in glass that has poor transmission for ultraviolet radiation, or the viewer must wear suitable goggles. Arcs were widely used for street lighting before the development of large incandescent lamps. We shall find that the electric arc also played a prominent role in the development of radiotelephony. Today arcs are utilized chiefly in welding equipment.

Figure 1-16 *The electric arc.*



1.8 DISCOVERY OF ELECTRICAL LAWS

With the availability of electrical sources for the supply of substantial currents at controlled voltage values, the characteristics of electrical circuits came under extensive analysis. Although many laws of mechanics were known, very few laws of electricity were recognized at the beginning of the nineteenth century. The modern era of quantitative analysis in electrical science was introduced by Georg Ohm in 1827. Ohm was a science professor who conceived of a physical property called *resistance.* Resistance in an electrical conductor was stipulated to oppose charge flow (current); moreover, Ohm asserted that the current value in a conductor was directly proportional to the applied voltage and inversely proportional to the resistance of the conductor. This principle is called *Ohm's law* and is the most basic law of electricity.