Audel™

Electrical Course for Apprentices and Journeymen

All New Fourth Edition

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Paul Rosenberg

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Contents

Introduction

An apprentice electrician prepares to become a journeyman typically during a four-year period. These four years include 2000 hours per year of on-the-job training, or a total of 8000 hours. During off-hours an apprentice studies electrical theory, methods, equipments, and the *NEC*.

My purpose in writing this book was to provide the apprentice or journeyman with most of the information he or she is required to know. I have drawn on my experience as a former instructor of apprentice and journeymen electricians to include most of the vital material on both electrical theory and its applications.

This book has been planned as a study course either for the classroom or as a self-taught program. It may be utilized without any other books on electrical theory.

Very little on the *NEC* is included since two other Audel books offer abundant information on it. *Guide to the National Electrical Code,* which is updated annually as the *NEC* is changed, gives a very complete interpretation of the *Code*. *Questions and Answer for Electrician's Examinations* can further help the electrician toward a thorough knowledge of the *NEC*.

Trigonometry is covered briefly in this book, because it is useful in making mathematical calculations of alternating currents. For the reader who is not familiar with trigonometry, there are other means of explanation.

It is not the intent of this book to give a complete discussion of *all* electrical subjects. However, with the basic information presented here, the apprentice or journeyman can gain an understanding of operational theory and progress even further, if he or she wishes.

I sincerely hope that this book will be of value to you, the electrician. It has been my good fortune to learn a great deal from others in our field, and I have presented here the information I have gained. Any knowledge that you or future electricians gain from this book will make my time spent in writing it worthwhile.

The basics of electricity really do not change, but the applications of these basics do change. Therefore, I hope that you will continue your studies throughout your career and keep abreast of the continual changes in the field. You will find that in modern society the person with the know-how is the person who advances.

A college degree is a valuable asset—get one if you can. But remember that much of the information offered by a degree program may be gained by self-study. Many people with technical know-how are needed to back up the engineering profession, and a technical education is receiving increased recognition.

I wish to extend my sincere thanks to the many fine people I've worked with through the years. Your contributions have been critical.

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Chapter 1

Electricity and Matter

Electricity is one of the great wonder-workers of our modern world. It is a force that powers thousands of inventions that make life more pleasant. Electricity is a property of certain particles to possess a force that can be used for the transmission of energy. Whenever electricity is used, you may be assured that an equal amount of some other form of energy was previously used to produce the electricity.

In order to gain an understanding of what electricity is, we must go into some study of matter, molecules, atoms, and elements. This is what may be termed the *electron theory*.

A Greek philosopher, Thales, in about 600 B.C., discovered that a piece of amber rubbed with a woolen cloth would attract pieces of chaff and other light objects, much as a magnet attracts iron filings. The Greek word for amber is *elektron* and it probably is from this word that the English words "electricity" and "electron" were derived. More on this phenomenon will be covered later.

Elements, Atoms, Molecules, and Compounds

All substances may be termed matter, and matter may be liquid, solid, or gaseous. A good example is water. Water may be a solid (ice), a liquid (water) with which we wash or drink, and a gas or steam (vapor), which we get when water is boiled. Whether it is ice, liquid, or vapor, its chemical makeup does not change; only the state in which it appears changes.

Elements are substances that can't be changed, decomposed by ordinary types of chemical change, or made by chemical union. There are over 100 known elements, distinguishable by their chemical and physical differences. Some common elements are copper, silver, gold, oxygen, hydrogen, sulfur, zinc, lead, helium, and uranium.

A *molecule* is the smallest unit quantity of matter that can exist by itself and retain all the properties of the original substance. It consists of one or more atoms.

Atoms are regarded as the smallest particles that retain the properties of the element and which, by chemical means, matter may be divided into.

Some of the more than 100 elements and their characteristics are given in Table 1-1. From this table and the symbols for the elements appearing in this table, it will be easier to gain insight concerning compounds. Some everyday compounds are

Water (H_2O): Two atoms of hydrogen and one atom of oxygen.

Sulfuric acid (H_2SO_4): Two atoms of hydrogen, one atom of sulfur, and four atoms of oxygen.

Salt (NaCl): One atom of sodium and one atom of chlorine.

Table 1-1 Elements and Their Characteristics

Atomic Number	***Element***	***Symbol***	***Atomic Weight***
13	Aluminum	Al	26.98
51	Antimony	Sb	121.76
18	Argon	A or Ar	39.948
56	Barium	Ba	137.34
4	Beryllium	Be	9.01
83	Bismuth	Bi	208.98
5	Boron	B	10.81
48	Cadmium	Cd	112.40
20	Calcium	Ca	40.08
6	Carbon	C	12.011
55	Cesium	Cs	132.905
17	Chlorine	Cl	35.453
24	Chromium	Cr	51.996
27	Cobalt	Co	58.93
29	Copper	Cu	63.54
9	Fluorine	F	19.00
79	Gold	Au	196.967
2	Helium	He	4.003
1	Hydrogen	H	1.008
26	Iron	Fe	55.847
82	Lead	Pb	207.21
3	Lithium	Li	6.94
12	Magnesium	Mg	24.32
25	Manganese	Mn	54.94
80	Mercury	Hg	200.61

(continued)

Table 1-1 ***(continued)***

Atomic Number	*Element*	*Symbol*	*Atomic Weight*
42	Molybdenum	Mo	95.94
10	Neon	Ne	20.183
28	Nickel	Ni	58.71
7	Nitrogen	N	14.007
8	Oxygen	O	16.000
15	Phosphorus	P	30.974
78	Platinum	Pt	195.09
19	Potassium	K	39.102
88	Radium	Ra	226.05
45	Rhodium	Rh	102.91
34	Selenium	Se	78.96
14	Silicon	Si	28.09
47	Silver	Ag	107.87
11	Sodium	Na	22.991
38	Strontium	Sr	87.62
16	Sulfur	S	32.066
90	Thorium	Th	232.038
50	Tin	Sn	118.69
74	Tungsten	W	183.85
92	Uranium	U	238.03
30	Zinc	Zn	65.37

Some forms of matter are merely mixtures of various elements and compounds. Air is an example; it has oxygen, nitrogen, helium, argon, neon, and some compounds such as carbon dioxide (CO_2) and carbon monoxide (CO).

One may wonder what all of this has to do with electricity, but it is leading up to an explanation of the electron theory, which follows.

Electron Theory

An atom may be roughly compared to a solar system in which a sun is the nucleus around which orbit one or more planets, the number of which depends on which atom we pick from the various elements. (Bear in mind that this is not a completely accurate description, as electrons seem to move in figure eights, rather than in circles. Nonetheless, the comparison between a solar system and an atom is useful.)

The nucleus is composed of protons and neutrons, and orbiting around this nucleus of protons and neutrons are electrons. An *electron* is a very small negatively charged particle. Electrons appear to be uniform in mass and charge and are one of the basic parts of which an atom is composed. The charge of the electron is accepted as 4.80×10^{-10} absolute electrostatic unit. This indicates that all electrons are alike regardless of the element of which they are a part.

A *neutron* is an elementary particle with approximately the mass of a hydrogen atom but without an electrical charge.

A *proton* is an elementary particle having a positive charge equivalent to the negative charge of an electron but possessing a mass approximately 1845 times as great.

From Table 1-1, we find the *atomic number* (number of protons in the nucleus) of hydrogen is 1, helium is 2, lithium is 3, beryllium is 4, etc. Figure 1-1 shows the atoms of hydrogen, helium, lithium, and beryllium, with the electrons orbiting around the nucleus of neutrons and positively charged protons. Notice that the positive charge of the protons in the nucleus equals the negative charge of the electrons and holds them in orbit.

Electrons may be released from their atoms by various means. Some atoms of certain elements release their electrons more readily than atoms of other elements. If an atom has an equal number of electrons and protons, it is said to be in balance. If an atom has given up some of its electrons, the atom will then have a positive charge, and the matter that received the electrons from the atom will be negatively charged. Some external force must be used to transfer the electrons.

Before progressing further, any electrical discussion must include *static electricity,* for a better understanding of insulation and conductors, as well as to carry on with the discussions of dislodging electrons. The word "static" means at rest. There are some applications where static electricity is put to use, but in other cases it is detrimental and must be avoided. We are faced with lightning, which is static electricity discharges attempting to neutralize opposite charges. Since we have to live with lightning's harmful effects, we should know how to cope with it. The methods of avoiding the harmful effects of lightning are not fully discovered but much progress has been made.

One method of dislodging electrons is by the friction of rubbing a hard rubber rod with a piece of fur. The fur will give up some

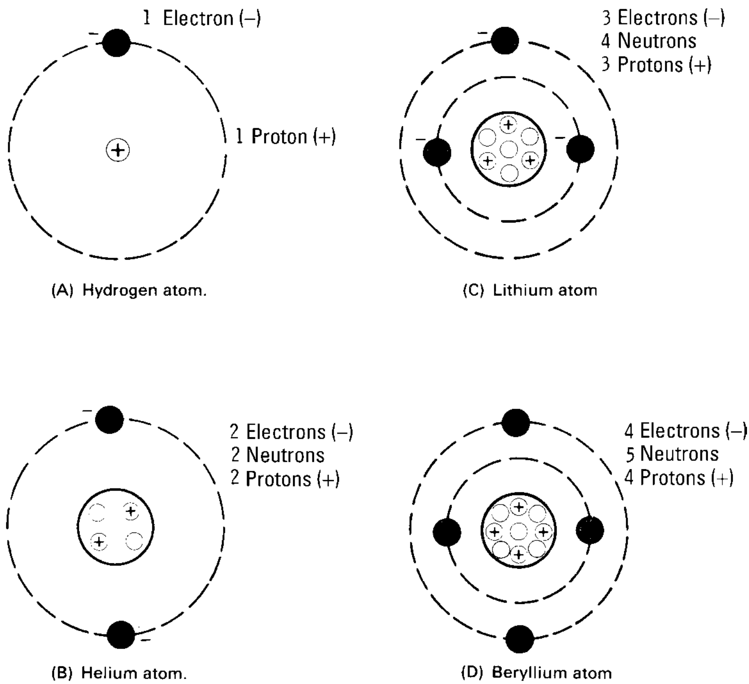

Figure 1-1 Atoms: electrons, neutrons, and protons. Electrons have a negative (–) charge, protons have a positive (+) charge, and neutrons are neutral.

electrons to the hard rubber rod, leaving the fur with a positive charge, and the hard rubber rod will gain a negative charge. Then, again, a glass rod rubbed with silk will give up electrons to the silk, making the silk negatively charged and leaving the glass rod positively charged.

What actually transpires is that the intimate contact between the two surfaces results in the fur being robbed of some of its negative electrons, thereby leaving it positively charged, while the rubber rod acquires a surplus of negative electrons and is thereby negatively charged. It is important to note that this surplus of negative electrons doesn't come from the atomic structure of the fur itself. It is found that, in addition to the electrons involved in the structure of materials, there are also vast numbers of electrons "at large." It is from this source that the rubber rod draws its negative charge of electrons.

If a hollow brass sphere is supported by a silk thread as in Figure 1-2 (silk is an insulator), and a hard rubber rod that has received a negative charge, as previously described, is touched to the brass sphere, the brass sphere will also be charged negatively by a transfer of electrons from the rod to the ball. The ball will remain negatively charged as it is supported by the insulating silk thread.

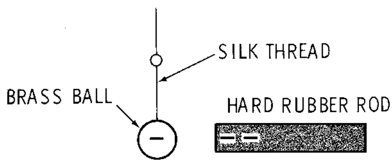

Figure 1-2 A negatively charged hard rubber rod touched to a hollow brass ball supported by a silk thread will negatively charge the brass ball.

Now if the same experiment is tried with the hollow brass sphere supported from a metal plate by a wire, the rubber rod will transfer electrons to the ball but the electrons will continue through the wire and metal plate and eventually to earth (see Figure 1-3).

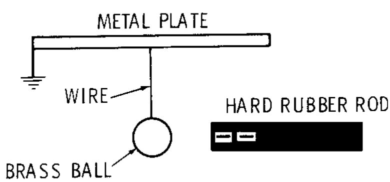

Figure 1-3 When a negatively charged hard rubber rod is touched to a hollow brass ball supported from a metal plate by a wire, the negative charge will move through the metal wire and on to earth.

When a body acquires an electrical charge as, for example, the hard rubber rod or the glass rod previously described, it is customary to say that the lines of force emanate from the surface of the electrified body. By definition, a line of electrical force is an imaginary line in space along which electrical force acts. The space occupied by these lines in the immediate vicinity of an electrified body is called an *electrostatic field of force* or an *electrostatic field.*

In Figure 1-2, the hollow ball was negatively charged and the lines of force emanated from it or converged on it in all directions (see Figure 1-4).

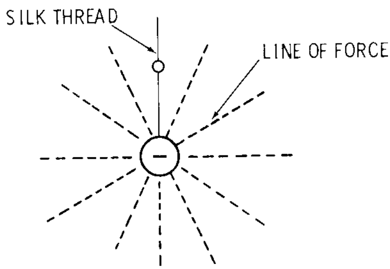

Figure 1-4 Lines of force from an electrically charged hollow ball emanate in, or converge from, all directions.

Static electrical charges may be detected by an *electroscope*. The simplest form of an electroscope is a light wooden needle mounted on a pivot so that it may turn about freely. A feather or a pith ball suspended by silk thread may also be employed for the purpose.

The electroscope most used was devised by Bennett and consists of a glass jar (Figure 1-5) with the mouth of the jar closed by a cork. A metal rod with a metal ball on one end (outside the jar) and a stirrup on the other passes through the cork, and a piece of gold leaf is hung over the stirrup so that the ends drop down on both sides.

When an electrified rod is brought close to the hollow brass ball, the electrostatic field charges the ball. In Figure 1-5, the rod is

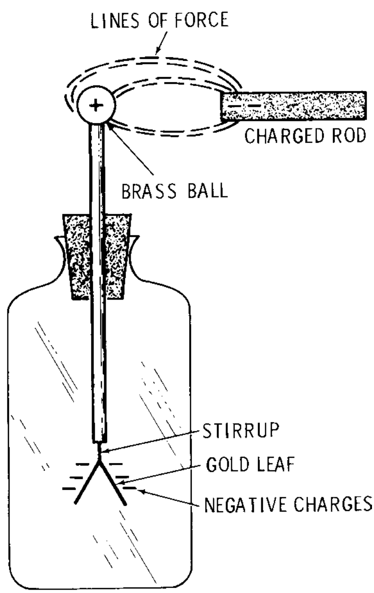

Figure 1-5 Gold-leaf electroscope.

negatively charged, so the electrons in the ball are repelled and the ball becomes positively charged. The electrons that were repelled from the ball go to the gold leaf, charging both halves of the gold leaf negatively, and the leaves fly apart, as illustrated in Figure 1-5.

Like charges repel each other and unlike charges attract. Since both halves of the gold leaf are charged the same, they repel. Remember that we have not touched the rod to the ball in this experiment; the electrostatic charges are transmitted by *induction.*

If a positively electrified ball (*A* in Figure 1-6) mounted on an insulated support is brought near an uncharged insulated body (*B-C*), the positive charge on ball *A* will induce a negative charge at point *B* and a positive charge at point *C*. If pith balls are mounted on wire and suspended by cotton threads, as shown, the presence of these charges will be manifested. The pith ball (*D*), electrified by contact with *B,* acquires a negative charge. It will be repelled by *B* and attracted toward *A* and stands off at some distance. The ball (*E*) is charged by contact positively and will be repelled from *C* a lesser distance because there is no opposite charge in the vicinity to attract it, while ball *F* at the center of the body will remain in its original position, indicating the absence of any charge at this point. This again shows electrostatic induction. The electric strain has been transmitted through the intervening air (*G*) between *A* and *B* and reappears at point *C.*

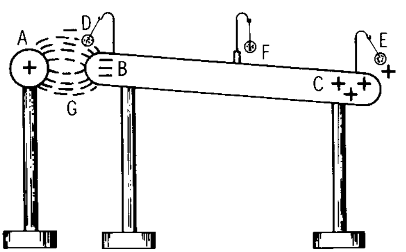

Figure 1-6 Illustration of charges produced by electrostatic induction.

In Figure 1-6, the air in the space (*G*) between *A* and *B* is called a *dielectric.* The definition of a dielectric is any substance that permits induction to take place through its mass. All dielectrics are insulators, although the dielectric and insulating properties of a substance are not directly related. A dielectric is simply a transmitter of a strain.

When a dielectric is subjected to electrostatic charges, the charge tries to dislodge the electrons of the atoms of which the dielectric is composed. If the stress is great enough, the dielectric will break down and there will be an arc-over. Dielectrics play a very important role in the theory of the electrical field.

Electric Current

We learned earlier that static electricity refers to electrical charges that are stationary—that is to say, a surplus of electrons, or the lack of same, that stay in one place, not in motion.

Electrons in motion constitute an *electric current*. Thus, if electrical pressure from a battery, generator, or other source is applied to an electrical conductor, such as a copper wire, and the circuit is closed, electrons will be moved along the wire from negative to positive. These electrons pass from atom to atom and produce current. The electrons that move are free electrons. They may be compared to dominoes set on end. If the first one is pushed over, it knocks the next one over and so on. This progression of movement of energy occurs at the speed of light, or approximately 186,000 miles per second.

During the early days of electrical science, electricity was considered as flowing from positive to negative. This is opposite to the electron theory. While in the study of this course the direction of flow might seem irrelevant, in electronic circuits the proper direction of flow is very important. Therefore, in our studies we will use the right direction of flow, namely, negative to positive in line with the electron theory.

There are basically three forms of electrical current, namely (1) direct current (DC), (2) pulsating direct current (pulsating DC), and (3) alternating current (AC).

Figure 1-7 compares the flow of water to DC. Pump *A* may be compared to a battery or a generator driven by some external force,

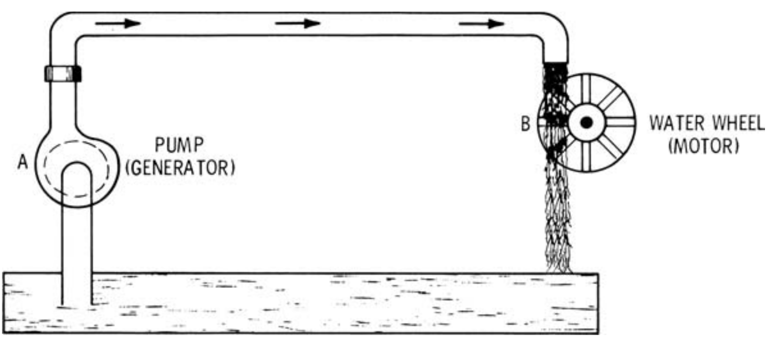

Figure 1-7 Analogy of direct current.

and wheel *B* may be compared to a DC motor, with the current flowing steadily in the direction represented by the arrows. This may also be represented as in Figure 1-8.

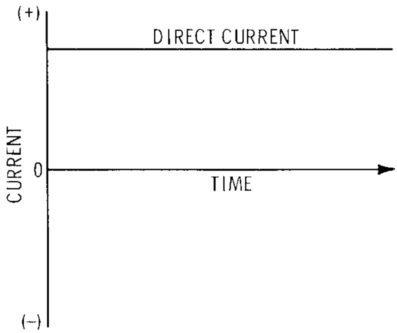

Figure 1-8 Graph representation of direct current (DC).

Now, if generator *A* in Figure 1-7 were alternately slowed down and speeded up, the current would be under more pressure when the pump was speeded up and less pressure when the pump slowed down, so the water flow would pulsate in the same direction as represented in Figure 1-9. It would always be flowing in the same direction, but in different quantities.

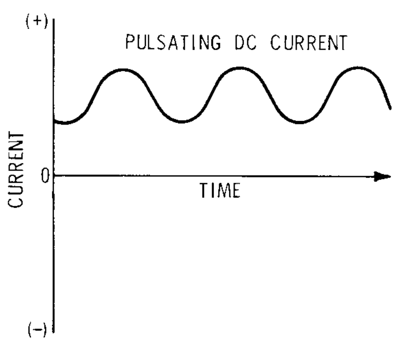

Figure 1-9 Pulsating DC.

In Figure 1-10 we find a piston pump (*A*) alternately stroking back and forth and thus driving piston *B* in both directions alternately. Thus, the water in pipes *C* and *D* flows first in one direction and then the other. Figure 1-11 illustrates the flow of AC; more will be covered later.

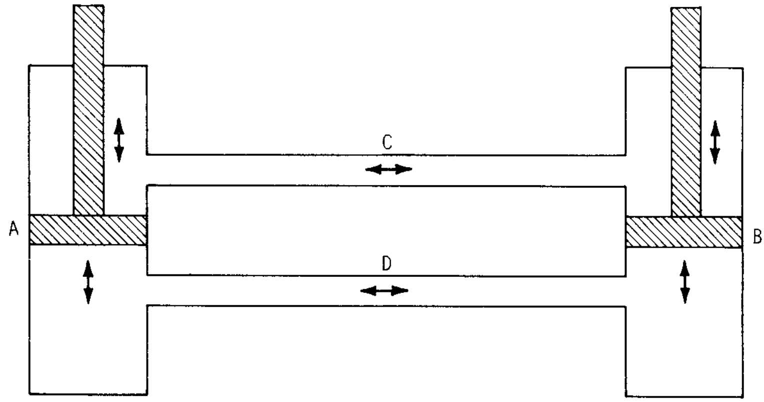

Figure 1-10 Piston pump analogy of alternating current.

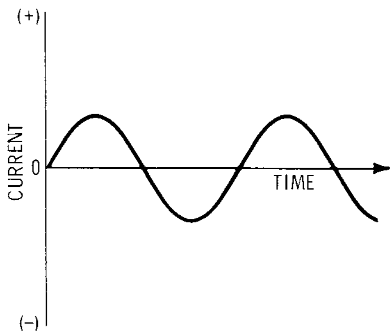

Figure 1-11 Graph representation of alternating current.

Insulators and Conductors

An insulator opposes the flow of electricity through it, whereas a conductor permits the flow of electricity through it. It is recognized that there is no perfect insulator. Pure water is an insulator, but the slightest impurities added to water make it a conductor. Glass, mica, rubber, dry silk, etc., are insulators, while metals are conductors.

Although silver is not exactly a 100 percent conductor of electricity, it is the best conductor known and is used as a basis for the comparison of the conducting properties of other metals, so we will call its conductivity 100 percent.

Some metals are listed here in the order of their conductivity:

Silver	100%	Iron	16%
Copper	98%	Lead	15%
Gold	78%	Tin	9%
Aluminum	61%	Nickel	7%
Zinc	30%	Mercury	1%

Questions

1. What is a neutron?
2. What is a proton?
3. What is an electron?
4. Sketch a boron atom and label its parts.
5. Two pith balls are negatively charged and supported by a dry silk thread. Draw a sketch showing their relative positions when they are brought close to each other.
6. Like charges (electrical) and unlike charges (electrical). Differencs?
7. What is static electricity?
8. What is electrical current?
9. What is a perfect insulator composed of?
10. Describe and draw an electroscope.
11. What is direct current? Illustrate.
12. What is pulsating direct current? Illustrate.
13. What is alternating current? Illustrate.