Practical Industrial Electronics

F. A. ANNETT

Practical Industrial Electronics

F. A. ANNETT

Associate Editor, Power
Life Member, American Institute of Electrical Engineers
Life Member, Association of Iron and Steel Engineers
Affiliate, Engineering Institute of Canada
Member, National Association of Power Engineers
Member, Institute of Power Engineers, Canada

381 ILLUSTRATIONS

McGRAW-HILL BOOK COMPANY, INC.

NEW YORK TORONTO LONDON

1952

PRACTICAL INDUSTRIAL ELECTRONICS

Library of Congress catalog card number: 51—12581

Preface

During the past 20 years, applications of electronic devices have made tremendous advances in practically every field of power and industrial engineering. Accordingly, many operating engineers and electricians, with little knowledge of these devices to guide them, are confronted with installing, operating, and maintaining electronic equipment. It was to help them that the author started to write a series of articles, published in *Power* from April, 1948, to November, 1951, under the general title "Electronics for the Power Engineer."

These articles tell in easy lessons what electrons are and describe the different kinds of electron tubes commonly used and how they are applied as power rectifiers, amplifiers, controllers, protective devices, and frequency changers in a wide variety of circuits. The series met with such favorable response that it was decided to compile them into this book.

A practical knowledge of the electron is a necessary background for a clear understanding of electron tubes and the circuits in which they are used, so the first chapter is devoted to this subject. The electron is presented as a simple and useful tool, rather than as a mysterious particle that only a high-browed physicist can comprehend. In a practical way this chapter shows how electron arrangements in atoms cause them to combine chemically, why some gases are inert, why some metals are light-sensitive and others are good conductors, why bodies become electrically charged, how a slow drift of electrons in a closed circuit constitutes electric-current flow, and how electrons are released from solids in hot-cathode and in light-sensitive tubes.

Changing alternating current to direct is a major application of electron tubes. Such tubes range from thimble size, good for a few microamperes, to great mercury-pool cathode designs that supply thousands of amperes. Because rectifiers are used so widely, three chapters are devoted to their applications, circuits, and operation.

Electronic relays, both instantaneous and time-delay, are the Jack-of-all-trades among electronic devices. The operation of several types is explained.

How oscillators operate has always been a stumbling block to practical electrical workers and to many engineers. Simple explanations based on hydraulic analogies make these devices easily understood. These explanations are then applied to commercial oscillators to show how they work.

Air-pollution laws have made practically every plant engineer conscious of smoke problems and electronic devices that indicate and record smoke density. Like smoke indicators, electronic flame-failure devices have come into wide use. They offer protection against explosion hazards, always associated with burning gas, oil, or pulverized coal in boiler furnaces. The operation of several designs is given in detail.

Adjustable speed is another broad field of applications of electronic equipment. These include variable-speed transmissions, magnetic drives, d-c motor and generator exciters, power and control units for d-c motors operating on a-c circuits, and electronic speed control of a-c motors. All these receive broad treatment.

Electrical fundamentals and elementary circuits are treated in separate chapters. But the reader is not left to wrestle with these fundamentals by himself. Instead, he is shown how they are applied in the operation of relay, smoke-detector, motor-speed-control, and other circuits.

Except in Chapter 4, direction of electron flow is used as direction of current flow. This is done in order to have current flow conform with electron flow from cathode to anode of electron tubes. It is not rational to say, as is sometimes done, that electrons flow in one direction and current flows in the opposite, particularly when a slow drift of electrons in a circuit is accepted as current flow. So if we accept electron flow as current flow and forget past mistakes, it eliminates much confusion.

The author thanks Philip W. Swain, editor, and Louis N. Rowley, executive editor, of *Power* for making this book possible; Miss Cora

F. Sanders, assistant editor, for copy-reading the manuscript of the original articles to keep my English on the straight and narrow path; and Joseph C. McCabe, for reading page proofs of the articles and making many constructive suggestions.

F. A. ANNETT

NEW YORK, N. Y.
December, 1951

Contents

CHAPTER 1. The Electron

Operation of all electronic devices involves methods of producing and controlling a flow of electrons. Therefore, we shall first learn what electrons are, how they are made available, and some laws that govern their action under different conditions.

Elements. All matter is composed of one or more of 92 elements found in nature, such as hydrogen, oxygen, nitrogen, carbon, lead, iron, silver, gold. An element is a substance that cannot be separated chemically into anything but itself. For example, hydrogen cannot be separated into anything but hydrogen no matter how small it is divided, nor can gold be changed chemically into anything but gold.

An atom is the smallest division that can be made of any element. Smallest and simplest is the hydrogen atom, while at the other end of the scale of elements is the uranium atom. It is the heaviest and most complex known, neglecting neptunium, plutonium, *americium,* and *curium,* recently created artificially.

Up to about 50 years ago the atom was believed to be the final division of matter. Then evidence began to accumulate that possibly it was composed of particles. Today through almost countless experiments by scientists we know this is so. Some 12 particles have been found in the atom. Of these, the three that we are most interested in are the following:

1. The electron, smallest subdivision of electricity, has a negative charge.

2. The proton, an elementary particle, has a positive electrical charge equal to the negative charge on the electron, but it weighs 1,836 times as much.

3. A neutron weighs about the same as a proton but is without an electrical charge; therefore it is electrically neutral.

In dealing with electronic devices the electron is Jack-of-all-trades.

Electrons, protons, neutrons, and probably the other particles are arranged in fairly well-defined patterns to build the different atoms.

Hydrogen Atom. This atom has a proton that serves as a nucleus about which a single electron rotates (Fig. 1-1). Here we have a solar system consisting of one sun, a single proton with a positive electrical charge about which revolves a single planet—an electron with a negative electrical charge.

Atoms and electrons are so small that they cannot be seen under the most powerful microscopes. The hydrogen atom, smallest and lightest, has a diameter of about four billionths of an inch. But the electron's diameter is only about one-hundred-thousandth part of the atom's diameter. Compared with their dimensions, space is very

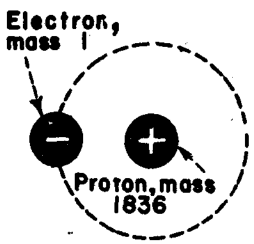

Fig. 1-1. The hydrogen atom has a proton that serves as a nucleus about which rotates a single electron.

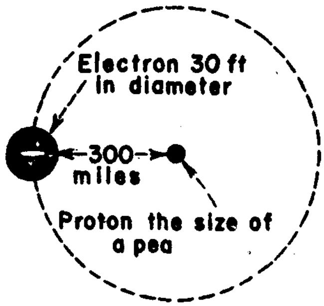

Fig. 1-2. This conception of the hydrogen atom was devised by the English physicist Sir Ernest Rutherford.

great between electrons and between them and the nucleus about which they revolve. Figure 1-2 shows Sir Ernest Rutherford's conception of the hydrogen atom. According to this famous English physicist, if we imagine the electron enlarged to 30 foot diameter, it would be 300 miles from its proton, which would be the size of a pea.

At ordinary temperatures the electron of the hydrogen atom has a velocity of about 75 miles per second in the orbit around its proton. The proton with its plus charge attracts the electron with its equal, negative charge so that they tend to fall together just as the earth tends to fall into the sun from gravitational pull. Because of their velocity, however, both earth and electron tend to fly out into space but are held in their orbits by the attraction between them and their sun or proton.

As we shall see later, increasing the energy of electrons by heat, light, or radiation causes them to accelerate in their orbits until some fly out into space. Thus, electrons may reach speeds that approach that of light.

Practically the total mass of the atom is in its nucleus. In the hydrogen atom the mass of the proton, or nucleus, is 1,836 times that of the electron. Because of its comparatively great mass the proton is very dense and, therefore, small compared with the electron (Fig. 1-2). The proton in the hydrogen atom is only 1/2,000 the size of the electron.

Isotopes. We may better understand helium, the next atom in the electron scale, if we consider the isotope of the hydrogen atom.

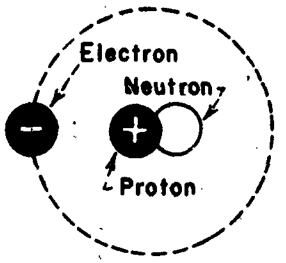

Fig. 1-3. The hydrogen isotope has a proton and a neutron that are bound closely together to form a nucleus.

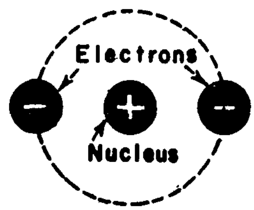

Fig. 1-4. The helium atom has two electrons that rotate in a single orbit around the compact nucleus.

Among all atoms, some are isotopes. They are identical with all the other atoms in a given element, but their atomic weight is different, which is due to the addition of one or more neutrons to the normal number in the nucleus. For example, the hydrogen atom has a single proton for a nucleus whereas its isotope has a proton and neutron bound closely together, as in Fig. 1-3. Because the neutron has practically the same mass as the proton, the atomic weight of the hydrogen isotope is double that of the hydrogen atom. One in about every 5,000 atoms of hydrogen is an isotope and is known as "heavy hydrogen." It was isolated by Dr. Harold Urey. Water containing this isotope is called "heavy water."

The helium atom, next in the electron scale, has a compact nucleus with two electrons traveling around it in an orbit (Fig. 1-4). The nucleus (Fig. 1-5) includes two protons with a positive charge equal to that of the two electrons. The neutrons have no charge but increase the atomic weight of the atom by an amount equal to their mass. A helium atom may be considered as two hydrogen isotopes compressed into a single atom; consequently, it has double the atomic weight.

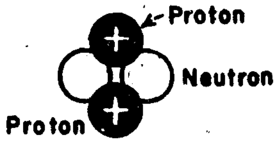

Fig. 1-5. In the nucleus of the helium atom two protons and two neutrons are bound closely together.

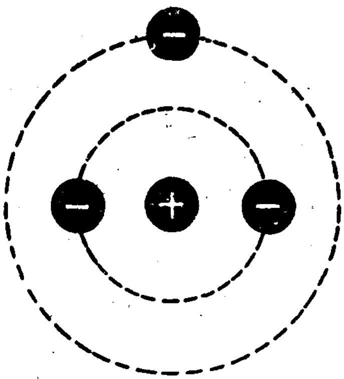

Fig. 1-6. The lithium atom has three electrons rotating about a nucleus: two in an inner circular orbit, one in an outer orbit.

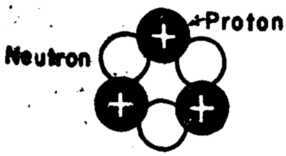

Fig. 1-7. The nucleus of the lithium atom, diagramed in Fig. 1-6, includes three protons and three neutrons.

A lithium atom (Fig. 1-6) has two electrons in an inner circular orbit, as in the helium atom, and one in an outer orbit rotating about a compact nucleus that includes three protons and three neutrons (Fig. 1-7). The electrical charge on the three protons in the nucleus equals that on the three electrons in the orbits, so the atom is in a state of electrical balance.

Succeeding Elements. The number of electrons in the outer orbit increases by one for each of seven succeeding elements, lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, until we reach neon, which has two electrons in its inner and eight in its outer orbit, as in Fig. 1-8. The next element in the atomic scale, sodium, has a third orbit in which a single electron rotates. Electrons in this orbit increase by one through seven succeeding atoms until we come to argon, which has eight (Fig. 1-8). Beyond argon the electron continues to increase by one for each succeeding element up to uranium,

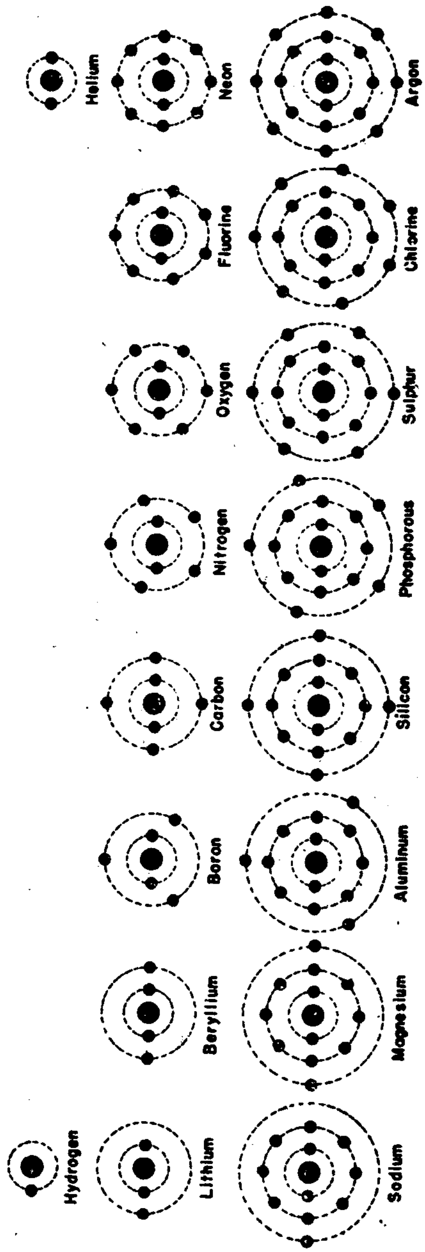

Fig. 1-8. After helium, with two electrons in a single orbit, the number of electrons in a second orbit increases by one for each of the eight succeeding elements: lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, and neon (an inert gas).

which has 92, arranged as in Fig. 1-9. This element has attracted much attention because of its use in the atomic bomb and as a proposed source of energy for power generation.

In the nucleus of each atom there are positively charged protons in an equal number to the negatively charged electrons outside. Combined with the protons are an equal number of neutrons in the simpler atoms and a greater number in the more complicated one. But this part of the atom is of little interest in the study of electronics because all phenomena that we shall study result from distribution and movement of electrons. For this reason we shall not devote further attention to the nucleus, which contains most of the energy of the atom and around which has developed the absorbing science of nuclear physics.

Electron Orbits. The illustrations so far used show the electron orbits in the same plane. According to the Bohr theory the orbit

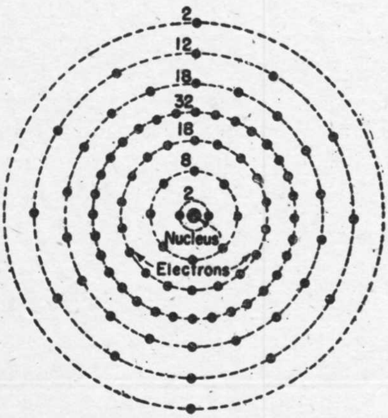

Fig. 1-9. The uranium atom, the most complex found in nature, has 92 electrons. It is notable for its use in atom bombs.

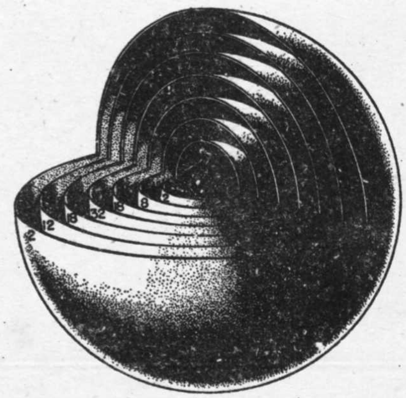

Fig. 1-10. The 92 electrons of the uranium atom are divided into seven shells as the diagram shows. The ball in the center is the nucleus.

of each electron is in a different plane to form what are called "space shells." That is, instead of the 92 electrons of the uranium atom being arranged in seven orbits in a single plane (Fig. 1-9), they are in seven space shells (Fig. 1-10), each electron moving in a different orbit. The numbers on the space shells indicate the number of electrons in each, the nucleus being shown in the center as a round