A RESOURCE RESEARCH IN ELECTRICITY

For American Industrial Arts Education Programs
with Implications for Teacher Education

A DISSERTATION

Presented in Partial Fulfillment of the Requirements
for the Degree Doctor of Philosophy in the
Graduate School of The Ohio State University

by

WILLIAM LUTHER DECK, B.S., M.A.
Southwest Texas State Teachers College
San Marcos, Texas

THE OHIO STATE UNIVERSITY

1955

Approved by:

[Signature]
Adviser
Department of Education
PREFACE

The commercialization of the phenomenon of electricity has assumed amazing proportions. The original presentation of lighting and telephone displays occurred only sixty years ago at the Columbian Exposition in Chicago in 1893. Less than 50 million dollars was spent for electrical equipment and service of all types during the year of 1900. This mushroomed to two billion dollars by 1940 and the current figure is approximately twenty billion dollars annually.

Such data cannot be ignored by those engaged in American public education, and especially by those in industrial arts education. The question of what to do about this problem has been accepted by this dissertation. Its organization and development have been designed especially to answer most of the questions that should be resolved by the industrial arts profession.

The names of many students of this subject should be acknowledged because the writer has been engrossed with the problem for some twenty years and has had the very real privilege of working directly with those in industry. Chief among the above is Professor Lawrence C. Secrest of the Industrial Arts Electrical Laboratory in the State Teachers College at DeKalb, Illinois. The writer is also keenly appreciative of the discerning guidance provided by his graduate major adviser, Dr. William E. Warner and by the other members of the committee, Dr. Earl W. Anderson and Dr. Andrew Hendrickson.

July 15, 1955

WILLIAM LUTHER DECK

ii.
# CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PREFACE</strong></td>
<td></td>
</tr>
<tr>
<td>I. <strong>NATURE OF THE DISSERTATION</strong></td>
<td>1</td>
</tr>
<tr>
<td>Nature of Electricity</td>
<td></td>
</tr>
<tr>
<td>Evolution</td>
<td></td>
</tr>
<tr>
<td>Phases</td>
<td></td>
</tr>
<tr>
<td>Terminology</td>
<td></td>
</tr>
<tr>
<td>Assumptions</td>
<td></td>
</tr>
<tr>
<td>Scope and Limitations</td>
<td></td>
</tr>
<tr>
<td>Impact on Industry</td>
<td></td>
</tr>
<tr>
<td>Impact on the Individual</td>
<td></td>
</tr>
<tr>
<td>Impact on Education</td>
<td></td>
</tr>
<tr>
<td>Statement of the Problem</td>
<td></td>
</tr>
<tr>
<td>Research Techniques Employed</td>
<td></td>
</tr>
<tr>
<td>II. <strong>ELECTRICITY IN EARLY TIMES</strong></td>
<td>17</td>
</tr>
<tr>
<td>The Heavy Hand of Superstition</td>
<td></td>
</tr>
<tr>
<td>Discovery and Uses of Magnetism</td>
<td></td>
</tr>
<tr>
<td>Development of Static Electricity</td>
<td></td>
</tr>
<tr>
<td>Evolution of Current Electricity</td>
<td></td>
</tr>
<tr>
<td>III. <strong>ELECTRICITY IN MODERN TIMES</strong></td>
<td>52</td>
</tr>
<tr>
<td>The Generation of Electricity</td>
<td></td>
</tr>
<tr>
<td>Industrial Uses of Electricity</td>
<td></td>
</tr>
<tr>
<td>Domestic Uses of Electricity</td>
<td></td>
</tr>
<tr>
<td>Medical Uses of Electricity</td>
<td></td>
</tr>
<tr>
<td>Electricity in National Defense</td>
<td></td>
</tr>
<tr>
<td>Electricity in the Future</td>
<td></td>
</tr>
<tr>
<td>IV. <strong>THE RESOURCE STUDY OF ELECTRICITY</strong></td>
<td>87</td>
</tr>
<tr>
<td>Characteristics</td>
<td></td>
</tr>
<tr>
<td>Magnetism</td>
<td></td>
</tr>
<tr>
<td>The Electron Theory</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td></td>
</tr>
<tr>
<td>Cells</td>
<td></td>
</tr>
<tr>
<td>Conductors</td>
<td></td>
</tr>
<tr>
<td>Measurement</td>
<td></td>
</tr>
<tr>
<td>Circuits</td>
<td></td>
</tr>
<tr>
<td>Condensers</td>
<td></td>
</tr>
<tr>
<td>Inductance</td>
<td></td>
</tr>
<tr>
<td>Chapter</td>
<td>Page</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Transformers</td>
<td>205</td>
</tr>
<tr>
<td>Relays</td>
<td></td>
</tr>
<tr>
<td>Switches</td>
<td></td>
</tr>
<tr>
<td>Dynamos</td>
<td></td>
</tr>
<tr>
<td>Transmission</td>
<td></td>
</tr>
<tr>
<td>Rectifiers</td>
<td></td>
</tr>
<tr>
<td>Annotated Bibliography</td>
<td></td>
</tr>
<tr>
<td>V. NATURE AND SCOPE OF INDUSTRIAL ARTS EDUCATION</td>
<td>218</td>
</tr>
<tr>
<td>Derivation of a Statement of Position</td>
<td></td>
</tr>
<tr>
<td>Resulting Objectives or Functions</td>
<td></td>
</tr>
<tr>
<td>Basic Programs or Scope of Industrial Arts</td>
<td></td>
</tr>
<tr>
<td>VI. ELECTRICITY IN THE INDUSTRIAL ARTS CURRICULUM</td>
<td>233</td>
</tr>
<tr>
<td>The Elementary School</td>
<td></td>
</tr>
<tr>
<td>The Secondary School</td>
<td></td>
</tr>
<tr>
<td>Atypical Cases</td>
<td></td>
</tr>
<tr>
<td>Technical Levels</td>
<td></td>
</tr>
<tr>
<td>Recreational Groups</td>
<td></td>
</tr>
<tr>
<td>Adult Interests</td>
<td></td>
</tr>
<tr>
<td>Service Fields</td>
<td></td>
</tr>
<tr>
<td>VII. ELECTRICITY IN INDUSTRIAL ARTS TEACHER EDUCATION</td>
<td>248</td>
</tr>
<tr>
<td>Situation in the States and Colleges</td>
<td></td>
</tr>
<tr>
<td>Essentials of the Three Degrees</td>
<td></td>
</tr>
<tr>
<td>Basic Laboratory Equipment</td>
<td></td>
</tr>
<tr>
<td>VIII. SUMMARY AND CONCLUSIONS</td>
<td>260</td>
</tr>
<tr>
<td>Findings of the Resource Study</td>
<td></td>
</tr>
<tr>
<td>Recommendations</td>
<td></td>
</tr>
<tr>
<td>1. Instructional Units</td>
<td></td>
</tr>
<tr>
<td>2. A Companion Dissertation</td>
<td></td>
</tr>
<tr>
<td>3. Administrative Officers</td>
<td></td>
</tr>
<tr>
<td>4. Teacher Education</td>
<td></td>
</tr>
<tr>
<td>5. Organized Experimentation</td>
<td></td>
</tr>
<tr>
<td>6. The Literature</td>
<td></td>
</tr>
<tr>
<td>7. Refresher and In-Service Training</td>
<td></td>
</tr>
<tr>
<td>8. The Industry Itself</td>
<td></td>
</tr>
<tr>
<td>SELECTED BIBLIOGRAPHY</td>
<td>266</td>
</tr>
<tr>
<td>AUTOBIOGRAPHY</td>
<td>273</td>
</tr>
</tbody>
</table>
Chapter I

NATURE OF THE DISSERTATION

This is a resource and program type of research. It focuses upon the electrical phase of the American technology with general reference to its impact upon man and society, and with special reference to what should be done about it by industrial arts education.

The industrial development of electricity is of only very recent origin, but in the short space of a half century has now become almost universal. It is a necessity in present day society that every individual know the intelligent application of it.

It is in agriculture as well as industry, in the arts as well as the sciences, in medicine and health as well as the home, and in manufacture and transportation as well as communication. In the future it may take its place in relieving more human ills. Today, it is possible for some industries to produce their product completely with electrical tools and automatic controls. The surroundings of the home can be lighted automatically by a narrow beam of light. Windows in the home can be closed automatically as a rain storm approaches.

The school subject of industrial arts education has been defined by Bonser (8, p. 5), Wilber (66, p. 2) and many others, as referring to those phases of general education which deal with industry: its tools, materials, processes, products and personnel, and with the problems that result from the interaction of these
basic elements. The leaders of industrial arts have been concerned to interpret the technology not only as regards its production, but its consumption too, hence this study.

NATURE OF ELECTRICITY

Electricity was vaguely perceived over the centuries. It still cannot be defined, but man has learned to use the charged particles of the atom. These particles, called electrons, were found to have tremendous effects. This new phenomenon produced heat, motion, light, and chemical effects after it was brought under control.

The speed of the electron is approximately 186 thousand miles per second. An electric current is the flow or movement of electrons. The opposition or resistance offered by the atoms of a conductor results in heat or light. The flow of an electric current through a conductor produces many invisible lines around it called magnetic lines of force. These magnetic lines of force produce the magnetic effect when a conductor is coiled about itself. This magnetic effect produces motion. Chemical change is created when an electric current is passed through an electrolyte or a liquid that conducts an electric current. This effect will store electrons, purify metals, or deposit one metal on another. Power is developed when a large number of electrons are placed in motion. This is accomplished by turning a series of coils of wire in a strong magnetic field.
EVOLUTION

This new phenomenon, electricity, has become a slave to every man, woman, and child. It developed in the five stages noted below. The first of these is superstition.

Superstition. This phase began long before the observation of Thales and continued to the close of the Civil War. The weight of superstitions about magnetism and electricity caused progress to be slow. They were gradually analyzed and discarded by experimentation.

Experimental. This period began with the observation of Thales 640-546 B.C. He was the first to deny that the attractive force of amber was supernatural power. He was the first to attempt to explain why it attracted straw and other material. The greatest vigor in experimentation was exerted during the eighteenth and nineteenth centuries. By the latter part of the nineteenth century the foundation of electricity was established. In this period, electricity was generated by water power. Small motors supplied power for machines by transmitted electricity. Electric railroads were established. The incandescent light was developed and the first commercial electric power became practical.

Industrial. The "Jumbo" generators and the engineering feats of Sprague and others attracted industries in the latter part of the nineteenth century. By the early part of the twentieth century electricity was favored by industry more than any other type of
energy as a source of power. This movement developed in all major industries of the world. The new power created flexibility in industries. It aided the standardization of parts, and reduced the cost of production. Edison and Westinghouse organized electrical engineers for production of electrical goods and machines.

**Domestic.** This phase started in the latter part of the nineteenth century, but made its greatest growth after the depression of 1929. Batteries at first supplied electrical power for street and home lighting. This proved to be too expensive and was discontinued. The discovery of new materials and techniques made electricity available for domestic and industrial use.

**PHASES**

The *superstition* phase is identified with many outstanding beliefs about amber, lodestone, and lightning. For example, many believed that the attractive power of amber was supernatural. The Roman priests wore the Samothracian rings in religious worship. Many believed the lodestones contained souls fallen from heaven. The belief that lightning was the wrath of the Gods prevailed for centuries. There was a long enduring belief that the diamond, and the odor of garlic and onions would destroy the power of the magnet. It was believed that powdered lodestone mixed with nettle juice would reduce fat. These and other superstitions will be enlarged upon in Chapter II. Superstitions caused some challenge and a small number made experiments to test them.
Experimental. This phase is identified by a tremendously large number of experimenters that were important in developing the new phenomenon into a science. These experiments began with the observation of Thales, the Greek philosopher of 640-546 B.C. Saint Augustine discovered that amber would attract straw and paper but not iron, and that the lodestone attracted metal or iron only. The Chinese developed the magnetic compass and it gradually made its way into Europe. Peter Peregrinus refined the Chinese compass and created the lubbers point. Robert Norman developed the dip needle. Experiments made by Franklin, Galvania, Volta, Gersted, Ampere, and others will be discussed in Chapter II.

Industrial. The experiments made by Michael Faraday and Joseph Henry and others were refined by experimenters Sprague, Edison, Westinghouse, Tesla, and many more in an attempt to find practical applications of the new science. These experimenters developed practical means of generating current electricity by mechanical means, and ways of transmitting it to industrial sites. For example, the "Jumbo" generators developed by Edison, the Niagara Falls power system, and the application of electric motors to machines by Sprague were attractive to industry. These developments and their influence on society will be expanded in Chapter III.

Domestic. The developments that grew out of the experimental and industrial phases made rapid expansion and developments of the new technology after the depression in domestic uses. This was accomplished by developing wider applications of electricity by
Westinghouse, General Electric, and other industries. George Westinghouse and Nicola Tesla developed the alternating current generator and the brushless motor. This development made transmission of current electricity possible over greater distances and more economical than direct current electricity. These developments made rural electrification possible and the great expansion in the commercial and domestic use of electricity. These developments will be treated in Chapters III and IV.

Phase of the Electron Tube. This began in the experimental stage. Edison made a discovery known as the "Edison Effect" in the latter part of the nineteenth century. Sir Alexander Fleming employed the "effect" and created the two element tube known as the diode. This device made possible the conversion of alternating current to the direct type. Lee De Forest created the triode by adding the third element, the grid, to the Fleming diode. This triode has many variations today and hundreds of applications.

The field of electronics is very closely allied to the subject matter of this dissertation. The electron tube is a phase of electricity, but is omitted for the following reasons. First, there is enough electronic content to develop a resource study equally as large and rich as Chapter IV. Second, there are phases of electronic development equally as interesting and important as the phases of electricity. Third, its historic development is as rich in material as the historic development of electricity and magnetism. Fourth, the applications of electronics to industry and domestic use are
just as numerous as electricity. Fifth, its role in industry as an automatic control of power and machines creates a phase of technology that needs interpretation.

TERMINOLOGY

The educational and scientific terms used in this dissertation are defined as follows:

Adult Education. Formal and informal instruction and aids to study for mature persons, or all activities with an educational purpose carried on by mature persons on a part-time basis, or any voluntary purposeful effort toward the self development of adults, conducted by public and private agencies, such as adult schools, extension centers, settlements, churches, clubs and Chautauqua associations, for informational, cultural, remedial, vocational, recreational, professional, and other purposes. It may use such forms of class or group gatherings as the colloquy, discussion, panel, forum, round table, reading circle, institute, tutorial class, and short course. It directs its activities toward such special subjects as citizenship, consumer problems, cooperatives, child welfare, farming, health, and industrial relations and to the field of art, literature, and science.

Amplifier, electric, a device to magnify electric impulses usually including one or more electron tubes.

Atypical, not of the typical character, irregular, unlike the type.
**Detector, radio.** A device for rectifying high-frequency electric current, as to vibrate a telephone receiver diaphragm, which of itself will not respond to such high frequency.

**Diode.** A vacuum tube with a cold or positive anode (plate) and a heated cathode, serving as a rectifier.

**Edison effect.** The flow of electrons from a heated cathode or filament to a cold or positive anode or plate.

**Electricity** is defined as the flow of free electrons through a metallic conductor.

**Electronics** is defined as the flow of free electrons through a vacuum or gas filled tube.

**Electrolyte.** A type of electrical conductor in which, when traversed by an electric current, there is a liberation of matter at the electrodes, either an evolution of gas or a deposit of a solid.

**Electrical-electronic industry.** A letter from the Chamber of Commerce of the United States reports that:

 Probably the best definition of this industry is the United States Bureau of the Census electrical machinery industry. This industry includes the manufacture of electrical industrial apparatus, electrical appliances, insulated wire and cable, engine electrical equipment, electric lamps, communication equipment, and miscellaneous electrical products.

**Elementary education.** It is the period of formal education beginning in childhood, usually at the age of five to seven years,
and ending approximately with adolescence, at the beginning of secondary education, or including grades one to eight, and sometimes nursery school and kindergarten. It is concerned primarily with general education including those skills, facts and attitudes that are required by society.

**Secondary education.** The period of education which usually consists of grades seven to twelve during which pupils learn to use independently the tools of learning that they have previously mastered. It is differentiated in varying degrees according to needs and interests. It may be terminal or preparatory.

**Services.** Performance of useful labor pertaining to business or industry, performance of official duties for a sovereign or state as public service, and military or naval duty.

**Technology.** Industrial science or systematic knowledge of the industrial arts.

These terms were developed from the fifth edition of *Webster's Collegiate Dictionary* and the (1945) first edition of Carter Victor Good, *Dictionary of Education*.

**ASSUMPTIONS**

The teacher and much that pertains to his success was examined closely in view of certain stated assumptions of this dissertation.

The basic assumptions are as follows:
1. Professional programs are based upon stated, assumed, or derived philosophies or policies.

It is believed that teacher education should reflect a cultural pattern which reflects the American way of life. Its leaders must be thoroughly familiar with the complicated problems of the technological society, and of the many proposals for directing individual development in living in a complex society.

2. Professional programs should exemplify the needs of a profession and lead out in its development.

The first professional need is to develop a curricula for certain clearly defined groups as for: normal groups at six levels, elementary, secondary, collegiate, adult, services, and camp and vacation; atypical groups such as crippled, partly seeing or blind, hard of hearing or deaf, mentally retarded, social maladjusted, and the gifted; and professional groups, such as baccalaureate and graduate levels.

A second obligation is in providing physical equipment for programs designed to attain orientation, technical, vocational and recreational.

The third need concerns the teachers and their qualifications. This includes their intellectual and mechanical aptitudes, their social and personal development, and their skills as well as their attitudes and perspectives.
3. Teachers in the field should be fully prepared to carry on their assignment as well as being able to project their programs in the light of the technological and social trends.

The industrial arts teachers are expected to develop a program that is functional and dynamic in nature. They must be conscious of an evolving technology and ready to adapt their program to the origins listed in Chapter V.

SCOPE AND LIMITATIONS

It was believed inadvisable to combine the two divisions of electricity and electronics after reviewing the resource material. It was the opinion of the advisory committee that a more plausible resource study could be achieved with one division.

Selected topic. In order to use the wealth of available resource material, it was necessary to limit the dissertation to a resource and program research in electricity for industrial arts.

Programs selected. College programs were selected in light of semester hours offered in electricity and course content. These came from researches made regarding industrial arts teacher education.

IMPACT ON INDUSTRY

The effect of electricity on industry was a gradual process. There were movements under way in the last part of the nineteenth century. For example, one and seven tenths billion incandescent light bulbs were in use, and 3/4 electric railways were operating,
small electric motors were operating elevators and other machinery.

The movement made some progress in industry shortly before
World War I. The war brought a halt to the progress, but soon after
its close, there was a period of rapid development and penetration.
Industrial enterprises tended more and more to use electrical
power in preference to any other form of energy. The movement
gained in momentum once the conversion of manufacturing processes
was made to the use of electrical power, and the industrial and
economic expansion of the principal countries became more and more
dependent on the increase in construction and equipment required
for the production of electricity or the utilization of it in
industrial enterprises. The electrification of homes has increased
the impact on industrial production, and will continue as the
economic status of the home is maintained.

IMPACT ON THE INDIVIDUAL

The influence of electricity made its showing just before
World War I. Human power at this time was almost equal to the tech-
nological. Soon after the war technological power was approximately
seven times greater than human. This increase in technological
power provided more employment, more goods, higher income, and a
higher standard of living. It has made a shorter working day, and
as a result man has more leisure time. It has lifted man from hard
wearisome labor to a position of an observer, or a tender of
machines. It has given man freedom in his work, and provides for
creativity. It demands that man be alert, have ability to analyse, see the relationship of many moving parts, and think in electrical terms and symbols.

It has made possible many automatic controls and devices to stop and start machines. This replaces man with a machine. However, man, in most cases, is still the tender. Many industries have been affected by automation. For example, glass, bottles, electric light bulbs, and electric generation plants are almost 100 percent automatic. In the light bulb industry 95 percent of all bulbs are made by automatic processes.

It has made a wealth of materials useful for man. For example, aluminum, asbestos, cerium, cobalt, helium, iridium, mica, molybdenum, platonium, radium, tantalum, and thorium.

Man can be more exacting in his work for new tools such as electric motors, generators, photo-electric cell, x-ray, magniflux, infra red ray, electrostatic field, high frequency heating have been developed.

**IMPACT ON EDUCATION**

Old educational institutions such as the home, and the church, weakened while new ones such as the printing press, industry, cinema, telegraph, telephone, radio, and television appeared and prospered. These have aided in forcing public opinion and mass education, and have brought great changes; for example, industrial civilization
with an ever expanding technology. Hence, formal education has received new significance in modern times and has become one of society's most powerful institutions.

STATEMENT OF THE PROBLEM

This dissertation is a resource and program research in electricity and the following objectives are developed:

To show the early and present historic development of electricity. This occurs in Chapters II and III.

To show the value and its application to agriculture, medicine, science, health, as well as its value and importance to power, manufacture, transportation, communication, construction, and personnel. These are developed in Chapters II and III.

To develop a resource study composed of the technical aspects of electricity. This is developed in Chapter IV.

To show the relationship of electricity to the nature of industrial arts. This is shown in Chapter V.

To develop example programs for the various groups of education. This is developed in Chapter VI.

To develop and propose a program for industrial arts teacher education with emphasis on electricity. This is developed in Chapter VII.

This dissertation includes an historic research on electricity in early times or from the age of superstition to the modern age, and is followed by a systematic and exhaustive resource or content study of contemporary electrical knowledge and practice reported under
seventeen headings enumerated below. By way of application, the subject matter thus recorded is then adapted by examples to the industrial arts curriculum from elementary to adults and several levels, and concludes with a chapter of implications for teacher education.

RESEARCH TECHNIQUES EMPLOYED

Usually there is more than one way of achieving a desired objective, and frequently a number of different approaches to a given question will produce better results than one. With this thought in mind, for this dissertation, various techniques were employed in securing data for this study.

Bibliographies. These include all available materials that had a bearing on this subject including books, pamphlets, and periodicals in science and education which were reviewed.

Historic. This material was found in small parts, and was screened from many books, pamphlets, and periodicals.

Experimental. Many hours were spent in the industrial arts electrical laboratory experimenting with mechanical and electrical devices, electrical circuits, and theory in an attempt to find new ways and methods of presenting the new technology to students.

Personal Interviews. Interviews with laymen, college students, industrial arts teachers and industrial arts department heads were made in regard to the electrical field.

Catalogues and Bulletins. Catalogs of various teacher colleges were obtained for program, nature of courses, and semester hours credit. State department of education bulletins were studied to
determine the type of program recommended for secondary education and the emphasis on electricity.

**Evaluation.** Subjective and objective tests were given to laymen, college students and industrial arts teachers to determine their competency in the broad and specific areas of electricity.

**Deduction.** The technique implied here means arriving at conclusions through an orderly procedure of summarizing factual material.

**Induction.** The use of this technique involved the inferring of general conclusions from particular parts. This method of arriving at conclusions was used throughout.

**Questionnaire.** A chart questionnaire was used to collect data pertaining to the number of semester hours offered in electricity by industrial arts teacher education.

**Letters.** Letters were sent to the twenty state departments of education concerning their programs of electricity.

**Dissertations.** The most current doctoral dissertations regarding the dissertation were reviewed.

**Personal Observations.** Personal visits were made to industrial arts electrical laboratories to study the program and content in action. This study opened with a chapter which has sought to identify the elements of the problem and the fields of inquiry which is concerned with resource material, programs, and teacher preparation.

Chapter II concerns the first phase of inquiry namely, electricity in early times, which has intrinsic value to this dissertation.
Chapter II

ELECTRICITY IN EARLY TIMES

This chapter is considered to be basic to the dissertation, because it is a resource study. What now follows is an historic analysis of four clearly discernible periods in the discovery and early development of electricity. These include, an examination of the heavy hand of superstition concerning the phenomenon of electricity that prevailed for many centuries, the ultimate discovery and uses of magnetism, the discovery and uses of static electricity, and the discovery and early uses of current electricity.

This chapter involves historic and bibliographic research. The encyclopedias have been freely consulted in addition to such authoritative references as Benjamin (4), Burlingame (13), Draper (22), Greenwood (31), Hodgins (36), and the industry itself. Major discoveries have been underlined to facilitate their review by industrial arts curriculum people and others concerned.

THE HEAVY HAND OF SUPERSTITION

Primitive man was ill prepared to understand the many evidences of electricity in nature and therefore rationalized about them as superstitions. The frightening nature of thunder and lightning were attributed to the angry Gods, and such odors as those emanating from onions or garlic were considered to be strong enough to destroy the magnetic qualities of the lodestone, which along with amber, were considered to possess supernatural powers.
SOCRATES (469–399 B.C.) in describing (4, p. 24) the divine character of the rings from Samothrace, a Greek island in the northeastern part of the Aegean Sea that had been visited by the Apostle Paul on his way to Macedonia, had this to say:

... but there is a divinity moving you, like that in the stone which Hippias calls a magnet, but which is commonly known as a stone of Hercules (i.e., Hercules). For that stone not only attracts other rings, but imports to them similar power of attracting other rings.

This superstition was so strong that Samothracian rings were used by many church people of early times. They were worn by the worshippers of Cabiri (4, p. 25), and later by the Roman priests. Socrates also states that the Samothracian rings became the usual pledge of betrothal in PLINIUS's time. The Cabiric priests theorized (4, p. 30) that the lodestone used in making the Samothracian rings were supernaturally influenced. The Cabiri people were not the only ones to use the lodestone in their worship. The priest of the Cybele wore talismans, a figure cut or carved from materials under certain superstitious observations (4, p. 80) of heaven, of which the following description is typical:

... the stones (betulæ or Phoenician lodestones) were probably pieces of magnetic iron from meteorites, worn as divining talismans by the priests of Cybele, who supposed them to contain souls which had fallen from heaven.

The Chinese also attributed the lodestone to divinity. Some of their offerings, such as a piece of red cloth, incense or gold paper were assembled in the form of a Chinese ship and burnt over a lodestone. Chinese navigators not only considered the magnetic
needle as a guide to direct their voyages through the ocean, but
believed the spirit which influenced its motions to be the
guiding deity of the vessel.

SAINT AUGUSTINE (354-430 A.D.) stated (4, p. 88) that when a
diamond was laid near iron, a magnet would not lift it, and would
drop iron already lifted if a diamond was held near it. This super-
stition lasted at least 1500 years. Alexander NECKAM, an English
monk, reported the same superstition in 1195 A.D.

One of the most interesting superstitions of this period was
the belief that the attractive power of the magnet would also be
weakened or destroyed by the touch or odor of onions or garlic.

Benjamin (4, p. 142) reports that:

..... among the superstitions relating to it, none for
example, was more common than the belief that its attrac-
tive power could be destroyed or weakened by the touch
or even the odor, of onions or garlic ....

This was a common belief and it also lasted at least 1500 years.

Baptista PORTA (4, p. 143) who experimented with the magnet in
the sixteenth century, ridiculed the delusion prevailing even in his
time which caused mariners, when in charge of the lodestone, to avoid
eating onions or garlic because either would deprive the stone of its
virtue, and by weakening it, would divert them from their true course.

Another superstition is reported by YELTON in 1569 in his book,
Certaine Sacrate Wonders of Nature. (4, p. 157) in which he describes
a "creagus" or "flesh magnet." of stone which cannot be removed with-
out tearing the flesh. This superstition lasted for at least three
centuries, because the wonder books of the time referred to a kind of "ademant which draweth unto it fleshe," and that "it hath power to knit and tie together two offending mouths of contrary persons, and draw the heart of a man out of his body without offending any part of him."

Robert NORMAN, an Englishman, did his experimenting in the middle of the sixteenth century, and disproved several superstitious ideas and beliefs. Among these were such items as (4, p. 219): a magnet carried on the person will cure cramps and gout, will draw poison from a wound, deaden pain and facilitate childbirth, draw gold from a well, speak with the voice of an infant when sprinkled with water, make a man mad when mixed with nettle juice and serpent fat, drive him from his kindred habitation and country, render a person gracious and take away fears and jealousies, cause one to be persuasive in his conversation, assist burglars because if burned in a house it would cause the inmates to believe the house to be falling down and them to flee, leaving the house for the thieves to seize anything they desired.

In the days of Pharaoh when God was showing him that He was a stronger power than Pharaoh, He commanded Moses (Exodus 9:23) to stretch forth his hand toward heaven, and the Lord sent thunder and hail, and the fire ran along upon the ground. In writing the law of Sinai, lightning and thunder accompanied the presence of God. Exodus 19:16 "and it came to pass on the third day in the morning, that there were thunder and lightning, and a thick cloud upon the
mount, and the voice of the trumpet exceeding loud, so that all the people in the camp trembled."

The church in the Middle Ages in Europe was the object of many (32, p. 585) superstitious ideas, and it was supposed that it had an influence in warding off disease, evil spirits, hurricanes, thun-
der and lightning, and malign influences of all kinds. It was the custom in many parts of Europe when a thunder storm approached to ring the bells in the steeples. Jacob Abbott states that when a storm passed away without doing any special damage, the peasants attributed their immunity altogether to the ringing, but if it proved severe, they attributed the results to not having rung the bells loud enough!

Other techniques were used in another part of Europe to appease the gods of thunder and lightning. Students were instructed in the art of determining the will of the gods by checking the location of the lightning. If lightning flashed in one zone, it was a favorable omen, but if it flashed in another, it was fatal. The accomplished augurs stood on lofty towers watching for a gleam of lightning or a peal of thunder, and they knew at once concerning what to expect.

The first known attempt to break with superstition (4, p. 33) was taken by THALES (640-546 B.C.) when he refused to account for the magnetic properties of amber as the priests and worshippers at Samothrace had done for centuries. Thales assumed a soul or a virtue to be inherent and existing in the magnet. Thales' doctrine of
the inherent soul therein was in direct contrast with the prevailing theories fostered by the priest of Cabiric mysteries, namely that the stone was supernaturally influenced.

LUCRETIUS (96-55 B.C.) a Roman poet, who wrote "On the Nature of Things," told of the Samothracian rings existing in 95 to 52 B.C., and described the binding power of the stone as having a continuous current. Lucretius said (4, p. 48) that there streamed from the stone "very many seed" or a current, if you will, which "dispels the air" which lies between the iron and the stone. This theory helped him to explain attraction. He was also the first to explain the repelling action of the lodestone, and he described the action of iron filings in a brass basin when the stone was placed beneath. This was the first time the magnetic field had been explained by noting its effect on iron filings, and not merely by the attraction and repulsion of one magnet to another.

PLUTARCH (46-120 A.D.) described (4, p. 50) the attraction and repulsion of the stone 150 years after Lucretius. It took many centuries for man to reach the conclusion that a magnet would attract on one end and repel on the other. It was long believed that the stone which repelled was totally different from the one that attracted.

SAINT AUGUSTINE (354-430 A.D.) made an important observation when he stated that he could not answer why the lodestone refused to move straw and yet snatched iron. This was the first observation
of the difference between magnetic attraction and charged materials, such as amber.

But some of these superstitions persisted, as for example in the eighteenth century (4, p. 502) concerning the application of electricity to the curing of human ills. This was the notion that fire existed in the human body capable of being kindled or expelled by electrification. This belief was found in America in 1683, and in Italy in 1733, and in Germany in 1744. BIANCHINI gives an account (4, p. 503) of the spontaneous combustion of Countess Cornelia Bandi, who retired one night in good health, only to be found next morning as a heap of ashes.

DISCOVERY AND USES OF MAGNETISM

Another forward step in the development of electricity was expressed in a poem written by WILLIAM, the Clerk, between 1159 and 1177. In the last three verses of the last stanza (4, p. 151) he said:

Note the way the needle tends
Through its place no eye can see
There the polar star will be

This is the first reference to the north and south directional pointing of the compass needle and was a long stride ahead in that it explains a phenomenon by natural and not supernatural causes.

A new concept on magnetism was reached by Roger BACON (1214-1294 A.D.) in the thirteenth century. He did a great deal of experimenting with the lodestone and magnets and concluded (4, p. 162) that the magnet was influenced by the four parts of the heavens.
This was an amplification of the idea held by William, the Clerk, who used only one part of the heavens, the Pole star. If Bacon did not actually discover the law of magnetic action (i.e. like poles mutually repel, unlike poles attract), he came very close to doing so.

Bacon had a friend by the name of Magister Petrus DE MAHARNE-CURIA or Master Peter DE MARICCURT. Bacon called him (4, p. 165) a "master of experiment." He was given the surname of "Peregrinus" or Pilgrim by the historians for his active part in the Crusades. Peregrinus did his work in the middle of the thirteenth century, and drew many conclusions that contributed richly to the development of electricity. He differentiated the poles of the magnet, revealed that unlike poles attract, showed how to detect magnetic poles and demonstrated that two poles persist in every part or fragment of a divided magnet. He proved that not only is an iron needle attracted by lodestone, but that it will assume an inclined or angular position when brought into proximity with it. He explained the stress existing in the medium surrounding the magnet, which was set in the direction of the lines of force emanating from the stone. He exhibited the nature of the magnetic field, and found the position of the poles on a globular magnet. He recognised the magnetic meridians upon its surface and was the first to perceive the correct way of measuring magnetic strength. He also discovered the mutability of magnetic poles, and that the poles of a weaker magnet could be reversed or obliterated by the inductive action of a stronger magnet.
He invented the first mariner's compass. It was the first to have a "lubber's" or fiducial point and a graduated scale. It was the first capable of being used to measure azimuth or bearing and the first to have a pivoted needle. This is fundamental to all electrical measuring instruments in which such an indicator is employed. He was the first to suggest the conversion of magnetic energy to mechanical energy in an organized machine to do useful work, and he was the first to suggest a magnetic or electric motor.

Very little was added during the following century (4, p. 190) to the discoveries of Peregrinus, nor was his compass improved. The next important discovery was that of magnetic variation by Columbus in 1492. "Variation" however was known by the Chinese (4, p. 197) as early as the eleventh century. There is no record, however, of any European recognizing the variation of the needle as a cosmic phenomenon before Columbus did so on his memorial voyage. This discovery did a great deal to promote shipping and navigation. Many countries started exploring and carrying on commerce that had not done so before this discovery. The world was circumnavigated in 1520 to 1522.

Another step in the understanding of electricity was the discovery of the dip or downward inclination of the magnetic needle. Peregrinus discovered (4, p. 211) the inclination of the needle to a globular magnet, but not to the earth. Hartmann, in 1544, discovered the inclination of the needle to the earth, but did not understand it. Robert Norman, an instrument maker of Bristol,
England, gave the first correct interpretation of the dip of the compass needle in 1576. Peregrinus discovered why the needle turned in line with magnetic force, Columbus explained the variation of the needle, and Norman discovered and measured its inclination. This resulted in two components, horizontal and vertical, or the magnetic field of force about the earth or a magnet.

Pietro SARPI made another discovery (4, p. 224) in the latter part of the sixteenth century. His genius was expressed in many fields: language, mathematics, history, astronomy, geometry, magnetism, botany, hydraulics, acoustics, and others. His refinement of magnetism was the destruction of the qualities of the magnet by heating it. This was a big blow to (4, p. 227) those who believed that the power of the stone was implanted by providence. Another important discovery by Giulio CESARE in 1586 revealed that iron could be magnetised without a magnet. He was the first to work with a magnetic field of force.

John Baptista PORTA, 1545–1615, was a student of Sarpi from whom he learned much. Each was skilled in optics, and knew that the radiation of light varied (4, p. 237) with the square of the distance between the surface on which it fell, and the source of radiation. They detected this similarity of the field around the magnet. Porta visualised a system to apply the mariner's compass to a new use in 1558 and it was the forerunner of the telegraph (4, p. 239):
To a friend, that is a far distance from us, fast shut up in prison, we may relate our minds, which I do not doubt may be done by two Mariner's compasses having the alphabet writ about them.

A similar statement (52, p. 9) concerns Porsa who referred to:

sympathetic needles magnetized by the same lodestone, mounted on separate dials with letters around their margins. When one needle turns, the other moves to the same letter.

William GILBERT, 1544–1603, an English physician, was first (4, p. 383) to investigate natural phenomena systematically (52, p. 14) and early recognized electricity to be different from magnetism, and as a new natural condition of force which he named. He suggested the correlation of gravity and magnetism with other natural forces, and a relationship between gravity, magnetism, and electricity. He recognized the earth to be a great magnet, capable of magnetizing iron and iron ore by induction. He determined the polarity of the earth and the true reason for the action of the compass. He discovered magnetic screening, conduction, saturation, the compound magnet, the mutual attraction of induction of lodestone and iron, and the pole piece or armature. He also discovered the nature of electrical charges and the degree of their permanence. He was also the first to invent the electrical, as distinguished from the magnetic, suspension, and the ordinary method of magnetization.

The first political use of magnetism was (4, p. 205) in March of 1493 when Columbus discovered that the line of magnetic variation was permanently fixed. MARTIN V (4, p. 205), had already given
Portugal all the territory which her mariners might discover between Cape Bojador and the East Indies. In March of 1493, ALBERGAR assigned all lands to Spain that were south and west of a line drawn from the Arctic to the Antarctic Pole, one hundred leagues west of the Azores. All the world to be discovered was partitioned between these two countries with the line of no variation to separate their respective possessions.

GALILEO GALILEI (1564–1642 A.D.) made the first announcement (4, p. 348) of the true effect of the armature or bar across the ends of a horseshoe magnet. He said that a magnet would lift its weight, but later stated that it would lift four times its weight.

DESCARTES (1596–1650) endorsed Gilbert's cosmic theories. He saw (4, p. 359) that there was a force, not merely radiating from magnet poles as Gabanus supposed, but traversing the stone from pole to pole in one direction and then traversing the stone externally from pole to pole in the opposite direction. Descartes discovered the endlessness of these lines of magnetic force, which he referred to as spirals or ribbons.

DEVELOPMENT OF STATIC ELECTRICITY

Otto VON GUERICKE, who was noted for his experiments and contribution in pneumatics, made the first static machine. It was composed of a ball of sulphur mounted on an axis that was turned by a crank and excited by the friction of the hands. He used the globe to show how it possessed certain characteristics (4, p. 396)
such as, impulsive virtue, conservative virtue or gravity, and
directive virtue or magnetic force. Artificial light was detected
and extended by Jean PICARD, a member of the Royal Academy of
Science who observed this phenomenon in a mercury barometer in
1675. Many experiments were made to discover the nature of this
light.

Francis HAWKESBE, an Englishman, found (4, p. 465) that rubbed
glass glowed because glass is an electric medium and is activated
by rubbing. He grew tired of rubbing glass tubes, however, so
placed a glass cylinder in his lathe in order to revolve it. This
was developed in 1709 (52, p. 11) and was called an electrical
machine. It was composed of a hollow glass sphere or globe which
was rotated by means of a belt and crank arrangement. Hauksbee
observed that if he rotated it at the proper speed and placed his
hand on the surface of the revolving glass globe, it would create
a light bright enough for reading. One experiment involved two
globes located within an inch of each other on separate lathes so
they could be rotated independently. He (4, p. 467) removed the
air from one and applied his hands to the other globe. Light ap-
peared in both globes and this was the first indication of mutual
induction. Hauksbee's achievements attracted wide attention.
Newton also experimented with glass globes between 1704 and 1717.

Watt was the first (4, p. 469) to see the similarity of the
crackling and light in the globes to the thunder and lightning of
nature, and won immortality from this observation.
John Wood, an Englishman (52, p. 11) discovered in 1726 that static electricity could be conveyed by a piece of wood. Up to this time, no one except von Guericke (4, p. 472) had attempted to cause electric "virtue" or current to pass from one body to another. Stephen Gray did this by placing corks in the end of a glass tube, and then wooden rods. He used iron, brick, tile, chalk, and vegetables to transmit electric "virture." He then experimented to see how far it would travel by using hemp thread and fishing rods, but his rooms were not large enough. He visited a friend by the name of John Godfrey in 1729 and (4, p. 473) experimented with longer lengths of rods which soon gave way to thread. He was able to electrify objects at the end of thread thirty-four feet long. Gray visited another friend by the name of Granville Wheeler in 1730 who became interested in these experiments and they sent electricity (4, p. 477) over 866 feet of wire.

Gray identified two types of materials, conductors and non-conductors, and these led to the discovery of electrical insulation. They supplanted (52, p. 11) Gilbert's classification of electrics and non-electrics. Another outstanding contribution was made in 1732 when he demonstrated (4, p. 477) that the electric charge or "virtue" of a glass rod could be communicated to another rod or line at a distance of one foot. This proved for the first time that a conductor or wire could induce a charge in another conductor with some distance between them. This is the second example of
__mutual inductance__.

Charles François de Cisternay Dufay, a member of the French Academy of Science, tried all of Gray's and Wheeler's experiments, and added many new materials which could not be electrified. He electrified metals which had not been before because of improper insulation. His most important discovery (4, p. 484) was that glass and crystal operated in exactly opposite ways to gum-copal and amber. This led to the discovery of (52, p. 11) two types of electricities. He called the electricity yielded by glass as __vitreous__, and that derived from gum as __resinous__. He discovered and announced the fundamental law of electricity that, "like charges repel and unlike charges attract." For example, __vitreous repels vitreous__ and __resinous repels resinous__, or __resinous attracts vitreous__ and vice versa. He found that any material could be electrified by insulating it on glass stands. He also found that moisture assisted the passage of current in thread, that items most easily electrified by friction were the worst conductors, and that those hardest to electrify by friction were the best conductors. He coined the terms "conductor" and "non-conductor."

Gray was stimulated by Dufay. The things he had said about the burning sparks of electricity aroused Gray's curiosity. He experimented with fire shovels, pokers, tongs, pewter plates, iron balls, and dishes of water. These were hung on silk threads, and (4, p. 486) the crackling sparks which resulted were inflicted on a white rooster and then on a small boy. He was astonished beyond
measure with an iron rod which exhibited the true brush discharge. He stated that, "the flames are real and they burn and crackle and explode. The effects at present are small, but there may be found a way in time to collect greater quantities of it, and consequently to increase the force of this Electric Fire." This seems to be the same thunder and lightning in Nature. This is the second comparison of the electric spark and its explosion to thunder and lightning.

DESAGUILIERS appeared on the scene after Dufay's death and became a prominent member of the Royal Society. He was the first (4, p. 489) to electrify or charge running water. Gilbert caused rubbed amber to attract a water drop. The Florentine Academy had drawn oil up in little viscous strings by the same manner, and Gray had electrified a soap bubble. Desaguilers found that water running through a copper fountain could be electrified so it would attract a string, or by holding a charged glass rod near a stream of running water, that it would bend toward the rod. He appears to have been the first to conceive of atmospheric electricity, and pointed out that a cloud or mass of vapor may be an electrified body. He also recognized that air could be rendered electrical, and supposed it to be made up of electrical particles which were constantly repelling one another.

The similarity of crackling electric sparks to thunder and lightning was recognized by Hauksbee, Wall, and Gray, and the conception held by Desaguilers of electrically-charged clouds and
atmosphere, were forerunners to Benjamin Franklin's famous discovery.

The early development of static electricity occurred in Greece, Italy, France, and England. The year of 1742 marks (4, p. 491) the beginning of an interest in static electricity and machinery in Germany. The German scientists were familiar, however, with the progress made abroad during the past fifty years, but the experiments that produced electric sparks or fire finally aroused the attention of the people. The philosophers became interested finally because fire was believed to be a material substance, and it was the idea of a human being becoming a torch that aroused the German mind.

Two leaders are given credit (4, p. 493) for stimulating an interest in electricity in Germany. These were Christian August HAUSEN and George Matthias BOSE. They developed a larger and more powerful electrical machine than the ones created by Von Quericke or Hauksbee. Bose did many interesting things with static electricity which won him the name (4, p. 495) of "modern wizard." He used several sizes of globes at the same time and produced glow discharges, and stated that they glowed, turned, wandered, and flashed, and that no name was so applicable to them as the Northern Lights. This was the first suggestion of the electrical origin of the aurora borealis.

Christian Frederick LUDOLFF, a member of the Berlin Academy, ignited warm "sulphuric ether" with an electric spark in 1744. He
ignited alcohol and turpentine, and Bose claimed to have ignited such liquids as alcohol, turpentine, butter, resins, sealing-wax, and sulphur. He successfully exploded gunpowder after arranging it so it would not be scattered by the discharge from the rod. He also made the first step (4, p. 497) toward the invention of an electric fuse, and there was no doubt that the electric spark and fire were the same.

Johann Gottlob Kruger explained the medical uses of electricity in 1743. Here begins the modern effort (4, p. 501) to apply electricity to the curing of human ills.

Christian Gottlieb Kratzenstein in 1744 (4, p. 502) made the first experiment to determine the effects of electricity on the human body. He observed a marked increase in pulse-rate, and an accelerated circulation predicted by Kruger, and the irritating contractual effect upon the muscles. This stimulated the desire to increase the size and charge of these machines.

Andrew Gordon, a Scottish monk and teacher at Erfurt, Germany, substituted a glass cylinder for the globe. Johann Heinrich Winkler, a professor at Leipzig, replaced (4, p. 506) the dry palm of the hand with a leather cushion rubber attached to the glass by springs, and rotated the cylinder with a cord and foot treadle. He was able by this means to revolve the cylinder 680 revolutions per minute. This created greater shocks and brighter sparks than any previous electrical machine and could be produced in any
weather, no matter how damp.

The practical use of electricity was approaching rapidly. The first to respond was Andrew Gordon, who invented (36, p. 81) the first electrical machine. Von Guericke generated it, Stephen Gray and Wheeler transmitted it, and Gordon used it to ring a bell (4, p. 507) composed of two gongs and a metal ball suspended by a silk line in proximity to one another. When the ball was electrified, it moved to one of the gongs, struck it, then was repelled to strike the other, which again repelled it. He also invented the first (static) electric motor. It was a metal star pivoted in the center, and having the points turned slightly to one side in the same direction. The reaction of the discharge of the electric machine caused the star to rotate. He also used electric charges to kill chaffinches, a sizable bird, to show the power of the sparks from his machine. The similarity of electrical flashes to lightning have been mentioned and when Gordon killed birds by them, another resemblance to lightning was recognized.

Dean VON KLEIST (4, p. 512) reported his findings on October 11, 1745, on an experiment to electrify a nail in a medicine vial shaped like a Florentine flask. He stated that strong action took place if mercury or alcohol were in the vial. He did many things with this apparatus, and found it would hold a charge (4, p. 514) for twenty-four hours. This was the beginning of the Leyden jar.
Wilhelm Jacobs GRAVESANDE and Peter VAN MUSSCHENBROECK were eminent Dutch physicists. They introduced the experimental philosophy and the Newtonian doctrines into their country (4, p. 516), and established a systematic study of these subjects at the University of Leyden.

Van Musschenbroeck was a student of Gravesande's, and decided to imprison or store electrical fluid in a jar by charging some water in it with an electrical machine. He stored a tremendous amount of static electricity in the jar, and when he touched it, he received such a severe shock (36, p. 85) that it knocked him unconscious. In 1746 (4, p. 519) Musschenbroeck wrote his friend Rene Marumur the following account:

I wish to inform you of a new, but terrible experiment which I advise you on no account to attempt. I am engaged in a research to determine the strength of electricity. With this object I had suspended a gun barrel by two blue silk threads which received electricity by communication from a glass globe which was turned rapidly on its axis by one operator, while another pressed his hands against it. From the opposite end of the gun barrel hung a brass wire, the end of which entered a glass jar, partly full of water. This jar I held in my right hand, while with the left I attempted to draw sparks from the gun barrel. Suddenly I received in my right hand a shock of such violence that my whole body was shaken as by a lightning stroke. The vessel, although of glass, was not broken, nor was the hand displaced by the commotion, but the arm and body were affected in a manner more terrible than I can express. In a word, I believed that I was done for.

This apparatus was called the "Leyden Phial" and later the "Leyden Jar." After its development, the philosophers saw in it
only a device for creating greater shocks than before with the
electrical machine. Abbot NICOLLET and Daniel GRAHAL killed birds
with its discharge. It was considered a great invention at the
time it was invented, because it could store electric charge and
produce discharges of unprecedented strength. It was the fore-
runner of the condensor which occupies a very important place in
electricity today.

Abbot Nollet entertained the king by discharging the Leyden
Phial through 180 of his guards, (4, P. 524) "who were all so
sensible of it, the surprise caused them all to spring up at once."
However, this was soon outdone by the Carthusian monks in Paris
who formed a line 900 feet long by means of iron wire of propor-
tionable lengths extended between every two men. When the extrem-
ities of this long "line" or wire came in contact with the elec-
trified phial, the whole company gave a sudden jump and all felt
the shock equally. This is the first indication of an electric
circuit.

Nollet did many interesting experiments with the electric
machine and the Leyden jar which added to the knowledge of elec-
tricity. One experiment was to discover the effects of electricity
on vegetables and animals. He (4, p. 527) planted mustard seed
in two receptacles, and maintained one in an electrified state for
eight days. He says, "the electrified seed had all sprouted by
the end of that time and had stalks fifteen or sixteen lines in
height, while only two or three of the non-electrified plants had appeared above the ground, and even these had stems not more than three or four lines high." He then experimented with animals, small birds and pigeons and concluded (4, p. 530) that in all cases there was a loss of weight.

Winkler of Leipsic discovered that when electricity had several paths to choose (4, p. 530) it appeared to traverse the one which was composed of the best conductor. Another individual interested in this was Louis Guillaume LE MONNIER, a French experimenter. He created the first circuit by discharging a Leyden jar through two persons, a chain, and a lake of water. A circuit was made thus early in 1746 including both water and a metallic conductor, over which passed the discharge of the jar, so that the two observers were shocked simultaneously.

The ability to store electric charges in the Leyden phial and the increased power from the electrical machines created other questions which caused more experimentation and study. Two important questions were: what distance will the electric charges travel, and how long will it take them to get there? The Royal Society assigned William WATSON to answer these questions. Watson started his experiments in 1747 to determine the distance that a charge would travel. His first experiment (36, p. 89) included 800 feet of water and 2000 feet of land, the second included 8000 feet of water and 2800 feet of land, and a distance of 12,276 feet was
transmitted in 1748, but his instruments were not accurate enough to determine the speed of the charge over the transmission lines.

LE MONNIER worked with long conductors, and sought to measure the velocity with which the electric charge ran over them. He also met with failure. He estimated the speed (4, p. 532) to be thirty times that of the velocity of sound in air. He also believed that the electric charge was communicated to bodies in proportion to their surface and not to their masses.

Watson (4, p. 536) expressed his idea of the law of resistance in 1747 as, "the resistance of a conductor to the passage of electricity, is proportional to its length and depends upon the material of which it is composed." This was the beginning of Ohm's basic law.

As the century drew to a close (4, p. 446) the growing commerce of England created a demand for more knowledge concerning the compass. This created more interest in the study of variation, and in 1580, William BURROWS determined the variation in London to be eleven degrees, fifteen minutes East. In 1622, Edmund GUNTER found it had diminished five degrees. In 1640, Henry BOND, a teacher of navigation in London (4, p. 446) published his Seaman's Calander showing the progressive nature of this secular variation. This was a major step forward and with these findings, commerce was increased, time reduced on trips, and people were benefitted by faster service.
The German artisans, and especially those in Leipsic in the fall of 1745 recognized that there was a market for the electric machine. So simple was the apparatus, and so astonishing its effects, that people bought it simply out of curiosity, and amused themselves at home by repeating the experiments they had seen.

John CLAYTON observed the sparking of Susanna SEWALL in 1653, and this was an important date (36, p. 75) because it is the first mention of electricity in America where most of the superstitions that developed in the Colonies followed the invention of the lightning rod.

HODGINS (36, p. 94) reports an earthquake in 1755 and the pastor of the Old South Church in Boston insisted that it was God's wrath directed at Franklin for attempting to ward off His vengeance with the lightning rod. This sort of thing continued for many years. Draper (22, p. 273) says that the use of rods was opposed as late as 1776 on the ground that "lightning is one of the means of punishing the sins of mankind, and of warning them from the commission of sin, so it is impious to prevent its execution."

Benjamin FRANKLIN became acquainted with electricity while visiting in Boston in 1746 where he met a Dr. SPENCEH (36, p. 90) from Scotland who showed him his crude apparatus and some experiments. The subject (4, p. 538) was entirely new to Franklin. One of the things that he did before he became interested in
electricity was to establish a Library Company in Philadelphia which was granted a charter in 1742. Franklin had made contact with Peter Collinson, a London merchant who was a member of the Royal Society, to purchase books and gather news for the Library Company. Franklin was thus able to get the latest developments concerning electricity from Europe.

Franklin repeated the experiments in Philadelphia and interested many others to experiment with static electricity. Three persons became very interested (4, p. 540) and included: Ebenezer Kinnersly, Thomas Hopkinson, and Philip Seng. Hopkinson became the first president of the American Philosophical Society.

Franklin's first contribution was the discovery of the effect of pointed bodies both in drawing and throwing off electrical fire. Pointed conductors had been electrified by Von Guericke, Gray, Dufay, and others, but Franklin showed how easy a pointed object could draw off an electrical charge from an electrified object. The distance (4, p. 541) of the points to the electrified object was greater than the blunt end object. This feature almost became a political issue abroad. He developed the single "fluid" theory of electricity which conflicted with Coulomb's two fluid theory and proposed the plus or positive, and minus or negative terms, to describe the action of the electrical "fluid."

European scientists had been unable to determine where the electric charge was stored in a Leyden jar (4, p. 558). Von Kleist
believed it to be in the man who held the jar; Musschenbroeck believed it to be in the water, and Watson believed it to be in the inner conducting layer. Franklin pulled the jar to pieces, and found (36, p. 91) the electric charge to be on the glass itself. He advised Collinson that the Leyden jar was charged positively within and negatively without.

EVOLUTION OF CURRENT ELECTRICITY

Franklin contributed the expression "electrical fluid" which replaced the term "electrical fire" used by the English and German philosophers. His replaced (4, p. 554) and survived many other expressions of this sort. Franklin demonstrated that electrical fluid could be used gradually. Never before had electrical fire shown itself in a circuit other than as a spark, shock, or explosion "with a violence and quickness inexpressible." This was the beginning of the electric current or "convection," the forging link between the Leyden jar and the voltic cell.

Another development by Franklin was the construction of a battery (4, p. 559) consisting of eleven large plates of sah glass separated by thin lead plates connected in series for charging, but before this he placed Leyden jars in parallel. This was the first arrangement of electrical sources in series or parallel.

The problem of analyzing the nature of lightning, which had not been solved by the Europeans, was Franklin's greatest and
certainly most spectacular contribution to the development of electricity. He experimented successfully with his theory of lightning and sent detailed plans to Collinson in England, and other leaders in France where they proved successful. However, these experiments did not do the thing desired by Franklin. He wanted to place his equipment high enough to draw the electrical fire from the clouds. This was a major problem for several years, and in the process he invented (52, p. 12) the lightning rod in 1749 and proved to the world in 1752 (4, p. 591) with his famous kite and key that static lightning and electricity were the same.

Kimmersley in 1748 discovered that the Leyden jar could be electrified as strongly by sparks delivered to the outside as to the inside. Kimmersley and Franklin created a motor that actually rang chimes. Sing developed a motor from cardboard that spun rapidly when a charged glass tube was placed close to the tips. He also developed an electrical machine equal to those made in England and on the continent.

The experiment that proved lightning and electricity to be the same, climaxed the long study of the relationship between nature's lightening and frictional electricity after which interest dropped and the experimentors turned to other work. Franklin entered politics and served as Ambassador to France.

A new discovery was taking place during this time in far away Italy, which brought new interest in the problem of developing
electricity. Dr. Luigi GALVANI, an Italian physiologist, discovered galvanic (chemical) electricity. Authorities (52, p. 13) disagree on the date of this discovery. One gives 1771, another 1780, and a third 1790. Galvani discovered that the legs severed from a newly killed frog contracted when touched at different points by two pieces of dissimilar metals that also touched one another. Galvani also studied electricity in relation to treating human ills and experimented with atmospheric electricity on the nerves of frogs. He connected them to rods leading to lightning conductors that were erected on his roof and found that the same convulsions appeared when lightning was seen as were caused by the two metals.

Galvani observed (31, p. 90) that the bodies of animals possessed a peculiar kind of electricity by which motion is stimulated through the nerves and muscles. He reasoned that positive electricity traveled through the nerves and negative through the muscles. He also reasoned (36, p. 98) that electricity and life were the same thing. This, however, is still debated. He almost succeeded in convincing the scientists of Europe with his theory. He overlooked the fact that a current flows when two different metals come in contact, which is the basic principle of the electric cell. At least one philosopher at the University of Pavia, Italy, did not believe him. Volta reasoned that nothing could have caused the legs to kick except the different metals, the copper hook and the iron grating from which the legs were suspended. He said they were
stimulated from without just as the frictional machine had shocked human beings.

Dr. VALLI stated (36, p. 100) that he could cause the legs to twitch without using any kind of metal. This gave Galvani more proof for his conclusion that electricity and life were the same, but Volta showed that in order to get the legs to twitch, the two parts of the frog must be unlike parts or else there would be no twitch.

The outcome of these experiments resulted in the most valuable contribution of all experimental philosophers to the development of electricity. In 1775 (31, p. 87) Volta announced the invention of an electrophorus, an instrument for generating a perpetual reservoir of static electricity by means of induction. His greatest discovery was the development of electricity in metallic bodies which resulted in his famous "Voltic Pile." This discovery was made in 1796, but according to Greenwood was not announced until March 20, 1800 in a letter to Sir Joseph Bank who in turn reported it to the Royal Society.

The Voltic Pile was composed of disks of copper and zinc which were separated by cloth soaked in a saline or acid solution. He also constructed the electric battery called the "crown of cups" which was composed of a series of cups containing a saline liquid with a strip of zinc and silver. The silver was connected to the zinc strip of the adjacent cup. This arrangement of the different metals
produced a large quality of electric energy or "fluid." Dickerson, in an address at Princeton College, said (31, p. 37) that "Volta gave to the world that new manifestation of electricity called Galvanism." This was the first means of producing and controlling the electric fluid, however, Franklin came very close to him in one of his experiments. Volta's contribution eliminated the electric machine and created a new era in electricity, in that it accompanied the discovery of current electricity upon which modern electrical science and industry is founded.

The discoveries of Volta caused the experimenters to almost forget about magnetism and frictional electricity. They could not see that there was any connection in Volta's pile and the magnetic compass used by Columbus on his great voyage. Hans Christian OERSTED is credited with finding in 1819 that magnetism and electricity are related (36, p. 107). His discovery was an accident. He was lecturing to some advanced students on electricity and demonstrating the heating of wire across a battery, when a compass was placed under the wire. He saw the behavior immediately, and other tests showed that the current flowing in the wire upset the compass. He realized from this that an electric current had exactly the same effect upon a compass needle as a magnet.

He explained his discovery on September 12, 1820 to the societies of Europe, telling them how the flow of electrical current in a wire produced a magnetic effect in a circular direction
around the wire which caused the compass needle to set itself at ninety degrees to the direction of current flow, and if the current was reversed, the needle would do the same. This discovery launched the tremendous field of electro-magnetism which is the foundation of modern electricity. This great discovery aroused the interest of all experimenters everywhere and stimulated many experiments with batteries and compasses. The progress of science, and especially of electricity, began to move forward at a tremendous rate as a result. It took the modern world more than twenty centuries to improve upon the Greeks. It was sixty years before Watt improved upon Newcom. It was twenty years before Oersted improved upon Volta, but it was only one week before another philosopher improved upon Oersted. That man was Andre Marie Ampere.

Exactly one week after Oersted announced his discovery, Andre Ampere (36, p. 112) on September 12, 1820, presented a theory of the relationship between electricity and magnetism which was much clearer than that presented by Oersted. He demonstrated that the deflection of a compass needle follows a fixed rule, namely that parallel wires carrying current attracted each other when the current flowed in the same direction and repelled each other when it flowed in the opposite direction. He showed that the force of attraction or repulsion is directly proportional to the strength of the current and inversely proportional to the square of the distance between the two wires. Ampere proved that a solenoid or coil of wire carrying a current behaves exactly like an iron magnet, that it
would react to the earth's magnetic field in the same manner as the compass needle. He also demonstrated that magnetism can be produced directly in a bar of soft iron by placing it in a solenoid. Ampere's week of intensive work was one of the most productive weeks in the development of electricity. James Clerk Maxwell called him the "Newton of electricity."

Ampere applied the electromagnetic action (31, p. 171) to an electric telegraph in 1820 and followed the suggestion of LA PLACE who found that the deflection of small magnets placed at the receiving end of twenty-six wires could be used to indicate the letter of the alphabet. This is similar to John Baptista Porta's idea of a practical use of the mariner's compass or sympathetic needles.

The American Standards Association (52, p. 17) named the standard unit of electric current, "ampere," in his honor.

Another important individual by the name of Humphrey Davy, an English baronet, discovered a valuable two-way characteristic of electricity in 1802, namely (13, p. 232) that an electric current will cause chemical decomposition. This discovery is known as electrolysis. This contributed richly to the science of pure chemistry and to the chemical industry.

A youth who asked to work for Sir Humphrey Davy was Michael Faraday who became one of the most celebrated chemists and physicists of England. He made many discoveries in the development
of electricity. His contributions started in 1821 (52, p. 18) with the discovery of magneto-electricity which produced motion or rotation of a wire carrying a current around a magnet. This was the beginning of the electric motor. He developed the theory that when electrification is produced either by friction, induction, or other means, the positive and negative charges are always equal. He developed the first direct current generator by rotating a copper disk between the poles of a horseshoe magnet. He proved that a current could produce a current. He and RUHMORFF (31, p. 210) devised the induction coil, a device for transforming low voltage to high voltage currents. This was the beginning of the transformer.

During Faraday's busy life in England, another scientist was making electrical history in Germany. His name was Georg Simon OHM who had been impressed (36, p. 114) by a demonstration showing the flow of heat in a metal was proportional to the difference in temperature at its two ends. Heat was a mysterious quality which was causing the scientists to wrangle at that time. Another mysterious virtue was electricity. Ohm generalized that there probably was some similarity between the two. He discovered that the flow of an electric current depended directly upon the difference in the potential (voltage) between the two ends, and further that when the pressure or voltage was constant, the flow of current varied inversely according to the resistance of a wire. This was announced to the scientific world in 1825-26.
This was a very great discovery, but it will be recalled that Watson of England also came very close to discovering this law too. This became the first means for controlling the flow of electric current mathematically, and stimulated the use of mathematics in the design of electrical machinery. Without it the commercial development of electricity would have been impossible. However, all of this was too much for the minds of 1826, because no one believed it. Even the minister of education (36, p. 114) who had charge of seeing to it that the young minds of England were not corrupted, intimated to Ohm that any physicist guilty of such baseless heresy was not wanted in a chair of physics.

A young scientist by the name of Joseph Henry was at work in Albany Academy, New York, during this same interim of time that Faraday and Ohm were making their contributions. Henry independently discovered many of Faraday's findings. He discovered induction, and experimented with large electro-magnets. He constructed (52, p. 21) the first electro-magnet motor which was the forerunner of present day motors. He developed an oscillating machine with an automatic pole changer in 1826. He also demonstrated a telegraph instrument over a mile of wire in 1831, and stated that everything was known to develop a commercial telegraph.

To Ampere, Oersted, Ohm, Faraday, and Henry is due the credit for discovering and clarifying the fundamental laws of science upon which present day electrical developments are based. Their
experiments were made from a few cents worth of materials and laid the foundation for many new industries, new jobs, and a life more pleasant for all.

The understanding of electricity was mired down for centuries by superstition until the coming of such men as the Greek philosopher, Thales (640-546 B.C.) and then even with the discovery of the magnetic variation of the compass by Christopher Columbus (1446-1506), did not become too well clarified as a science for 2400 years or until following the Renaissance and the coming of Benjamin Franklin (1706-1790 A.D.) and his European contemporaries: Galvani (1737-1798), Volta (1745-1827), Ampere (1775-1836), Oersted (1777-1851), Davy (1778-1829), Ohm (1787-1854), and Faraday (1791-1867).

As a resource and program study, this dissertation has been concerned in this early chapter, to trace the story of the shift from an age of superstition to an age of science as regards the phenomenon of electricity, and will now investigate and report what happened in the rush to clarify and exploit the phenomenon in the chapter that follows.
Chapter III

ELECTRICITY IN MODERN TIMES

Chapter II traced the phenomenon of electricity from the fog of superstition through several hundred years of discoveries that identified and projected the uses of magnetism, of static, and finally of current electricity. The present chapter traces man's exploitation of these discoveries into what has been characterized as "the age of electricity."

The chapter has been divided into six parts: the Generation of Electricity, Industrial Uses of Electricity, Domestic Uses of Electricity, Medical Uses of Electricity, Electricity in National Defense, and Electricity in Science and the Future. This chapter is considered to be transitional, insofar as a resource study is concerned, because it lies between the origins involved and the detailed or logical analysis of the resource, as such. The chapter involves contemporary history in this respect, including the economic and political as well as the technical, and the techniques employed of necessity have been largely bibliographical.

Industrial and periodical literature have been drawn upon widely in addition to the encyclopedias and a variety of authors including: Blackmore (7), Bosch (9), Burlingame (13), Dawhurst (21), Forbes (25), Gernsback (28 and 29), Gray (30), Greenwood (31), Hawks (33), Haynes (34), Kovacs (41), Manchester (44), Mantell (45),
Martinez (46), Mumford (50), Poling (68), Ryan (74), Thompson (79), and Yates (88).

THE GENERATION OF ELECTRICITY

The development of electrical power has skyrocketed since World War I and the pioneering discoveries and researches that were reported in Chapter II. In England (25, p. 293) for example, approximately one million kilowatts were consumed in 1906, but this expanded four-fold in thirty years and cost one-tenth of the earlier prices. The kW rate (13, p. 215) dropped from 25 cents in 1882 to 3.4 cents in 1937, and is now delivered (21, p. 686) at from 1 to 4 cents, depending upon the service required.

The capacity of electrical generating equipment shipped in 1952 was 10,577,500 kW. This rose to 14,375,200 kW in 1953. The sale of electricity (11, p. 244) amounted to $6,614,700,500.00 in 1953, an increase of 11 percent or $654,000,000.00 over 1952. Commercial and Industrial customers increased from 5,878,946 in 1953 to 6,081,564 and Utility customers increased 1,446,342 during that period.

The United States and Canada limited the diversion of water for power purposes of the Niagara Falls to 36,000 cubic feet per second for Canada, and 20,000 cubic feet per second for the United States. This was the beginning of another method of producing electricity. In 1895, the United States harnessed this power with three generators capable of generating 5000 volts each. Today
these generators produce 11,000 volts at 25 cycles each. Much of this energy is used in nearby electrochemical industries for the manufacture of aluminum, artificial graphite, calcium carbide, carborundum, cyanamide, ferro-silicon, liquid chlorine, titanium, and vanadium. The development at Niagara Falls was the beginning of a vast system of dams throughout the nation. The following are some examples:

**Colorado River Basin.** The Bureau of Reclamation in 1951 proposed ten dams on the Upper Colorado River and its tributaries in five states. The Upper Colorado River Commission in 1953 proposed to Congress that they authorize 20 power and irrigation dams on the Upper Colorado and its tributaries. When this system is developed, 1,602,000 kilowatts of power will be produced. This is about ten times the amount of electricity now developed in the area. The dams proposed for this system are as follows: Blue Mesa on the Gunnison in Colorado, Gross Mountain on the Yampa River in northwestern Colorado, Crystal Mesa on the Green River near Colorado-Utah line, Flaming Gorge on the Green River in Wyoming, Glen Canyon on the Colorado River in northern Arizona, Navajo on the San Juan River in northwestern New Mexico, and the Whitewater on Gunnison River in western Colorado.

**Columbia River Basin.** The hydroelectric potential of this and the Puget Sound area is estimated to be approximately 30 million kilowatts or about 35 percent of the total available hydroelectric power of the nation.
This system has planned, or under construction, power projects totaling 13,775,000 kilowatts (including authorized projects of 3,964,000 kilowatts). Of this total, 2,540,000 kilowatts are private or municipal and the remainder federal. There are 26 dams of various sizes built or being built on main streams and tributaries. The important dams in this system are: Chief Joseph begun in 1953, and upon completion to have 27 generating units to supply 1,728,000 kilowatts of power. It will be second in size to Grand Coulee in the production of power. Grand Coulee, or Roosevelt Lake, was completed in 1942. It has 16 generators capable of generating 2,370,000 kilowatts and is located on the Columbia River in Washington. McNary was begun in 1952, and had two 70,000 kilowatt units in operation in 1953. It is to be completed in 1956 with 14 generating units developing 980,000 kilowatts of power, with a peak load of 1,127,000 kilowatts. Six additional units can be added if required. Other dams in this system are Albeni Falls in Idaho, Detroit on the North Santiam River in western Oregon, Hungry Horse on the Flathead River in Montana, Ice Harbor on the Snake River in Washington, Lookout Point on the Middle Fork of the Willamette River in Oregon. Other projects have been planned for this system especially the Libby in Montana with 10 generating units capable of developing 1,030,000 kilowatts, and the Hells Canyon in Idaho with a capacity of 1,430,000 kilowatts of power.
Missouri River Basin. The federal government has 12 hydro-electric plants in operation in this basin with an installed capacity of 247,700 kilowatts, and 11 other projects under construction to supply an additional capacity of 1,468,000 kilowatts by 1960. The following are examples in this system: Fort Peck on the Missouri River in Montana; Fort Randall on the Missouri River in South Dakota started producing 320,000 kilowatts in 1953; Garrison is expected to be completed in 1955; Gavins Point in South Dakota was begun in 1952, and is expected to produce 100,000 kilowatts of power in 1956; and Oahe in South Dakota is expected to be completed in 1959 with an installed capacity of 425,000 kilowatts of power.

Roanoke River Basin. This system will have 11 dams. The first of these was the John H. Kerr, dedicated in 1952. It will generate 204,000 kilowatts of electric power. The second was the Philpott completed in 1953, which generates 14,000 kilowatts of power. Roanoke Rapids in North Carolina was begun in 1953, and upon completion will have a capacity of 90,000 kilowatts.

Savannah River Authority. Senators from Georgia and South Carolina secured passage of a law permitting the construction of a Savannah River Authority to supervise the construction of dams on that river. The system will include the Clark Hill, under construction, and ten other dams that will produce 761,000 kilowatts of power.
Tennessee Valley Authority. This system is composed of several dams. It had an installed capacity of 5,540,000 kilowatts in 1952. Approximately 64 percent of this total is in hydro-electric plants, with 36 percent in steam plants. This system sold about 7,000,000,000 kilowat hours to the federal government in the fiscal year of 1953. The residential use of electricity (11, p. 684) exceeds 4,300 kilowatt hours as compared with 2,257 per customer in the nation.

The total installed electric capacity in September 1953 was:

Hydraulic stations 21,498,505 kilowatts
Internal Combustion Engines 2,138,182 kilowatts
Steam stations 63,961,601 kilowatts

The production of electricity in large quantities is accomplished with dynamos. These vary in capacity (83, p. 254) from one to 160,000 kilowatts, and are driven by internal combustion engines, hydraulic turbines, and steam prime movers. Dynamos generate either direct or alternating current. Alternating current can be transmitted greater distances over high-lines with less line loss than direct current. Direct current has advantages for certain industrial uses such as electroplating, electrolysis, certain types of industrial motors, elevator and street railway operation. Approximately 95 percent of all electricity generated in electrical central stations of the United States is alternating current.
A total of 500,522,435,000 kilowatt hours were produced in the United States in 1953 which was an 11 percent increase over 1952. **Fuel burning power plants** (11, p. 244) produced 326,739,525,000 kilowatt hours or 75.9 percent of this total. **Water power plants** generated only 103,934,118 kilowatt hours in 1953 which was an 18 percent drop in this type of production. **Coal consumption** by electric utility power plants increased to 114,332,867 tons in 1953 which was an increase of 8 percent over 1952. Electric utilities increased the **gas consumption** over 15 percent in 1953. The consumption of **oil** increased over 39 percent in 1953.

**Privately** owned utilities (11, p. 244) produced approximately 81 percent of the total output of electric energy in 1953. The federal government, the municipalities, the public utilities, rural electric, and state projects, produced the remainder.

**Private** companies owned approximately 79 percent of the nation's generating capacity in 1953. The remainder was divided among the federal government, the municipalities, the public power districts, rural electric cooperatives, and state agencies.

A new form of energy, according to Dewhurst (21, p. 577), will soon take its place in generating electric power. The research studies in the Oak Ridge Laboratories proved that nuclear power can be harnessed in large power plants at costs estimated to be competitive with coal at approximately ten dollars per ton. Dewhurst
says, "the displacement of coal, natural gas, petroleum, and perhaps water power may be small even as far ahead as 1960, but by that year may well be proceeding at an unprecedented rate."

**INDUSTRIAL USES OF ELECTRICITY**

Sir Humphrey Davy discovered the process of electrolysis out of which has come the giant electrochemistry industry. This industry employs an electric current to decompose compounds of various kinds. This is done by passing electric current through electrolytic materials as acids and most molten salts. The industry is responsible for the production of many metals by this process according to Mantell (45, p. 115), in his book, *Sparks from the Electrode*. These include beryllium, calcium, lithium, and magnesium, in addition to a number of metals which are refined by this process, including antimony, arsenic, copper, gold, nickel, platinum, selenium, silver, and tellurium. For example, 375 ounces of gold are recovered annually on the average (45, p. 29), from every million pounds of copper, in addition to 25,000 ounces of silver and 0.5 ounces of platinum. These involve some 25 percent of the gold and 80 percent of the world's silver, in addition to other by-products such as cobalt, copper, lead, nickel, platinum, palladium, and rhodium.

The employment of this process has made it possible to reduce the size and weight of several electrical appliances, notably that
of the transformer while also improving its efficiency. Another notable example of this point is the development of the five HP polyphase motor which weighed 716 pounds in 1900, 191 pounds in 1935, and only 148 pounds in 1954. The motor of 1900 occupied 19,700 cubic inches of space which was reduced to 4,380 cubic inches in 1935 or 77 percent. Electrolysis has also been used to produce certain important gases such as hydrogen and oxygen, and the nitrogen that is used in explosives and fertilizers.

Many industrial materials are currently being produced by the electric furnace including aluminum, carborundum or silicon carbide, calcium carbide which forms acetylene gas when mixed with water, carbon disulfate, graphite, chromium and magnesium which produce hardened steel, vanadium which improves the quality of steel, phosphorous, and tantalum which has replaced carbon filaments in electric lamps because of its higher melting point and lower consumption of electricity.

The electric furnace has also made possible the development of transistor materials by fusion. These have not only conserved electricity and materials, but have contributed richly to the production of hearing aids, radios, and television sets.

Electroplating is another major industry that employs electrolytic action. This action deposits a metal on a basic industrial metal to protect it from corrosion and wear or to improve its aesthetic value. Corrosion deserves wide attention since it leads
to losses approaching $1,000,000,000.00 per year. It involves the coating by and of a variety of metals including chrome, copper, gold, and nickel. In addition to plating, metals are also cleaned, repaired, and prevented from rusting by this process, and certain materials such as wood, leather (even including baby shoes), and plastics may be coated or decorated.

The use of electrostatics is another increasingly important use of electricity in business, industry and government, especially as regards the filtering of air and water. The domestic use of electrostatic techniques is increasing, especially as regards the protection of walls and furnishings from becoming dirty and the relief of persons afflicted with respiratory troubles. Industry uses it in certain processes, as for example in the production of drugs, films, food, and other sensitive items where impurities would spoil the product.

Mumford (50, p. 168) estimates the annual extra cost of keeping clean while living in Pittsburgh to be $2,610,000.00 including $1,500,000.00 for laundry, $750,000.00 for general cleaning, and $360,000.00 just for the cleaning of curtains. Electrostatic methods are also used to clean or purify water and especially that discarded as a result of industrial processes, before it is returned to local lakes or streams.

An electrostatic device known as a "Cottrell" has been invented to remove chemicals and other poisons from industrial exhausts at
a tremendous saving of property and crops, as well as lives. For example, when the orange growers of Riverside, California, threatened to sue a cement plant in this connection, a Gortrell was installed which not only ended the nuisance, but served to recover nearly 100 tons of cement particles daily in addition to a goodly amount of potash.

The electrostatic precipitator manufactured by Koppers of Pittsburgh is used in smelting plants to reclaim gold and is effective with particles as small as a millionth of an inch. These remove as high as 98 percent of the impurities from industrial fumes and solids.

The electron tube is another remarkable development that is now used very widely. According to Yates (88, p. 302) the expenditures of industries depending on electron tubes of various types amounts to one and one-third billion dollars annually. The following industries are especially dependent upon these tubes, and make large annual purchases of them: Sound pictures with $750,000,000.00, long distance telephones with $250,000,000.00, broadcasting receivers with $200,000,000.00, radio and electronic tube industry with $75,000,000.00, medical and industrial with $20,000,000.00, radio communication with $8,000,000.00, and the recording industry with $3,500,000.00.

The motion picture and telephone industries would be helpless without vacuum tubes. Steel industries are becoming heavily
indebted to the electron tube. Industries of the United States are looking more and more to the photoelectric cell and vacuum tube for help in reducing costs and speeding production. Many new techniques and applications of the electron tube have developed in attempting to solve these problems, and a great industry has developed as a result. For example, Manchester (14, p. 24) estimates the volume of electronic goods sold in 1941 to be $300,000,000.00 and three years later or in 1944 to be $4,500,000,000.00. This is an increase of 1,500 percent. Fortune magazine (26, p. 133) substantiates these data. General David Sarnoff of the Radio Corporation of America stated in the New York Times on December 20, 1954, page 42, that the sales and services of the corporation amounted to 930 million dollars for 1954.

The transportation industry is increasingly full of examples that involve the use of electricity including the storage battery, generator, electrical circuit, and appliances of the automobile, the airplane, and shipping. There are virtually hundreds of instruments available for use on airplanes that involve electricity.

The following are examples of airplane instruments activated by an electric current: absolute altimeter, electric fuel quantity gauge, fuel pressure gauge, mixture indicator, oil pressure gauge, position instruments such as landing wheels, wing flaps, radio compass, radio range receiver, tachometer, as well as temperature indicators, such as cabin and engine head temperatures.
The science of "Stereatronics" is very new and refers to the performance of certain solids by the use of electronics, including the crystal microphone, the crystal pickup used on phonographs, and even the cleaning of tools. The Galena crystal, or "cat whisker," that was used in radios during the period of World War I, is an example of a stereatonic. No one ever knew why it worked, but it was able to separate the carrier from the audio-frequency waves and deliver them to headphones loud and clear enough to be heard. Stereatonic devices are already contributing to the reduction in size, weight, and cost of a variety of products, including radios and television sets.

DOMESTIC USES OF ELECTRICITY

The greatest use of electricity has been by residential consumers where the number of customers has risen (11, p. 244) from 1,313,009 in 1937 to 41,497,272 in 1953 involving the current use of 2,289 kW per customer. Melvin H. Glick, a contractor and builder in St. Louis, developed (2, p. C-14) a 1,000 home community in 1954 that was hailed by the industry as indicating the trend of providing deluxe comfort. This involved heating and cooling controlled by interior and exterior thermostats that automatically adjust heating or cooling units to any temperature desired, and to changes in weather as well.
It is estimated (21, p. 193) that 2,500,000 vacuum cleaners, 2,500,000 washing machines, and 9,500,000 irons will be sold to the American housewife annually by 1960. Over 6,000,000 television sets were sold during 1952 and nearly 4,000,000 during the first half of 1953. Columbia Broadcasting System reports (69, p. 76) that 27,500,000 families or 58 percent of the total, owned television sets by the end of 1954.

The number of refrigerators sold in 1952 was 3,413,602 units and in 1953 was estimated (11, p. 245) to be 5,000,000 units. Dewhurst estimates (21, p. 194) that the increase of refrigerators sold during the period from 1940 to 1960 will be 84 percent and provide an ultimate average of more than 5,000,000 units per year. General Electric Company (55, p. 3) is experimenting with a refrigerator referred to simply as Model ER-10. It includes walls only one half inch thick, magnetically sealed doors that can be opened from either side, a spigot of running cold water, and ice that can be produced in any cube size or in crushed form if desired.

Eldon L. Richardson, home market manager of the Minneapolis Honeywell Regulator Company, predicts that electronic temperature regulators will be used in at least 50,000 American homes by the end of 1954 and that air conditioning will be as common as automatic heating within ten years. He expects that no home built in a warm climate will be without air conditioning by that time.
A heating and cooling device was announced (55, p. 3) in 1952 that came in the form of a \textit{packaged heating} unit that keeps a home comfortable throughout the year. This device burns no fuel, the only energy required being the electricity consumed in running its compressor and fan. It extracts the heat from the air during the summer by means of the refrigeration process, but during the winter, heat is extracted from the outside air and circulated by a compressor through the coils of refrigerant over which a stream of air is circulated into the home. This particular system of air conditioning has been installed (55, p. 7) on the barge, "Blind Pass," which is operated in the Gulf of Mexico by the Texas-Levington Shipbuilding Corporation.

The increasing use of air conditioning has created a major problem for the utilities because of the increasing demand for electricity in midsummer so they have turned to the use of electricity for heating purposes in winter in order to provide a year round balance of power consumption. This has already stimulated an increase in sales of at least twenty-one manufacturers of electrical heating appliances.

\textit{Newsweek} Magazine (58, p. 77) reports a survey that indicates 100,000 new homes will be equipped in 1954 with electric heating devices at a cost of $95,000,000.00, and that the total number of installations of this sort is currently 250,000 units. The industries concerned estimate that 1,000,000 homes will be heated
electrically by 1960. Present types of electrical heating include: thermostatically controlled glass panelled wall units in each room, wire coil inserts in ceiling panels, and heat pumps.

The use of electric heat is naturally going to depend upon the cost per kilowatt hour. The Union Electric Company of Missouri estimates that at an annual rate of one and three-fourths cents per KW, the cost for a five room home will range between $135.00 and $325.00. While this may sound high, it will be recalled that many older homes were originally lighted by electricity when the cost was as much as twenty-five cents per KW. Producers feel that the cost of electric heating will be no deterrent, once the public appreciates the many advantages involved. A spokesman states that “electricity will soon take the fire out of heating, just as it once took the fire out of lightning.” The advantages of heating by electricity include noiseless operation, even heat, cleanliness, safety, and controlled composition of the air, especially as regards those suffering from respiratory troubles.

High frequency heating is beginning to attract attention because of its application to the kitchen where a large sized roast can be cooked within a few seconds by this means.

Electricity has been used widely in the automobile and many further applications are seen especially concerning its safer use. Hugo Greensback, for example (29, p. 25), believes that 75 percent of all traffic accidents could be eliminated by the use of
photoelectric cells to control lights, brakes, and throttles,—by the use of radar to control speed, collisions, and parking,—and by the use of magnetic forces to repel or attract other cars or objects. Whereas the driver of an automobile going 70 miles an hour will travel 100 feet in a second of reaction time, the action of the electrical devices listed above is instantaneous (i.e., at the rate of 186,000 miles per second).

The Oldsmobile was the first to use electronics as regards the automatic control of headlight beams, in addition to which air conditioning, "power" brakes, and steering, window controls, antenna control, and automatic transmissions are some of the more recent innovations that involve electricity.

The Bell Telephone laboratories have developed two-way radio for mobile units which are now widely used, being tied in with both toll and radio circuits. Bell (73, p. 6) installs such equipment for $25.00 and the monthly rental rate is $15.00 in addition to the regular charges for toll calls.

It is estimated that something over 200 applications of electricity are in use today on the modern farm. These include lighting, heating, communicating, pumping, milking, washing, cleaning, cooking, sewing, grinding, testing, and many other applications. Some of the more technical and unique of these include: plowing, stimulating plant and animal growth, curing hay, and the like.

Antoine Jean MOLLET (4, p. 527) was the first to use electricity
(static) to stimulate plant and animal growth. Sir William Siemens (1823–83) successfully used arc lights (33, p. 97) in a greenhouse to accelerate the growth of beans, barley, cauliflower, oats, peas, raspberries, strawberries, and wheat. His conclusion was that an arc light would produce chlorophyll almost as well as sunshine. Hawks reports (33, p. 97) a similar experiment in Kew Gardens, London, in which the stimulated beds produced plants almost twice the size of those receiving normal light. Hawks further describes (33, p. 98) an experiment by Donald Woodward in Leroy, New York with an electric plough that used 100,000 volts to "impregnate" a field and claimed not only to restore fertility and accelerate growth, but to destroy bacteria, grubs, and weeds. He reports germinating beans, potatoes, and wheat within five days, whereas sixteen were required normally.

Manchester (44, p. 289) describes a machine using twenty-four electrodes and employing 16,000 volts used by the farmers of the Imperial Valley of California to electrocute the seeds of weeds as well as to destroy insects and fungus in the soil before the crops are planted, similar to the practice of using steam for this purpose in modern greenhouses.

Greenwood (31, p. 253) describes a method of curing hay by the use of electricity involving not only heat, but circulation:

Sanderson used to dry hay in the sun and sometimes lost tons of it because he and his men could not stack it quickly enough when thunderstorms swept the valley. Sanderson has not dried hay in the open since 1930. It matters little to him now whether the sun is shining or
not. The Susquehanna dries his hay for him. He distributes the hay in a long tunnel, into which a motor and fan blow hot air, and it is better hay, richer in food value, than any he ever fed to his cattle in the days of sweat.

England has been curing hay similar to this for some time. Their system involves the circulation of air. It (11, p. 163) employs an electric motor and fan which forces air through the stack of hay. The hay is stacked on a channel with openings every ten feet. Drums three feet high and two and a half feet in diameter are placed over these openings, and are pulled up as the stack develops, leaving a shaft for air to pass. A five horsepower motor is used with a fan large enough to absorb its full power. The temperature is measured twice daily with a thermometer placed about three and a half feet in from the side. The blowing of green hay continues for ten to fifteen hours in order to remove the surface moisture. Afterwards, the fan is used for one-half hour every twenty-four for the next ten days. This is done in order to hold the temperature within certain limits. It also controls the bacterial action. Stacks of 15 to 100 tons have been cured without the aid of preheated air.

Dr. Romanoff, a poultry specialist of the Experiment Station at Cornell, has invented (80, p. 28) an electronic device to grade and weigh eggs by means of a five-watt oscillator producing fourteen megacycles of frequency tied into a link connected coil which contains the egg. It seems, in this connection, that fresh
infertile eggs have a higher conductivity and a lower dielectric constant than fresh eggs. This device is not able to detect such things as blood spots, cracked shells, or imperfect yolks.

MEDICAL USES OF ELECTRICITY

The oldest and best understood use of electricity in medicine (33, p. 241) involves the x-ray which has become highly useful in locating foreign objects and studying the size and shape of organs and bones of the body, in addition to the movement of food.

X-ray has been used also as a curative agent in connection with cancer, skin diseases, and ulcers. The nervous system is not sensitive to x-rays. Hawks, however, reports a stunting effect on young animal growth as well as upon cancerous and other cells including sweat glands and hair follicles such as in the treatment of ringworm.

Electrotherapy has been recognised at least since 1919 when Cambridge started granting diplomas in "medical electricity" as well as in radiology, and the universities of France as well as the United States followed suit. It involves high frequency heat and is another application of electricity to medicine that has become very important. It is used either in surface or deep therapy treatments, as for example with sinuses, ulcers, and infected cavities.
Dr. Reginal G. Bickford of the Mayo Clinic has developed (71, p. 47) an electronic device activated by the brain which normally has a range of from one to one hundred microvolts and frequencies of from one to forty cycles per second. When a patient undergoes anesthesia, the energy output of the brain increases, but as the depth increases, the energy output decreases gradually as the effects of the anesthesia become stronger. The results are used to determine and control the rate and/or amount used.

The electroencephalograph (72, p. 29) is another electronic apparatus which is used to record the electrical waves or action potentials of the brain. This machine has been used with great success to diagnose and localize brain tumors, various forms of epilepsy, and to follow the progress of patients being treated for these conditions.

The electrocardiogram makes a graphic record (79, p. 28) of the voltages created by the pulsing of the heart. The source of these potentials is the nerve impulse. Each section of tissue becomes electronegative momentarily, with respect to the rest of the body. This device is used widely to measure the impulses that cause the heart to expand and contract, and is a good prognosticator of heart conditions.

The electric "knife" is another type of high frequency instrument commonly used by surgeons. The knife resembles a large
pencil, one side of the circuit of which is attached to the patient and the other to the surgeon. The result (31, p. 271) seals the blood vessels severed by the operation and no blood is lost. This eliminates shock that would otherwise result from the loss of blood.

The use of ultrasonic waves for diagnosis and treatment has been widely employed in Europe and involves sound waves beyond the upper limits of hearing which create heat in body tissues. There are many uses of ultrasonic waves and some of the most important are chemical and biological as well as medical. Some of the chemical effects are: mixing oil and water into homogeneous, stable emulsions, — dispersing metals during the process of electrolysis by bombarding the anode with ultrasonic waves, — coagulating smoke into larger and heavier particles which causes them to drop, — and cleaning watches or delicate instruments.

Some biological effects are: disintegration of Arabacins eggs, killing of fish and frogs, and inactivation of tobacco mosaic virus. Some medical effects include the detection of empty or full organs such as the bladder, heart, kidneys, liver, spleen, and stomach. Gallstones, kidney and bladder stones are easily detected, and ultrasonic waves have been used to treat arthritis, infections, myalgia, neuralgia, malignant tumors and prostates. Gernsback reports (28, p. 19) the biological effect of electricity used to study ovulation. Since the female egg is extremely small, it is
almost impossible to trace it. It is possible, by electronic means, to learn the exact time of ovulation merely by connecting one electrode over the abdomen and the other to the wrist of the subject. The instrument records the varying "electric potential" and temperature. It has been found that a woman's electric potential increases to a peak, and that her temperature is also highest at that moment of ovulation.

A pacemaker for stopped hearts was invented (76, p. 95) by Dr. Paul M. Zoll of Harvard. It plugs into a standard 110 volts circuit and converts into waves and impulses which can be varied in strength and length. It can be adjusted from 25 to 90 impulses per minute. These are carried from the negative electrode on one side of the patient's chest to the positive electrode on the other. A human heart that has stopped beating can be shocked back into action and made to keep pumping for days if necessary, or until it is strong enough to circulate the blood through the body.

The neurocalometer employs a combination of a thermocouple and a galvanometer to measure areas of heat on the human body. It indicates pressure areas by locating areas of heat. The pressure areas create heat and are located with a thermocouple which sends a small electric current through a galvanometer, the reading of which indicates the amount of current in proportion to the heat. The neurocalometer is connected to an electronic device which makes a graph of the heat areas. The two are known as a neurocalograph.
ELECTRICITY IN NATIONAL DEFENSE

The military and political uses of electricity for national defense have multiplied tremendously since World War I. For example, (30, p. 111) only two planes of the RAF were equipped with transmitters in 1914 when the principal means of communication with the ground and with other planes was accomplished via pocket flash-lights, the wiggling of the wings, and other stunts. Airplanes possessed few instruments and electricity was not used much beyond that required for the operation of the engine.

The situation today is vastly different on land and sea, as well as in the air. The modern warship operates its guns and turrets, its radio and radar, its light and heat, its elevators and signals, all with electricity. The sensitive feelers on the wings of an airplane record the formation of ice and automatically turn on the mechanism to get rid of it. The automatic pilot has been perfected to a point where it will take the plane over the target better than the pilot. The bombsight eliminates the human factors of anxiety and fatigue and is but another of some 200 such instruments, dials, and controls in the cockpit of an American heavy bomber that are activated by means of electricity.

The ground forces are also highly electrified. Personnel in tanks, trucks, and jeeps, as well as those on foot, are able to communicate with each other. Anti-aircraft units are aimed and fired automatically with electro-mechanical devices. Such things
have been developed and perfected according to Gray (30, p. 138) at least since 1929. The army also uses electro-magnetic locators which employ the principle of electro-magnetic induction, to locate and destroy landmines and unexploded missiles.

Ordnance makes many uses of electric devices such as photo-electric cells, electro-magnetic waves, oscillators, and electronic chronoscopes in the production of ammunition and shells.

The Navy has developed an electronic analog computer for firing guided missiles (68, p. 76), which permitted the accumulation of data leading to improved operation. This made it possible recently to solve a difficult wing and surface problem involving a rocket and 100 man days at a cost of $3,000.00 in place of a normal 3000 man days of effort, costing $73,000.00. It has been estimated (60, p. 28) that the highly complex missiles of today are 70 percent electronic. They employ five guiding principles:

1. Precept, meaning pre-takeoff adjustment.

2. Terrestrial, meaning that the machinery of the missile will react to the earth's magnetic forces, to some electrical stimulus, or to a gravitational field.

3. Celestial, meaning the use of stars for guiding a missile.

4. Radio, meaning the control of a missile by one or more transmitting stations, either on the ground or from other planes in flight, but this system is susceptible to jamming by the enemy.

5. Inertia, meaning the use of gyroscopes and accelerometers instead of electrical or electronic devices.
The Gruman F6F Helcat was developed (61, p. 42) into a guided missile during the Korean war. It is a propeller driven craft and includes many electronic controls, among which is a television eye. It carries a one ton bomb load and is controlled by a mother plane. These helcat missiles were used on targets considered to be extremely hazardous.

A completely automatic marine pilot system (57, p. 12) has been developed by the Navy to follow any course. This auto-pilot guides the rudder through a course with an average of variation of less than one-half of one degree. Fuel is saved from the reduction of rudder movement, and smoother sailing results. This device has an automatic compensator which trims when there is more force or resistance on one side of the vessel than the other. A weather adjustment reduces rudder action in heavy seas which reduces hull stress. The instrument requires a very small amount of maintenance as compared to other automatic steering systems.

Since the use of all such apparatus by military or civil personnel involves a variety of mathematical appreciation, it is a commentary indeed to learn of a report (30, p. 154) made by Admiral Nimitz in 1941 concerning the failure of 68 percent of the graduates of twenty-seven leading colleges for admission into the naval ROTC. Some 3,000 applicants were rejected, out of 8,000 cases reviewed, simply because of their failure to pass an entrance examination in arithmetic.
ELECTRICITY IN THE FUTURE

Astronomy uses many applications of electricity in the study of heavenly bodies, including the measurement of temperature, star intensity, distance, movement, and the like.

The radio telescope is a broad-band receiver and a highly sensitive directional antenna. The Bell Telephone Laboratories succeeded in intercepting radio signals from outer space with it as early as 1932. The new radio telescope of Cambridge, England will be used to study as many as 1,000 radio stars or suns, of which several outshine the Earth's sun. Many new wonders are being discovered in the sky with this new type of equipment. For example, the brightest radio star was found in the constellation of Cassiopeia, a northern circumpolar constellation east of Cepheus, on the opposite side of Polaris from the Dipper, (70, p. 80). The star is in the clouds of the Milky Way which is 100,000,000 miles in diameter and in a state of turmoil, with filaments of gas moving up to 1,000 miles per second. Wavelengths have been discovered from this star that range from one-quarter of an inch to sixty inches in length.

The analysis and forecasting of weather has become much more accurate with the use of electrical equipment. Radio and television have become very valuable in broadcasting news of the weather. Millions of dollars worth of property and products are saved every year as a result of the rapid method of distributing weather
information. A system of weather stations is being developed in the United States which is to be equipped to forecast and track tornadoes. This will not eliminate the destruction of some property, but it will reduce the loss of life. Man has worked toward the day when weather forecasts could be made for several days ahead. Otto Trotzauer, a Vienna scientist, claimed (2, p. B-12) he had invented a device which would make the art of predicting weather foolproof. He told the press that his "electric meter" which measures electric currents of the atmosphere allows "sure predictions" for as many as three days in advance.

The desire to forecast weather in advance became a command during World War II.

A high speed electrical computer in Princeton, New Jersey, known as the "Maniac," does the mathematics required in long range forecasting by doing some 20,000,000 additions, subtractions, and multiplications in an hour and a half. It is not completely accurate, but is more so than man, and much faster. With the Air Force, Navy, and the Weather Bureau cooperating, it is hoped that its accuracy will increase to 100 percent. The computer is eight feet high and eight feet long, and is a maze of tiny tubes, resistors, and condensers connected in a vast network.

Radiosonde or "RAOB" observations of the weather (34, p. 168) consist of a thermometer, a hygrometer, a barometer known as a baroswitch, and a radio transmitter which emits these three elements
in radio signals on a frequency of 72.2 megacycles. There are two models of the radiosonde in the United States, one of which is at the Washington Institute of Technology.

Automatic weather stations have been installed in areas not suitable for habitation. These operate from mountain tops, islands, swamps, and even from buoys anchored in the ocean. Each station transmits the atmospheric pressure, wind direction, and wind velocity on three megacycles. Each is powered by a storage battery, and turned on eight times daily by a program clock. The battery lasts for approximately five months under normal conditions.

The General Electric Company has developed (57, p. 13) a weather recorder that has a radioactive point which collects electric charges from the atmosphere. These are measured by a sensitive photocell, and are marked on a slow moving chart with a stylus. A thin red line remains close to the center line of the chart on clear days. The instrument is so sensitive that it will show the outbreak of showers within a radius of 450 miles. An approaching storm builds up a negative charge which sends the line to the left and each flash of lightning is marked by a sharp swing to the center. Warm and cold fronts high up in the atmosphere can be detected by this electrical device.

Electrical energy (9, p. 46) can be transformed into ultrasonic energy by the use of transducers. There are two types: magnetostriction and piezoelectricity. The former employs the
principle that an iron rod undergoes a change in length when it is magnetized. The latter is based on the principle that if a slice is cut from a quartz crystal, and pressure is applied to opposite faces of the slice, it will develop equal opposite electrical charge in turn. Also, by placing a quartz under the electrical pressure of a definite frequency, it will oscillate at this frequency along its electrical axis. This principle is used to generate ultrasonic waves. A crystal which will oscillate at a definite frequency is selected. One face is fixed while the other is left free to vibrate when acted upon by the electric charge. Waves will be generated if the free side of the quartz is in contact with air, water, oil, or any other fluid.

Psychology is making wide use of electricity and electronic devices in learning more about man. Criminology is employing the electron tube not only to reveal a criminal's presence, but to record his emotional response to questions. A photoelectric cell or an electric circuit, causes an alarm or lights to go on. The photoelectric cell operates infra-red or ultra-violet light which is visible only to the operator. The psychogalvanometer or "lie detector" can be used to reveal the visceral emotional response to questions. The instrument does not have legal status, but it has aided in bringing about many confessions. Fred T. Blakemore (7, p. 80) described a new type of lie detector in 1953 which measures: blood pressure, respiration, psychogalvanic skin reflexes
and contraction of the muscles of the thighs and arms. This type of detector is much more accurate than the psychogalvanometer.

The phenomenon of electricity in the world of tomorrow will be applied in many more economic and more fascinating as well as safer ways. It will also be generated and controlled in more efficient means. This will bring improvements and new techniques for electricity into the home, industry, medicine, power, and personal use.

The home will probably have the same amount (110 or 220 volts) of electrification as today. The applications of electricity will increase, and this will be possible through new materials. An air conditioner may be developed without any moving parts, to provide for both cooling and heating. Engineers believe this to be possible with the transistor. Ultrasonic waves will be employed in freezers, garbage disposal, and irons, as well as in refrigerators and washing machines. The barbecue pit will employ high frequency heating which is already being used in some experimental kitchens today. The oven may be equipped with a stereotron camera (RCA calls them TV eyes) to view the condition of a roast or other items without lowering or opening the door.

Communications in the home will greatly improve in the future as to size and weight. The radio will be much lighter and smaller. Dr. Irving Wolff of the Radio Corporation of America believes (74, p. 68) it will have a small loud-speaker and a plastic plate
with some lines and bumps in it. The lines will be a printed circuit or metal strips etched into the plastic, and the bumps will be little solides that will do all the work. A very small battery will supply all the power required for a year. Engineers also predict that the telephone will be changed considerably. One model will operate with push-buttons, and another will operate with the turn of a dial, a spoken word, and in a few seconds see and hear the person desired. Long-distance dialing on a nationwide basis is coming according to Bill Nunn (53, p. 116), but before this can be accomplished, nationwide local dialing must be completed. This alone will take ten to fifteen years. Television will change most of all. General Electric engineers are working on flat screens that will hang on the wall or stand on a table. This will be made possible by phosphor particles or a stereatron that gives off light when power is applied to it. This material used with a portable television camera will provide a "closed communication circuit" within the home. This will allow parents to check on children in the play room as well as checking the caller at the front door.

Doors in the home can be made to open automatically as an individual breaks a beam of light, or actuates a capacity switch. Garage doors will open automatically by breaking a beam of light, or energizing a photoelectric cell with the beam of a head light, or by actuating a sensitive circuit with a high frequency wave. Radar will be employed to direct the lawn mower about the lawn,
and it will be controlled by remote control.

**Home lighting systems will operate automatically** (74, p. 65) as the sun goes down. The artificial illumination will come from the entire ceiling, or walls, or windows instead of from isolated bulbs. This will be made possible by glass panels that will light when current is applied to them. Windows will allow natural light to pass in the day time, and will supply artificial illumination at night.

**Industry.** Solar electric power will probably be too expensive to operate industries. However, stereatrons may revolutionize the operation of industry. The outstanding advancement and development at the present are computers such as the desk-size developed by Sylvania. These computers are cool in operation, small in size, and more efficient than the larger sizes. The large computers of today are doing many industrial chores, particularly in accounting and inventorying. Dr. Samuel B. BERTNORF of Westinghouse believes (74, p. 71) one computer can do a better job of controlling machines than individuals and in much less time. According to Dr. Bertdorf, one computer would require approximately one second to check and control a hundred machines.

**Medicine.** A new thermometer will soon be made available to doctors. This employs a stereatron that reacts to heat. It is powered by a small battery and will show a patient's temperature within seconds. A dentist's drill will soon employ ultrasonic waves,
produced by a stereotron, that can vibrate 29,000 times a second. It will drill without creating heat, and will operate quietly with less pain.

**Power.** The sun showers the earth with more than one quadrillion (1,000,000,000,000) kilowatt-hours (74, p. 70) of energy daily. Most of this energy goes to waste. The greatest achievement up to the present of converting sunlight directly into power has been only about one percent, such as in the photoelectric cells used in a photographer's light meter. The Bell Laboratories (53, p. 117) have developed a battery that converts light directly into electric current. Its working parts never wear out, and it consists of ten razor-blade-thin wafers of especially treated silicon, a common element of sand. It is about the size of a light meter (74, p. 70), but is six times more efficient.

**Personal Use.** According to Dr. Clifford WITCHER (74, p. 71) a blind scientist at Massachusetts Institute of Technology, electricity will be used also to direct and guide the blind. At present Dr. Witcher is working on a preliminary device which indicates to the blind person the whereabouts of curbs, stairs, and similar "stepdown" obstacles. A blind person carries a boxlike apparatus with a light which scans his path, and when the beam strikes something, its reflection causes the handle to vibrate. **Hearing aids** carried by the hard of hearing will be much lighter and more efficient. The discovery of new materials will make possible
hearing aids small enough to be concealed in the ear-piece of glasses.

Dr. Harold S. Osborne, retired chief engineer of the American Telephone and Telegraph Company, makes a startling prediction (53, p. 87) concerning the personal use of electricity:

Let us say that in the ultimate, whenever a baby is born anywhere in the world, he is given a telephone number for life. As soon as he can talk, he is given a watchlike device with ten little buttons on one side and a screen on the other. Thus equipped, when he wishes to talk with anyone in the world, he will take out the device and punch a number on the keys. Then, turning the device over, he will hear the voice of his friend and see his face on the screen, in color and in three dimensions! If he does not see and hear him, he will know that the friend is dead.

Stereopaths, or solids which are capable of controlling electric current, will play a vital role in the future applications of electricity. Dr. Henry O'Brien (74, p. 71) manager of Sylvania Electric's physics department said, "you might sum up the significance of the new science this way. First came electricity, then electronics. Now we are beyond electronics into something just as far-reaching." General David Sarnoff, chairman of the Radio Corporation of America (ibid) states, "Science and electronics are moving so fast that in ten years everything we are now seeing will be so obsolete that we will not recognize them."
Chapter IV
THE RESOURCE STUDY OF ELECTRICITY

A systematic investigation concerning the nature of electrical content was launched in 1950, the results of which are now reported.

Techniques Employed. Everything on the subject in the libraries at Ohio State University and from most of the technical publishers was reviewed and the pertinent items were not only read for resource materials, but included in the annotated bibliography of 50 items which concludes this chapter. Electrical engineers, physicists, manufacturers and distributors were canvassed and the findings recorded. The results were submitted for criticism and refinement to a staff of twenty industrial arts specialists, (i.e., teachers of electricity) with the following results. Some of the resource material in this chapter of the dissertation has been gathered informally by the writer over a period of thirty years. It has been under constant check and revision most of that time. To document each item is not felt to be necessary because of the frequency of its occurrence in the list of resources. The findings now follow:

CHARACTERISTICS

Electricity is described as the property of certain substances such as amber, glass, vulcanite, silk, and fur when activated by
friction to attract, or as a fundamental quality in nature consisting of elementary particles of electrons and protons. These elementary particles are opposites, electrically, i.e., the electrons are negatively charged and the protons are positively charged. The symbols used to identify these charges are plus for positive and minus for negative.

The term "electricity" came from the Greek word *eiktron* meaning amber. William GILBERT used it for the first time in his writing in 1600 A.D. See Chapter II. There are three kinds of electricity: static, dynamic, and radiant. The ancient Greeks used a word *statis* meaning to stand. The English word "static" derived from it means to stand still. It is applied to all bodies at rest or in equilibrium. The term "static electricity" means electric charges or electrons at rest, or stationary on the surface. A body that has more electrons on its surface than protons has a negative charge, and conversely a body that has more protons than electrons has a positive charge. The quantity of the charge whether electrons or protons can be measured, and the unit of measurement is the coulomb which is equal approximately to a charge of $6.28 \times 10^{18}$ electrons. It is easier to express a large number like this as: $6.28 \times 10^{18}$, equals one coulomb.

Static electricity is produced by two methods: friction and induction. A glass rod can be charged with static electricity by
rubbing it with silk, or a stick of sealing wax with a piece of flannel. The glass loses electrons and becomes positively charged in the first case. The opposite is true in the second case. This kind of electricity is often referred to as frictional electricity. If a positively or negatively charged rod is held close to a piece of paper or pith ball, it will become electrified by induction, i.e., an electrical charge will be imparted before the rod makes contact. The induced charge will be opposite to the charge on the inducing body or the one electrified by friction.

Substances when electrified are called \textit{vitreous}, and those that behave like sealing wax are called \textit{resinous} electricity. See also Chapter II for the contributions of Dufay and Benjamin Franklin. Franklin called the former \textit{positiva} and the latter \textit{negative} electricity.

Constant research and experimentation with materials to determine how they could be electrified, gradually developed the flow and control of electrons which is known as \textit{dynamic} electricity. See also Chapter II for the works of Alessandro Volta.

Dynamic electricity means current electricity, or electrical current, or the movement of a charge, or electrons in motion. Dynamic electricity has two charges: positive and negative. These are relative terms but are helpful in describing and locating the parts of a circuit.
Dynamic electricity is produced by the following methods: heat, light, motion, and chemical. It is classified as two types: direct voltage and current, and alternating voltage and current. Constant research has resulted in more and better applications of it. These have brought a third type of electricity into use which is known as radiant electricity. This is the type in which the electrical effects vibrate or oscillate very rapidly, in the form of wave motion. This type of electricity is used to transmit intelligence from transmitters of all types, e.g. standard broadcast, frequency modulation, short wave, and television. This type makes use of all frequencies which improve and speed electrical communication.

Laws of Electrification were developed from the study and use of static and dynamic electricity, as follows: like charges repel, and unlike charges attract. These laws are very important in understanding the operation and repair of electric motors, generators, solenoids, door chimes and many other electrical appliances.

Some authorities have placed magnetism in the class with static, dynamic, and radiant electricity because electrical energy can be generated from it, and this energy can create magnetism.

MAGNETISM

"Magnetism" is the property of molecules of certain substances such as iron, steel, alnico, and permalloy. Magnetism is produced
by a magnet which is a body having the properties of polarity, attraction, and repulsion found in the lodestone. This phenomenon was discovered about 640 B.C. Magnets are classified as natural and artificial. Natural magnets are pieces of iron oxide which possess magnetism when found in the earth. Artificial magnets are classified as three types: permanent, temporary, and polarized. When steel comes in contact with a magnet, it is magnetized and attracted to the magnet. When removed it retains some of the magnetism and this makes it a permanent magnet. When a steel bar is placed inside of a coil of wire carrying a direct current, it will be magnetized by the lines of force around the coil, and will retain part of the magnetism after the current is stopped. Thus, it too becomes a permanent magnet.

The poles of permanent magnets are marked with a letter "N" or with a line cut in the steel. The south pole is marked with a letter "S" or by no mark at all. Colors are sometimes used to identify the poles. Blue is used to indicate north or the pole from which the lines of force emanate, and red is used to show the south pole or the pole which the lines of force enter. Much irregularity has been found in this marking system.

Soft iron is magnetized and attracted to a magnet, and as long as it is in contact with the magnet, it is a temporary magnet. It is temporary because the iron loses its attractive power as soon as it is detached from the magnet. Soft iron will become a
magnet when it is placed in a coil of wire carrying direct current, but as soon as the current is stopped, the iron loses all of its magnetic power. This type of magnet is called an electromagnet.

The combination of a permanent magnet and an electromagnet is called a polarised electromagnet. The total flux or circuit is under the influence of the permanent magnet alone in this type but when a current passes through the electromagnet, the polarity of the cores will be strengthened, or neutralised, and may even be reversed. These magnets are used in telephone ringers and other similar devices. The polarized relay is used in telegraph circuits.

Magnetic materials are divided into three types: magnetic, non-magnetic, and diamagnetic. Magnetic types are forcibly attracted by a magnet. These are called paramagnetic. Para comes from the Greek word para, meaning beside. It is used with magnetic substances to show that they are attracted by a magnet. For example, alnico, cobalt, iron, manganese, nickel, permalloy, and steel are magnetic. These materials are also known as ferromagnetic. Non-magnetic materials are those that cannot be magnetized. For example, glass, paper, wood, pure iron, and an alloy elinvar, also brass and copper, are not affected by magnetic force or flux.

Certain materials are repelled by a magnet. These are known as diamagnetic and include most of the metals and many of the non-metals. For example, bismuth is the strongest of these. Next in
order are: aluminum, antimony, copper, glass, paper, pure zinc, and phosphorus. Dia comes from the Greek word dia which means across. It is used as a prefix in connection with magnetic substances to show that they are repelled by a magnet. For example, bismuth in the form of a needle, when placed in a magnetic field between a north and south magnetic pole, will turn straight across the magnetic lines of force. The constant search and work with metals to determine their action with magnetic lines of force, lead to the development of the magnetic compass. This was the first instrument to use the magnetic lines of the earth, and a piece of magnetized metal or permanent magnet. A permanent magnet in the compass aligns itself with the magnetic lines of the earth in relation to the laws of magnetism.

Magnetic circuits have the following: magnetomotive force or poles, flux, and reluctance. Magnetomotive force (m.m.f.) is the magnetic potential difference between two poles. This is produced by the alignment of the electrons and protons in a material that can be magnetized. This force results in a magnetic field around the metal. The field is composed of magnetic lines, which is also known as flux.

Magnetic "flux" or lines of force cut through all materials especially the ferromagnetic or paramagnetic. When a paramagnetic substance is cut by the lines of force or flux, it is magnetized. This is called magnetic induction. All materials, even the
paramagnetic materials, offer some reluctance or opposition to the flux. Reluctance is the force against magnetic flux which permeates a material. It is equal to the magnetomotive force divided by the magnetic flux.

Magnetic induction is the process by which a substance is magnetized or becomes a magnet when it is placed in the flux of a permanent or electromagnet. The word "induction" comes from the Latin word *inductus* which means to bring in. The word induction comes from the Latin noun *inductio* which means the act of bringing in, or initiation.

The inductance of steel is less than iron because it has higher reluctance to the magnetic flux and there will be few lines of force to permeate it. This can be demonstrated by sprinkling iron filings on both metals while in a magnetic field. The steel will have fewer filings clinging to it because there are fewer magnetic lines of force that have become established. This causes its magnetomotive force to be weak due to the high reluctance of the steel. "Magnetic field," "lines of force," and "flux" are terms used to describe the space about a permanent, temporary or electromagnet. A magnetic field is the space occupied by the lines of force which flow between or around the magnetic poles. There are two ways to determine the field of a magnet: by a compass needle, and by iron filings.

The molecular theory states that every molecule of a magnetic substance is a small magnet. In an unmagnetized material, the
molecules are arranged in a random pattern to neutralize themselves. When in a magnetized state, the magnets line up with the flux lines so their poles align in the same direction.

A more complete theory attributes magnetism to the motion of the electrons around and within the atom. The planetary or valence electrons revolve around the nucleus, and according to the latest belief, the electron spins around an axis through its center. A substance that is highly magnetized has a large number of electrons revolving around the nucleus and spinning on their axes in the same direction. However, some electrons may not be controlled. For example, steel does not, due to its reluctance, yield to magnetism as easily as iron. Its electrons do not align themselves in a favorable position to aid magnetism. Several attempts must be made with a great deal of magnetizing force to completely magnetize it. When most of the electrons are revolving around a nucleus in the same direction, and they are rotating in the same direction on their axes which are aligned, magnetism increases tremendously. In a completely magnetized state, the rotation of the electrons and the axes of rotation are aligned, and give a strong magnetic field because the fields produced by the rotating electrons are additive. Metal, in this condition, is in a saturated state. This occurs when an increase in magnetizing force does not add to the magnetism.

This theory helps to explain many facts about magnetism. For example, a magnet loses some of its magnetism when hammered or
dropped. This happens because some of the electrons are jarred out of alignment which reduces or neutralizes their magnetic field. Heat also causes a magnet to lose its magnetism. Atoms and electrons increase their speed with an increase of temperature. This allows the electrons to change their position which has a weakening effect on the magnet. A magnetic bar when broken in two pieces becomes two independent magnets. This is due to the alignment of the axes of rotation. The new poles which appear at the breaks are simply a collection of the poles that have been there all the time, but after the break are for the first time in an independent and recognizable state. Ferromagnets reach a saturation point. Magnetism increases tremendously when all of the axes of rotation are aligned. Beyond this, any increase in the magnetizing force produces no further magnetic effect.

There are two characteristics of ferromagnetic materials which cause them to be good magnets. These are permeability and reluctance. Permeability means the ease that magnetic lines of force may penetrate a material. For example, soft iron has a very high permeability, several times higher than air. Permalloy, an alloy of iron and nickel, has a permeability about 30 times that of soft iron. These metals have many uses because of their high permeability. For example, iron is used for making laminated cores for armatures, transformers, relays, solenoids, power chokes, and field coil cores for generators and motors. Permalloy is used for
laminated cores in transformers where heat is to be kept at a minimum. Heat is developed in all of the items listed above, and is caused by eddy currents.

Reluctance or reluctivity is the resistance to flux. It is the name given to that property of materials which oppose the creation of magnetic flux in them. It is the reciprocal of permeability. In electric circuits, the property of substances which oppose or limit the flow of current, is called resistance. An analogous property in magnetic circuits, is reluctance. Nearly all substances in electric circuits have different resistance properties. Some have a small amount, while others have great opposition to the flow of electrons. Nearly all materials in magnetic circuits except magnetic metals, have practically the same reluctance. For example, iron and permalloy have a relatively low reluctance while air, steel, and other items have a higher reluctance. The reluctance of steel makes it difficult for a magnetic flux to align the axes and the rotation of the electrons into a position to aid magnetism. However, this same opposition does not allow the electrons to shift back to their original positions causing the steel to become a permanent magnet. This characteristic causes the steel to retain some of the magnetic flux, and because of this it has a high remanence.

Ferromagnetic metals are affected by magnetic lines of force. Non-magnetic materials are also affected by these lines, but do not become magnetized. For example, a magnet placed on a piece
of glass will attract and hold filings on the opposite side. There is no magnetic insulator or insulation. Iron and permalloy are the best conductors because of their low reluctance and high permeance. They make very good screens. For example, soft iron rings are placed in instruments and watches to make them non-magnetic because an iron ring will conduct magnetic lines around the mechanism. A magnet will attract through glass, mica, wood, in fact through anything except soft iron.

Man's study of magnets and magnetic materials has aided him in understanding the magnetic field of a much larger magnet, the earth. Its magnetic field has absorbed men's interest for many centuries. The magnetic field about the earth has similar characteristics to the magnetic field about a permanent magnet. The earth behaves like a permanent magnet with the "magnetic south pole" located in Boathis near the Hudson Bay in the northern part of Canada approximately 1,400 miles from the "geographic north pole." The "magnetic north pole" is located in Antarctica about 1,300 miles north of the "geographic south pole." Magnetic lines of force emerge from the magnetic north pole and make their way northward over the earth to the magnetic south pole. There they enter the earth and make their way back to the magnetic north pole to complete their magnetic circuit. The magnetic poles are continuously, but slowly, changing their positions.
After the development of the compass needle, some new characteristics of the magnetic lines of force about the earth were discovered. For centuries the lodestone and the magnetized bar were observed to swing in a horizontal position and point toward the horizontal component of the magnetic lines of force which is very strong at the magnetic equator, gradually decreasing to zero at the magnetic poles.

Another force was discovered many centuries later. The magnetic needle was observed to dip slightly as the compass was moved away from the magnetic equator. The needle dipped toward the north magnetic pole in the northern hemisphere and toward the south magnetic pole in the southern hemisphere, but not at the magnetic equator. The vertical component or dip is zero at this point but gradually increases to a maximum at the poles. This discovery led to the development of the dip needle.

The vertical component of the earth's magnetic field is known as inclination. Maps are available which show points of equal inclination. Lines that connect points of equal inclination are known as isoclinic lines. The line connecting points of zero inclination is the magnetic equator.

The angle between the magnetic and geographical north pole is known as declination. Points of equal declination are shown on navigational maps. Declination is commonly known as variation. The line connecting all points of zero declination is called an
agonic line. This line is found across the United States from the Great Lakes to the east side of Florida. The lines connecting all points of equal variation are called isagonic lines. These lines are east and west of the agonic line. They are also called easterly and westerly variation.

The earth's magnetic field has some interesting phenomena. Some of these are the Aurora Borealis (Northern Lights) and the Aurora Australis (Southern Lights) which are observed almost nightly in the Arctic and Antarctic circles and which extend as high as 600 miles. These are very similar in behavior. They appear as dim streaks of pale light with tinges of red. The streaks radiate into a fan shape pattern and often have a trembling, flowing motion. When the lights appear, compass needles, telegraph lines, radios, and many other electrical devices are affected.

The explanation of the Aurora is based on the electron theory. It is believed that electrons are emitted constantly by the sun. These create a stream of cathode rays which are visible in a partial vacuum, and at 600 miles, such a vacuum could exist. The cathode ray is deflected or repelled by the earth's magnetic field, and this is probably the reason why the rays appear near the poles of the earth. Another theory is that the earth shifts a small amount causing some of the magnetic lines to cross, resulting in light of various colors.
The earth is continually discharging a constant current of over 1000 amperes into the air. However, this is a very infinitesimal part per square foot or even per square mile of the earth's surface. No satisfactory explanation as to the source of this supply of negative electricity has been developed. The atmosphere, in fine weather, is usually positively charged in relation to the earth's surface. In rainy weather it is usually negative but may be positively charged. The theory and nature of magnetism is very similar to the theory of electricity.

THE ELECTRON THEORY

There are two main theories: the electrical fluid theory which has two parts: the single and two fluid theory, and the displacement theory.

All matter, such as liquids, solids, and gasses, is composed of atoms. These are made up of protons, neutrons, and planetary electrons. The nucleus is composed of neutrons and protons. Planetary electrons revolve around a nucleus. The outermost planetary electrons are referred to as the valence electrons because they can be given or taken by other atoms. The neutrons are neutral but the protons are positively charged. The planetary electrons are negatively charged and balance the charge on the protons. The planetary electrons are alike in all materials. They have a mass of only \( \frac{1}{1836} \) of the hydrogen atom. It would take approximately
3 \times 10^{28} \text{ electrons to weigh one ounce, and the package would be considerably smaller than the head of a pin. A proton weighs almost as much as a hydrogen atom. A normal atom has as many protons or positive charges as negative planetary ones. There are two applications of this theory: the chemical and the electrical.}

The \textit{chemical application} involves the combination of two or more atoms. For example, a sodium atom has 11 electrons in rings of 2, 8, and 1; a nucleus of 11 protons and 12 neutrons. An atom may give a \textit{valence} electron in the outer ring to some other atom. When this occurs the atom becomes an \textit{ion} with a positive charge. A chlorine atom has 17 electrons in rings of 2, 8, and 7; a nucleus with 17 protons and 18 neutrons. A chlorine atom will take another electron in the outer ring to stabilize the electrons there. When this occurs an atom becomes an ion with a negative charge. When a chlorine atom takes the valence electron from the sodium atom, the two ions combine to form \textit{table salt}.

The \textit{electrical application} involves materials such as glass, fur, flannel, and others such as silver and copper that have an easy movement of the planetary electrons. Solids are composed of protons, neutrons, and planetary electrons. The protons and neutrons are believed to be fixed, but the electrons are believed to be easily moved or transferred from one material to another, or to move freely within the material. This movement of the
electron is brought about by friction, heat, light, motion, and chemical action. If a glass rod has no electrical charge, the electrons and protons are equal in number and their charges are neutral. When the glass rod is rubbed with a piece of silk some electrons are moved from it to the silk. The rod is deficient in electrons and has a positive charge, and the silk has an excess of electrons which gives it a negative charge. When vulcanite or hard rubber is stroked with catskin, electrons are transferred from it to the vulcanite, which becomes negatively charged while the catskin becomes positively charged. When materials are in this state they are electrified. In order to have electrification, there must be either an excess or deficiency of electrons. When the movement or transfer of electrons from one material to another is caused by the methods named above, an electric current flows. The electron theory is valuable in explaining the flow of electric current from materials in cells, batteries, generators, photoelectric cells, vacuum tubes of all sorts, ion traps, and circuits. It is helpful in explaining how voltage or pressure is developed.

VOLTAGE

This term is defined as electrical pressure. A number of other terms have been used to identify the same thing. Some of the most commonly used are: electromotive force, potential difference, pressure, voltage, and volts.
Materials can be charged or electrified by friction, motion, light, heat, and chemical action. When electrified, they have either an excess or deficiency of electrons. Those having an excess have a negative charge, and those with a deficiency have a positive charge. A state of electrification of this kind creates a potential difference or pressure. For example, if carbon and zinc are placed in an electrolyte of sulphuric acid and pure water, they will electrify themselves freely, i.e., one will give up electrons and the other will attract them. If there is no external circuit and load to use, the electrons will pile up and exert a pressure that can be measured with a high resistant instrument or voltmeter which opposes rapid escape. The pressure indicated is the potential difference, electromotive force, pressure, voltage, or volte. This voltage or pressure will continue as long as the materials can liberate the free or planetary electrons, but as soon as these are exhausted, the potential drops to zero and the materials become neutral. Voltage will drop across a component part in a circuit when it is required to overcome the resistance to force the current through. It is consumed in overcoming the resistance, and work is done which results in heat.

Voltage is developed by friction, heat, light, motion, and chemical action. The earth has been established arbitrarily as zero potential. The evaporation of moisture and the movement of air currents along the surface of the earth help to carry the
electrons discharged from the earth into the atmosphere. These may become concentrated in the atmosphere and create a potential difference between the earth and the atmosphere. This difference or voltage is equalized by lightning.

A coil of wire rotated between two strong electromagnets cuts the magnetic flux and creates a pressure or piling up of electrons on the brushes.

Two dissimilar metals when placed together, such as copper and iron, and heated in a flame will develop a potential difference that can be measured with a sensitive galvanometer. The greatest electromotive force or potential difference is developed when antimony and bismuth are connected together as a thermoelectric couple.

Light striking a photosensitive material will cause electrons to escape and cause a potential difference between two materials. This difference is indicated by a sensitive galvanometer. A sensitive light meter employs this principle. Copper and zinc when placed in a glass of pure water with salt added makes an electrolyte which acts on the two metals and causes electrons to be set free. One metal gives off electrons and the other attracts them. This results in an electromotive force or voltage.

There are three types of pressures or potential differences: direct, pulsating, and alternating voltage. Direct voltage maintains a steady pressure at the terminals of a circuit. It is
developed by cells, batteries, direct voltage generators, and rectifiers. The cells and batteries will drop off in pressure with age and gradually become dead. Pulsating direct voltage is developed by cells, batteries, and generators. Cells and batteries cannot depolarize rapidly enough to keep a steady current. When a cell or battery depolarizes, the pressure increases, and as they polarize, the pressure drops off. Auto generators and other direct voltage generators maintain a pulsating direct voltage which is good for charging batteries and burning lights, but not for radio and television.

Alternating voltage is constantly changing from zero to maximum, then back again. This completes a cycle which is composed of two "alternations." The standard number of cycles for home lighting in the United States is 60 per second. There are, however, a few systems of 25 and 50. Industry, radio, and television employ much higher cycles per second. These are expressed as frequency and this is used to describe the changes in voltage per second, or 60 times a second, or simply, "60 cycles per second." Another term associated with alternating voltage is alternation. There are 60 positive and 60 negative changes or 120 alternations per second. This type of voltage changes 120 times a second. One alternation is 1/120 of a second long. This may seem to be very fast, but electrons travel 186,000 miles a second.
Phase is another term used with alternating voltage. Any point on a cycle is called a phase point. For example, voltage starts at zero phase or point, and builds up through 30, 60, and 90 degree phases, then returns through 120, 150, and 180 degree phases, after which it builds up in the opposite direction to 270 degree phase, then returns finally to 360 degree or zero phase.

Alternating voltage not only changes in direction, but in value. This is important to consider in dealing with pressure. At any phase or point in the cycle, the voltage is different. The maximum or peak values occur at phases 90 and 270 degree. The maximum value at these phases is 173. Since the voltage varies from zero to maximum, an average value will occur between these extremes. A practical way of determining average value is with a voltmeter. Multiplying the reading of a voltmeter by 1.57, will give the maximum value or voltage. The value of alternating voltage in practical work is neither instantaneous nor average. An effective value is used to make alternating voltage compare as nearly to direct voltage as possible, which is the standard.

When pressure or electromagnetic force is attached to a circuit, electrons will flow from one material to another in the cell or battery. This flow or movement of electrons is referred to as current.
Current can be produced in metal, air, or vacuum. Electrons can be removed from atoms. Materials composed of certain types of atoms allow freedom in the movement of planetary electrons. For example, aluminum, silver, and copper provide easy movement. Atoms lie close together in these materials, which makes it possible for the planetary electrons to overlap. These have a negative charge which causes them to repel each other, and when one is made to move, all of them move along the conductor at the same time.

When one end of a conductor in a circuit is connected to a source of voltage which maintains a supply of negative electrons, and the other end of the circuit is made positive, the planetary electrons within the wire or conductor are repelled from the negative end and are attracted to the positive. These electrons are set in a definite drift or movement from atom to atom toward the positive side of the source of pressure. It is this drift or movement of the electrons which constitutes an electric current within a conductor, be it air, metal, or vacuum. When the positive protons of an atom remain practically fixed in the material, the current is attributed to the movement of electrons.

An electric current is regarded as some kind of fluid which "flows" from positive to negative. Many textbooks make statements similar to the following: "when it is necessary to designate the direction of flow, the term 'current' is used to represent positive
to negative flow, and electron flow is used to represent a drift of electrons from negative to positive. "Current flow is opposite to the electron flow." This is confusing and difficult to apply, especially in the vacuum tube.

There are several kinds of current or dynamic electricity, such as: direct, alternating, pulsating, continuous, interrupted, eddy, and damped.

**Direct** current is supplied by batteries and generators. It moves in a steady direction. It will rise and fall when the battery becomes old and cannot depolarize rapidly enough. This is also known as fluctuating current, because it never touches zero.

**Alternating** current is supplied by generators. It commonly reverses itself at fixed intervals or 60 times a second. This rate is referred to as "cycles per second," and the frequency of change is the frequency in cycles. There are 60 positive and 60 negative alternations of current per second, in a house circuit.

**Pulsating** current is supplied from generators and half-wave rectifiers. The current rises and falls similar to alternating current, but it never falls below zero. It always swings from zero to high positive, then back to zero again.

**Continuous** current is supplied by cells and batteries, and rectifiers. Cells and batteries provide fluctuating current with age. A rectifier will give a continuous current as long as it functions.
**Interrupted** current is the kind that starts and stops. This is supplied by breaker points in an automobile ignition system, and by a vibrator in an auto radio and other devices where the vibrator is used.

**Eddy** currents are produced in the iron cores of generators, motors, transformers, choke coils, field coils, magneto, and relays. This type of current is created by magnetic lines of force cutting through metals used in the cores of the appliances named above. This current is undesirable in some appliances. Eddy currents are desirable in a self-inductance motor where the currents flow at right angles to the magnetic lines of force that produce them.

**Damped** current is an oscillatory type which reverses its direction of flow many times a second. It builds to maximum amplitude then progressively diminishes to zero. The discharging of a condenser through a coil of wire produces this type of current.

**Phase** applies to current in the same manner as it applies to voltage or pressure. It is also used to indicate that voltage and current arrive at the same phase point at the same time. If they do, they are in phase; if not, they are out of phase. It is also used to describe the type of alternating current: single, two and three phase.

Voltage or pressure creates a potential difference across a circuit and when this is applied, electrons move from the negative
to the positive terminal. When an electric current flows, a magnetic field builds up around the wire in proportion to the current. This same thing happens when an alternating current is applied to a circuit; however, a magnetic field around the wire will have the same characteristics of the current producing it. The pulsation of the current creates characteristics that are not associated with direct current. These are inductance, capacitance, reactance, and impedance.

Voltage created by magnetic lines collapsing back into a wire, is called self-inductance. An alternating circuit involving motors, transformers, chokes, and other appliances with one or more coils, develops a great amount of self-inductance which opposes the flow of current which produces it. If a circuit contains both resistance and inductance, it will cause the current to "lag" behind the voltage approximately 90 degrees, (i.e.) is called "out of phase."

Alternating circuits also have other components which affect current. These are capacitors or condensers. For example, a capacitance motor uses an electrolytic condenser for starting and running. A capacitor charges fairly quickly, and if an attempt is made to increase the charge by increasing the current, it will oppose the increase and react against the charging current. This reaction is known as "capacitance reaction," and will "lead" the voltage by approximately 90 degrees.
Every circuit, whether direct or alternating, contains resistance due to the nature of the material. Another characteristic of an alternating current is the presence of a combination of resistance and inductance, or resistance and capacitance, or resistance, inductance and capacitance. Any of the combinations is called impedance. They are measured in ohms and are represented by the letter \( Z \). When current flows in a direct or alternating current circuit, it produces one or more effects: magnetic, chemical, heating, and ionizing.

A magnetic effect is produced by direct as well as alternating currents. This possesses the characteristics of the current which produces it. For example, direct current develops a steady field unless the current is pulsating. The density and area of the field will be in proportion to the number of amperes. The field collapses back into the wire when the current stops flowing. The collapse of a magnetic field creates a counter-electromotive force by self-inductance. By coiling the wire, the magnetic field around a single coil is added to the adjacent coil and so on for the length of the coil. Such a field becomes very strong. If a soft laminated iron core is placed inside of the coil, the magnetic field becomes highly concentrated and possesses tremendous strength. This effect creates motion in instruments, motors, speakers, and other devices.
Alternating current produces a magnetic field around a wire, but it has a pulsating movement in keeping with the current. The building up and collapsing of the magnetic field makes possible another characteristic, mutual inductance. This makes it possible to induce (by the magnetic effect) a voltage and current into an independent circuit. For example, the secondary of a transformer will have a voltage and current induced into it by mutual inductance from the magnetic field produced by the primary winding of the transformer.

A magnetic field of pulsating and interrupted direct current will produce a voltage and current by mutual inductance in an independent circuit. This voltage and current is alternating, and it can be increased or decreased by step-up and step-down transformers.

Another effect of current is heating. When current is forced through a conductor with a certain amount of resistance, voltage is required to push the current through. This results in work, and heat is produced. Such an effect is achieved in many appliances such as lights, heaters, stoves, radio and television tubes.

Direct current is used for measuring heating effects. For an average current of 10 amperes, the maximum alternating current used is determined by multiplying it by 1.57. The maximum alternating current is equal, therefore, to 15.7 amperes, and when multiplied
by a constant of .707, is equal to 10.09 amperes. An effective alternating current of 10.09 amperes is equivalent to a direct current of 10.09 amperes, and will produce as much heat as the direct current. The heating process in most all cases is rather costly.

An electric current also produces chemical change. If a current is passed through a conducting solution, it will be decomposed into its component parts. This is referred to as electrolysis. For example, water can be decomposed into hydrogen and oxygen.

Electrolysis is used to refine metals such as aluminum and copper. Metal is used as an electrode to project electrons into solution, causing pure metal to be carried with them to be deposited on the other electrode. This is known as electrolytic refining. Gold, nickel, silver, and chromium plating are done in a similar manner by using the part to be plated as one electrode and the plating metal as the other. As a current travels through a solution, the electrons deposit the plating metal uniformly over the object to be plated.

Another use of electric current is in the ionization of gas. For example, if a current at sufficiently high pressure is sent through a rarefied gas, it breaks up or ionizes the gas into negative electrons and positive ions. This is usually accompanied by the emission of light, the principle employed by fluorescent lamps and neon signs.
These effects are also used to generate or produce current by four different ways: chemical, heat, light, and motion. Either direct or alternating current can be generated by turning an armature with a large number of coils in series or parallel in a strong magnetic field produced by a direct current. The coils are connected in parallel for low voltage and high current. This is used in electroplating. For high voltage and low current, the coils are connected in series on the armature.

A second method of generating electric current is chemical. Volta was probably the first to discover this process. A zinc electrode is dissolved by sulphuric acid. The zinc (Zn) combines with the solution (SO₄) and the hydrogen (H) of the acid is set free.

The positive hydrogen ions that form in a cell pass through the electrolyte to the positive terminal. They lose their positive charge when they reach this terminal and are set free in the form of gas. If these bubbles are not neutralised, they will cover the positive electrode, and result in polarization.

A third way of generating a current is by the use of heat. This is known as thermoelectric, and it can be demonstrated several ways. For example, connect or twist two unlike wires such as copper and iron together. Connect the other two ends to a sensitive galvanometer. This arrangement is called a thermoelectric couple. When the twisted ends are heated, a current will flow in one
direction through the circuit and the galvanometer will indicate
the flow. Conversely, if the temperature of the thermojunction is
below the free ends, which may be done by holding a piece of ice
on the thermojunction, current will flow in the opposite direction.
The electron theory helps to explain this action. When the joint
is heated, the electrons are driven from the negative side or
iron wire, and are attracted to the positive side copper wire.
They flow to and through the positive side and back to the nega-
tive side of the joint.

Thermoelectric metals include: antimony, bismuth, copper,
iron, lead, and silver. Alloys include: advance (i.e. copper and
nickel), alumel (i.e. aluminum and nickel), chromel (i.e. chromium
and nickel), constantan (i.e. carbon, copper, iron, nickel,
phosphorus, and silicon), and platinum with rhodium.

A practical application of thermoelectricity is to measure
heat. The thermocouple is used to measure cylinder head and
crankcase temperatures on aircraft engines. Pyrometers are used
to measure temperatures above those indicated by the mercurial
thermometer. The thermoelectric battery is capable of producing
3 to 10 amperes of current capable of running a small motor,
lighting an incandescent light, or charging a storage battery.

Electric current can also be generated by light waves, such
as a light meter to determine the level of light. This instrument
is made of materials sensitive to light. A current thus caused
is indicated on a sensitive galvanometer or milliammeter. A photoelectric cell is another device which is made of material sensitive to light. When a beam of light strikes its cathode, electrons are liberated and attracted to the anode. This device has many practical applications.

A great deal of space has been used in describing the types, effects, and methods of producing electric current. Another item concerns how to measure an electric current.

An amper is defined as a current composed of $6.28 \times 10^{18}$ electrons flowing by a point each second. Ampere, the scientist, thought this number was too large for practical use so he called it “one” ampere. The symbol used to represent electric current is “I” for intensity, or rate of flow, which is measured with the ammeter or the milliammeter, the latter of which measures in thousandths of an ampere.

Cells

Pressure and current are produced by an electric cell. This is composed of two dissimilar materials placed in a wet or semidry electrolyte which acts chemically on one of them. If two or more of these cells are connected in series or parallel, a battery is formed. If two unlike materials such as carbon and zinc are placed in a liquid or semidry electrolyte so they do not touch or short, and if the electrolyte is such that it will act on one of the materials, an electrical pressure and current will be generated.
If an external circuit is connected to the cell, an electric current will flow from one material to the other, for example, carbon is positive and zinc is negative. The amount of pressure developed by this chemical action depends upon the material of the plates and the electrolyte. The size of the plates and the distance between them has no bearing upon the electrical pressure and current generated.

There are two main classifications of cells: primary and secondary. A cell that ceases to produce current after a period of use, and must be renewed by replacing a used-up plate and electrolyte is known as a primary cell. These cannot be recharged, and there are two types—wet and dry cells. Wet cells were the first electric batteries. These supplied the first pressure and current, and were in existence before mechanical means of generating electricity was attempted. The important experiments which underlie the principles of electricity were performed with this type of cell. These cells also took the name of the circuit for which they were designed, such as closed or open circuits.

Closed circuit cells are applied in telegraphic work. A continuous flow of current is in this circuit except during the sending of a message. Examples of this type are the gravity cell, sometimes referred to as the crowfoot, the Daniell and the Edison-Lelande cell. These are good for telegraphic work because they depolarise quickly, making it possible to deliver a contin-
uous current. Two actions must be reduced in this cell: local action, and polarization.

Polarization is the collection of hydrogen gas bubbles on the positive electrode of the cell. This insulates the positive electrode from the electrolyte which results in a very high resistance.

The original closed-circuit cell was composed of copper, zinc, and an electrolyte composed of a simple solution of copper sulphate crystals and water. These crystals, commonly known as blue vitriol, copper vitriol or blue stone, are produced by the action of sulphuric acid on copper and copper oxide. The usual size was a gallon jar with the zinc fastened to the top and the copper on the bottom. Two pounds of blue vitriol were added and eventually the electrolyte separated into two solutions—the one at the top being clear and the one on the bottom being blue. This is called a gravity cell. And, this type of electrolyte makes it possible for the hydrogen gas to escape easily, providing almost a completely depolarized cell.

Open-circuit cells are used in telephone work, which requires a current that will flow only while conversation is actually going on. It is not necessary, therefore, to have a cell which can depolarize itself as in telegraph circuits. The telephone circuit is in use for such a short period that there is ample time for the cell or battery to depolarize while not in
use. However, the telephone requires more current than the telegraph, so this results in rapid polarization.

Dry or semidry cells are not really "dry." The electrolyte is in the form of a paste containing sufficient moisture to cause chemical action. The oxygen given off by the manganese dioxide unites with the hydrogen gas and forms water, and would drown if holes were not eaten through the zinc can by the sal ammoniac which allows air to enter and dry out the moisture. When this happens the cell becomes dead. Dry cells are rated at 1.5 volts. This is determined by the electrode and the electrolyte. The voltage and the useful life of the cell is determined by the use to which it is put. They are not intended for long, heavy use.

Multiple cells are made by connecting intermediate or large flashlight cells in series, parallel, series-parallel, or parallel-series. Multiple cells are designated as "A", "B", and "C" batteries. These have a large number of applications, for example, in radio and in hearing aids.

Dissipated cells are really dry cells. They do not deteriorate as long as they are kept dry. Water is added when the cell is put into service, and a maximum current is produced in 24 hours.

Silver-chloride cells deliver a small current. They are expensive because of their silver contents, but have salvage value for the same reason.
Cells are connected in the same manner as hitching teams of horses: abreast, tandem, and tandem-abreast as follows: in parallel, series, series-parallel, and parallel-series.

Secondary cells can be recharged or their charges renewed by passing a current through them in the opposite direction to their delivery. The recharging current is usually supplied by a direct current generator, or a rectifier working on an alternating current of 110 volts. Battery grid plates are cast from a mixture of pure lead and antimony. This gives structural strength and provides recesses into which active materials can be forced in paste form. Two dissimilar compounds of lead are used in making storage or secondary cells. Lead peroxide forms the active material on the positive plate, and its color is dark brown. Spongy lead makes up the active material on the negative plate, and its color is dark gray. Negative grids are connected, but with a space left between them, and the positive grids are joined together. These two sets of grids are placed so they interleave with each other, and are prevented from touching or shorting by separators. These have grooves of ridges cut with the grain, if made of wood. The ridges are placed next to the positive plates with the grooves in a vertical position which allows the lead peroxide and spongy lead to fall to the bottom of the case. Separators are made of basswood, cedar, cypress, and Port Orford cedar or other porous wood. These thin separators are boiled in
an alkaline solution to neutralize any organic acid. Hard rubber
and plastic sheets with fine perforations are also used as sepa-
rators. Spun glass separators are used in some batteries.

The chemical action of a cell occurs when it is being
charged (i.e., an electric current from an external source is be-
ing passed through it, and its energy is changed into chemical
energy), and when it is being discharged (i.e., when a reverse of
the reaction takes place and it develops and sends an electric
current into a circuit). The chemical action within the cell dur-
ing discharge is such that the unlike compounds on the positive
and negative plates tend to become similar. This is caused by the
chemical action in the electrolyte. It gives up part of its
sulphate to the positive plate which changes the lead peroxide to
lead sulphate. At the same time, part of the electrolyte's sul-
phate combines with the spongy lead of the negative plate to
become lead sulphate.

A storage cell or battery cannot function without a certain
amount of sulphation. This is similar to polarization in the pri-
mary cells because it can stop the flow of current. A normal
amount of sulphation produces a chemical action on the plates,
and is essential to producing a current. It is not harmful as
long as it can be controlled, but trouble sets in as soon as its
control is lost. Excessive sulphation may result from any of the
following: increasing amounts of paste loosened from the grids,
clogged separators, buckled plates, battery allowed to remain uncharged, continuous low charging, and old age. The size of the plate in a storage cell or battery, as in the primary cell, has no bearing on the voltage. A lead storage cell in an open circuit has a voltage of 2.2, and its working voltage is 2 volts per cell. The amount of current that a cell can produce depends upon the size of the plate. The more plate surface exposed to the electrolyte, the greater chemical action and this causes more current. Plates cannot be made very large and remain convenient to handle, but the number of them can be increased. There are two commonly used batteries, the lead storage battery and the Edison or nickel-iron alkaline storage battery, which has some advantages over the former.

**CONDUCTORS**

These are classified as good, and poor conductors. Good ones contain: acid, aluminum, brass, carbon, carbon gas, copper, german silver, gold, iridium, iron, lead, mercury, nichrome, nickel, phosphor-bronze, platinum, salt in solution, silver, steel, tin, and tungsten. Some of these are better conductors than others. For example, copper is better than tungsten, and tungsten is better than nichrome. However, nichrome is not a poor conductor.

Poor conductors include: alcohol, cotton, dry air, dry leather, dry paper, dry wood, sdomite, glass, gutta percha, kerosene,
mica, oil, paraffin, plastics, porcelain, pure water, resin, rubber, shellac, silk, and wax.

Properties that affect transmission include: coefficient of expansion, conductivity, elastic limit, modulus of elasticity, melting point, pounds per cubic inch, resistivity, specific gravity, tensile strength, and area. The industrial arts teacher will be able to apply only a few of these such as: area, length, material, and temperature. These are used in determining the resistance of a given length of wire or conductor, or the space a given length will occupy if coiled. To summarize these, the resistance of a wire varies inversely as the circular mil area, directly with the length, with the material, and with the temperature. The conductors listed above are formed into several types of wire: bare, flexible, magnetic, solid, and stranded. Solid wire is drawn into various sizes designated as gauges. These range from 4-0 (i.e., 0000) down to 48. The larger the gauge number the smaller the diameter.

Many electrical appliances use magnetic wire in coils of various sizes and shapes, e.g., chokes, generators, motors, relays, solenoids, and transformers. The wire in each of these is wound quite tightly and must therefore be insulated. Magnetic wire may be solid or stranded and must be insulated to prevent the coils from touching or shorting. The insulating material used on
magnetic wire is as follows: enamel, cotton, silk, or a combination of these. Wire is pulled through several baths of special varnish which applies a thin coat of insulation. This is called "enamel" and the finished product is called enamel wire. Cotton is a good insulator when dry; therefore, cotton thread wound closely enough to cover the surface forms a layer of insulation. One layer is called, single-cotton-covered (S.C.C.) and two layers are called, double-cotton-covered (D.C.C.). Silk is used on the smaller sizes of wire instead of cotton because it provides the same insulation in less space. There are two types of covering: single-silk-covered (S.S.C.) and double-silk-covered (D.S.C.). A combination of these provides for cotton-enamel (C.E.) and silk-enamel (S.E.) magnetic wire. The enamel has a better insulation action than cloth, but a layer of cotton or silk over the enamel provides protection against mechanical injury. Conductors vary widely in the kind and application of insulation and protective coating employed. No one type of wire could meet all the requirements of modern technology. Therefore, a wide variety of insulation and sizes of wire have been developed. Some of the most common are: cords, flexible armored cable, lead-sheathed, non-metallic sheathed, rubber covered, service-entrance, and weatherproof.

The properties of electrical conductors involve coiling, skin effect, and capacity reaction. These hinder the transmission of
voltage and current, and are produced by pulsating and alternating current. **Coiling magnetic wire** to be used as a choke, solenoid, relay or transformer, will create a reaction if it carries alternating or pulsating direct current. This is called: self-inductance and mutual-inductance. **Self-inductance** is the term applied where a change in the current in a conductor induces a current in the conductor itself. This is made possible by magnetic lines of force cutting across adjacent coils of wire. Induced current is called back-electromotive-force or counter-electromotive-force because it is out of phase with the original current by 180 degrees. This creates resistance to the original current and is in addition to the physical resistance. **Mutual-inductance** is the reaction caused by magnetic lines of force cutting back and forth across the primary and secondary windings of a transformer. Voltage and current are applied in the primary winding, which produce a magnetic field and induce voltage and current in the secondary. As magnetic lines of force cut back and forth through the secondary, a current is induced which develops a magnetic field of its own around it. As this varies, it induces a voltage in the secondary by self-induction, and is out of phase with the induced voltage and current by 180 degrees. This offers resistance to the flow of electrons in addition to the physical resistance in the secondary.
Skin effect is the result of a conductor having greater current density on its surface than along its axis. This effect is produced by magnetic lines of force that build up around and within a conductor carrying alternating or pulsating current. The magnetic lines within a conductor create a greater counter-electromotive-force by self-induction at its center, than at the surface. This forces the current to flow toward the surface of the conductor. Counter-electromotive-force or self-inductance requires no energy to overcome it, but energy is necessary to overcome the increase in resistance due to skin effect.

There are three types of voltage distributing systems: two wire, three wire, and four wire systems. A two wire system is very common for all direct or alternating circuits. Two conductors are needed for a complete path or circuit. One conductor carries the current from the source to the load, and the current returns through the other to the source if there are no leaks, shorts, or grounds.

A three-wire system was developed by Edison and is still called the "Edison" system. Two generators were connected in series which added the voltage of one to the other, and developed a greater voltage output. A power company can save approximately 25 percent of all its wire and insulators in a transmission system of this type and achieve the same result. This has an advantage of two voltages for the operation of electrical equipment. A 120 volt
supply is obtained from one hot wire. A 240 volt supply is obtained across two hot wires. The greatest advantage of the three wire and three phase system is that three separate power circuits may be served at once, while six wires would be needed in a two-wire system. A popular and frequently employed system used to service the home is a three-phase four-wire system. This has one neutral and three hot wires. There are three possible ways to obtain 220 volts and three possible ways of obtaining 127 volts from this system.

Wiring calculations are made by an electrical engineer or technician. Some cities allow home owners to make additions to the electrical system of their homes. A farmer may need another circuit in order to supply power for his lights, motor, or other appliances. The individual making these additions must know how to figure the following calculations: the size of wire to be used (the current in any wire must not exceed the amount of safe carrying capacity), and the voltage drop must be determined. For example, if lights are operated on a system with a variation of more than 5 percent in the voltage, the illumination will vary. The voltage drop should not exceed 2 or 3 percent.

Branch conductors carry current from the main or feeder lines to the loads. These are made from number 14 wires with a current carrying capacity of 15 amperes, or number 12 wire with a current carrying capacity of 20 amperes. The former should
not be more than 29 feet long or have over 12 outlets. The latter may be as long as 45 feet. Conductors are classified as to their carrying capacity. However, the size of the wire and the current carried do not determine the classification. This is figured by the maximum rating permitted by the protective device, such as a fuse or automatic circuit breaker.

The term **feeder** is used to identify those conductors which connect the **service entrance switch** to the branch conductor. These are large enough to supply all the branch wires with maximum current. All service entrance wires should be of ample size, at least number 6 gauge, so they will not handicap the system by the amount of electric current available. These wires connect the transformer with the watt-hour meter and the service entrance switch. Either two or three-wire systems are used in single-phase, and either three or four-wire systems are used in three-phase.

The **conductivity** and **resistance** of conductors and the resistance of insulation are determined by several testing devices. A Wheatstone bridge is probably the best testing device. There are several types in use. It can measure very small resistance, and the most common range is from one to 100,000 ohms. A voltmeter-ammeter method for measuring the resistance of a conductor is very common. Galvanometers and ammeters are used in many instances to measure the resistance of materials used for insulation.
An instrument to test insulation is called a "Megger." This consists of a hand-driven direct-current generator and a direct-reading ohmmeter. The ohmmeter reads directly in megohms (1 megohm equals 1 million ohms). This gives the instrument its name. Generators rated at 500, 1000, or 2000 volts are used in the instrument. A "Megohmer" is another instrument used in testing high resistance. It consists of a six-volt storage battery, instead of the direct-current generator in the megger, and a uni-directional test potential of 500 to 600 volts produces a steady potential difference.

These two instruments are used chiefly in testing the resistance of insulation used in dynamo-electric machines, power and communication lines, signaling and train control equipment, high-tension insulation, wiring in buildings and in moving craft.

MEASUREMENT

The measurement of electricity has challenged man for centuries. Probably the first instrument used to indicate electrical action in a circuit was the compass, and later the galvanometer which is the foundation of all instruments. The three elements to be measured are: current strength, resistance, and voltage. There are occasions to measure the inductance of a coil, and the capacity of a condenser.
Measuring instruments are classified as: electrical, electronic, and non-electrical. **Electrical** test instruments are galvanometers of various types, ammeters, and voltmeters. They obtain their power from the circuit or the source of power under test and measure direct or alternating potentials and currents. **Electronic** test instruments are of various types. The most common is the vacuum tube voltmeter used to test or measure current, voltage, resistance, and other things. These instruments operate from the 110 volt supply line, and generate a great deal of their own power with vacuum tubes. They are sensitive, take a very small current from the circuit under test, and cause a very low voltage drop. **Non-electrical** test instruments do not require any current, such as the hydrometer used to test the specific gravity of a storage cell or battery.

Edison's electrical system made it necessary to develop some commercial and legal way to measure or control electricity. The standards of: amperage, ohm, and volt were soon developed. These were standardized by an act of Congress on July 12, 1894. This act defined units of current, electromotive force, resistance, and established their units in centimeter-gram-seconds. Ampere or current was defined as the amount of current which passed through a standard solution of silver nitrate, and deposited silver at a rate of 0.001118 grams per second. A more practical definition is that "one ampere will flow in a circuit when a voltage of one
volt is applied across a circuit of one ohm. "Resistance or ohm was defined as the resistance at zero degree Centigrade temperature of a column of mercury 106.3 centimeters long and weighing 14.4521 grams. A more practical definition is that "a circuit with a pressure of one volt and a current of one ampere will have a resistance of one ohm."

A volt or "electromotive force" was defined as the 1/1.0183 part of the potential difference at zero degree Centigrade of the Weston Standard Cell. A more practical definition is that "a circuit of one ohm and a current of one ampere will have a pressure of one volt."

The measurable effects of electricity include: heat, light, mechanical or motion, chemical, electromagnetic, and electrostatic. Heating is produced when electric current flows through a wire which provides resistance. Due to this effect, the wire becomes longer. Expansion is used to measure the current. There are two instruments which use this effect, and they are hot wire and thermocouple instruments.

Several instruments employ a lighting effect, e.g. neon lamps to indicate voltage. A pocket tester is commonly used by linemen and trouble shooters. It is used in an electric sewing machine to indicate the voltage of the power supply. It is also used in tube testing instruments to indicate shorts. A motion effect is also used. It is produced by the attraction and
repulsion of magnetic fields about coils carrying current. A chemical effect is employed to determine the exact amount of current in a circuit. This is accomplished by the use of current through an electrolyte of silver nitrate and water, and for each ampere of current flowing between the cathode and anode, 0.001118 grams of silver will be deposited on the anode. The anode is weighed before placing it in the silver nitrate solution, and weighed again upon its removal. This principle is also used in copper and silver voltmeters.

Electromagnetic and dynamic instruments employ coils of wire which carry current from the supply line. This causes a magnetic field to form about the coils which replaces the permanent magnet. The attraction and repulsion of the magnetic fields of moving and stationary coils provides the means to indicate the voltage, current, and watts of a circuit. When two bodies are charged electrically, there is always a small mechanical force acting on them called electrostatics. This force or effect tends to force the two bodies apart if the charges are alike, and to pull them together, if the charges are unlike. Electrostatic attraction and repulsion are similar to magnetic attraction and repulsion. The effect is very small, however, in comparison to the magnetic effect. When a very high voltage is applied between two plates of an electrostatic instrument, the force or effect is great enough to be measured.
The two most commonly used effects for measurement of electricity are heat and magnetic qualities. The instruments involved are classified as: permanent magnet, electrodynamic, and electrostatic. For direct voltage and current measurement, the permanent magnet D'Arsenval (pronounced dar-son-val) movement is practically the only type used because it is extremely sensitive. D'Arsenval used a moving coil instead of the moving magnet or compass needle, and a fixed permanent magnet instead of a fixed coil.

A meter scale can be extended to any desired value of current by the use of shunts, thus, thousands of amperes may be determined by an apparently delicate mechanism. The same permanent magnet movement used to measure values of current can be used to measure voltage by adding resistors in series with the moving coil of the meter to increase the total resistance to the pressure of the voltage measured. Several resistors may be used in the instrument and connected to the meter with a selector switch, thus making a multiple range meter. The total resistance of the resistor and moving coil must be such that the maximum potential difference of current flow will cause deflection.

An instrument should be dampened for test purposes but not overly so, because the pointer of an overly dampened instrument will be slow to reach its position. The needle of a properly dampened instrument will swing quickly to the point and come to
rest with only two or three over swings. A properly damped instrument provides for fast reading and the short oscillations indicate there is no friction present. Permanent magnet instruments give full scale readings with coil currents from 5 to 20 milliamperes. When measuring currents higher than 20 milliamperes, additional parts called auxiliaries must be added.

The sensitivity of voltmeters is expressed by ohms-per-volt. This is the voltage drop across the moving coil which is necessary to bring about deflection. The current required should be as low as possible because it is drawn from the circuit under test and creates a voltage drop which causes a lower voltage reading than actually exists. The number of ohms-per-volt indicates the amount of current drawn from the circuit by the instrument. A small amount of current will be drawn under test if the ratio of ohms-per-volt is high. This will cause a small voltage drop in the circuit, and result in a more accurate reading. A 20,000 ohms-per-volt sensitivity will produce a more accurate reading than a 1000 ohms-per-volt rated meter.

A rectifier is another auxiliary that may be added to a moving coil instrument. It makes possible the measurement of alternating potentials and currents. The application of the alternating potentials to a rectifier circuit develops a direct current output to the instrument. Rectifier current-measuring instruments are available with full-scale readings as low as
100 microamperes. Voltmeter readings vary from one to 1,000 or more volts.

The resistance of rectifier instruments is affected considerably by changes in temperature. There is a 5 percent change in resistance with either a drop or rise of 10 to 15 degrees in temperature. This is especially true when an instrument has been calibrated for reading at room temperature. Rectifier meters are affected by the frequency of alternating potentials and current. This is due to the capacity of the conductor used on the rectifying disc and its oxide coating. This characteristic tends to provide more current around a direct-current movement with an increase in frequency. Errors are negligible for work up to 10,000 cycles, after which there is a steady drop. A thermocouple is another auxiliary that may be added to a moving coil, permanent magnet instrument. It supplies a direct current. The addition of the thermocouple makes an alternating current measuring instrument. This is very fine for measuring high frequency potentials and currents.

Electrodynamometers are low frequency instruments that employ two or more sets of coils. One is composed of two stationary coils and the other of a movable coil. The attraction and repulsion of the magnetic fields about these coils results in their relative motion. The stationary coils are large enough to allow the movable coil to be mounted in their center. The three coils are connected
through the spiral springs. When the current is reversed, the turning or torque developed remains clockwise and can therefore be used to measure low frequencies by direct as well as alternating current. The scale on this instrument is not divided uniformly as on the permanent magnet type. The torque produced on the moving coil varies as the square of the current. The spaces on the scale are closely compressed at the start and difficult to read, but on the finish are large and easily read. This scale is often referred to as the square law scale and the instrument is called the dynamometer.

Electrodynamometric instruments are damped by attaching an air vane to the moving coil. This vane is enclosed in a damping box which damps out the oscillations of the needle attached to the moving coil. Electrical damping is the most satisfactory. These principles are employed in ammeters, voltmeters, and wattmeters.

Moving Iron Vane Instruments are very good for measuring currents and potentials. They employ one of two methods: Attraction, and repulsion of magnetic fields. The attraction method is called a plunger vane meter and is also referred to as a suction coil meter. This consists of a solenoid that carries current. A magnetic field develops when current flows that draws a soft iron plunger or core into the solenoid. This plunger is attached to a pointer. The stronger the current, the further the plunger will
be drawn into the solenoid, which draws the pointer farther across
the scale. The plunger and pointer return to zero by either
gravity or springs. The meter will operate on either direct or
alternating current. If it is used as an ammeter, the solenoid
is wound with a few turns of large gauge wire, but if it is used as
a voltmeter, the solenoid is wound with many turns of small size
wire.

A repulsion type meter employs the repelling force of two
electromagnets and is classed as concentric, or as a radial vane
meter. A concentric instrument is composed of a coil of wire and
two cylindrically bent soft iron vanes. One is fixed to the in-
side wall of the coil and is wedge shaped. The other is mounted
on a shaft to which the indicating pointer is attached. The
stationary vane becomes magnetised when current flows through the
coil. The moving vane becomes magnetised with the same polarity,
so the vanes repel each other, causing the pointer to indicate
the number of amperes or volts. The rotation is opposed by a
spiral spring which brings the pointer back to zero. If the in-
strument is used as an ammeter, the coil is made of a few turns of
large size wire, but if it is used as a voltmeter, it is made with
many turns of fine wire. It can be used on both direct and al-
ternating current, but operates better on direct current because
the short vanes have smaller reversals or errors caused by residual
magnetism.
The radial type of instrument works on the same principle as the concentric type. The difference is in the shape of the iron vanes. These are flat and mounted inside the coil. They are magnetized by a magnetic field, so their polarity will be the same and result in repulsion. The movable vane will move away from the fixed one. The rotation will indicate the current or voltage. Rotation is opposed by a spiral spring and this deflection is approximately equal to the square of the current, so a square law scale is used. This instrument is used either for alternating or direct voltage or current.

Inclined coil instruments are very common. They have a coil mounted at an angle to the shaft. This coil is mounted to the case and does not move. The shaft to which the indicating needle is mounted passes through this inclined coil. Two soft iron vanes are mounted obliquely on the shaft. When the needle is zero, the vanes lie in the plane of the field coil. When current flows through the stationary coil, a field of magnetic lines builds up about its center, and the soft iron vanes line them up regardless of their direction. This instrument can be used to measure either direct or alternating potentials and currents.

An induction instrument employs the same principle of operation as that used in a split-phase motor. It consists of an aluminum disc, a laminated core, two windings called primary and secondary, and an indicating device. The primary winding is
attached to the circuit tested. A magnetic field builds up in the laminated core and induces a current in the secondary by transformer action that flows through the aluminum disc and back to the other side of the winding. The current in the secondary winding also creates a magnetic field in the laminated core and through the disc. The two magnetic fields, one on the primary and the other on the secondary, pulsate 90 degrees out of phase and cause a rotating field. This instrument is used for measuring alternating current only. It is quite accurate for frequencies with wide limits and has a long scale which extends nearly 360 degrees, providing very accurate measurement.

Transformer instruments are designed to measure large alternating currents and potentials. They are equipped with a transformer that extends the range in the same manner as the shunt does for the direct current type of meter. The primary winding contains one or more turns of large size wire and is connected in the circuit so the total load flows through it. The secondary winding contains a large number of small gauge wires and is connected across an ammeter, usually of 5 amperes of current, for full scale deflection. This type of instrument can measure currents up to 1000 amperes in the primary and 5 amperes in the secondary.

Frequency instruments. These are used for high frequency measurements such as 100,000 cycles per second or higher. The high reaction of the coils at frequencies higher than 25, 50, or 60
permits a very small current to flow, hence making them useless. There are two instruments that are suitable for making high frequency, alternating current measurements: hot wire, and thermocouple types.

A ballistic galvanometer concerns the measurement of induction and capacity accomplished by checking the currents, such as those produced by induction, in a coil and condenser discharge with a D'Arsonval or ballistic galvanometer. It is constructed like all other galvanometers with the exception of a heavier moving element with a wider coil to give it a longer period of swing.

Electrical instruments are extremely valuable to the electrician, the industrial arts teacher, and the layman. They provide a means to determine the electrical pressure and current in a circuit. However, electronic measuring instruments have become popular and useful since 1906. Electronic instruments are those that employ vacuum tubes of various types and sizes. These are connected to a 110 volt alternating supply source. The vacuum tubes serve as amplifiers, and the rectifiers, of alternating to direct current. The amplifiers receive a very small current from the circuit under test and amplify it to cause a reading on a meter, or a visual curve on a cathode ray tube. These may also generate a signal and amplify it large enough to be measured. There are several types of electronic instruments, the vacuum
tube voltmeter, the cathode ray oscilloscope, the signal generator and the tube tester. They are seldom used in electricity, but very extensively in electronics.

Vacuum tube voltmeters employ the characteristics of a vacuum tube to measure voltage with a minimum effect on the circuit. An instrument with 20,000 ohms-per-volt is more sensitive than one with 1,000 ohms-per-volt. An electrical voltmeter is not sensitive enough to measure voltage and current of high frequency circuits, so an instrument of much higher sensitivity is required. This is made possible by the high sensitivity obtained from incorporating a high input resistance for both alternating and direct potentials. These instruments can measure power frequencies of 25, 50, and 60 cycles up to many megacycles of radio frequencies.

There are many different designs of electronic or vacuum tube voltmeters, and it is almost impossible to mention all of them. However, those in most common use include: grid rectifier, slide-back, bridge, diode rectifier, bridge amplifier, contact potential, and cathode follower.

A cathode ray oscilloscope or oscillograph is an important instrument in electrical investigations of all sorts. It is a curve indicating voltmeter and uses very little energy from the circuit under test. It is fast in operation and has proved to be extremely useful in designing and servicing electronic circuits. It makes use of a special tube about 17 inches long, and the
diameter varies from one up to 20 inches or more. The most popular size for electronic servicing are two, three, and five inch sizes. It includes: two high gain amplifiers, an oscillator of adjustable frequencies, a synchronizing circuit, and a voltage supply.

**Signal generators** are electronic instruments employing vacuum tubes capable of furnishing radio-frequency, audio-frequency, marker generator, video signals, and square waves.

**Hook-on instruments** are hooked over a wire in a circuit where the voltage or current is to be checked. There are no mechanical connections, i.e., no wires connected to the instrument. It can be held with a handle, and hooked over the wire with the same hand. The instrument is designed with multirange scales for wide application, being selected by a switch at the base of the instrument and at the top of the handle. In some instruments of this type, pushing the selector switch to the left gives full scale ranges of 15, 60, 150, or 600 amperes, and pushing the switch to the right gives 150 or 600 volts.

**Resistance** is the opposition offered to the movement of electrons in a circuit composed of electrical components. An electron has a mass of $\frac{1}{1845}$ of a hydrogen atom, or $9.03 \times 10^{-23}$ grams. This mass or weight requires a certain amount of space to move in a conductor. If a conductor lacks this space, it is a poor
conductor or has high resistance. Every circuit, whether direct or alternating, will have resistance due to the nature of the material.

The freedom of movement of electrons within conductors or within a potential source determines the amount or rate of movement. If the electrons are securely attached to the nucleus, a tremendous electrical pressure is necessary to cause them to move along the conductor, in which case it is a poor conductor. However, if a small amount of potential difference in pressure is required to move the electrons from the nucleus, it is a good one. The energy used to overcome the resistance in a circuit causes a voltage drop that results in heat. This must not be too great for effective operation. The resistance of a conductor depends on: the material of the conductor, its length, its cross section or area, and its temperature. The resistance of a conductor is directly proportional to its length and inversely proportional to its cross section. The resistance of a metal conductor rises with increases in temperature, and the resistance of carbon and electrolytes decreases with increases in temperature. The resistance of a circuit is a controlling factor over voltage and current. It took many years to work out the relationship, and it was accomplished in 1826 by Georg Simon Ohm. Resistance in a circuit was called Ohm in honor of the discoverer. The relationship between volts, amperes, and ohms was the basis for
measuring resistance as follows: the current flowing in a conductor is directly proportional to the electromotive force and is inversely proportional to the resistance. This can be stated as follows: the current in a circuit in amperes is equal to the voltage impressed on the circuit in volts, divided by the resistance of the circuit in ohms. The algebraic formula is as follows:

\[ I = \frac{E}{R} \quad \text{or} \quad \text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \]

\[ \text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \]

If any two of the three elements are known, the third can be determined. For example, if current and ohms are known, the voltage or pressure in a circuit equals the current in amperes multiplied by the resistance in ohms between the two points, or \[ E = IR \]

\[ \text{Voltage} = \text{Current} \times \text{Resistance} \]

or \[ E = \text{Volts} = \text{Amperes} \times \text{Ohms} \]

Resistance can also be determined if the current and voltage are known, and is expressed in the following manner: resistance in ohms of a circuit equals the voltage impressed on the circuit divided by the current in amperes, or \[ R = \frac{E}{I} \]

or \[ \text{Resistance} = \frac{\text{Voltage}}{\text{Current}} \]

\[ \text{Ohms} = \frac{\text{Volts}}{\text{Amperes}} \]

Ohm's law is the basis for all electrical calculations for direct current, but does not apply to alternating current. The characteristic in an alternating circuit is impedance, a combination of resistance and inductance, or resistance and capacitance, or a combination of all three. The law can be applied
when impedance is known. Impedance is symbolized by the letter "Z", and is substituted for "R" in the formula. For example, \[ I = \frac{E}{Z}, \quad Z = \frac{E}{I}, \quad Z = IL. \] This law can be applied to the entire circuit or to portions of it. When the circuit is carrying direct current, the voltage in volts equals the current in amperes in the circuit multiplied by the resistance in ohms. When applied to a part of a circuit, the voltage drop in volts is equal to the current in amperes in the part multiplied by the resistance in ohms of the part. This basic law is important. An easy method to master it is illustrated in the following diagram:

This is interpreted as follows: To determine \( E \) (voltage) place the finger over \( E \), this leaves \( I \times R \); to determine \( R \) (ohms) place the finger over \( R \) which will leave \( \frac{E}{I} \); \( I \) can be determined in the same manner.

Resistance measuring devices include: Wheatstone bridge, slide wire bridge, voltmeter, ammeter, and voltmeter-ammeter combination, ohmmeter, vacuum tube voltmeter, and oscilloscope or
oscillograph. Resistance measurement in the industrial arts laboratory is made easier and faster with devices such as voltmeters, ammeters, ohmmeters, and vacuum tube voltmeters.

CIRCUITS

A circuit is a continuous path over which an electric current flows. This path is composed of component parts as appliances connected together with wire of varying degrees of resistance. A circuit may have the following faults: closed, shorted, grounded, or open. A closed circuit has no means of stopping the flow of current. This happens when the switch becomes locked or shorted. When some other and usually shorter path is forced or taken by the current, other than the normal path properly provided, the circuit is said to be shorted. For example, high tension transmission lines mounted on poles may touch and short. When a line in a circuit which should be insulated from the earth or frame of a machine touches the earth or frame, it is said to be grounded. When a conductor, wire, or appliance breaks or burns in two or burns out, the fault is called an open circuit. This is not complete unless it has a source of potential difference applied across it. This force causes electron flow within the conductors and component parts. The control of electron flow within a circuit may involve several methods. However, calculations for complex circuits may be solved by Kirchoff's law. It is deducted
from Ohm's law and the first law is concerned with current, namely, there is as much current flowing away from any point in a circuit as toward it. His second law is concerned with the electromotive force around a closed circuit, and is as follows: around any closed circuit, the sum of the voltage drops is equal to the sum of the applied voltage. This can be stated: the voltage drop must equal the voltage rise.

There are several ways of joining electrical components to form circuits: series, parallel, combination, capacitive, and inductive. When electrical devices or appliances are connected end-to-end or in tandem to form a single continuous path for the flow of electrons, they are said to form a series circuit. This circuit is often referred to as a constant current circuit. The total voltage applied to a series circuit is equal to the sum across the several parts of the circuit. Such an arrangement is used to control the voltage within a circuit. In general, the voltage required to cause current in a direct circuit is proportional to the resistance, i.e., the higher the resistance, the higher the voltage.

The coils on the armature of a direct or alternating voltage generator are in series. This causes the voltage generated in each coil to be added to the adjacent coil. The resistance of a series circuit is the sum of all the individual resistances of
a continuous path. This applies to alternating or direct current circuits. However, if the series circuit has an inductance or capacitance, or both, the reactance is added to the resistance of the circuit. Advantages of the series circuit are: control of voltage, current of a definite value, voltage balanced to the resistance of the circuit load.

A parallel circuit is composed of two parallel wires carrying the voltage and current from the supply source to the circuit load. When wet or dry cells are connected in parallel, the positive terminals are first connected and then the negative terminals. The voltage remains the same as a single cell. The total current becomes the sum of the currents of all the cells. Generators can also be connected in parallel, positive to positive and negative to negative, in order to increase the output. The coils on the armature of a low voltage generator are connected in parallel in order to get a higher current, for example, in automobile and electroplating generators.

Resistance in parallel circuits is smaller than the smallest resistor in the group. When two appliances are connected in parallel with a 110 volt source, the total resistance is less than the resistance of either branch. For example, one ampere of current will flow when a 110 ohm lamp is connected across a 110 volt supply. If a second lamp of the same resistance is connected in parallel to the first, it will also draw one ampere. The current
supplied by the source is two amperes, but the total resistance is
\[ R = \frac{E}{I} = \frac{110}{2} = 55 \text{ ohms}. \]
This reduction in resistance makes it possible for the source to supply the second amperes.

The advantages offered by parallel circuits are: resistance can be controlled for a limited electromotive force, the total resistance of a group of resistors can be reduced to a fraction of an ohm, the voltage of cells can be controlled when the resistance of the external circuit is lower than the internal resistance of the cells, a path is provided for the current when the amount to be used is greater than that which can be passed through a single cell.

Combination circuits are made by connecting series and parallel circuits together. This is often referred to as series-parallel or parallel-series circuit. The term network or compound is often used in describing this type of circuit, and is used especially in radio and communications circuits. Calculations for this type of circuit are determined by the application of Ohm's law, and the rules for series and parallel circuits. There is no clear procedure to follow in solving this complex circuit, but there are two simple rules that can be applied: reduce the parallel branches to an equivalent series resistance, and then solve as a series circuit. If the circuit includes inductance or capacitance or both, their reactance must be determined in resistance before
the above rules can be applied. The advantage of this circuit makes it possible to add and subtract a small part of the value of component parts in order to increase or decrease their total value which improves the efficiency of the circuit.

Capacitive circuits are composed of one or more capacitors or condensers connected in series, parallel, or combination. A capacitor is an electrical device which stores electrons or takes a charge of electricity to be held until discharged by a short-circuit or by a discharge through it. The amount of energy that can be stored in a capacitor is directly proportional to the area of the plates and inversely proportional to their separation. Capacitors are used extensively in motors, generators, automobile ignition systems, and telephones. They are also used extensively in electronic circuits such as radio, television, radar, transmission, and fluorescent lighting. The advantages of a capacitive circuit are: hum can be removed or reduced, ripple of current can be rectified or reduced, current can be held at a constant rate, voltage can be increased in a circuit, for example, the voltage in the primary circuit of an automobile ignition system may reach 250 volts. This will cause magnetic fields to collapse faster and result in higher induced voltage. Inductance can be reduced in a circuit or balanced by capacitance which reduces or neutralizes the voltage lag. Resonance or tuned circuits are made
by paralleling inductance and capacitance.

An **inductive** circuit is one that causes the generation of an electromotive force in itself, or in an adjacent circuit. This is created by direct pulsation or by an alternating current across a coil of wire wound on an air or iron core. Motors, generators, transformers, chokes, relays, and ignition coils are examples of inductive circuits. Inductance can be connected in parallel in order to reduce the total reactance. When so connected the number of electrical paths are increased so this increases the conductivity of the circuit. Inductance in a circuit creates opposition to current change but aids voltage change. When the current drops, it tends to maintain the current's original level. This behavior results in inductive reactance which occurs in direct current circuits when the current is pulsating or the circuit is made and broken by an automatic switch. However, it is greater in an alternating-current circuit which has a definite frequency. The advantages of inductive circuits are that: current ripple is reduced, inductance serves as resistance to the voltage source in series or parallel, current load can be reduced or neutralized, and rectifier circuits can be improved and voltage increased.

**Magnetic** circuits concern magnetic lines of force or magnetic flux which always establishes closed loops about the substance they occupy. The magnetic circuit about a bar magnet consists of
the path through the magnet and the surrounding space. Magnetic circuits can be arranged in series, and the number of magnetic lines through all sections is the same. The flux density of the various parts may be different. The "reluctance" of a series circuit is the sum of the reluctances of the various parts. The magnetomotive force in a series magnetic circuit is the sum of the pressures required to establish the flux in each of the parts. Magnetic circuits in practice, are often in parallel. Multipolar and bipolar dynamos are examples of machines with parallel magnetic circuits. The laws for parallel electrical circuits apply also to magnetic circuits, for example, the magnetomotive force which forces the flux through one path forces it through all other parallel paths. Chokes, transformers, bipolar and multipolar coils are mounted on iron or steel cores. The coils are energised with current, and establish flux about the coil and core which is the magnetic circuit. The flux increases and decreases with the increase and decrease of current. However, when the current decreases the flux or magnetism decreases much slower. This is due to the resistance of the molecules of the material in changing position which causes the magnetic flux to lag behind the magnetising force. This lag is called hysteresis. In pulsating direct and alternating current machines, the magnetising force and flux are constantly changing, which results in the conversion of some power to heat. There is always hysteresis or
loss in an iron or steel core with each cycle of electric current. The greater the number of alternations per second the greater the hysteresis. For this reason, the iron used in alternating current machines such as armatures, field coils, transformers, etc., must be selected with great care. Annealed steel has less loss than steel. Advantages of a magnetic circuit include: transfer of electrical power from one circuit to another without direct contact, step-up or step-down in alternating voltage, long transmission lines, generation of direct and alternating current, production of motion, electrical and electronic measuring instruments, amplification of sound, holding and loading machines such as magnetic clutches, chucks, and brakes, magnetic separation pulleys used to separate steel and iron particles from sand and pulverized materials.

Three phase circuits are combinations of three, single phase circuits. Instead of using one single winding on the armature of a generator or alternator, three windings are equally spaced by 120 degrees. Each is referred to as a phase. Power can be taken from each by connecting separate leads to each end of the windings. This would mean two line wires to each coil or a total of six wires in all. The coils are usually connected by two methods which require only three or four wires to transmit the power. A delta or mesh connection is one method of joining the coils of a three phase armature. The term mesh is seldom used in this country.
The three phases are joined so they form either the Greek letter delta or a wye.

The power, supplied to the line by either delta or wye wound generators is the same. Loads such as motor and transformer windings, lights, and other appliances may be connected in either delta or wye circuits. The same current, voltage, and power relations are used for delta and wye loads as for three phase generators.

CONDENSERS

A condenser is a device composed of two conductors separated by an insulating material called a dielectric such as air, glass, mica, oil, paper, or wax. The two conductors may be any kind of metal. However, the most commonly used are aluminum and lead sheets insulated from each other by waxed or paraffined paper. The metal may be cut in long narrow strips or sheets of various sizes. The strips are rolled into tubular shapes. The condenser is also known as a capacitor because it has the capacity to store energy or electrons. The function of a capacitor is to: store electrons, block the flow of direct current while allowing alternating and pulsating current to flow, smooth out ripple in current, filter out undesirable frequencies in electronic circuits, couple two electronic circuits, prevent arcing of contact points such as breaker points in an automobile ignition system, reduce or remove
static electricity such as the sparking or arcing of generator brushes, produce frequencies of all sizes due to its ability to charge and discharge, and cause magnetic lines of force to collapse faster than normal. These functions have created many sizes and types of capacitance.

The amount of charge that a condenser receives from each volt is referred to as the capacitance of the condenser. The unit of capacitance is the farad, and is represented by the symbol "C". This unit was chosen in honor of Michael Faraday. A condenser has a capacitance of one farad when applied voltage of one volt causes it to take a charge of one coulomb. The unit, micro-farad or μF (one millionth of a farad or $10^{-6}$ farads) and micro-micro-farad or μμF (one millionth of a micro farad or $10^{-12}$ farads) are used in electrical and electronic circuits because the farad is too large for practical use.

Capacitance depends upon the: area of the plates, kind of material used in the dielectric, and the thickness of the dielectric. The dielectric has a great effect on the capacitance of a condenser. For example, when glass is substituted for air as a dielectric, the capacitance is increased approximately eight times. Capacitors using mica, paraffin, transformer oil, paper, and various other materials for dielectrics have a higher capacitance than do those which employ air.

Condensers are either variable or fixed. Variable condensers
are classified as broadcast, transmitter, and adjustable called padders or trimmers. Broadcast or receiver condensers are constructed with two sets of plates. One is movable, called the rotor which operates freely between the second set called the stator. The movement of the rotor causes capacitance to vary. The dielectric is air which has an assigned dielectric constant of one. The plates are made of aluminum, brass, or copper. The variable condenser is used in parallel with an induction coil. The capacity of broadcast capacitors ranges from 250 to 500 microfarads. Maximum value is obtained when the rotor plates are meshed with the stator. For short wave reception, the capacitance is about 150 micro-micro-farads. For high and ultra high frequencies, the capacitance value ranges from 25 to 150 micro-micro-farads.

Transmitter variable condensers are constructed in the same manner as the broadcast receiver type with one exception. The transmitter type is usually constructed with a larger air gap because the voltage between them is considerably higher.

Adjustable condensers consist of two or more metal plates separated by air or mica. The capacity is varied by adjusting the position or distance between the plates with a screw. The plates are made of aluminum or spring steel. They are used to create a better balanced circuit by connecting them in parallel with the large variable. This increases the total plate area and the capacitance. Also, they may be used to tune a circuit to a
definite frequency such as the intermediate frequency transformer which may have an adjustable condenser across one or both windings in order to tune to a given frequency such as 455 or 456 kilocycles.

Fixed capacitors have their capacitance built in, and are not changeable except by connecting in series, parallel, or combination. The dielectrics used in fixed condensers are: paper, mica, electrolyte, and oil. The paper condenser consists of long strips of metal foil separated by waxed paper, and rolled together to form a compact unit. Mica condensers are composed of metal foil and thin sheets of mica stacked in alternate layers and inclosed in a bakelite moisture proof case. The dielectric is mica and the conductors are aluminum foil plates. This condenser is used extensively in electronic circuits, such as in a radio frequency by-pass, in couplers, and in filters. Their capacities range .00005 to .02 micro-farads. The capacity is determined by the BMA color code.

Electrolytic condensers are composed of two or more metal plates separated by an electrolyte. The dielectric is a thin layer of oxide film formed on the surface of the positive plate of the condenser. This film has the peculiar characteristics of aluminum and a few other metals. It is formed when immersed in a certain electrolyte and an electric current passes through the metal and electrolyte. The aluminum foil is the positive, and the electrolyte the negative plate. The capacity of the electrolytic
condenser usually ranges from one to 1000 micro-farads, and it has self-healing qualities. There are two types of electrolytic condensers: wet, and dry. **Oil condensers** are similar to the paper type with the exception of the dielectric. Oil or oil impregnated paper is used for the dielectric. The reason for this is the voltage which is usually 600 or higher. Under such conditions, a paper condenser would not last very long. This type is used in transmitter circuits.

Condensers are connected in three ways: series, parallel, and combination. When in series, the plate area is reduced, which reduces the capacity to a value smaller than the smallest capacitance in the series. When in parallel, the plate area increases the storage space. This increases the capacitance to the sum of the values of the condensers in the group.

Condensers may be connected in series-parallel or parallel-series. There is no specific rule to use in calculating the capacitance. The simplest procedure is to solve those parts of the circuit that are in parallel, and those that are in series. Then solve as a series or parallel circuit. The result will be an increase or decrease of capacitance. This type of arrangement provides a method for obtaining capacitance which the series or parallel method cannot provide.
INDUCTANCE

Inductance is a very important function. It is measured in "henrys." A circuit has an induction of one henry if a current change of one ampere per second causes an induced voltage of one volt. The henry is too large for practical use so a millihenry and microhenry are commonly used. No modern electrical appliances could exist without inductance. Batteries would still be used for lighting. It has made possible the low cost and universal use of electric power and light. Induction is the process by which an electro-motive force is produced in a circuit by varying the magnetic field, and is called electromagnetic induction. A magnetizable body becomes activated when in a magnetic field or in the flux set up by a magnetomotive force, and is called magnetic induction. An electrical conductor becomes electrified when near a charged body which is called electrostatic induction.

A straight wire carrying a direct or alternating current has an electromagnetic field or lines of force around it. This electromagnetic field will be in direct proportion to the current in the wire, and will fluctuate with it. If another straight wire were close to it, a current would be induced in it which would flow in the opposite direction to the inducing current. A magnetic flux is produced around the wire in the opposite direction to the original one. This field opposes the original and when the
opposition is balanced, the induced current is stopped. A law in relation to these two forces is as follows: an induced current is always in such a direction that its field opposes any change in the existing field.

**Induction coil** is the term used for the form on which a conductor is coiled to concentrate the electromagnetic field produced by the flow of current. This coil was used originally to prevent fluctuation. It was the forerunner of the induction transformer. The induction coil is a device with some form of interrupter for changing direct current to high alternating current-voltage. It consists of two windings: primary and secondary. The winding that receives the energy from the power source is the primary winding, and is made of a few turns of fairly large wire. The number of turns and size of wire depend on the current and voltage to be carried. The primary winding may be wound on three types of cores: iron, closed, and air. Iron cores are solid, powdered, and laminated. Solid cores are not satisfactory because the eddy currents and hysteresis are too great. Powdered cores are used in permeability tuning to change the induction of a coil by moving the core in or out of the coil in order to make a resonant circuit. This is used in several types of circuits such as radio, intermediate frequency, and television. The laminated core is made of a special grade of silicon steel. This is properly annealed, and
causes low hysteresis. This means a small amount of energy is required to magnetize or demagnetize the core during each alternation. Such steel will last almost indefinitely. The rapid and continual change of the magnetic flux will cause a change in ordinary iron and steel, and the hysteresis increases after a period of time coupled with reduced efficiency. When this happens, the core is said to have aged. This core is used in all types of audio and small power transformers. **Closed cores** are in the form of a rectangle. This is made of laminated strips of silicon steel. Half of the primary and half of the secondary are wound on one side of the rectangle and the other halves are wound on the other. The magnetic flux flows in a closed metal ring. Other types of cores are more efficient, for example, the shield type in which the secondary is wound on top of the primary, and both windings are on the same core. The **air core** is an open type or hollow form. The secondary winding is on one end of the form and the primary is wound on top of it. This type is used for high frequency amplification such as radio, frequency modulation and television.

**Interrupters** are electrical, electronic, or mechanical devices used to open and close an electric circuit rapidly or periodically such as: vibrators and breaker points. An interrupter is used in the primary circuit of an induction coil. This causes the current to start and stop and to develop magnetic flux variations which causes an induced alternating voltage in the secondary winding.
Self-induction is the property of a circuit that opposes any change in the amount of current in the circuit. This property is created by the rise and fall of the electromagnetic lines of force across a coil of wire. As these lines cut across adjacent coils of wire, they induce voltage and current and it tends to prevent the original current from building up to maximum. As the current reaches a maximum, the electromagnetic lines also reach a maximum. If the original current is reduced, the electromagnetic lines collapse back into the coil and produce a current in the same direction as the original.

The induced voltage is called back or counter electromotive force. The back force in a coil depends on physical characteristics such as its length, thickness, diameter, number of turns, size and thickness of form material, and the magnetic qualities of its core. When an alternating or pulsating current flows through an induction coil, the variation in the magnetic field about each turn induces a voltage and current in each adjacent turn, and the induced current flows in the opposite direction to the original. This opposition is called inductive reactance, and is expressed in ohms. Inductance reactance is indicated by the symbol $X_L$. It depends upon the frequency of the current, the number of cycles per second, and the size of the inductance.
Inductive reactance offers enough opposition to current flow, to cause it to lag behind the voltage somewhere between zero and 90 degrees. There will be some capacitance in an alternating current circuit which will prevent an exact reading of 90 degrees.

Mutual inductance is the magnetic flux linkage between two coils. When an induced current flows in the secondary or independent coil, a field of magnetic flux is created about it. This field cuts across the primary and induces a voltage in it by mutual induction which is out of phase 180 degrees. The magnetic flux about the primary winding induces a small current by self induction and the magnetic flux about the secondary winding also induces a second voltage in itself by self-induction. In order to have mutual induction, there must be a varying magnetic flux caused by interrupting the current in the primary coil. The conductors may be a set of straight wires which will not increase or decrease the voltage, but by coiling wire of various sizes, mutual induction will increase the output of the coil. The electromotive force delivered by the secondary winding will be greater than the primary winding if the secondary has a large number of turns of small gauge wire, or it may be smaller if the secondary winding has fewer turns than the primary. This type of induction coil is often called an induction transformer.
Induced voltage caused by magnetic flux depends upon the linkage of lines with a conductor. If a conductor is moved parallel to the magnetic lines of force, the linkage is zero and the induced voltage and current is also zero. If the conductor is moved perpendicular to the magnetic flux, the induced voltage and current will be maximum because the linkage is 90 degrees. In summary if a change in position or the strength of the magnetic flux that passes through or is interlinked with a circuit is made, an electromotive force will be induced in the circuit proportional to the rate at which the number of lines are altered.

Electromagnetic flux is measured in "oersteds." An oersted is the strength of the magnetic field one centimeter from the axis of a straight wire carrying a current of five amperes. If the current is increased or decreased, the electromagnetic flux will vary proportionately.

Induction applies to a number of electrical applications such as transformers for increasing or decreasing voltage and current for transmission purposes, relays for automatic operation and for quick, safe remote control, chokes for rectifying and filtering purposes, amplification of sound, transmission of sound, generators, motors, buzzers, and bells.

Electrostatic induction is found in every day life in the following ways: scuffing one's shoes on a rug causes a charge to
accumulate which can induce a charge in another body by mutual induction. Sliding on fabric or plastic with a wool suit will develop a charge that can induce a charge in another body by mutual induction. Clouds are frequently charged with static electricity, and can charge other clouds or objects by induction. Induction creates the opposite charge in the subjected body which may result in a spark or flash of lightning between the two bodies or clouds.

Rapidly revolving belts such as sander belts, or belts for power transmission create electrostatic induction. Electrical machinery creates an electrostatic charge which may render permanent damage to the insulation material by discharging through the insulation. Gasoline trucks moving through the air and the earth's magnetic flux, create a static charge. Metal chains are suspended from the tanks to the ground in order to dissipate the induced charge. Sandblasting machines create a tremendous electrostatic charge by sand moving at high speed through the hose.

Commercial uses of electrostatic induction include: articles dipped in paint are "dusted" by electrostatic induction created with a negative charge of 85,000 volts. The painted object is grounded or made positive, while the grid over which the object passes is negatively charged at 85,000 volts. Dust particles are removed from the air by circulating air over electrically charged plates. Coated abrasives are made by applying grains of abrasives
to the backing material with a powerful electrostatic field. Abrasive materials are separated by applying a powerful electrostatic charge to a conveyor belt which carries the abrasive materials over a separator. Electrostatic paint systems employ an electrical ground on objects to be sprayed, and passes them through an electrostatic field charged at about 100,000 volts. The painted particles are positively charged and are repelled by another positively charged particle, but are attracted to the negative or grounded object. This method results in a 40 to 60 percent saving of paint.

TRANSFORMERS

The transformer is one of the most important of all electrical appliances. It is similar to an induction coil with the exception of the interrupter in the primary circuit. Alternating current replaces the interrupter, and can be transmitted to a region of consumption more economically than by direct current. It has no moving parts, is simple, rugged, and durable. It requires very little attention, and has a very high degree of efficiency, even as high as 90 percent. A transformer employs the principles of induction whereby the energy from an alternating circuit is received in one electrical circuit and delivered at a higher or lower voltage to the load.
There are several principles of operation similar to the induction coil. The relationship between the electric current and the magnetic field about the wire carrying the current is the same in the primary circuit of the transformer as it is in the induction coil. The current is constantly changing in the primary circuit, and is accomplished by the frequency of the alternating current. This is obtained in the induction coil by the interrupter. Magnetic conductivity is very important, and in order to concentrate the magnetic lines of force, a metal core is used. For example, when iron replaces the air in a coil, the number of magnetic lines threading through the core may be increased as much as 2000 times. Assume that a certain current causes 300 lines about an air core, and if iron replaces the air core, the magnetic lines may be increased to 600,000. However, some grades of iron vary greatly in their conductivity. Retentivity must be very low in order for the hysteresis to be low, i.e., if the metal used for the core does not lose its magnetism quickly as the magnetic lines collapse, a large amount of energy will be consumed during the next alteration to overcome residual magnetism.

Similar materials are used in an induction transformer and coil. However, a bundle of soft iron wire may be found in inexpensive induction coils. Commercial power transformers are similar to induction coils, but much larger. There are two major
types with a large number of variations. A shell type of transformer has both electrical circuits on the center core with the outside parts making a complete metal path around the coils and creating a shield around them. The shell type is generally more suitable for low voltage and high current output. The core type of transformer has a rectangular core with space between the sides for the coils. One half of the primary and secondary is wound on one side and the other halves are wound on the other. Commercial transformers are never wound with the primary on one side and the secondary on the other. When a primary is wound in two halves, they are connected in series to the supply source, and the two halves of the secondary are also connected in series. The core type transformer is generally more suitable for high voltage and low current output.

A distributed core of the composite type is a combination of core and shield. It has one large center and four smaller cores serving as shields. A spiral type core is a continuous piece of steel approximately 10 feet long coiled into a ring. The spiral core was first used as a transformer. One electrical circuit is wound usually by hand around the core, while the other is a single conductor passing through the center of the spiral core.

The spirakore type is wrapped around the straight part of the coils which are wound first.
A hipersil core is first wrapped into a ring or rectangle then cut, forming two semicircles or "U" shaped halves. These are annealed and impregnated in order to hold the laminations together and reduce eddy currents. The ends of each core are ground smooth in order to make the air gap as small as possible. These are slipped into the coils and secured with a metal band.

Feet iron cores are made from a series of flat strips of steel shaped around a form. The ends lap. Two of these ring shaped cores are placed with their straight sides together while the coils are wound around them. When completed, the ends come back into place forming a tight joint.

A round-wound core is made up of a series of sheet steel strips which vary in width. The widest strip is used in the center with the narrowest on the outside. This arrangement gives the core a cross shape, instead of a square, cross section.

There are two main circuits in a transformer: electrical and magnetic. The electrical circuit is composed of two independent circuits: primary and secondary. The primary is composed of a large number of turns of small gauge wire which receives the energy from the supply circuit. It may be wound on the core first or on top of the secondary winding. The secondary is the electrical circuit that receives energy from the primary by mutual induction. It may increase or decrease the output voltage. The
former would be a step-up and the latter a step-down winding. Thus, when the voltage is increased, a corresponding decrease in current is obtained, and vice versa.

There are two types of windings generally used in electrical transformer circuits: concentric and interleaved. Sometimes there are several coils forming the winding that are assembled concentrically. These may be circular and tubular in form which means wound with a relatively large number of turns per layer with a small number of layers. This type is usually used for low-voltage winding. High-voltage windings, circular in form, may be built up with a number of thin disc coils assembled side by side. In general, the concentric type winding is used with core type construction. Coil winding formed by assembling individual coils side by side is called interleaved. These are referred to as pancake coils. Such coils may be rectangular or circular in shape. Interleaved windings may be used with either core or shell construction. Most all large shell type transformers employ this winding.

The magnetic circuit is the material that provides a path of low resistance or reluctance to the flow of magnetic flux produced by the currents in the electrical circuits. The material best suited for magnetic circuits is annealed silicon steel. This has
a high permeability to magnetic flux and low hysteresis. A magnetic circuit may be made in core and shell form. Three types of lamination are used for the various forms of construction. These are "E" plates, "L" plates, and "I" plates. The "E" plates are used in small shell, small voltage transformers. The "L" plates are used in distribution transformers of medium capacity of both shell and rectangular cores. And, the "I" plates are used for the large size distribution and power transformers of various sizes.

The losses in a transformer are due to iron and copper losses. Iron losses are composed of two types: hysteresis, and eddy currents. Hysteresis represents the loss of energy required to reverse the direction of the flux in a magnetic circuit. It is proportional to the weight of the iron, the frequency of the flux, and approximately, to 1.6 power of magnetic density. The changing of the flux in a magnetic circuit generates a current in the laminated core at right angles to the path of the flux. This is known as an eddy current that flows in each lamination. The total are called eddy currents. When these create heat, energy is lost. The eddy loss is proportional to the total weight of the iron, the square of the magnetic density, and the square of the frequency of the flux.

Copper loss refers to the energy lost in a winding when the transformer is under load. It is composed of: the energy required
to overcome the resistance of the winding, and small eddy currents flowing in the copper wire. The loss due to overcoming the resistance of the winding is expressed as $I^2R$. This is due to the temperature of the winding since the resistance of copper varies with temperature. Eddy current loss is due to the leakage of magnetic flux through the air. This is reduced by an increase in temperature because less current flows in the winding and less flux is developed, therefore less leakage.

Transformers are classified according to their use: instrument, street lighting, distribution, substation, transmission, and welding. Instrument transformers supply current and voltage for measuring instruments. This type has a low volt-ampere capacity. The current type is a series transformer because the primary is connected in series with the power supply. When the primary has a large current rating, it may consist of a straight conductor passing through the center of the core. This is used on switchboards to determine the current. Voltage transformers are used to step down or reduce the voltage on the secondary winding in order to make safe switchboard connections. Street-lighting transformers operate from a constant current source that supplies current to a number of high candlepower lamps connected in series. The constant current source works automatically to increase or decrease the impressed voltage on the circuit as the current tends to rise and fall.
**Distribution** transformers use power from the supply line and deliver it directly to an appliance. These range in size from one and a half to 500 kilovolt-amperes. Oil is used for insulation and cooling in the high voltage type, but the small, low voltage types are operated without oil.

**Substation** transformers are self-cooled and are smaller than distribution types. However, it is difficult to make a sharp distinction between the two. **Power transmission** transformers are located in or near a central or substation, or source of power. They are used to step-up or step-down voltage for the economical transmission of power. This type is air, water, or oil cooled.

The self-cooled is the most common. An air blast is sometimes used where an oil cooled type would provide a fire hazard. There are several methods of cooling transformers, such as: dry-type, oil-immersed, oil-immersed water cooled, oil-immersed forced-oil cooling, oil-immersed with air blast, and air blast cooling. Large transformers have three windings instead of the usual two. This type has many applications. It is used primarily to connect **synchronous condensers** to the line to correct the power factor, to supply a closed delta circuit while the other two windings are connected in a star, and to interchange power from one system to another.

The **autotransformer** or **compensator** has only one winding. Part of it is used for low voltage, and all of it is used to develop
high voltage. Any transformer in which the primary and secondary are in common, constitutes an autotransformer. It is also used to reduce the starting voltage on alternating current induction and synchronous motors. Starting transformers are connected in open star or open delta. The star connection gives better starting voltage for large machines and a better balanced voltage. The open delta connection is used for small machines and for a simpler voltage control. This type of transformer has many applications, but only three will be named: as a balancer with rotary converters for supplying direct current for three wire systems, as a preventive in bridging across successive taps in a power transformer as the voltage ratio is changed while the transformer is carrying a load, and as a balance coil in a three wire distribution system. The construction of the autotransformer requires less copper and iron which makes it less expensive than other types. However, it is more dangerous.

Many two phase generators were installed in the early days. Power was transmitted on the primary side over a two phase circuit. The secondary distribution circuit provided energy for two phase motors and single phase lighting. The development of new techniques in generating and transmission of alternating current brought about a three phase generating system, and today, practically all of the electrical power generated is by a three phase alternator. Three phase power is transmitted on the primary side, and the
secondary distribution circuit delivers energy to two and three phase motors, and to single phase lighting. Many two phase motors are still in operation, and the connection of a three phase transformer to a two phase transformer makes possible their continued operation.

A single phase transformer can be connected in approximately thirty different ways. The two most commonly used methods are: voltage and phase transformation. Voltage transformation is accomplished by: single, double and triple phase. Phase transformation is accomplished by: three to single phase, three to two phase or two to three phase, three to two and three phase, three to six phase, and two to six phase.

RELAYS

These are protective instruments for rotating machines, transformers, buses, lines, and many other electrical appliances, by automatically opening an overloaded circuit. They can also make or close circuits by remote control as for example, in the wiring systems now employed in homes and public buildings. The relay in such a circuit makes use of a low voltage on the switch, and makes possible the use of a small size wire in the switching circuits. The relay is an electromagnetic switch employing an armature to open or close contactors. A small current through the coil actuates the armature, and controls a
heavy duty circuit at the points. For example, a telegraph relay
that closes the contact points in a second circuit, has its own
source of power. A relay operates on a small current, and can be
made sensitive by use of taps on the current coil. Relays and
circuit breakers can clear a short circuit in less than one-tenth
of a second. The current coil is composed of several thousand
turns of small wire which makes possible a large number of amperes
turns with a small current.

The electrical relay was the first type to be developed, as
for example, the telegraph. This relay may be either alternating
or direct current. The alternating current type is classified
as: overcurrent, differential, current balance, distance, im-
pedance, and temperature or overpower. Two of the most common
are: overcurrent and differential. The overcurrent relay is
classified as inductive, directional, non-directional, and in-
stantaneous. The contacts of an overcurrent relay close when the
current flowing through the coil exceeds a predetermined pressure.
This type of relay is connected to a circuit through the current
transformer in order that the current in the secondary of the
transformer is made proportional to the current in the primary.
The most common is the induction type which is similar in principle
to the watt-hour meter. It has a movable disc driven by an
electromagnet. The operating coil of a relay is tapped to provide
for adjusting to various values of pickup. A range from four to sixteen amperes is commonly used on this type. It has an inverse-
time characteristic, i.e., the contact closing time is fast for high operating coil currents, and slow for low operating currents. Also, the operating time for a given current is adjustable. With these two adjustments, inductive relays may be used in selective systems.

The differential relay is similar to the inductive. It has a movable disc assembly on which is mounted a movable contact. Instead of a retaining spring, it has an additional electromagnet that, due to current flow, provides a restraining torque to hold the contact points open during operation. A differential relay controls the current entering and leaving each phase of winding on or in the apparatus being protected. The entering and leaving currents are equal or directly proportional in normal operation. If a short occurs between two windings, more current is required to energize the coils of the relay which causes the switch or circuit breaker to trip. Differential relays are used to protect transformers, buses, and rotating machines. In protecting an appliance, for example, a relay is placed in each phase of it, and on each incoming and outgoing line of the transformer. This type of relay is identified by the code number 87. A direct current type is classified as: power directional, underpower, overcurrent, and flash. Some of these can be used on alternating current, for example, the power directional relay. The function
of the direct current type is the same as the alternating.

A second group of relays is classified as high speed or electronic. The electronic relay is a combination of electrical relays and vacuum tubes. There are several types of these such as impedance and impedance-reactance. An electronic relay can be designed to operate on actuating circuits of five million ohms or megohms, and can be designed to operate on an actuating contact of only .004 of a second. Electronic relays have many applications such as: signaling, testing materials, detecting seams in cloth and broken threads in looms, testing conductivity of solutions, maintaining constant temperature, sorting small parts, and as floatless liquid-level switches.

SWITCHES

Switches are of three types: mechanical, electrical, and electronic. A mechanical switch is a device for completing, interrupting, or changing the connections in an electric circuit. There are many kinds and types of switches, some of the most common of which are: knife, push button, toggle, tumbler, rotary, push and pull, slide, wafer, and micro. The knife switch comes in the following classifications: single pole single throw, single pole double throw, multiple pole single throw, multiple pole double throw, rocker, plug, rod, and double pole double throw reversing. The push button type has the following poles: reciprocal, spring
loaded, and multiple. The **toggle** switch is classified as single pole single throw, single pole double throw, multiple pole single throw, and multiple pole double throw. In selecting any one of these switches, the amount of current the switch will carry must be considered. The **tumbler or mercury** switch is a silent arcless type which consists of a glass tube containing mercury. When the glass tube is tilted, the mercury flows to the end containing two electrodes and completes the circuit. The **plug** type switch comes in the following variations: closed circuit, open circuit, and multiple circuit jack. The **rotary** switch is constructed in the following shapes: the drum which is constructed as a single or multiple pole, the rheostat, the disc, and the cam. The **push-pull** switch is a form of jack, and has many applications. The **slide** switch is popular. The **water** switch is made as a diaphragm and as a thermostat. The **micro** switch is silent and useful. It requires a small movement to make and break the circuit and comes in the following types: pin, leaf, plunger, roller, and hinged.

**Controllers** are devices for regulating the operation of electrical appliances. They serve as a switch in many instances and perform the following functions: starting and stopping, reversing, regulating speed, and dynamic braking. There are two commonly used controllers: face plate and drum, which are capable of reversing the current in certain appliances such as motors.
Electrical switches include: magnetic and solenoid or circuit breaker types. A magnetic switch consists of an operating coil on an iron core and an armature. The air gap is usually a permanent part of the magnetic circuit and prevents the armature from sticking when the coil is de-energized. The air gap is usually made of some non-magnetic material such as brass or bronze as well as air. Magnetic line switches are used for the following reasons: a push button can be used instead of a heavy switch, the contacts carry a small current which prevents operator shock, burns, or eye injuries, considerable distance is possible between operator and appliance, controls may be arranged from several positions such as in the use of conveyors, automatic controls via a float, pressure or limiter switch instead of a push button, and low voltage as well as overload protection.

Circuit breakers are used like switches and there are three types: thermal, magnetic, and thermal magnetic tripping. In the low current ratings, automatic tripping is accomplished by a thermal device. This is composed of a bimetallic element and is calibrated in such a way that the normal flow of current does not cause deflection. However, an abnormal flow of current from an overload or short circuit causes it to heat and open the contact points by a spring action. The magnetic or solenoid tripping element is used on large current equipment for opening a circuit automatically when the current exceeds a predetermined amount.
The principle of the circuit breaker is the attraction between an electromagnet and its armature, or between a solenoid and its iron core. When the current reaches a predetermined value, the coil becomes energized to a point the armature releases a spring through trigger action, which causes the circuit to open. The most common form of overload circuit breaker is available for all classes of service such as breakers for outlet boxes, for protecting instruments and for other equipment. Circuit breakers may be made to open instantaneously or by time limiting action. Other features may be added such as a "no voltage" coil for opening the circuit when the voltage drops to a predetermined level, or a "shunt-trip" device for opening the circuit by push button at conveniently located positions, or a "reverse-current" arrangement for opening the circuit. Circuit breakers with thermal-magnetic trip combinations have an inverse time tripping characteristic for overcurrents up to about ten times the rating listed on the name plate, and an instantaneous magnetic tripping for short circuits.

Electronic switches are extremely accurate and fast. For example, to observe separate phenomena simultaneously on a cathode-ray oscilloscope screen, such as voltage and current waves in a transformer, requires a switch that can operate at a faster rate than the oscillating frequency and resolving time of the eye. In another case, an electronic switch is used in high voltage welding to space the welds between two pieces of metal that are moved
between two circular electrodes. In order for the metal to heat and cool properly, the primary circuit of the transformer is interrupted at a definite rate by an electronic switch which can space the spots approximately one-twelfth of an inch apart for a pressure tight seam on 22 gauge metal.

Switches are made from various kinds of materials. Conductors are made from four kinds of materials: brass, copper, silver, and mercury. Each of these has a very low resistance to the flow of current. The base material of switches is made from: bakelite, fiber board, plastic, or porcelain.

Switches must have low heat characteristics and be designed to carry a certain amount of current, for example, circuit breakers range from 50 to 50,000 amperes, and some even higher for a short duration. Switches must have a high resistance to corrosion which would result in high resistance to current flow, and they must have low abrasive tendencies. Brass, copper, silver, and mercury have very low abrasive characteristics which prevents rapid mechanical wear.

Another protective device is the fuse. These are used to protect a line or electrical appliance from overload, undue strain, and attendant heat effect. They come in several types: common or "plug fuse," cartridge, linkage, Fusatron, and Fustat. A fuse is located on the load side of a switch in order to remove the power from the fuseblock when the switch is opened. Each line from
a switch box to the load should be fused. A "plug fuse" is rated in amperes of 10, 15, 20, 30, etc. The fuse rating should not be larger than the current rating of a circuit, for example, a 30 ampere fuse in a 10 ampere circuit would permit considerable damage to the circuit and the appliances concerned. A cartridge type of fuse is used in automobiles. It slips into a spring holder to complete the circuit and comes in various sizes. A linkage fuse is similar to the cartridge fuse except that it is housed in a hard paper tube with flat metal pieces on each end that slip between spring clips. The Fusetron is a patented fuse with a high time-lag that makes it possible to draw a large current for a short time as in starting a motor. The Fusetron has a thermal cutout added to the fuse link. This opens the circuit on overload, and it has a time lag so it will not open in the case of a harmless overload. The fuse link is larger than that used in the ordinary fuse. It protects against short circuits only. The Jusstat is another patented fuse designed to prevent too large a fuse or any bridging material, such as pennies, from being used. By a special adapter, the Jusstat will fit the regular Edison socket.

DYNAMOS: MOTORS AND GENERATORS

A machine that converts mechanical into electrical energy or electrical into mechanical energy, is a dynamo. When a dynamo is driven by a prime mover, and electrical energy is generated, it is
called a *generator*. It is rated in kilowatts that can be produced without over heating. When electrical energy is supplied to a dynamo and its output used to drive other machines, it is called a *motor*, and is rated in horsepower.

Generators and motors are constructed with the following parts:

- **Armature** which is made of sheet steel laminations insulated with laminating varnish to reduce eddy currents. **Field coils** mounted on pole cores made of sheet steel laminations insulated with laminating varnish to prevent eddy currents, and pole cores connected to the *field yoke* or frame which make a *path* for magnetic lines. The yoke is made of cast or rolled steel, and except in large machines, supports the bearings of the armature and commutators or slip rings that allow current to flow into or out of the armature windings through *stationary carbon brushes*. Slip rings are made of copper and commutators are made of copper segments insulated from each other and the shaft with mica. Slip rings are insulated from the shaft in like manner. When these become shorted to each other or the shaft, the armature is *grounded*.

The *field coils* are mounted on the pole cores and are placed around the yoke or frame to form north and south poles. A motor or generator with a *single north and south pole* is called *bipolar*, and a machine with four or six poles is called a *multipolar dynamo*.

There are two types of generators: direct and alternating current. *Direct current generators* are of two types: separate, and
self-excited field coils. The voltage variation of the former is not very great as the load changes because the field coil strength is maintained at a constant voltage. Because of this, it has good regulation and is used for electroplating, charging batteries, and wherever a steady voltage is required.

A self-excited generator stimulates its own field coils by various arrangements: series, shunt, compound, and third brush. When the field coils of a self-excited generator are connected in series with the armature, it is a series wound generator. The field coils are wound with a few turns of large gauge wire because the current must flow through the field windings. Voltage regulation is difficult in this type of generator since the variations occur as the load requirements vary. Series generators were once widely used for operating arc lamps for street lighting, but are no longer of much practical value. A knowledge of the series generator is helpful in understanding the compound generator.

If the field coils are connected in parallel with the armature, it is called a shunt wound generator. In this type of generator, the field coils are wound with many turns of fine wire which causes the resistance to be fairly high. Many methods have been developed to regulate the shunt generator, which works best when adapted to a circuit where the load is fairly constant.

A compound wound generator is a combination of series and shunt. It, therefore, has two sets of coils, one of heavy wire connected in series with the armature and the other of smaller wire.
connected in parallel. These coils are often placed one over the other on the pole cores. When the parallel winding is across the armature only, it is called a short shunt, and when it is connected across both the armature and the series winding it is called a long shunt. The short shunt is subjected to a higher potential drop than the long shunt.

An alternating-current generator supplies nearly all electric current used in homes and industry. Alternating current has the advantage of being simpler to produce and more efficient to transmit. Alternating current generators are also called alternators, and are as follows: revolving field, and revolving armature. A revolving field is common in alternators. It revolves inside a stationary armature. This type of construction allows the armature winding to be insulated, and to withstand high voltage. The speed of the revolving field determines its design. For example, a high speed turbine alternator has two poles, and an engine driven alternator may have as many as thirty poles. The revolving field has many advantages over the revolving armature because low direct current is supplied to the slip rings, and there is no arcing or leakage at the rings due to high voltage as in the revolving armature. Slip rings on a revolving field are not as difficult to insulate as they are on a revolving armature.

Alternators are classified as: single, double, and triple phase generators. The armature inductors are included in one
winding in single phase alternators and are generally connected in series so their individual electromotive forces will be added. A two-phase alternator has two separate armature windings, and in a bipolar alternator these two windings would be placed 90 degrees apart. Each winding generates the same voltage, but due to their inductive position, the electromotive forces are 90 degrees apart in phase. A three-phase alternator consists of three separate windings symmetrically spaced on the armature to produce three equal voltages, 120 degrees apart in phase. When two or more electromotive forces are generated on one armature, the alternator is called a polyphase alternator.

Most alternators are three-phase machines, and the windings are connected either delta or wye. A delta connection will supply more current to the load than the wye. The current in each line is equal to the square root of three times the current generated in one winding. A wye, "Y" connected winding will deliver the greatest electromotive force to the load. The voltage is equivalent to the square root of three times the electromotive force generated in one phase or winding. A three-phase alternator, either delta or wye, can be connected to a three-phase circuit.

Direct current motors are bipolar or multipolar, and are classified with reference to field excitation in the same manner as direct current generators: shunt, series, and compound. A shunt motor has field coils connected in parallel with the armature
coils. The field coils consist of a large number of turns of fairly fine wire of comparatively high resistance. This motor is classed as constant speed even though its speed decreases slightly with increase load. Shunt motors are employed where loads do not vary greatly, and constant speed is important. They have good starting and operating torque.

The field coils in a series motor consist of a few turns of heavy wire because they are in series with the armature windings, and carry the total current drawn by the motor. Series motors have a very high starting torque, and can move tremendous loads. They are used in streetcars, electric locomotives, cranes, and automobile starters. As a series motor slows down under load, its counter electromotive force decreases. This allows more current to flow, which accounts for the increase of its pulling power. Large series motors without load will develop very high speed, and will cause the armature to fly apart due to centrifugal force. Series motors should, therefore, never be disconnected from their loads. Series motors are always connected directly or through gears.

A compound motor is a combination of the shunt and series, and has a shunt and series winding on each pole. If the series opposes the shunt winding, the motor is differentially wound, but if they add, it is cumulatively wound. A differentially wound motor has nearly a constant speed because an increase in the load causes
a decrease in counter electromotive force, and allows the armature
to take more current from the line. This additional current flow-
ing in the series coils causes a stronger flux that acts against
the shunt field flux, decreasing the total flux crossing the
armature gap. In a **cumulatively** wound motor, the shunt winding is
added to the series winding in order to provide a strong increase
in current for loads. When the load decreases, the flux of the
series field decreases and the armature speed increases to keep the
electromotive force from decreasing. The shunt field prevents the
motor from racing. This motor is used where loads vary from no
load to a heavy overload such as on shears, punch presses, elevators,
rolling mills, and reciprocating machines.

**Alternating current motors** are classified as single, and poly-
phase. **Single phase** motors may be divided into three classes:
commutator, induction, and synchronous motors.

**Commutator motors** come in series: repulsion, and repulsion-
induction types. The **series motor** is composed of as few turns in
the field coils as possible. This is in contrast to the direct
current series motor. A sufficient flux is obtained by using a
low reluctance magnetic circuit. The armature reactance is reduced
by compensating windings in the pole faces. The compensating
winding may be short circuited on itself, but in this case, is
**inductively compensated**, and used on alternating currents only.
The compensating winding may be connected in series with the
armature and field. In this case, it is conductively coupled and used on either alternating or direct current. All parts must be laminated in order to reduce eddy currents. Some alternating current series motors are built for traction service, and are designed to operate on twenty-five cycles or less per second. Fractional horse-

power motors are designed to operate on 60 cycles, and may operate satisfactorily on 110 or 220 volts of direct current. This type of motor is called universal. The series motor has a high starting torque and operates at high speed with light loads.

The repulsion motor has a rotor identical to the direct current motor armature. The rotor revolves in a magnetic field, and is short circuit ed in the magnetic field at a predetermined angle by connecting the brushes together with a low resistance connector.

The repulsion-induction motor has a rotor with two windings: a squirrel cage winding consisting of copper bars placed in the bottom slots, and above these are the regular direct-current windings connected to the commutator. The copper bars are permanently short-circuited. The repulsion winding is connected to the commutators on which ride short-circuited brushes. The compensating windings are open circuit ed during starting, but as soon as the speed comes up to the proper amount, a centrifugal switch connects them in series with the main winding. This very popular motor is used where high starting torque and constant running speed is required. The sizes vary from one-quarter to five horsepower, but larger
A shading pole single phase induction motor has slots cut in each pole structure which admits a single loop of heavy copper wire on each pole. These are known as shading coils, and this part of the pole is called a shading pole. The field structure of this motor resembles a transformer. The main winding connects to the supply source and serves as the primary winding. Each shading coil corresponds to a secondary winding short circuited upon itself. With alternating current in the primary, current is induced in the shading coils, and sets up a magnetic flux about each shading pole. This magnetic flux is out of phase with the inducing flux approximately 90 degrees, so the axis of the shading pole is approximately at right angles to the axis of the main pole, consequently, the conditions for establishing a rotating field are accomplished, and the starting torque is assured. However, the starting torque created by the shading pole is small. The motor, therefore, is used only in one twenty-fifth horsepower or smaller sizes such as in electric clocks and in some phonograph motors.

The development of inexpensive condensers of large capacitance and small volume has made possible the capacity motor. This type of single phase induction motor has two phase-windings, 90 degrees apart. One is the starting and the other is the running phase. The running phase is connected directly across the voltage supply.
and the starting is in series with the voltage supply. The running phase offers a great deal of inductive reactance, and causes the current to lag behind the voltage. The inductive reactance created by the starting phase is offset by the capacity of the condenser, and with sufficient capacitance, the current in the starting phase can be made to lead the voltage. This reaction causes the current to be out of phase. This sets up a rotating field.

Capacity motors are divided into three groups. In the first case, the capacitor is used for starting only. The starting phase and the capacitor circuit are opened with a centrifugal switch when the motor attains proper speed. This arrangement is the least expensive of the three types. In the second case, the condenser is used for running as well as starting, and is not disconnected by a centrifugal switch. Condensers of paper dielectric are most commonly used. The motor has a very high power factor during normal running, as well as in starting. This is the most expensive of the three. In the third case, condensers of large capacitance are used for starting, and smaller capacitance is used for normal running. Capacity motors are generally available in sizes of one horsepower or less.

The repulsion start-induction motor actually starts as a repulsion motor. The armature is constructed like a direct-current
motor, i.e., the windings are connected to commutator segments. In order to convert a rotor of this type to an induction motor, it is necessary to short out the commutator segments. The repulsion start-induction run motor is built for high starting torque. The usual sizes range from one-half to fifteen horsepower. However, special ratings as high as 40 horsepower are available.

The single phase synchronous motor is constructed in several types such as for clocks, phonographs, and timing devices. The synchronous rotor revolves at the same speed of the revolving magnetic field in the stator, i.e., it is in step or phase with the energizing source. A shifting field is obtained by shading coils on the pole faces as in the split phase type. The rotor is made of hardened magnetic steel. The starting torque is developed from the effect of low eddy currents in the iron rotor and by the effect of hysteresis.

Polyphase motors are classified as: asynchronous, and synchronous. An asynchronous motor does not lock in step with the frequency of the energizing force, and it is called an induction motor, which is classified as squirrel cage, double squirrel cage, wound rotor, and commutator brush shifting. Polyphase motors have two or three windings, one for each phase, and can be connected in delta or wye. The currents in these windings alternate continually and progressively, and produce the revolving magnetic
field that drags the rotor along with it. The current is supplied by a polyphase generator.

Synchronous motors are so named because the rotor revolves at the same speed of the revolving magnetic field in the stator. Large polyphase synchronous motors have three windings. One, an alternating current stator or armature winding that produces a revolving magnetic field when polyphase alternating current is applied. The second is a direct current or rotor winding that creates a fixed polarity. This winding must be energized with direct current. The third is a damper or squirrel cage winding, and consists of heavy copper bars imbedded in the direct current pole faces and shorted together by end rings. This winding helps start the motor by induction and prevents hunting. This is caused by a sudden change in the alternating current voltage in the direct current field excitation, or in the mechanical load.

A synchronous motor has two advantages: constant and variable speed. Some of the disadvantages are: separate rotor excitation, subject to hunting, greater cost per horsepower, very careful handling, more auxiliary equipment for control and handling, and a special form of clutch to connect it to the load. A synchronous motor is used to drive compressors for refrigerators, air conditioning, air compressors, textile looms, cement grinders, rubber processing machines, paper pulp grinders, and frequency
changers, or on any load requiring 25 horsepower or more that requires constant speed, but not a heavy starting torque. Another common practice is driving direct current generators where a steady source of current is needed such as in electroplating.

Controls for motors and generators are in many instances integral parts of them. Direct current generators are controlled by methods used to excite the field such as a third brush. Welding generators are controlled by damping plates, selector and electronic switches. Alternating current generators are controlled by varying the direct current in the rotor winding or the speed of it. This is obtained by a rheostat in the circuit or by reducing the speed of the prime mover.

Direct current motors are controlled by placing resistors or rheostats and governors in the armature or field circuits. Polyphase motors are controlled by compensators or autotransformers that reduce the impressed voltage at the time of starting. Resistors and rheostats can be connected with switches to reduce the current in the rotor. Also brushes may be shifted in starting to reduce the torque. Capacity motors are controlled by magnetic switches, autotransformers, and centrifugal switches. Induction motors are controlled by shorting the commutators such as the repulsion start induction run, or brush shifting such as in the adjustable speed induction motor. Also auto-starters and switch boxes are used in starting. Controls common to more than one type
of motor include: centrifugal switches, mechanical clutches which operate centrifugally, thermal protectors or circuit breakers, reverse switches, and changes in wiring or design.

TRANSMISSION

Transmission is the transfer of electrical energy from one location to another through conductors, by radiation, or induction. A transmission line is a set of conductors used to transfer signal energy from one location to another or to transmit current over long distances for power purposes. The theory of transmission is based on the following: resistance, leakage, inductance, and capacitance. The resistance of materials has been a big problem in the large scale transmission of electrical energy. It was a limiting factor in the early direct current systems. With the improvement of conductors and insulating materials, and the development of the transformer and better circuits, the transmission of alternating current is now possible over 300 miles from the generating plant.

The development of the transformer has made possible a system of increasing the voltage to a very large amount. Transmission voltage is made at 20,000 volts because higher voltages result in leakages to the atmosphere, the ground, and to arcing between lines.
Transmission lines are produced in several types: overhead, underground, single-phase, three-phase alternating, and direct current.

Lightning arrestors help to discharge high lines of excess voltage generated in the line by lightning. Lightning protectors are located on the supporting structure in such a way that they form an air gap, large enough to allow excess voltage to leak off to the ground. Reactors or coils of wire without an iron core are used with lightning arrestors. Lightning is alternating current in character and of tremendously high frequency. A small coil of wire offers very little inductive resistance to a 60 cycle current, but will offer tremendous inductive resistance to high frequency lightning. A coil of a few turns will offer so much opposition to high frequency lightning that it will seek a path of lesser resistance and this is the air gap between the lightning arrester and the ground.

One of the most interesting events in present day electrical engineering is the transmission of extremely high voltages. As it increases, the line loss in watts decreases, and the efficiency improves. Line loss is the resistance of the line times the current squared. The smaller the current transmitted, the smaller the line loss in watts. This can be accomplished with a step-up transformer, i.e., as the voltage increases, the current decreases. Transmission wire size can be decreased by increasing the voltage. If the voltage is doubled, the resistance of the wire can be
increased four times without increasing the line loss. In selecting a transmission wire, a size must be selected that will maintain a balance between the initial cost and the cost of line loss which is referred to as running cost. The initial cost increases as the size of wire increases, whereas, the cost in line loss decreases as the size increases. Lord Kelvin developed a formula that determined the most economic area for a conductor: it should be of such an area that the value of power loss per year equals the interest cost per year of the money invested in the line. Another reason for using small size wire for high voltage transmission is that it offers less weight per mile, less wind resistance, less ice hazard, and less line supporting material is needed to support the high line. Each of these reduces the initial cost.

RECTIFIERS AND CONVERTERS

A rectifier is a device that changes alternating to pulsating direct current. It may be: a vacuum tube, a gaseous tube, a vibrator, a copper-oxide device, selenium, crystal, a commutator, bulbs, mercury, multi-anode, and ignitron. The vacuum tube is used widely as a rectifier of high voltage. It is often referred to as the "hard-vacuum rectifier" because it has the ability to withstand the high reverse voltage across the tube during half of the cycle. The hard vacuum tube has a high vacuum state, and it can be used as a half wave, or as a full wave rectifier. The
half-wave rectifier employs only one-half of the alternating current or one alteration. The vacuum tube has two elements: a filament or heating element and one plate. This type of tube is called a diode. A full wave rectifier consists of a hard vacuum tube with a filament and two plates. The tube is also referred to as a diode. It is connected in the secondary circuits of a step-up transformer.

Gas added to a vacuum tube forms a casegau rectifier. This type is referred to as a soft vacuum tube because the gas ionizes when voltage is applied in the reverse direction. Therefore, reverse voltage must be kept at a low value in order to prevent conduction. The soft vacuum type is a low voltage rectifier, but is connected to the same type of transformer as the hard vacuum. It may be employed as a half or full wave rectifier. The current supplied by these rectifiers is used in radios, amplifiers, and other appliances requiring direct current which must be filtered in order to remove the ripple or pulsations. In some instances, such as relays and motors, the current can be used without filtering.

A vibrator is an electromagnetic device that converts direct to pulsating direct current in the primary of a step-up transformer or induction coil. The secondary will generate high alternating voltage and current. A vibrator is used in automobile, radio, and
some public address systems to increase the six volt supply to a high alternating voltage. Vibrators are classified as: non-synchronous and synchronous. A \textit{synchronous} type interrupts the direct current and rectifies at the same time the high voltage alternating current developed across the secondary of the step-up transformer.

\textbf{Selenium rectifiers} are similar to copper-oxide types. However, the rectification is done by a different type of material composed of either nickel plated steel, aluminum, or iron washers coated with selenium. Selenium is a non-metallic element resembling sulphur. When selenium is first applied, it has a black polished surface, but this is changed by several heat treatments to a gray crystalline form. Selenium is coated with a special alloy to provide a good electrical contact. Rectification takes place between this coat and the selenium. Electrons flow easily from the alloy coat to the selenium, but meet high resistance in the reverse direction. The pressure need not be great on the disc to make contact for rectification. The expansion and contraction of the assembly does not effect the electrical contact as it does in copper-oxide types.

\textbf{Crystal rectifiers} are used as detectors in crystal sets to rectify radio frequency. The detector utilizes a crystal such as silicon or galena in contact with a wire to rectify the incoming radio signal. The crystal allows only half of the radio wave to
pass. It is, therefore a half-wave rectifier. Galena is composed of lead and sulphur. Current can flow from the contact wire or cat whisker through the galena crystal, but cannot flow in the reverse direction. Carborundum has similar characteristics.

The commutator is a mechanical rectifier placed on the shaft of a direct current generator to rectify the alternating current generated by armature windings.

The recticon and the tungar are commonly used bulbs for rectification. These have a cathode and anode and are completely filled with argon, an inert gas that comprises the rectifying medium. The bulbs are interchangeable and work on a mutual induction transformer, or an auto-transformer. However, the commonly used transformer has two windings, primary and secondary. An auto-transformer is more dangerous to use because any one of the three leads will give a severe shock.

A mercury arc rectifier is popular for battery chargers. It was the first to become available for changing alternating to direct current. It is an electric device which employs a small pool of mercury as a cathode, and one or more positive electrodes made of graphite enclosed within a glass container. The mercury arc rectifier works with a step-up transformer. The secondary usually has a center tap for proper connections that allow the rectifier to function as a full-wave rectifier.
The multi-anode rectifier is a mercury arc type with several anodes for operation on polyphase current. This type of rectifier is highly perfected, and is now replacing many converter and motor-generator sets. It is possible for this type of rectifier to deliver a current of 4000 amperes at 500 volts.

The ignitron rectifier is a modification of the mercury arc. It utilizes, in addition to the graphite anode and mercury pool, a third electrode called the ignitor, the tip of which is partly submerged in a pool of mercury. It is made of silicon carbide which has a high resistance. When the ignitor is positive, a small arc is formed between its tip and the mercury. If the anode is positive when the arc is started, a hot spot develops on the mercury cathode, and causes current to flow through the load circuit.

Ignitrons are constructed in single anode units which makes a closer spacing of anode and cathode, and reduces the arc voltage drop to approximately twelve volts. This low voltage on the arc accounts for part of its efficiency. Ignitrons are connected in three, six, and twelve units for operation as multi, single anode rectifiers. Since the ignitron is an electronic device and starts instantly, it is used almost exclusively in electric welding because starting and stopping must be accurately timed.

The converter is a device, usually rotary, for changing electrical energy from one form to another such as alternating to direct, or direct to alternating current. When direct is changed
to alternating current, the machine is called an inverted converter or simply an inverter. It resembles a motor or a generator and has an armature which carries a commutator on one end and a set of collector rings at the other with laminations and windings between. One winding connected to the commutator serves as a direct current generator while the other, connected to the slip rings, serves as the alternating current motor.

Rotary converters are designed to operate on single or poly-phase current. There are several types of these: synchronous, rotary, inverted, frequency, dynamotor, and motor generator. The synchronous converter changes alternating to direct current, or direct to alternating current with a single armature including slip rings and commutator. The alternating current motor is synchronous and keeps the commutator in step with the alternating current being converted. The rotary converter type is a synchronous converter. The inverted converter is also a synchronous converter for changing direct to alternating current. A frequency converter is a machine for changing one alternating current frequency to another.

The dynamotor is a rotating machine for changing direct to alternating current of desired frequency and voltage. There is a common magnetic circuit with two armature windings, two commutators and two sets of slip rings. A motor-generator is directly connected to one or more generators for the purpose of converting a power line voltage to other desired voltages, or frequencies.
The resource material of electricity is practically unlimited. However, the data in this chapter were restricted to the characteristics of electricity, magnetism, the electron theory, voltage or pressure, electric current, cells, conductors and insulators, the elements of electricity, measuring instruments, circuit types, condensers and their reaction, induction and its importance, transformers and their value, relays, switches, dynamos, electrical transmission, rectifiers and converters.

This material provides an important resource for developing a foundation in the fundamentals of electricity.

Chapter V will analyse the nature of industrial arts education in order to determine how the above findings may be worked into this curriculum.

ANNOTATED BIBLIOGRAPHY


Information and experiment units of alternating current: principles of generation, frequency, resistance, inductance, capacitance, solution of series-parallel circuits, resonance, wye and delta systems, power measurement, transformers, induction motors, dry disc rectifiers. Suitable as a basic reference in vocational courses.


An excellent coverage of the basic electrical theories. Included are treatments of theory, magnetism, current, circuits, cells, induction, motors, generators, and transformers. It might well be used by the advanced secondary school student.

Fundamentals of direct and alternating current theory. Explains the fundamental operating principles and construction features of a wide variety of generators and motors including series wound, shunt wound, compound wound, synchronous, single phase, polyphase and universal types. Applications, characteristics, selection, maintenance, and trouble shooting. Excellent illustrations. Recommended as a basic reference for industrial arts on high school level.


An excellent text for the novice. The authors have confined their discussion to the most elementary principles of electricity; i.e. magnetism, currents, circuits, busses and signal systems, induced currents, transformers, and batteries. They have deliberately refrained from using language too technical for the beginner to understand. The book is extremely well illustrated, and in the explanation of the theories many familiar analogies are used.


Mathematics involved in circuits where the electrical effects of A-C current is critical. Examples and illustrations of vectors, impedance, power factor, Kirchoff's Laws, and the characteristics and calculations for three-phase circuits. Exercises in calculation involving addition, subtraction, multiplication, reciprocal and powers, polar coordinates, division, and powers and roots.


Content involves rectifiers, converters, motor application, alternating currents, industrial motor application and industrial motor controls. This book could serve as a source of reference for other textbooks used in a classroom in junior and senior high school.


Contents: Direct currents, alternating currents, electric currents, electric machinery, direct currents, electric machinery, alternating current. Good book for beginners in electricity. Also good for a reference book to support other books.


The book is divided into 22 sections, each one being written by a specialist in his particular area. It is a comprehensive working manual of the radio science, including virtually everything connected with radio starting with fundamental background with emphasis on practice through television and acoustics. Contains many tables and curves. The book is a very fine reference book and is easily understood although it is written on an engineering level.


The text is designed to meet the needs of small high school classes that desire to add a course of radio theory and servicing. The sets to be built by the students have been designed to use many salvaged parts. Laboratory work can be started the first day with the one-tube set. A chapter on FM receivers and television receivers is included.

A book that explains the "how" and "why" of electronic equipment and assumes no previous study of physics or chemistry. A basic discussion of the constitution of matter and the flow of electricity is followed by sections on current rectifiers, sources of light, picture-transmission, electron-microscope, radio compass, etc. (Seventy-one line drawings plus excellent photographs) Best used in high school.


This book is divided into two divisions: Theory of Alternating Currents, and Alternating Current Circuits. The first section briefly covers the theory of alternating currents, bringing in inductance, resistance, capacitance, impedance, etc., and their effects upon the circuit. The second section is devoted to problem solving covering these various effects upon the circuit. This entire book would find its greatest use in the hands of an instructor for use as a teacher guide on these subjects.


A clearly written statement of the fundamental principles of electricity. Parts I and II consist of sections on magnets and their applications, electrostatics, electron theory, current, conductors, insulators, circuits, resistance, direct current motors and generators.


Contents of this book divided into two parts. First, Ohm's law, elementary electricity, current, resistance, pressure and voltage. Second, electric circuits, resistance, induced electromotive force, modern D-C machines, D-C generators, D-C motors, heat work, and power units. A good book for beginners.

A classroom text and a shop manual. In Part I will be found the simple, but fundamental, working principles of electricity, magnetism, electric circuits, direct current, alternating current, coils, condensers, transformers, elements of radio, small motors and electricity in the home. In Part II directions are given for the construction and use of experimental apparatus, shop equipment, and class projects.


Presents basic material of radio required for all types of radio work. Covers each topic of radio in such a way as to make clear the functioning of a complete radio system. The reader need have only an elementary knowledge of algebra, as the book is written with a minimum reference to mathematics and is not strictly an engineers book. It would be good in high school for someone who really wants to delve into radio.


The book is a story of the capture and use of radio waves. It deals with the atom and electrons; how electricity was discovered; how an electric bell works; the first wireless wave receiver; invisible forces and unexpected sparks; Heinrick Hertz, the father of radio; a plunge into deep water; how the wireless waves are caught; how the captured wireless waves are detected; the thermionic valves (tubes). The book is well illustrated. This book would be a good reference and would be good in a junior high school electronic laboratory.


This book provides a source of and construction principles for electrical mechanisms, models, and demonstration equipment. It is written for the use of laymen and students in school shops. Differences in British terminology are negligible. Many illustrations and schematic drawings. Should be useful in planning and building electrical apparatus in school situations.

This book gives a wide coverage of the relays and electro-magnets in common use. Complete with photographs, sketches, and wiring diagrams to illustrate and clarify the subject matter. This book would find its best use in the hands of the teacher instructing in these subjects.


Theory and applications of electron tubes in numerous situations. Pictures, graphs, and schematic diagrams are inserted for clarification. Special and new tubes are discussed.


This book contains valuable electrical information which is fundamental and practical for industrial arts. Its content consists of magnetism and how it is related to electricity, sources of electricity and electrical energy, the flow of electricity and conducting materials, heat from electricity applied to everyday problems, house wiring, electrical conduits and switches, communication by means of electrical transmission, electrical power and the electrical generator and motor, with applications.


Contains many calculations, use tables, formulas, a list of all National Electric Code Articles pertaining to each particular use. It is a technical reference for engineers in industrial electric wiring. The book would be too technical and too far advanced to be recommended even as a reference for high school use. The book is one of a series of technical reference books on electricity by Mr. Lincoln.

This book has two main divisions: fundamental electrical instruction by the I.C.S. Staff, and electrical measuring devices by Paul MacGahan. The first division offers good material on the fundamentals of electricity, but it would find its most valuable use as a review of a more detailed introduction to this subject. The second division handles, quite well, a discussion of electrical measuring devices, their fundamental principles of design, construction, and use. Both sections cover the ground quickly and lightly. Not recommended as a text but rather for reference.


This book is a review of the early discoveries and developments which led to the creation of the great electrical industries of today. Many pictures of original models of inventions in the electrical field appear in this book. The story of their development is told in non-technical language.


A reference book describing principles, terms, devices, tools, and materials as they apply to radio and electronics, and including developments in radio transmission and reception, sound pictures, public address, photocells, short wave, and television. Profusely illustrated with schematic and circuit diagrams, various charts and tables. Items are listed alphabetically.


The purpose of this book is to teach the theory of the radio receiver and how to service it. This book is not recommended for beginners or for those in the advanced stages of radio, but for the intermediate pupils. This text begins with electrical and radio theory and continues to the more difficult aspects of radio, bringing in, where it applies, concepts of general electricity.

The book contains two volumes. Volume I includes History of Communication, wave motion, waves in ether, a simple radio receiving set, aerial-ground system, the tuner, the reproducer, the detector, wave form, the antenna coupler, electron flow, vacuum-tube detector, audio frequency control, and superheterodyne receiver. Volume II is a more thorough treatise on the same general subjects as Volume I. The book is not technical, can be easily understood by the layman and could be used on the senior high school level.


The book deals with the mathematical analysis of the operation of electrical circuits at high frequencies, includes high frequency alternating currents, resonance phenomena, coupled circuits, thermonic vacuum tubes, amplification, modulation, detection, production of H. F. currents, electric wave filters, transmission lines, electromagnetic waves, reflection and refraction, electrochemical systems. The book is written on a level for graduate students in electrical engineering, assuming a knowledge of calculus and alternating currents. It contains many tables, formulas, and curves. It is a very authentic reference book for use on the college level.


This book is designed as a first level course in the fundamentals of electricity. This text is written in a very clear, concise manner. Everything included is of importance in the study of electricity. The book starts with a chapter on Magnetism and continues through the basic aspects of electricity to a treatment of rectification of current. The book presents many excellent illustrations of visual aids paramount to the learning of electricity.

This book describes experiments that can be performed with simple or easily constructed apparatus, illustrating a number of principles of electricity. Radio and electronics are not included. Contains a bare minimum of information concerning the tools and materials needed to perform experiments and build apparatus.


A story of the beginning of wire, wire rope, the processes of making wiring, and of the John A. Roebling family, builders, who were some of the first to use wire rope in building bridges. The book does not contain anything specific on electricity, but the story of wire is closely related to electricity and as the book is written as a story and not a text, it would be good for leisure reading in high school or junior high school.


This monograph is to be used as a guide to instructors and students who wish to become familiar with the use of the cathode ray oscillograph and to understand the interpretation of the various oscillograph patterns which are fundamental to an understanding of electronic circuits. Contains photographs of actual conditions of voltage in some typical circuits used in electronic control.


Explains fundamentals and practical details carefully and clearly: vision deception, image splitting, cathode ray scanning, pattern scanning, and synchronism, sound transmission, wave forms, aerials and feeders, vision receiver, tube supplies and power packs, large screen television, color and stereoscopy, artistic aspects, future trends, adjustments and faults. Very well illustrated. Highly recommended as a basic electronics reference.

First part, nomenclature, operation, and use of electron tubes in industry. Illustrations range from the diode to the thyatron with detailed discussions on industrial functions. Second part, special tubes and their use as lighting controls.


Intended as reading material for grades 6-8, and describes ways by which electricity is generated, stories of inventions and discoveries in electricity, and directions for experiments and construction activity. Useful sections on measuring electricity and the principles of electroplating.


A book based upon the fundamental background of electrical engineering principles and a minimum of mathematics. Deals primarily with the behavior and application of electron tubes in electrical apparatus. A college text.


This book begins with basic ideas and effects of electricity, deals with wires, cables and their electrical properties, direct current electric circuits and measurements, alternating current electric circuits and measurements, magnetism and electromagnetism, electromagnetic induction, transformer action, and transformers, generators direct and alternating current, motors, direct and alternating current, list of visual aid and history of great men in electrical science. Would be a good reference in senior high school or college.


A fair treatise of the elementary principles involved in currents, magnetism, circuits, transformers, batteries, etc. However, it is not comparable to the more recent texts of similar nature.

Specifically concerned with theory and principles of magnetism, electrostatics, electromagnetics, electronic theory of metals, electromagnetic wave generation, transmission, and reception. Discussion includes laws, equations, experiments, applications and phenomena concerned with each topic.


A technical treatment of the operation, maintenance, and repair of electric motors, generators, transformers, relays and other types of equipment. The author has tabulated the symptoms, troubles, causes, and remedies for many equipment failures, and includes circuit diagrams of apparatus under consideration. One chapter on the economic use of electric power by industry. Probably limited to use by the teacher and advanced students.


Discusses in non-technical terms, the basic electron theory, and how electronics is used in transportation, communication, medicine, industry, and lighting. Subjects include x-ray, radar, and atomic energy. Somewhat lacking in illustration, but well-organised and clearly written.


This is an excellent reference book which summarises the body of engineering knowledge that is the basis of radio and electronics. With the exception of a limited amount of information concerning television, this book does not treat the developments that have occurred since the war in the field of electronics. This is an extremely technical work and not recommended for use other than reference.

This book includes only the elementary electrical principles and their application to modern communication practice and to industrial electronics. The following electrical features are considered: electrical power and energy, electrical conductors, measurement of resistance, Ohm's Law, Kirchhoff's Law, batteries, generators and motors, inductance, capacitance, alternating currents, and electrical communication systems. History and general theory have been omitted.


Intended to give a clear insight into the fundamentals of electronics and to present its practical applications. Mathematics and highly complex material are avoided. Pictorial representations are of principles and theories rather than apparatus. Should be interesting and readable for high school students.


Kinds of motors available, what makes them run, what they will do, how to repair them. Includes single phase induction, split phase, capacitor start, two value capacitor, single value capacitor, repulsion-induction, shaded pole, polyphase induction, synchronous, selfy, and direct current types. Illustrated. Recommended as a basic reference for general shop on high school level.


This book discusses the principles underlying the electrical design of alternating current transmission lines. Such things as inductance and capacitance of conductors, performance of short and long transmission, line conductors and supporting structures are discussed. This book is most suited for students at University and Technical college levels.

This book treats the following areas, radio waves and wave travel, wave form pictures, principles of: the vacuum tube, tuning, receiving set using direct-current tubes, phones and speakers, power supply, alternating current tubes and receiving sets, short wave sets, oscillators and transmitters, radiotelephone transmitters, aerials, ultrashort-wave sets, looking ahead in radio and a list of radio abbreviations. This book is well illustrated, and would be a good book in junior or senior high school laboratory.


Written to provide a foundation of basic electrical information for the later specialization of armed forces personnel. Subjects are: magnetism, electrostatics, primary cells, storage batteries, Ohm's law, electro-magnetism, meters, heating, work-energy-power, induced e.m.f., motors, mutual and self-induction, and current rectification. Applicable at junior and senior high level.


The book is divided into two parts. The first part consists of a series of practical jobs arranged in chronological order, starting with very simple ones and proceeding to more difficult ones. The second part consists of ten chapters of text on the fundamentals of electricity and is intended as a supplementary study in connection with the jobs.


A brief story of television. Includes: historical development, photo electric tubes, cathode ray tubes, scanning, transmission and reception, optical devices, distribution, color television, electronic eyes, television programs, facsimile, snooperoscope, radar, radar television, electronic microscope. Illustrated, non-technical. Suitable for a basic understanding of principles of television on junior or senior high school level.
Chapter V

NATURE AND SCOPE OF INDUSTRIAL ARTS EDUCATION

This chapter concerns the derivation, the objectives and the programs of industrial arts education in American schools. It forms a basis on which to project what should be done concerning the findings of Chapter IV when applied in Chapter VI.

DERIVATION OF A STATEMENT OF POSITION

Industrial Arts teachers are concerned primarily with education concerning life in an increasingly involved technology and have established their programs firmly as a result, by presenting this truism as a postulate along with other equally obvious assumptions, the first of which involves:

Biological Basis. A child grows and learns (63) through physical and mental activity. These have bearing upon the selection and development of educational experiences, and are determined by the following:

1. Physiological factors. These provide the means. At first it is activity for activity's sake (61, p. 4) but as the nervous system matures, the activities become more purposive. During the first two or three years of life, there is an uneven body growth. Muscle coordination has not developed and there is a clumsiness in the use of the body. Gradually the limbs, trunk, muscles, and nervous system mature and coordination results. Strength at
first is limited, but increases with development. It almost doubles between six and nine years of age. When a child reaches the intermediate grades, he has gained a great deal of strength and control. Activities requiring greater precision, endurance, and strength may be used (R, p. 41) without great effort and danger of injury. During adolescence, there is a loss in motor control. Children in this stage of development should therefore select activities which will facilitate growth.

2. Mental factors. Children in the early school years are naturally interested in sensory and motor activities (R, p. 42) such as sights, sounds, handling tools and materials, and in relatively coarse or rough construction work. Their curiosity is very active and leads to much learning through trial and error. The interest span is short, but grows rapidly and especially with reference to the adult activities of the community. The desire to manipulate tools and materials leads to creating miniature houses, roadways, stores, airplanes, trains, cities, and other things suggested by community and adult life.

There are many changes in mental activities and attitudes in the years of the middle grades. Ability to plan grows, and interests increase. The practical activities of the community command increasing attention (R, p. 43). The ability to analyze develops, which makes a wider range of meanings possible. Patience
develops in mastering such controls or skills as are needed to bring about desired results. The ability to play and work with a group makes possible many activities. Clubs and other limited scope groups develop at the end of the elementary period.

Bonser (8, p. 43) states that at about the eleventh and twelfth years, there develops an interest in outstanding characters. The heroes of history who overcame great obstacles and achieved success are fascinating. Curiosity also becomes more objective and there is a tendency to become scientific. This according to Bonser gives science, religion, and social relationships a prominent place if presented in a natural way. This is a period of curiosity and of interest in human affairs, problems, and values. It is a period when sympathy in one's personal problems is desired and appreciated. Occupations take on significance and especially what they have to offer as a life work.

The growth and development of these physical and mental factors results in several desires, or impulses, according to Bonser, who referred to them as manipulative, investigative, aesthetic, and social.

a. The *manipulative impulse* at first is aimless, and activities are sensory and motor. They are engaged in for their own sake, for example, in handling tools and materials, driving nails, sawing a board, flashing a light, or watching a toy electric motor. A second stage results when an aim or plan is defined. For example,
as in making a flashlight work by replacing the batteries or bulb, or in making a boat or wagon out of wood, with nails and hammer. There is no detail to the plan, but satisfaction comes from making something and from the activity itself. The manipulative impulse continues to develop through various levels of education in the increase of skill required in the production of clearly conceived objects that may lead to more investigation than manipulation.

b. The investigative impulse causes children to make many observations. These result in such questions as: What? Why? or What for? Children are led to physical activities and in some instances, mental and physical activities are combined. Investigation is indicated by such questions as How? such as in the construction of a sword or kite.

c. The aesthetic impulse is manifested very early in life when a child becomes aware of bright objects and seeks to handle and collect them. He shows a preference for certain clothes and colors in the objects about him. This impulse matures when the elements of design such as proportion, balance, emphasis, rhythm, as well as harmony and variety enter into the selection of everyday articles.

d. The social impulse in early form is expressed in the desire to play with others. This matures in many ways and a social poise or well being results.
Industrial arts supplies an ideal medium of materials, facilities, and problems for doing things children need and want to do to satisfy these impulses. Industrial arts provides opportunities for self-expression in many media and the potentialities of children are nurtured as a result. This great feature of industrial arts results in orientation regardless of age, sex, race, intelligence, aptitude, or even occupation.

**The Economic Basis.** Primitive man lived a simple but precarious life. The skills of hunting, fishing, and agriculture absorbed his time. His tools were crude, his transportation slow, and his communication almost nil. But, as he made progress in the shaping of tools, and in the using of materials, life became easier, even though it was more complex. This process has continued down through the ages and many types of economy have resulted, including serfdom, feudalism, guilds, agrarian, frontier, and so on. The development of science and technology have resulted finally in patterns of transportation, manufacture, construction, the generation of power, and communications, the like of which has been unparalleled in man's history. The principles of economic life are much the same today as they were in early times, but their interpretation has become obscure by their complexity. For instance in the division of labor, in occupational specialisation, and in the organisation and development of industry, which
has been nothing short of spectacular as per the following from Dewhurst (21, Appendix 32).

In 1850, 79 percent of the power produced came from animals, 15 percent from man, and only 6 percent from technological means. This resulted in the production of one billion horsepower hours of energy (predominantly animal power). The following table reveals what has happened in the short space of a century as the result of the development of technology in the United States from 1850 to 1960.

<table>
<thead>
<tr>
<th>Years</th>
<th>% Animal Energy</th>
<th>% Human Energy</th>
<th>% Tech. Energy</th>
<th>Billion HP Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850</td>
<td>78.8</td>
<td>15.4</td>
<td>5.8</td>
<td>1.0</td>
</tr>
<tr>
<td>1900</td>
<td>51.7</td>
<td>10.5</td>
<td>37.5</td>
<td>31.3</td>
</tr>
<tr>
<td>1920</td>
<td>20.8</td>
<td>5.7</td>
<td>73.5</td>
<td>145.0</td>
</tr>
<tr>
<td>1940</td>
<td>6.4</td>
<td>3.6</td>
<td>90.0</td>
<td>260.4</td>
</tr>
<tr>
<td>1960</td>
<td>1.3</td>
<td>2.4</td>
<td>96.3</td>
<td>471.6</td>
</tr>
</tbody>
</table>

Technology has changed the lives of every man, woman, and child of the nation. The United States changed after 1900 from a debtor to the wealthiest nation of the world. This tremendous change was made possible by the use of electrical, chemical, and other types of power and procedure. The prospects which lie ahead, through the harnessing and use of atomic power are difficult even to imagine because man's life will be so radically unlike that of his ancestors. His universal need for greater sophistication
in all things technological, becomes ever more apparent and critical.

**The Social Basis.** This origin of industrial arts is concerned with political, consumer, cultural, and historic elements such as the following:

1. **The political element** has reference to the way society organizes itself. The basic concept of the American way of life includes recognition of: the unique worth of the individual, the value of reflective thinking, the use of the method of intelligence, the enjoyment of free enterprise, and so on.

One is free in the United States to develop his potentialities, but this freedom carries many responsibilities with it, such as: to refrain from interfering with the considerate development of others, and to foster such traits as tolerance, social sensitivity and efficiency. To accomplish these responsibilities, according to Wilber (R6, p. 7) requires that individuals participate in a variety of experiences.

In a totalitarian form of government, the individual exists only for the state. The democratic concepts described above are not permitted to exist. Industrial arts as such, could not flourish in a totalitarian society.

**The Historic Basis.** Industrial arts has a rich but confusing professional heritage. Writers have referred to its progress as far back as the Renaissance. Documentary evidence
concerning "practical" or "useful" education dates back more than 2000 years before the birth of Christ. The stone tablets excavated at Ur in Chaldea (81, p. 12), record the laws under which young people learned to do practical things. The Code of Hammurabi (2250 B.C.) refers to several examples of practical or industrial activity.

The rush of events in the fifteenth and sixteenth century (5, p. 30) comprised a period of awakening that resulted in the so-called industrial revolution and the ultimate need for types of industrial arts activity in the schools. The first of these was the invention and development of printing by Gutenberg in 1450. The second was the revival of classical learning, and the third was the Reformation. These three events began to bear fruit for education. Bennett (5) states that two fundamental ideas were developed during this period upon which "manual arts" was developed as such. The first of these is that sense impressions are the basis of thought and consequently, knowledge. The second is the related idea of learning by doing. He stated further that the object method of teaching was developed first and later the laboratory method. Out of these developed the value of work, of tools and materials, and of doing something skillfully, as a basis for rational behavior.

Martin LUTHER saw the function of the school, and the duties of economic life marching side by side uninterrupted. RABELAIS in
France, saw the advantage of approaching the abstract and remote through the concrete and near at hand. Richard MULCASTER in the latter part of the sixteenth century, believed "the hand, the ear, and the eye to be the greatest instruments whereby the receiving and delivery of learning is chiefly executed." Francis BACON said that the way to study nature was to learn through the senses. John Amos COMENIUS believed that instruction in words and things should go together. Samuel HARTLIB (1600-1670), Sir William PETTY, and John LOCKE (1632-1704) of England visioned handwork as a means of improving the methods of education to give it a more scientific and practical content. Jean Jacques ROUSSEAU (5, p. 80) believed the child should work in a workshop, and "labor with his hands" to the profit of his mind." His recognition of the fact that manual arts provides a means of mental training marked the beginning of a new era in education.

While PESTALOZZI (5, p. 119) was establishing his object method of teaching in the early part of the nineteenth century, the industrial revolution was expanding rapidly in Europe. The need for mechanical and scientific means for doing "things," created many important problems. These resulted in such schools as the Industrial Lyceum in England and the Mechanics Institute in America.

Several countries began to recognize the need for technical training. For example, Hue SLOYD or homecraft was introduced in
Sweden. Della VOSS developed a system of exercises to train railway apprentices in Russia. This caught the interest of American school people as a result of the Russian exhibit at the Centennial Exposition in Philadelphia in 1876, and was widely adopted with modifications in the United States.

John DEWEY (20, p. 33) at the turn of the century also emphasized that people learn by doing. In his School and Society (20, p. 33) he states:

This means that these occupations in the school shall not be mere practical devices or modes of routine employment, the gaining of better technical skill as cooks, seamstresses, or carpenters, but active centers of insight into natural materials and processes and points of departure whence children shall be led out into a realization of the development of man.

The first formal work of this kind (81, p. 13) was called manual training by RUMBLE in 1880, and the emphasis was on hand skills.

The second period of such work was called manual arts by Bennett (16, p. 441) in 1893 and the emphasis was still on hand skill, but the philosophy was extended to include useful and well designed articles. The introduction of the Sloyd system in Boston by LARSSON in 1890 influenced the American movement.

But, something was going on in America that was being missed by these programs. This was the phenomenon of industry. The third period, therefore, was referred to by RICHARDS, HUSSELL,
Boneski, and others (81, p. 14) from 1902 to 1910, as **industrial arts**. This term implied that all of the old that was good should be retained, but that the point of reference would now be **industry** and not the hand. The junior high school movement was launched in 1910 to provide for broad **orientation**. Another concept called for **diversification** rather than **specialization** of skills. Still another idea called for the use of **many materials** and **experiences** in the **basic techniques** employed by industry.

**RESULTING OBJECTIVES OR FUNCTIONS**

The above permits an almost obvious set of conclusions concerning the objectives of industrial arts education. The **first** of these stems from biological and economic sources and concerns the overpowering need for **orienting** youth in the technology both as regards how it is produced as well as how it is to be consumed. This objective embraces the entire program of industrial arts as a phase of general education from the pre-school through college to adult levels.

The **second** of these objectives grows out of the first and concerns the **technical**, or **competency** function. This objective of industrial arts involves critical thinking, planning and organization, as well as skill, and may result in new methods, processes, and products, as well as understandings. The technical function is a way of life, contributing to the social, cultural, economic, and political aspects of it.
The third concerns **consumer literacy** which industrial arts achieves through orientation, experimentation, investigation, and manipulation. This objective of industrial arts promotes wide understanding and wise use of all types of manufactured goods. Many new items are added each year to the list of consumer goods. Out of the consumer literacy purpose evolves the cultural function. Bonser early pointed out that industrial arts is concerned with the ability "to choose and use the products of industry wisely." This involves design, form, fitness, function, and use in the broadest sense.

Directly related to the consumer function is the opportunity provided by industrial arts for young people to visualize abstractions. Those who have difficulty in developing or understanding abstract ideas are able to solve or clarify these problems in terms of experience. For example, many who have been unable to master fractions or geometry, find little difficulty in learning to measure accurately by constructing an industrial arts project. HILLIARD (35, p. 69) says "learning through experience is very different from textbook study. Doing a practical project in electrical wiring gives a pupil more exact appreciation of an electric circuit than he could obtain from merely reading on the subject and studying diagrams."

The **fourth** is a life long purpose and concerns the **recreational** function. It is based upon biological and economic factors which
make it one of the most important bases of the industrial arts program.

In summary, WILLER (86, p. 43) lists the objectives of industrial arts in general education as follows:

1. To explore industry and American industrial civilization in terms of its origin, history, organization, materials, processes, operations, products, and occupations.

2. To develop recreational activities in the area of constructive work.

3. To increase an appreciation for good craftsmanship and design, both in the products of modern industry and artifacts from the material cultures of the past.

4. To increase consumer knowledge to a point where everyone can select, use, and maintain the products of industry wisely.

5. To provide information about, and experience in, the basic possibilities of many industries, in order that students may be more competent to choose an occupation.

6. To encourage creative expression and aesthetic appreciation of all industrial materials and products.

7. To develop desirable social relationships, such as tolerance, leadership and fellowship, and tact.

8. To develop a reasonable amount of skill in a number of basic industrial processes.

BASIC PROGRAMS OR SCOPE OF INDUSTRIAL ARTS

The derivation of industrial arts and an examination of its objectives, next calls for an enumeration of the programs required. These include five major types or groups: conventional, technical, professional, recreational, and service, as follows:
Conventional. These involve elementary, secondary, collegiate, and adult types. Children at all levels of the elementary school are materially assisted in their growth in this (technological) type of society, by experiences resulting from work in industrial or practical arts, and especially from an integrated program such as that described by Bonser (8), and his followers (81), (86). Adolescents in the secondary schools would be technically and culturally illiterate if denied the broad orientational, introductory and advanced technical experiences which describe industrial arts at these levels. College students of all types, also live in the technology and must also not be denied such work, but traditionally are, simply because the college world clings to its classical tradition. The adult as a result of an increasing longevity, enjoys more and more leisure especially following retirement, continues to live in the environment of a soaring technology and must not be denied such work, on a consumer as well as a recreational basis.

Technical and/or Terminal Types. These are to be found in the secondary schools, the junior colleges, and the private and corporation schools, simply because all are involved and concerned.

Professional Types. These concern (63), (81) the three degrees: the baccalaureate, the master's, and the doctorate. The first is focused on technical competency, and results in just that. The second is focused on the master teacher, and the third is considered to be a research and leadership degree.
Recreational Types. These again concern (63), (81) the entire population and have resulted in literally thousands of constructive interests involving tools, materials, processes, products, and phenomena— all the way from pop guns to hot rods, or from etching to bookbinding, or from weaving to upholstering, or from toy repair to motor boat operation, or from bird houses to real houses,— and so on without end.

Service Types. These concern industry, the armed forces, agriculture, business, the medical world (i.e. occupational therapy), foreign service, and all other types where elements of the industrial arts program have become so useful, and especially in its phenomenal development and growth during and since World War II.

This chapter has concerned the nature and scope of industrial arts education as per the above derivation and implementation. The problem now, therefore, is to select and project those elements of the electrical resource study presented in Chapter IV,-- into the curriculum phase called for by Chapter VI.
Chapter VI

ELECTRICITY IN THE INDUSTRIAL ARTS CURRICULUM

Chapter IV involved a systematic analysis and presentation of the seventeen principal divisions comprising the highly complex content of "electricity," as such. Chapter V presented a philosophical, bibliographical and field study review of the nature and scope of industrial arts as a major program of American education extending from the elementary school through adult and service levels. This chapter combines the findings of Chapters IV and V with reference to a series of basic and typical learning units at each level.

THE ELEMENTARY SCHOOL

This concerns either six or eight grades, and assumes that units on electricity will be initiated in the classroom and developed on an integrated basis with the technical assistance of an industrial arts specialist.

Lower Primary. This is the most elementary level for activity concerning any aspect of the technology. It is a familiarization period involving play, the simplest of integration and an optimum of imagination.

Electrical toys of all types should be introduced and exploited including telephones, telegraphs, lights, phonographs.
automobiles, trains, boats, cranes, and even radios. The following organization and procedure are suggestive:

1. Unit: "Electricity in Our House"

2. Purpose: Familiarization and Sampling Experiences

3. Item: Electric Toys

4. Activity: Demonstrations or "Show and Tell"

5. Discussion: Integrational leads to: technical, social, recreational, safety, and consumer activity and understanding.

6. Other Items: dry cells, bell wire, sockets, bulbs, switches, keys, bells, buzzers, compasses, magnets, glass and rubber rods, silk, voltmeter, transformer, pithballs, hard rubber comb, milliammeter, . . . .

Intermediate. This is considered to be a period of community-wide understanding including technical, economic, occupational, social and historic, as well as certain elementary scientific phenomena as follows:

1. Unit: "Electricity in Our Community"

2. Purpose: Technical and Economic Sampling

3. Items: Examples of Electricity in the Home and Community

4. Activity: Exploration, Integrational leads, as above

5. Discussion: Same as above

6. Detailed Plan:

a. Specific Purposes

1) To learn where electricity is generated in the community

2) To learn about methods of generating electricity

3) To learn how it is transmitted to factories, homes, schools, stores, and shops
4) To study the kinds of work performed by workers

5) To learn how many volts of electrical power comes to your home

6) To learn how to read a kilowatt hour meter

b. Content

1) Generation of electricity
2) Transmission systems
3) Alternating and direct current
4) Voltage
5) Circuits
   a) Parallel
   b) Series

c. Materials

1) Pictures of power lines and towers, generating plants, (steam and water), substations, and transformers.
2) Step-down transformer 6 to 8 volts. (Train transformer for power station)
3) Alternating current voltmeter (0-110)
4) Alternating current ammeter (0-10)
5) Wire, switches, bulbs and sockets
6) Sand table
7) Coca cola unit on electrical power

d. Procedure: Teacher and Pupils Should

1) Visit electric power plant

2) Make map showing location of plant in community
3) Make sand table model

4) Use transformer for power plant
   a) Connect wire and bulbs to low voltage circuit
   b) Light model houses
   c) Measure voltage and current
   d) Connect several lights in parallel and in series, check voltage and current in each case

The brightness of lights will be controlled by the amount of load (light bulbs) connected to the transformer. Series circuit will increase resistance.

e. Method

1) Discussions and demonstrations by teacher and pupils

2) Individual activity
   a) Connect lights to transformer
   b) Measure voltage and current
   c) Make parallel and series circuits

3) Group activity
   a) Make model houses
   b) Make sand table model of power station
   c) Make map of community
   d) Visit power plant

4) Tell or write stories about electricity in the community

5) Fill in pictures, blanks in Coca cola work book
6) Films and slides
7) Visit industrial arts electrical centers


1) Where does the community get its electrical power?
2) What method of generation is used to generate electrical power?
3) How is electrical power transmitted to the community, to your home?
4) How many transmission wires connect to your house?
5) What is the purpose of the kilowatt-hour meter?
6) What kind of circuit was used in the sand table models?
7) What kind of circuit is used in your house, community?
8) How is a voltmeter connected to a circuit?
9) How is an ammeter connected to a circuit?
10) How many people work at the power plant?
11) Does your father, mother, brother or sister work at the power plant?
12) How can you help the community in conserving electrical power?
13) What safety measures can you use with electricity?
14) What additional knowledge would you like to gain about electricity?

g. General Information. In the space below, write a short account of what you have learned from any field trips, or other group activities connected with this unit.
Upper Grades. The new element here concerns esthetics and the sciences in addition to elementary principles of chemistry and physics, but not necessarily referred to as much:

1. Unit: "Electricity: Why, What, Where and How"
2. Purpose: Wide Sampling of Available Resources
3. Items: All available examples
4. Activity: Increasing Emphasis on Esthetics and Science
5. Discussion: Every possible lead and evaluation
6. Other Items: Making a wet cell, wiring a play house, testing current, measuring heat, charging batteries, connecting cells, creating static electricity, making a compass, making a telegraph, making a telephone, making a magnet, making a transformer, doing electroplating, using the Coca Cola unit, building a crystal radio set, . . . .

THE SECONDARY SCHOOL

This concerns six years of adolescence and involves two major educational levels described by the junior and the senior high school where the basic purposes are first orientational, then technical and recreational.

Junior High School. This is the period of systematic orientation with examples of each of the seventeen divisions or categories of electricity presented in Chapter IV, prefaced by background examples selected from Chapter II. The unit which follows was chosen for its richness in the basic phenomena of electricity.

1. Unit: "Build an Induction Coil to Increase Voltage"
2. Purpose: Orientation
3. Items: Coils, Batteries, Switches, Wire, Meters
4. Activity: Construction and Testing
5. Discussion: Immediate and Related
6. Other Items: Motors, transformers, relays, electromagnets, charts, films, slides, trips, telephones, radios, radars, television, amplifiers, high frequency cooking and lighting.

**Senior High School.** This is the period for the development of technical competence including involved construction, operation and maintenance. Combinations of the categories described in Chapter IV are experienced and mastered. The unit which follows was chosen for its representativeness.

1. Unit: "Construction and Use of a Superheterodyne Radio"
2. Purposes: Orientation, technical, and Recreational
3. Items: Matched Kit (Superheterodyne)
4. Activity: Construction, Testing, Practice
5. Discussion: Immediate and Related
6. Detailed Plan:
   a. Specific Purposes
      1) To learn the difference between tuned radio frequency and the superheterodyne circuit
      2) To develop the electrical and mechanical function of each component part
      3) To identify, construct and operate a superheterodyne receiver
   b. Content
      1) Definition of tuned radio frequency receivers
      2) Definition of superheterodyne receivers
3) Intermediate frequency and how it is obtained
4) Receiver oscillator and oscillation
5) Mixer, oscillator, first detector
6) Tubes and tube markings
7) Transformers of various types
8) Resistors, condensers and their markings
9) Solder and soldering
10) Speakers and baffles
11) Wire and size
12) Circuits and color codes
13) Power supply and types

The instructor should present the electrical function of each component. Each part will also have a mechanical function, but this phase has always been emphasised in industrial arts.

c. Materials. These should include a kit of matched parts for the construction of a superheterodyne receiver.

1) Testing equipment
   a) Ohmmeter
   b) Ammeter
   c) Voltmeter or
   d) Multimeter
   e) Signal generator
   f) Audio signal generator
   g) Oscillograph
h) Wattmeter

1) Tube tester

2) Soldering irons and guns, solder, paste, wire, insulating material (such as spaghetti), chassis, stand-off terminals, metal screws, ... .

When soldering leads to the chassis or ground, the instructor should indicate the electrical function and action between the soldered points on the chassis. These should be combined in order to limit the electrical action through the chassis between the points.

d. Procedure: the student should

1) Assemble a one-tube tuned receiver
   a) Test voltage and current of the receiver
   b) Test or measure resistance in the circuit
   c) Test the capacitors for shorts or "opens"
   d) Determine the types of circuits in the receiver such as parallel, series, and combination

2) Assemble a two-tube receiver or add a second tube to the first, and recheck all points and parts

3) Assemble a three-tube receiver or add the third tube to the two-tube set, and repeat all steps in the above

4) Add a fourth tube. This receiver will now have enough power to operate a loud speaker. This number of tubes creates the following stages:
   a) Antenna
   b) Radio frequency
c) Detector

d) Audio

5) Assemble a five tube superheterodyne receiver which will have the following stages:

a) Antenna, including oscillator, mixer, first detector and amplifier

b) Input intermediate frequency

c) Output intermediate frequency or second detector

d) Audio amplifier and speaker

This receiver will have good volume. All tests in the above steps should be done as the receiver is assembled. The signal generator is used to align the intermediate transformer stages to the proper signal or frequency printed on the circuit diagram or on the can of the transformer. An audio frequency generator is used to check the audio amplifier for reproduction of audio frequencies and distortion characteristics. The oscillograph is used to check the frequency patterns, and distortion characteristics. It may be used to check the voltages.

e. Methods

1) Discussions and demonstrations

2) Individual activity such as

a) Measuring voltage

b) Measuring current

c) Testing tubes

d) Balancing intermediate transformers
3) Group activities such as
   a) Assembling parts on chassis
   b) Reading schematics
   c) Giving demonstrations
   d) Giving reports
4) Visits to radio repair shops
5) Films on radio servicing
6) Slides on radio circuits and parts
7) Mock-ups, charts, diagrams, pictograms, books, tube charts, resistor and condenser color code charts

f. Other experiments

1) Substitute open or shorted condensers for good ones in the circuit and note results
2) Substitute resistors of different values in the circuit and note results by measuring voltages and currents
3) Add a tuning eye to the superheterodyne to aid tuning. Can a tuning eye be employed on the tuned radio frequency receiver?
4) Add an automatic volume control circuit and note the results. Block the circuit on the superheterodyne receiver and note the results
5) Add a volume control including treble and bass
6) Add phono-jacks and a switch for phonograph pickup
7) Check tubes to determine their quality

g. Evaluation: Student self-check list

1) What is the difference between tuned radio and a superheterodyne?
2) What is the electrical function of the power transformer?

3) What do the letters and numbers on radio tubes indicate?

4) Describe the colors used in radio circuits

5) Determine the size of the resistor from the following colors: Red, orange, and blue.

6) How is the end of a condenser that connects to ground determined?

7) What is the best type solder to use in making connections in radios?

8) How is the voltmeter connected to a circuit to measure voltage?

9) How is the ammeter connected to the circuit to measure current?

10) What does the detector do in a radio circuit?

11) What is the purpose of an audio stage?

12) What is a cold solder joint?

13) Did you gain a better appreciation of your radio service man?

14) What ways can the radio service man help you?

15) What ways can you help the electrician?

16) What additional information would you like to gain?

h. Teacher check list of student behavior

1) Attitude toward work and class members

2) Courtesy

3) Safety consciousness

4) Willingness to cooperate
5) Willingness to share with others

6) Workmanship

"ATYPICAL" CASES

Many categories of abnormality are involved and must be properly diagnosed and prescribed before course work can be planned. The atypical child needs to exploit his strengths (mental or physical or social) and may be expected to progress just as far as the normal child in certain specialties.

TECHNICAL LEVELS

This concerns specialisation and mastery of some field of electricity normally in a technical institute or junior college. Practice and skill are involved and a breadth of background is to be achieved and required permitting employment either in technical or sales aspects of the field chosen. Examples include: house wiring, radio and television service, telephone, telegraph, appliances, air conditioning, automotive, farm equipment, power and generating plants, . . . .

RECREATIONAL GROUPS

These usually start with highly developed or specialised interests that need only to be given encouragement, the principal example of which is amateur (i.e. "Ham") radio transmitting and receiving via an FCC license.
ADULT INTERESTS

These programs must be kept flexible in order to satisfy a wide range of interests of adults in this field such as the repair of electrical appliances, building electrical apparatus such as: a remote control radio, an electrical organ (even from kits sold for that purpose), high fidelity phonographs and radios, automatic door openers, automatic light controls, . . . .

The following example is suggestive of an appropriate plan:

1. Unit: Clean, repair and adjust an auto generator.
2. Purposes: Consumer.
3. Items: Auto generator, battery, lathe, mica undercutter, test meters, and tools.
4. Activity: Cleaning, repairing, assembling and adjusting.
5. Discussion:
   a. The case
   b. Armature
   c. Field coils
   d. Voltage regulator
   e. Cleaning, assembling
   f. Adjustments
6. Other items: Air conditioner, automatic dimmer, electric fuel pump, electric gasoline gauge, horns and relays, ignition system, lights, signaling indicators, . . . .
SERVICE FIELDS

These include literally hundreds of foreign, military, industrial, business, and agricultural applications. The course or service work involved must be chosen from their needs and may include: organization, training, manufacture, sales, operations, maintenance, and field service.

This chapter has concerned the development of electricity as a basic part of the educational program represented by the industrial arts curriculum. It has embraced the seventeen principal divisions reported in Chapter IV, which represent the content of "electricity" as such, and has applied these at appropriate levels and programs of the total program.

The next and most vital problem concerns the preparation of teachers to carry out so comprehensive and technical a task. This is the subject of Chapter VII.
Chapter VII

ELECTRICITY IN INDUSTRIAL ARTS TEACHER EDUCATION

This chapter was prepared at the suggestion of President John G. Flowers of the Southwest Texas State Teachers College at San Marcos and of Dr. Earl W. Anderson, Professor of Teacher and Higher Education at The Ohio State University. It concerns the extremely important problem of preparing teachers to handle the subject matter and the programs revealed and implied by Chapters II, III, IV, V, and VI of this dissertation, and of course, to discover any bottlenecks or deterrents to progress that may be involved.

SITUATION IN THE STATES AND COLLEGES

A preliminary inquiry was made concerning the recommendations and offerings of twenty state departments of education in regard to the study of electricity in their secondary schools. The following twelve responded: California, Florida, Iowa, Louisiana, Minnesota, Missouri, North Dakota, Ohio, Oklahoma, Oregon, Texas, and Utah. The following eight did not respond: Arizona, Arkansas, Kansas, Idaho, Nevada, New Mexico, South Dakota, Washington State. Gists of the responses now follow:

California (15, p. 25) reports dealing with electrical principles and skills in wiring and repairing appliances at "Level II," presumably the junior high school, with occupational requirements at "Level III," presumably the senior high school, and with an elective offering at "Level IV," presumably the junior college.
Florida (24, p. 8) recommends an orientation unit of "power" (which is defined as including electricity) in the junior high school.

Iowa (37, p. 92) is satisfied merely to recommend that their pupils "learn about electricity."

Louisiana (43, p. 46) recommends four unnamed courses in electricity of semester length for its secondary schools as follows: two periods per week of "lecture," two periods of "laboratory" and one period of "drawing."

Minnesota recommends an 18 to 45 clock-hour "course."

Missouri (49, p. 8) recommends one credit in electricity composed of 5 sixty-minute periods per week, per year. They refer to the importance of electricity in the home, on the farm, and in industry, and make a point of any secondary school being "inadequate," if it fails to offer such work.

North Dakota (62, p. 1) is satisfied merely to recommend that some undefined "electricity be offered" in the secondary schools.

Ohio (63, p. 4) refers merely to electricity being "basic" to the industrial arts program.

Oklahoma recommends that a six to nine week "unit" of electricity be offered in the junior high school.

Oregon (64, p. 10) recommends 18 weeks of "practical electricity" in the tenth grade and states that such work is "basic to vocational guidance."
Texas recommends that "electricity be taught" from six to nine weeks in the junior high school and that it be "more advanced and technical" in the senior high school.

Utah (84, p. 21) is satisfied merely to endorse work in electricity for the junior and senior high school.

The situation in the states is comparable to that in the teacher education programs. For example, Walter K. Williams, Jr. of Florida, working in behalf of the American Council on Industrial Arts Teacher Education, listed (1) the electrical course credit offerings reported by 200 colleges in 1952, from which the following data have been compiled:

<table>
<thead>
<tr>
<th>Sem. Credits</th>
<th>No. of Colleges</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>3</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>48</td>
<td>1</td>
</tr>
<tr>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>53</td>
<td>1</td>
</tr>
<tr>
<td>55</td>
<td>1</td>
</tr>
<tr>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>72</td>
<td>1</td>
</tr>
<tr>
<td>78</td>
<td>1</td>
</tr>
</tbody>
</table>

200 cases
It can be seen from these reports that: (a) while some of the states have acknowledged the presence and importance of "electricity" in modern day technological life, they frankly have not faced up to analyzing it or to the serious need for implementing it in their industrial arts programs at any level, and (b) the colleges present a very unbalanced, and even an inconsistent pattern of programs in which well over half or 124 of them offer less than a single 5-credit course while at least 15 others have adopted absurdly extended sets of highly specialised offerings of a trade, technical, or engineering nature. Such data, therefore, permit the conclusion that neither the states nor the colleges have accepted their responsibility for organizing and projecting what is now required for electricity in the industrial arts curriculum at all levels.

**Essentials of the Three Degrees**

William E. Warner (84), in an unpublished lecture, has listed the assumptions and the patterns for each of the three degrees in industrial arts education as follows:

**The Baccalaureate is a Technical Competency Degree.** It should be comprised of approximately 50 percent of broadly defined technical or major course work, 25 percent of pedagogical and professional course work and 25 percent of related academic course work, in the following patterns:

1. **Selective Factors.** See the Cleveland Conference Outline
2. **Freshman.** Vestibule Laboratory of Technology
   Mathematics, English, Composition, Speech, Physical Education, Military . . . Continuous Club Participation


5. Senior. Professional Emphasis. Consumer Literacy Training. Practice Teaching, Educational Psychology, Guidance and The Senior Laboratory of Technology

6. Placement. Follow-up, Advancement

As regards the subject matter of electricity presented in Chapter IV, and a subsequent or similar presentation to be done in electronics, this degree should include prerequisites in mathematics and physics and be followed by a series of technical and professionalized or integrated learning units, like those indicated in Chapter VI, to the extent of approximately 9 semester credit hours in the junior and senior years. These should consist of three 3-credit technical courses:

1. **Principles of Electricity** to comprise the subject matter of Chapter VI.

2. **Principles of Electronics** to comprise the subject matter of the companion dissertation on this subject recommended and outlined in para 2 on p. 262.

3. **Electrical Operations** to comprise the use of the appliances from agriculture, business, home, and industry listed on pages 255 and 256, climaxd by a degree of mastery in communications and especially the achievement of and F.C.C. license for the operation of an amateur radio station.
The vestibule course for freshmen should include a variety of orientational and interest holding problems including circuits, tests, and mock-ups illustrating basic phenomena.

The professional courses for seniors that follow the technical sequence outlined above should involve course of study development at all levels including the layouts, equipment, and supplies involved.

The MA is a Master Teacher Degree. It should be comprised of approximately 70 percent professional and advanced technical course work in industrial arts education and 30 percent of broad professional work outside the major, in the following pattern:

1. Selective Factors. Including all Technical Prerequisites. Check Leadership Record of Staff, Quality of Research, Library, and Resources. Type of Community, Forums, and Fraternity Programs. Physical and Social Setting.
2. Industrial Arts Education. Doctrine, Programs, Curricula, Organisation, Shop Planning, Research, Seminar, and Thesis. The Senior Laboratory of Technology
3. Professional. Educational Philosophy, Secondary (and/or Elementary and Adult) Education, School Administration, ...
4. Placement, Follow-up, Advancement

Electricity should be found in philosophy, curriculum, organization and administration, and school shop planning courses.

The Doctorate is a Leadership Degree. It should be comprised of a major and two or more pertinent minors as follows:

1. Selective Factors. Fitness of Candidate. Prerequisite, the BS and MA Degrees Described Above
2. Matriculation Program. Courses and Preparatory Work. Examinations in the major and the minors
3. Leadership Training. Forums, Authorship, Associational Activity, Teaching, and Developmental Field Work
4. Research Program. Dissertation and Examinations
5. Placement, Follow-up, Advancement
Electricity should be found in a laboratory research course or practicum at this level, and be projected or developed by the candidate in the field at least on a developmental basis in connection with his training.

**BASIC LABORATORY EQUIPMENT**

An industrial arts teacher education "Electrical Center," should include from 1000 to 3000 square feet of *instructional* space in addition to from 200 to 1000 square feet of *auxiliary* space composed of display, office, storage, and supply areas,—and not less than an initial budget of $20,000.00 for equipment and supplies as outlined below:

The following is a basic list of *apparatus, appliances, and aids* that are necessary for presenting the data referred to in this dissertation and especially their many applications in:

1. *agriculture*, 2. *business*, 3. *home and community*, 4. *industry*, and (5) *science and the future*. The list assumes proximity or easy access to a maintenance, general, or metal and wood shop, and does not include such common office or laboratory fixtures as cabinets, chairs, desks, display cases, files, tables, and tool racks, that would be required by an instructional center.

**Apparatus.** This includes:


* Most desirable

Ohmmeter.* Oscillograph. Oscilloscope.* Panel. Pyrometer. Syn-
chronoscope. Thermocouple.* Test sets. Vacuum tube voltmeter.*

Voltmeters:* AC and DC. Wattmeter.*

2. Generators: AC and DC types of high and low voltage.*

Electronic types: audio-frequency and radio, and sweep.*

3. Supplies: Bulbs:* fluorescent, incandescent, and mer-

Growler.* Hardware:* all types. Induction coils. Magnets:*

all types. Tape:* friction, plastic and rubber. Tool kits:* Trans-
fomers:* audio, power, and radio. Tube sockets:* all types. Tube tester.* Vacuum tubes:* all types. Vibrators:* synchronous and nonsynchronous. Wet cells.* Wire:* magnetic, nichrome, stranded, and solid of all coverings and gauges. Wire gauges.*

Appliances. These include:


* Most desirable
houses.* Incubators.* Infrared heaters.* Milking machines.

Motors.* Fans. Pumps.


Calculators. Communications:* facsimile, intercom, radio, tele-

graph, telephone, teletype, television closed circuit. Duplicators.


Heaters:* air and water. High Fidelity.* Irons. Lawnmowers.


Mixers. Ovens. Radio: amateur station, FM, superheterodyne, radio


Telephones. Television:* black and white, and color. Thermostats.*

Toasters.* Vacuum cleaners. Waffle irons.* Washing machines.

4. Industry


b. Production. Controls:* automatic, heat, light, pressure. . . . Counters.* Conveyors.* Diathermy* (high fre-

quency heating). Door openers.* Electroplating.* Gener-

ators:* AC and DC, single and polyphase, high and low voltage

* Most desirable
types. Infrared (i.e. to dry paint). Magnaflux. Magnetostrictor (i.e. ultra-sonic wave cleaner, ...). Microwaves (i.e. cookers). Motors: AC and DC single and polyphase.

Photoelectric cells.* Pyrometers.* Timing devices.* Ultrasonic waves (i.e. for drilling).* X-ray.

c. Communication. Facsimile. Loran. Piezoelectricity (i.e. constant radio frequency generation).*


Teletype. Television.

d. Transportation.


* Most desirable

**Aids.** These include:


This chapter was included to draw attention to some of the principal bottlenecks involved in the progress of electrical instruction in American schools. Teacher education has failed to clarify and implement its objectives particularly as regards the

---

* Most desirable
complex resources of "electricity", and state departments of education have actually given little more than lip-service support.

These in addition to the virtual absence of the resource or content studies necessary to prepare courses and manuals of instruction, plus woefully inadequate laboratories and equipment, serve to explain, but not to condone the present situation. Each of the three degrees has been examined for program essentials and recommendations, in keeping with the findings of Chapters V and VI and a $25,000 list of essential laboratory apparatus, appliances, and aids has been included to assist in stimulating the progress that must be made.
Chapter VIII

SUMMARY AND CONCLUSIONS

This dissertation includes an historic research on electricity in early times,—or from the age of superstition to the age of science,—and is followed by a systematic and exhaustive resource or content study of contemporary electrical knowledge and practice reported under seventeen headings enumerated below. By way of application, the subject matter thus recorded is then adapted by examples to the industrial arts curriculum from elementary to adult and service levels, and concludes with a chapter of implications for teacher education.

FINDINGS OF THE RESOURCE STUDY

These are prefaced by two background chapters, one entirely historic, and the other a preliminary or contemporary view of the spread and increasing use of electricity in agriculture, industry, science, and the future. The major resource chapter includes a presentation of each of the following seventeen subject matter headings or categories: (1) characteristics, (2) magnetism, (3) electron theory, (4) voltage, (5) current, (6) cells, (7) conductors, (8) measurement, (9) circuits, (10) condensers, (11) induction, (12) transformers, (13) relays, (14) switches, (15) dynamos, (16) transmission and (17) rectifiers. A fully annotated list of fifty major technical references concludes this chapter.

260
The nature and extent of industrial arts education is next
examined after which examples of proposed instructional units of
electricity are presented for each level: elementary, secondary,
technical, adult, and service. This is followed by a special chap-
ter of suggestions and implications for teacher education.

RECOMMENDATIONS

The technical development and commercial use of electricity
and electronics has come with a rush, or for all practical pur-
poses, since the turn of the century. It is now an eighteen
billion dollar industry and affects the lives of every person in
the United States. Even so, the U. S. Office of Education reports
that not more than 10 percent of the 30,000 industrial arts teachers
involved have received training in this subject and fewer than
3 percent offer it as a program of realistic proportions. The find-
inge of this study have stimulated the following conclusions and
recommendations.

1. Instructional units in electricity must be taught at all
levels, elementary through adult or from magnetism through elec-
tronics, by the conclusion of the secondary school. Its integra-
tional possibilities are enormous and must be exploited, including
the mathematics, science, economic, and certainly the cultural
implications.
These units are taught by the home room teacher. They should be prepared from electrical topics and devices interesting to children. For example, a compass, a magnet, toy animals with attached magnets, as well as topics similar to the following: "What causes the light to come on?", "What causes my toy electric train to go?", "What causes my toy electric iron or stove to get hot?" These topics should grow out of art, numbers, stories, and other activities that have electrical subject matter. The teacher should aid children at all levels in the development of these units. The teacher should have the help of the industrial arts teacher, state consultant, and representatives of electric machinery industry. In-service and refresher courses offered by teacher training institutions would be of value to the classroom teacher. Similar procedures should be used in developing instructional units for secondary, adult and teacher college levels.

2. A companion dissertation on electronics should be done so the subject matter of that field can be made available to industrial arts and technical education people. A similar set of subdivisions to the seventeen listed in Chapter IV include the following: (1) waves, (2) detection, (3) theory, (4) measurements, (5) rectifiers, (6) circuits, (7) tubes, (8) receivers, (9) amplifiers, (10) resistors, (11) capacitors, (12) modulators, (13) inductors, (14) oscillators, (15) resonators, (16) antennas, and (17) transmitters.
3. Administrative officers at state and local level need to clarify their appreciation of electricity and the need for it in the schools at all levels by making explicit recommendations as well as arranging for the necessary funds. Administrative officers could do these by making studies of resource materials and working directly with industrial arts teachers of electricity, with elementary school teachers, and with consultants of electric manufacturing companies such as Edison Electric, General Electric, Westinghouse, and Light and Power.

4. Those in charge of teacher education need badly to clarify their purposes, to offer much better programs than at present, and to work toward better standardization.

Those in charge of teacher education programs of electricity can clarify their purpose by (1) determining qualifications of the industrial arts teacher as to attitude, perspective, knowledge and skills, (2) the industrial arts teacher must be prepared to carry out his assignment as well as be able to project his program in light of the trends in technology and society.

These programs can be increased to three courses as follows:
(1) Principles of Electricity to comprise the subject matter of Chapter IV, (2) Principles of Electronics to comprise the subjects of the companion dissertation described above, (3) Electrical Operations to comprise the use of appliances from agriculture, business, home and industry listed on pages 255 and 256, climax by an F.C.C.
license for the operation of an amateur radio station. These courses would aid standardization.

5. Organised experimentation and development work needs to be encouraged by all professional associations with a direct interest in this field, particularly the American Industrial Arts Association, and by such programs as the Ford Awards Program. This work would be concerned with electrical activities, laboratory equipment, visual aids, and constant search for wider applications of apparatus, appliances, and aids.

6. The literature necessary to this field has not been developed, and this development needs to be stimulated by industrial arts consultants and teachers, after which it will need to be revised periodically to keep pace with the rapid advancements.

There is a great need for text books and suitable stories of electricity for the elementary school. Secondary school texts are limited in scope or total coverage of electrical subject matter. Books are plentiful with engineering features which are too difficult for most secondary pupils. Books for adult and teacher education have the same characteristics. Libraries, museums, technical journals as well as electric companies have valuable materials concerned with appliances, applications, aids and historical materials of electricity. Industrial arts teachers and consultants using these materials and working closely with electric companies can improve the literature.
7. **Refresher and in-service training courses** will need to be offered as the above recommendations are achieved, in order not only to keep the industrial arts profession abreast of trends, but to fill the present void. These should be done by teacher training institutions.

8. The electric machinery industry should take more initiative in trying to understand and appreciate the significance of the programs described in Chapter VI and to cooperate actively in their development. The industry must be made aware by industrial teachers of the needs of the electrical programs at all levels. For example, junior electric and electronic sets are now available for school use. Dry and wet battery kits are greatly needed, as well as small electric motors and generators.

9. Since most industrial arts teachers will be teaching adults at one time or other, methods and techniques of teaching them should be included in the curriculum. Students planning to teach industrial arts should supplement their theoretical learning by observation in YMCA's, evening high schools, and technical institutes.
SELECTED BIBLIOGRAPHY

1. American Council on Industrial Arts Teacher Education. 


27. Furnas, Clifford Cook. The Next Hundred Years, the Unfinished Business of Science. Baltimore, Williams and Wilkins, 1936, 434 p.


63. Ohio, State Department of Education. *Suggested Outline of Syllabus for Electrical Unit*. Columbus, 1953.


78. Sotzin, Reber A. *Equipment List and Recommendation for California State Colleges.* Mimeographed. San Jose, State College


AUTOBIOGRAPHY

I, WILLIAM LUTHER DECK, was born in Pontotoc, Texas on September 6, 1912 and received a diploma from the high school of London, Texas in 1930. My B.S. degree in industrial arts education and social science was obtained from the Southwest Texas State Teachers College at San Marcos in 1939 and my M.A. degree in industrial arts education was received there in 1940. My residence work on the doctorate in education was done in 1949-50 at The Ohio State University.

Following a year on the faculty at San Marcos, I was given leave in 1941 to teach navigation and meteorology in the Air Force in which I was commissioned and became a Captain, and received C.A.A. ratings for all aviation ground school subjects, later becoming Director of Instruction and Coordinator of Flying for the Civil Pilot Training program. While in the Air Force, I attended Washington and Lee University and did a tour of duty with a B-29 Group in the Southwest Pacific, returning to San Marcos in 1946, where I am now an associate professor of industrial arts education.