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IDENTIFIERS	Military Curriculum Project

ABSTRACT

This self-paced correspondence course for independent study in electricity was adapted from military curriculum materials for use in vocational education. This basic course is designed to provide the student with some fundamentals of electricity--not with specific job skills. The seven lessons of the course each have a lesson assignment sheet with objectives, materials required, and suggestions. The lessons cover the following topics: electrostatics; electrokinetics; Ohm's Law and direct current circuits; alternating current, inductance, and capacitance; resistive-capacitive and resistive-inductive circuits; operation and characteristics of vacuum tubes; and operation and characteristics of transistors. Each lesson contains objectives, text, and review exercises. The answers to the exercises are programmed so that additional information is provided in the case of an incorrect choice, and immediate feedback is given on a correct choice. A 50-question multiple choice final examination, without answers, is included with the package. (KC)

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

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- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
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Military Curriculum Materials
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The National Center for Research in Vocational Education
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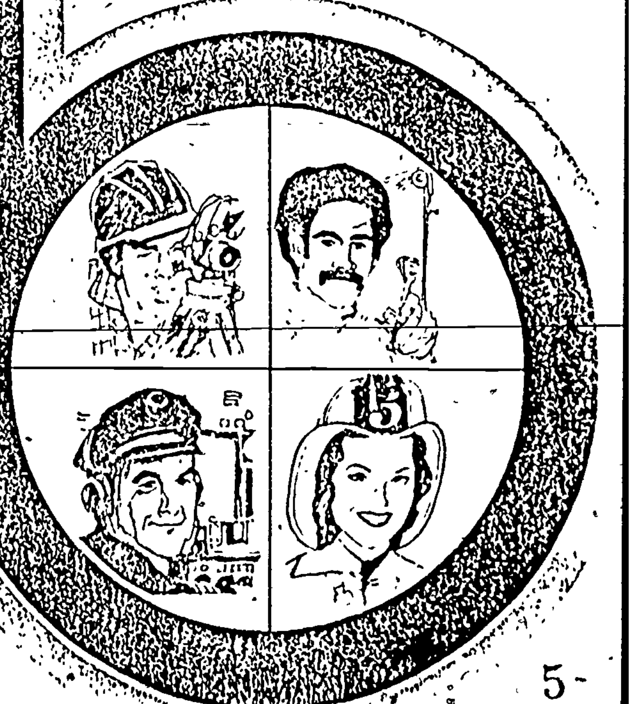
Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education



Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
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Springfield, IL 62777
217/782-0759

NORTHWEST
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FUNDAMENTALS OF ELECTRICITY

Table of Contents

Developed by

United States Army

Development and Review Dates

Unknown

Occupational Area:

Building and Construction

Cost: $3.75 **Print Pages** 181

Availability:

Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Suggested Background.

None

Target Audiences

Grades 10-adult

Organization of Materials:

Lesson assignments with objectives, text materials, and suggestions, lesson exercise questions with programmed answers, and course examination

Type of Instruction

Individualized, self-paced.

Type of Materials.

		No. of Pages:	Average Completion Time:
Fundaments of Electricity			
Lesson 1	– Electrostatics,	18	Flexible
Lesson 2	– Electrokinetics	25	Flexible
Lesson 3	– Ohm's Law and Direct Current Circuits	14	Flexible
Lesson 4	– Alternating Current, Inductance, and Capacitance	9	Flexible
Lesson 5	– Resistive-Capacitive and Resistive-Inductive Circuits	11	Flexible
Lesson 6	– Operation and Characteristics of Vacuum Tubes	29	Flexible
Lesson 7	– Operation and Characteristics of Transistors	34	Flexible
Exercise Response List		29	
Examination		8	

Supplementary Materials Required

None

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Course Description

This is a basic course designed to provide the student with some fundamentals of electricity. It does not include electrical tasks or specific job skills The seven lessons each have a lesson assignment sheet with objectives, materials required, and suggestions. They cover the following topics

Lesson 1	—	*Electrostatics* is divided into two sections. The first section on electrification covers attraction and repulsion, the structure of matter, atomic structure, and charging by contact and induction The second section on electrostatics covers electric fields and lines of force.
Lesson 2	—	*Electrokinetics* discusses current, resistance, voltage and magnetism.
Lesson 3	—	*Ohm's Law and Direct Current Circuits* explains circuit components, circuit fundamentals, and circuit analysis, power, and resistors.
Lesson 4	—	*Alternating Current, Inductance, and Capacitance* discusses alternating current and its comparison with direct current, describes inductance and capacitance and their presences in a.c. circuits, and gives methods used to determine the amount of inductance and capacitance in an a.c. current.
Lesson 5	—	*Resistive-Capacitive and Resistive-Inductive Circuit* is divided into two parts. The first part dealing with RC circuits discusses wavelengths, circuit response, time constants, charts, and power. The RI section discusses circuit-response, time constants and power in a series RI circuit.
Lesson 6	—	*Operation and Characteristics of Vacuum-Tubes* discusses electron emmission, diodes, triodes, and multi-electrode tubes.
Lesson 7	—	*Operation and Characteristics of Transistors* covers transistor functions, transistor material, electrical charges inside a semiconductor, electron-hole movement, electron-hole movement in a single crystal, the relationship of transistors and diodes, bias, movement of charges in a diode, transistor symbols, transistor circuits, common emmitters, common circuits, collector circuits, amplification, transistor characteristic curves, transistorized equipment, and testing transistors with an ohmmeter.

This basic course is designed for student self-study. Each lesson contains objectives, text and review exercises. The answers to the exercises are programmed so that additional information is provided in the case of an incorrect choice, and immediate feedback is given on a correct choice A fifty multiple choice final exam is included with the package, but answers are not available.

CORRESPONDENCE COURSE

of the

U.S. ARMY ORDNANCE

CENTER AND SCHOOL

ORDNANCE SUBCOURSE NUMBER

98

FUNDAMENTALS OF ELECTRICITY

SEPTEMBER 1973

(IMPORTANT INFORMATION ON BACK COVER)

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CORRESPONDENCE COURSE
of the
US ARMY ORDNANCE CENTER AND SCHOOL

ORDNANCE SUBCOURSE NUMBER 98, FUNDAMENTALS OF ELECTRICITY
(24 Credit Hours)

INTRODUCTION

This subcourse has been designed to provide you with a general knowledge of the fundamentals of electricity and basic electronics. It should be of great help to you in any further study of equipment electrical systems.

This subcourse consists of seven lessons and an examination organized as follows:

Lesson 1 Electrostatics
Scope—To familiarize you with the theory of static charges.

Lesson 2 Electrokinetics
Scope—To familiarize you with the theory of moving charges.

Lesson 3 Ohm's Law and Direct Current Circuits
Scope—To familiarize you with Ohm's law and the parameters of direct current circuits.

Lesson 4 Alternating Current, Inductance, and Capacitance
Scope—To familiarize you with the fundamentals of alternating current and its interactions with inductance and capacitance.

Lesson 5 Resistive-Capacitive and Resistive-Inductive Circuits
Scope—To familiarize you with the characteristics of RC and RL circuits.

Lesson 6 Operation and Characteristics of Vacuum Tubes
Scope—To acquaint you with the basic principles of operation and application of vacuum tubes.

Lesson 7 Operation and Characteristics of Transistors
Scope—To familiarize you with the operation, characteristics, and construction of transistors.

Examination

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CHECKLIST OF TEXTS AND MATERIALS FURNISHED

Ordnance Subcourse No 98
September 1973

No texts, other than the attached memorandums in lessons, are used in support of this subcourse. Therefore, you are not required to return any texts to the US Army Ordnance Center and School,

This subcourse may contain errata sheets. Make certain that you post all necessary changes before beginning.

Return all unused franked envelopes to the US Army Ordnance Center and School at the same time you send in the answer sheet to the examination.

Note. - The following publications were used in the preparation of this subcourse:

TM 11-661	Electric Fundamentals (Direct Current)
TM 11-681	Electric Fundamentals (Alternating Current)

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CORRESPONDENCE COURSE of the US ARMY ORDNANCE CENTER AND SCHOOL

LESSON ASSIGNMENT SHEET

Ordnance Subcourse No 98	Fundamentals of Electricity
Lesson 1	Electrostatics
Credit Hours	Three
Lesson Objective	After studying this lesson you will be able to state the: 1. Principles of electrification and magnetism. 2. Theory of electrostatics to include electric fields and lines of force and their effect on charged and uncharged bodies.
Text	Attached Memorandum
Materials Required	None
Suggestions	None

STUDY GUIDE AND ATTACHED MEMORANDUM

1. INTRODUCTION.

a. There are two fundamental and invisible forces which are responsible for the wonders of electricity: electric and magnetic. These are the forces which make possible the operation of electric motors, generators, lights, and other electrical apparatus. To become a good repairman of any electrical system an understanding of these forces is essential.

b. In this lesson we will concentrate on the study of static charges; later, we will study moving charges, magnetism, and the operations and characteristics of electrical components.

2. ELECTRIFICATION.

a. Early history. The ancient Greeks found that a yellowish resin called amber, if rubbed, will attract small bits of wood shavings. They also learned that the invisible force about a piece of amber so rubbed is different than the force about a magnetized piece of iron; i.e., the force about the amber, a nonmagnetic substance, does not attract

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magnetic substances; while a magnetic force does not attract a nonmagnetic substance, such as wood shavings. Later it was discovered that many other substances such as glass and rubber, after being rubbed with a piece of fur, wool, silk, etc., exhibit the same characteristics as amber; i. e., they attract bits of paper, wood, and certain other light objects.

(1) In 1733, a Frenchman named DuFay observed that when a piece of glass is rubbed with cat's fur, the glass and the cat's fur both become electrified, but that the glass will attract some charged objects that are repelled by the cat's fur and vice versa. From this observation he concluded correctly that there are two exactly opposite kinds of electricity.

(2) Benjamin Franklin introduced the terms positive (+) and negative (-) into the science in order to distinguish between the two different kinds of electricity. Franklin defined a positively charged body as one which exhibits the same kind of charge as that associated with a piece of glass after it is rubbed with silk. He defined a negatively charged body as one which exhibits the same kind of a charge as that associated with a rubber rod after it is rubbed with cat's fur. He defined as electrically neutral all bodies which exhibit no charge.

(3) Further study and experimentation since Franklin's time have added much information regarding the characteristics of electric charges and forces.

b. Attraction and repulsion. The forces of attraction and repulsion between electrically charged bodies may be demonstrated as follows: One end of a rubber rod is rubbed with fur and then suspended by a piece of string (fig. 1A). When a second rubber rod has been electrified the same way and its charged end brought near the charged end of the suspended rod; the latter turns away (fig. 1A) showing repulsion. If, instead of the second rod, the fur is brought near the charged end of the suspended rod, the latter turns toward the fur (fig. 1B). If a glass rod, rubbed with silk, is brought near the charged end of the suspended rod, there is attraction (fig. 1C), but when the silk is used, there is repulsion (fig. 1D). Since the fur and the glass both attract, these have the same kind of electricity and are said to be positively charged. The rubber and silk are said to be negatively charged. This experiment shows that two kinds of charges or electricity exist. It also demonstrates a rule concerning the action of one kind of charge on another.

(1) Figure 1A shows that two negative charges repel each other. Figure 1C shows that positive and negative charges attract each other, and figure 1E shows that two positive charges repel each other. This attraction or repulsion is mutual and is expressed in the following fundamental laws: LIKE CHARGES REPEL EACH OTHER; UNLIKE CHARGES ATTRACT EACH OTHER, or, THE FORCE BETWEEN TWO LIKE CHARGES IS ONE OF MUTUAL REPULSION; THE FORCE BETWEEN TWO UNLIKE CHARGES IS ONE OF MUTUAL ATTRACTION.

(2) Also, it has been found that the force of attraction or repulsion between two electrical charges varies directly with the product of the quantities of the charges and inversely with the square of the distance between them. This may be expressed by the following mathematical equation:

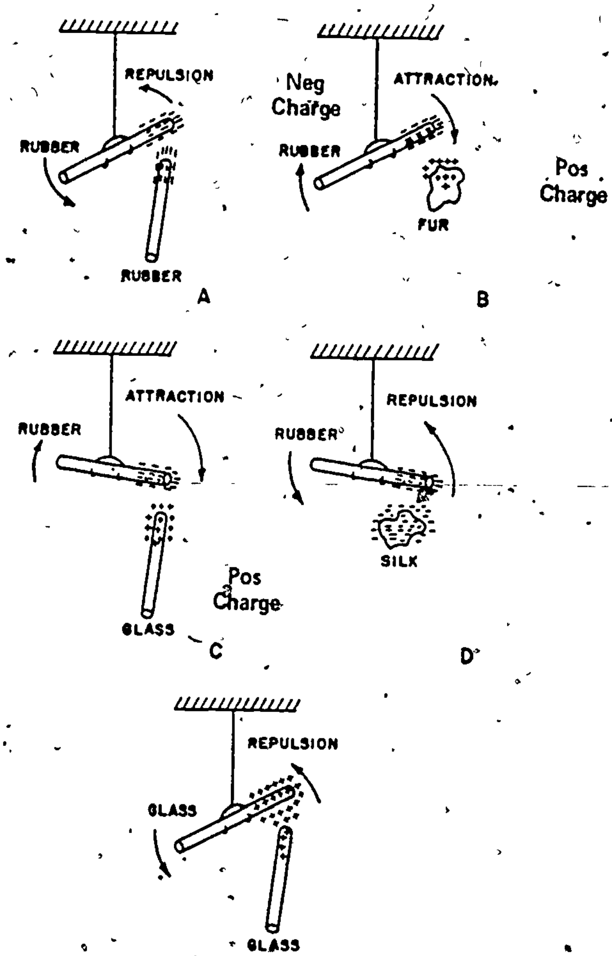

Figure 1. Attraction and repulsion of charged bodies.

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$$F = \frac{q1\ q2}{ed^2}$$

where F = force,

d	=	distance between charges,
q1	=	quantity of one charge,
q2	=	quantity of second charge, and
e	=	dielectric permittivity of the medium in which the charges are located. In vacuum, $e = e_0 = 1$.

The force is one of attraction if the charges are unlike and one of repulsion if the charges are alike.

c. Structure of matter. Matter may be defined as any substance that has weight (mass) and occupies space. Examples of matter are the air we breathe, water, cars, the clothing we wear, and our own bodies. From these examples, we can conclude that matter may be found in any one of three states; namely, solid, liquid, or gaseous.

(1) All matter consists of one or more basic materials which we call elements. Scientists have definite proof that 102 elements exist and believe that there are several others as yet undefined. In chemistry, an element is defined as a substance that can be neither decomposed (broken up into a number of substances) by ordinary chemical charges nor made by chemical union of a number of substances. Copper, iron, aluminum, and gold are examples of metallic elements; oxygen, hydrogen, and sulfur are nonmetallic elements.

(2) A substance containing more than one constituent element and having properties different from those of the elemental constituents is called a compound. For example, water is made up of two parts hydrogen and one part oxygen. Therefore, water is a compound.

(3) A molecule is defined as the smallest particle of matter which can exist by itself and still retain all the properties of the original substance. If we take a drop of water, a compound, and divide it until we have the smallest particle possible and still have water, that particle is known as a molecule. An idea of the size of molecules may be obtained by imagining that a stone is first broken into two pieces, and that this process is carried on indefinitely. The smallest particle of stone which could be obtained by this process would be a molecule. Actually, it is impossible to crush a stone into its molecules; we can only crush it into dust. One small particle of dust is composed of thousands of molecules.

(4) An atom is defined as the smallest part of an element that can take part in ordinary chemical changes. The atoms of a particular element are of the same average mass, but their average mass differs from that of the atoms of all other elements. For simplicity, the atom may be considered to be the smallest particle that retains its identity as part of the element from which it is divided. Figure 2 shows that a molecule of water is made up of two atoms of hydrogen and one of oxygen. Since there are 102 known elements, there must be 102 different atoms or a different atom for each element. All substances are made of one or more of these atoms. Just as thousands of words can be made by combining the proper letters of the alphabet, so thousands of different materials can be made by chemically combining the proper atoms.

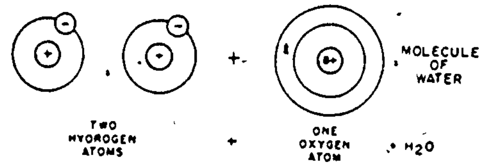


Figure 2. Water molecule.

(5) Although it was formerly believed that the atom was the smallest particle of matter, it is known now that the atom itself can be subdivided into still smaller, or subatomic particles: electrons, protons, and neutrons.

d. Atomic structure. Figure 3 shows how three aluminum atoms would probably appear if magnified 100 million times, surrounding the positively charged nucleus are negatively charged electrons that continually revolve at a very high speed. The electron theory explains that the atoms of all elements (copper, gold, oxygen, etc.) are similarly constructed of a central nucleus and revolving electrons.

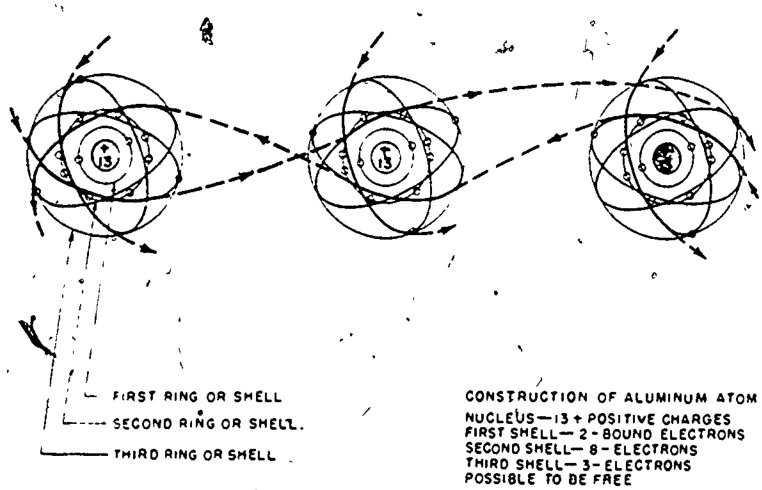


Figure 3. Three atoms of aluminum.

e. Examples of atomic structure.

(1) Figure 4A represents the atomic structure of the simplest of all atoms, the hydrogen atom. It contains one electron revolving around one proton which acts as a nucleus. Because the negative charge on the electron is exactly equal to the positive charge on the proton, the atom is electrically balanced or neutral. An atom is always electrically balanced - the number of electrons equals the number of protons.

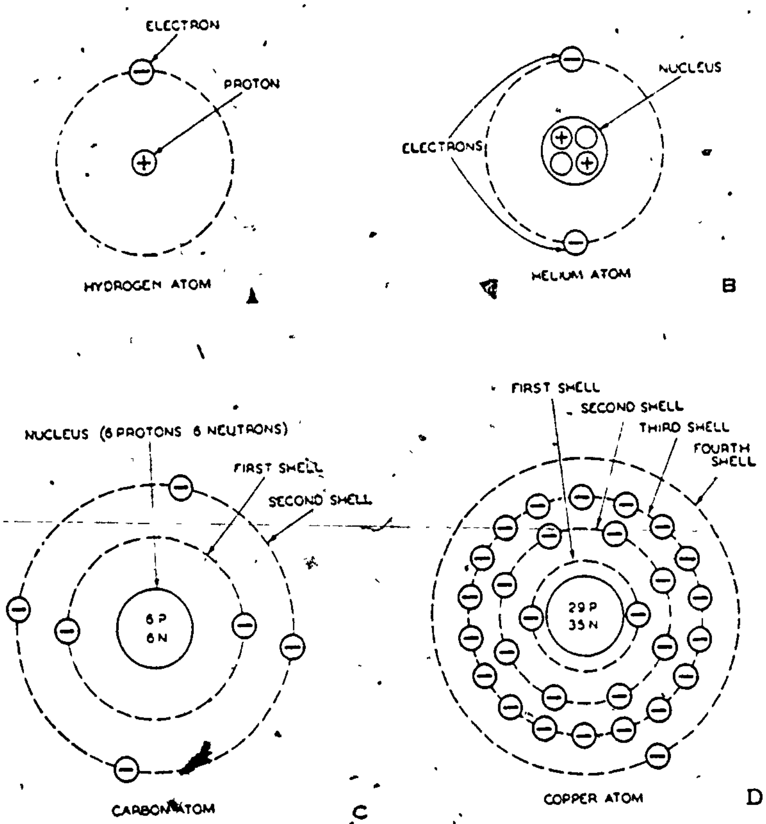


Figure 4. Structure of atoms.

(2) Figure 4B represents the helium atom. The nucleus of the helium atom contains two neutrons and two protons. The positive charges of the two protons are just balanced by the negative charges of the two revolving electrons and the electrical charge on the entire atom is again neutral.

(3) Atoms of other elements are more complex than the hydrogen and helium atoms. For example, figure 4C represents the structure of the carbon atom. Note that the six orbital electrons revolve in two separate rings or shells.

(4) In figure 4D an even more complex atom is shown; namely, the copper atom. The nucleus is composed of 29 protons and 35 neutrons. The orbital electrons revolve in four separate shells, only one electron revolves in the outer shell.

f. The building blocks. The electron theory shows that the only difference among the various elements is the number and arrangement of the electrons, protons, and neutrons of which each atom is composed. There is no difference between the electron in an atom of copper and the electron in an atom of aluminum, or any other element. There is no difference between a proton in one atom and a proton in another atom of a different element. Likewise, the neutrons in the atoms of various elements are thought to be identical. Since all matter is composed of atoms and all atoms are composed of positively charged particles called proton, negatively charged particles called electrons, and uncharged particles called neutrons, it follows that the proton, electron, and neutron are the fundamental building blocks of the universe.

g. Characteristics of subatomic particles.

(1) Electrical. The electrical charge of the proton is exactly equal and opposite to that of the electron; i.e., the proton and electron contain exactly equal amounts of opposite kinds of electricity. Because it is believed that no smaller amount of electricity exists, the charge on the electron or proton is the elemental unit of electrical charge. However, the elemental unit is too small a quantity of electricity for practical purposes and a larger unit of charge called the coulomb is commonly used. One coulomb of electricity contains over 6 million, million, million (6.28×10^{18}) electrons. Neutrons are uncharged particles.

(2) Physical. Electrons and protons are approximately spherical particles of matter. The diameter of an electron, approximately 0.00000000000022 inch, is about three times the diameter of a proton. Despite its smaller diameter, a proton has a mass 1,850 times greater than the mass of the electron; that is, a proton is 1,850 times heavier than an electron. The diameter and mass of a proton and a neutron are approximately the same. Relatively speaking, there are great distances between the electrons and the protons of an atom even in solid matter. It has been estimated that if a copper one-cent piece could be enlarged to the size of the earth's path around the sun (approximately 186,000,000 x 3.14 miles), the electrons would be about the size of baseballs and would be about 3 miles apart. What then keeps the electrons in their orbits? In order to better understand this phenomenon, we must continue our study of energy as evidenced through the forces of nature.

h. Charging by contact. Figure 5A shows a neutral body with equal numbers of electrons and protons. If, as shown in figure 5B, a negatively charged body is placed in contact with the neutral body, electrons will pass from the charged body to the neutral body. If the negatively charged body is then removed, the body that was originally neutral will possess an excess number of electrons and will, therefore, be negatively charged (fig. 5C). If, during the above experiment, a positively charged rod had been used instead of the negatively charged rod, the neutral body would have lost some of its electrons to the positively charged body and the neutral body then would have acquired a positive charge. In either case, the neutral body is charged by contact and becomes charged with the same polarity or kind of charge as the charging body.

i. Charging by induction. A second method of charging a neutral body is by induction.

(1) Suppose that a neutral body is again suspended by a piece of string (fig. 6A), and suppose that one end of this neutral body is connected to another large neutral body, ground or earth, by means of a switch.

(2) If, as shown in figure 6B, a negatively charged rod is brought near to, but not in actual contact with, the neutral body, the negatively charged body will repel electrons on the neutral body and will cause some of these electrons to flow into the ground.

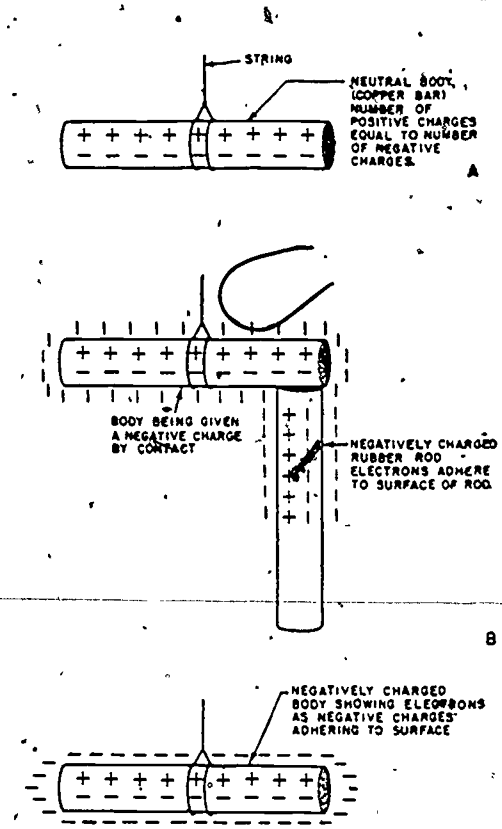


Figure 5. Charging by contact.

(3) If the switch is opened before the rod is removed, the suspended body will have more protons than electrons and, therefore, will be positively charged (fig. 6C).

(4) If a positively charged rod had been used instead of the negatively charged rod in the above experiment, electrons would have gone from ground into the suspended body; consequently, the netural body would have acquired a negative charge. In each instance there is no actual contact between the body to be charged and the charging body; no electrons pass from one to the other. This method of charging is called charging by induction.

3. ELECTROSTATICS.

a. Electric field and lines of force. Just as lines of force are used to represent the direction of the magnetic force associated with one or more permanent magnets, they can also be used to represent the direction of the electric force about one or more charged bodies. For example, suppose that a charged body is placed under a piece of glass and some short brush bristles are then sprinkled over the top of the glass. When this is done, the bristles which fall close to the charged body and other bristles in the vicinity of the charged body move somewhat before coming to rest. It can be concluded, therefore, that the charged body is exerting a force on the bristles. Since there is no physical contact between the charge and the bristles, we say that the charge produces action at a distance. It is often said that the charge creates a field of force in space. Also, examination of the pattern formed by the bristles on the glass reveals that the bristles aline themselves in definite directions (a fact which leads us to attribute a direction to the forces in the electric field). No matter how many times the above experiment is repeated, it will be found that the bristles always arrange themselves into a radial pattern (provided that no other strong electric charges are in the vicinity to distort the electric field). This radial pattern is represented by radial lines of force in A or B of figure 7.

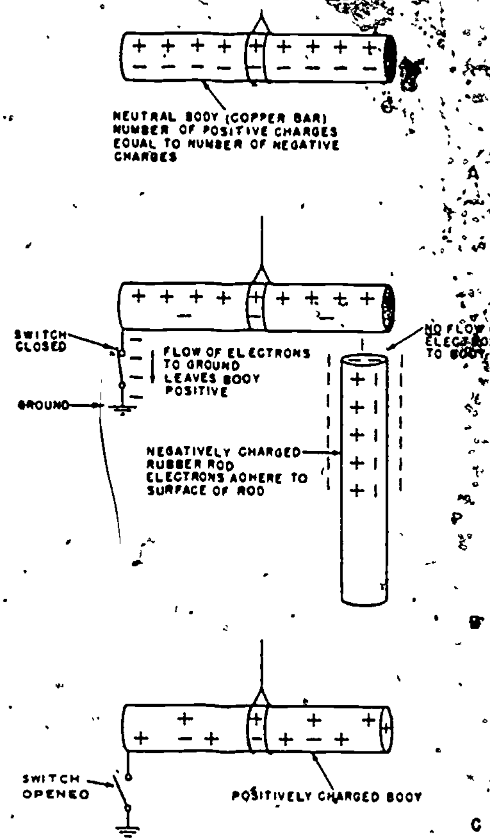
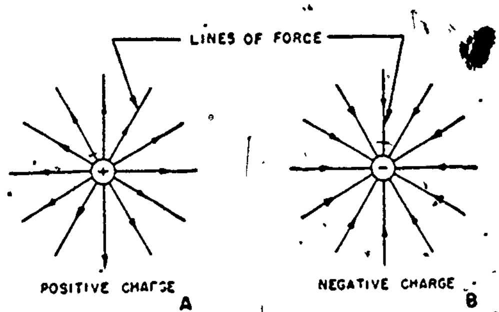


Figure 6. Charging by induction.



A. Lines of force about a positive point charge
B. Lines of force about a negative point charge

Figure 7. Point charges.

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b. Exploring an electrical field. An electrical field about a charged body is explored by the use of another charged body known as a test charge. By agreement, a unit positive charge is always used as a test charge. A method of exploring an electric field with a test charge is as follows: suppose a test charge is carried from point to point in the vicinity of some charged body. Then, we find that at every point the test charge is acted upon by a force having both magnitude and direction. That is, as it is carried from point to point, the test charge experiences a force which varies in strength and direction. Thus, the electric field intensity at any point in the field is defined as the force which a unit positive charge would experience if placed at this point. For example, if the unit positive test charge were carried in the vicinity of a negatively charged body, the force on the test charge would be one of attraction (mutual attraction of unlike charges). However, if the test charge were carried in the vicinity of another positive charge, the force acting on the test charge would be one of repulsion (mutual repulsion of like charges).

c. Electric lines of force. An electric line of force is, by definition, a line which at every one of its points gives the direction of the resultant electric force acting on a unit positive charge if placed at this point. In other words, the tangent to the line at any point is the direction of the electrical field intensity at that point A and B of figure 7 are examples of lines of force representing electric fields.

(1) Coulomb discovered experimentally that the force of attraction or repulsion between two point charges of magnitude or strength q1 and q2 separated by a distance d is given by the formula—

$$F = \frac{\pm q_1 q_2}{ed^2}$$

in which e = a constant, characterizing the medium in which the charges are located. The plus sign is used if q_1 and q_2 have like charges and the minus sign is used if q_1 and q_2 have unlike charges A point charge is a charge which can be considered to be concentrated at a point and a way of attaining this in practice is to charge a sphere of very small radius. In this case, the charge would occupy negligible volume and might be treated as a point charge. However, it must be realized that a point charge is an idealization which cannot possibly be attained, since the smallest unit of charge is that of the electron which occupies a definite amount of space. Therefore, in view of what has been said, Coulomb's law can be interpreted as giving the force between two charges, the physical dimensions of which are small compared with the distance between them.

(2) Figure 7A shows the lines of force which represent the electric field produced by a positive point charge. The field is radial, since the force on a unit positive test charge if placed in the field would be along the line connecting it to the field charge. Since both charges are positive, the force is one of repulsion. which explains the direction of the arrows on the electric field lines. Since, by definition, the field intensity at any point is the force on a unit positive test charge placed at this point, we can find the magnitude of this force by using Coulomb's law and making q_2, the test charge, equal to 1. Thus, the electric field intensity at any point distant d from the point charge q_1 is:

$$F = \frac{\pm q_1 \times 1}{ed^2}$$

This equation shows that the field intensity varies inversely as the square of the distance from charge q. The letter F is used to denote electric field intensity. It is customary in mapping the field to draw more lines in regions of greater intensity; with this convention, regions far away from charges would have a smaller number of lines drawn per unit area than regions closer to the charges. Notice that the field diagram for a negative point charge is essentially that of a positive point charge, except that the arrows are reversed. This follows since the force on the test charge would then be one of attraction.

d. Lines of force associated with two charged bodies. In order to picture the field when more than one charge is present, use the principle of superposition.

(1) This means that to find the force on a unit positive charge when two charges are present, the following steps are taken:

(a) Find the force caused by charge No. 1 acting alone.

(b) Find the force caused by charge No. 2 acting alone.

(c) Find the resultant by totaling the two forces, taking into account the directions of the forces.

(2) To grasp this more fully, consider the following illustration. Suppose it were possible to have two point charges of equal magnitude and opposite signs located at the same point (fig. 8). Then at any point in space a unit positive charge would experience two forces, one of repulsion caused by the positive charge and one of attraction caused by the negative charge. Since the superimposed charges have equal magnitudes, the forces would be equal and thus would have a resultant force equal to zero. This condition is shown in figure 8.

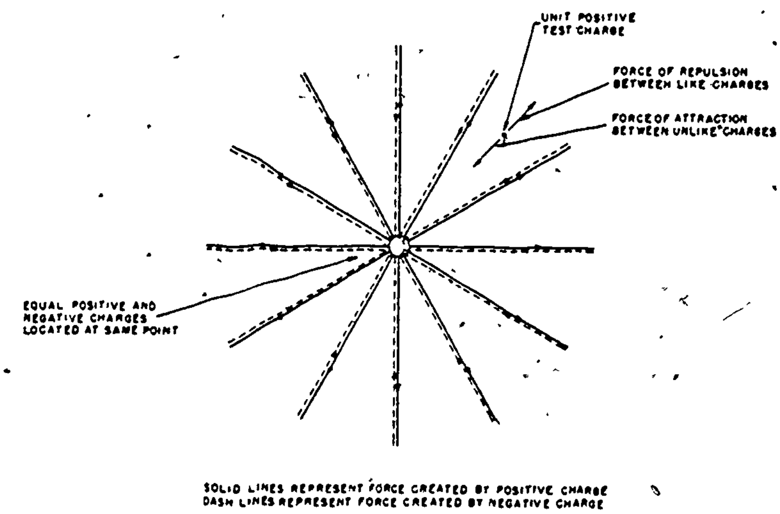


Figure 8. Superposition of unlike charges of equal magnitude.

(3) Now, let us find by the same method the field due to two point charges which are separated. It must be understood that, despite the fact that the test charge will be subjected to two forces, it can only move in response to the resultant force. (In the case of two equal and opposite charges located at the same point, the resultant force on the test charge at any point in the field was found to be zero. This means that the test charge will not tend to move, but will remain at rest.)

(a) Figure 9 shows the test charge being acted upon by two forces: the force caused by the positive charge, and the force caused by the negative charge. Since the test charge can only respond to the resultant force, and since it can only move in one direction, it actually experiences a displacement in the direction of the resultant force. Thus the direction of the electric field at the point of the test charge is shown by the direction of the arrow on the resultant force in figure 9.

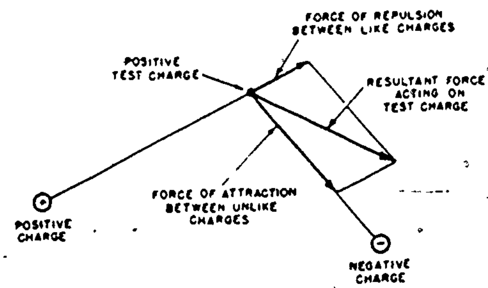
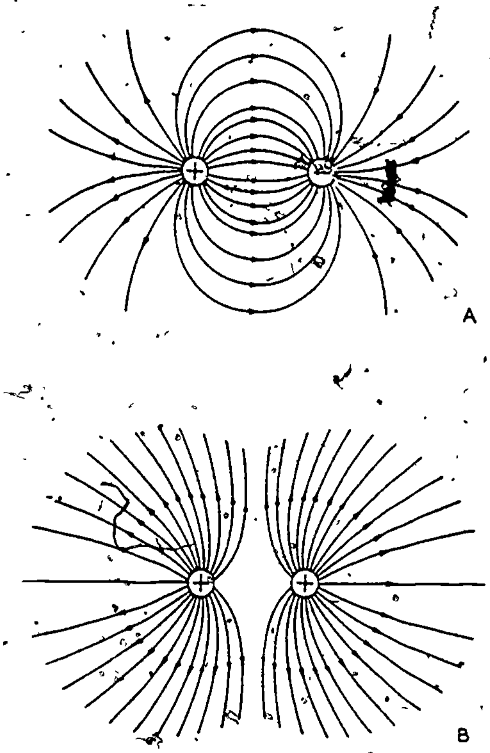


Figure 9. Resultant of forces exerted by unlike charges.

(b) By using this method, it is possible to determine the direction of the electric force at any point on the field produced by two equal and unlike point charges or two equal and like point charges (A and B of fig. 10). The lines of force represent the direction of the resultant force at every point in an electrical field. Note that in figure 10B, the point midway between the charges experiences zero resultant force, thus, a test charge placed at this point would remain at rest.

e. Potential difference. A difference of potential exists between the terminals of a battery. For this reason, if a battery were connected as shown in figure 11, electrons in the wire would be repelled from the negative terminal and attracted to the positive terminal. As a result, a movement or flow of electrons through the wire would take place. In practice, it is customary to use the words potential and voltage interchangeably. So, for the two plates A and B, one can speak of either the voltage rise in going from A to B or the voltage drop in going from B to A. Consider the following example: Plate A is at a potential of 2 volts and plate B is at a potential of 3 volts (the volt is the unit by which potential is measured, as will be explained later). The rise in potential in going from A to B is 3 - 2 = 1 volt. The drop in potential in going from A to B is 2 - 3 = -1 volt. (There is actually a drop in potential in going from B to A.) The potential drop in going from B to A is 3 - 2 = 1 volt. Thus we see that for any two points A and B, the potential rise in going from A to B is the same as the drop of potential in going from B to A. Either of these quantities may be negative, as shown by the example. Wherever the word potential is used, the term voltage can be substituted. As mentioned previously, potential or voltage is measured in volts. Thus a volt is essentially work per unit charge. When we say that the voltage of a battery is 100 volts, we mean that the voltage or potential rise in going from the negative to the positive terminal is 100 volts. The negative sign that is used in battery diagrams does not mean that the negative plate is actually at a negative potential but merely that with respect to any reference point, it is at a lower potential than the plate marked plus. The term ground is very often used in electricity as a reference point. Thus, in a radio set, component parts are connected to the metal chassis which, in turn, is connected to ground. In this case, the chassis is the reference point. In trolley systems with overhead wires, the rails are connected to the earth or ground to prevent any injury to a person stepping on them.



A. Lines of force associated with unlike charges
B Lines of force associated with like charges

Figure 10. Lines of force for like and unlike charges.

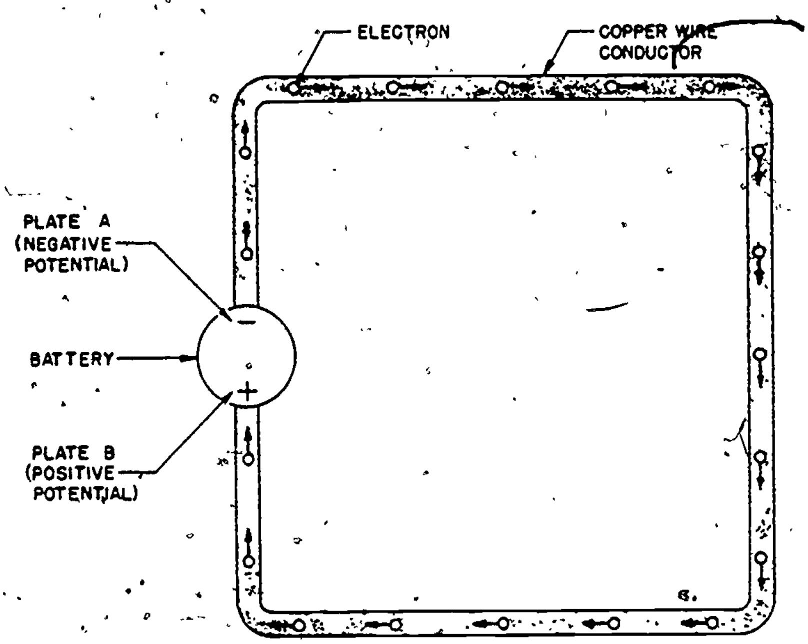


Figure 11. As a result of chemical action in the battery, plate B is higher in potential than plate A, and electrons flow through the wire from A to B.

LESSON EXERCISE QUESTIONS

Instructions for use of the answer sheet:

1. The procedure by which you will answer the exercise questions in this subcourse is probably new to you. The information is presented in a programed instruction format where you immediately know whether or not you have answered the questions correctly. If you have selected an incorrect answer, you will be directed to a portion of the study text that will provide you with additional information.

2. Arrange this subcourse booklet and your answer sheet so that they are convenient. Each exercise question has three choices lettered a, b, and c. Your answer sheet has three groups of numbers for questions 1 through 200. The numbers indicated for each question represent the a, b, or c choices. The exercise response list is in the appendix to this subcourse. It contains a listing of 3-digit numbers in numerical sequence. Each number is followed by a response that either reinforces a correct answer or gives you additional information for an incorrect answer.

3. To use this system proceed as follows:

a. Read the first exercise question and select the choice you think answers the question correctly. Go to the question 1 area of your answer sheet and circle the 3-digit number that corresponds with the choice you selected.

b. After you have identified the 3-digit number, locate it in the exercise response list. If you selected the right choice, the first word of the response will be "CORRECT.". This tells you that you have answered the question correctly. Read the rest of the response which tells why your choice was correct and then go to the next question.

c. If the word "CORRECT" is NOT the first word of the response, you have selected the wrong answer. Read the rest of the response and then turn to the area in your study text that is mentioned. There you will find the information necessary for you to make another choice. Be sure to read all of the response because it will help you select the correct answer and it also provides more information. Line out the incorrect 3-digit response on your answer sheet.

d. After you have reread the reference, select another answer and circle the 3-digit response for that choice. Again check the number of this second choice with the response list to see if your choice is now correct and to obtain more information about your choice. If your second choice is still not correct, line out the 3-digit response on the answer sheet and continue until the correct answer is selected. When you have answered all of the questions in an exercise, count the number of lined out responses and see how well you did.

4. You will notice that the lesson exercise question numbers continue consecutively from lesson to lesson. This allows you to use one answer sheet for the entire subcourse.

5. After you have finished the exercise questions for all lessons, fold and seal the answer sheet so that the USAOC&S address is on the outside. Drop the answer sheet in the mail so the school will know you have completed the study portion of the subcourse and are now ready for the examination.

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EXERCISE

1. The common electrical term used to designate work per unit charge is the

   a. ampere.
   b. coulomb.
   c. volt.

2. Which of the following is NOT a subatomic particle?

   a. Electron
   b. Molecule
   c. Neutron

3. According to DuFay there are how many kinds of electricity?

   a. 1
   b. 2
   c. 3

4. The smallest particle of a substance that can exist by itself and still retain all the properties of the original substance is known as the

   a. nucleus.
   b. molecule.
   c. atom.

5. A substance consisting of two or more elements is called a

   a. combination.
   b. composition.
   c. compound.

6. The polarity of a test charge used to explore an electric field is by agreement always

   a. negative.
   b. neutral.
   c. positive.

7. If two positive electrically charged bodies are brought close together they will

   a. attract each other.
   b. repel each other.
   c. not affect each other.

8. Anything that has weight (mass) and occupies space can be classified as

   a. an atom.
   b. a compound.
   c. matter.

9. A test charge is used to

   a. verify the presence or absence of a charge.
   b. discharge a previously charged body.
   c. charge a previously neutral body.

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(22

10. What is the formula for determining the electric field intensity at any point?

a. $F = \pm q_1 \times 1/ed^2$
b. $F = \pm q_1 \times q_2/ed^2$
c. $F = \pm q_1 \times q_2/ed$

11. If the electric charge of one of a pair of charges is doubled, the force between the two charges will

a. decrease by half.
b. double.
c. quadruple.

12. What term is often used in place of "potential" in common usage?

a. Amperage
b. Current
c. Voltage

13. How would the original force between two point charges be affected if the distance was doubled?

a. Double
b. Decrease by half
c. Decrease by three-quarters

14. A substance that cannot be broken up or made by ordinary chemical action is referred to as

a. an atom.
b. a compound.
c. an element.

15. How many states is matter found in?

a. 1
b. 2
c. 3

16. When a neutral body is charged by induction it will be

a. negatively charged.
b. of opposite charge than the charged body.
c. the same charge as the charging body.

17. Which of the following materials would NOT be attracted by a piece of amber?

a. Iron
b. Wood
c. Paper

18. Approximately how many elements are known today?

a. 97
b. 102
c. 110

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19. The electric charge on an electron is

a. equal and opposite to a proton.
b. larger and opposite to a proton.
c. equal and opposite to a neutron.

20. If a neutral body is touched by a positive electrically charged body for a short period of time

a. electrons will flow from the positive body to the neutral one.
b. the positive body will reverse its polarity and become negative.
c. the electrons will flow from the neutral body to the positive body.

21. If an atom has a nucleus with eight protons and six neutrons, how many electrons will be in the outer shells?

a. 8
b. 6
c. 2

22. Which statement is NOT correct?

a. Neutrons and protons have about the same mass
b. Neutrons have a heavier mass than electrons
c. Neutrons and electrons have about the same mass

23. Which of the known elements has the simplest atomic structure?

a. Hydrogen
b. Carbon
c. Copper

24. Which of the following is NOT an element?

a. Helium
b. Silver
c. Water

25. One coulomb is defined as consisting of

a. 6.0×10^{18} protons.
b. 6.28×10^{18} electrons.
c. 6 million million protons.

CORRESPONDENCE COURSE of the US ARMY ORDNANCE CENTER AND SCHOOL

LESSON ASSIGNMENT SHEET

Ordnance Subcourse No 98	Fundamentals of Electricity
Lesson 2	Electrokinetics
Credit Hours	Three
Lesson Objective	After studying this lesson you will be able to: 1. State the three factors of an electric circuit and describe their effect on a each other. 2. Describe the phenomena of moving charges.
Text	Attached Memorandum
Materials Required	None
Suggestions	None

STUDY GUIDE AND ATTACHED MEMORANDUM

1. INTRODUCTION.

a. General. There are three fundamental factors present in every electric circuit; current, voltage, and resistance. Thus, it is important that a precise explanation of each of these be given.

b. Kinetic. The first lesson of this subcourse introduced you to the principles of static charges. Now we will see what happens when those charges are made to move.

2. CURRENT.

a. Definition of an electric current. The term current means running or flowing, and an electric current is a flow of electrons caused by negative charges tending to move from points of lower potential to points of higher potential. When the current in a circuit flows at the rate of one coulomb per second the resulting term is one ampere (1). Thus, an ampere is the unit of intensity in the flow of an electric current. Current flow requires a closed path from a negative (-) terminal to a positive (+) terminal.

b. Types of current. There are two types of current flow in general use and these are the ones of interest to us,

(1) Direct current is a current that flows in one direction only and maintains the applied voltage at a constant level.

(2) Alternating current is a current that reverses direction at regularly recurring intervals (cycles) with a subsequent rising and falling of the applied voltage.

c. Evidence of electric current. The flow of electrons (electric current) makes itself evident to the average person in one of four ways, transmission of power, production of heat, magnetism, or chemical action.

(1) Current flowing through a transmission line carries electrical energy from distant powerplants to consumers instantly, silently, and efficiently, in any quantity desired. It is the most economical method for transporting power ever devised, and without it we could not utilize the vast amounts of power produced at our hydroelectric dams.

(2) Current always produces heat when it flows through a conductor. The amount of heat produced depends on the material and size of the conductor, and on the amount of current flowing. For example, electric irons and toasters must have heating elements that will produce enough heat to be practical. The light produced by an electric bulb is caused by the current flowing through the thread-like conductor called the filament. This filament must be heated so that it glows. However, the conducting wires that carry the current to the filament must not become hot enough to glow.

(3) Current produces magnetism when it flows through a wire. This is a very important effect, for it is the operational basis of millions of electrical units such as generators, motors, and electromagnets. Without this effect, there is no known way to generate electricity cheaply or to convert it into mechanical energy for the purpose of performing work.

(4) Current produces chemical action when it flows through a liquid. Examples of this effect are the charging of a storage battery, the electroplating process, and the separation of precious metals from their ores. Electric shock is the unpleasant and sometimes dangerous sensation of a direct application of voltage to the human body. The effect of current flow on the body cells is chemical. We often speak of voltage as the cause of shock but the fact is that the current really does the damage. The pain and violent muscular contraction are due to the effect of current on the nerve centers and on the nerves themselves, for they are the best conductors in the body and also the parts most seriously injured.

d. Measurement of current. Current is measured with an ammeter. Since the construction of this instrument is beyond the scope of this lesson, only the method of using the ammeter in a circuit will be given (fig. 1).

(1) Figure 1A shows the proper way of connecting the ammeter. The instrument is put in series with the load, so that the positive terminal of the ammeter is connected to the positive terminal of the battery. If the connections were reversed, the meter would deflect downscale, and the initial impact of the needle with the lower side of the case might bend it considerably.

(2) Figure 1B shows the wrong way of using the ammeter. Notice that with this circuit the ammeter is directly across the battery terminals. The meter is of low resistance and not designed to withstand even moderately high voltages. Consequently connecting an ammeter across the line will usually burn out the meter movement.

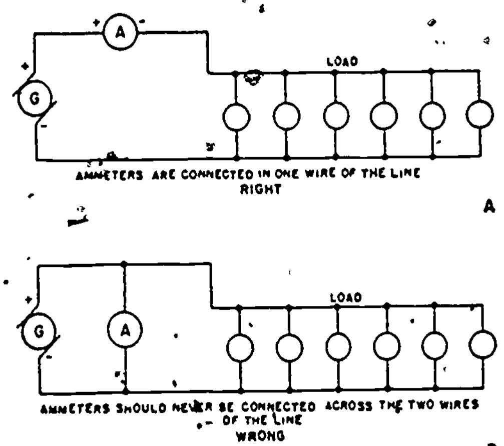

Figure 1. Correct and incorrect usage of an ammeter.

3. RESISTANCE.

a. General. Electric current is just like most people—therefore it always tries to find the easiest way. This is the basis for a very important rule, current will always take the path of least resistance.

b. Resistivity. Resistivity is the tendency of a material to hold on to its electrons. The more free electrons the lower a materials resistivity; the smaller the number of free electrons the higher the material resistivity.

c. Conductors. Conductors are those materials (usually metals) that have many free electrons and permit the easy passage of current.

d. Insulators. Insulators are those materials that have only a few free electrons and thus oppose the flow of current.

e. Semiconductors. Semiconductors are materials that fit in neither the conductor nor insulator classes. They are used today in transistors which are discussed in a later lesson.

f. Resistance. Resistance (R) is a material's total opposition to current flow because of its size, shape, length, temperature, and resistivity. Actually, the effect of temperature is on the property of resistivity; increasing the temperature increases the resistivity and thus increases the resistance of the material (except for some special cases such as carbon). Temperature usually has fairly little effect on the resistance of a material. The length and cross sectional area are another matter however. R (resistance in ohms) = p 1/A, where:

p = resistivity.

1 = length in centimeters.

A = cross sectional area in square centimeters.

From the formula you can see that the resistance is directly proportional to the material's length, thus the longer a conductor the more resistance encountered by current. Resistance on the other hand is inversely proportional to cross sectional area, the more cross sectional area a conductor has, the easier current can flow.

g. Common conducting materials.

(1) The fact that copper is used as a conducting material to a greater extent than any other material is accounted for not only by its high conductivity and comparatively low cost, but also by the excellence of its physical characteristics in general. It has high tensile strength (49,000 to 67,000 pounds per square inch for hard-drawn copper), relative freedom from atmospheric corrosion, and is easily soldered.

(2) Silver has the highest conductivity of all metals but, because of its high cost, is only used when peak performance is more important than cost. Silver is used in measuring instruments and low-loss transmission lines.

(3) Aluminum is the principal competitor of copper in high-voltage transmission lines. It has a resistivity of 2.828 microhms ($1 \text{ ohm} \times 10^{-6}$) per cubic centimeter at 20°C., as compared with 1.7241 microhms for copper, making its conductivity 61 percent of that of copper. The density of aluminum is 2.67, or only 30 percent of that of copper. For example, if two transmission lines, one made of copper and the other made of aluminum, are to transmit the same amount of power with the same loss in transmission, the aluminum line will weigh about half the copper line. The total cost of the two installations will be the same only if the price of aluminum per pound is twice that of copper.

(4) Metallic alloys exhibit numerous interesting characteristics, especially with respect to temperature coefficient and resistivity. Manganin, for example, which is an alloy of 84 percent copper, 12 percent manganese, and 4 percent nickel, has a very low temperature coefficient (.000006) which makes it very useful in the construction of measuring instruments and their accessories, in which constancy of resistance, independent of the heating effects of current, is important.

4. VOLTAGE.

a. General. If we are going to have a flow of electrons (electric current), we need some sort of force to supply a pressure to move the electrons. This force is voltage, it is often referred to as e.m.f. (electromotive force) or potential; it is measured in units called volts (E).

b. Volts. One volt is defined as the amount of e.m.f. necessary to force one ampere of current through a conductor whose resistance is one ohm. You will study this relationship in more detail when Ohm's law is discussed in the next lesson.

c. Measurement of voltage. Voltage is measured by connecting a voltmeter in parallel with the circuit under test (fig. 2A). A voltmeter is usually of high resistance and is not designed to withstand any appreciable current, thus it should NEVER be placed in series with the circuit load (fig. 2B). In fact most voltmeters have coils designed for currents in the low milliampere (0.001 amp.) range. Proper polarity must also be carefully observed to prevent meter damage, i.e., positive meter terminal to positive voltage, and negative terminal to negative voltage.

d. Sources of voltage. There are several sources of voltage supply such as: d.c. generators, a.c. alternators, and batteries. Batteries are one of the most important sources of voltage for military equipment as they are fairly light and portable. Batteries do not require some sort of mechanical power to develop electrical energy as they depend on chemical reaction.

e. Cells and batteries. At one time a cell was considered to be a single unit, such as a voltaic cell, which furnished a source of electricity. Also, a battery was defined as a combination of two or more cells connected together in order to obtain higher voltages or longer operating life. However, this distinction between the cell and battery is no longer valid. Instead, the terms cell and battery are now used interchangeably.

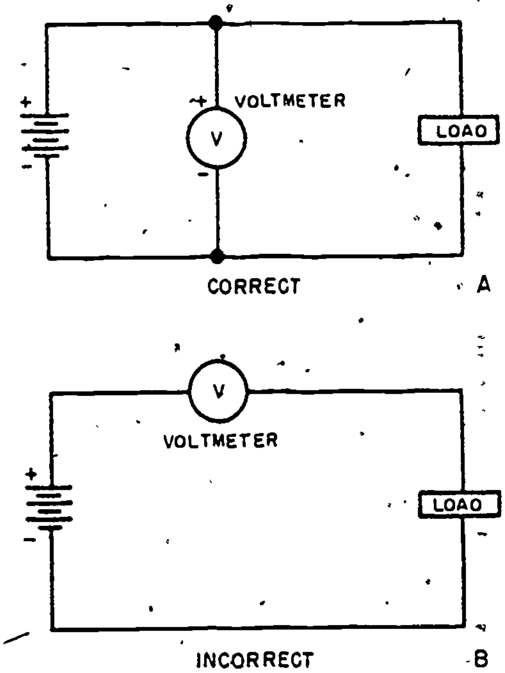

Figure 2. Correct and incorrect usage of a voltmeter.

(1) Primary cells. All cells or batteries are classified under two general headings, primary cells and secondary cells. The voltaic cell described below is a primary cell, a name given to any cell in which an electrode is consumed gradually during normal use, and cannot be restored to its original useful state by recharging electrically. For example, in the voltaic cell, the zinc electrode disintegrates gradually with use as zinc ions are produced and enter the solution of sulfuric acid. However, most primary cells in general use are not of this type. Instead, the use of these wet primary cells is confined to laboratory, experimental, and special-purpose work. Most primary cells are of the so-called dry type. Common examples of dry cells are those used in flashlights, portable radios, etc. A dry cell can be used for a considerable period of time but it must be discarded when one of its electrodes is worn out or consumed. It is not practical to rebuild a dry cell. Dry cells are used extensively in military communication equipment and furnish an e. m. f. for a variety of circuits.

(2) Secondary cells. In a secondary cell, an electrode is not destroyed during normal use. The secondary cell may be renewed or recharged electrically when it becomes run down. Common types of secondary cells are the storage batteries used to supply energy for electrical parts in automobiles.

f. Chemical explanation of cell operation. When two electrodes are placed in a solution in order to make a voltaic cell, a chemical action takes place. The most important result of this chemical action is that one of the electrodes is given a positive charge and the other electrode is given a negative charge. Thus, there is a difference of potential, or e.m.f., between the two electrodes and a source of electricity is available. An understanding of how the chemical action produces an e.m.f. requires some knowledge of chemistry.

(1) Whenever an acid or salt is mixed with water to make a solution or electrolyte, two actions occur. First, the acid or salt is dissolved in the water and, second, a chemical process called ionization takes place. That is, some of the substance that has dissolved in the water breaks up into tiny particles which carry electrical charges. These particles are called ions. An ion is defined as a particle of subatomic, atomic, or molecular dimensions that carries either a positive or negative electrical charge. The ion is positive if it has a deficiency of electrons and is negative if it has an excess of electrons. For example, when H_2SO4 (sulfuric acid) is dissolved in water, some of the particles break down and form H^+ (hydrogen ions) (each of which has a single positive charge) and $SO4^{--}$ (each of which has two negative charges). Figure 3A shows how some of these ions are distributed throughout the solution. The entire solution is electrically neutral, i.e., it contains equal numbers of these positive and negative charges.

(2) Other electrolytes break down as follows:

(a) $CuSO4$ (copper sulfate). Upon ionization this becomes:

Cu^{++}(copper ion) and

SO_4^{--}(sulfate ion).

(b) NH_4Cl (ammonium chloride). Upon ionization, this becomes:

$NH4^+$ (ammonium ion) and

Cl^- (chloride ion).

(3) It has been shown that ionization occurs when sulfuric acid is placed in water, but that the solution has no external electrical effect because it contains equal numbers of positive and negative charges; i.e., the sulfuric acid solution does not produce electricity.

(4) When a dilute sulfuric acid solution is placed in a glass container and a zinc electrode is immersed in the solution (fig. 3B); some of the zinc dissolves and produces positively charged zinc ions, each zinc ion so produced leaves two electrons on the zinc electrode. The zinc ions are designated as Zn^{++}, indicating two positive charges, while the electrons on the electrode are designated as negative charges (=). The excess positive ions in the solution cause the solution to become positively charged. The excess electrons on the zinc electrode, on the other hand, cause the electrode to become negatively charged. A difference of potential then exists between the zinc electrode and the solution of sulfuric acid. Also, the positive zinc ions are attracted by the negative zinc electrode, and they accumulate around it.

(5) When a copper electrode is immersed in the solution (fig. 3C) some of the positive H (hydrogen ions) leave the solution and go to the copper electrode. Each of these hydrogen ions that reaches the copper electrode combines with an electron in a copper atom to form hydrogen gas. The loss of electrons from the copper causes the copper electrode to become positively charged with respect to the solution. The hydrogen gas is designated as H^{0} and the positive charges on the copper are designated by plus signs (+).

(6) Because the zinc electrode is negative with respect to the solution, and the copper electrode is positive with respect to the solution, it follows that the zinc electrode is negative with respect to the copper electrode. Actually, the potential difference between the electrodes is approximately 1.08 volts d.c. for this particular type of cell.

(7) If these two electrodes are connected by a conductor, electrons will flow through the conductor from the negative zinc electrode to the positive copper electrode. When the electrons leave the zinc electrode more zinc turns into zinc ions, thus replenishing the electrons on the zinc electrode. The newly formed positive zinc ions also repel the positively charged hydrogen ions and cause some of them to be deposited on the copper electrode. Here they combine with the electrons arriving from the zinc electrode through the conductor and turn into hydrogen gas. In this manner the charge on each electrode is kept almost constant and their potential difference remains practically the same.

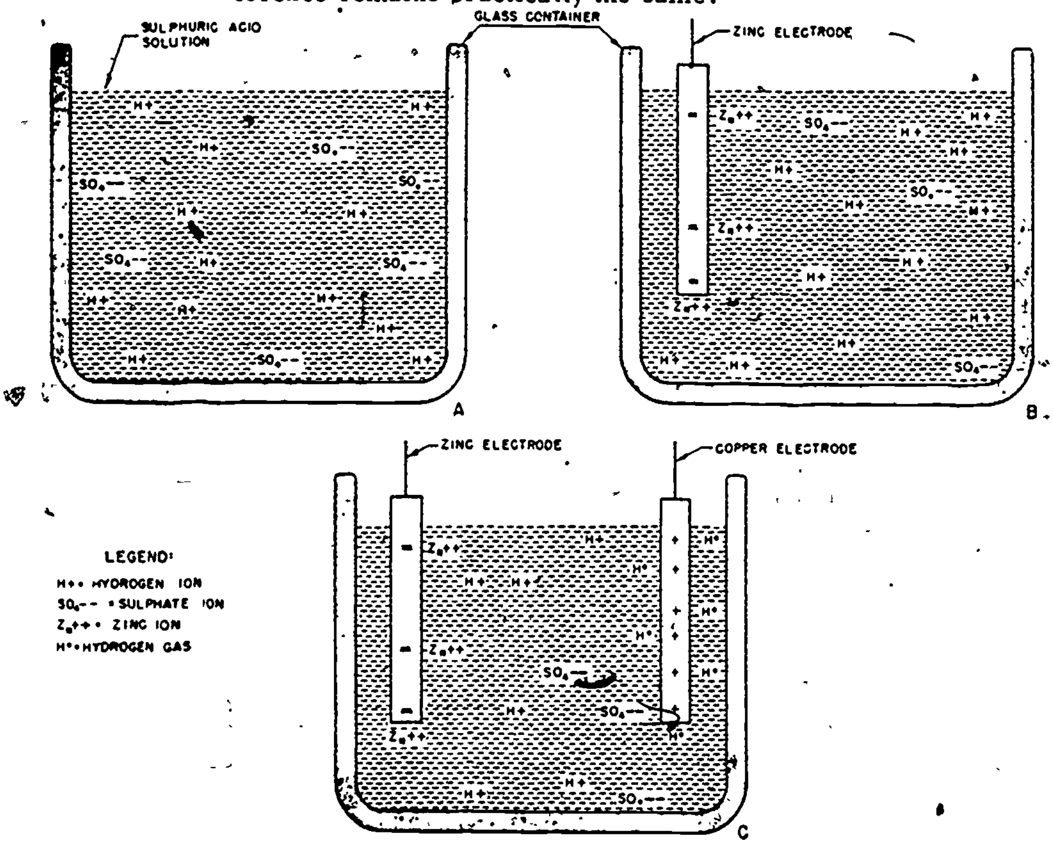

Figure 3. Chemical action of the voltaic cell.

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(8) When the zinc ions enter the solution they attract and combine with the sulfate ions to form zinc sulfate which remains dissolved in the solution. If the electrodes remain connected by a conductor, current will flow in the conductor until all the zinc turns into ions (dissolves in the solution of sulfuric acid) at which time current flow will cease.

(9) It is not expected that a student will long remember the details of the chemical action in the voltaic cell. However, it is expected that a student will remember that chemical reactions can be used to furnish a source of electricity or e.m.f.

5. MAGNETISM.

a. General. The ancient Greeks knew that certain stones, found in the town of Magnesia in Asia Minor, had the property of attracting bits of iron. Quite appropriately, they called these stones magnetite. Legend tells of a shepherd who thrust his iron staff into a hole containing magnetite and found to his dismay that he was unable to remove it. Another story dating back 2300 years relates how Ptolemy Philadelphos had the entire dome of a temple at Alexandria made of magnetite in order that he might suspend a statue in mid-air. The experiment was a failure. Today, it is known that magnetite is an iron ore possessing magnetic qualities. In other words, magnetite is an unrefined product of nature and is a natural magnet.

(1) The two fundamental—and invisible—forces which are responsible for the wonders of electronics are electric force and magnetic force. These are the forces which make possible the operation of electric motors, generators, lights, doorbells, measuring instruments, and other electrical apparatus; they are the forces which comprise those invisible electromagnetic waves which travel through space at the speed of light to give us radio, television, radar, and the other electronic communication systems.

(2) This section of the lesson presents many of the effects associated with magnetic force. It is magnetic force that attracts small bits of iron and steel to the end of the ordinary horseshoe magnet. It is magnetic force which swings a compass needle toward the north. Although most of the devices which utilize magnetic force can be classified as "modern," the more fundamental aspects of magnetic force—those dealing with magnetism—are as ancient as history itself.

b. Magnetic compass. The orientals learned that if a piece of magnetite were mounted or suspended in a horizontal plane and allowed to rotate, it would turn so that one particular end always pointed toward the north. The Europeans later learned of this discovery and used it as a magnetic compass to aid in navigation. Because of this property, the piece of magnetite came to be known as a leading stone or lodestone.

c. Artificial magnets. Although pieces of magnetite are natural magnets when taken from the earth, they now have only historic value. Better magnets are made in a wide variety of sizes and shapes and are used extensively in electrical apparatus. The bar magnet, horseshoe magnet, and compass needle are common types of artificial magnets.

(1) It has been found that pieces of iron and steel become magnetized when they are brought in contact with, or close to, a strong magnet. This process is called inducing magnetism. Magnets (either small or large) made from soft iron are called temporary magnets. Any magnet which loses its magnetism rapidly is called a temporary magnet.

(2) Any magnet which retains its magnetism over a long period of time is called a permanent magnet. The amount of magnetism retained by a material after the magnetizing force has been removed is called residual magnetism. Steel magnets usually are permanent magnets.

(3) Another method of making an artificial magnet by induction is by stroking an iron or steel bar with a strong magnet. When this method is used, it is important that all strokes be made in the same direction.

(4) The best method of making artificial magnets is by electrical means and is explained later.

d. Magnetic and nonmagnetic substances. The invisible magnetic force which exists in the space surrounding a magnet is capable of attracting pieces of iron and steel. For this reason, iron and steel are called magnetic substances.

(1) There are other magnetic substances which are attracted by a magnet but not so strongly as iron and steel. The more common of these substances are cobalt, nickel, and manganese. However, it is interesting to note that some of the best permanent magnets are made from alloys of these substances. The ability of a material to retain its magnetism is called retentivity. Since steel retains its magnetism longer than soft iron, steel has greater retentivity than soft iron. It follows that a material with good retentivity will have a large amount of residual magnetism and will make a good permanent magnet.

(2) Most other substances are not attracted by a magnet and are said to be nonmagnetic. Examples of these nonmagnetic substances are air, wood, paper, glass, copper, aluminum, lead, tin, and silver.

(3) Magnetic force acts through any nonmagnetic substance, as can be demonstrated by moving a permanent magnet beneath a piece of paper or glass on which is sprinkled iron filings. As the magnet moves, movement of the filings can be observed.

(4) Magnetic force is mutual to both a magnet and a magnetic substance. For example, a magnet can be attracted to a firmly held piece of iron or steel just as strongly as the iron or steel is attracted to the magnet.

e. Magnetic poles. When iron filings are sprinkled over the entire area of a magnet, it can be noticed that those filings which fall near the ends of the magnet will be attracted to form bunches of tufts; scarcely any filings which fall near the center of the magnet will be so attracted. Thus, it can be seen that the bar magnet has two distinct regions, or poles, each pole indicating the area or region where the magnetic force is greatest. The same is true of a horseshoe magnet which is, in effect, a bar magnet bent so that the poles are closer together.

(1). When a bar magnet is suspended so that it is free to swing in a horizontal plane, it is found that the magnet will swing around and then come to rest with one end of the magnet pointing nearly due north. Also, it can be found that regardless of the number of times this experiment is repeated, the same end of the magnet always comes to rest pointing north. Thus, it can be seen that there is a difference in the direction of the magnetic forces which act at the two poles of the magnet. Long ago, when this fact was first established, it was decided arbitrarily to call the north-seeking pole of the magnet the north pole. Likewise, the south-seeking pole of the magnet was called the south pole. These designations for the poles of a magnet are still used. In fact, permanent magnets frequently are marked "N" at the north pole and "S" at the south pole.

(2) When a bar magnet is broken into two parts, and the pieces brought into contact with iron filings, it will be found that the filings will bunch at both ends on each of the pieces, thus proving that each piece has two poles. It can also be found that one of the poles is a north pole and the other is a south pole. The piece which contains the north end of the original magnet will have a south pole at the break; and the piece containing the south pole of the original magnet will have a north pole at the break. Regardless of the number of times a magnet is broken, each piece will have its own north and south pole.

f. Earth as a magnet. The fact that a suspended magnet, anywhere upon the surface of the earth, always points toward the north indicates that the earth itself is a huge natural magnet (fig. 4). Note that the poles of the magnet are far below the surface of the earth, and that the magnet is somewhat inclined from the north and south geographic poles. Since the pole of any compass points to the north, that magnetic pole of the earth which is near the north geographic pole must be of south magnetic polarity, and the magnetic pole near the south geographic pole must have north polarity. The north geographic pole is referred to as true north, and the south geographic pole as true south. The deviation from the true north, which at some places is very large, is called the magnetic declination of the station. Remember that magnetic north is merely the direction in which the north end of a compass needle points.

g. Molecular theory of magnetism. A common and one of the simple theories of magnetism is that a piece of iron or steel consists of millions of tiny elementary magnets. These tiny magnets, which are so small that they cannot be seen with a microscope, may consist of atoms or molecules so alined as to form iron or steel crystals. Before a piece of iron or steel has been magnetized, these tiny magnets may be thought of as being jumbled at random with no definite order (fig. 5A). If the north pole of an inducing magnet is drawn over the bar, it attracts the south poles of the tiny magnets and turns them so that they will aline themselves in a given direction (fig. 5B). This definite alinement of molecular magnets will give the bar a north pole at one end and a south pole at the other end.

h. Attraction and repulsion of magnetic poles. If a bar magnet is suspended so that it is free to swing about in a horizontal plane, the magnet normally comes to rest with its north pole pointing toward north. However, if the north pole of a second magnet is brought toward the north pole of the suspended magnet the latter magnet will be pushed away. The same results will be obtained if the south pole of the second magnet is brought toward the south pole of the suspended magnet. Thus, it can be seen that the magnetic forces existing in the space surrounding like magnetic poles cause mutual repulsion of the poles.

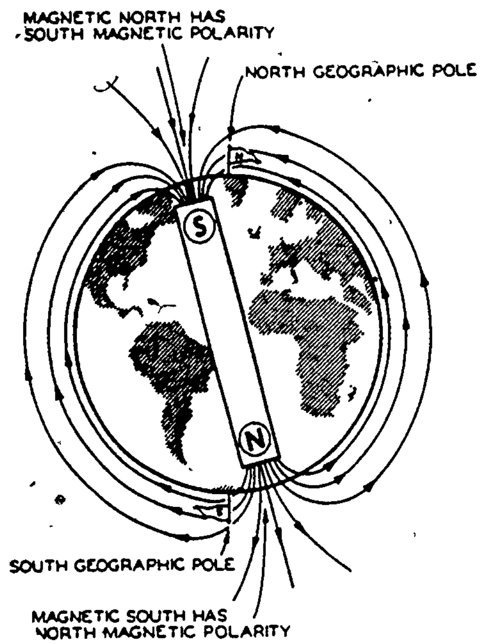


Figure 4. Earth as a magnet.

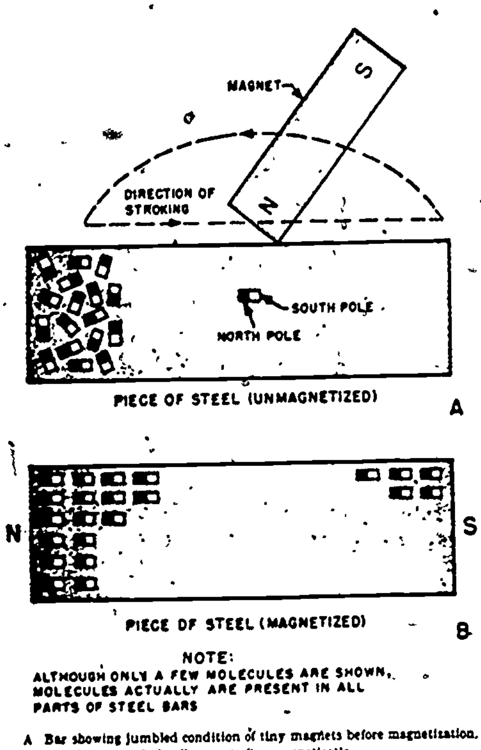


Figure 5. Alinement of molecules.

(1) Another demonstration of the repulsion of like magnetic poles is shown by the following experiment. Two strong permanent magnets are placed on a table top in a parallel position, so that the north pole of one magnet is directly opposite the north pole of the other magnet. The south poles of the magnets are also opposite each other. As one bar magnet is pushed steadily toward the second magnet, invisible magnetic force pushes, or repels, the second magnet. Thus, both magnets move across the table top.

(2) If a bar magnet is again suspended so that it is free to swing about in a horizontal plane, it will be observed that when the north pole of a second magnet is brought toward the south pole of the suspended magnet, the two poles will be pulled together and will cling to each other until they are separated by manual force. If the south pole of the second magnet is brought close to the north pole of the suspended magnet, it will be observed that these two poles will also be pulled together, and manual force is required to separate the poles. Thus, it can be seen that the magnetic forces about the unlike poles of two magnets will cause the two magnets to be attracted.

(3) The above facts are used as a basis for the fundamental law of magnetic forces which is: LIKE MAGNETIC POLES REPEL EACH OTHER; UNLIKE MAGNETIC POLES ATTRACT EACH OTHER. Or, THE FORCE BETWEEN TWO LIKE POLES IS ONE OF MUTUAL REPULSION; THE FORCE BETWEEN TWO UNLIKE POLES IS ONE OF MUTUAL ATTRACTION.

i. Factors affecting magnetic force. The amount of magnetic force existing in the space surrounding a magnet can be estimated roughly by measuring its lifting power. However, there are various conditions, other than the magnet itself, which will cause the lifting power to vary. Some of these conditions are: the kind of magnetic material to be lifted, the shape of the material to be lifted, the manner in which the material is applied to the magnet, and the shape of the magnet. A more accurate method for measuring the strength of a magnet, and the method most commonly used, is by measuring the force of attraction or repulsion that the magnet has on another magnet of known strength. That is, the effects that magnets have upon one another is the measure of their strength.

(1) The force of attraction or repulsion between them. When the poles are separated by a considerable distance, no visible effects are apparent. It is only after the like poles are brought close to each other that the suspended pole is repelled. Likewise, it is only after the two unlike poles are brought close together that the suspended pole is attracted. Thus, it can be seen that the magnetic force of attraction or repulsion between two magnetic poles increases very rapidly as the distance between the two poles is decreased. With suitable measuring equipment, it can be shown that this force varies inversely with the distance squared. This expression simply means that if the distance between the two poles is halved, the force becomes four times as great; if the distance is reduced to one-third, the force becomes nine times as great; if the distance is reduced to one-fourth, the force becomes sixteen times as great; if the distance is reduced to one-fifth, the force becomes twenty-five times as great, and so on. This expression holds true whenever the two magnetic poles are separated in a vacuum.

(2) The force of attraction and repulsion between two magnets also varies with the amount of force that the individual poles of the magnets are capable of exerting. In other words, the force of

attraction and repulsion varies with the strength of the poles. The strength of a pole, in turn, varies with its size, the material from which it is made, and its degree of magnetization.

j. Magnetic field. It has been shown previously that a magnetic force exists in the space surrounding a magnet and that this force is capable of acting on other magnets or magnetic substances. The space which surrounds a magnet is called the external magnetic field. (The complete field consists of the external field plus the field through the substance of the magnet.) Thus, a magnetic field may be defined as a region wherein magnetic forces act.

(1) Certain facts concerning the nature of the magnetic field about a magnet can be obtained by exploring such a field with an ordinary compass. (The needle of any compass is a small permanent magnet.)

(a) When a compass is placed near the south pole of a bar magnet, the compass needle will swing about and come to rest with the north pole of the needle as close as possible to the south pole of the bar magnet. In this position, the south pole of the compass needle is as far away as possible from the south pole of the bar magnet (fig. 6A). This action is easily explained by the first law of magnetic forces which states that like magnetic poles repel each other and unlike magnetic poles attract each other.

(b) When the compass is placed at the other, or north pole, end of the bar magnet, the needle swings and then comes to rest with the south pole of the needle as close as possible to the north pole of the bar magnet (fig. 6B).

(c) When the compass is placed near the center of the bar magnet, the force existing in the magnetic field causes the needle to come to rest in the position shown in figure 6C.

(d) In figure 6D, a number of compasses have been placed at various positions in the magnetic field of a bar magnet. Note that the compass will point in different directions as its position in the magnetic field is changed.

(e) Thus, by exploring the magnetic field about a bar magnet, it is found that one important characteristic of a magnetic field is that it has direction which varies from point to point.

(f) Another important characteristic of the magnetic field about a bar magnet is that the intensity of the field decreases very rapidly with distance from the poles. For example, when the exploring compass is placed a few feet away from the bar magnet, the compass needle is not visually affected by the presence of the magnetic field. Only when the compass is brought to within a certain distance of the bar magnet will the magnetic forces in the field be sufficiently strong to cause the compass needle to swing.

(g) From the above experiments with an exploring compass, it is found that the magnetic field about a bar magnet is characterized by a force which varies in direction and intensity from point to point in the field.

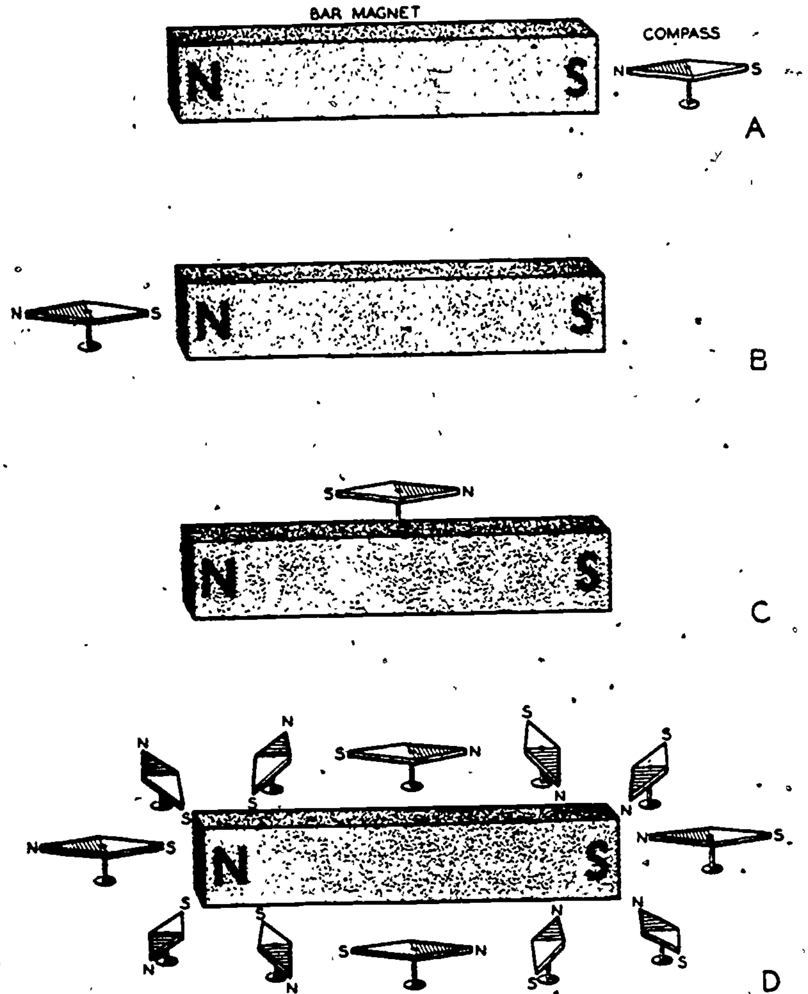


Figure 6. Effects of magnetic field on compass needle.

(2) A representation of the magnetic field about a bar magnet can be obtained by means of an experiment using iron filings.

(a) This experiment can be performed by placing a piece of paper over a table top and sprinkling some iron filings over a large area of the paper (fig. 7A).

(b) A bar magnet is then dropped into the center of the area containing the filings (fig. 7B). As the magnet reaches the table, it will be noted that many of the filings near the poles of the magnet are attracted to the magnet, and slight movement of most of the other filings takes place. In short, the filings rearrange themselves because of the magnetic field about the magnet.

(c) If the table is gently tapped, the filings completely rearrange themselves and the pattern about the magnet then appears similar to that shown in figure 7C. Regardless of the number of times that this experiment is repeated, the filings will always arrange themselves in approximately the same pattern as that shown.

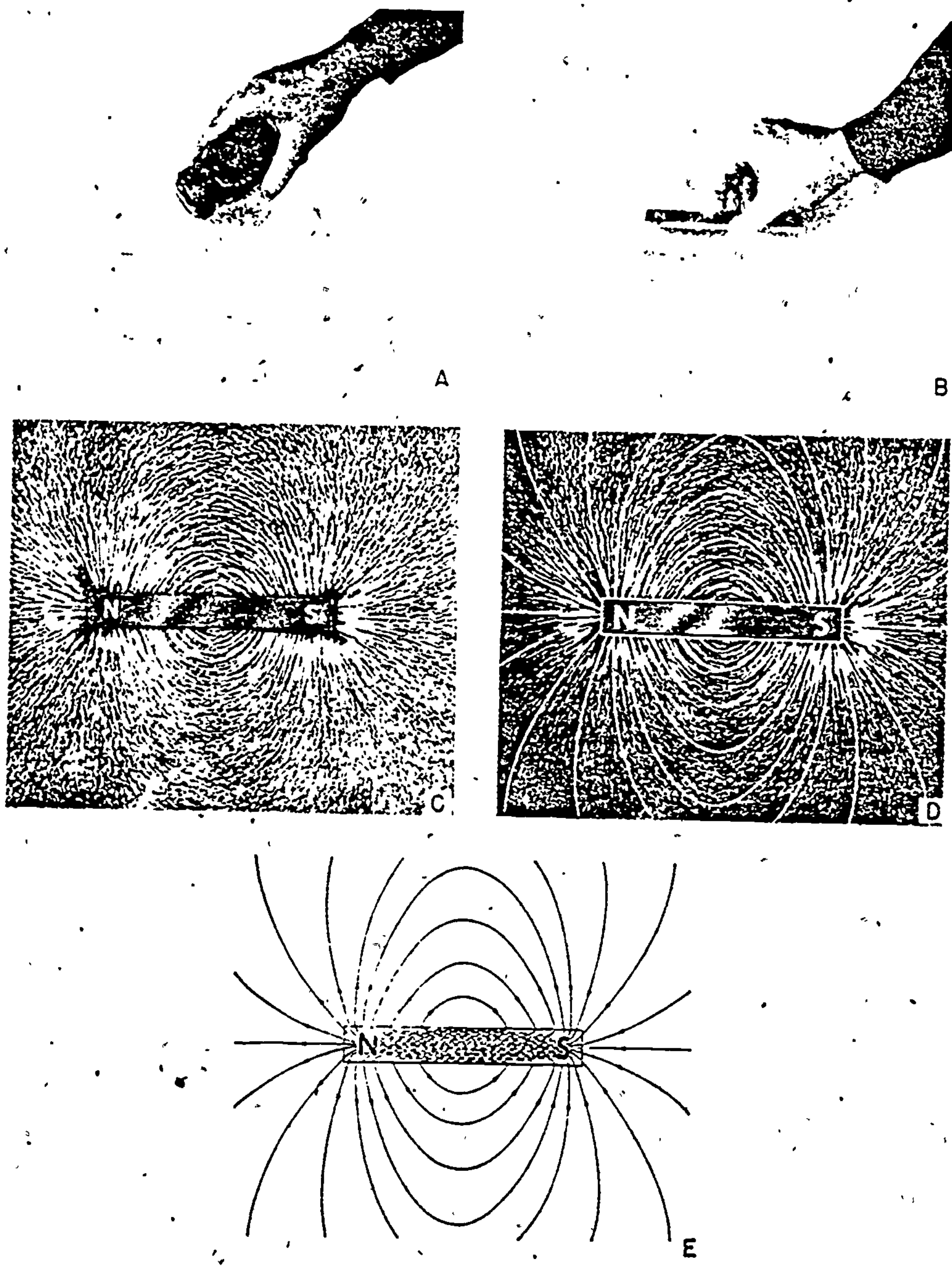


Figure 7. Pattern formed by iron filings about a bar magnet represents the magnetic field about this magnet.

(d) The explanation of why this pattern always forms is quite simple. Pieces of iron or steel become magnetized by induction when they are brought in contact with, or close to, a magnet. Thus, each of the tiny iron filings about the bar magnet becomes a small magnet with a north and south pole of its own. Each of these filings (or magnets) is affected by the direction and intensity of the magnetic field about the bar magnet, and alines itself in the same manner as a compass needle, in response to the magnetic field.

(e) Observe that the force of the magnetic field is greatest near the poles; many of the filings are attracted and adhere to the magnet showing distinct alinement. As the distance from the poles increases, the field becomes less intense, and the action of the force on the iron filings is less apparent. At the edge of the pattern, as shown in figure 7C, the effect on the filings is hardly discernible.

(f) This iron filings experiment has long been used to represent the nature of the magnetic field about a magnet, and it gives a conception of the direction and intensity of the magnetic forces which act in the field. However, it should be remembered that the pattern formed in this experiment is not the magnetic field itself, the magnetic field is invisible, but only a representation of the manner in which the magnetic forces of the field act on magnetic substances within the field.

k. Lines of force. Frequently, it is desired to represent by a drawing the direction and intensity of the magnetic field about a magnet. This can be done by drawing a picture of the pattern obtained when iron filings are placed about the magnet and, in the case of a bar magnet, such a drawing would be similar to that shown in figure 7C. However, this method is difficult and time-consuming. A simpler and more commonly used method is that of arbitrarily representing the forces in a magnetic field by drawing a few lines called lines of force.

(1) Figure 7E shows lines of force as they are usually drawn to represent the magnetic field about a bar magnet. By studying these lines of force, it can be seen that their overall pattern is similar to the overall pattern formed by the iron filings about the magnet.

(2) Note that arrowheads have been placed on each of the lines of force shown in figure 7E. Also note that the direction of each arrowhead is away from the north pole and toward the south pole of the magnet. In other words, the arrowheads indicate that lines of force leave the magnet at the north pole and enter the magnet at the south pole. Within the magnet, the direction of the force is assumed to be from the south pole to the north pole, so that a continuous loop is formed by each line of force. The direction of these lines was defined arbitrarily long ago as the direction in which the north pole of a compass needle will point if placed at any point along a line of force.

(3) Actually, the magnetic field completely fills the space about a magnet and does not exist only in a single plane, such as along a table top. This field can be shown to extend out to great distances and, theoretically at least, throughout all space, with the intensity of the field decreasing very rapidly as the distance is increased. Figure 8 shows how the field of force extends in all directions about the bar magnet. The end views show the line of force leaving the north pole and entering the south pole.

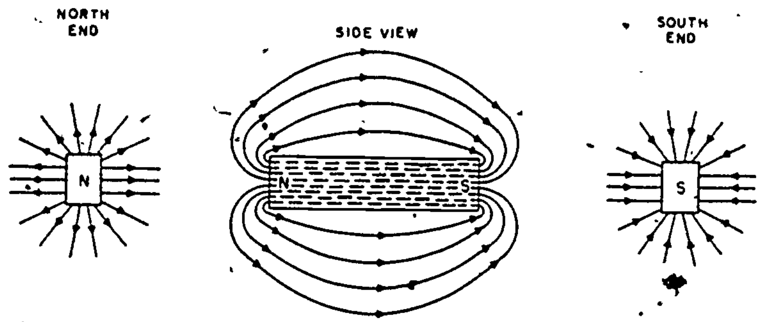


Figure 8. Field of force about a bar magnet.

(4) Lines of force are also used as an indication of the strength or intensity of the magnetic field. We said that magnetic force (field strength) varies inversely with the square of the distance. This law is not strictly true in practice since it is based on the assumption that the lines of force from a pole face emanate from a point somewhere within the magnet. Actually, the lines of force do not converge to a single point within the magnet. Figure 9 shows a magnet face of 1 square centimeter area. It is obvious that there are more lines of force passing through the square centimeter area ABCD than pass through the same size area EFGH which is located the same distance from the pole face. This means that the field intensity is greater in area ABCD than in EFGH as indicated by the greater number of lines passing through ABCD. The farther away from the pole one goes, the less the field intensity will be. When the lines emanate from a point, the number of lines through a given area will vary inversely with the square of the distance that the area is from the point—not from the pole face. With a long magnet the field intensity will be nearly as shown in figure 9, and the law, the inverse as the square of the distance, will be almost true. But if the magnet is short and thick, the field will be more uniform for quite a distance from the pole and the distance-square law will be less accurate.

l. Characteristics of magnetic fields. Thus far, only the pattern of the magnetic field associated with a single bar magnet has been considered. Actually, this pattern of the magnetic field is only one of an unlimited number of possible patterns that can be produced by using one or more magnets.

(1) If the area surrounding the north pole of one bar magnet and the south pole of a second bar magnet is sprinkled with iron filings, the pattern in figure 10A will be obtained. Note the similarity between this pattern and the pattern of filings about a single bar magnet. Figure 10B shows the distortion of this magnetic field which occurs when a third magnetic pole is brought into the region. Note that the intensity of the magnetic field is greatest near the poles of the magnets and that in the small area midway between the two like

poles the filings appear to lie as if unmagnetized. This is actually the case, because midway between the two like poles the magnetic force produced by one pole is equal to, and in opposition with, the magnetic force produced by the other pole.

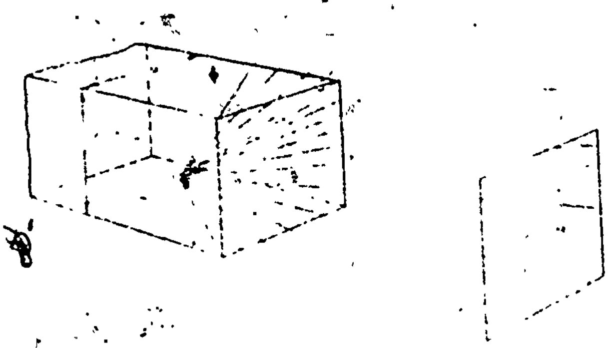
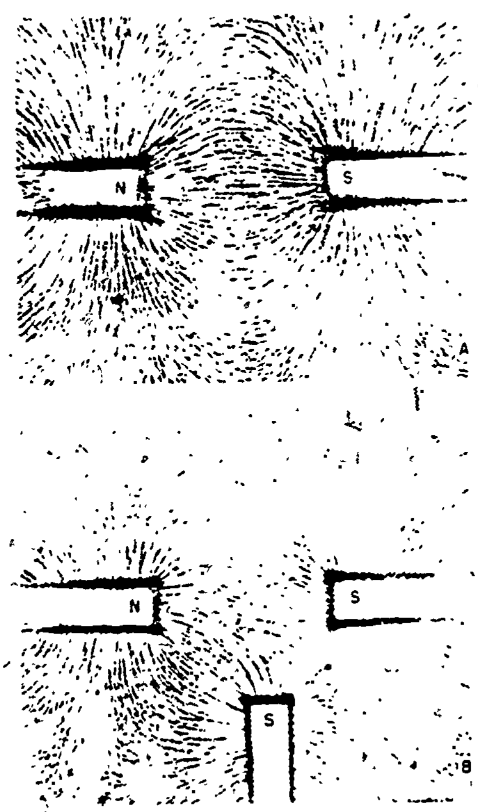


Figure 9. End of a magnet showing how field intensity varies with distance from pole.

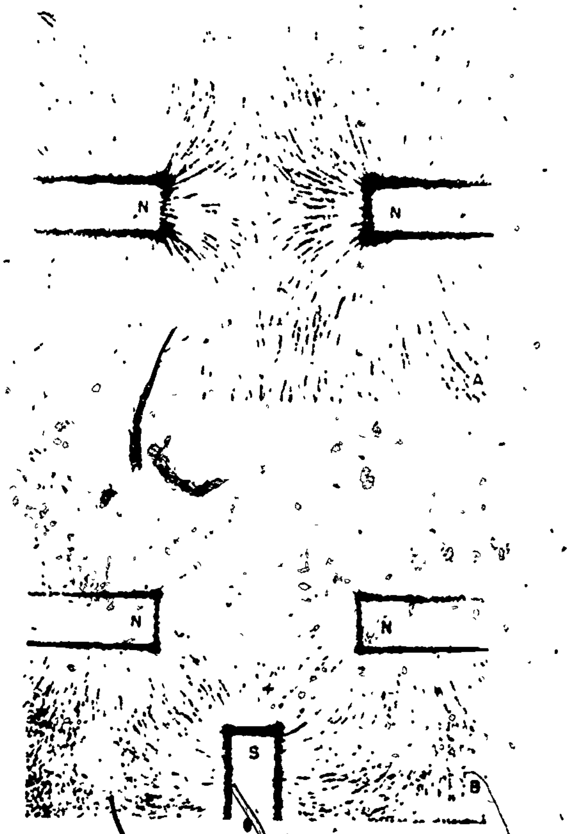


A. Iron filings pattern about unlike magnetic poles
B. Distortion caused by insertion of a third magnetic pole

Figure 10. Lines of force.

(2) Figure 11A further illustrates the manner in which magnetic forces act to produce a magnetic field. In this case, the magnetic field contains forces of repulsion. Again note that the magnetic force is strongest near the poles and decreases very rapidly as the distance from the poles is increased, while at a point midway between these like poles there is a magnetic field of zero intensity.

(3) Figure 11B shows the distortion of the field which occurs when a third pole is brought into the region. Again, it can be observed how the magnetic field is more intense between unlike poles and less intense between like poles. Close scrutiny of the figure will reveal another small area where the magnetic forces act in opposition to produce a resultant force of low or zero intensity.



A. Iron filings pattern about like magnetic poles.
B. Distortion caused by insertion of a third magnetic pole.

Figure 11. Lines of force.

(4) Figure 12 shows the lines of force associated with a horseshoe magnet. The pattern formed by these lines of force is different from the physical position of the poles with respect to the magnet and to each other. Although these lines of force have a different pattern, or configuration, the characteristics of the magnetic field remain the same; i.e., the magnetic field strength at a point to point in the field.

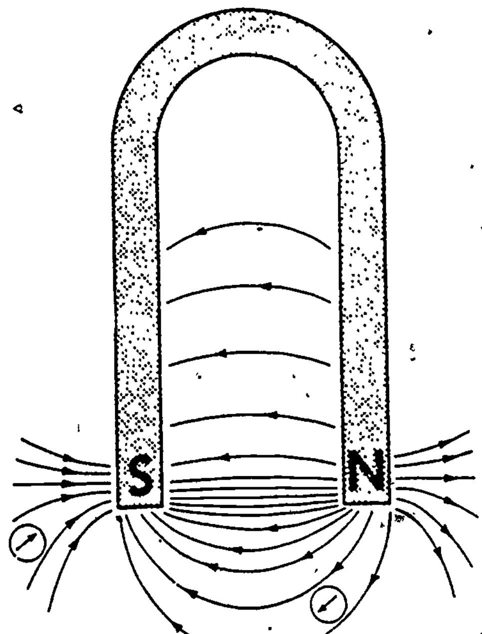


Figure 12. Lines of force associated with a horseshoe magnet.

m. Electromagnets. If a piece of magnetic material, usually soft iron, is placed within a coil through which current is flowing the magnetic properties of the coil are tremendously increased. The reason for this increase in magnetic strength is because soft iron is more permeable than air, and therefore provides a better path for the lines of force (flux) than air. The inside of any coil is considered as the core whether it be air or of some magnetic material. If a coil is wound on a core of magnetic material, it is called an electromagnet (fig. 13). The coil may be wound with one or more layers of wire from one end to the other and back, providing, of course, that the current flows around the core continuously in the same direction. Any magnetic material may be used as the core for an electromagnet. However, soft iron or soft steel generally is used because the retentivity of those materials is so low that they have the characteristic of retaining very little residual magnetism when the current stops flowing. This is a very important feature in electrical equipment such as relays. On the other hand, a piece of hard steel when inserted into a coil in which current is flowing becomes a permanent magnet. That is, due to its retentivity, it will retain a large amount of residual magnetism when the current ceases to flow. Electromagnets are widely used in electrical equipment, including relays, motors, generators, radios, and transformers. The U-type electromagnets (fig. 13B) are used in telephone receivers, coin operated machines, and many other similar applications.

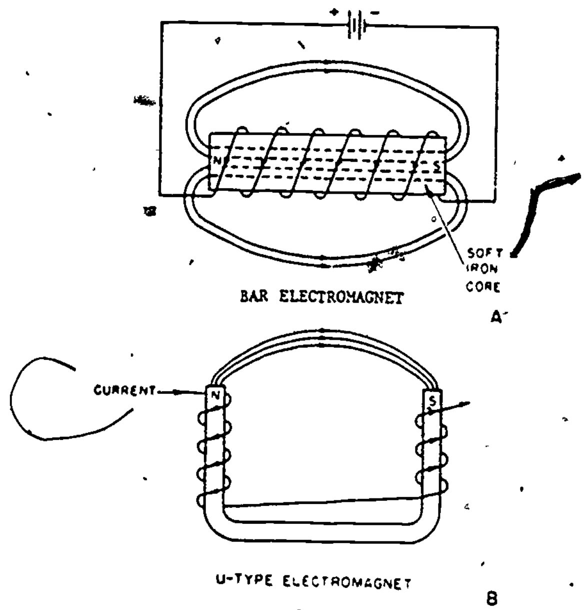
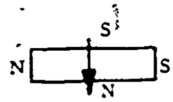


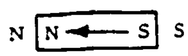
Figure 13. Types of electromagnets.

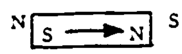
OS 98, 2-P21

EXERCISE

26. If a compass were placed in the center of a bar magnet in what position would the needle rest?

a. 

b. 

c. 

27. What is the symbol for voltage?

a. E
b. I
c. P

28. What happens to the resistance of a conductor if its cross section in square centimeters is doubled?

a. Increases twice
b. Reduces by half
c. No effect

29. What causes current to flow?

a. Low resistance of a material
b. A path for current
c. Presence of an e.m.f. in a circuit

30. The direction of magnetic lines of force is generally considered to be

a. from the south pole to the north pole.
b. perpendicular with a line between poles.
c. from the north pole to the south pole.

31. When the coil of a d.c. electromagnet is wound with more than one layer of wire, it is necessary for the current in all layers to flow

a. counterclockwise from positive to negative.
b. in opposite directions.
c. in the same direction.

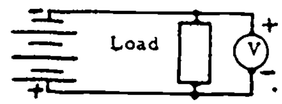
32. What are the units of measurement for current?

a. Amperes
b. Volts
c. Ohms

33. A magnet that has great retentivity is usually a

a. electromagnet.
b. permanent magnet.
c. temporary magnet.

34. Which is the correct way to connect a voltmeter to measure the load voltage?

a.


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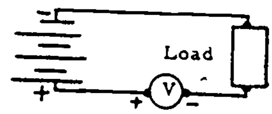
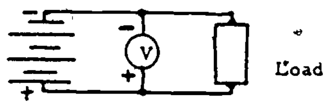


c.


35. The north end of a compass needle points toward magnetic north because

a. the north pole is the most magnetic.
b. unlike poles repel each other.
c. magnetic north has south magnetic polarity.

36. The battery used in a common flashlight is

a. dry cell.
b. secondary cell.
c. storage battery.

37. What is resistance?

a. A material's total opposition to current flow
b. A property arising only from the finding energy of atoms
c. A flow of charge through a given path

38. What is the unit of measure used for electromotive force?

a. Ampere
b. Volt
c. Watt

39. A relay electromagnet usually has a core made of

a. copper.
b. soft iron.
c. steel.

40. Copper probably is the most common electrical conductor used today.. Which of the following is NOT a reason for its wide use?

a. Tensile strength
b. Low cost
c. Light weight

41. What is necessary to make a material a good conductor?

    a. Many free electrons
    b. Many electrons
    c. Few free electrons

42. Which would NOT be used to define an ion?

    a. Atomic dimensions
    b. Neutral electric charge
    c. Positive electric charge

43. What metal has the highest conductivity?

    a. Aluminum
    b. Copper
    c. Silver

44. Which characteristic of current is the basis for generation of electricity by a car generator?

    a. Chemical action
    b. Magnetism
    c. Production of heat

45. Current will flow through the

    a. path of least resistance.
    b. path of maximum resistance.
    c. shortest available path.

46. A primary cell is one that

    a. can be recharged.
    b. cannot be recharged.
    c. uses a liquid electrolyte.

47. What underlies the operation of all batteries?

    a. Interaction of electrodes and a solution of an electrolyte
    b. The potential difference between two points in a conductor
    c. The resistivity of certain conductors

48. A magnetite magnet is

    a. an artificial magnet.
    b. a bar magnet.
    c. a natural magnet.

49. What happens if a large steel bar magnet is broken in half?

    a. One piece becomes a north pole and one becomes a south pole
    b. One piece remains a magnet and the other loses its magnetism
    c. Both pieces become small bar magnets

48

50. Magnets made from soft iron are called

a. temporary magnets.
b. permanent magnets.
c. natural magnets.

QS 98, 2-P25

CORRESPONDENCE COURSE
of the
US ARMY ORDNANCE CENTER AND SCHOOL

LESSON ASSIGNMENT SHEET

Ordnance Subcourse No 98	Fundamentals of Electricity
Lesson 3	Ohm's Law and Direct Current Circuits
Credit Hours	Three
Lesson Objective	After studying this lesson you will be able to: 1. Describe Ohm's law and its use to analyze a d.c. circuit. 2. Describe the difference between a series and a parallel circuit.
Text	Attached Memorandum
Materials Required	None
Suggestions	None

STUDY GUIDE AND ATTACHED MEMORANDUM

1. INTRODUCTION.

a. The first two lessons of this subcourse made several references to the fact that the use of electricity is a means to an end; electricity is a very useful tool in performing many difficult tasks.

b. Now we are about to take a long stride in the direction of understanding electrical apparatus, for this lesson will make use of the fundamentals studied earlier, as we delve into the laws of direct current circuits.

c. This lesson will introduce you to the laws and equations which can be used to analyze d. c. circuits.

2. CIRCUIT COMPONENTS.

a. It isn't hard to see that if electrons are to move between points of different potentials some sort of a path must be provided. The best path commonly found is a length of some material which is a good conductor. An electrical circuit consists of a closed path through which current could flow if a potential difference were supplied.

b. Electrical circuits are diagramed schematically by means of standard symbols, some of which are given below. Others will be introduced in subsequent lessons.

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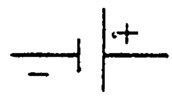
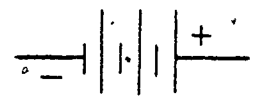
September 1973

(1) Sources of potential (and current).

(a) Batteries:



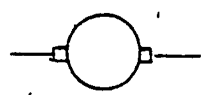
One Cell



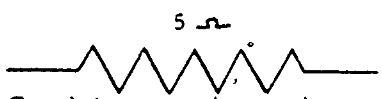
Multi-cell

The longer of the two vertical lines in a battery symbol indicates the positive terminal.

(b) Generators:

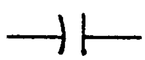
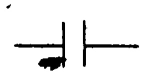


(2) Resistors:

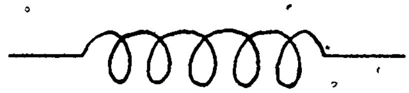


The Greek letter Ω (omega) represents ohms

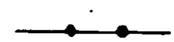
(3) Capacitors:

 or 

(4) Inductors:



(5) Switches:

open  closed 

c. There are three fundamental quantities of immediate interest in any d.c. circuit: the applied potential (E), the current flowing in the circuit (I), and the resistance of the circuit (R). A fourth important parameter arises from these three; i. e., the power dissipated in the circuit (P).

3. CIRCUIT FUNDAMENTALS.

a. The parameters of d.c. circuits are as obedient to the law of conservation of energy as are all other natural phenomena. The formulation of this law as it applies to d.c. circuits was performed by Ohm, hence, the relationship $E = IR$ bears his name. Verbally stated, Ohm's law is: in any direct current circuit the current is directly proportional to the amount of voltage, and inversely proportional to the amount of resistance. If any two of the quantities E, I, and R pertaining to a given circuit are known, the third can be found by simple algebraic rearrangement of the fundamental equation. Thus:

(1) $E = IR$, or voltage equals current times resistance.

(2) $I = E/R$, or current equals voltage divided by resistance.

(3) $R = E/I$, or resistance equals voltage divided by current.

b. A resistance circuit does not require time to respond to a change in voltage or current, but responds immediately and without distortion. Consequently, a resistive circuit is said to have an ideal transient response. This will be an important point in the development of future lessons.

c. Direct current circuits may be arranged in any of several ways. They may be either series circuits, parallel circuits, or a combination of both. Such combinations are usually called series-parallel circuits. The nomenclature of the circuit is based upon the type of path offered to the current by the circuit.

4. CIRCUIT ANALYSIS.

a. A series circuit offers only one path for current flow; i.e., all the current flowing in the circuit passes through every item in the circuit successively as it moves from negative to positive potential. The schematic diagram (fig. 1) is a series circuit because there is only one way the current can get from the negative electrode to the positive electrode, and that is to pass through each of the resistances in turn.

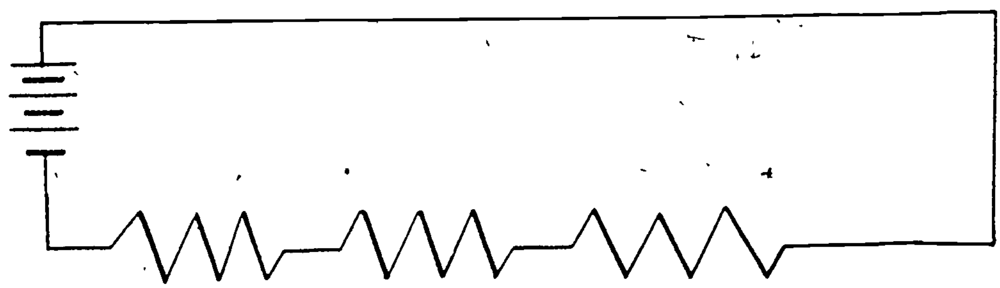


Figure 1. Resistance in series.

b. A charged battery is a source of electrical potential energy. If we connect a conductor between the electrodes of the battery (short circuit the battery) the potential is lost almost immediately because there is very little to impede the discharge of the battery. However, if we insert resistance into the line between the electrodes the situation changes. It takes energy to force current through the resistance, so the resistor will cause a loss of energy external to the battery—in effect, a potential drop across the resistor. This potential can be found by Ohm's law. In a series circuit the following are always true:

(1) The total resistance equals the sum of all the resistances in the circuit ($R_t = R_1 + R_2 + R_3 + \ldots\ldots R_n$).

(2) The sum of the voltage drops across the individual resistances in the circuit is equal to the applied voltage ($E_t = E_1 + E_2 + E_3 + \ldots\ldots\ldots E_n$).

(3) The current is the same everywhere in the circuit ($I_t = I_1 = I_2 = I_3 = \ldots\ldots\ldots I_n$).

(4) Interruption of the circuit at any point will cause current flow to cease throughout the entire circuit.

c. Here is a problem that you are probably familiar with. A set of Christmas tree lamps is wired one lamp after the other (fig. 2A). You know that when one lamp in the set fails the complete string goes out. Usually, you have to get a new lamp and try it in each socket in turn until the set lights again. This kind of a light set is called, quite naturally, a series hookup. You can see that each of the five lamp filaments is a resistance. Does this make it any harder to find the total resistance so that you can work out Ohm's law? No harder at all. If you have a number of resistors all connected together in a line, like five trailers being towed one behind the other, you can easily get the total resistance by adding them together. It's like coupling five trailers, each weighing five tons, and attaching them to a tractor. The total weight to be towed, of course, is twenty-five tons. It's the same with a number of resistances all strung out in the same line so that the current has only one path to flow. To get the total resistance, we add all the individual resistances together.

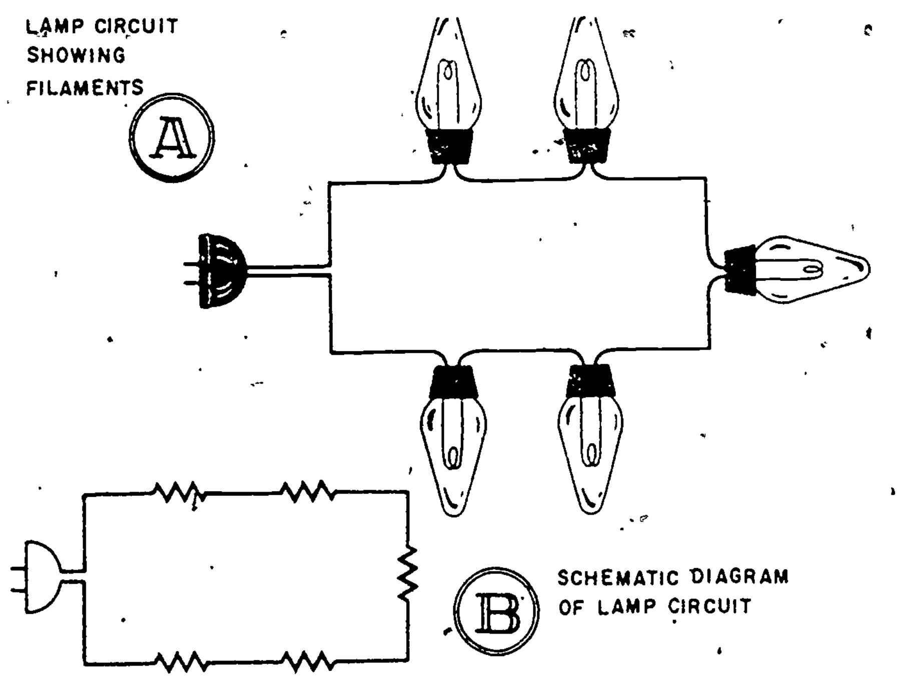


Figure 2. Picture and schematic diagram of Christmas tree lamps.

(1) Assume that you have the Christmas series lamp string of figure 2 and that when you plug it into the electric wall socket you measure a current of .15 ampere. You can easily find the resistance of the five lamps. Remember, the .15 ampere that goes into one lamp, goes into every other lamp. You know that the voltage furnished from the socket in the wall is 110 to 120 volts. Let's take the higher voltage (E) that you already know is 120 volts. You also know that the current flow is .15 ampere (I). So, by applying Ohm's law, some simple division will give you the total resistance. (R = E/I)

(a) E = 120 volts; I = .15 amperes; R = (?).

(b) 120 = .15 x R or

(c) R = 120/.15 = 800 ohms.

(2) The total resistance of the circuit is 800 ohms, but we still do not know what the resistance of each individual lamp is. If the resistances in the circuit are all equal the problem is greatly simplified. ~~In this case it is fairly~~ safe to assume that the similar lamps have similar resistances. The resistance of each lamp then is simply the total resistance divided by the total number of lamps:

(a) $R_n = R_t$/number of resistances.

(b) R_n = 800/5 = 160 ohms.

If the resistances are not all equal the problem becomes slightly more complicated, and you must use a different method to find the individual resistances.

(3) Assume that you have a series circuit in which the current is 2 amperes and the applied voltage is 120 volts. You have five resistors of different values in the circuit. You know that if there is current flowing through a resistor there must be a voltage present. Of the total voltage of 120 volts, some is used in pushing the current through one resistor, some is used in pushing the current through the second, and so on, until all the voltage is used. If you know how much of the voltage is consumed for each resistor, you can find the value of that resistor.

(4) All you have to do is read the voltage across the resistor and divide it by the current—which you know is 2 amperes. In other words, apply Ohm's law. But, how do you find out how much voltage is used by each resistor? The easiest thing to do is measure it with a voltmeter.

(5) Assume for this problem that you have measured the voltage across each of the five resistances in the circuit we are talking about, and you have gotten the readings shown in figure 3. Since the current in a series circuit is the same anywhere in the circuit, the current through each resistor is 2 amperes. You can find the value of R 1 by dividing 10 volts by 2 amperes and obtaining the resistance of 5 ohms (R 1 = 10/2 = 5 ohms). The other four resistances can be figured in a similar manner:

(a) R2 = 20/2 = 10 ohms.

(b) R3 = 20/2 = 10 ohms.

(c) R4 = 30/2 = 15 ohms.

(d) R5 = 40/2 = 20 ohms.

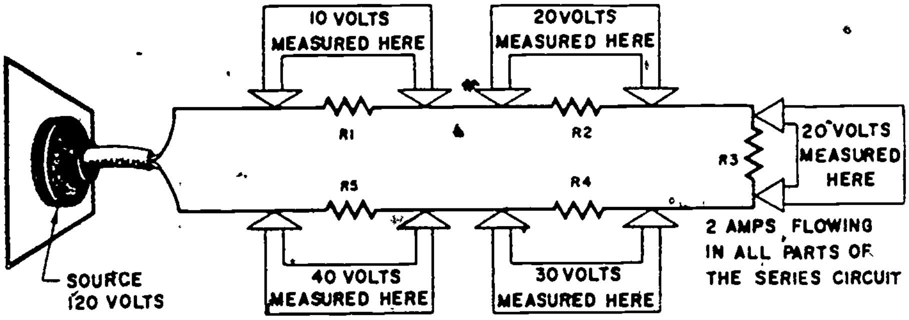


Figure 3. Series circuit showing individual voltages.

(6) The total result can be checked by adding the individual resistances together and checking them against the circuit's total resistance.

(a) $R_t = R1 + R2 + R3 + R4 + R5$.

(b) $R_t = 5 + 10 + 10 + 15 + 20 = 60$ ohms.

(c) $R_t = E_t/I_t = 120/2 = 60$ ohms.

d. The second type of direct current circuit is the parallel circuit. The parallel circuit is just the opposite of the series circuit; it is any circuit that has more than one complete path for the flow of current. You can see in figure 4 that current will flow from the negative terminal of the battery to A, through R_1 to D, and then to the positive battery terminal, just as if it were a common series circuit. But, the current can also flow from the negative terminal to B, through R_2 to C, and to the positive battery terminal. Thus, you see, there are two possible paths for current to flow through. What actually happens is that the current flows from the negative battery terminal to A, here it divides with part of it flowing through R_1 and part of it through R_2, and two separate currents then come together again at D and flow on to the positive terminal as a single current.

(1) The first rule of a parallel circuit then makes sense when it states that the total current in a parallel circuit is equal to the sum of the currents in each branch. If a current of 2 amperes was flowing through R_1, and 4 amperes was flowing through R_2, the total current would then be 6 amperes ($I_t = I_1 + I_2 + I_3 + \ldots I_n$) or for this particular case $I_t = 2 + 4 = 6$ amperes.

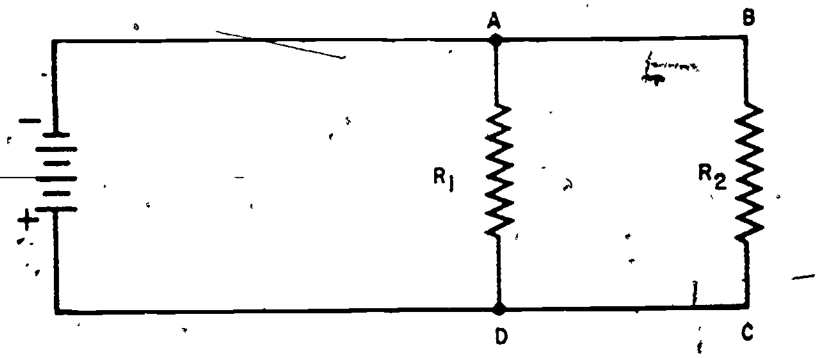


Figure 4. Parallel circuits provide more than one path for current.

(2) The second rule concerns the action of the applied voltage. The voltage, unlike the current, does not divide or take two paths. If you measure the voltage from A to D (across R_1), and then the voltage from B to C (across R_2), they would be the same. These two voltages in turn would be equal to the applied voltage ($E_t = E_{R1} = E_{R2} = E_{R3} = \ldots\ldots E_{Rn}$). Ohm's law still applies and you can easily find the total resistance in a circuit where there's more than one resistor (equal or unequal). You can use E = IR to find how much of the current flows one way (through R_1) and how much current flows the other way (through R_2). REMEMBER these two rules that you have just studied about the characteristics of a parallel circuit.

(3) In parallel circuits we have generally the same problem as in series circuits; namely: how to find the total circuit resistance and the values of each of the individual resistances. However, to find the total resistance in a parallel circuit when the values of the individual resistances are known is a more involved process than in a series circuit. The total (effective) resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances. The reciprocal of a number is 1 divided by that number. Thus the reciprocals of 2, 5, and 8 are:

(a) Reciprocal of 2 = 1/2 or .5.

(b) Reciprocal of 5 = 1/5 or .2.

(c) Reciprocal of 8 = 1/8 or .125.

The reciprocal method for solving a parallel circuit expressed as a formula would look like this, $R_t = \frac{1}{1/R_1 + 1/R_2 + 1/R_3 + \ldots 1/R_n}$

If we were to use the reciprocal method to find the total resistance of the circuit in figure 5 the solution would be as follows:

(a) $R_t = \frac{1}{1/R_1 + 1/R_2} = \frac{1}{1/2 + 1/4}$.

(b) $R_t = \frac{1}{2/4 + 1/4} = \frac{1}{3/4} = 4/3 = 1\text{-}1/3$ ohms.

If you notice, the total (effective) resistance is always less than either of the two individual resistances. This is a mathematical fact that will always be true in a parallel circuit and provides a very convenient method of checking your calculations. If the total resistance answer is greater than any of the individual resistances in a parallel circuit the answer is wrong.

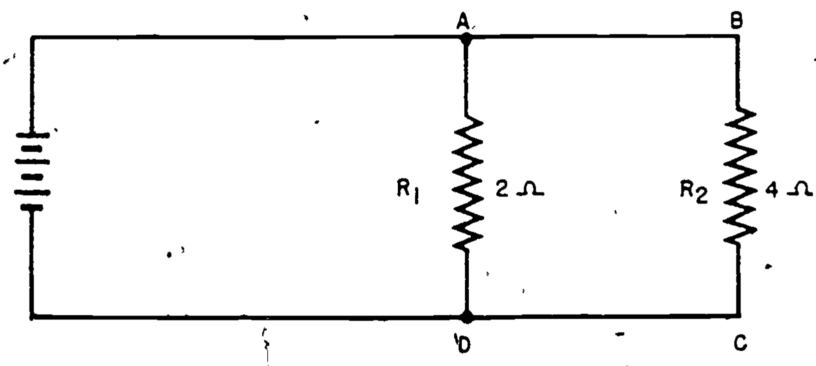


Figure 5. Parallel circuit problem.

(4) There is an easier way to find the resistance of a parallel circuit that has only two resistances in parallel. To find the resistance of the circuit in figure 5 we will now use the "product over the sum" method. This means that you'll divide the product of the two resistors by the sum of the two resistors. Here's how it is done:

(a) $R_t = \frac{R_1 \times R_2}{R_1 + R_2}$

(b) $R_t = \frac{2 \times 4}{2 + 4} = \frac{8}{6} = \frac{4}{3} = 1\text{-}1/3$ ohms.

REMEMBER this method as it is easier to use than the reciprocal method. It is usually more convenient to consider only two resistances at a time when a circuit has many resistors, solving each set of two by the "product over the sum" method until the circuit is reduced to one equivalent resistance (fig. 6).

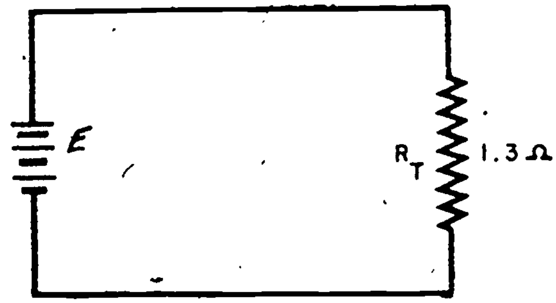


Figure 6. Circuit equivalent to circuit shown in figure 5.

(5) Finding the equivalent resistance of a parallel circuit with a number of equally valued resistors is very easy and quick. All that is necessary is to divide the value of one of the resistors by the number of resistors in the circuit. To solve the circuit in figure 7 you would proceed like this:

(a) R_t = R/Number of resistors in parallel.

(b) $R_t = 20/4 = 5$ ohms.

REMEMBER this formula only holds true where all of the resistors in parallel are of equal resistance.

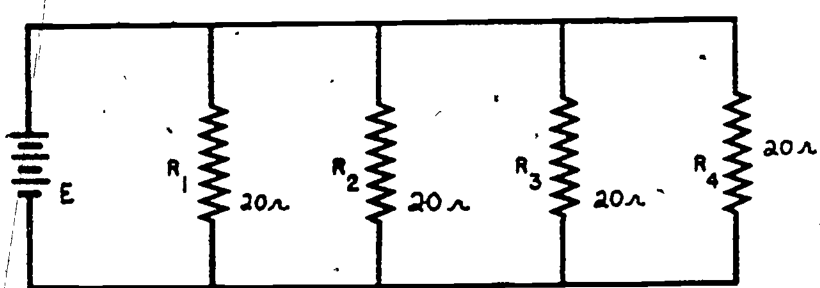


Figure 7. Four equal parallel resistances.

e. The third and last type of d.c. circuit is the series-parallel circuit. As the name implies the circuit is a combination of the two circuits you have just finished studying. Most circuits are of the series-parallel type. To solve this type of circuit you must systematically isolate groups of parallel and series resistors and solve them for their respective equivalent resistances. This process is continued until there is only one equivalent resistance remaining.

5. POWER.

a. As was mentioned previously when we insert resistors into a circuit it takes energy to force the current through the resistance. Since it takes energy to force the current through a resistance, that resistance must dissipate this energy in some manner. It does so by converting the energy into heat and it is important to know how much will be generated so that we can provide a large enough resistor to withstand it. Sufficient ventilation must also be provided. We must know how much energy will be consumed by the entire circuit so that we can provide a large enough power source. Both of these questions are answered by the same formula.

b. The power used by a resistance is directly proportional to the current in amperes and the voltage in volts. The product of these (current and voltage) gives the power in watts. By algebraic substitution we can use other combinations of current, voltage, and resistance to find the power.

(1) $P = EI$.

(2) $P = I^2R$.

(3) $P = E^2/R$.

As long as the current is given in amperes (I), the voltage in volts (E), and the resistance (R) in ohms, the power (P) will be expressed in watts (W).

c. Let us assume that we have a simple circuit where E = 10 volts, I = 5 amperes, and R = 2 ohms. We can find the power used in this circuit by any of the following three formulas.

(1) $P = EI = 10 \times 5 = 50$ watts.

(2) $P = I^2R = (5)^2 \times 2 = 25 \times 2 = 50$ watts.

(3) $P = E^2/R = (10)^2/2 = 100/2 = 50$ watts.

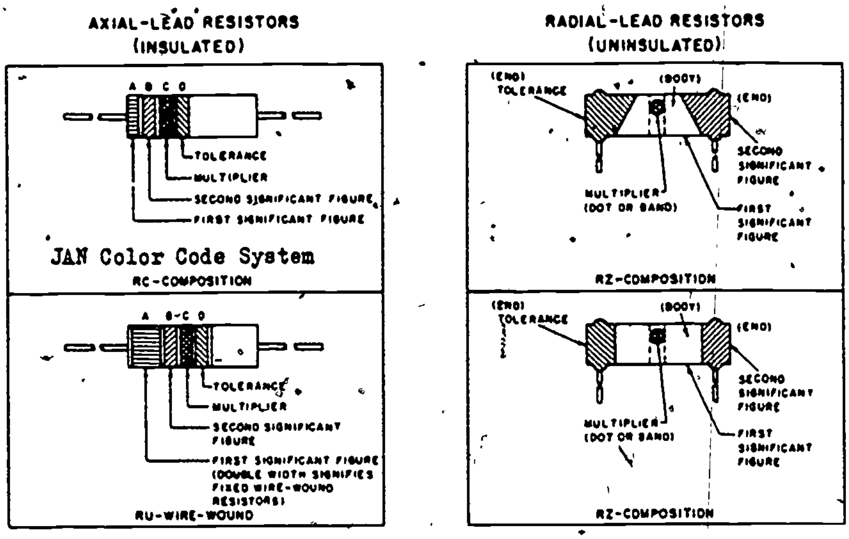
d. To find the total power in a circuit containing more than one resistor you merely add all the values of power calculated for the individual resistors. The total power may also be found by using any one of the three formulas that we just mentioned; however, the values used for E, I, and R must be the total voltage, current, and resistance for the complete circuit.

6. IDENTIFYING RESISTORS.

a. We must be able to tell the value of a resistor so that we can replace them when they become bad. Many resistors are too small to permit the printing of the value on the resistor itself; therefore, the JAN (Joint Army Navy) color code was developed. Each digit 0 to 9 was assigned a particular color and these colors are arranged in bands on the resistors, in a standard manner, to denote the resistor's ohmic value. Figure 8 illustrates four methods of marking resistors; you will be responsible only for the JAN color code. It would be advantageous to memorize the colors and the value they represent. Figure 8 also contains several band marking examples to assist you in learning the code.

b. Resistors also vary in wattage ratings because of the various power factors involved (par. 5a) and, if defective, must be replaced with one of like size or larger. A decrease in watts below the derived value ($W = I^2R$) may cause the resistor to overheat with resultant damage or change in accuracy.

RESISTOR COLOR CODE MARKING
(MIL-STD RESISTORS)



RESISTOR COLOR CODE

BAND A OR BODY*		BAND B OR END*		BAND C OR DOT OR BAND*		BAND D OR END*	
COLOR	FIRST SIGNIFICANT FIGURE	COLOR	SECOND SIGNIFICANT FIGURE	COLOR	MULTIPLIER	COLOR	RESISTANCE TOLERANCE (PERCENT)
BLACK	0	BLACK	0	BLACK	1	BODY	± 20
BROWN	1	BROWN	1	BROWN	10	SILVER	± 10
RED	2	RED	2	RED	100	GOLD	± 5
ORANGE	3	ORANGE	3	ORANGE	1,000		
YELLOW	4	YELLOW	4	YELLOW	10,000		
GREEN	5	GREEN	5	GREEN	100,000		
BLUE	6	BLUE	6	BLUE	1,000,000		
PURPLE (VIOLET)	7	PURPLE (VIOLET)	7				
GRAY	8	GRAY	8	GOLD	0.1		
WHITE	9	WHITE	9	SILVER	0.01		

*FOR WIRE-WOUND-TYPE RESISTORS, BAND A SHALL BE DOUBLE-WIDTH
WHEN BODY COLOR IS THE SAME AS THE DOT (OR BAND) OR END COLOR,
THE COLORS ARE DIFFERENTIATED BY SHADE, GLOSS, OR OTHER MEANS

EXAMPLES (BAND MARKING):
10 OHMS ±20 PERCENT BROWN BAND A, BLACK BAND B, BLACK BAND C, NO BAND D
4.7 OHMS ±5 PERCENT YELLOW BAND A, PURPLE BAND B, GOLD BAND C, GOLD BAND D

EXAMPLES (BODY MARKING)
10 OHMS ±20 PERCENT BROWN BODY, BLACK END, BLACK DOT OR BAND, BODY COLOR ON TOLERANCE END
3,000 OHMS ±10 PERCENT ORANGE BODY, BLACK END, RED DOT OR BAND, SILVER END

Figure 8. Color code for resistors.

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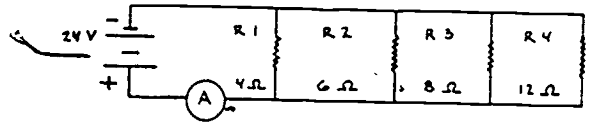
EXERCISE

51. What is the total resistance (ohms) of circuit No 1?

a. 30
b. 15
c. 1.6

Circuit No. 1



52. What is the voltage drop (volts) across R2 of circuit No 1?

a. 24
b. 12
c. 6

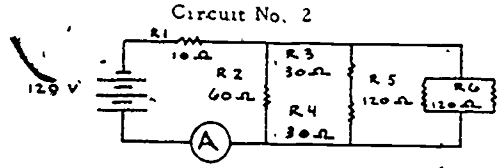
53. What is the current value (amperes) at point A of circuit No 1?

a. 1.5
b. 6
c. 15

54. What is the total resistance (ohms) of circuit No 2?

a. 15
b. 30
c. 185

Circuit No. 2



55. What is the voltage drop (volts) across R1 of circuit No 2?

a. 40
b. 60
c. 80

56. What is the current value (amperes) at point A of circuit No 2?

a. 0.324
b. 0.648
c. 4.0

57. What is the voltage drop (volts) across R3 of circuit No 2?

a. 20
b. 40
c. 80

58. If you saw this symbol  in a schematic diagram, you would know that it represents a

a. switch.
b. battery.
c. inductance.

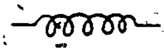
59. How is the total resistance of a d. c. series circuit obtained when the applied voltage is 220 volts?

a. Add the resistor values (ohms) in the circuit
b. Apply the formula R1 x R2 x R3 =
c. Sum the resistor values and divide the result by the voltage

60. Which statement is TRUE as regards a pure resistive circuit?

a. Requires time to respond to a change in voltage or current
b. Does not require time to respond to a change in voltage or current
c. Responds immediately but is distorted

61. Which is the symbol for a resistor?

a. 
b. 
c. 

62. A d. c. circuit having more than one complete path for the flow of current is called a

a. series circuit.
b. short circuit.
c. parallel circuit.

63. What is the equivalent resistance of two 5,000-ohm resistors in parallel?

a. 2,500 ohms
b. 5,000 ohms
c. 10,000 ohms

64. If the voltage across two 80-ohm resistors in parallel is 240 volts, what is the total current in the circuit?

a. 3 amps
b. 6 amps
c. 8 amps

65. The formula for finding the power in a circuit is

a. P = EI.
b. E = IR.
c. I = E/R.

66. How many watts of power are used in a 110-volt electric toaster with 55 ohms of resistance?

a. 55
b. 110
c. 220

67. When 200 volts are applied to a d. c. circuit having a 400-ohm and 250-ohm resistor in parallel, how many volts can be measured across the lesser resistance?

a. 100
b. 150
c. 200

68. What is the current reading (in amperes) of a 110-volt electric iron if the heating unit has a resistance of 50 ohms?

a. 0.5
b. 2.2
c. 22.0

69. A d. c. circuit has two resistors in series and a 120-volt power supply with a current flow of 0.2 ampere. If there is a voltage drop of 40 volts across one of the resistors, what is the resistance (ohms) of the other?

a. 100
b. 200
c. 400

70. A voltmeter reads a potential drop of 26.0 volts across a 50-ohm resistor. How much current is flowing through the resistor?

a. 0.52 amp
b. 1.92 amps
c. 76 amps

CORRESPONDENCE COURSE
of the
U.S. ARMY ORDNANCE
CENTER AND SCHOOL

LESSON ASSIGNMENT SHEET

Ordnance Subcourse No 98 . . . . Fundamentals of Electricity

Lesson 4 . . . . Alternating Current, Inductance, and Capacitance

Credit Hours . . . . Four

Lesson Objective . . . . After studying this lesson you will be able to:

1. Describe alternating current and its comparison with direct current.
2. Describe inductance and capacitance and state why they are present in a. c. circuits.
3. Give the methods used to determine the amount of inductance and capacitance in an a. c. circuit.

Text . . . . Attached Memorandum

Materials Required . . . . None

Suggestions . . . . None

STUDY GUIDE AND ATTACHED MEMORANDUM

1. INTRODUCTION.

a. Thus far, we have been concerned only with direct current; i.e., current that flows in only one direction through an external circuit. Such a current can be varied by changing the magnitude of the applied potential.

b. What would happen, though, if we reversed the polarity of the potential source on a d. c. circuit? The current flow would reverse naturally, because electrons always travel from the negative electrode to the positive.

2. ALTERNATING CURRENT.

a. Direct current can vary in magnitude and may even pulsate, as long as the direction of current flow does not change. Normally, we think of direct current as reaching some value in a very short time, and maintaining that value as long as the circuit is unbroken.

b. If the current in a circuit reverses direction, it is called ALTERNATING CURRENT. In addition, conventional a. c. is continuously changing in magnitude, and periodically changing in direction.

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September 1973

c. Although direct current was the first source of commercial electric power, it has several inherent disadvantages which overshadow its apparent simple nature. Chief among these features is the fact that direct current cannot be transmitted over long distances without intolerable losses of power. Alternating current, on the other hand, is easily transmitted across country. In addition, the ability to radiate a.c. power from an antenna opened the entire field of radio communication as we know it today.

d. The principles governing magnetic fields enable man to convert mechanical energy to electricity by the use of generators. We will not be concerned with the operation of these machines. We note, however, that the electrical output of a.c. generators is continuously changing in magnitude and direction, and is therefore a source of a.c. potential.

e. If an a.c. potential is graphed as a function of time, the waveform is a sine wave (fig. 1).

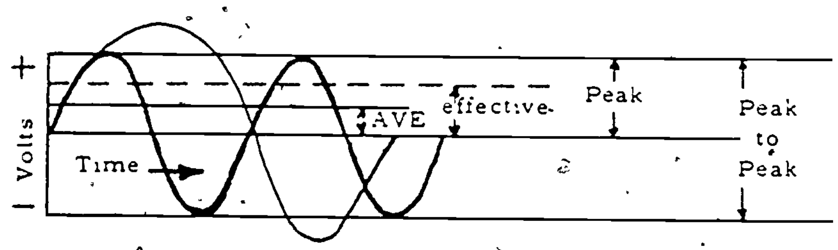

Figure 1. Sine wave.

f. It is immediately apparent that this waveform is constructed by continuously repeating one pattern. This unit, which arbitrarily begins at zero, builds up to a positive maximum, decreases through zero to a negative maximum, and then returns to zero, is called a CYCLE.

g. Since this variation of potential occurs during a discreet period of time, a particular source may be characterized by the fixed rate at which the polarity reverses. This rate is termed FREQUENCY and is given in units of c.p.s. (cycles per second). Now, when you hear someone refer to conventional household current used in the United States as being 60 cycles per second, you know that the potential source supplying the system performs a complete reversal of polarity sixty times a second. Such current is often termed merely "60 cycle," the unit of time is understood to be seconds by convention.

h. In describing the magnitude of an a.c. current or voltage, you will encounter four different values. All of them are useful in certain applications, so you will need to become familiar with their interpretation.

(1) The instantaneous value of a.c. voltage or current is the exact value at a particular instant of time. These values are normally represented by lower case letters; i.e., for current, and for voltage.

(2) The maximum instantaneous value is termed the peak value, and is represented by a capital letter (I_m or E_m).

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(3) The average value of an alternating current or voltage is the average value over one-half cycle. This has been calculated to be 0.637 times the peak value; for example, $I_{avg.} = 0.637 I_m$, or $E_{avg.} = 0.637 E_m$.

(4) The value of current or voltage normally indicated by an a. c. ammeter or voltmeter is the effective value. The effective value is the equivalent d. c. value, and is 0.707 times the peak value ($I_{eff} = 0.707 I_m$). The term, root mean square (r. m. s.), is commonly used for effective value.

3. INDUCTANCE.

a. Inductance is that property of an electrical circuit which tends to oppose a change (increase or decrease) of current. By analogy, you may think of inductance as the inertia of an electrical system.

b. In order to gain an understanding of the principles underlying inductance, we must recall that electrons in motion are surrounded by a magnetic field. Such a field surrounds every current carrying conductor.

(1) By coiling wire we are able to sum these lines of force and produce new and stronger fields. This is similar, in some respects, to the increased elasticity produced by coiling steel wire to form a spring.

(2) These new lines of force issue from one end of the coil and return to the opposite end as in a magnet.

(3) The strength of this field is related to the amount of current flowing in the coil. Any variation in the current changes the magnetic field intensity inducing an e. m. f. or voltage on the coil. This property of a coil is known as SELF-INDUCTANCE.

(4) Faraday's law states that the e. m. f. induced in any circuit is dependent upon the rate of change of the magnetic lines (flux) linking the circuit.

(5) Lenz's law adds to this by stating that the induced e. m. f. is always in such a direction as to oppose the change of current which produced it. For this reason, the induced voltage is called a counter e. m. f.

(6) Both of the foregoing laws may be summarized by the formula $e = -L\,di/dt$, where e is the induced voltage, L is the inductance, and di/dt is the rate of current change.

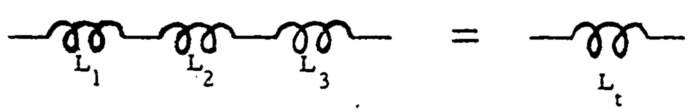
c. Inductance is measured in units of HENRIES By way of definition, a henry is the inductance of a circuit in which a current change of one ampere per second causes a counter e. m. f. of one volt. A henry is a large unit, and is seldom used in electronics work. Units of more practical values are the millihenry (1mh = 10^{-3}h), and the microhenry (1μh = 10^{-6}).

d. You will recall from previous lessons that a resistor is an element which limits the flow of d. c. in a circuit. A resistor also limits a. c. flow. Since a. c. is continuously changing in magnitude however, inductors that oppose this change produce an additional resistive effect. This opposition, termed INDUCTIVE REACTANCE, depends upon the frequency of the current and the inductance of the coil. It may be calculated from the formula $X_L = 2\pi fL$. Where X_L is the symbol for inductive reactance in ohms, f is in c. p. s., and L is in henries. This formula merely states that the inductance is proportional to the frequency. The voltage also will be affected by the inductive reactance and is expressed by the formula $E = IX_L$, or the voltage will equal the current times the inductive reactance.

e. The limitation of current and opposition to change caused by an inductor produces a delay in time between the application of the maximum voltage, and the realization of the maximum current flow. This is a phase shift, and amounts to a 90° change across a pure inductor. Thus, the current through a coil is said to "lag" the applied e.m.f. by 90°.

f. Circuit analysis.

(1) Inductors connected in series offer only one path for current flow. The total inductance of two or more inductors connected in series, and shielded from one another, is the numerical sum of the individual inductances (fig. 2).



$$L_t = L_1 + L_2 + L_3$$

Figure 2. Inductors in series circuit.

(2) Inductors connected in parallel provide alternate paths for current flow. The total inductance of such an arrangement is calculated as the reciprocal of the sum of the reciprocals of the individual inductors, provided the coils are shielded to prevent mutual inductance between the coil (fig. 3).

$$L_t = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

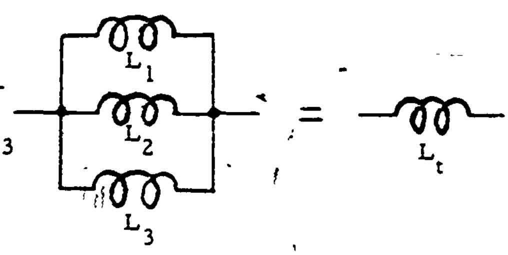


Figure 3. Inductors in parallel circuit.

(3) These formulas correspond directly to the ones previously derived for resistors.

g. Inductances are normally identified by printed values on the exterior, rather than by color coding.

4. CAPACITANCE.

a. Capacitance is that property of an electrical circuit which tends to oppose a change in voltage. You will soon realize that capacitance produces an effect opposite and complementary to that produced by inductance.

b. Although this effect is present to some extent in all circuits, it is most pronounced in particular elements called capacitors. A capacitor, or condenser as it is sometimes termed, consists physically of any two conductors separated by an insulating material called a dielectric.

c. Since we did not mention capacitance in our discussion of d. c., you might wonder how it affects such a circuit.

(1) The truth is that a capacitive effect is only noticeable in d. c. circuits during opening or closing of the circuits when it opposes the change in voltage. Thus, it is said to block d. c. and present an open circuit condition.

(2) In addition, however, a capacitor stores electric charge on its plates. If you connect a capacitor to the terminals of a d. c. potential source, the voltage forces electrons on to one plate of the capacitor. Although these electrons cannot pass through the dielectric unless the breakdown voltage is exceeded, they can repel electrons from the opposite plate. The electrons from the second plate flow back to the positive terminal of the potential source, and the capacitor is said to be charged.

(3) Current flows through the circuit while the capacitor is charging, but stops when the capacitor is fully charged. Compare this to the current through an inductor, which is initially small and gradually increases, and you will agree that the effects are opposite, but complementary.

(4) If you reverse the lead wires on the capacitor, it will discharge through the potential source and charge with the opposite polarity. (A capacitor may also be discharged by disconnecting it from the circuit, and shorting its terminals. In this case, the energy is released in a spark.)

d. Alternating current is constantly changing polarity at a fixed frequency; therefore, a capacitor in an a. c. circuit will be constantly charging and discharging at the same frequency.

e. If both d. c. and a. c. are impressed upon a capacitor it will block the d. c. but "pass" the a. c. due to the constant charging and discharging.

f. It was discovered experimentally that for a fixed capacitor the ratio of charge to the voltage causing it is always constant. This gives us the formula $C = \frac{Q}{E}$ as a means of calculating capacitance, where C equals capacity, Q equals the charge on one plate of the capacitor, and E equals the applied voltage.

g. Capacitance is measured in units of FARADS.

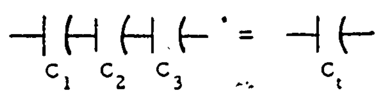
(1) A farad is the capacitance possessed by a capacitor on one plate of which one coulomb of charge is deposited by one volt.

(2) Although the capacitance of five millionths of a farad (0.000005) might appear rather small, many electronic circuits require capacitors of much smaller value. Consequently, the farad is a cumbersome unit and far too large for most applications. The microfarad, which is one-millionth of a farad (1×10^{-6} farad), is a more convenient unit. The symbols used to designate microfarads are μF and MFD. In high frequency circuits even the microfarad becomes too large and the unit micromicrofarad (one-millionth of a microfarad) is used. The symbols for micromicrofarads are $\mu\mu$F and MMFD. However, the name "picofarad" (pF) is preferred in place of micromicrofarad. In powers of ten, one picofarad (or one micromicrofarad) is equal to 1×10^{-12} farad.

h. The opposition of a capacitor for a. c. is found to decrease with increasing frequency and capacitance. CAPACITIVE REACTANCE, which is given the symbol X_c and is measured in ohms, is calculated from the formula $X_c = \frac{1}{2\pi fC}$, where f is the frequency of the a. c. source, and C, the circuit capacity in farads, and 2π is 6.28.

i. Circuit analysis.

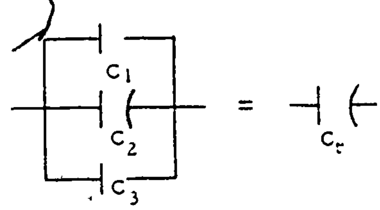
(1) Capacitors in series total like resistors in parallel; i.e., the equivalent capacitance of two or more capacitors in series is the reciprocal of the sum of the reciprocals of the individual capacitances (fig. 4).



$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

Figure 4. Capacitors in series circuit.

(2) When capacitors are connected in parallel, the equivalent capacitance is computed as the numerical sum of the individual capacitances (fig. 5).



$$C_t = C_1 + C_2 + C_3$$

Figure 5. Capacitors in parallel circuit.

j. We have seen how a voltage applied to a capacitor produces an instantaneous current response. Because of the charging process involved, the voltage across a capacitor cannot build up instantly. This time delay is again termed a phase shift. For a pure capacitor, the voltage is said to "lag" the current by 90°. Since the voltage is normally taken as the reference, however, we may reword this and say that the current "leads" the voltage by 90°.

k. Capacitors are rated according to their storage capacity in terms of farads. In addition, they are also rated for a safe working voltage. This is a value safely below the dielectric breakdown voltage (i.e., the voltage at which the dielectric breaks down and conducts electricity).

l. Capacitors are identified with the standard color code used on resistors. There are two marking codes presently employed; e.g., the JAN (Joint Army-Navy), and the RMA (Radio Manufacturer's Association). An understanding of these codes is not necessary for our purposes.

EXERCISE

71. What describes the effect produced by capacitance in comparison to inductance?

    a. Alike
    b. Opposite
    c. Both block d. c.

72. What is the exact value of an a. c. voltage or current measured at a particular instant of time called?

    a. Effective value
    b. Peak value
    c. Instantaneous value

73. If a 60-cycle alternator delivers 220 volts to a capacitor having a capacitance of 14.5 microfarads, the capacitive reactance in ohms will be

    a. 18.
    b. 183.
    c. 546.

74. A standard 0- to 100-ampere ammeter is connected in series with the output of an a. c. generator. If the peak current is 100 amperes, what value will be indicated on the meter?

    a. 70.7 amperes
    b. 90 amperes
    c. 100 amperes

75. Which is correct as regards a purely capacitive circuit?

    a. Voltage and current are in phase
    b. Current will lead voltage by 90°
    c. Voltage will lead current by 90°

76. Which is a characteristic of an inductor?

    a. Tends to oppose a change of current
    b. Does not resist current changes
    c. Tends to oppose a change in voltage

77. Which characteristic of a capacitor is TRUE?

a. Current lags the voltage by 90°
b. Voltage across capacitor builds up instantly
c. Instantaneous response to current when voltage is applied

78. Inductance is usually associated with a. c. circuits. It is present in a d. c. circuit ONLY at the time when the current is

a. increasing.
b. decreasing.
c. changing.

79. Which procedure is used to determine the total inductance of two or more inductors connected in series?

a. Product over the sum
b. Sum of individual inductances
c. The reciprocal of the sum of the reciprocals of individual inductors

80. What is another term for the r. m. s. value of alternating current?

a. Effective value
b. Instantaneous value
c. Peak value

81. Which decreases the opposition of a capacitor to a. c.?

a. Low frequency
b. Low voltage
c. High frequency

82. The counterpart of inductance in electrical circuits is capacitance. The properties of capacitance are such that when a d. c. potential is impressed across an uncharged capacitor; the current flow will be

a. constant.
b. low, gradually increasing.
b. high, gradually decreasing.

83. What is the graphic portrayal of potential over a period of time called?

a. Flattop wave
b. Sine wave
c. Sawtooth wave

84. The capacity of a capacitor is expressed as the ratio of the charge on the plates to the voltage impressed across them. If a capacitor will store 0.2 coulomb on its plates when connected across a 440-volt circuit, its capacity in microfarads is approximately

a. 44.
b. 220.
c. 455.

85. The maximum voltage delivered by an a. c. generator is 770 volts. What is the average voltage impressed across a load in series with the generator?

a. 490.49
b. 544.39
c. 1,089.09

86. A radio repairman needs to replace an 8-microfarad capacitor in his company commander's radio, but cannot locate one in his shop supply. Rather than deadline the item for parts, he can replace it with

a. a 4-microfarad capacitor and a 16-microfarad capacitor in series.
b. two 16-microfarad capacitors in series.
c. two 4-microfarad capacitors in series.

87. A coil has an inductance of 3 henries. Neglecting its resistance, at what rate will the current increase when the coil is connected directly across a 24-volt battery?

a. 0.125 amp per second
b. 0.8 amp per second
c. 8.0 amps per second

88. A high frequency choke (coil) is required for a radio transmitter. It is determined that an inductance with 10,000-ohm reactance will reduce the 5-megacycle signal current to a value of 2.5 milliamperes. What is the voltage of the signal?

a. 10
b. 25
c. 34

89. What is the opposition in a coil called?

a. Resistance
b. Henries
c. Inductive reactance

90. The voltage rating for motors and generators is given in terms of the effective value. However, the insulation of the conductors is required to withstand the maximum (peak) voltage that is developed. The windings of a 115-volt a. c. motor will be subjected to a maximum voltage of approximately

a. 125.
b. 162.
c. 180.

CORRESPONDENCE COURSE
of the
US ARMY ORDNANCE CENTER AND SCHOOL

LESSON ASSIGNMENT SHEET

Ordnance Subcourse No 98 . . . . Fundamentals of Electricity

Lesson 5 . . . . Resistive-Capacitive and Resistive-Inductive Circuit

Credit Hours . . . . Three

Lesson Objective . . . . After studying this lesson you will be able to:

1. Describe the characteristics of resistive-capacitive and resistive-inductive circuits.

2. Describe the use of waveforms in analyzing resistive-capacitive and resistive-inductive circuits.

Text . . . . Attached Memorandum

Materials Required . . . . None

Suggestions . . . . None

STUDY GUIDE AND ATTACHED MEMORANDUM

1. INTRODUCTION.

a. Thus far in our study, we have been concerned only with individual circuit elements and their interaction with direct and alternating currents. Now we will proceed to investigate combinations of resistors, capacitors, and inductors. In the circuits discussed in this lesson the components are assumed to be ideal, and stray effects or imperfections are considered absent. You should realize, however, that actual resistors, capacitors, and inductors are not ideal; i.e., a resistor possesses some inductance, an inductor possesses resistance, capacitance is present between the turns of wire, and a capacitor possesses some resistance.

b. The analysis of both RC (resistive-capacitive) and RL (resistive-inductive) circuits will involve WAVEFORMS. A waveform can be described best as any rise or fall of voltage or current over a finite period of time and can be drawn as a graph of the changing current or voltage plotted against time. A variety of waveforms are produced by electronic circuits; those that do not follow the pattern of the sine wave are called nonsinusoidal waveforms. Originally, such waves were regarded as undesirable distortions of sine waves. Today, the study of such waves has been extended to determine new ways of producing and utilizing them. There are two types of nonsinusoidal waves: the aperiodic wave which appears only once or at irregular intervals, and the periodic wave which is repeated at constant intervals. Unless specifically designated as aperiodic, all waves discussed here will be periodic waves.

c. Any instantaneous change in voltage may be classified as a step voltage. The change may be either a sudden increase (positive step) or a sudden decrease (negative step).

2. RC CIRCUITS.

a. General. The response of any circuit to a step voltage can be determined by using Kirchhoff's law which states that the sum of the voltage drops in any closed circuit is equal to the applied voltage. For an RC circuit, this may be shown by the formula: $E = E_R + E_C$. You will recall from our previous lesson that the charge on a capacitor cannot change instantaneously. A capacitor without any resistance would charge up immediately. But this never happens because there is no perfect capacitor, every capacitor has some resistance. Therefore, a capacitor always needs time to charge.

b. RC circuit response. In a series RC circuit a capacitor charges to a voltage equal to the applied voltage provided sufficient charging time is allowed. After the capacitor has charged to the applied voltage, and the applied voltage remains constant, a current ceases to flow in the circuit because the capacitor offers infinite resistance to the flow of direct current. When the applied voltage is removed, and a discharge path is provided, the capacitor discharges through the circuit. The time required for the capacitor to charge or discharge determines the characteristics of the output waveform. Because RC circuits are used extensively for producing the various transients required in electronic systems, a thorough understanding of RC circuits and their responses to various types of input pulses is essential.

(1) Positive step. Consider a positive step voltage E being applied to a series RC circuit as shown in figure 1A. At the instant E is applied, the total voltage appears across the resistor because the capacitor is initially uncharged and current equal to E/R is flowing to the capacitor. The current starts to charge the capacitor and a voltage then appears across C. Because the sum of E_C and E_R must equal E (Kirchhoff's law), the voltage across R begins dropping as the capacitor charges. If the voltage across the resistor is decreasing, the current through the resistor must also be decreasing. Because of the decreasing current, the capacitor charges at a slower and slower rate. After a short time, the capacitor is fully charged and its voltage is equal to the applied voltage, thus, current no longer flows. Waveforms of the current and various voltages are shown in figure 1.

(2) Negative step. Let the applied voltage suddenly be changed to zero a negative step voltage, then, with no voltage impressed upon the capacitor, the contained charge flows through the resistor and the capacitor discharges. Initially, a voltage equal to the earlier applied voltage is present across the capacitor, and the polarity of the voltage causes the discharge current to flow opposite to the charge current. As the voltage across the capacitor decreases there is less driving force behind the current and the current gradually decreases. The storage of energy in the capacitor is somewhat analogous to the action of a spring - push one way on a spring and energy is stored, release the pressure and the spring gives up its stored energy by pushing back the other way.

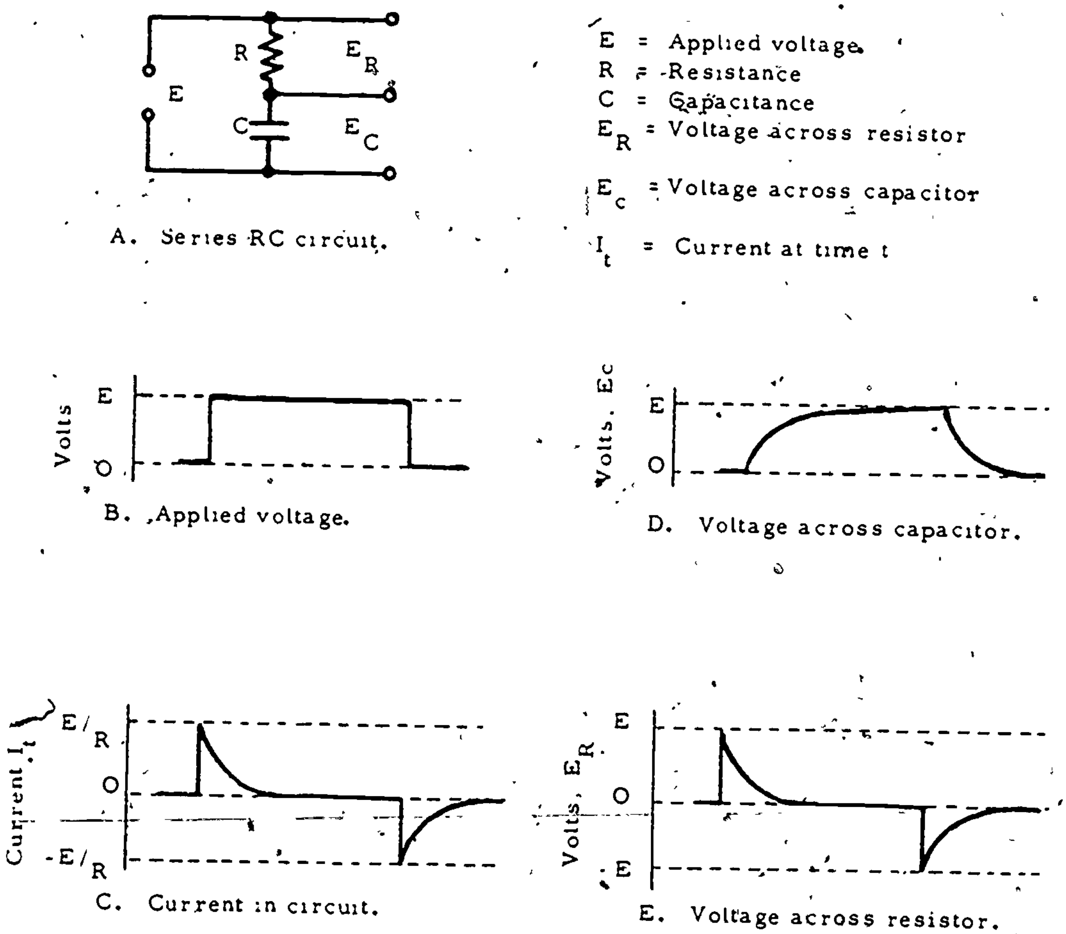


Figure 1 Series RC circuit and its response to a positive step voltage followed by a negative step voltage.

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c. RC time constants. The action of an RC circuit on a step voltage may be expressed by the time constant for the circuit. The shapes of waveforms for all RC circuits are generally the same, the differences arise only in the length of time required for the circuit to charge or discharge. Since the curves taper and approach their limiting values very slowly (according to theory the curves never really reach the limits; however, in practice the difference becomes negligible), some arbitrary point on the curves must be selected to describe them. The circuit time constant is defined as the time required for a variable, such as capacitor charge, to change by 63.2 percent of the total change caused by a step voltage. Although the value 63.2 percent may seem an unusual number, its use greatly simplified the mathematical computations of circuit response. For an RC circuit, the time constant is given by the expression:

$$T = RC,$$

where, T = time in seconds.
R = resistance in ohms.
C = capacitance in farads.

If the capacitance were increased the time constant would become longer—a larger capacitor contains a greater charge, and the charge requires longer to flow out through the resistor. Furthermore, if the resistance were increased the time constant would also become longer—a large resistance hinders the current flow more causing a longer time to be required for the current's passage. If either or both the resistance and capacitance are decreased the time constant will decrease correspondingly.

d. Universal time-constant chart. Since the waveforms for different RC circuits are similar, a universal curve has been constructed (fig. 2). The vertical axis is marked as relative percent of voltage or current, and the horizontal axis is marked in terms of time constants. Two curves are drawn so that the chart may be used for either increasing or decreasing values.

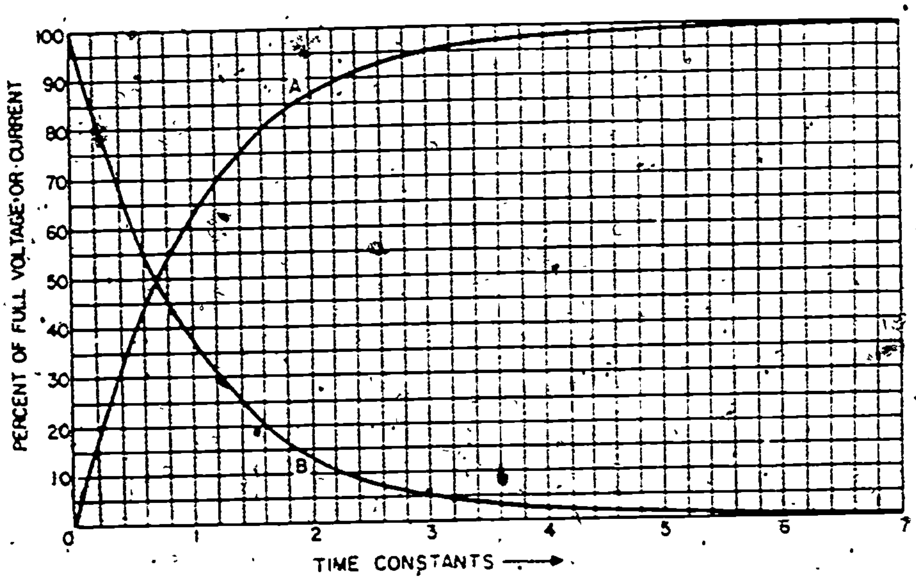

Figure 2. Universal time-constant chart.

(1) Consider an RC circuit with the following components: a 5,000-ohm resistor and a 1,000 pF (picofarad or micromicrofarad or 1×10^{-12} farads) capacitor. Applying the formula for the time constant, we find that the circuit has a time constant of 5 μsec (5 microseconds). $T = RC$ or $T = 5 \times 10^{-12} = 5 \times 10^{-9}$ seconds.

(2) What will be the current flow and voltages across the resistor and capacitor 10 μsec after a 45-volt battery is connected in the circuit? Remembering that the current flow in the circuit will instantaneously jump to its maximum and then die out gradually, we will use curve B of the universal time-constant chart. The maximum current at the instant the voltage is applied is found by Ohm's law:

$I = E/R$, $I = 45/5000 = 9 \times 10^{-3}$ amperes or 9 ma.

Looking at the universal time-constant chart, we find that curve B is equal to about 13 percent after 2 time constants (10 μsec for our circuit). Therefore, the current flowing is 13 percent of 9 ma, or 1.17 ma. Notice how the current quickly approaches zero after a number of time constants have passed; i.e., the current is considered equal to zero after 7 time constants.

(3) The initial voltage across the resistor will be 45 volts; but the voltage will decrease as the capacitor charges. Using curve B again, at a time equal to two time constants, we find that the resistor voltage has decreased to 13 percent of its original value and now is 5.85 volts (0.13 x 45). The capacitor voltage may now be found by two methods. Kirchhoff's law states that the sum of the voltage drops must equal 45 volts; thus, since E_R is 5.85 volts, E_C must be 39.15 volts. We can also use the chart (fig 2). Remember, the capacitor voltage starts at zero and increases to its maximum; therefore, curve A will be used. The maximum capacitor voltage will be 45 volts. After two time constants, curve A has a value of 87 percent; therefore, the capacitor voltage after two time constants will be 39.15 volts (0.87 x 45). In a similar manner, the universal time-constant chart may be used for any RC circuit and a step voltage; however, the chart may not be used for waveforms other than step voltages.

Note. - For applied voltages, other than step voltages, the circuit response may be approximated by considering the applied voltage as a series of stairsteps, each of which is a step voltage. Values for each step must be computed before proceeding to the next step.

e. Use of power in an RC circuit. A circuit component receives power which is equal to the product of the current flow and the voltage across the component. Power used by the resistor is equal to $I_t E_R$ and is dissipated in the form of heat. Power stored by the capacitor is equal to $I_t E_C$ and is stored in the form of the potential energy of the charge.

3. RL CIRCUITS.

a. General. You learned in the previous lesson of this subcourse that the flow of electric current in an inductor cannot change instantaneously. A finite length of time is required to effect any change because of the magnetic field which must build up or collapse according to the change. However, many times in electronic equipment a signal voltage will change rapidly or even instantaneously in the form of a positive or negative step voltage. Suppose a resistor and an inductor were connected in series and a step voltage were applied, what would be the waveform of the current flowing or the waveform of the voltage across the inductor? This portion of the lesson will show you how a simple RL circuit responds to voltage changes and how you may calculate the current and various voltages.

b. RL circuit response to a step voltage. Let us now consider a series RL circuit to which we will apply a step voltage. The resulting response of the RL circuit is quite important because several similar circuits are used in the antitank missile system.

(1) Positive step voltage. As in the discussion of RC circuits we will again make use of Kirchhoff's law, the sum of the voltage drops in any closed circuit is equal to the applied voltage, to determine the response of our series RL circuit. Let a positive step voltage of value E be applied to the circuit as shown in figure 3A. A current will attempt to flow in the circuit; however, the inductor will not allow an instantaneous change (in this case, increase from zero) of current flow. At the instant the voltage is applied the inductor creates a back (counter) e.m.f. which prevents current flow. A flow of current cannot be disassociated from the magnetic field. If no field has built up, no current can flow. Since no current is flowing, there is no voltage drop across the resistor and, by Kirchhoff's law, the entire voltage E appears across the inductor as E_L. Although back e.m.f. of the inductor prevents an instantaneous change of current, a gradual increase in current does occur. Studying the circuit a fraction of a second after the step voltage has been applied, we find a small, though increasing, amount of current flowing. Since current is flowing through the resistor a voltage drop must be present across the resistor. Now, by Kirchhoff's law, the voltage drop across R and that across L must equal the applied voltage E; so, a voltage drop is also present across L. Because the current is increasing, the voltage across R is increasing and thus the voltage across L is decreasing. The voltage across R increases until E_R equals E and the maximum possible current is flowing; consequently, the change of current ceases and a steady-stage of equilibrium is maintained. Voltage and current changes may be shown graphically as in figure 2. The closer the current gets to the limiting value (when all voltage appears across R and none across L), the slower the current tends to increase. According to theory the current never reaches the limiting value but in practice the difference quickly becomes negligible.

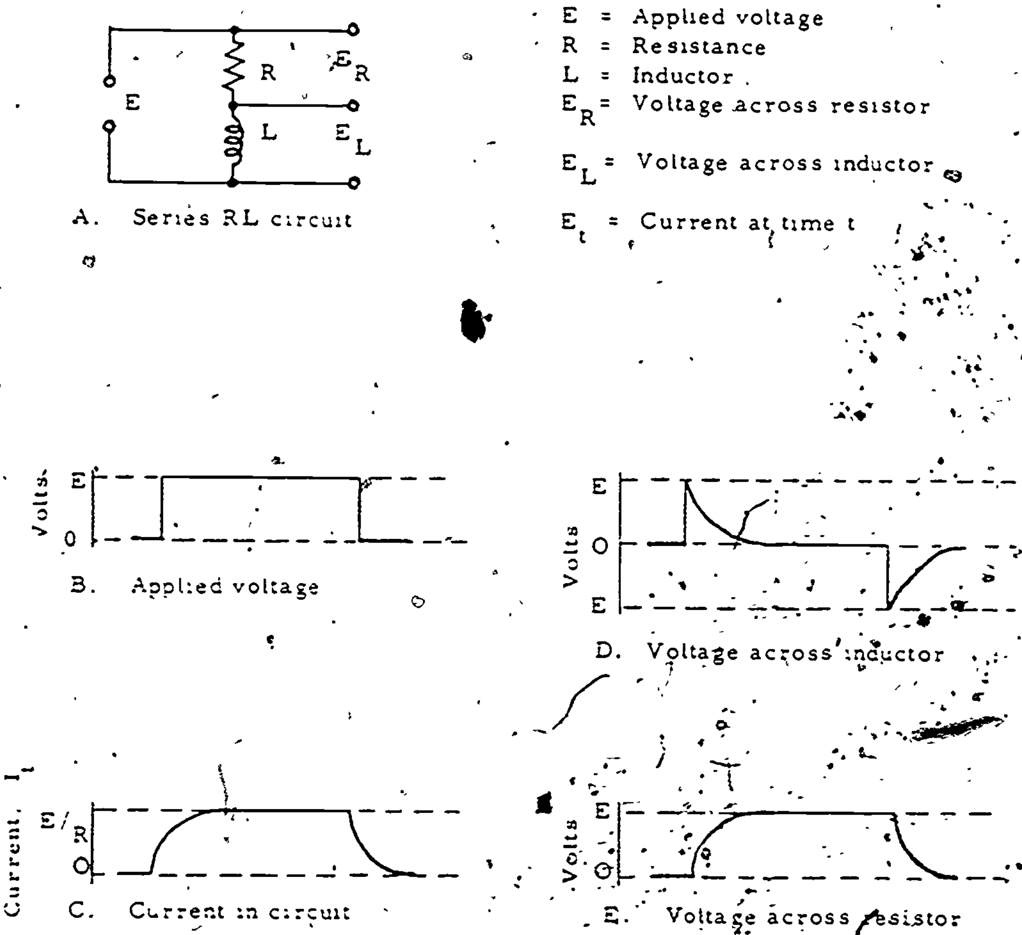

Figure 3. Series RL circuit and its response to a positive step voltage followed by a negative step voltage.

(2) Negative step voltage. As you recall from your previous study of inductors, the building of a magnetic field around the coils provides the back e.m.f. when lines of flux cut adjacent ~~turns of~~ wire. When a negative step voltage is applied the collapse of the magnetic field, which was built up by the flowing current, again provides an e.m.f. countering the current change. Removing the applied voltage E will give a negative step voltage. At the instant the voltage is removed, the current, having no driving force, attempts to stop and would do so were the inductor not in the circuit. The inductor contains stored energy in the form of its magnetic field. This field, which was produced and maintained by the moving charges composing the electric current, will collapse in the absence of a sustaining current. As the field collapses, the flux lines move inward and again cut adjacent turns of wire and induce an electric voltage in the coil. Although the induced voltage also has a field, the net result is a conversion of the total field into a decreasing electric current. The direction of this current is such as to oppose the change of current; the action tends to maintain the previous current (Lenz's law). Current through an inductor cannot stop instantaneously anymore than it can start instantaneously. When the negative step voltage is applied to an RL circuit, the current gradually decreases and the voltage across the resistor gradually decreases. When a steady current flows there is no voltage across the inductor; however, with E suddenly removed, the collapse of the inductor's magnetic field causes a voltage to suddenly appear across the inductor and then gradually die out as the energy of the field is used. As the magnetic field collapses, it becomes weaker causing the current to decrease and approach zero. A set of curves may be drawn to show current and voltages resulting from the negative step voltage; these curves are shown in figure 2.

Note.—Care must be exercised when a negative step voltage is obtained by opening a switch. An open switch places a very high resistance in the circuit. The action of the inductor is to maintain the current which had been flowing. The current from the inductor attempts to flow through the high resistance and an extremely high voltage across the switch is created. The voltage builds up to the point at which air breaks down and an arc jumps across the switch. The arc can be prevented by using a discharge resistor which is wired so that as the applied voltage is removed, a low resistance path is provided for the current.

c. RL time constants. The effect of any particular RL circuit may be described by the time constant for that circuit. As for RC circuits, the time constant is that time required for a variable of the circuit to change by 63.2 percent of the total change introduced by a step voltage. For a positive step voltage, the time constant is the time required for the current to achieve 63.2 percent of the equilibrium value, or the resistor voltage to reach 63.2 percent of the step voltage or the inductor voltage to decrease to 36.8 percent of the step voltage (when E_L reaches 37.8 percent of the original voltage across the inductor, 63.2 percent of the total change has been accomplished). The value of the time constant is defined as:

$$T = \frac{L}{R}$$

where T = time in seconds,
L = inductance in henries.
R = resistance in ohms.

The time constant for an RL circuit may be used in conjunction with the universal time-constant chart to determine voltage and current at any particular instant. The procedure is identical to that for RC circuits.

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d. Power in a series RL circuit. While current is flowing in the RL circuit, the resistor is receiving power equal to I_tE_R. The power going to the resistor is dissipated in the form of heat and can never be recovered. Whenever the current is increasing in the circuit, power is also drawn by the inductor. The power going into the inductor is equal to I_tE_L and is stored in the form of a magnetic field. When the current decreases, the inductor puts power back into the circuit as the magnetic field collapses. The expression for power returned to the circuit is the same as that for power taken from the circuit.

EXERCISE

91. What is the purpose of switching a low-value resistor across the RL circuit at the moment a battery is switched out of the circuit?

    a. Allow the inductor's magnetic field to collapse
    b. Sustain the current which is flowing
    c. Prevent arcing in the switch

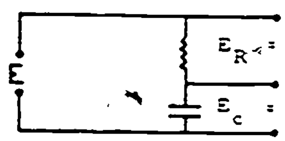
92. What will happen if the wire connecting the resistance and inductance in figure 3A is cut while current is flowing in the circuit?

    a. A high voltage spark will jump across the wire as it parts
    b. Nothing
    c. Current will cease and the inductor will maintain its stored energy

93. In circuit No 1, what is the voltage (volts) across the capacitor 500 μsec after the positive step voltage has been applied?

    a. 1.5
    b. 28.5
    c. 30

Circuit No 1:



1,000,000 Ω (ohms)

50 pf (picrofarad or micromicrofarads)

E is a positive step voltage of 30 volts.

94. In circuit No 1, what is the voltage (volts) across the 1-million ohm resistor 20 μsec after the positive step voltage has been applied?

    a. 28.5
    b. 20.1
    c. 9.9

95. What is the time constant (μsec) of circuit No 1?

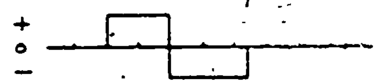
    a. 50
    b. 5
    c. 0.5

96. Which series combination of circuit elements will have the shortest time constant?

a. A 1000-μf capacitor and a 100-ohm resistor
b. A 6000-μhenry inductor and a 300-ohm resistor
c. A 4000-μhenry inductor and a 10,000-ohm resistor

97. A positive voltage of 0.2 second followed by a negative voltage of 0.3 second is what kind of waveform?

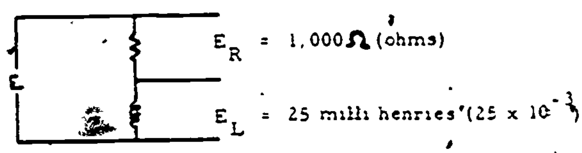
a. Aperiodic, sinusoidal
b. Periodic, sinusoidal
c. Aperiodic, nonsinusoidal



98. In circuit No 2, what is the voltage (volts) across the inductor 75 μsec after the positive step voltage has been applied?

a. 20.0
b. 10.0
c. 1.0

Circuit No 2:



E is a positive step voltage of 20 volts.

99. In circuit No 2, what is the current (ma.) flowing through the resistor 50 μsec after the positive step voltage has been applied?

a. 17.4
b. 11.3
c. 8.7

100. In circuit No 2, how much time (μsec) after the positive step voltage has been applied is required for the current to reach the steady-state?

a. 25
b. 100
c. 175

101. In circuit No 2, what is happening to the magnetic field 25 μsec after the positive step voltage has been applied?

a. Increasing
b. Collapsing
c. Not changing

102. Let a step voltage of 1 volt be applied to a series circuit of a 100-μf capacitor and a 1000-ohm resistor. Which has occurred after a time interval of 1 time constant?

a. Voltage across the capacitor has decreased by 0.368 volt
b. Voltage across the resistor has become 0.368 volt
c. Current has ceased to flow

103. What characteristic of an inductor is primarily responsible for the output waveform of the RL circuit?

a. Opposition to changes in current flow
b. Aiding changes in current flow
c. Opposition to changes in voltage

104. What becomes of the energy supplied to a series RC circuit?

a. Dissipated as heat and some stored as electrostatic charge
b. Dissipated as heat and some stored as magnetic field
c. Stored as both electrostatic change and heat

105. If the values of a resistance and capacitance in a series RC circuit are each halved, the time constant

a. is cut in half.
b. remains the same.
c. is reduced by three-fourths.

106. What is the form of the stored energy in a series RL circuit when a steady current is flowing?

a. Magnetic field around the inductor
b. High temperature of the resistor
c. Electrostatic charge on the inductor

107. Shortly (1 time constant) after a positive step voltage is applied to a series RL circuit

a. E_R is increasing and E_L is decreasing.
b. E_R is decreasing and E_L is increasing.
c. E_R is decreasing and E_L is decreasing.

108. What phenomena is responsible for the back e. m. f. created by an inductor?

a. Interference of flux lines from adjacent turns of the inductor
b. Induction of voltage as flux lines cut adjacent turns of the inductor
c. Cancellation and reinforcement of flux lines within the inductor

109. At what time constant is the current from a discharging RC circuit considered equal to zero?

a. 0
b. 1
c. 7

110. Shortly (1 time constant) after a negative step voltage is applied to a series RC circuit

a. E_R is increasing and electrostatic charge is decreasing.
b. E_R is decreasing and electrostatic charge is decreasing.
c. E_R is decreasing and electrostatic charge is increasing.

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CORRESPONDENCE COURSE
of the
US ARMY ORDNANCE
CENTER AND SCHOOL

LESSON ASSIGNMENT SHEET

Ordnance Subcourse No 98	Fundamentals of Electricity
Lesson 6	Operation and Characteristics of Vacuum Tubes
Credit Hours	Four
Lesson Objective	After studying this lesson you will be able to:
	1. Describe the construction and operation of vacuum tubes.
	2. State the different types and application of vacuum tubes.
	3. Describe the construction of graphs used in determining vacuum tube characteristics.
Text	Attached Memorandum
Materials Required	None
Suggestions	None

STUDY GUIDE AND ATTACHED MEMORANDUM

1. INTRODUCTION.

a. Electron tubes and transistors form the nuclei of most modern electronic apparatus. The great diversity of electronic applications stems directly from the use of versatile electron tubes and transistors. Today, transistors are rapidly replacing tubes in many applications; however, there are still a great number of jobs that can be done best only with tubes. Electron tubes are not going slowly into extinction; they will be used for a great many years to perform jobs for which they are the most efficient and practical means. This lesson will begin your study of electron tubes while transistors will be discussed in the next lesson.

b. An electron tube may be considered as a kind of valve for controlling the flow of electrons. Various special features are constructed into tubes to allow certain specific types of control. In an electron tube free electrons are produced and then flow through space, usually a vacuum, and impinge on a target. The flow of electrons constitutes a current; control over this current is the key to the tube's versatility.

c. During his experimentation with the incandescent lamp Thomas Edison discovered a phenomenon that he couldn't explain. If a second conductor were placed inside the glass envelope and connected through an ammeter to the positive end of the voltage source, a current was measured; however, if the connection were to the negative pole of the voltage source, no current was measured. The British scientist Sir J. J. Thomson later explained the Edison effect (electron emission) as being caused by a flow of electrons through space from the very high temperature, negatively charged filament (cathode) to the positively charged plate (anode). The two-electrode tube found use as a rectifier because current could flow in one direction only, thus alternating current could be easily converted into direct current. Radios used the tube as a detector. In 1907, Lee DeForest improved the vacuum tube by placing a third electrode between the existing electrodes. Small variations in the voltage of the new electrode produced correspondingly large variations in the current flowing through the tube. The new electrode was called the control grid and its incorporation allowed the vacuum tube to amplify relatively weak signals. The DeForest tube was one of the more significant milestones in the development of electronics and radio. Today, several additional controlling grids have also been installed to increase further the versatility of the electron tube.

d. Tubes may be classified according to their construction and function. Vacuum tubes are those in which air and gases have been evacuated. Some tubes, gas-filled tubes, have a special inert gas present inside their envelopes. The cathode (source of electrons) may be heated directly by an electric current or indirectly by radiation of heat from a separate filament (heater); in some cases, electrons are virtually pulled out of the cathode by an extremely intense electric field. A tube which contains two elements is known as a diode. Three elements compose a triode, and four elements a tetrode. Five- and six-element tubes are pentodes and hexodes, respectively. Sometimes, two diodes and two triodes - or any combination of the above assemblies are placed inside the same envelope, then, the tube is a duo-diode, a diode-triode, etc. Tubes are also called, according to their function, rectifiers, amplifiers, detectors, mixers, oscillators, and photoelectric tube cathode ray tube, etc.

2. ELECTRON EMISSION.

a. General. Because an electron tube accomplishes its purpose by the control of a stream of electrons, a reliable, steady, convenient source of electrons is necessary. Presently, there are four methods which are used to produce the necessary electron stream: thermionic emission, secondary emission, photoelectric emission, and cold-cathode emission.

b. Thermionic emission. In a conductive metal the electrons of each individual atom are rapidly orbiting around the nucleus of the atom. The nature of the forces holding the electrons is such that occasionally an electron may move its orbit from one nucleus to the next. A great number of electrons moving in the same direction constitutes an electric current. The speed at which the electrons orbit is dependent upon the temperature of the material; i. e., the higher the temperature, the faster the electrons are moving in their orbits and the more energy they possess. At a certain temperature, different for each material, the energy of the electrons has increased to the point that the force holding the electron in the atom is overcome and the electron flies away from the nucleus. The escape energy is called the work function (given in units termed electron volts) and is different for each material. The lower the work function of a material the easier electrons may escape, or, stating the idea differently, the lower the work function, the lower the temperature at which emission begins. For each emitter, the rate of electron emission increases as temperature increases above the lower limit of emission temperature. An upper limit is dictated by the melting point of the material. A material which has a low work function is desirable in electron tubes as too high a temperature causes the emitter to burn because a perfect tube vacuum is not attained and it also brings the material near its melting point thus reducing structural strength. The most satisfactory materials are tungsten, thoriated tungsten, and metals coated with alkaline earth oxides.

c. Secondary emission. Secondary emission is not used commonly in electronic tubes to produce the electron stream. However, secondary emission does occur in tubes and thus must be understood. If an electron were flying very rapidly through space and suddenly hit a material, the energy of motion of the electron must be used up in some manner. In some materials, the energy from a bombarding electron is transferred to the electrons of the material. The additional boost of energy may be enough to allow some of the electrons to overcome the material's work function and escape as secondary electrons. Secondary emission can take place in a tube when electrons hit the plate, but this action is undesirable and steps must be taken to reduce the effect. This will be gone into in more detail later in the lesson.

d. Photoelectric emission. Photoelectric emission is utilized only in a few special purpose tubes. Light possesses discreet "bundles" of energy called photons. When light falls upon a surface, the energy is distributed partially to the light that is reflected and partially to the surface. A few materials, such as silicon, have the ability to use the energy of light photons to speed up electrons of the material. Here again, if the electrons can overcome the materials work function, emission can occur.

e. Cold-cathode emission. The fourth type of emission is cold-cathode. In the previously described methods, the electrons gained moving or kinetic energy and escaped; however, in the cold-cathode method the energy is potential—like a rock about to fall. By using another electrode that is very highly charged, an extremely intense electric field is brought near the emitter. As electrons carry a negative charge they are strongly attracted to the postive electrode; in fact, so strong is the field that the electrons are actually pulled out of the emitter just as gravity pulls on a rock. Because the very high voltages required introduce many problems, cold-cathode emission is not commonly used.

3. DIODES.

a. General. Although the diode was the first vacuum tube to be generally used and its configuration is relatively simple, the use of diodes is still incorporated in the majority of modern electronic equipment. The most common uses are in rectifier and voltage regulator power supply circuits. Many of the principles involved in the operation of the diode are common to triode and multielement tubes.

b. Construction. A representative diode tube is shown in figure 1 with the various components identified. The filament serves here as an electron emitter but in other tubes it might be used solely to heat a small oxide-coated cylinder concentric with the plate. The plate, of course, receives the electrons liberated by the emitter. A getter is included within the glass envelope to maintain a good vacuum. After the tube is sealed off, the getter is flashed with an applied voltage and produces a compound which absorbs gases that might be present in the tube. The whole structure is enclosed in a glass or metal envelope that is sealed after the tube has been evacuated of air and gas. Electrical connections from the electrodes to the pins are made by a special alloy wire passing through the glass. The wire has thermal expansion characteristics identical to those of the glass thus forcing a tight seal to be maintained at all temperatures. The schematic symbols for a diode are shown in figure 2A, configurations for the enclosure of two diodes in the same envelope are shown in figure 2B.

c. Operation. For the diode to operate, a filament voltage must be applied to heat the cathode to operating temperature and a voltage applied between the cathode and plate. When these two voltages are applied, free electrons will be emitted from the cathode and an electric field will be present between the cathode and plate to act upon the electrons. If the plate is positive with respect to the cathode, the plate will attract the freed electrons and a current will flow from the cathode to the plate. If the plate is negative with respect to the cathode, electrons will be repelled by the field and no current will flow. Thus, we can state a few conclusions about the action of a diode:

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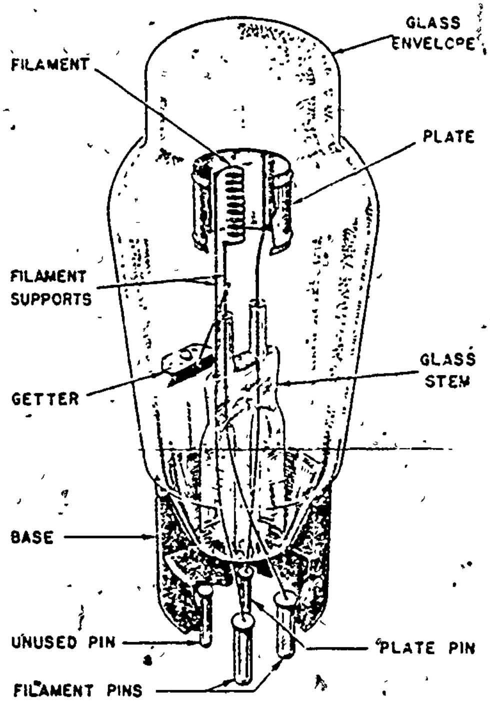

Figure 1. Construction of a diode electron tube.

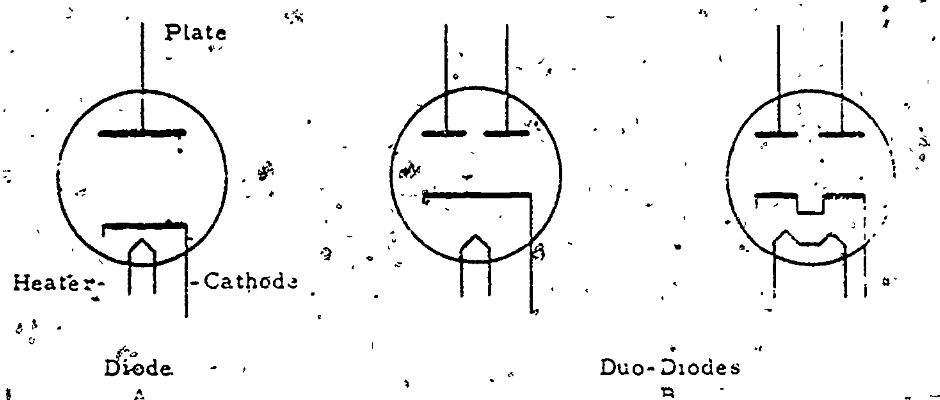

Figure 2. Schematic symbols for diode and duo-diode electron tubes.

(1) Current flow in a diode occurs when the plate is positive relative to the electron emitter.

(2) Current will not flow in a diode when the plate is negative relative to the electron emitter.

(3) A diode can behave like a control valve, automatically allowing or blocking current flow.

(4). If two diode systems are combined in a single envelope, the action of each remains the same.

d. Space charge. To have an accurate concept of the actions taking place, we must study the electron movement very carefully. The maximum values of electron emission, plate current, and plate voltage are determined by the actions of the electrons.

(1) Suppose the plate were absent, but the emitter were functioning, what happens to the electrons? An electron uses most of its surplus energy as it overcomes the emitter's work function, the electron escapes with a low velocity and remains close to the emitter surface. After many electrons have escaped, a cloud of free electrons, called a space charge, exists a short distance from the emitter surface. Because the space charge is composed of electrons, an electric field is set up between the space charge and the emitter. The emitter is positive relative to the electron cloud even though it is negative relative to the plate. The density of the electron cloud is greatest at points near the cathode. The effect of the electric field is to repel electrons being freed from the emitter. Electrons which are freed with a very low velocity are then repelled back into the emitter. For any one temperature of the cathode, the rate of electrons entering the cloud will eventually be equal to the rate of electrons ejected from the cloud back to the cathode. The density of the electrons in the cloud will remain constant. The constant density of the cloud is termed critical density and the equilibrium is called emission saturation. Thus, we see that the space charge has a controlling influence upon the emission of electrons from the cathode.

(2) Now, let us bring the positively charged plate into its position. Immediately, an electric field is established between the plate and the space charge (fig. 3). Notice that there are actually two fields present between the plate and cathode. One field is from the space charge to the cathode, and the second field is from the space charge to the plate. Actually then, the plate attracts electrons out of the charge which, in turn, acts as a reservoir for electrons emitted from the cathode. If electrons are drawn by the plate, the ability of the space charge to repel electrons is reduced and additional electrons from the cathode enter the space charge. When electrons equal to one ma. of current are drawn from the space charge by the plate, electrons equal to one ma. of current will be added to the space charge by the emitter. The space charge is a very handy thing to have in the tube. Most cathodes are designed to emit a great number of electrons. The space charge causes most of the electrons to return to the cathode and only the necessary ones are used. However, a large supply of free electrons is always present as a reserve. Were the space charge absent, a low voltage would induce very high currents in the tube and shorten the emitter life. Because of these controls the flow of current is described as space charge limited.

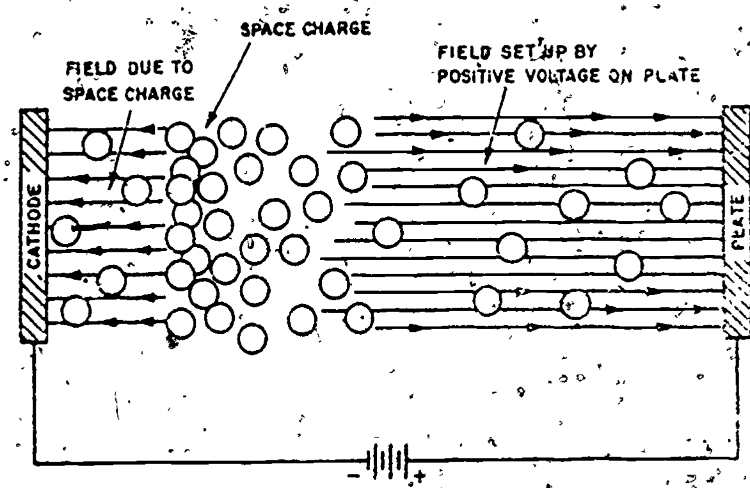

Figure 3. Schematic representation of a diode space charge and the associated electric fields.

e. Characteristics. In a diode (or any other electron tube) a definite relationship exists between each of the different variables; i.e., the plate voltage and plate current are interdependent; the electron emission and cathode temperature are related. If we construct a graph which shows the value of plate current for each value of plate voltage, we have a characteristic curve (fig. 4). Characteristic curves can be drawn for all of the various relationships. Each point on the curve represents a specific set of values for plate current and plate voltage. The curve also shows how a change in the plate voltage produces a corresponding change in plate current. In the 24-40 volt range the curve is almost straight and is termed linear, meaning that voltage and current are proportional in that range. The curve 1-10 volts is not straight and is termed nonlinear, the mathematical expression of which can be quite complex. The curve shown has been constructed for a particular cathode temperature. If the cathode temperature were changed, the critical density of the space charge would change and slightly different conditions would exist in the tube. For a different cathode temperature, another curve would have to be drawn. The new curve would bend down a little faster or a little slower, depending upon the direction of the change in temperature. If the curves for several different temperatures were plotted on the same graph, we would have a family of curves (fig. 5).

(1) The d.c. plate resistance of a diode. If the diode has a controlling influence on the flow of current there must be some resistance to the current's passage. The resistance of a diode is dependent upon the spacing and size of the electrodes, the condition of the space charge, and the energy dissipated by the electrons in their motion. In contrast to resistors, the resistance of electron tubes generally is not constant. The diode presents an infinite resistance to current flow in one direction and a variable resistance to current flow in the opposite direction. The d.c. plate resistance is the opposition presented to the flow of current from a d.c. voltage across the plate and cathode. The value of the resistance can be calculated easily from Ohm's law (R = E/I) using information taken from the characteristic curve. Using figure 6, we find that the d.c. resistance of a typical diode at a plate voltage of 20 volts is 500 ohms.

$R_p = E/I$, or: $R_p = 20/.040 = 500$ ohms

Likewise, the d.c. resistance at 28 volts is 422 ohms and at 8 volts is 800 ohms. Notice that the resistance changes and depends upon the plate voltage.

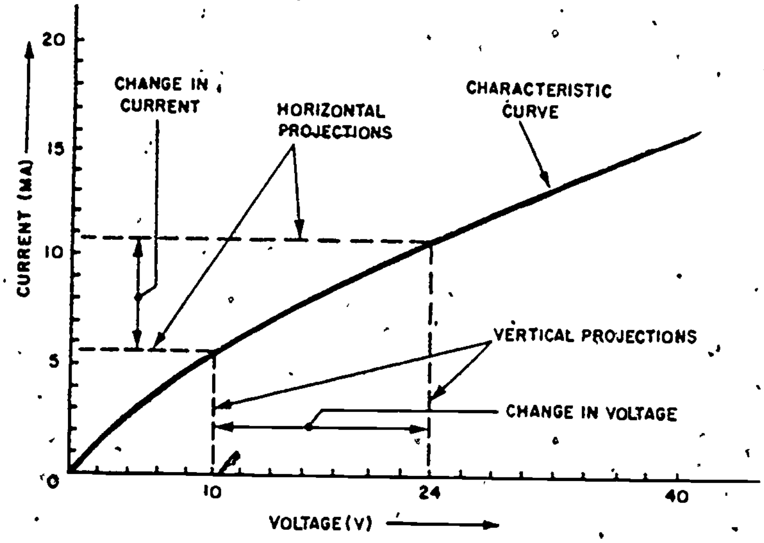

Figure 4. Plate-current, plate-voltage characteristics for a typical diode.

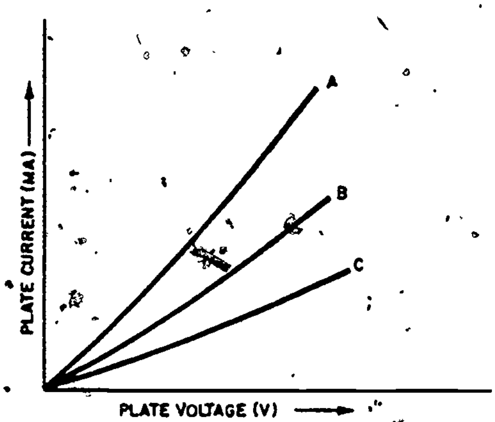

Figure 5. Plate family for a diode.

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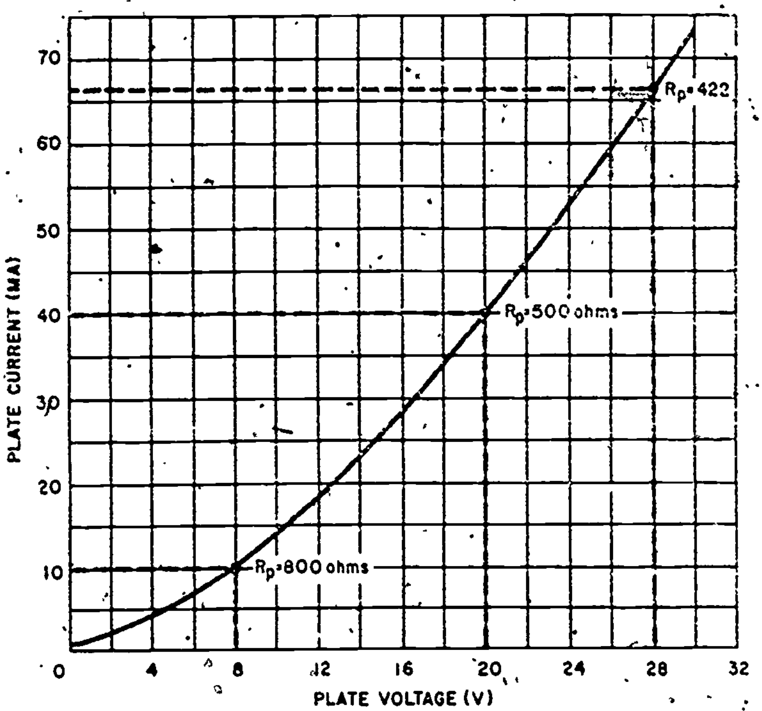

Figure 6. Calculation of R_p from a plate-current, plate-voltage characteristic.

(2) The a.c. plate resistance of a diode. The a.c. plate resistance of the diode is defined as the resistance of the path between the cathode and plate to the flow of an alternating current inside the tube. The plate resistance is the ratio of a small change in plate voltage to the corresponding change in plate current.

$$r_p = \frac{\Delta e_p}{\Delta i_p}$$

where r_p is a.c. plate resistance (ohms),
Δe_p is a small change in plate voltage (volts),
Δi_p is a small change in plate current (ma).

The value of rp may be calculated using information from the characteristic curve as shown in figure 7. At 20 volts the a.c. plate resistance is 320 ohms.

$$r_p = \frac{21.6 - 18.4}{.045 - .035} = \frac{3.2}{.010} = 320$$

For accurate results, the small changes should be taken so that the values evenly bracket the desired voltage or current. The smaller the changes used, the more accurate the results (providing, of course, the curve values may be read accurately). There is an appreciable difference between a.c. plate resistance and d.c. plate resistance, the a.c. value being about half the d.c. value. Such a difference is generally true for all types of vacuum tubes.

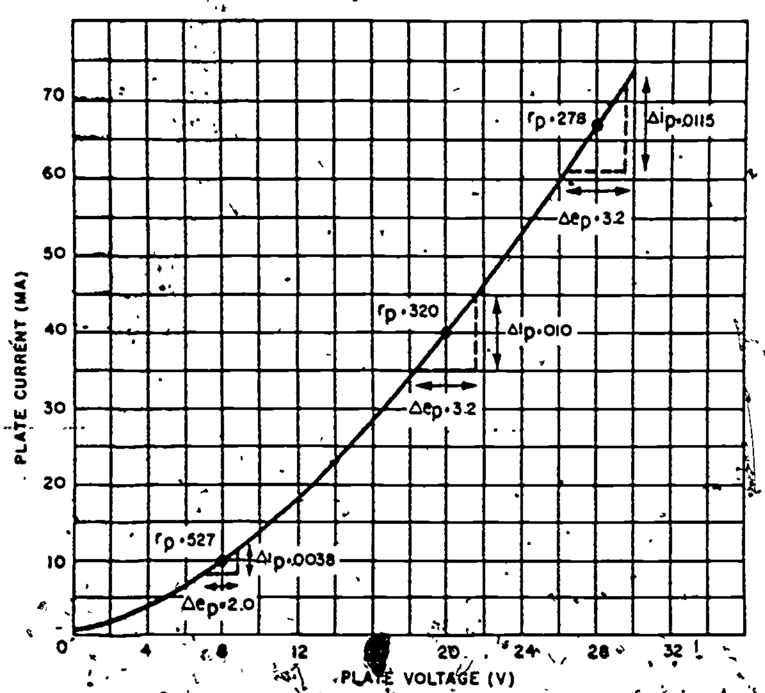

Figure 7. Calculation of r_p from a plate-current, plate-voltage characteristic.

(3) Static and dynamic diode characteristics. Up to this point, we have been discussing the diode itself and have assumed that no load was placed in the plate circuit; such conditions are called static. Let us now consider a circuit as the one shown in figure 8. Plate current flows through R_L to the battery, the voltage drop across R_L being the output of the tube. The characteristic curves of the tube are altered by the presence of the load and are now called dynamic characteristics. If no load is in the circuit, we have the static characteristic as shown by the line $R_L = 0$ in figure 9. If R_L equals 1,000 ohms or 10,000 ohms, line 1 and line 2, respectively, show the dynamic characteristics of the tube. When the load resistance is many times larger than the tube resistance, the changes which occur in the tube resistance become unimportant in relation to the total resistance encountered by the current—the change of tube resistance is only a small percentage of the total resistance. Because the load resistance does not change with changing current, the characteristic curve for plate current and plate voltage becomes essentially linear. The greater the load resistance, the more linear the dynamic characteristic. A linear dynamic characteristic is quite desirable since proportionality between plate voltage and plate current is assured.

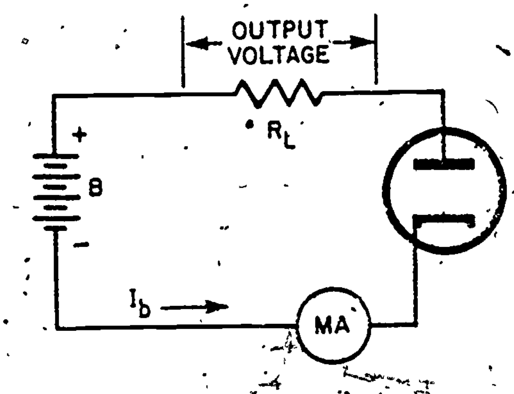

Figure 8. Diode circuit with load.

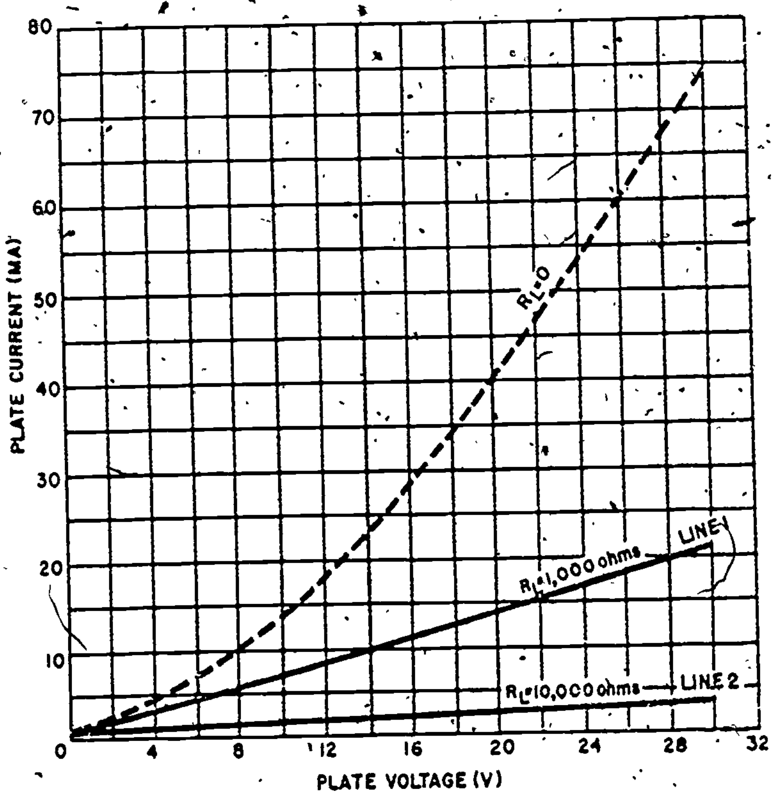

Figure 9. Dynamic characteristics for a diode with different loads.

4. TRIODES.

a. General. The use of radio and electronic equipment came of age when a control grid was interposed between the plate and cathode. Lee DeForest first developed the control grid in 1907, and he called the new tube with three elements a triode (fig. 10). In a triode, the functions of the emitter and plate elements remain the same as in a diode. However, the grid gives the tube remarkable versatility because the grid allows the triode to control and amplify the voltages which are impressed across the cathode and grid. The control grid can stop electron flow almost completely, or act as a valve controlling the instantaneous value of the current.

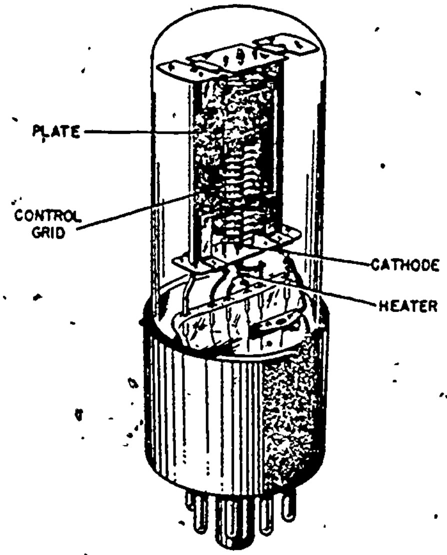

Figure 10. Construction of a triode.

b. Construction and symbols. The physical makeup of a triode is shown in figure 10. A control grid, constructed as a helical coil of fine wire, is present between the cathode and plate; otherwise, the construction is quite similar to that of a diode. Other geometrical arrangements are also used, but the differences are not too great. A triode is indicated on a schematic diagram by the symbol shown in figure 11.

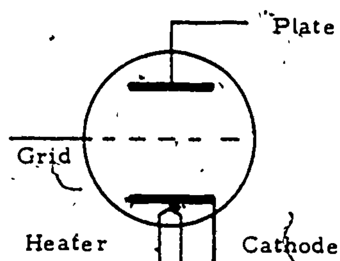

Figure 11. Schematic symbol for a triode.

As is the case for diodes, two triodes may be encased in the same envelope, or a diode and a triode may be enclosed together. The element assemblies operate independently.

c. Voltage supplies. The triode has several associated circuits that supply the voltages required to maintain the tube elements at their proper working potentials. Two triode tube types and their associated voltage supply circuits are shown in figures 12A and B. The only difference in the two types is that in A the cathode (filament) is heated directly by its connection with battery B, while in figure 12B a separate heater element is utilized. The power sources here consist of batteries A, B, and C where the A supply is the source that provides current through the heater element of the tube (or cathode); likewise, the B supply supplies the high-voltage positive potential to the plate; and the C supply makes the grid negative relative to the cathode. The latter relationship is explained in paragraph d. Figures 13A and B are schematics illustrating and identifying the various voltage supplies, circuit names and extents pertaining to the triode tubes.

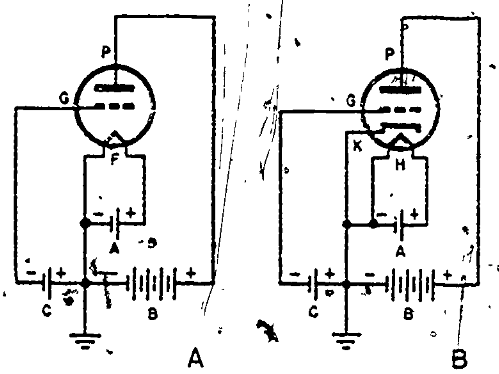

Figure 12. Voltage supply circuits for triodes.

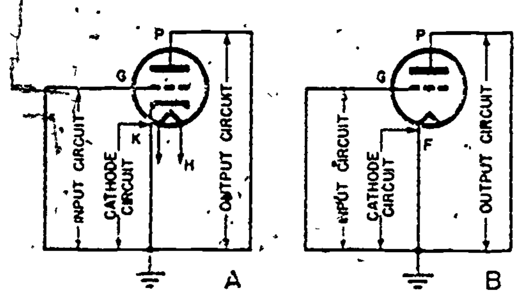

Figure 13. Identification of circuits associated with the triode.

d. Electrostatic field in a triode. The effect of varying the grid potentials and its relationship to the space charge is shown in figure 14. In these diagrams K indicates the cathode, P is the plate, G is the grid (the individual wires are represented by the large dots), B depicts the plate power source, and C the negative supply to the grid. The tiny dots represent the space charge between the cathode and the plate and the arrows indicate the direction of current flow. When the cathode of the triode reaches its proper operating voltage a space charge is created just as in the diode. The effect of the grid on this space charge is the controlling influence on the current flow.

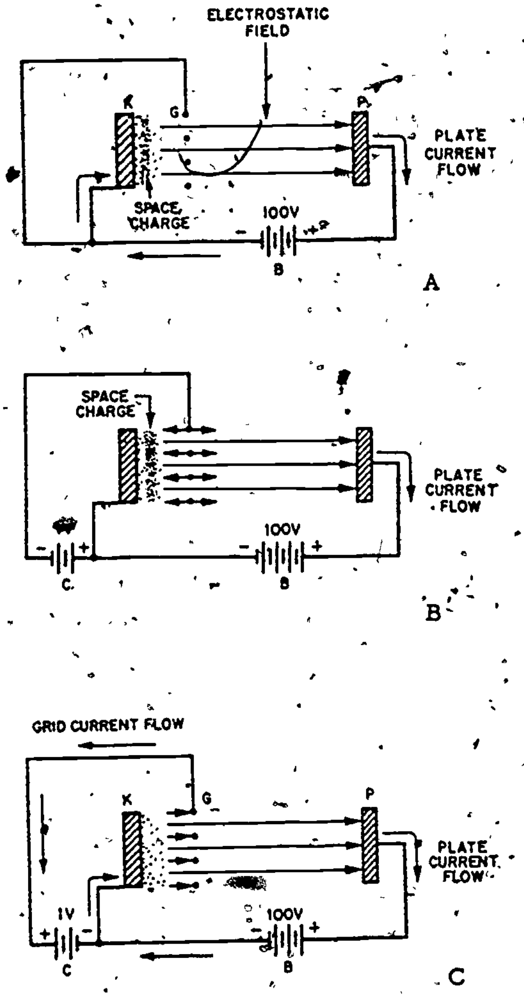

Figure 14. Effect of grid potentials on the space charge and electric fields in a triode.

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(1) In figure 14A, the grid is at the same potential as the cathode and the electrostatic field is almost identical to that of the diode. However, there is a very slight difference since there is a field from the space charge to the grid, just as there is a field from the space charge to the cathode. In essence though, we have not altered the operation much from that of a diode. The spaces between adjacent wires of the grid allow electrons to pass through to the plate; however, some electrons strike the grid even though there is no force attracting them. The electrons striking the grid flow in the grid circuit and constitute a grid current. So, except for the grid current, the action is not much different from that of a diode.

(2) Now let us place a negative potential on the grid as shown in figure 14B. The presence of a negative charge introduces fields orginating from the grid—these fields are shown by the arrows between the plate and cathode in the drawing. Consider the effects of the newly introduced fields. The electrons of the space charge are repelled away from the grid and a fewer number manage to pass through the grid to the plate. As the grid becomes increasingly negative, the force of repulsion becomes greater and eventually a point is reached at which no current can flow. When no current can flow, the tube is said to be cut off. Because the grid is much closer to the space charge than the plate, a small voltage change on the grid will have a greater effect on the current flow than an identical voltage change on the plate. Or, we might say, a small change of grid voltage can produce a large change in electron flow. If a small voltage variation appears on the grid it will be represented by a large change in current flow.

(3) The third possibility for grid voltage is positive. When the grid goes positive, which is not done too frequently in most electronic equipment, the fields are distributed as shown in figure 14C; again the arrows indicate fields. Now, the field due to the plate is substantially reinforced by the field of the grid. A great number of electrons are thus extracted from the space charge and high current flows through the tube and also through the grid circuit. Such an arrangement allows us relatively little control over the current flow and consequently is not generally used.

(4) From the above discussion, the desirability of a negative charge on the grid is evident. The negative potential allows control of tube conduction and amplification of signals presented to the grid. A pictorial representation of the control action is shown in figure 15. The curves on the left are grid voltages and those on the right are the corresponding plate currents. The numbers such as 3 and 3' represent identical instants of time in the two circuits. Notice that an alternating voltage on the grid (fig. 15C) does not produce an alternating plate current. Instead, the plate current (fig. 15D) is a varying direct current. The plate current may also be thought of as the sum of a steady direct current, the current flowing when grid voltage is zero, and an alternating current caused by the changing grid voltage. The plate current, as in the diode, can never go negative. Observe also that although the grid voltage may vary slowly or quite rapidly, the plate voltage will vary accordingly. For the most part, the waveform of the plate current will be the same as that of the grid voltage—the variations which do exist will be discussed later. Since a positive grid is undesirable and a varying

signal might drive the grid positive, a bias voltage is added to the grid as shown in figure 16. If the maximum positive amplitude of a sine wave is 3 volts, then a bias voltage of -3 volts will keep the grid negative. The bias voltage adds to the signal and causes the grid to vary between -6 volts and 0 volts. Usually the bias will be somewhat larger than the greatest expected positive peak to allow the tube to operate on the linear portion of its characteristic. This characteristic will be explained next.

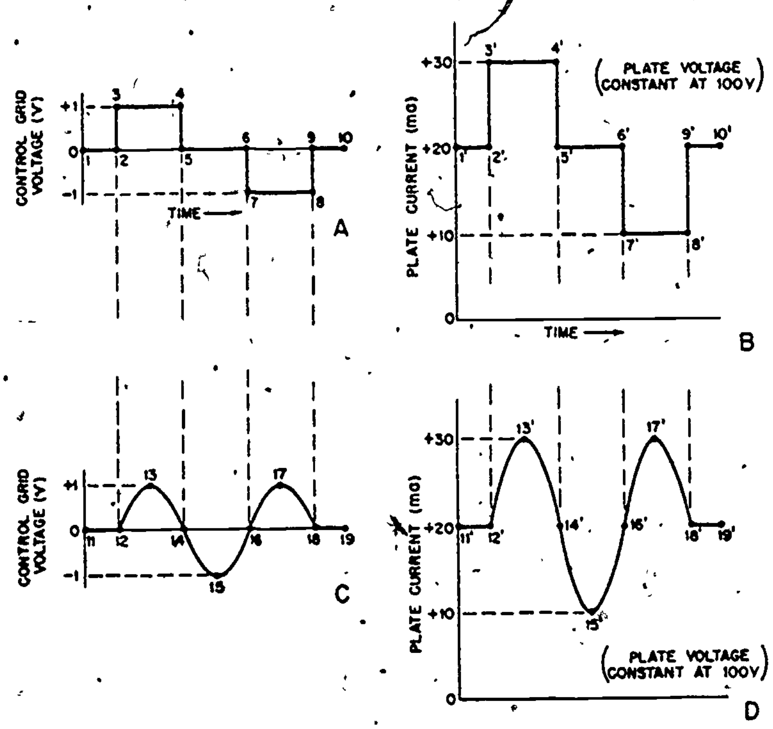

Figure 15. Grid voltage and plate current waveforms for a triode.

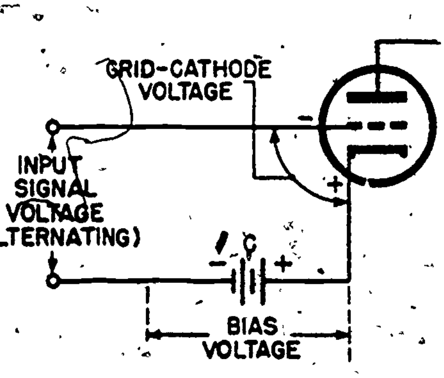

Figure 16. Use of bias voltage with a triode.

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e. Characteristic curves for the triode. The relations between the various voltages applied to the cathode and the effects produced are quite important. Since the interdependence of the variables generally cannot be expressed by simple equations, characteristic curves are used to portray the variations. Tubes are also described by certain constants. An understanding of the characteristic curves and tube constants is required for later study of tube applications. Before studying the tube parameters, you must be familiar with the notation used to indicate the various voltages and currents. Study figure 17 carefully. Generally, the capital letters E and I are used for average values while the small letters e and i are used for instantaneous values. The subscripts denote a particular circuit or element.

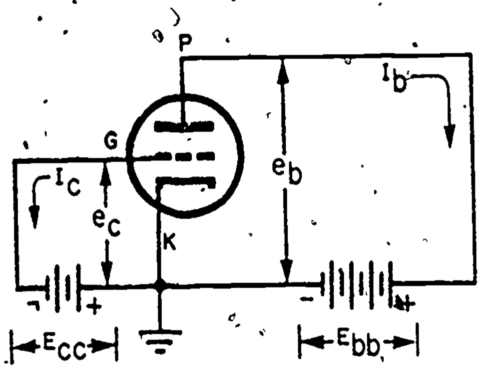

Figure 17. Nomenclature of triode circuits.

(1) Static plate-current, grid-voltage characteristic. The arrangement of elements in a triode causes three basic factors to influence the flow of plate current: emitter temperature, control-grid voltage, and plate voltage. The emitter temperature will be disregarded because we assume that the emitter is operated at its proper temperature. We are left with three variables: grid voltage, plate voltage, and plate current. The interdependence of these variables may be shown as characteristic curves. Figure 18 shows the plate-current, grid-voltage characteristics of a typical triode. Notice that as the grid becomes increasingly positive, the plate current increases but only up to a limit at which the curve levels off. The limit, at A, is called the plate-current saturation point. Plate-current saturation occurs when the plate is drawing electrons as fast as the emitter can produce them. Tungsten filaments allow plate-current saturation; however, oxide-coated filaments produce such copious electron emission that the plate never does collect all the electrons even at high grid voltages. The characteristic curve starts to drop again at high grid voltages because secondary emission begins to take place at the plate; also, electrons begin to be attracted to the positive grid. The point at which the grid voltage completely stops all plate current is called cut off, which, in figure 18, occurs at -6 volts. A family, called the grid family, of plate-current, grid-voltage curves is shown in figure 19. The family of curves provides a great deal more information about tube operation then an individual curve. The positive region of grid voltages has been eliminated because grids are usually biased to assure negative operation. All of the curves have the same general shape, but each has a different cutoff point. Observe that increasing the plate voltage increases the negative grid voltage required to reach cutoff.

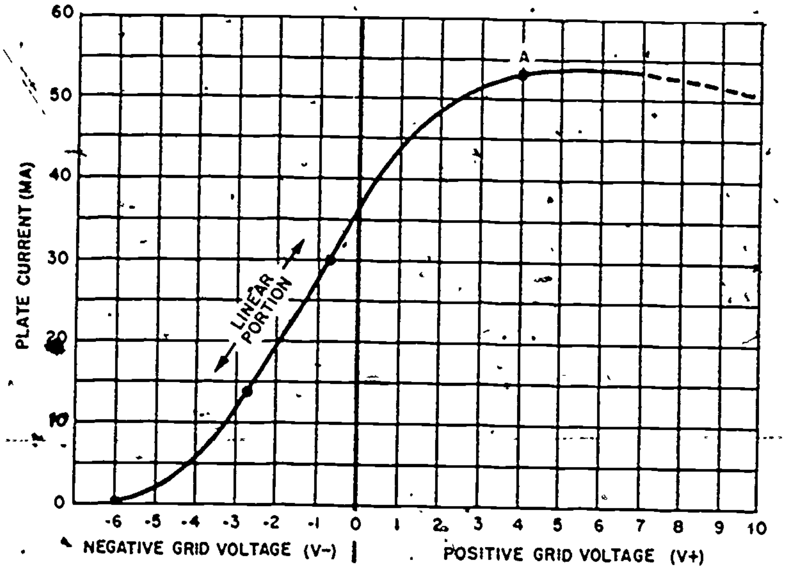

Figure 18. A typical static plate-current, grid-voltage characteristic curve for a triode.

(2) Static plate-current, plate-voltage characteristics. Another important family of curves, the plate family, for the triode is composed of the plate-current, plate-voltage curves. Figure 20 shows such a set of curves for the 6J5 triode. The grid family and the plate family display the same information but in slightly different forms. While the grid family shows plate current for small changes of grid voltage and fixed changes of plate voltage, the plate family shows the effects of small changes of plate voltage and fixed changes of grid voltage.

f. Tube constants. Both families of characteristic curves may be used to determine tube constants. Three primary tube constants are used: amplification factor, a.c. plate resistance, and transconductance.

(1) Amplification factor. The ratio of change in plate voltage to change of control grid voltage while plate current remains unchanged is known as the amplification factor. We may write the mathematical expression as:

$$u = \frac{\Delta e_b}{\Delta e_c}, \quad i_p \text{ constant}$$

where u = amplification factor (a number without units)

Δe_b = change in plate voltage

Δe_c = change in grid voltage

i_p = plate current.

The amplification factor can be found easily on the grid family of figure 19. Let us find the amplification factor when the grid is operating near -8 volts. A 50-volt change of plate voltage (from D to C in fig. 19) is produced by a 2.6-volt change of grid voltage (from B to C in fig. 19). Care must be taken that the line BC represents constant plate current. The amplification factor is 19.2.

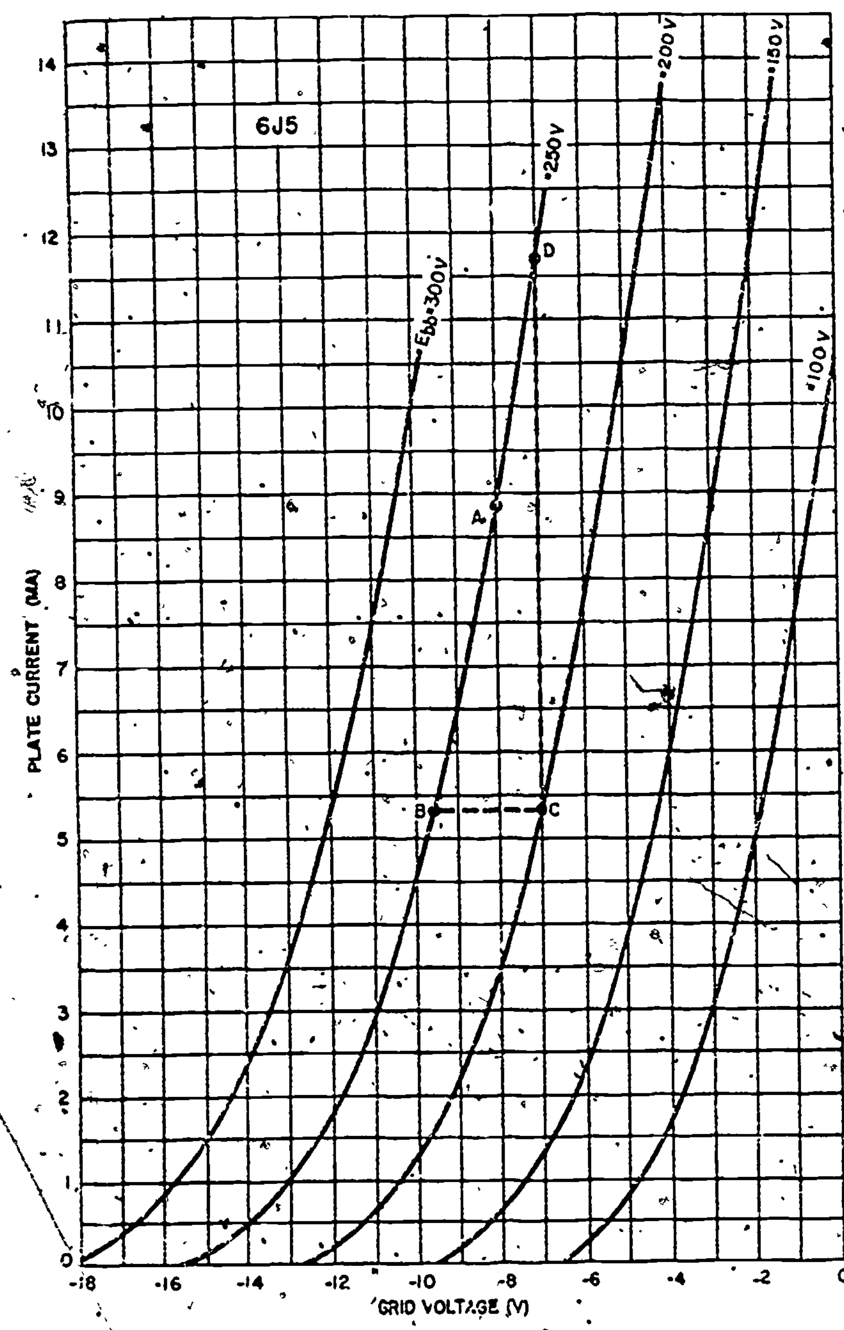

Figure 19. Grid family for a 6J5 triode.

$$u = \frac{\Delta e_b}{\Delta e_c}, \quad u = \frac{50}{2.6} = 19.2$$

Each change of grid voltage produces a change of plate voltage 19.2 times larger. Remember that the changes are important, not the absolute values. The value of u will be slightly different for different values of the constant plate current. The value of u can be found from a plate family graph in a similar way, taking care that a change of plate current is not included.

(2) Plate resistance. Both d.c. plate resistance and a.c. plate resistance for a triode are defined identically as for a diode but with the additional restriction that the grid voltage must remain constant. Using the curve for any constant grid voltage in the plate family, you may find the d.c. resistance and the a.c. resistance in the same manner as for the diode.

(3) Transconductance. Changing the plate voltage or the grid voltage or both causes changes in plate current. Transconductance, also called mutual conductance, expresses the relationship between plate current and grid voltage. By definition:

$$g_m = \frac{\Delta i_b}{\Delta e_c}, \; e_b \text{ constant}$$

where g_m = transconductance (mhos)
Δi_b = change in plate current (amps)
Δe_c = change in grid voltage (volts)
e_b = plate voltage.

Given a quantitative interpretation, transconductance is the ampere-change in plate current per volt-change in grid voltage. The unit of transconductance is the mho (ohm spelled backwards). Because the mho is a large unit, the umho, 1×10^{-6} mho, is commonly used. Either family of curves may be used to find the value of transconductance for a tube. Using the plate family in figure 20, we will find the transconductance for a constant plate voltage of 200 volts. Let the grid voltage change from -4 volts to -6 volts, the corresponding change in plate current (remember plate voltage must remain at 200 volts) will be from 13 ma to 7.7 ma. We then have

$$g_m = \frac{\Delta i_b}{\Delta e_c}, \quad g_m = \frac{.0130 - .0077}{6 - 4} = \frac{.0053}{2} = .00265 \text{ mho}$$

or 2,650 umhos.

The transconductance of a tube is an important tube constant and is commonly used for comparing tubes. A tube with a transconductance of 2,500 is a better tube than one with a transconductance of 1,500; the higher transconductance tube will give a greater signal output from an identical input to the grid.

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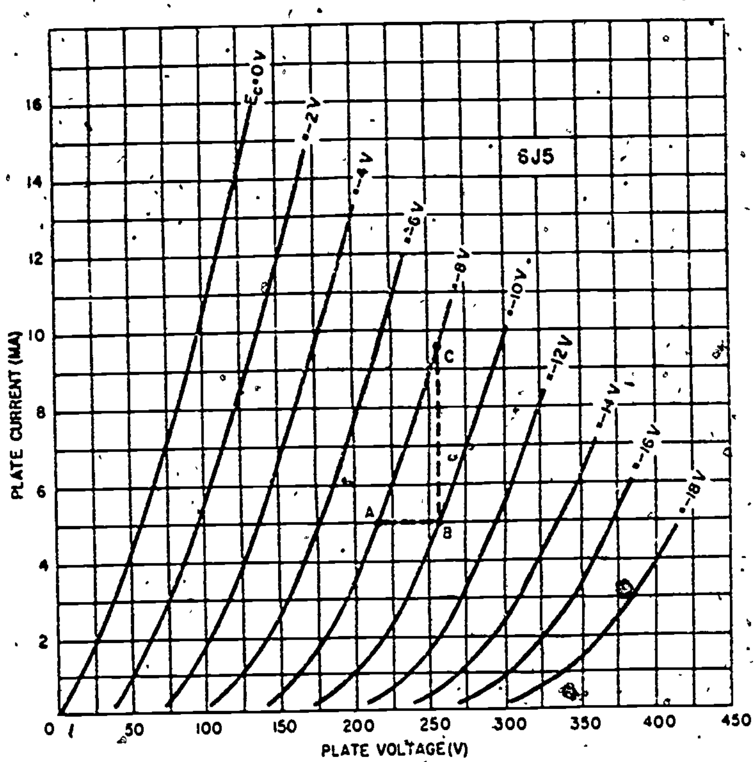


Figure 20. Plate family for a 6J5 triode.

(4) Relation between tube constants. The three tube constants which we have been discussing are interrelated and various expressions may be derived by combining the equations given. The nature of these relationships is shown in figure 21. Notice the constancy of μ and the nearly inverse relation between g_m and r_p. The operating voltage applied to a tube will determine the precise values of each of the constants.

g. Dynamic characteristics. If a tube is to be useful, it must have a load in its plate circuit as shown in figure 22. The presence of a plate load alters the static characteristic curves causing new dynamic characteristic curves. Because of the load, there are two voltage drops in the plate circuit: one across the load, and one across the internal resistance of the tube. The sum of these two drops must always equal the value of the B supply. When current is flowing a portion of the B supply appears across the load, and the plate voltage is reduced.

(1) Loadline. The effect of the load can be predicted by using a loadline with the static characteristic for the plate family. Let us consider a 25,000-ohm load in the plate circuit and a 350-volt B supply (fig. 23). At zero plate current, no voltage appears across the load and the plate voltage is 350 volts - 0 ma.; thus, 350 volts is one point (y) on our loadline. The maximum current through the plate circuit is found by Ohm's law, I = E/R; I = 350/25,000 = 0.014 or 14 ma.; so, 14 ma. and zero volts is the second point (X) on the loadline. Connecting the two points establishes our loadline; all variations of current and voltage in the tube will occur along this line. The point on the loadline at which the grid is biased is known as the operating point.

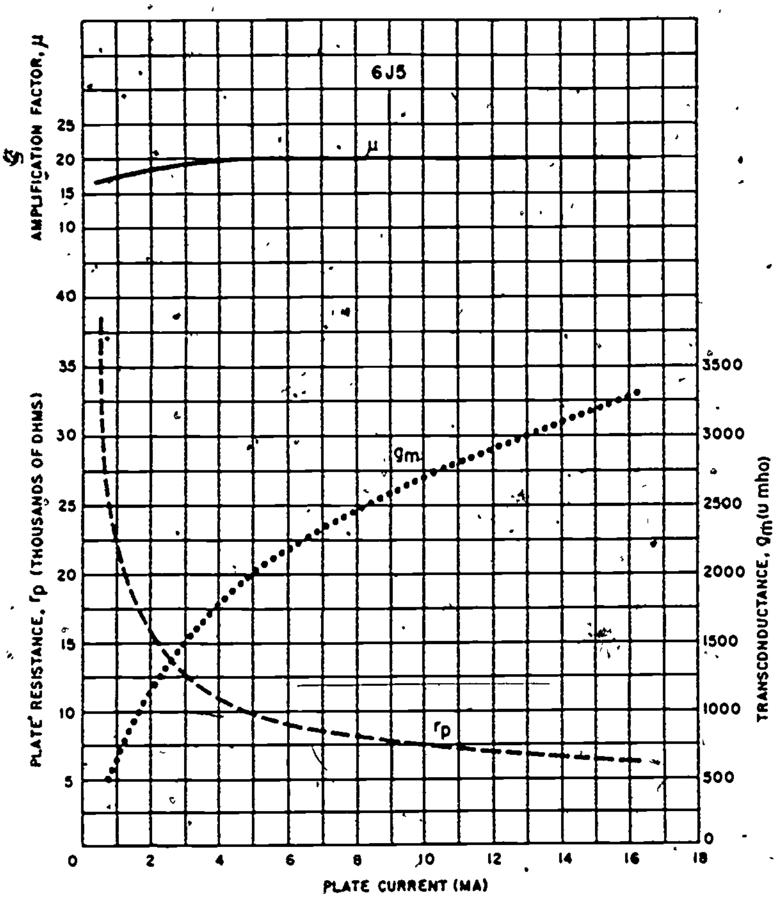


Figure 21. Variation of tube constants for the 6J5 triode.

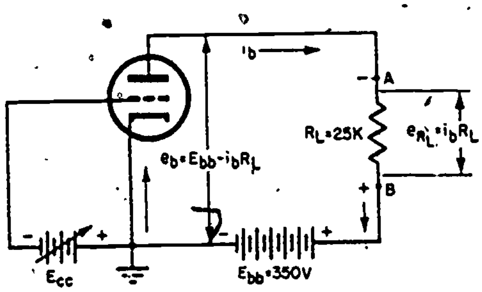
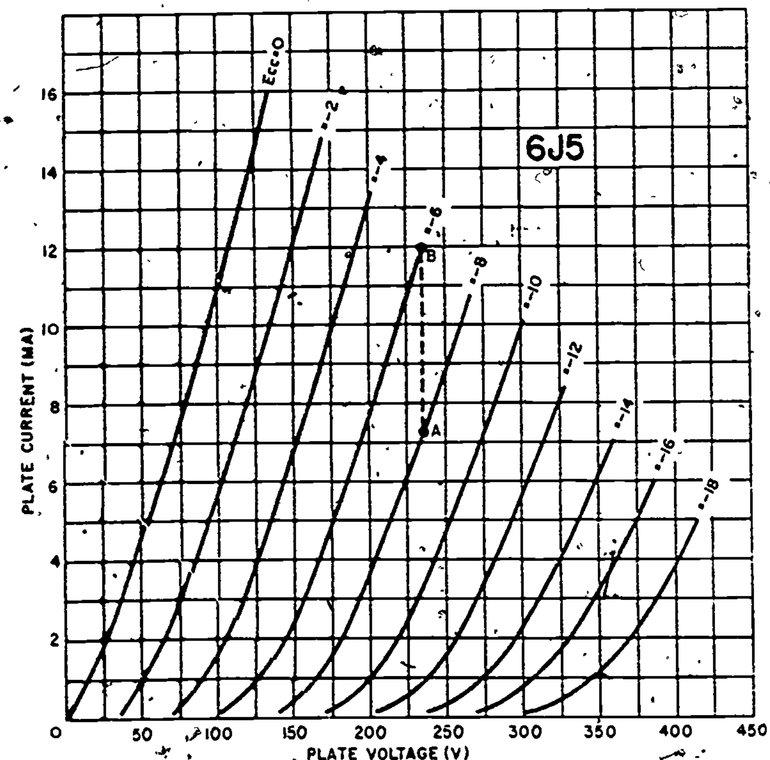


Figure 22. Triode with a load in the plate c



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3. Construction of the loadline for a 6J5 triode and a 25,000-ohm load.

(2) Dynamic transfer characteristic. The loadline can now be used to construct the dynamic characteristic curves of the grid family to show the tube performance with a load in the plate circuit. Figure 24 shows how points along the loadline are transferred to their corresponding location on grid-voltage and plate-current coordinates. For example, point N is 8.9 ma, -2 volts grid voltage, and 130 volts plate voltage, while point N' is also located at 8.9 ma, -2 volts grid voltage, and 130 volts plate voltage. By using several ifferent loads and their corresponding loadlines, a grid family dynamic transfer characteristic curves may be constructed as wn in figure 25. Notice that the dynamic transfer characteristic es are much less steep than the static characteristic curves; ver, the dynamic curves are more linear. As the value of the ncreases, the curves become less steep and more linear.

le amplifiers. We have talked earlier about how the triode n. Now we can study the process more closely by using cteristic for a particular load. Let the characteristic t the operating conditions for a triode and a particular overned by the bias voltage, has been selected so that put voltage will occur on the linear portion of the lly to see how the plate-current waveform reproduces e output voltage can now be calculated from the plate

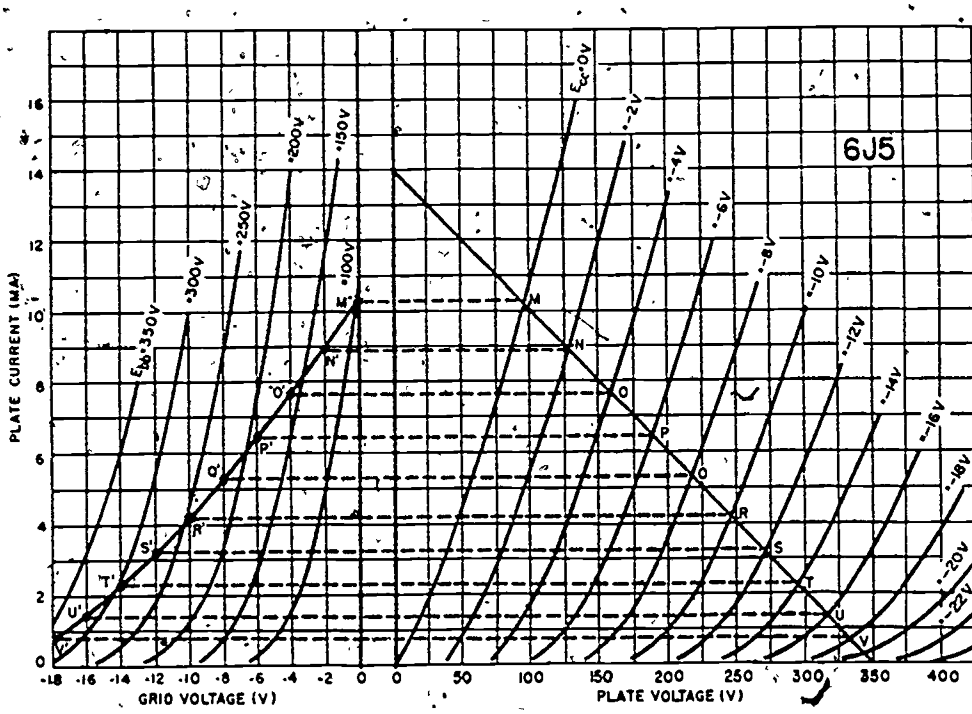

Figure 24. Use of the loadline to construct a dynamic transfer characteristic of the 6J5 triode.

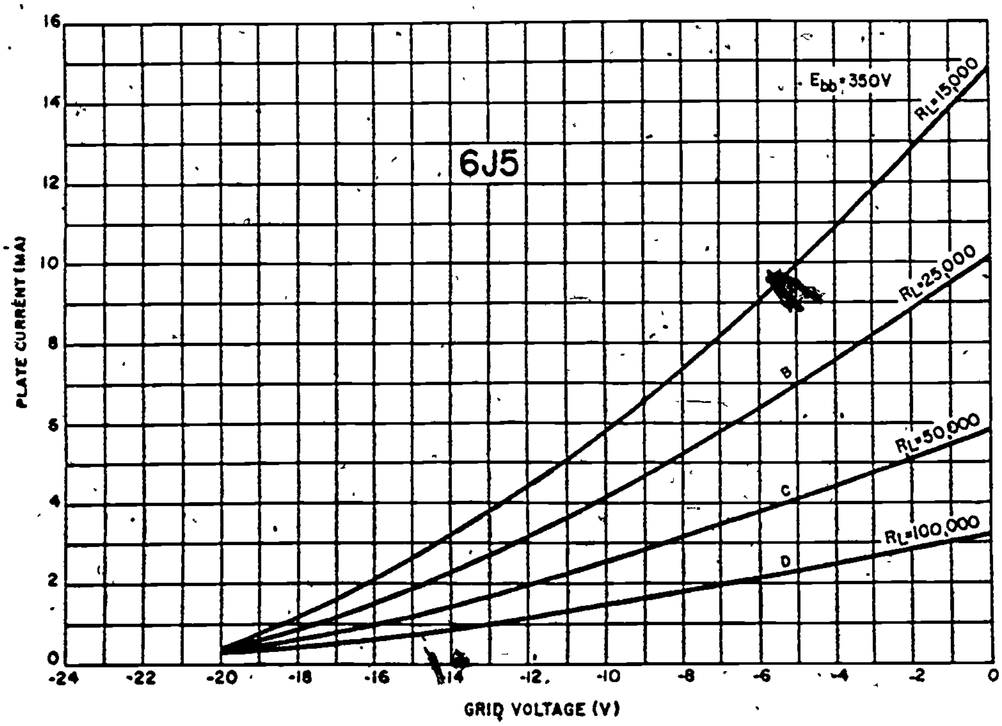

Figure 25. Grid family of dynamic transfer characteristics for the 6J5 triode and several different loads.

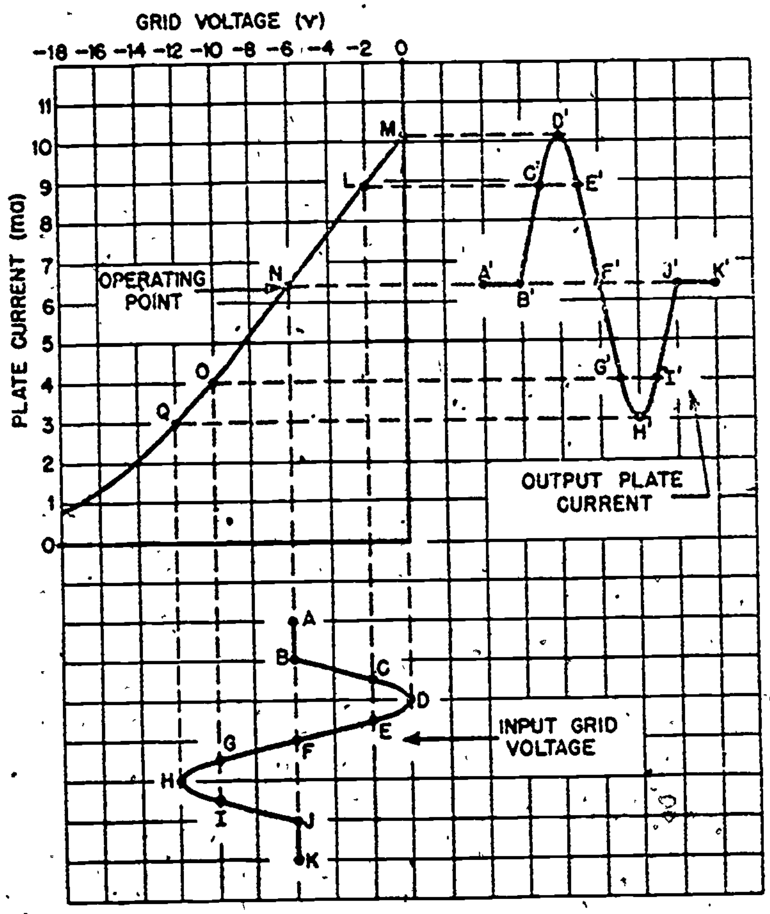

Figure 26. Use of the dynamic transfer characteristics to predict plate-current waveform from grid-voltage waveform.

5. MULTIELECTRODE TUBES. Since the principles you have learned up to this point are common to multielectrode tubes, our discussion here will be limited to the effects of additional tube elements and the end results of their addition.

a. Screen grid. The screen grid is constructed similar to the control grid and is placed between the control grid and the plate; the resulting tube is called a tetrode. A positive voltage, less though than that of the plate, is placed upon the screen grid. The location of the screen grid reduces the amount of capacitance which is present between the plate and the control grid. Presence of such capacitance allows a path for high frequency signal to leak from the plate back to the grid. A typical plate family for the tetrode is shown in figure 27. The irregularity of the curves will not be explained here. The tetrode, because of the limited region of linear operation, high voltage requirements, and secondary emission at the plate, is nearly obsolete today.

b. Suppressor grid. By adding another grid between the screen grid and the plate, we have a pentode (fig. 28) which obviates most of the difficulties of the tetrode and produces an extremely useful tube. The new grid is called the suppressor grid and has as its function the reduction of secondary emission at the plate. A low negative voltage is placed on the suppressor (G3) or it is connected to the cathode; electrons which have been accelerated by the control grid (G1) and screen grid (G2) easily pass through the suppressor grid, but low speed electrons from secondary emission are repelled back into the plate. A plate family of characteristic curves for a 6SJ7, a common pentode, is shown in figure 29. In general, the a.c. resistance may be several hundred times greater than for a triode, the amplification factor may also be as much as one hundred times greater than for a triode, transconductances of pentodes and triodes are comparable. The pentode is one of the most widely used tubes today.

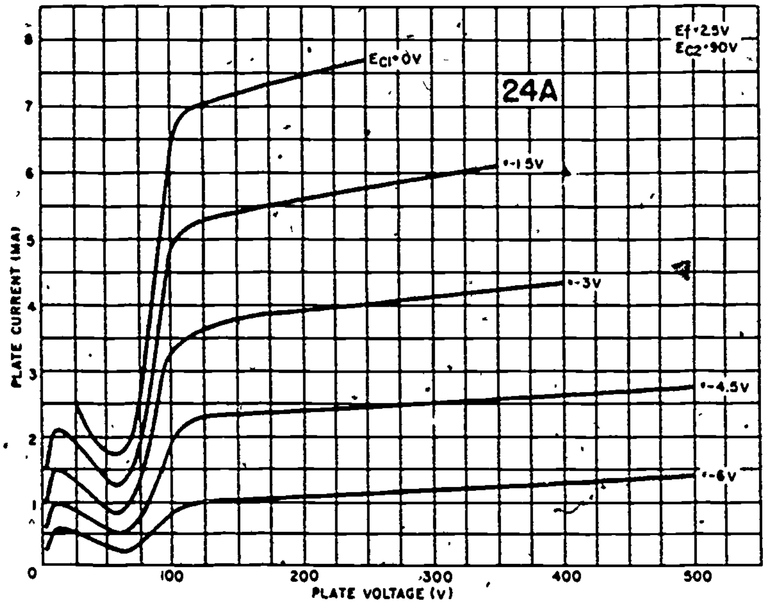

Figure 27. Plate family for a 24A tetrode.

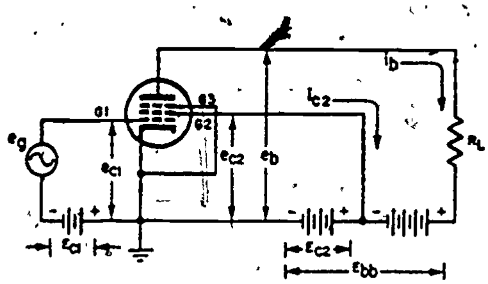

Figure 28. Nomenclature of a typical pentode circuit.

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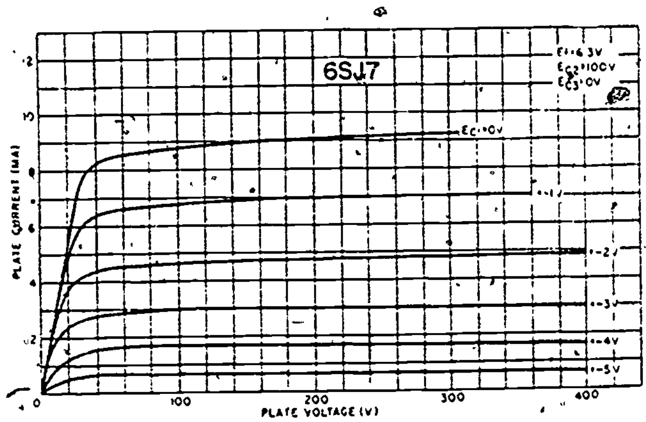


Figure 29. Plate family for a 6SJ7 pentode.

EXERCISE

111. An electron tube can be best compared to a

a. resistor.
b. switch.
c. valve.

112. The most common method of producing a stream of electrons in a vacuum tube is the

a. cold-cathode emission method.
b. secondary emission method.
c. thermionic emission method.

113. The diode vacuum tube would be found in which circuit?

a. Rectifier
b. Oscillator
c. Mixer

114. What is the main purpose of the screen grid?

a. Increase amplification factor
b. Decrease secondary emission
c. Decrease plate to control grid capacitance

115. The formula for alternating circuit plate resistance is

a. $r_p = \frac{\Delta i_p}{\Delta e_p}$.
b. $r_p = \frac{\Delta e_p}{\Delta i_p}$.
c. $R = \frac{\Delta e_c}{\Delta i_b}$.

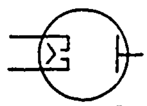
116. What causes secondary emission?

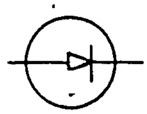
a. Application of heat
b. Cold cathode ionization action
c. Electron collision

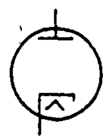
117. What quantities are required to plot a family of plate current-plate voltage (plate family) curves for a triode?

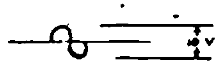
a. Grid resistance, grid voltage, and plate current
b. Plate voltage, plate current, and grid voltage
c. Plate resistance, grid voltage, and plate current.

118. Which is the schematic diagram of a diode vacuum tube?

a. 

b. 

c. 

119. If a triode with a -6 volt bias receives a sine wave on its grid that looks like this (), the grid voltage will vary between

a. -6 and -1.
b. -1 and -11.
c. 0 and -11.

120. How many grids are contained in a pentode tube?

a. 3
b. 4
c. 5

121. When referring to a vacuum tube circuit the symbol "e" means

a. battery potential.
b. external voltage.
c. instantaneous voltage.

122. Current will flow through a diode when the plate

a. potential is equal to the cathode.
b. is positive compared to the cathode.
c. is negative compared to the cathode.

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123. The operating point on the loadline is the point of

a. grid bias voltage.
b. grid input voltage.
c. plate supply voltage.

124. What pentode tube component reduces the effect of secondary emission

a. Control grid
b. Screen grid
c. Supressor grid

125. What element in a tube permits certain vacuum tubes to control and amplify voltages

a. Cathode
b. Control grid
c. Filament

126. What value of grid voltage reduces plate current to zero?

a. Zero
b. Negative 5 volts
c. Cutoff

127. To determine the loadline for a vacuum tube you would need a set of static curves for the tube type, the value of the load resistor, and the

a. grid bias voltage.
b. plate resistance.
c. plate supply voltage.

128. The symbol for transconductance is gm; its unit of measure is

a. mhos.
b. farads.
c. ohms.

129. What is the approximate difference in values between the alternating current plate resistance and the direct current plate resistance?

a. 3/4
b. 2/3
c. 1/2

130. When the diode load resistance is increased, the dynamic characteristic becomes more

a. erratic.
b. linear.
c. nonlinear.

131. A vacuum tube with which value of transconductance would give the greatest signal output for equal input signals?

a. 4,500
b. 3,000
c. 2,000

132. Which two vacuum tube constants have a nearly inverse relationship to each other? ///

a. gm and rp
b. rp and u
c. u and gm

133. If the vacuum tube in a circuit is completely cut off (nonconducting), the voltage measured from the plate to ground would be

a. Ebb - ec.
b. Ebb.
c. Ebb - Ecc.

134. What is defined as the ratio of plate voltage change to control grid voltage change while plate current remains unchanged?

a. Amplification factor
b. Plate resistance
c. Mutual conductance

135. The space charge density in a diode vacuum tube is greatest near the

a. cathode.
b. getter.
c. base.

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CORRESPONDENCE COURSE
of the
US ARMY ORDNANCE CENTER AND SCHOOL

LESSON ASSIGNMENT SHEET

Ordnance Subcourse No 98 . . . . Fundamentals of Electricity

Lesson 7 . . . . Operation and Characteristics of Transistors

Credit Hours . . . . Three

Lesson Objective . . . . After studying this lesson you will be able to:

1. Describe the construction and operation of transistors.
2. Describe the characteristics of transistors and their comparison with vacuum tubes.
3. Describe the construction of graphs used to determine the characteristics of transistors.
4. Describe procedures used in testing and replacement of transistors.

Text . . . . Attached Memorandum

Materials Required . . . . None

Suggestions . . . . None

STUDY GUIDE AND ATTACHED MEMORANDUM

1. INTRODUCTION.

a. General. The use of transistors in electronic equipment increases with each passing day. They are rapidly replacing electron (vacuum) tubes in both commercial and military equipment.

b. Fundamentals. Fundamentally, the transistor is a valve which controls the flow of current carriers (electrical charges in motion) through the semiconductor crystal material of which it is made. As the current carriers pass through the transistor they are controlled as easily as if the same current carriers were passing through an electron tube (which the British actually call a valve). The transistor's ability to control current carriers and their associated voltages makes it potentially the most useful single element in modern electronic equipment.

2. HISTORY.

a. Crystal rectifier. The first use of a crystal semiconductor as a rectifier (detector) was in the early days of radio. A crystal was clamped in a small cup or receptacle and a flexible wire (cat-whisker) made light contact with the crystal. Tuning of the receiver was accomplished by operating the adjusting arm until the cat-whisker was positioned on a spot of the crystal that resulted in sound being received in a set of ear phones. Tuning a variable capacitor provided maximum signal although frequent adjustment of the cat-whisker contact point was usually necessary.

b. Point contact diode (fig. 1). Point contact diodes (germanium rectifiers) were used during World War II for radar and other high frequency applications replacing electron tube diodes. The point contact diode has a very low shunt capacitance and does not require heater power; these properties provide a definite advantage over the electron tube diode. It is identical in principle with the crystal rectifier mentioned previously and consists of a semiconductor, a metal base, and a metallic point contact. The connections to the point contact diode are an external lead welded to the metallic point contact, and an external lead welded to the metal base.

c. Point contact transistor (fig. 2). The development of the point contact transistor was announced in 1948. The physical construction is similar to that of the point contact diode except that there is an additional lead with a metallic point contact on the semiconductor. One lead is called an emitter lead, the other a collector lead. When the two metallic points are properly biased with respect to the metal base, the point contact transistor is capable of producing a power gain.

d. Junction diode (fig. 3). The development of the junction diode was announced in 1949. It consists of a junction between two dissimilar sections of semiconductor material, one section of which, because of its characteristics, is called a P-type semiconductor. The connections consist of a lead to the P-type semiconductor and a lead to the N-type semiconductor. The junction diode handles larger amounts of power than the point contact diode, but it also has a larger shunt capacitance.

e. Junction transistor (fig. 4). The development of the junction transistor was announced concurrently with the development of the junction diode. The transistor consists of two PN junctions and its operation is similar to that of the point contact transistor. The junction transistor permits more accurate prediction of circuit performance, has a lower signal-to-noise ratio, and is capable of handling more power than the point contact transistor.

3. TRANSISTOR FUNCTIONS.

a. Amplification. The transistor may be used as a current, voltage, or power amplifier. For instance, a stronger signal current may be obtained from a transistor than is fed into it. A signal of 1 milliampere fed into the input circuit of the transistor may appear as 20 milliamperes at its output. Various circuit arrangements provide for various amounts of signal amplification.

b. Oscillation. The transistor may be used to convert direct-current energy into alternating current; i.e., it may be used as an oscillator. When functioning in this manner the transistor draws energy from a d. c. source and, in conjunction with a suitable circuit arrangement, generates an a. c. voltage.

c. Modulation and demodulation. The transistor used in various circuit arrangements can provide amplitude modulation (variation in amplitude of an AF signal) or frequency modulation (variation in frequency of an RF signal). Demodulation (detection) of amplitude-modulated or frequency-modulated signals may be accomplished with transistors. These circuits are well suited for miniature transmitters intended for short range applications.

d. Miscellaneous. The transistor may also be used to modify the shape of signal waveforms. Waveform shaping is vital in various types of radar, teletypewriter, computer, and television circuits. The use of transistors increases the payloads of today's guided missiles and satellites because they permit smaller and lighter circuitry.

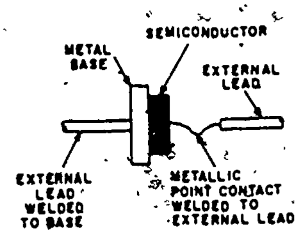

Figure 1. Physical construction of point contact diode.

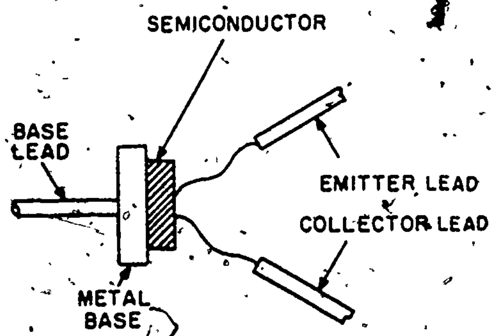

Figure 2. Physical construction of point contact transistor.

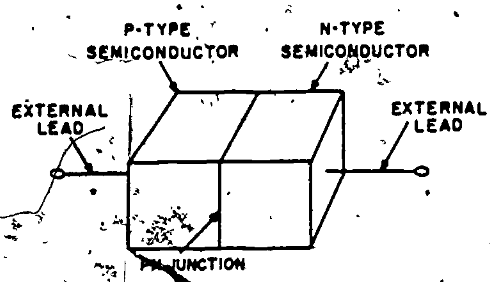

Figure 3. Physical construction of junction diode.

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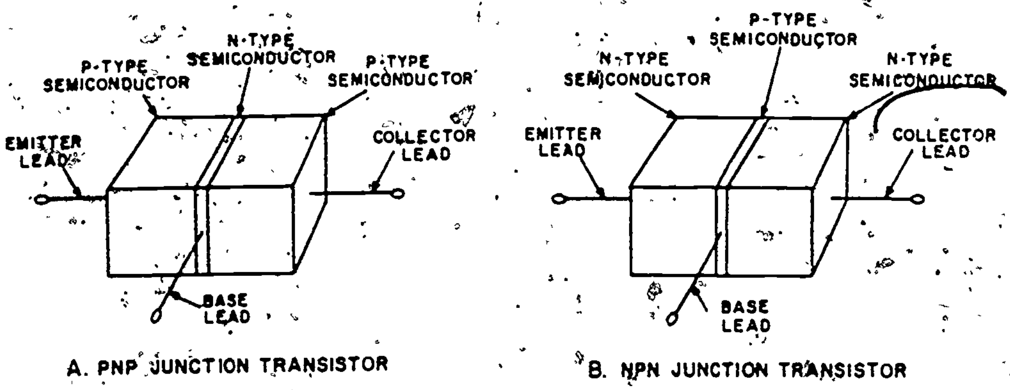

Figure 4. Physical construction of PNP and NPN junction transistors.

4. COMPARISON WITH ELECTRON TUBES.

a. Efficiency and voltage requirements. The transistor power efficiency is greater than that of the electron tube because the transistor does not require warmup time, and it does not require a large d.c. voltage to operate. Other advantages of the transistor are its useful life, its noise level, and its size and construction.

b. Useful life. Life expectancy is a very important consideration in the application of any electronic device. A transistor that is hermetically sealed in glass or metal will withstand a variety of situations that an electron tube cannot withstand. For example, a transistor, even though it is immersed in water will operate for long periods of time with very little noticeable effect on its operating frequency. It also will withstand centrifugal force, gravity, and impact tests that would completely shatter an electron tube. Although transistors are a comparatively new development and complete data on their life expectancy are not yet available, it has been estimated that they can operate continuously for approximately 8 years, a time much greater than the life of the average electron tube.

c. Noise level. The noise level of a transistor is approximately 20db (decibles) with a frequency input of 1,000 cycles per second. In comparison, the average electron tube has a lower noise level for the same frequency input. When a transistor is used with a higher frequency input, the noise level becomes considerably lower.

d. Size and construction. A power amplifier electron tube is shown in figure 5A, and a power amplifier transistor is shown in figure 5B. The construction of the electron tube permits efficient dissipation of heat. Although the transistor must also dissipate heat, the size is noticeably smaller. The flange-type construction of the transistor cover provides heat dissipation. In some cases a special metallic heat dissipator must be used. A medium power electron tube and a medium power transistor are shown respectively in C and D, figure 5. Note that the construction of the electron tube is much larger than that of the transistor. A miniature electron tube and a miniature transistor are shown in E and F of figure 5. The construction of the electron tube is again much larger than the transistor. Notice that the power transistor (fig. 5B) is smaller than the miniature electron tube (fig. 5E).

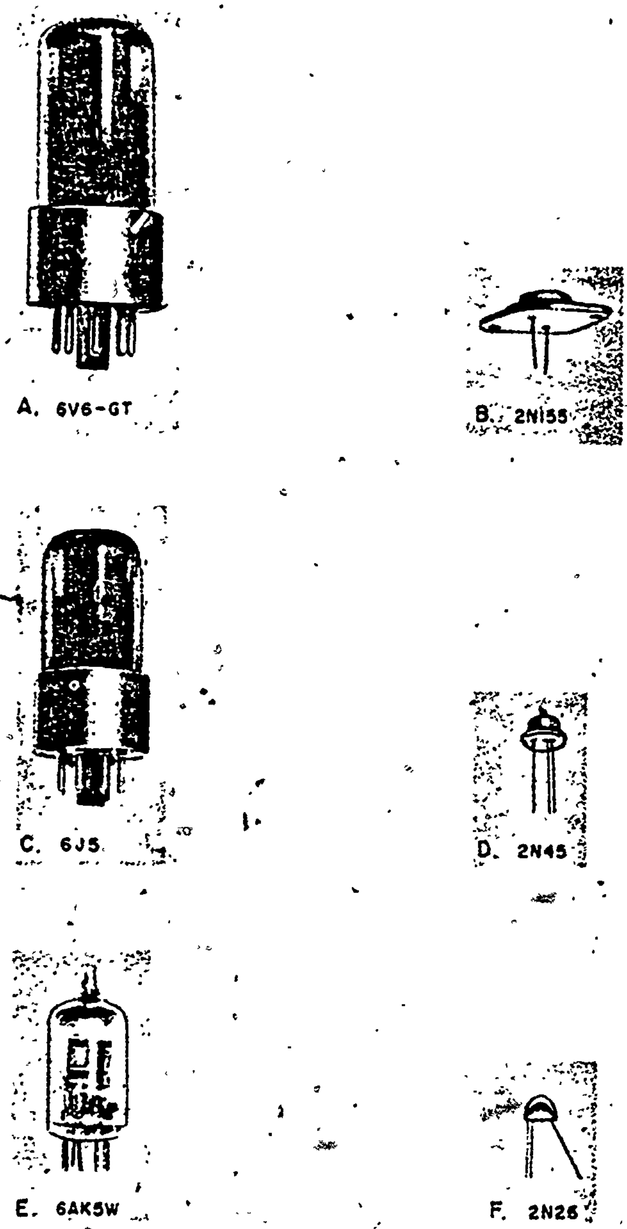

Figure 5. Comparison of transistors and electron tubes.

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e. Special circuit components for use with transistors. The lower current and voltage requirements of transistors simplify the problems encountered in miniaturization of components. Transformers, capacitors, and resistors may be miniaturized as shown in the right column of figure 6. The use of printed circuit board (not shown) eliminates all connecting wires and helps make transistor circuits more compact.

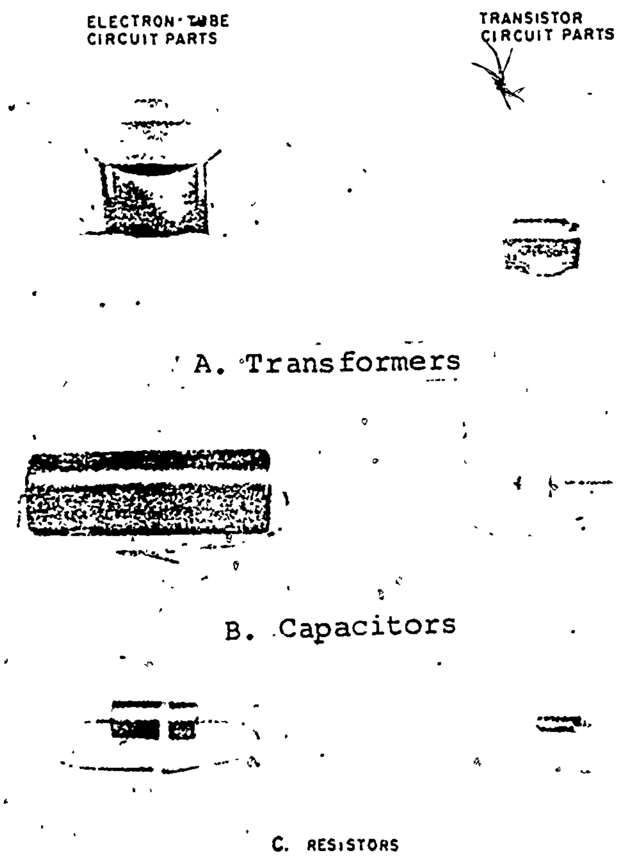

Figure 6. Circuit components used with transistors and electron tubes.

5. TRANSISTOR MATERIAL.

a. Semiconductors. The secret to the almost magic operation of transistors lies in the crystal material from which they are made. The crystals are called semiconductors because they have a higher resistance than ordinary conductors like copper or aluminum, and a lower resistance than ordinary insulators like rubber or plastic. The resistance of the crystal material is somewhere between that of the conductor and insulator; thus, transistors are called semiconductor devices.

b. Processing. Special semiconductor crystal materials such as germanium and silicon are used in transistors. Before use, the materials are specially refined into as pure a state as possible, then, the pure crystal is carefully contaminated by the addition of selected elements to give it the desired characteristics.

c. N-type semiconductors.

(1) A crystal becomes an N-type during the treating process after being refined. In this process, an element such as phosphorous or arsenic is mixed into the germanium or silicon crystal. These elements are called N-type impurities because they give the crystals a majority of negative charges.

(2) Figure 7 shows a magnified view of an emitter crystal removed from an NPN transistor. You can see that the crystal contains several plus and minus signs representing electrical charges. It's easy to see that there are more negative charges than positive charges. For that reason crystals of this type are called N-type, the N, of course, meaning negative.

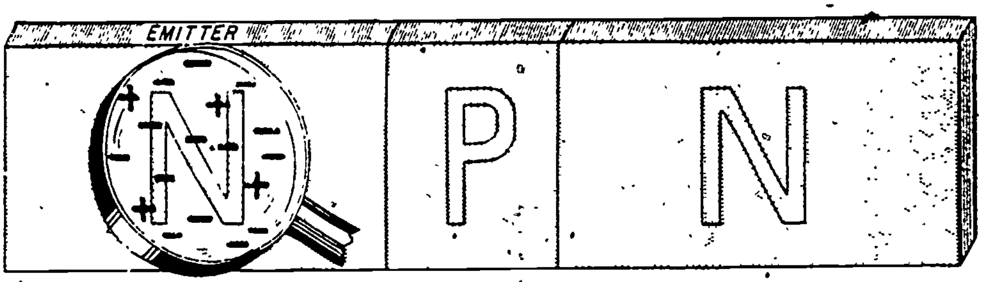

Figure 7. Looking inside the emitter crystal.

d. P-type semiconductors.

(1) You know that impurities are used to charge N-type crystals. Well, the same thing is true for P-type crystals and the impurities needed are elements that give the crystals positive charges. The P type impurities are usually aluminum or indium.

(2) Taking the base section from the transistor and magnifying it (fig. 8) shows that the base crystal also has negative charges. But you can see that the base charges are different than those in the emitter for the base has a majority of positive charges and a minority of negative charges. Therefore, the base crystal is a P-type, the P, of course, standing for positive.

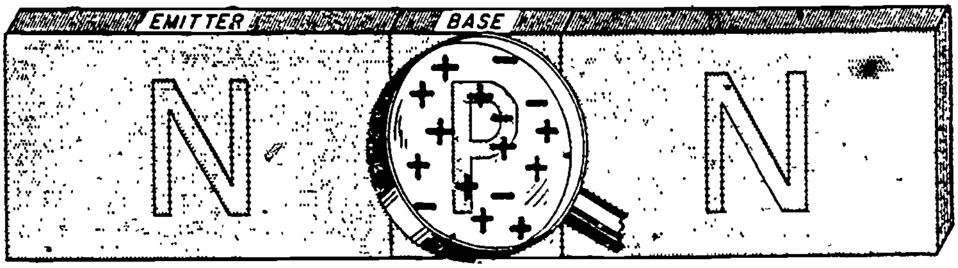

Figure 8. Looking inside the BASE crystal.

e. Two main types of transistors.

(1) The crystal combination we have been discussing so far is called an NPN transistor because it consists of a P-type crystal sandwiched between two N-type crystals (fig. 9A).

(2) There is another crystal arrangement used in transistors consisting of an N-type crystal sandwiched between two P-type crystals. It is termed the PNP transistor (fig. 9B) and has a majority of negative charges in the base section and a majority of positive charges in the emitter and collector crystals.

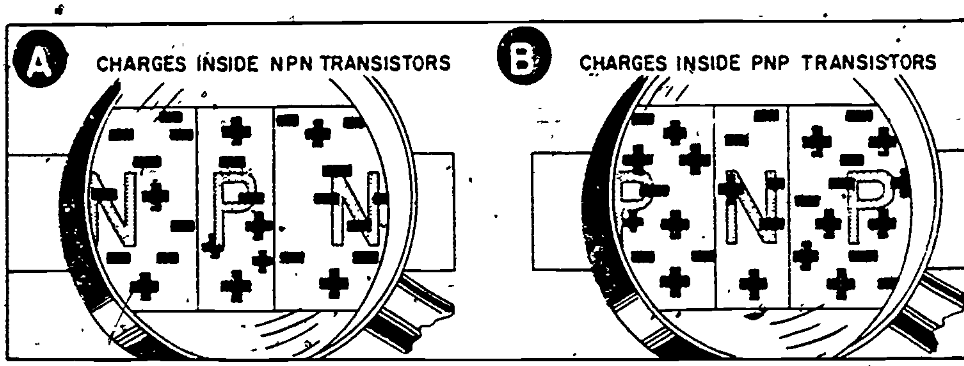

Figure 9. Looking at the NPN transistor.

6. ELECTRICAL CHARGES INSIDE A SEMICONDUCTOR.

a. Negative and positive charges. The charges you have seen in the preceding types of transistors have other names beside negative and positive. They are commonly called electrons and holes; electrons are the negative charges, and holes are the positive charges.

b. Holes. The idea of considering a hole as a positive charge may seem very strange if you haven't heard it before. But the idea is reasonable if you consider a negative charge as something that has many electrons, and a positive charge as something that is lacking electrons. You always have thought of an electron as a negative charge. Now the engineers want us to think of a positive charge as a space that is missing an electron. This space then, because it is missing an electron, is called a hole.

7. ELECTRON-HOLE MOVEMENT.

a. General. To simplify your understanding of the electron-hole structure of transistors, think of the transistor as a three-section egg crate; figure 10 illustrates this comparison. In figure 10A you see an NPN transistor and the three-section egg crate. Consider the eggs as electrons (N-type charges) and the empty spaces as holes (P-type charges). Notice that the two N-type sections have a lot of eggs (electrons), but very few holes. The P-type section in the middle is just the opposite, it has many holes but very few electrons.

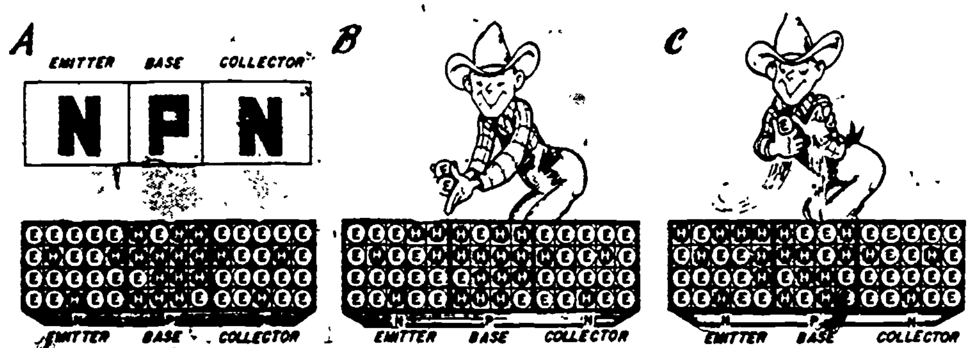

Figure 10. Comparing a transistor with an egg crate.

b. Movement of charges. Now if someone takes several eggs from the N-section (emitter) and places them in the P-section (base) as in figure 10B, what happens? Well, as you can see in figure 10C, moving the eggs from emitter to base has increased the number of holes in the emitter and reduced the number of holes in the base. So, in effect, what has happened is this:

(1) Electrons have moved from emitter to base.

(2) Holes have moved from base to emitter.

c. Purpose. The purpose of this comparison is to make sure you realize that holes and electrons move in a transistor in opposite directions. In the explanations that follow keep the egg crate idea in mind and it will be easier to see how the holes and electrons move.

8. ELECTRON AND HOLE MOVEMENT IN A SINGLE CRYSTAL.

a. Repulsion and attraction. The old law of like charges repelling each other and opposite charges attracting each other applies to electrons and holes. Figure 11A shows how electrons and holes obey this law when a battery is connected across an N-type transistor crystal. Remember that the single crystal is like one section of the egg crate.

(1) Figure 11B shows that electrons (negative charges) are attracted to the positive terminal and flow into the battery.

(2) For every electron that leaves the crystal, another electron enters from the negative terminal of the battery (fig. 11C).

(3) Each electron that goes into the battery leaves a hole (positive charge) behind it (fig. 11D). The holes left behind and all other holes in the crystal are attracted to the negative terminal. These holes do not flow into the battery—they move only inside the crystal.

(4) As the holes arrive (fig. 11E) they are refilled by electrons coming into the crystal from the negative terminal. In other words, for every electron that leaves the crystal, another electron enters the hole left behind. The total number of electrons flowing determines the amount of current flow.

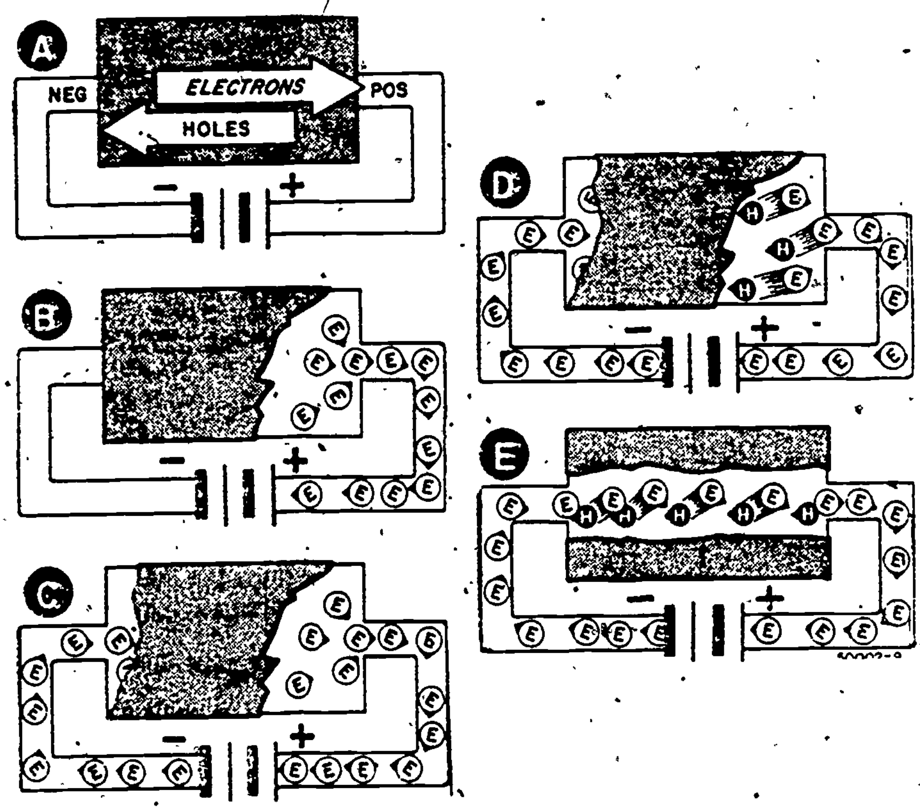

Figure 11. How charges move in single crystal.

b. Reversing the battery.

(1) Reversing the battery as in figure 12 reverses the direction of movement of holes and electrons in the crystal. The electrons, of course, still move toward the positive terminal, and holes move toward the negative terminal.

(2) Reversing the battery, however, does not have any effect on the amount of current flowing in the circuit. This is a very important point in your study of transistors. Remember if you reverse the voltage connected across a single semiconductor crystal, the amount of current flowing does not change. It is only when you use two or more crystals together that you get a current-controlling effect.

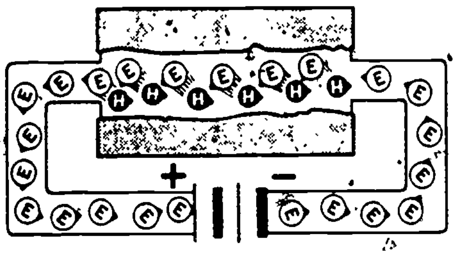

Figure 12. Reversing battery.

9. RELATIONSHIP OF TRANSISTORS AND DIODES.

a. As you know a transistor has three semiconductor elements: emitter, base, and collector. All transistors have the same three elements whether they are NPN-type or PNP-type. To see just how these semiconductor elements control current, we'll cut the transistor in half and consider the action of each half separately. Then we'll bring the two halves together again and apply what we have learned to the complete transistor.

b. Figure 13 shows an NPN transistor cut in half. Each half forms a crystal diode. In other words, each half can control current just like a diode tube. Notice that each diode section consists of an N-type and P-type crystal. You know that the N-type has a negative majority charge (more electrons) and the P-type has a positive majority charge (more holes). It's this difference in majority charges that makes a crystal diode act as a oneway current device. Connecting a battery across each crystal diode shows the current controlling action.

10. BIAS.

a. General. Connecting a battery across a diode one way causes the current to flow easily; reversing the battery connection makes the diode act like an open circuit to current flow. The two ways you can connect a battery across a crystal diode are referred to as forward and reverse bias, respectively.

b. Forward bias (fig. 13A). Connect the negative battery terminal to the N-crystal and the positive terminal to the P-crystal; this makes the diode act like a short circuit allowing high current flow.

c. Reverse bias (fig. 13B). Connect the negative battery terminal to the P-crystal and the positive terminal to the N-crystal. This makes the diode act like an open circuit resulting in so little current flow that the amount is considered to be zero.

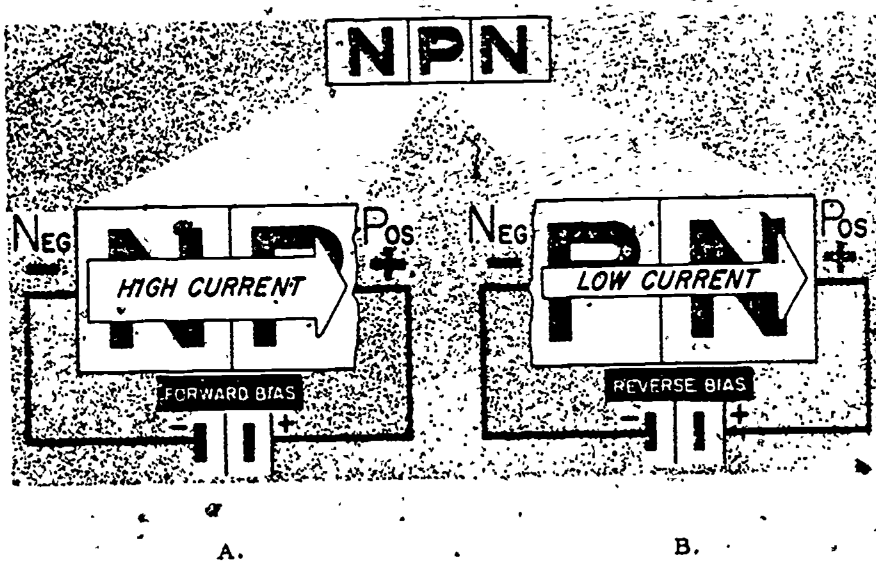

Figure 13. Showing two diode sections of a transistor.

11. MOVEMENT OF CHARGES IN A DIODE.

a. General. When a battery is connected to a diode the charge movement obeys the law of attraction and repulsion. Electrons inside the crystal are repelled from the negative voltage terminal and attracted to the positive voltage terminal. Holes inside the crystal are repelled from the positive voltage terminal and attracted to the negative voltage terminal.

b. Forward biased diodes (fig. 14). The negative voltage pushes electrons in the N-area toward the P-area and the positive voltage pushes holes in the P-area toward the N-area. Because of the force applied by the voltage source the electrons and holes penetrate the junction between the two crystals. Electrons getting through to the P-area are quickly attracted to the positive voltage and move through the conductor to the battery. Every electron that moves out of the crystal leaves a hole behind; the positive voltage then pushes these holes into the N-area. The holes getting into the N-area are attracted to the negative voltage; electrons from the battery fill these holes arriving at the negative voltage side. Notice that for every electron leaving the crystal, another one moves into the crystal. Also notice that the movement of charges which make up the current flow consists of majority charges—not minority charges.

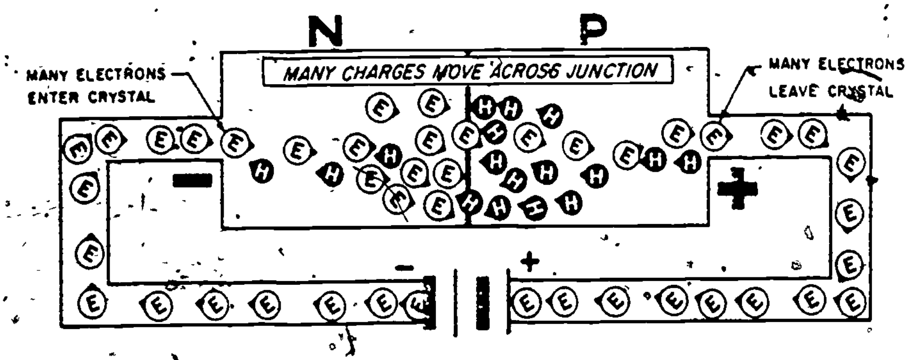

Figure 14. Forward biased diode.

c. Reverse biased diodes. Remember the battery connections are now just the opposite of a forward biased diode; observe figure 15. The negative minority charges (electrons) in the P-area are pushed through the junction to the N-area, while the majority positive charges (holes) are held in the P-area by the applied negative battery potential. The positive minority charges (holes) in the N-area are forced to penetrate the junction into the P-area, while the majority negative charges (electrons) are held in the N-area by the positive battery voltage. The electrons forced into the N-area are attracted by the positive voltage; the few electrons that leave the crystal leave a few holes behind. Since only a few electrons have left the crystal, only a few can enter the crystal from the negative voltage side to fill the holes. Thus we have only a very small current flow, so small in fact it generally is considered to be zero.

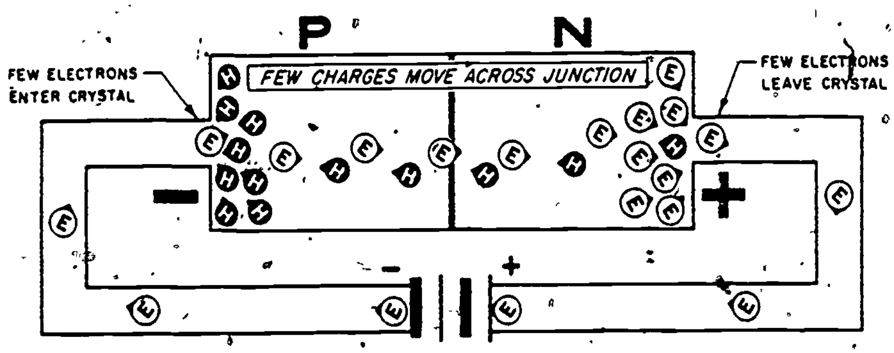

Figure 15. Reverse biased diode.

d. Summary. The majority charges move in a forward biased diode and since there are many of these a large current can flow. The minority charges move in a reverse biased diode and since there are only a few of these charges only a very small current can flow—for our purposes zero current.

12. TRANSISTORS.

a. Assembling diodes into a transistor. Putting the forward and reverse biased diodes back into the transistor, as in figure 16, we notice that the emitter to base (NP) diode section is forward biased and the base to collector (PN) diode section is reverse biased. Transistors are always biased this way except for special circuit applications. This bias method is used for both NPN and PNP transistors (fig. 17). The proper battery connections can easily be determined by adding another alternate letter to the transistor type (for example NPNP or PNPN). The last letter gives the polarity of voltage applied to the collector. The emitter is at the opposite potential, with the base very close to it, but generally not quite as extreme.

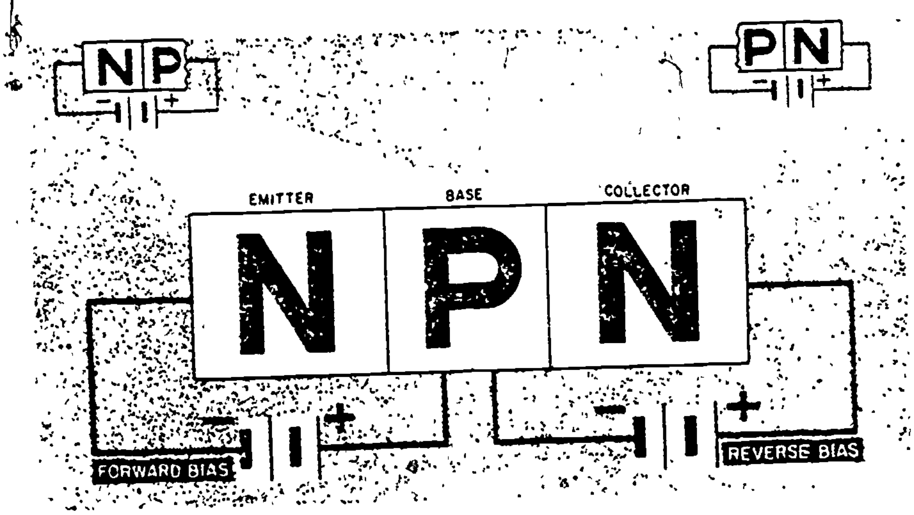

Figure 16. Putting the diodes back into the transistor.

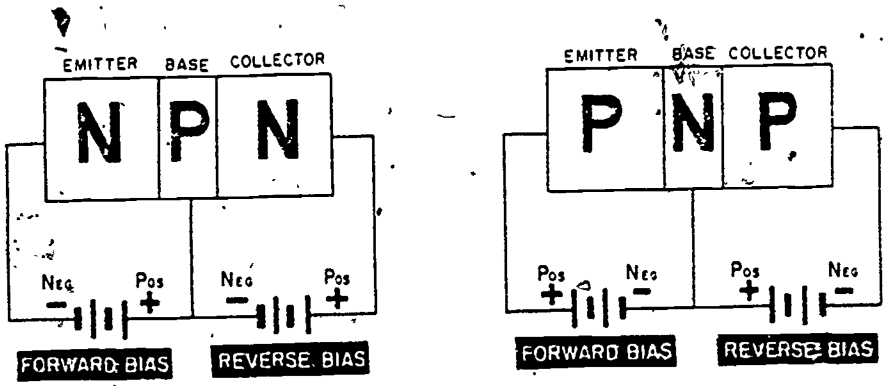

Figure 17. Bias methods for NPN and PNP transistors.

b. How the charges move in an NPN transistor. Consider the action of the NPN transistor shown in figure 18. The transistor is currently biased with the forward bias on the emitter-to-base junction and reverse bias on the base-to-collector junction.

(1) The bias voltage on the emitter-to-base junction causes electrons (N-type majority charges) in the emitter crystal to move toward the base crystal. The base is a much thinner (about 0.001 inch) crystal than either the emitter or collector crystals. Therefore, since the electrons are moving at a tremendous rate of speed, most of them (actually about 95-99 percent) pass through the thin base crystal and go to the collector. The few electrons (from 1 to 5 percent) that do not penetrate the base are attracted to the positive voltage on the base. These few electrons cause a very small base current flow.

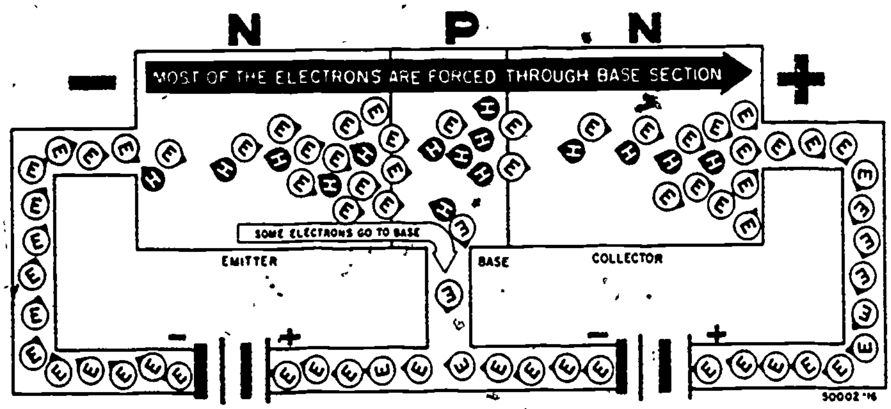

Figure 18. Movement of charges in NPN transistor.

(2) The great number of electrons that go to the collector are attracted to the positive terminal of the battery. These electrons leave the collector and enter the battery causing collector current flow. Every electron that moves out of the collector leaves a hole behind it and these are forced in the opposite direction by the positive collector voltage. These holes penetrate the thin base crystal and go to the emitter. For every hole that reaches the emitter, another electron goes to the collector.

(3) This gives you an idea of the current-controlling action of an NPN transistor, of which the most important thing to remember is that the forward bias (connected across the emitter and base) controls the amount of collector current flow. In other words, if you make the base more positive, collector current rises. If you make the base less positive, collector current drops. A little later in this lesson you will see how a weak signal voltage can be used to control the forward bias voltage and thus produce an amplified signal in the collector circuit.

c. Movement of charges in a PNP transistor. The principles of operation for the NPN and PNP transistors are basically the same. The only differences result from the crystal arrangements (fig. 19).

(1) Forward bias voltage on the emitter-to-base causes holes (majority P-type charges) to move toward the base. Most of the holes penetrate the base crystal and enter the collector area.

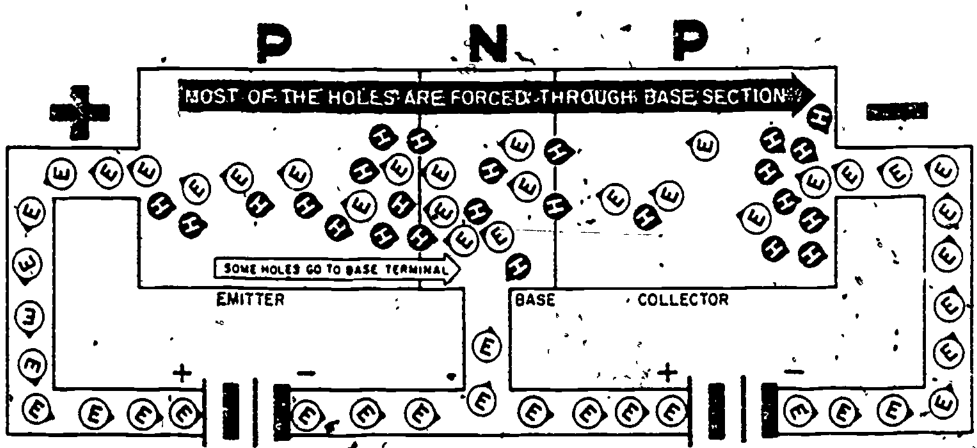

Figure 19. Movement of charges in PNP transistor.

(2) As the holes arrive in the collector area they are filled by electrons coming from the negative collector voltage. These electrons pass through the thin base crystal and go to the emitter. There are also a few electrons from the negative base voltage that fill the few holes that didn't get from the emitter to collector.

(3) All the electrons that go to the emitter are attracted to the positive emitter voltage and flow into the battery. Every electron that moves out of the emitter leaves a hole behind. All the holes left behind move from the emitter, through the base, to the collector.

d. Summary. Current flows through an NPN transistor from emitter to collector, but from collector to emitter in a PNP transistor. Electrons constitute the main current through an NPN transistor, ~~while~~ holes are the main current carrier in the PNP transistor. Therefore, a negative voltage on the base of an NPN transistor will stop current flow (shut the transistor off), but a PNP transistor will require a positive voltage to halt the hole flow, thus stopping current flow in the circuit.

13. TRANSISTOR SYMBOLS.

a. Symbols. Figure 20 shows the two schematic symbols used for transistors—one is used for the NPN and the other for the PNP transistor. Both symbols show the emitter, base, and collector. The collector and emitter are drawn at an angle to the base in both symbols. But notice, the emitter is determined by the use of an arrow. The collector doesn't have an arrow.

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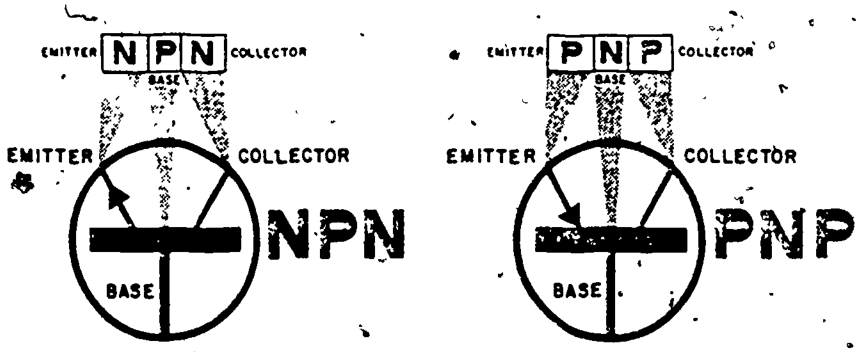

Figure 20. Transistor symbols.

b. NPN or PNP. The direction of the emitter arrow indicates whether it's an NPN or a PNP transistor. Notice that the emitter arrow points away from the base in the NPN transistor, but toward the base in the PNP transistor. Remember that the emitter arrow always points away from the direction of current flow and you will have no trouble determining if the symbol represents an NPN or a PNP transistor. Another way to associate the proper symbol with the correct transistor is to remember: NPN (NP) arrow does NOT POINT to the base; PNP (P) arrow DOES POINT to the base (fig. 20).

14. TRANSISTOR CIRCUIT.

a. Basic transistor and vacuum tube circuits. The three basic transistor circuit arrangements are very similar to common vacuum tube circuits. Notice that the phase relationship of input and output signals is the same for the transistor circuits and their equivalent vacuum tube circuits. The input and output signals are 180° out of phase only in the common emitter and common cathode circuits. The other circuits have the same phase relationship between input and output (fig. 21).

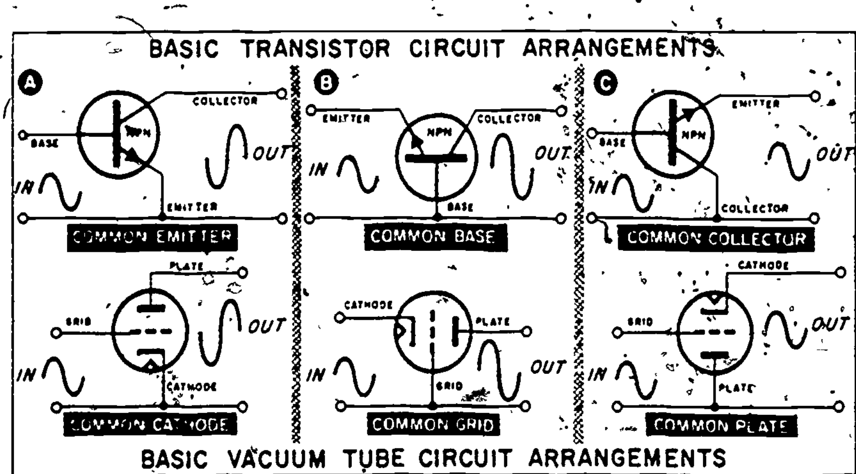

Figure 21. Comparing basic transistor and vacuum tube circuit arrangements.

(1) The common emitter (fig. 21A) has the emitter common to the base input and the collector output signals. This is like the common cathode vacuum tube circuit.

(2) The common base (fig. 21B) has the base common to the emitter input and the collector output signals. This is like the common grid vacuum tube circuit.

(3) The common collector (fig. 21C) has the collector common to the base input and emitter output signals. This is similar to the cathode follower or common plate vacuum tube circuit.

b. Comparing transistor and vacuum tube circuits. Now compare the actual transistor circuits with their equivalent vacuum tube circuits shown in figure 22. Notice that both sets of the circuits are arranged the same way. The input circuits of both transistors and vacuum tubes have a signal generator in series with the bias battery; also, the output circuits both have a load resistor and battery.

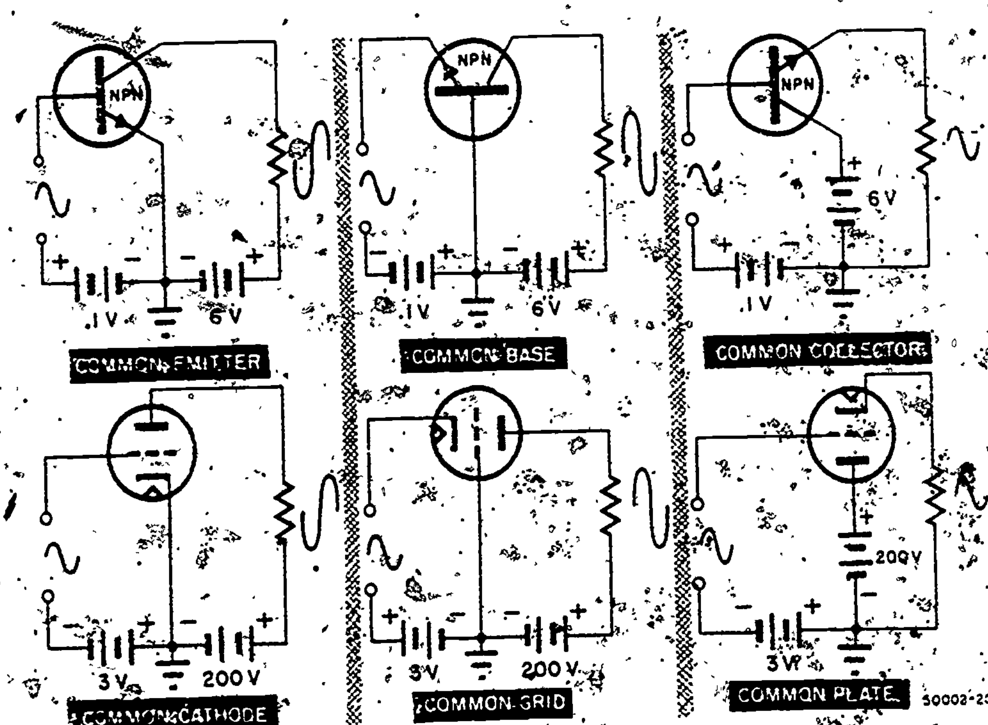

Figure 22. Comparing transistor and vacuum tube circuits.

So with regard to input and output signals, transistor and vacuum tube circuits work the same way. The main differences between the circuits are the voltage values used and the bias polarities. Note carefully the following circuit differences.

(1) Vacuum tubes use filaments and require a filament voltage source—transistors have no filaments.

(2) Transistors operate from much smaller voltages. You can see the collector batteries are only 6 volts as compared to the 20?-volt plate batteries.

(3) Bias voltages are only 0.1 volt for the transistors and 3 volts for the vacuum tubes.

(4) Finally, the amount of current that flows in transistors (NPN in this example) is controlled by the base-to-emitter voltage. In vacuum tubes it is the grid-to-cathode voltage that determines how much current flows.

Note. —To show you how each of these three circuits works, we will discuss each one separately. We will use the same transistor circuits we have been discussing (fig. 22). But instead of using a signal generator directly in series with the bias voltage, we will use a transformer coupling (fig. 23). That way the transformer secondary acts like a signal generator in series with the bias voltage. The circuits that we will discuss use NPN transistors. Should we wish to use PNP transistors it would merely be necessary to reverse the polarities of the batteries. Remember, in the case of a PNP transistor, current flows from collector to emitter not from emitter to collector as in the NPN.

15. HOW THE COMMON EMITTER WORKS.

a. Reverse bias connection. Looking at figure 23, the first thing you probably wonder is—how do you get reverse bias from base-to-collector if the battery isn't connected to the base? Actually the collector battery does connect to the base through the 0.1-volt battery. In other words, the difference in voltage between the base and collector is 6 volts minus 0.1 volt, which equals 5.9 volts. This means that the base is at a negative 5.9 volts as compared to the collector—this is reverse bias.

b. No input. Before the signal is applied the positive 0.1 volts on the base causes current to flow toward the base. As you know, most of the current goes to the collector and very little gets to the base. Current flow in the collector output circuit causes voltage to develop across the output which is taken across the collector and emitter as shown.

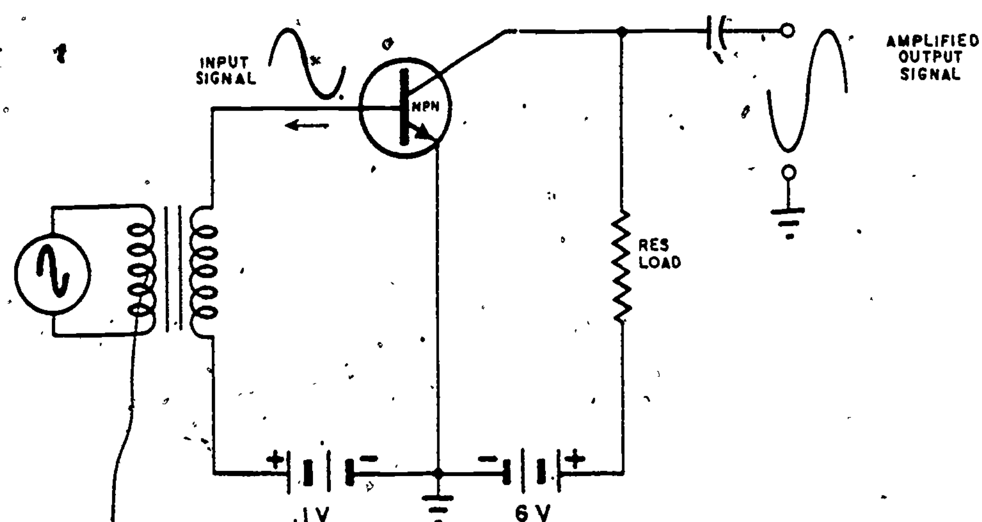

Figure 23. How the common-emitter circuit works.

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c. Positive input. As the input signal rises in the positive direction, the signal voltage adds to the +0.1-volt battery voltage. Higher positive voltage makes the transistor conduct more, causing the collector current to rise. Higher collector current means that the output voltage drops, thus providing a negative output signal alternation. (The reason the output voltage drops when collector current increases is the same as for vacuum tubes—a rise in plate current always causes a drop in output voltage when the output is taken across plate and cathode.)

d. Negative input. When the input signal drops in the negative direction, the signal voltage subtracts from the 0.1-volt battery voltage. This makes the base less positive compared to the emitter, so less electrons move from the emitter to the collector. Therefore the collector current drops. A drop in collector output current causes the output voltage to rise, thus providing the positive alternation of the output signal.

e. Output. Notice that the amplified output signal is 180° out of phase with the input signal.

16. HOW THE COMMON BASE CIRCUIT WORKS.

a. Reverse bias connections. In the common base circuit (fig. 24) you can see that the reverse bias is not a problem. The negative side of the collector battery goes directly to the base and the positive side of the battery goes to the collector through the load resistor.

b. No input. Before a signal is applied, the transistor operates with only 0.1-volt forward bias. The amount of current that flows is the same as in the common-emitter circuit.

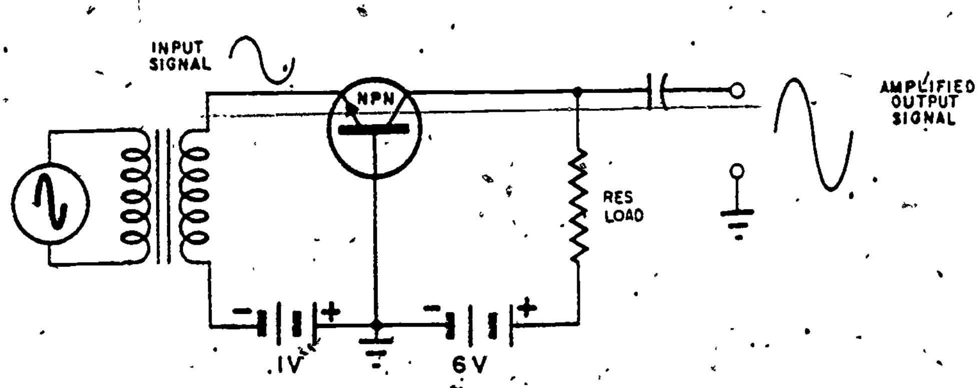


Figure 24. How the common-base circuit works.

c. Positive input. The positive input alternation subtracts the 0.1-volt battery voltage making the emitter less negative and causing the transistor to conduct less. This causes a rise in the collector output voltage, thus providing a positive alternation.

d. Negative input. The negative input alternation adds to the 0.1-volt battery voltage making the emitter more negative and causing the transistor to conduct more. This causes a drop in the collector output voltage, thus producing the negative output alternation.

e. Output. Notice that the amplified collector output is in phase with the input signal.

17. HOW THE COMMON COLLECTOR CIRCUIT WORKS.

a. Reverse bias connections. Notice in the common collector circuit (fig. 25) that the reverse bias is obtained in the same way as in the common emitter circuit; again it is through the 0.1-volt battery making the reverse bias 5.9 volts.

b. No input. Before a signal is applied, the transistor operates with only a 0.1-volt forward bias, just as in the two previous cases.

c. Positive input. During the positive input alternation the forward bias voltage increases. This causes the transistor to conduct more. The current through the emitter (res. load) causes a positive output voltage rise.

d. Negative input. On the negative input alternation the forward bias decreases. Less current flows through the emitter (res. load) causing a negative output voltage.

e. Output. In the common collector circuit the output signal is less (slightly) than the input signal and the output and input signals are in phase.

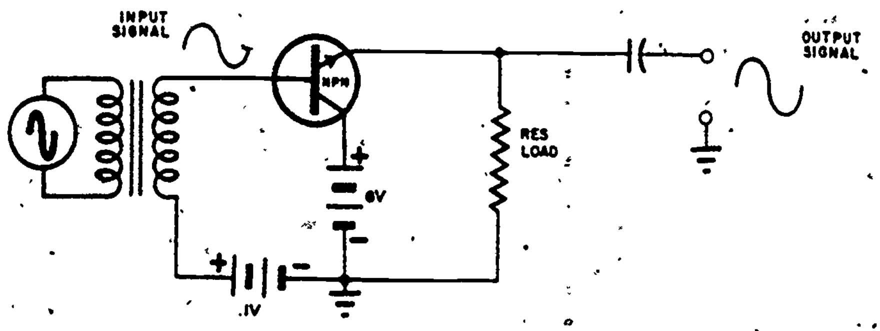


Figure 25. How the common-collector circuit works.

18. HOW TRANSISTORS AMPLIFY.

a. Base-to-emitter voltage. So far you've seen how a change in base-to-emitter voltage causes a change in collector current. This is the key to transistor amplification. A very small change in input signal voltage causes a great change in collector current. The change in collector current then causes a change in output voltage across the collector output circuit. The output voltage change is much greater than the input change so you have amplification.

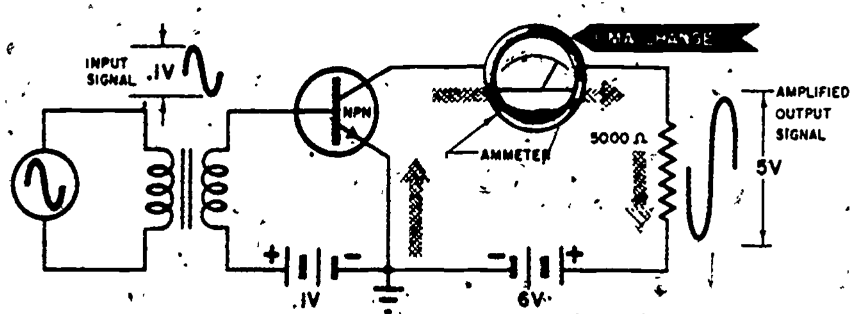


Figure 26. Transistor amplification.

b. Determining voltage gain. Now let's use some actual values and you'll be able to get a clearer idea of what happens. Suppose we have a 0.1-volt input signal, as shown in figure 26, causing a 0.001 amp (1 ma) change in the collector current. If the load resistance is 5,000 ohms, we can find the output voltage by applying Ohm's law ($E = I \times R$). Multiplying $0.001 \times 5,000$ gives 5 volts ($E = I \times R = .001 \times 5,000 = 5V$); therefore, the amplified output signal is 5 volts. To find out how much voltage gain the circuit provides, divide the 5-volt output by the 0.1-volt input; i.e., gain $\frac{E_{out}}{E_{in}} = \frac{5}{0.1} = 50$. The answer is 50, so this circuit provides a voltage gain of 50.

c. Summary. You see, therefore, that transistor amplification is not much different than vacuum tube amplification. In a tube, it's a change in grid-to-cathode voltage causing a change in plate current that gives amplification. In a transistor, it is a change in base-to-emitter voltage causing a change in collector current that does it.

19. SELF-BIAS.

a. Bias batteries. You may be wondering how it is possible to have a forward bias battery as small as 0.1 volt. Actually, we don't use batteries this small because they are not available. Instead, we use conventional batteries such as the 1.5-volt, 6-volt, or even 22.5-volt types to get the 0.1 volt we need.

b. Forward bias. We get the low forward bias voltage by using the voltage drop across the emitter-to-base resistance. Less then 10 percent of the emitter current flows into the base circuits. This amounts to about 0.0001 amp. (.1 ma) when the base is a positive 0.1 volt. To determine base resistance, use Ohm's law ($R = E/I$). Dividing 0.1 volt by 0.0001 ma ($R = .1/.001 = 1,000\Omega$) shows that the base resistance is 1,000 ohms. So you see, as long as the base current is 0.1 ma, the voltage across the 1000-ohm emitter to base resistance is the 0.1-volt bias we want.

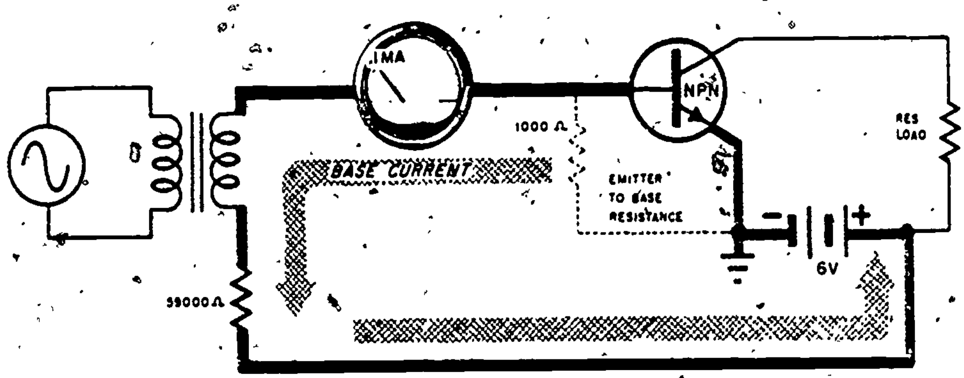


Figure 27. Using the emitter-to-base resistance to develop bias.

This is shown in figure 27 where the base voltage is obtained by using the 6-volt collector battery. You can see that there is a 59,000-ohm resistor, and a transformer secondary in series with the 1,000-ohm emitter-to-base resistance and the 6-volt battery. Since the transformer coil is only a few ohms, you can ignore its resistance. This means that the total resistance is 60,000 ohms across the 6-volt battery, which allows only 0.1 ma to flow. Using Ohm's law this is ($I = E/R$): or,

$$I = \frac{E}{R} = \frac{6}{60,000} = 0.0001A = 0.1\text{ ma}$$

c. Bias limiting resistor. The 59,000-ohm resistor is sometimes called a bias limiting resistor since it is used to limit the amount of base current that develops the bias voltage. The current through this resistor is sometimes called bias current. So you see, in transistors the operating bias voltage is determined by the bias current. The higher the bias current, the greater the forward bias voltage developed across the emitter-to-base resistance. Since the resistance of a transformer coil is only a few ohms, remember that you need a bias limiting resistor to prevent excessive current flow through the transistor. Without this resistor, the transistor will burn out.

20. TRANSISTOR CHARACTERISTIC CURVES.

a. General. Calculation of the current, voltage, and power gain of a common emitter transistor amplifier (fig. 28A) can be accomplished by using the common emitter output static characteristic curve (fig. 28B). The output characteristic curves plot the collector current against the collector voltage with the base current as the fixed value. (This family of curves is equivalent to the plate curve family of the common vacuum tube. Remember from your previous lesson that we plotted plate current against plate voltage while holding grid voltage constant.) The known information about the amplifier is as follows:

(1) Collector supply voltage is 10 volts.

(2) Load resistor R2 is 1,500 ohms.

(3) The emitter base input resistance (ri) 500 ohms.

(4) The peak-to-peak input current is 20 μa.

(5) The operating point (X) is 25 μa of base current and 4.8 volts on the collector.

b. Loadline (fig. 28B). The first step in the procedure is to establish the loadline of load resistor R2 on the output characteristic curve. This is done by locating and connecting points Y and Z of the loadline. This is basically the same procedure as you used last lesson to calculate the loadline of a vacuum tube.

(1) When the collector current is zero, the total collector supply voltage (10 volts) equals the collector voltage (Vce). Point Z (one point of loadline) then is at the 10 volt mark on the horizontal axis.

(2) When the voltage on the collector is zero the total collector supply voltage (10 volts) is dropped across load resistor R2 (1,500 ohms). The total current (Ic) then is:

$$Ic = Vce/R2 = \frac{10}{1,500}$$

$$Ic = 0.0066A = 6.6 \text{ ma.}$$

Point Y (second point of the loadline) then is at the 6.6 ma. mark on the vertical axis.

(3) Connecting points Y and Z with a straight line establishes the loadline.

c. Operating point and waveforms (fig. 28B). The operating point is located at point X on the loadline. This point is the intersection of a line drawn vertically from the 4.8-volt (collector voltage) mark on the horizontal axis to the 25 μa curve of base current. Since the peak-to-peak input current is 20 μa, the deviation is 10 μa above the operating point (point M) and 10 μa below the operating point (point N).

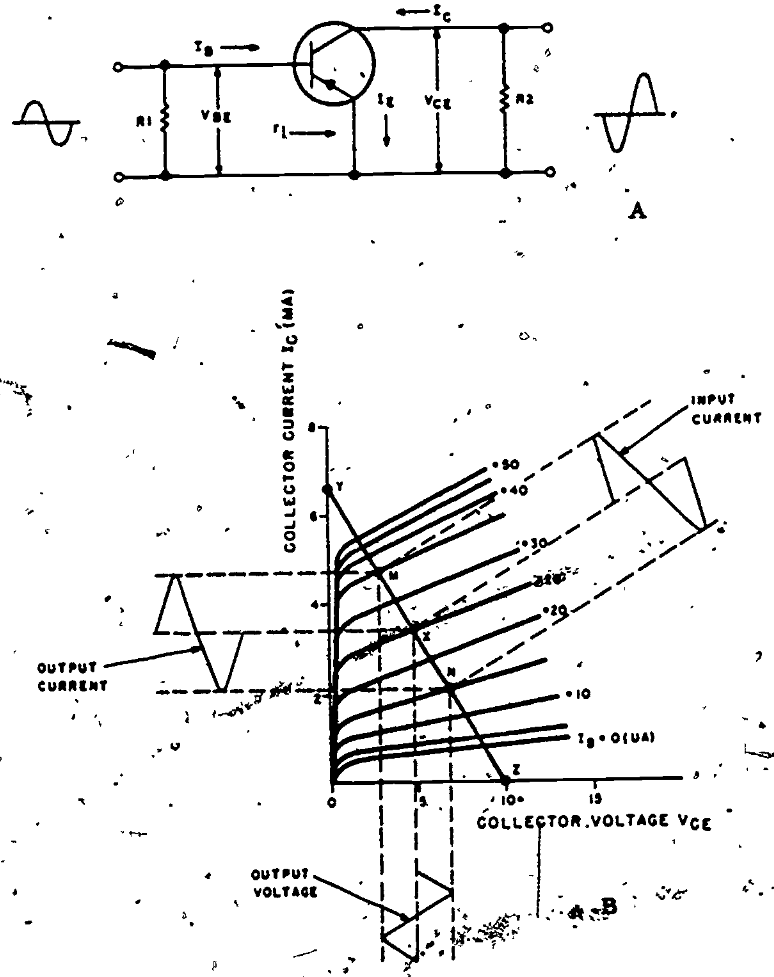


Figure 28. CE amplifier and its output characteristic curves with loadline.

(1) Establish the waveform for the input current by extending a line (perpendicular to the loadline) from operating point (X) and each deviation point (M and N).

(2) Establish the waveform for the output current by extending a horizontal line through the vertical axis from the operating point and each of the deviation points (M, N and X).

(3) Establish the waveform for the voltage by extending a vertical line through the horizontal axis from the operating point and each of the deviation points (M, N and X).

d. Current gain. Current gain in this configuration is the ratio of the change in collector current to the change in base current.

(1) Determine current gain as follows:

$$Ai = \frac{I_c}{I_B} \quad (\Delta \text{ denotes change})$$

$$= \frac{I_c \max - I_c \min}{I_B \max - I_B \min}$$

(2) Substitute known values in the formula:

$$Ai = \frac{4.7 \text{ ma} - 2.1 \text{ ma}}{35 \text{ A} - 15 \text{ A}}$$

$$\frac{2.6 \text{ ma}}{20 \mu a} \quad \frac{2.6 \text{ ma}}{0.02 \text{ ma}}$$

$$Ai = 130$$

The current is amplified 130 times.

e. Voltage gain. Voltage gain in this configuration is the ratio of the change in collector voltage to the change in base voltage.

(1) Determine the voltage gain as follows:

$$Av = \Delta VCE / \Delta VBE$$

(2) Solve for Δ VBE. The change in input voltage is the change in input current multiplied by the input impedance (500 ohms).

$$\Delta VBE = \Delta I_B r_i$$

$$= 20 \mu a \times 500 \text{ ohms}$$

$$= .00002 \text{ amp} \times 500 \text{ ohms}$$

$$\Delta VBE = .01 \text{ volt}$$

(3) Substitute known values in the formula (1) above.

$$Av = \frac{6.7V \;\; 2.7V}{.01} = \frac{4V}{.01V}$$

$$Av = 400$$

The voltage is amplified 400 times.

f. Power gain. The power gain is the voltage gain times the current gain.

(1) Determine the power gain as follows: $G = AvAi$

(2) Substitute known values obtained in d and e, above, previously.

$$G = 130 \times 400$$

$$G = 52{,}000$$

The input power is increased 52,000 times in going through the transistor.

g. Constructing a dynamic transfer characteristic curve. The loadline on the output static characteristic curve tells a great deal but not as conveniently as does another type of characteristic curve. From the effects of the transfer static characteristic curve, a resultant curve known as the dynamic transfer characteristic curve (fig. 29) is formed. It has become common practice, when studying the behavior of the collector current under the influence of a signal current applied to the base to show the dynamic transfer characteristic and to plot the input signal and the resultant collector current along this characteristic. In figure 29, the output characteristic with the 1,500 ohm line (fig. 28B) is repeated. In addition, the transfer static characteristic is drawn to the left. To show the collector-current base-current curve, which represents the collector current corresponding to certain base currents and the effect of the load in creating the effective collector voltages, the 1,500-ohm loadline will be projected on the transfer static characteristics. The two families of curves have three attributes in common—a common collector current axis, like values of base current, and like values of collector supply voltage, although the last two named are illustrated differently. To project the effect of the loadline on the transfer static characteristics, it is necessary to plot the collector current values for each value of base current (P-Z) shown on the output characteristic curve. This is done as follows:

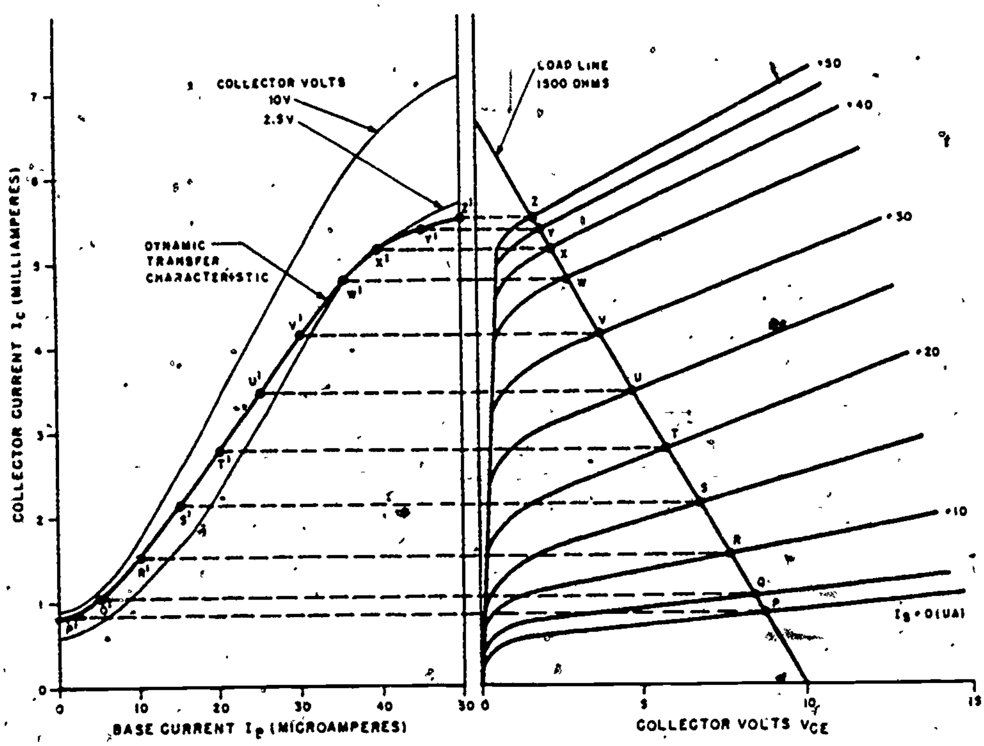


Figure 29. Construction of dynamic transfer characteristic curve from output static characteristic curves with loadline and forward transfer static characteristic curves.

(1) Extend a horizontal line from point P of the output characteristic curve P' ($I_B 0$ and $I_C 0.85$ ma) of the transfer static characteristic curve.

(2) Extend a horizontal line from each of the remaining points (Q through Z) to locate Q' through Z' of the transfer static characteristic curves.

(3) Connect points P' through Z' sequentially to establish the dynamic transfer characteristic curve.

(4) The two curves on the transfer characteristics marked 2.5V and 10V are obtained with the collector voltage held constant and the output a.c. short circuited. This is a static condition. The collector voltage of the dynamic transfer characteristic curve is not shown as a constant value since the collector voltage now varies because of the presence of the load resistor. (Note - The dynamic transfer characteristic curve for the transistor is equivalent to that for the electron tube, as discussed in the previous lesson.)

h. Signal analysis with dynamic transfer characteristic curve.

(1) When the proper operating point is established and if the change of base current is within the linear portion of the dynamic transfer curve, the transistor will operate linearly (linear operation, fig. 30).

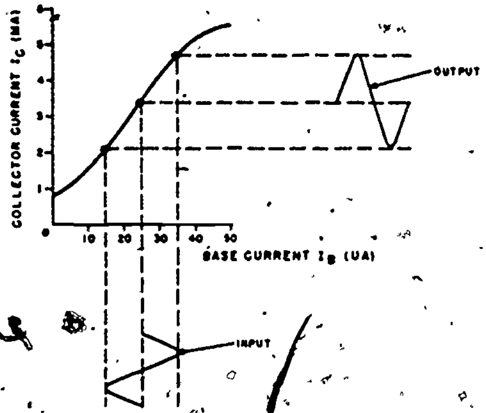


Figure 30. Dynamic transfer characteristic curve, showing linear (Class A) operation.

When the transistor is operating linearly, the amplified output signal will be an exact reproduction of the input signal. Class A amplifiers are operated in this manner.

(2) When the proper operating voltage is established and if the change of base current exceeds the linear portion of the dynamic transfer characteristic curve, the input signal is overdriving the transistor and the amplified output signal will be distorted (fig. 31).

(3) When the improper operating point is established, the change of base current will automatically cause the linear portion of the dynamic transfer characteristic curve to be exceeded. The location of the operating point will determine whether the negative or the positive change of base current will exceed the linear portion (fig. 32).

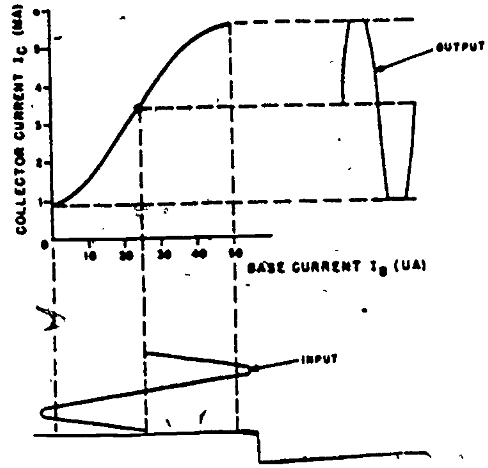


Figure 31. Dynamic transfer characteristic curve showing overdriving.

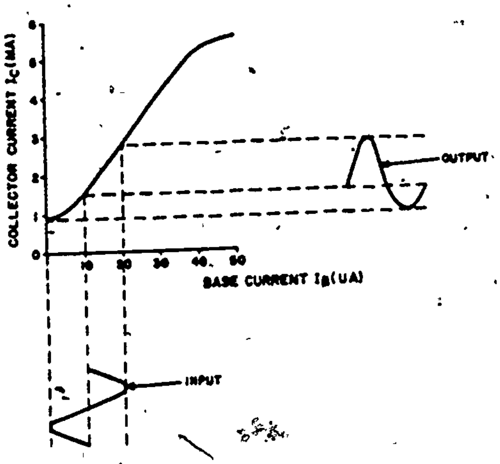


Figure 32. Dynamic transfer characteristic curve showing nonlinear operation.

21. WORKING WITH TRANSISTORIZED EQUIPMENT.

a. Handling transistor circuits. In your work you may have to replace parts in transistor circuits when they go bad. Most transistor circuits use miniaturized parts. They're the same kind of parts used in other circuits, such as resistors, capacitors, and coils, but they have been scaled down to match the size of the tiny transistors. This means that you must be extra careful in handling the parts and using your soldering gun. The parts are smaller then usual and thus more fragile then normal sized components.

b. Transistor mountings. Figure 33 shows three different transistors and the socket that is used to mount them. Notice that the socket holes are not equally spaced. The unequal spacing is used to prevent plugging the transistor in the wrong way. As you can see, the hole for the base lead is in the middle. The collector hole on the right is spaced farther from the base than the emitter hole on the left, There is a round transistor socket also used in which the holes are placed in a semicircle and a straight line both, but the holes are spaced the same as the one we just discussed.

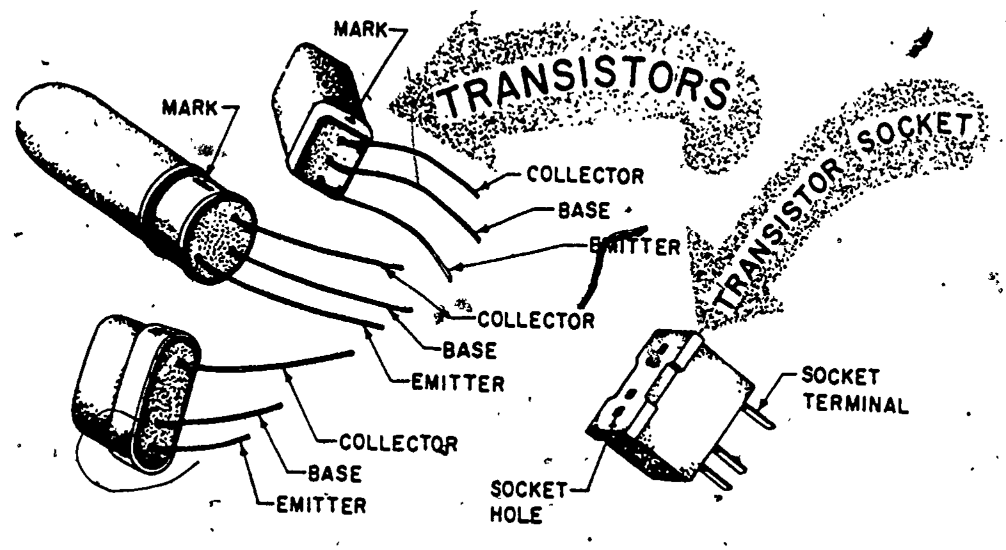


Figure 33. Typical transistors and mounting socket.

c. Connecting transistors. You will have no problem when plugging in the transistor shown on the lower left of figure 33. The transistor fits into the socket only one way because the transistor leads are spaced the same way as the socket holes. The other two transistors have an easily recognized mark on one side to identify the collector. You must be careful to insert the transistor leads in the proper socket holes. If you plug it in the wrong way, you'll burn out the transistor. When soldering be sure to remove the transistor from the socket if possible. If you must solder directly to the transistor leads (some equipment does not use sockets), use a low voltage iron (35-40 watts) and use a clip or long nose pliers on the lead between the iron and the transistor as a heat sink (fig. 34). Transistors are very sensitive to heat and failure to use a heat sink will invariably ruin the transistor.

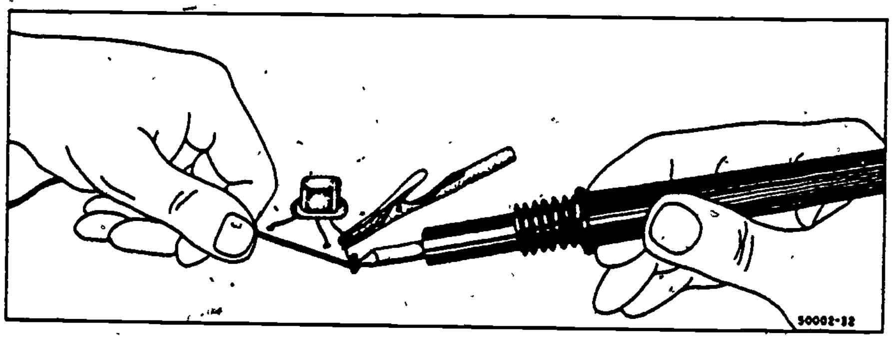


Figure 34. Using the "heat-sink" method to solder transistors.

22. TESTING TRANSISTORS WITH AN OHMMETER.

a. General. There are many test sets made especially for testing transistors but by using a simple ohmmeter we can determine whether a transistor has an open or short circuit, or even if it is a NPN or a PNP transistor.

b. Preparing the ohmmeter. First you must determine the polarity of the ohmmeter leads so that you know whether you are applying negative or positive voltage to the transistor elements. Check the polarity using a voltmeter. In the multimeter TS-352/u (which we will use for discussion), the jack marked ohms is negative (-), and the jack marked - DC + AC is positive (+).

CAUTION. —When checking transistors, do not use the low-range resistance scales of the ohmmeter or any range that allows more than 1 ma of current to flow, or you will burn out the transistor. The R x 1000 scale of the TS-352/u is quite satisfactory.

c. Testing NPN transistors. Use the following procedure to determine if a transistor is an NPN type or if it is defective. Use figure 35 as a reference. Numbers in the figure correspond to the step numbers.

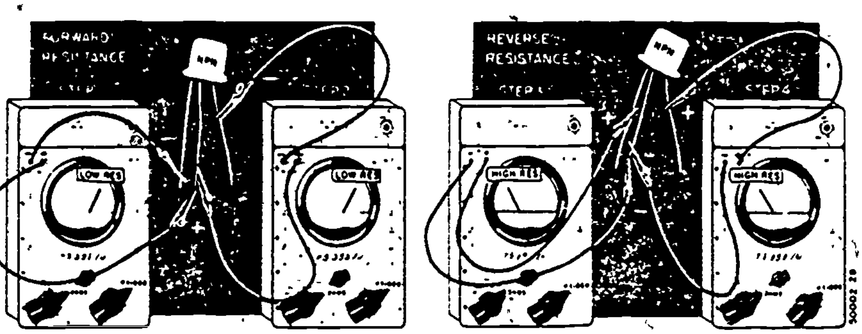


Figure 35. Testing NPN transistors using Multimeter TS-352/U.

(1) Connect the ohmmeter leads across the emitter and base as shown. Since this is a forward bias condition (for NPN transistor), the meter should show a low resistance reading.

(2) Now connect the meter leads across the base and collector. The voltage polarity tells you this is a forward bias connection and the meter should indicate low resistance again.

(3) Now check the emitter-to-base again but use reverse bias connection as shown. You should get a high resistance reading.

(4) Finally check the base-to-collector again using reverse bias. You should get a high resistance reading.

If the transistor is shorted you'll get a low resistance reading for both the forward bias and reverse bias measurements. If the transistor is open, you'll get a high or infinite resistance reading for both measurements. If either diode section of a transistor is shorted or open the transistor must be replaced. Before replacing a transistor, check its circuit for abnormal voltage which may have caused the trouble.

d. Testing PNP transistors. You test PNP transistors in the same way that you test NPN type. Of course, the meter connections must be just the reverse of those used for the NPN. Figure 36 shows how to make the test.

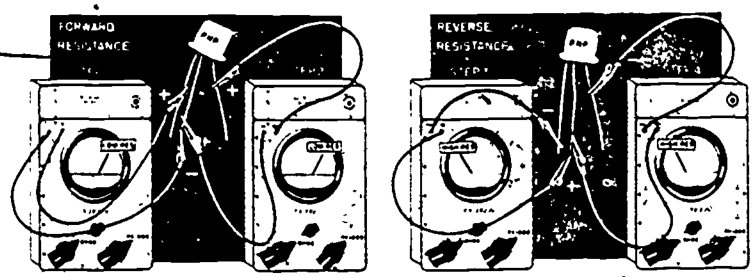
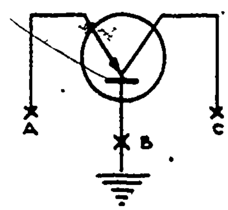


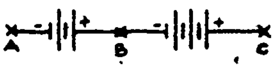
Figure 36. Testing PNP transistors using multimeter TS-352/U.

EXERCISE.

136. Which would be the proper connection for this circuit?



a. 

b. 

c. 

137. Positive charges and negative charges in transistors

a. move in the same direction.
b. move only in the crystal.
c. move in opposite directions.

138. How does the output of the common collector circuit compare with the input signal?

a. In phase and slightly more voltage
b. In phase and slightly less voltage
c. Out of phase and slightly more voltage

139. The resistance of transistor crystal material is

a. higher than most conductors but lower than most insulators.
b. higher than most insulators but lower than most conductors.
c. equal to most common conductors.

140. If a heat sink is not used when soldering a transistor lead what is likely to happen?

a. Melt the lead
b. Poor solder connection
c. Ruin the transistor

141. Approximately what percentage of the electrons flowing through a transistor are attached to the base?

a. 0 to 1
b. 1 to 5
c. 15 to 30

142. What are the main current carriers in the PNP transistor?

a. Electrons
b. Holes
c. Neutrons

143. In a P-type transistor crystal the minority charges are

a. protons.
b. holes.
c. electrons.

144. The arrow in the transistor symbol will always

a. indicate the base element.
b. point in the same direction as current flows.
c. point in the opposite direction to current flow.

145. Which common electronic circuit component functions much like the transistor?

a. Capacitor
b. Electron tube
c. Inductor

146. How can a transistor that is suspected of being shorted be tested?

a. Cannot be tested
b. Megger
c. Ohmmeter

147. If you reverse the battery connections to a single crystal the

a. amount and direction of current flow remain the same.
b. amount and direction of current flow change.
c. amount of current flow stays the same, direction of current reverses.

148. It has been estimated that a transistor can operate continuously for how many years?

a. 8
b. 6
c. 4

144

149. In an NPN transistor the current flows from

a. base to emitter.
b. collector to emitter.
c. emitter to collector.

150. The positive charges of a transistor

a. move through the whole circuit.
b. move only in the crystal.
c. do not move at all.

151. A transistor is constructed from

a. carefully contaminated crystals.
b. pure refined crystals.
c. synthetic refined crystals.

152. A crystal diode is usually used to

a. control direction of current flow.
b. amplify weak signals.
c. convert direct current to alternating current.

153. What voltage change in a transistor performs the same function as the grid-to-cathode voltage in a tube?

a. Collector-to-ground voltage
b. Base-to-collector voltage
c. Base-to-emitter voltage

154. In transistor theory the positive charge is referred to as

a. an electron.
b. a hole.
c. a neutron.

155. A reverse biased diode is generally considered as permitting

a. large amounts of current flow.
b. reversed current flow.
c. small amounts of current flow.

156. A transistor normally has how many elements?

a. 2
b. 3
c. 4

157. What semiconductor sections of a transistor are usually forward biased?

a. Emitter to collector
b. Emitter to base
c. Base to collector

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158. If we put a positive (+) signal voltage on the base of an NPN common emitter circuit the

a. output voltage will decrease.
b. output voltage will increase.
c. collector current will decrease.

159. What type charges move in a reverse biased diode?

a. Majority
b. Minority
c. Negative

160. What is the thinnest crystal in a transistor?

a. Base
b. Collector
c. Emitter

146

ANSWER SHEET

FOR KEYPUNCH ONLY

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S/C ORD 098 3

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LAST FIRST MI

GRADE ______________ SSAN ______________

ADDRESS ______________________________

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If this is a new address check here ☐

NOTICE

Refer to the instructions preceding lesson exercise question 1 in your study text for information on the use of this answer sheet and the exercise response list. After your selections of choices for all exercise questions have been circled, tear this sheet out of the subcourse, fold it as instructed on the address side, and mail it to the school.

	a	b	c		a	b	c		a	b	c		a	b	c		a	b	c
1.	104	501	536	41.	437	523	333	81.	245	405	460	121.	625	346	515	161.	428	613	114
2.	223	657	595	42.	349	639	274	82.	360	440	624	122.	484	255	399	162.	201	552	443
3.	421	309	243	43.	277	394	647	83.	600	365	122	123.	217	698	436	163.	509	373	660
4.	241	483	527	44.	539	496	699	84.	233	526	339	124.	334	503	139	164.	180	481	230
5.	375	166	612	45.	113	408	392	85.	565	282	271	125.	593	388	291	165.	357	272	554
6.	690	110	427	46.	522	397	299	86.	175	684	488	126.	111	650	331	166.	586	366	174
7.	562	290	420	47.	191	642	412	87.	434	150	575	127.	633	252	479	167.	343	151	686
8.	630	197	463	48.	358	662	253	88.	651	363	154	128.	216	438	528	168.	120	519	495
9.	579	143	661	49.	500	379	416	89.	225	474	672	129.	411	198	671	169.	626	246	314
10.	547	685	342	50.	116	493	204	90.	400	136	352	130.	558	169	398	170.	487	652	203
11.	289	578	231	51.	164	415	533	91.	371	535	202	131.	368	697	275	171.	285	433	540
12.	635	409	235	52.	629	195	520	92.	513	266	446	132.	144	467	656	172.	618	155	361
13.	429	396	636	53.	311	505	498	93.	106	654	543	133.	476	502	123	173.	473	658	249
14.	103	112	529	54.	167	239	323	94.	644	262	454	134.	602	258	450	174.	211	566	489
15.	119	336	178	55.	304	442	227	95.	387	518	181	135.	229	303	598	175.	182	351	681
16.	510	276	452	56.	631	350	590	96.	159	374	605	136.	168	441	305	176.	308	466	588
17.	236	382	524	57.	677	206	425	97.	557	127	332	137.	472	680	125	177.	538	265	105
18.	101	490	362	58.	389	402	147	98.	410	619	212	138.	359	157	576	178.	445	187	646
19.	521	391	369	59.	316	638	403	99.	247	451	587	139.	534	380	244	179.	153	542	312
20.	628	378	426	60.	194	553	268	100.	328	551	186	140.	675	221	401	180.	234	655	458
21.	486	124	582	61.	393	570	477	101.	199	301	614	141.	287	589	606	181.	670	283	550
22.	541	492	242	62.	284	367	109	102.	693	131	459	142.	354	695	189	182.	302	430	148
23.	326	133	597	63.	207	545	648	103.	431	607	250	143.	641	297	499	183.	574	317	240
24.	293	485	637	64.	422	138	508	104.	281	480	512	144.	163	596	386	184.	165	345	564
25.	248	330	288	65.	615	504	417	105.	561	286	318	145.	546	322	257	185.	325	663	261
26.	152	295	423	66.	145	407	218	106.	115	507	238	146.	226	449	514	186.	622	176	456
27.	296	591	643	67.	580	205	376	107.	601	222	419	147.	418	130	609	187.	592	269	616
28.	573	390	432	68.	621	177	603	108.	414	190	659	148.	506	395	196	188.	208	517	327
29.	537	213	256	69.	468	669	320	109.	355	611	172	149.	294	604	406	189.	585	413	107
30.	192	264	117	70.	134	497	694	110.	687	439	329	150.	424	158	353	190.	277	673	132
31.	581	471	341	71.	385	448	170	111.	140	381	569	151.	645	219	548	191.	135	319	461
32.	279	617	324	72.	200	555	307	112.	384	667	193	152.	128	583	254	192.	683	185	370
33.	691	577	292	73.	674	184	516	113.	610	118	556	153.	321	453	676	193.	494	251	525
34.	259	679	298	74.	567	260	682	114.	149	447	209	154.	171	364	620	194.	544	469	232
35.	347	572	129	75.	228	608	161	115.	462	335	623	155.	653	237	464	195.	267	530	649
36.	156	594	278	76.	372	141	696	116.	338	666	404	156.	435	692	146	196.	668	263	455
37.	179	563	491	77.	549	665	210	117.	108	224	300	157.	560	102	337	197.	315	160	632
38.	465	584	188	78.	444	220	313	118.	599	664	142	158.	310	532	270	198.	137	511	340
39.	215	634	482	79.	688	559	173	119.	306	121	640	159.	214	475	571	199.	568	383	280
40.	457	627	356	80.	100	344	531	120.	183	470	273	160.	678	162	348	200.	478	689	126

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EXERCISE RESPONSE LIST

SUBCOURSE 98
FUNDAMENTALS OF ELECTRICITY

SEPTEMBER 1973

DEPARTMENT OF ARMY WIDE TRAINING SUPPORT
US ARMY ORDNANCE CENTER AND SCHOOL
ABERDEEN PROVING GROUND
MARYLAND

NOTICE

The inclosed responses are listed in numerical order. After making a circle around the number of your choice on the ANSWER SHEET, check the same number on the exercise response list. If you selected the correct answer, the response will indicate it with the word "CORRECT" appearing as the first word. Read the response for further information and then proceed to the next question. If the response shows you have not selected the correct choice, read the information presented to find out why your choice was wrong and where you can find the correct answer. The suggested references are designed to cover major teaching points in each lesson, thus reinforcing the student's learning process.

REMINDER! Be sure to PRINT your name, grade, social security account number, subcourse number, and date in the top left corner of your answer sheet before you start your first exercise.

RESPONSE NUMBER	RESPONSE
100	CORRECT. The usual AC ammeter or voltmeter will indicate the R.M.S. or effective value.
101	At one time this might have been true but not today. Check para 2c(1).
102	CORRECT. This is true except for special circuit applications.
103	A substance is composed of many atoms. Check para 2c(1) again.
104	An ampere is a unit of measure of the current flowing through a conductor. A different term is used to designate work per unit charge. Check para 3e again.
106	The longer the positive step voltage is applied, the greater will be the voltage across the capacitor. Take another look at para 2c.
108	Grid resistance is not required to plot this type of curve. Check para 4e(2) again.
109	CORRECT. Most circuits are a combination of series and parallel circuits.
110	If the polarity is neutral, there is no charge. Check para 3b again.
111	The control grid voltage is what controls the plate current. Please read para 4e(1) again.
112	Actually a compound is a type of substance. Have another look at para 2c(1).
113	CORRECT. Just as water will flow downhill.
115	CORRECT. Collapse of the magnetic field will reproduce the energy.
116	CORRECT. Soft iron is used for temporary electromagnets such as relays.
117	CORRECT. However, the magnetic field does not exist only on a single plane but fills the space about a magnet.
118	Since a diode only has two electrodes it cannot be used as an oscillator. Please read para 3a again.
119	Remember, we are talking about the forms that matter can take. Check para 2c and try again.
121	CORRECT. The 10-volt sine wave indicates 5 volts positive amplitude. The 6-volt bias will cancel this out leaving 1 volt. Adding the 6-volt bias to the 5-volt portion of the sine wave gives 11 volts. So the grid voltage will vary between 1 and 11 volts.

150

122 A sawtooth waveform represents the current in a circuit in which DC voltage was applied and immediately removed. Review para 2e.

123 Ebb represents the supply voltage. Check para 4g and fig 22 again.

124 Do not confuse neutrons with protons. Have another look at para 2e.

125 CORRECT. This is in accordance with the old law of repulsion and attraction.

127 Periodic waves appear at regular intervals. Please read para 1b again.

128 CORRECT. A crystal diode can control the direction of current flow just like an electronic tube diode.

129 CORRECT. This must be true since like poles repel each other.

130 Partially true. Remember, we are discussing a single crystal. Take another look at para 8b.

131 CORRECT. Since a time constant is considered to be 63.2 percent of a total change caused by a step voltage, 36.8 percent remains. When 1 volt is first applied to the circuit, 1 volt will appear across the resistor. By the time 1 time constant has passed, 36.8 percent appears across the resistor. The remaining 63.2 percent will appear across the capacitor.

133 There is a type of atom that has only one electron and one proton. Check para 2e again.

134 CORRECT. $I = \frac{E}{R} = \frac{26.0}{50.} = 0.52$ amp.

136 CORRECT. The effective value is 0.707 times the peak or maximum value, so, Eeff = 0.707 Em or $\frac{Eeff}{0.707} = \frac{115}{0.707} = 162$ volts.

138 CORRECT. Since the value of the resistors is the same, we can find the effective resistance by dividing the value by the number. ($\frac{80}{2} = 40$; so, $I = \frac{E}{R} = \frac{240}{40} = 6$ amps.)

139 CORRECT. A suppressor grid is placed between the screen grid and the plate. It passes the high speed electrons from the control and screen grids but stops the low speed electrons from secondary emissions.

140 An electron tube does offer resistance to current flow; however, this is not the complete story. Read para 1b again.

141 Think of inductance as the inertia of an electrical system. Remember that every conductor that carries an electrical current is surrounded by a magnetic field. Review para 3a.

142 CORRECT. This symbol indicates two main elements: a cathode and a plate.

143 Not quite true. Check para 3b and try another choice.

144 CORRECT. GM is transconductance in MHO's while Rp is plate resistance in ohm's.

145 The larger the amount of resistance the more power is consumed. Have another look at para 5c.

146 There was a vacuum tube in use at one time that had four elements and was called a tetrode; however, it is now obsolete. A transistor normally does not have this many elements. Please check para 9a again.

147 Inductance is shown by a different symbol. Please read para 2b(1)(a) again.

149 The control grid of an electron tube controls amplification. Review para 5a and try another choice.

150 The rate of increase of current is what determines the strength of the induced EMF. Remember, the induced EMF is always in a direction so as to oppose the change of current that caused it. Please read para 3b(6).

152 Remember, like poles repel—unlike poles attract. Read para 5j(1)(c) again.

154 Since we know the reactance of the coil and the current value we can use Ohm's law to find the voltage. Check para 3d and try another choice.

156 CORRECT. In this type of cell an electrode is consumed during use.

157 CORRECT. However, a small change in input voltage causes a large change in collector current.

158 CORRECT. The positive charges in this case are considered to be holes and though they are attracted to the negative terminal they never leave the transistor.

159 This is a resistive-capacitive circuit, so to find the time constant you must multiply the resistance by the capacitance, or $T = RC$, $T = 10^2 \times (10^3 \times 10^{-6}) = 10^{-2}$ seconds. This is not the shortest time constant. Check para 2c and 3c.

161 If you will think about the operation of a capacitor you will see that this is not true. Check para 4j and try another choice.

162 Of the three crystals in a transistor one is much thinner than the other two; however, it is not the collector. Take another look at para 12b(1).

163 At times the arrow might point to the base element, but this is not its purpose. Please read para 13b again.

164 Remember the rule for resistance in a parallel circuit. The total resistance is always less than the smallest resistance in the circuit. Please read para 4d(3) again.

166 What we are looking for is a substance composed of two or more elements. A special name is used. Check para 2c(2) again.

167 Circuit No 2 is a series-parallel circuit and must be reduced to a simple equivalent circuit before it can be solved. Please read para 4e again.

168 Remember, the arrow always points away from the direction of current flow. Please read para 13b and check fig 19.

169 CORRECT. The greater the load resistance, the more linear the dynamic characteristics become.

170 If AC and DC are applied to a capacitor, the AC will be passed and the DC will be blocked. A more positive answer can be found in para 4a.

171 An electron has a negative charge. Take another look at para 6b.

172 CORRECT. By the same token a charging RC circuit is considered fully charged at 7 time constants.

173 This procedure could be used when the inductors are connected in parallel but not when they are connected in series. Check para 3f(1) again.

175 The procedures used for determining the effect of capacitors in series is the same as those used to determine the effect of resistors in parallel. Reread para 4i(1) before making another selection.

177 CORRECT. According to Ohm's law $I = \frac{E}{R}$, so $I = \frac{110}{50} = 2.2$ amps.

178 CORRECT. Matter exists as a solid, liquid, or gas.

179 CORRECT. This is governed by the type, length, and diameter of the material.

181 The time constant is equal to the resistance in ohms times the capacitance in picofarads. Please read para 2c again.

183 CORRECT. Three grids plus a cathode and a plate make five main elements; thus the word "pentode."

184 CORRECT. To solve this problem we say the capacitive reactance is equal to the reciprocal of two times pi (3.1415), times the cycle per second, times the capacitance, or $xc = \frac{1}{2\pi FC} = \frac{1}{2(3.14)(60)(14.5 \times 10^{-6})} =$ 183 ohms.

186 CORRECT. As we already learned one time constant is 25 μsecs. According to the time constant chart the current reaches a maximum value or steady state after 7 time constants. So, 7 x 25 = 175 μsecs.

188 This is a unit of measure for electrical power. Take another look at para 3f.

189 A neutron is an uncharged particle of an atom and is not involved in current flow. Read para 12d again.

190 CORRECT! This is the principle of operation of all types of inductors.

191 CORRECT. This is how a battery produces electricity.

192 Not quite true. Check para 5k(2) for a better understanding of a magnetic force field.

193 CORRECT. This method employs the use of heat to produce a stream of electrons.

194 This would be an undesirable trait. Check para 3b again.

195 Remember, this is a parallel circuit. Take another look at para 4d(2).

196 One of the main advantages a transistor has over a vacuum tube is its long life expectancy. Read para 4b again.

197 A compound is composed of two or more unlike elements. Take another look at para 2c.

198 AC plate resistance equals the small change in plate voltage divided by the small change in plate current. Read para 3e(2) again.

199 CORRECT. Since 25 μsecs is equal to only 1 time constant, the current is still increasing. Therefore, the magnetic field is increasing also.

200 The effective value of AC is the equivalent DC value. Take another look at para 2h(1).

202 CORRECT. When the switch is opened current attempts to continue to flow. This builds up a high voltage which eventually will cause the current to jump across the open switch. The resistor provides a path for the current and prevents arcing at the switch.

204 Natural magnets are made of such material as magnetite which has been magnetized by nature. Better magnets can be made artificially. Check para 5c(1).

205 Answering this question does not require any calculation since there is a rule that states the action of voltage in a parallel circuit. Check para 4d again.

206 This question was partially solved in question 55. Review this question and also para 4e.

207 CORRECT. The total resistance of a parallel circuit is always less than the value of the lowest individual resistance.

209 CORRECT. The screen grid is similar to the control grid and is placed between the control grid and the plate. The resulting tube is called a tetrode.

210 CORRECT. That is why in a pure capacitive circuit the voltage will lag the current by 90°.

212 CORRECT. Since the voltage is decreasing, curve B of the time constant chart (fig 2) will apply. Thus, 75 μsecs represents 3 time constants $T = L/R = (25 \times 10^{-3})/10^3 = 25 \times 10^{-6} = 25$ μsecs or 1 time constant. 75 μsecs = 3 time constants. The chart shows that at 3 time constants, 5% of the voltage is across the inductor, so .05 x 20 = 1.0 volt.

213 A path must be available before current can flow. However, something else causes it to flow. Please read para 4a.

214 The majority changes move in a forward biased diode but not in a reversed bias diode. Please read para 11d again.

215 Copper is not a suitable material for the core of an electromagnet. Please read para 5m again.

216 CORRECT. The formula for determining transconductance is the same as that used to determine resistance. However, to avoid confusion, the unit of measure for resistance (OHM) is reversed (MHO) when determining transconductance.

217 CORRECT. The grid should be biased to insure that it will remain negative. The range of voltage applied to the grid is known as the operating point.

218 CORRECT. In order to calculate the wattage we need to know the current. So, using Ohm's law, $I = \frac{E}{R} = \frac{110}{55} = 2$ amps. We now can use this formula to find the wattage: $P = E \times I = 110 \times 2 = 220$ watts.

219 This is a partially correct answer. Check para 5b for the complete story.

220 Actually, induction is produced in a DC circuit in the same way that it is produced in an AC circuit. Please read para 3a.

221 A heat sink would not have any effect on the solder connection. Take another look at para 21c.

222 Do not confuse induction with capacitance. Read para 3b again.

223 A proton is a negatively charged unit of an atom. Please read para 2c(5) again.

224 CORRECT. This will allow the plate family graph to show the effects of small changes of plate voltage and fixed changes of grid voltage.

225 The opposition in a coil is measured in ohms the same as resistance; however, it has another name. Please read para 3d again.

226 Almost any electrical component can be tested in some way. Check para 22a again.

227 As shown in question 54, circuit No 2 is a series-parallel circuit and must be reduced to a simple series circuit in order to arrive at the unknown values. Check para 4d again.

228 A capacitor does not affect current the same way as it does voltage. Please read para 4j again.

229 CORRECT. The space charge causes most of the electrons to return to the cathode with only the necessary ones being used.

231 Perhaps you do not fully understand the formula used to find the intensity of a force field. Check para 2b(2) again.

233 The ratio of charge to the voltage causing it is always constant. Please read 4f again.

235 CORRECT. Voltage is actually the difference in potential between two points.

236 CORRECT. Since amber is a nonmagnetic material it would not attract a magnetic material such as iron.

237 Not exactly true. Review para 11c and try another choice.

238 An electrostatic charge is associated with a capacitor,-not an inductor. Please read para 3d again.

239 CORRECT. Since R5 and R6 are 120 ohms each, we can combine their resistance by using the like method. $RT = \frac{1 \text{ resistor}}{\text{No of resistors}} = \frac{120}{2} =$ 60 ohms. Resistors 3 and 4 are in series so we can add them giving us 60 ohms. We now have 3 parallel resistors of 60 ohms each. Using the like method $(\frac{60}{3} = 20)$ we have reduced the parallel resistances to an equivalent of 20 ohms. Resistance R1 is in series so we add that to our parallel resistance; i.e., $R1 + RT = 10 + 20 = 30$ ohms total resistance.

241 A nucleus is part of an atom. Check para 2c(3).

242 CORRECT. Though they are smaller, protons are much heavier than electrons.

243 There are not this many basic kinds. Please read para 2a(1) again.

244 Another name for a transistor is semiconductor. Take another look at para 5a.

245 Capacitors do not respond to AC in the same way as inductors. Please read para 4h again.

247 CORRECT. In this case, the current is increasing so curve A of the time constant chart will be used. The maximum current is $I = E/R = 20/10^3 = 2 \times 10^{-3}$ or 20 ma as shown in question 98. Thus, 50 μsec = 2 time constants. The time constant chart shows that the value at 2 time constants is 87 percent; so $87 \times 20 = 17.4$ ma.

248 Since the electrical charge on a proton or electron is too small to be measured practically, the couldmb was developed as a unit of measure. However, it does not equal the charge of 6.0×10^{18} protons. Check para 2g(1).

250 Unlike a capacitor, an inductor responds instantly to a change in voltage. Take another look at para 3b.

252 Plate resistance is not considered when constructing a loadline. Review para 4g(1) and try another choice.

253 CORRECT. It is also considered a permanent magnet.

254 A transistor called an oscillator can be used for this purpose but not one diode by itself. Please read para 9b again.

255 CORRECT. An electric field is present between the cathode and plate. If the plate is positive with respect to the cathode, electrons will flow from the cathode to the plate; however, if the plate is negative with respect to the cathode, the electrons will be repelled by the electric field.

256 CORRECT. EMF (voltage) is what provides the force necessary in an electrical circuit.

257 Inductance is that electrical property that tends to resist a change in current. Some inductors are specifically designed for this purpose and are called "chokes." Please read paragraph 1 again.

258 A vacuum tube presents an infinite resistance to current flow in one direction and a variable resistance to current flow in the opposite direction. Please read para 4f(1) again.

259 When measuring voltage, the correct polarity must be observed when connecting the voltmeter. Check para 4c again.

260 The ammeter will indicate the effective current. Please read para 2h(4) again.

262 CORRECT. The time constant is 50 μsec. 20 μsec is 2/5th of a time constant. Since the voltage will be decreasing, use curve B of the time constant chart (fig 2). You will find that 2/5th of a time constant equals 0.67 percent of the applied voltage; i.e., 0.67 x 30 (applied voltage) = 20.1 volts.

264 Remember that a magnet has two unlike poles. One attracts and the other repels. Check para 5k(2).

266 The resistor is provided for a special purpose. Check para 3b(2) again.

268 This is a partially correct answer. Check para 3b.

270 Actually, the collector current will increase which, in turn, affects the output voltage. Check para 15c.

271 The average voltage is never as much as the maximum voltage. Take another look at para 2h(3).

273 Beside the grids, a pentode tube contains other elements. Please read para 5b again.

274 This term could be used to define an atom though it would not be true in all cases. Check para 4f.

275 The transconductance of a tube is very important and is commonly used to compare tubes. Check para 4f(3) and try another choice.

276 CORRECT. This is always true when charging by induction.

277 This metal does have a high conductivity but not the highest. Please read para 3g(2) again.

278 "Storage battery" is the term normally used for a group of wet cells such as the automobile battery. Check para 4e(1).

279 CORRECT. They are used in the same way as gallons per minute is used to indicate the flow of water through a pipe.

281 CORRECT. A resistor dissipates energy as heat while a capacitor stores it in the form of an electrostatic charge.

282 To calculate the average value of alternating current you need only consider one-half of a cycle since the other half is of exactly the same magnitude but different polarity. Please read para 2h(3) again.

284 A series circuit is a rather simple circuit where the current value is the same throughout. Please read 4d again.

286 Any change in the resistance or capacitance has to affect the time constant. Please read para 2c again.

287 Though most of the electrons pass through the base to the collector, a percentage of them are attracted to the positive voltage on the base. Please review para 12b(1).

288 This seems like a very large amount but it is not enough. Check para 2g(1) again.

289 Changing the strength of either of the charges will affect the strength of the force. Check para 2b(2) to see how.

290 CORRECT. If one was positive and the other negative they would attract each other.

291 A filament is used in some vacuum tubes as an emitter. In other tubes it is used as a heater. Please read para 4a again.

292 Actually, just the opposite is true. Check para 5d(1) and try another choice.

293 There are 102 known elements. Helium is one of these. Please read para 2c(2) again.

294 A few electrons are attracted by the positive voltage at the base; however, most pass through the base. Check para 12d.

295 Read para 5j(1)(c) to understand the effect of a magnetic field on a compass.

296 CORRECT. Voltage is an electromotive force. Thus the letter E is used.

297 In this type of crystal the majority charges are positive. Review para 11c and try another choice.

298 CORRECT. This is the only way to connect a voltmeter to an electrical circuit.

299 Actually, the electrolyte used in this type of cell is damp but it is classified as dry. Please read para 4e(1).

300 This is a partially correct answer. Review para 4e(2) and try another choice.

301 Sorry, but it requires a negative step voltage to collapse the magnetic field. Please have another look at para 3a and 3b.

303 The purpose of the getter is to maintain a good vacuum in the tube. Please review para 3d(1).

304 CORRECT. As we found out in question 54, the total resistance of circuit No 2 is 30 ohms. Now we need the total current, so $\frac{E}{R} = I = \frac{120}{30} = 4$ amps. Therefore, the voltage drop across resistor 1 is $IR = E = 4 \times 10 = 40$ volts.

305 CORRECT. This is the symbol for a PNP transistor.

306 Consider the sine wave as having 5 volts positive and 5 volts negative. Review para 4d(4) and try another choice.

307 CORRECT. The maximum instantaneous value is called the peak value.

309 CORRECT. Positive and negative.

310 CORRECT. A positive input signal added to the positive base voltage causes the collector current to increase. Higher collector current causes the output voltage to drop.

311 An ammeter placed at point A in circuit No 1 would indicate the total amperage of the circuit. Please read para 4d(1) again.

313 CORRECT. Alternating current is always changing in magnitude and direction. Direct current changes in magnitude at the precise moment the circuit is opened or closed. For example, the circuit through an automobile coil primary winding is opened and closed by the points thus causing induction.

316 CORRECT. The total resistance in a series circuit is equal to the sum of the individual resistances.

318 CORRECT. $T = RC; T = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

320 CORRECT. Forty volts dropped across the first resistor leaves 80 volts to be dropped across the second resistor. Since this is a series circuit, the current will be the same or 0.2 amperes. So $R = \frac{E}{I} = \frac{80}{0.2} = 400$ ohms.

321 There is no collector-to-ground voltage. Check para 18c and try another choice.

322 CORRECT. Like an electron tube, a transistor functions as a valve to control current flow.

323 To solve this circuit, it must be reduced to a simple circuit. Do this by starting with the branches farthest away from the voltage source. Check para 4e again.

324 These are units of measure that indicate the resistance of an electrical circuit. Check para 2a again.

326 CORRECT. A hydrogen atom consists of one proton and one electron.

328 As learned in previous questions, the time constant for circuit No 2 is 25 μsecs. Since the current is increasing, curve A of the time constant chart will tell us when the steady-state occurs. Please read para 3b and 3c again.

329 This is a partially correct answer. Review para 2b(2) and try another choice.

330 CORRECT. And one coulomb moving across a cross section of a conductor in one second is equal to one ampere of electrical current.

331 CORRECT. Also, the higher the plate voltage, the more negative voltage required on the grid to reach cutoff.

332 CORRECT. Any wave that does not follow the sine wave pattern is considered nonsinusoidal. Because there is a difference in time between the positive and negative voltages, this particular wave is considered a periodic.

333 Free electrons are necessary to provide electrical conduction. Check para 3c again.

334 The control grid allows the tube to function like a valve in controlling the flow of electrons; thus controlling the instantaneous value of current. Take another look at para 5b.

335 CORRECT. The AC resistance in ohms is rp; Δep is a small change in plate voltage in volts; and Δip is a small change is plate current in MA.

336 Matter is defined as anything that has weight and occupies space. Please read para 2c again.

337 The base-to-collector is usually reverse biased. Check para 12a again.

338 Application of heat is the primary means of producing electron emission and is called thermionic emission. Take another look at para 2c.

339 CORRECT. Formula $C = \frac{Q}{E}$ is used to calculate capacitance where C = capacity, Q = the charge on one plate and E = the applied voltage. Thus $C = \frac{Q}{E} = \frac{0.2}{440}$ = 445 microfarads.

341 CORRECT. The current flow must be the same in all layers in order for the magnetic field to be effective.

342 In order to provide the desired results, the distance d must be squared. Please read para 3c(2) again.

344 The instantaneous value of alternating voltage or current is the exact value at a particular instant in time. Please read para 2h(4) again.

346 The smaller case letter "e" is used to represent something other than external voltage. Please read para 4e and try another choice.

347 The magnetic force of both poles is the same. Please read para 5f.

348 The emitter is about the same thickness as one of the other crystals. Review para 12b(1) and try another choice.

349 An ion can be the size of an electron, an atom, or a molecule. Please read para 4f again.

350 Remember that current is the same throughout a series circuit but is divided among the different branches of a parallel circuit. Review question 55 and check para 4e again.

352 A motor constructed to withstand this much voltage would operate satisfactorily; however, its cost would be higher than necessary. Take another look at para 2h(4).

353 In one type of transistor the positive charges are the main current carrier. Better read para 8a(3) again.

354 Electrons constitute the main current through an NPN transistor. Please read para 12d again.

355 At zero time constant, the change has just started. Review para 2d for a better understanding of RC circuits.

356 Actually, copper is heavier than most other conductors. Check para 3g(1) again.

358 An electromagnet would be an artificial type. Check para 5a again.

359 Partially true. Review para 17e for a more positive answer.

360 Capacitance is defined as that property of an electrical circuit that tends to oppose a change in voltage. Check para 4c(3).

362 Someday there might be this many known. Check para 2c(1).

363 CORRECT. Inductive reactance affects voltage the same way as resistance. So, Ohm's law can be used to determine the voltage, or $E = IXL = 10,000\ (2.5 \times 10^{-3}) = 25$ volts.

364 CORRECT. A hole is present because an electron is missing. Since an electron is a negative charge, we can consider the hole left by the electron as a positive charge.

365 CORRECT. Two curves, one above and one below the horizontal axis, represent a complete electrical cycle.

367 A short circuit is undesirable because a portion of the intended circuit path has been bypassed. Read para 4d again.

368 CORRECT. The higher the value of transconductance, the greater the signal output will be.

369 A neutron does not have any charge. Check para 2g(1) and try another choice.

371 The magnetic field would collapse if a resistor was present or not. Please read para 3b(2) again.

372 CORRECT. Henries are the units of measurement for inductance. The inductance of a circuit in which a current change of 1 ampere per second causes an EMF of 1 volt is equal to 1 henry.

374 This is an RL circuit so in order to find the time constant the inductance is divided by the resistance. ($T = L/R$, $T = 6 \times 10^3 \times 10^{-6}/3 \times 10^{-5} = 2 \times 10^{-5}$.) This is not quite the shortest time constant. Please read para 2c and 3c again.

375 Two or more elements combined would be a combination of elements; however, there is a special name for substance of this nature. Please read para 2c(2).

376 CORRECT. Since the same voltage is applied to all branches of a parallel circuit, the voltage across the 250-ohm resistor will be the same as that across the 400-ohm resistor or 200 volts.

378 The neutral body would become the same polarity as the charged body. Check para 2h.

379 A magnet will not lose its magnetism just because it is broken in half. Check para 5e(2).

380 The material used in the construction of transistor crystals determines if they are positive or negative. Review para 5a and try another choice.

381 This is not really a good description of an electron tube. Take another look at para 1b.

382 If you will read para 2a you will see that all material is either magnetic or nonmagnetic.

384 This method requires the use of very high voltages and because of this it is not commonly used. Review para 2 and try another choice.

385 They are alike to a certain extent since they both oppose something in an electrical circuit. Please read para 4a again.

386 CORRECT. Current flow is always opposite the direction the arrow is pointing.

387 CORRECT. The time constant equals the resistance times the capacitance: $T = RC = 10^6 \times (50 \times 10^{-12}) = 50 \times 10^{-6} = 50\ \mu sec$.

388 CORRECT. The first electron tube that could amplify voltages was developed in 1907 and was called a triode.

389 A switch is represented by quite a different symbol. Check para 2b(1)(a) and try another choice.

390 CORRECT. The larger the cross sectional area of the conductor, the less will be its resistance.

391 If this were true the atom would not be balanced. Check para 2g(1).

392 This is not always true. Check para 3a and try another choice.

393 CORRECT. This is the symbol used to represent resistance. The value in ohms might be shown by the Greek letter Ω (Omega).

394 This metal is the most widely used for electrical conduction. However, this is partially due to its low cost. Please read para 3g(2).

395 Life expectancy is a very important consideration in the application of any electronic device. Review para 4b and try another choice.

396 This might seem logical; however, when solving the formula for determining the Force Field, the square of the distance is used. Please read para 3c(1) again.

397 CORRECT. Cells of this type are usually discarded when they are discharged.

398 Remember, the load resistance is not changing with the changing plate current. Check para 3e(3) and try another choice.

399 One of the characteristics of a diode is its ability to act like a control valve by allowing or blocking current flow. Review para 3c and try another choice.

400 The effective value of a 115-volt line could easily surge to 125 volts with the peak value somewhat higher. Please read para 2h(4) again.

401 CORRECT. Transistors are made of sensitive material. A heat sink will absorb most of the heat before it reaches the transistor.

402 CORRECT. This particular symbol indicates a multicell battery.

403 Not quite true. Read para 4b(1) and try another choice.

404 CORRECT. In some materials an electron being emitted by kinetic energy will strike another electron causing it to gain enough momentum to escape the emitter.

405 A capacitor acts like a storage battery and tends to store voltage. Take another look at para 4h.

406 CORRECT. In the NPN transistor there are a few electrons that do not penetrate the base but are attracted to the positive base voltage. However, most electrons move from the emitter through the base and to the collector.

407 The wattage output of any electrical appliance is directly related to the voltage and resistance. Please read para 5c again.

408 Remember that resistance is an opposition to the flow of current. Please read para 3a again.

409 Current is the flow of electrons through a conductor. Check para 3e again.

410 The initial voltage will be 20 volts; however, across an inductor the voltage decreases as time progresses. Check para 3b and fig 2 again.

411 Plate resistance is the ratio of a small change in plate voltage to the corresponding change in plate current. Review para 3e(2) and try another choice.

412 This will affect current flow from a battery but it does not cause a battery to operate. Please read para 4f again.

414 You should understand the functioning of an inductor better if you will take another look at para 3b(2).

415 Two methods can be used to solve this circuit; the reciprocal method or the product divided by the sum method. Read para 4d(3) again.

416 CORRECT. Each will have a north and south pole.

417 This formula is Ohm's law for finding the current when only the voltage and resistance are known. Check para 5b and try another choice.

418 Not quite correct. Check para 8b and try another choice.

419 Both ER and EL cannot increase or decrease at the same time. Take another look at para 3b.

420 All electrically charged bodies affect each other in some way. Please read para 2b(1) again.

421 In order to be useful, there must be more than this. Check para 2a(1) again.

422 In order to find the total current we must first find the total effective resistance. Review para 4d and try another choice.

423 CORRECT. The north pole of the magnet attracts the south pole of the compass, and the south pole of the magnet attracts the north pole of the compass.

424 Any external flow of current requires the movement of electrons which are negative charges. Please read para 8a(3) again.

425 Eighty volts would be dropped across R3 and R4. Review question 55 and check para 4e for help in solving the problem.

426 CORRECT. If a negatively charged body were used, the electrons would flow from it to the neutral body.

427 CORRECT. This will provide uniform test results.

429 This is true for the strength of the charges but not for the distance. Check para 3c(1).

431 CORRECT. Counter EMF created by applying voltage to an inductor opposes any change in the flow of current.

432 The size of the cross sectional area of a conductor and its length determine the resistance. Check para 3f again.

434 Inductance in a circuit tends to oppose or slow down the rate of change (increase or decrease) of current flow. Please read para 3b(6) again.

435 A diode has two parts; however, a transistor has more. Read para 9a again.

436 The operating point is governed by something besides the plate supply voltage. Please read para 4g(1) and try another choice.

437 CORRECT. Free electrons in a conductor provide electrical conduction. The greater the number of free electrons, the easier it will be for the current to flow.

438 The farad is the unit of measure for capacitance. Please read para 4f(3) again.

439 CORRECT. At first the voltage across the resistor will be at maximum but will decrease as the electrostatic charge in the capacitor decreases.

440 Think of a capacitor as an elastic body such as a spring which offers little opposition to an applied force at first but provides increasing opposition as it is compressed or extended. Please read para 4c(3) again.

441 Not quite true. Review para 13b and take another look at fig 19.

442 In order to solve this problem you must know the total current of the circuit. Refer back to question 54 and para 4d.

444 Usually one does not think of induction in connection with direct current. However, an automobile coil operates on the principle of induction and direct current. Please read para 3a.

446 Stopping of the current will cause the magnetic field to collapse. Please read para 3b(2) again.

447 Allowing secondary emissions at the plate is one of the undesirable characteristics of the screen grid. Please read para 5a again.

448 CORRECT. Capacitance opposes a change in voltage while inductance opposes a change in current.

449 The megger is actually a type of DC generator used to test the resistance of electrical insulation. Please review para 22a.

165

450 Mutual conductance is the ampere changes in plate current for each 1-volt change in grid voltage. Take another look at para 4f(1).

451 To solve this problem you must use some of the information gained in question 98. Check para's 3b and 3c.

452 This is true when charging by contact but not when using the induction method. Check para 2i again.

453 Not quite true. Please read para 18c again.

454 Remember, the time constant equals the resistance times the capacitance. Check para 2c and fig 2.

457 Because copper has a high tensile strength is one reason why it makes a good conductor, especially in transmission lines. Check para 3g(1) again.

459 At this period of time the capacitor is not fully charged so current has to be flowing. Take another look at para 2b.

460 CORRECT. The reactance of a capacitor is calculated from the formula $Xc = \frac{1}{2\pi FC}$.

462 The AC plate resistance is equal to the change in plate voltage divided by the change in plate current. Take another look at para 3e(2).

463 CORRECT. Therefore, we could say that matter is anything and everything except a vacuum.

464 CORRECT. In fact the current flow is so small it is considered to be zero.

465 The flow of electrons or current is measured in amperes. Read para 4a again.

467 Remember that rp is AC plate resistance while μ represents an amplification factor. Please read para 4f(4) again.

468 Recall the rule for current in a series circuit. The same current flows throughout the circuit. Check para's 3b and 4a.

470 Not quite true. Check para 5b and try another choice.

471 In this case each layer would tend to cancel the effect of the other. Have another look at para 5m.

472 In previous lessons you learned that unlike charges attract and like charges repel. Please read para 7c again.

474 The henry is a unit of measurement of the inductance of a coil. Please read para 3d again.

475 CORRECT. In a reverse biased diode the electrons are in the minority. Since there are only a small amount, very little current can flow.

476 Adding a load to the plate will add a voltage drop, making two voltage drops in the plate circuit. The sum of these voltage drops must equal the supply voltage. Read para 4g and check fig 22.

477 This symbol is used to show inductance in a circuit. Check para 2b(2) again.

479 CORRECT. The plate voltage at zero plate current is one starting point of the loadline.

480 This type of circuit does not have a magnetic field. Please read para 2e again and try another choice.

482 Steel has a high retentivity and therefore is not suitable for use in relay electromagnets. Check para 5m again.

483 CORRECT. If a molecule is reduced in size, the substance is changed.

484 Usually a difference in potential is what causes electrons to flow. Read para 3c again.

485 Silver is a metal composed of a single element. Not like steel which is composed of iron and other elements. Check para 2c(2).

486 CORRECT. There are always the same number of electrons as there are protons.

488 This would be true for resistors but not for capacitors. Please review para 4i again.

490 CORRECT. This is all that is known at present.

491 This would be called current—not resistance. Please read para 3f again.

492 Though they are smaller, neutrons do have a larger mass than electrons. Check para 2g(2) again.

493 Soft iron does not make a good permanent magnet since it does not have much residual magnetism. Please read para 5c(1) again.

496 CORRECT. All generators depend upon this characteristic in order to produce electricity.

497 The current is directly related to the voltage and the resistance. Please read para 4c(1) again.

498 CORRECT. The total current of a parallel circuit is equal to the sum of each branch. $I_t = I1 + I2 + I3 + I4$; therefore, since applied voltage is 24V, $I1 = \frac{24}{4} = 6$ amps; $I2 = \frac{24}{6} = 4$ amps; $I3 = \frac{24}{8} = 3$ amps; and $I_t = 6 + 4 + 3 + 2 = 15$ amps.

499 CORRECT. Therefore, there is little current flow.

500 Every magnet must have two poles. Please read para 5e(2) again.

501 This is a term used for the measurement of electrons. One coulomb contains over 6.28×10^{18} (quintillion) electrons. Please read para 3e again.

502 CORRECT. With the tube not conducting there is no voltage drop across the load; therefore, the entire voltage will be dropped across the plate.

503 A pentode tube does have a screen grid. It is used to reduce the capacitance that is present between the plate and the control grid. Review para 5b and try another choice.

504 This formula would be used to find the voltage of a circuit. Please read para 5b again.

505 This would be true if resistance R1 was the only resistance in the circuit. However, there are three others that must be considered. Check para 4d(1) again.

506 CORRECT. Due to its construction, the life expectancy of a transistor is much longer than that of a vacuum tube.

507 A resistor dissipates energy in the form of heat; it does not store it. Check para 3d and try another choice.

508 Since the two resistors are of equal value it is fairly easy to find the total current. Please review para 4d again.

510 At times this might be true. To understand charging by induction fully, read para 2i.

512 For all practical purposes an electrical circuit does not store energy in the form of heat. Please read para 2e again.

513 CORRECT. This would have the same effect as opening a switch in the circuit without a resistor.

514 CORRECT. However, care must be taken not to introduce more than 1 ma of current through the transistor or it will burn out.

515 CORRECT. By the same token the small case letter "i" is used to indicate the instantaneous current.

516 The voltage is not used to find the capacitive reactance of a capacitor. Please read para 4h again.

518 The time constant is equal to 63.2 percent of the total change caused by application of a step voltage. Take another look at para 2c.

520 The rule governing voltage in a parallel circuit is quite different than that used for a series circuit. Please read para 4d(2) again.

521 CORRECT. That is why an atom is always balanced.

522 A primary cell is the type that is used in most flashlights. Check para 4e(1).

168

523 Not completely true. Check para 3c and try again.

524 Actually, paper would be attracted by a piece of amber. Check para 2a again.

526 In a fixed capacitor, the amount of capacitance remains the same regardless of a change in voltage. Take another look at para 4f.

527 All substances are made up of atoms; however, an atom cannot exist by itself. Please read para 2c(3) again.

528 As discussed in previous lessons, the ohm is the unit of measure for resistance. Take another look at para 4f(3) and try another choice.

529 CORRECT. There are 102 known elements. All matter is made up of one or more of these elements.

531 In fact, the peak value of an alternating current is the maximum instantaneous value. Please review para 2h(4).

532 Higher input voltage does not increase the output voltage. Please read para 15c again.

533 CORRECT. Using the reciprocal method, $RT = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4}}$ or,

$$RT = \frac{1}{\frac{1}{4} + \frac{1}{6} + \frac{1}{8} + \frac{1}{12}} = \frac{1}{\frac{15}{24}} = 1 \times \frac{24}{15} = 1.6 \text{ ohms.}$$

534 CORRECT. This is the reason transistors are called semiconductors.

535 The current through the circuit will gradually decrease when the battery is switched out of the circuit. Take another look at para 3b(2).

536 CORRECT. Voltage is the term used to indicate potential difference.

537 Actually, resistance impedes the current flow. Check para 3t again.

539 Chemical action is what generates electricity in a storage battery. Please read para 3g(2) again.

541 Neutrons and protons have about the same mass and are about the same size. Check para 2g(2) again.

543 CORRECT. Since 50 μsec is the time constant, 500 μsec represents 10 time constants and the voltage across the capacitor will be equal to the full applied voltage of 30 volts.

545 Finding the resistance in a parallel circuit is quite different from finding that in a series circuit. Please read para 3d(5) again.

546 In some respects a capacitor functions somewhat like a storage battery. Please read para 1 again.

547 CORRECT. The polarity of the point being tested would determine which sign, plus or minus, would be used.

548 Natural materials such as germanium and silicon are usually used in the construction of transistors. Check para 5b.

549 Current is affected by inductors but not by capacitors. Please read para 3j again.

551 Since we already know what a time constant is for circuit No 2, this problem is not too difficult to solve. Check para's 3b and 3c and fig 2 again.

553 CORRECT. A resistive circuit is said to have an ideal transient response.

555 The peak value is the maximum value. Check para 2h(1) again.

556 In order for an electron tube to be used as a mixer, it must have more than two electrodes. Take another look at para 3a.

557 This answer is partially correct. Check para 1b and try another choice.

558 Application of a load will change the tube characteristics from static to dynamic. Take another look at para 3e(2).

559 CORRECT. The only difference in computing the induction and the resistance in a circuit is the unit of measurements used.

560 There is no biased voltage from the emitter to the collector. Check para 12a again.

561 At first glance this might appear true; however, remember that the time constant is equal to the product of the resistance and capacitance. Take another look at para 2c.

562 The effect that charged bodies have on each other is the basis used in the construction of motors and generators; however, two positive charged bodies do not attract each other. Read para 2b(1) again.

563 The atoms in a conductor do have something to do with its resistance to an electrical current. But a better answer can be found in para 3f.

565 CORRECT. The average value of alternating voltage or current is the average over one-half cycle or 0.63.7 times the peak value. So V avg = 0.637 x V m = 0.637 x 770 = 490.49 V.

567 CORRECT. An ammeter indicates the effective value which is 0.707 times the peak value.

569 CORRECT. Because an electron tube can slow or increase the flow of electrons it can be compared to a valve.

570 This symbol represents a generator or motor. Take another look at para 2b(2).

571 In a sense this is correct; however, negative charges are not always in the majority nor are they always in the minority. Take another look at para 11c.

572 One of the rules of magnetism is that unlike poles attract each other. Check para 5f again.

573 The size of the cross section area of a conductor greatly affects its resistance; however, in this case, it would not be doubled. Check para 3f.

575 CORRECT. Using the formula E = L di/dt (where E is the voltage, L, is inductance, and di/dt is the rate of current change), we can say that the voltage divided by the inductance equals the rate of current change in amperes. $\frac{E}{L} = di/dt = \frac{24}{3} = 8$ amps per second.

576 The output signal of the common emitter circuit is out of phase with input signal. Please read para 17e again.

577 CORRECT. A permanent magnet will retain its magnetism over a long period of time.

578 CORRECT. This is true because the force is equal to the product of the quantities of the two charges divided by the square of the distance between them.

579 CORRECT. The test charge will be acted upon by a charged body.

580 The rule for determining voltage in a parallel circuit is not the same as that used with a series circuit. Please read para 4d again.

581 Direct current always flows from negative to positive. Check para 5m and try another choice.

582 If this were true the atom would not be electrically balanced. Please read para 2e for a better understanding of the construction of an atom.

583 By itself the crystal diode does not amplify. Take another look at para 9b.

584 CORRECT. Direct measurements can be made with the voltmeter.

587 The first procedure in solving this problem is to find the maximum current. Take a look at para's 3b and 3c and fig 2.

589 CORRECT. Most of the electrons are traveling at a sufficient speed to pass through the thin base material and go to the collector.

590 CORRECT. An ammeter located at point A will indicate 4 amps, the total current in the circuit. Since we found the total resistance in question 54, we can use Ohm's law: $It = \frac{E}{R} = \frac{120\ V}{30\ ohms} = 4$ amps.

591 This is the symbol for current. Check para 4a and try another choice.

593 A cathode is the element that emits electrons. Check para 4a and try another choice.

594 This type of cell is a wet type and can be recharged electrically when it is run down. Take another look at para 4e(1).

171

595 A neutron is a part of some types of atoms; therefore, it must be classified as subatomic. Take another look at para 2c(5).

596 This might seem logical, but it is not true. Take another look at para 13b again.

597 Copper has 29 protons, 29 electrons, and 35 neutrons. Take another look at para 2e.

598 The base is simply a mount for the rest of the tube components. Check para 3d(1) again.

599 This symbol indicates two cathodes and one plate. It is not the symbol for a basic diode vacuum tube. Take a look at fig 2.

600 A flattop wave is used to portray DC voltage applied to a circuit until after the current has reached its maximum and remained there for a given time. Please read para 2e again.

601 CORRECT. At first the entire voltage is present across EL creating an EMF and preventing the flow of current. After a short time, the voltage at EL decreases and appears across ER.

602 CORRECT. This is one of three primary tube constants that must be considered when constructing tube characteristic curves.

603 The greater the resistance, the less will be the current. Check para 3a(2) again.

604 Not in an NPN transistor. Take another look at para 12d.

605 CORRECT. Dividing the inductance by the resistance we find the time constant $T = L/R$; $T = 4 \times 10^3 \times 10^{-6}/10^{-4} = 4 \times 10^{-7}$. This is the shortest time.

606 This is a little too many. Take another look at para 12b(1) and try another choice.

607 This is not a characteristic of an inductor. Please read para 3b again.

608 CORRECT. Voltage applied to a capacitor produces an instant current; however, due to the charging process, voltage buildup is delayed.

609 CORRECT. Two or more crystals must be used together to change the amount of current flow.

610 CORRECT. It is also used in voltage regulator power supply circuits.

611 If you will check para 2d and fig 2 you will see that this is not true.

612 CORRECT. A compound is made up of two or more different elements.

614 Because only 25 μsecs have passed since the application of the positive step voltage, the magnetic field must be changing in some way. Check para's 3a and 3b.

615 CORRECT. Power in watts is equal to the voltage multiplied by the current (amperes).

617 Volts are used to indicate the amount of electromotive force in a circuit. Please read para 2a again.

619 I think you are headed in the right direction. Make sure your mathematics are correct and check para 3b and fig 2.

620 A neutron is an uncharged particle of an atom. Review para 6b and try another choice.

621 The current can easily be calculated by using Ohm's law. Take another look at para 3a(2).

623 Resistance. The voltage divided by the current is one of the basic rules of Ohm's law; however, different symbols are used to represent the small values involved. Please read para 3e(2) again.

624 CORRECT. Capacitance is a kind of electrical inertia opposite in effect to inductance and similar to the property of elasticity in mechanical systems.

625 The symbol "E" is usually used to indicate battery potential. Check para 4e again.

627 CORRECT. Silver is a better conductor than copper; however, its high cost makes its general use prohibitive.

628 This would be true for a negatively charged body. Please read para 2h.

629 CORRECT. The total voltage is dropped across each resistance.

630 The item we are looking for contains many atoms. Check para 2c again.

631 The current value at point A would be the same as the entire circuit. Review question 55 and check para 4e again.

633 The loadline will indicate the grid bias voltage. Please read para 4g(1) again.

634 CORRECT. Since soft iron has low retentivity, it makes a good core for a relay electromagnet.

635 We could liken the potential of an electrical circuit to the pressure of a water system. Take another look at para 3e.

636 CORRECT. This is because the square of the distance is used when solving the formula.

637 CORRECT. Water is composed of two elements: hydrogen and oxygen.

638 The formula used to find resistance in a series circuit is much simpler than this. Check para 4b(1).

639 CORRECT. An ion must have either a negative or a positive charge.

640 Almost true. Review para 4d(4) and try another choice.

641 Protons are positive charged particles in the nucleus of an atom. Please check para 11c again.

642 This is what causes current to flow. Check para 4f again.

643 P is the symbol for power. In electrical circuits it indicates wattage. Please read para 4a again.

644 Remember, voltage across the resistor is at the maximum value when first applied; then gradually decreases until the capacitor is fully charged. Please check para 2c and fig 2.

645 CORRECT. Materials such as silicon and germanium are refined in as pure a state as possible and then contaminated with impurities to give them the desired characteristics.

647 CORRECT. However, due to its high cost, it is used only for special purposes.

648 This would be true for a series circuit but not for a parallel one. Check para 3d(5) again.

650 Not always true. It depends upon the plate voltage. Review para 4e(1) and try another choice.

651 The inductive reactance of a coil depends upon the frequency of the circuit and the inductance of the coil. Please read para 3d again.

653 A forward biased diode allows a large amount of current flow because the majority charges are moving. Take another look at para 11c.

654 In order to solve this problem the time constant must be found. Check para 2c again.

656 The value of each tube constant is determined by the operating voltage applied to the tube. Review para 4f(4) and try another choice.

657 CORRECT. A molecule contains a number of atoms. For example, a molecule of water contains two hydrogen and one oxygen atoms.

659 Not quite true. Check para 3b(2) and try another choice.

661 A test charge is used in the exploration of an electrical field but not to charge a neutral body. Please read para 3b again.

662 This is a shape of a magnet. Please read para 5a again.

664 This symbol is used sometimes to indicate a diode but not one of the vacuum tube type. Check fig 2 again.

665 A capacitor acts something like a storage battery. Please review para 3j and try another choice.

666 This method of emission uses a high electric field to attract electrons from the emitter. Review para 2c and try another choice.

667 As a rule this method is undesirable. Please read para 2 again.

669 If you will remember that current flow in a series circuit is always the same throughout the circuit, you should have no trouble solving this problem. Review para's 3b and 4a.

671 CORRECT. AC plate resistance is about one-half the value of DC resistance in almost all vacuum tubes.

672 CORRECT. This opposition acts like resistance to the flow of current and is measured in ohms.

674 The opposition of a capacitor to AC depends upon the frequency and the capacitance. Check para 4h again.

675 This should not happen if the correct soldering iron is used. Please read para 21c again.

676 CORRECT. A change in base to emitter voltage causes a change in the collector current.

677 CORRECT. We found out in question 55 that the voltage drop across R1 is 40 volts. That leaves 80 volts to be applied to each parallel leg. Since R3 and R4 are of equal value (30 ohms), one-half of the voltage applied to this leg will be dropped at R3. To solve this problem we need to know the current at R3. So, $I = \frac{E}{R} = \frac{80}{60} = 1\text{-}1/3$ amps, thus, $E = IR = 1\text{-}1/3 \times 30 = 40$ volts dropped across R3.

678 CORRECT. The reason for this is to make it easier for the electrons to pass through the base on their way from the emitter to the collector or vice versa.

679 This would be the correct way to connect an ammeter but not a voltmeter. Please read para 4c again.

680 This answer is partially correct. Check para 7c and try another choice.

682 The ammeter will indicate the effective current which is never as much as the peak current. Take another look at para 2h(4).

684 CORRECT. Since the two capacitors are of the same value, we can use the reciprocal method; i.e., $\frac{1}{C1 + C2} = CT = \frac{1}{1/16 + 1/19} = 8$ microfarads.

685 This formula is almost correct. Check para 3c(2) again.

687 Consider a negative step voltage as a removal of applied voltage. Take another look at para 2b(2).

688 Induction in a circuit is determined in the same way as resistance. Please read para 3f(1) again.

690 A test charge is used in exploring electrical fields. The same charge must be used in all tests in order to provide uniform results. Check para 3b.

691 As a rule it is not desirable for an electromagnet to have a large amount of retentivity. Check para 5d(1) again.

692 CORRECT. The transistor can be compared to the three element vacuum tube—the triode.

693 Voltage across the capacitor would be increasing not decreasing. Please read para 2b again.

694 Remember, the more resistance, the less current. Take another look at para 4c(1).

695 CORRECT. Therefore, it will take a positive voltage applied to the base to stop current flow.

696 There is something that tends to oppose voltage changes, but it is not inductance. Please read para 3a again.

697 Transconductance is also called mutual conductance and expresses the relationship between plate current and grid voltage. Read para 4f(3) again.

698 The grid does have a small voltage applied to it; however, it is not called the operating point on the loadline of the graph. Please read para 4g(1).

699 Any generation of electricity will produce a certain amount of heat. In this case heat is an undesirable byproduct. Check para 5k(2) again.

CORRESPONDENCE COURSE

of the

US ARMY ORDNANCE

CENTER AND SCHOOL

EXAMINATION

Ordnance Subcourse No 98 . . . . Fundamentals of Electricity

Credit Hours . . . . One

Lesson Objective . . . . To test your knowledge of all material presented in this subcourse.

Suggestions . . . . Before starting this examination, it is suggested that you review all lessons studied in this subcourse.

Texts . . . . All Attached Memorandums used in this subcourse.

Materials Required . . . . None

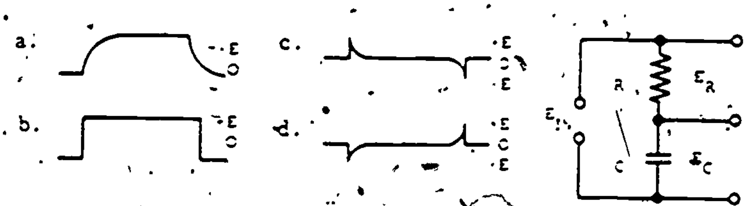
(Do not send these pages in—use the answer sheet provided for recording and mailing your solution.)

Requirement - 50 Questions - Weight 100 - All items are weighted equally.

MULTIPLE CHOICE

(See instructions on answer sheet provided)

1. What is the output waveform across the capacitor if a positive step voltage is applied to the circuit illustrated?



2. Which element will reflect the greatest space charge density?

   a. Screen grid
   b. Control grid
   c. Plate
   d. Cathode

3. What color code represents a 3,200-ohm resistor with a 10-percent tolerance?

   a. Red, orange, red, and gold
   b. Orange, red, red, and silver
   c. Orange, red, orange, and gold
   d. Red, orange, orange, and silver

4. What is the RC time constant, in seconds, of a circuit of R = 100K ohm and C = 0.00001 of a farad?

   a. 100
   b. 10
   c. 1.0
   d. 0.1

5. What factor does NOT affect the resistance of a conductor?

   a. Cross-sectional area
   b. Length of conductor
   c. Material of conductor
   d. Type of insulation

6. What are the MAJORITY-type charges in an N-type crystal?

   a. Electrons
   b. Holes
   c. Neutrons
   d. Protons

7. What current is indicated by an AC ammeter?

   a. Instantaneous
   b. Peak
   c. Effective
   d. Average

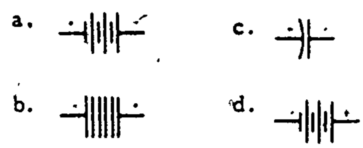
8. What BEST describes current flow in any circuit?

   a. Electrons
   b. Holes
   c. Protons
   d. Neutrons

9. Which output is produced if an AC signal is applied to the control grid of a triode tube?

   a. An alternating plate current
   b. A varying negative DC plate current
   c. A varying positive DC plate current
   d. A varying positive and negative plate current

10. Which symbol designates a properly connected battery?



11. In what direction do the majority charges move in a PNP transistor?

   a. Collector to emitter
   b. Emitter to collector
   c. Base to collector
   d. Base to emitter

12. In which circuit is the current the same value throughout the entire circuit?

   a. Parallel-shunt
   b. Series
   c. Series-parallel
   d. Shunt

13. What charge will attract a positive charge of electricity?

   a. Positive
   b. Negative
   c. Balanced
   d. Neutral

14. How will a capacitor respond in a circuit that has both DC and AC applied?

   a. It will act as a battery
   b. It will act as an open to both DC and AC
   c. It will block the DC
   d. It will block the AC

15. What is the phase relationship of the voltage and current in a pure capacitive circuit?

   a. Voltage leads the current by 90°
   b. Voltage and current are in phase
   c. Current leads the voltage by 90°
   d. Current lags the voltage by 180°

16. According to Coulomb's law, the force between two electric charges will vary inversely with the

   a. distance between them.
   b. substance between them.
   c. square of the distance between them.
   d. square of the potential between them.

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17. What unit is equal to a flow of electical charges at the rate of one coulomb per second?
    a. Ampere
    b. Farad
    c. Milliampere
    d. Volt

18. How is the time constant in an RC circuit affected if the value of the resistor is halved?
    a. Increased by one-fourth
    b. Increased by one-half
    c. Reduced by one-half
    d. Reduced by one-fourth

19. What happens to the energy in a series RL circuit if a steady flow is applied?
    a. Dissipated as heat and some stored as a magnetic field
    b. Dissipated as heat and some stored as an electrostatic charge
    c. Stored as both an electrostatic charge and heat
    d. Stored as both a magnetic field and an electrostatic charge

20. What material, if rubbed on a glass rod, will produce positive electricity?
    a. Cat's fur
    b. Wool
    c. Rat's fur
    d. Silk

21. Which alphabetical symbol represents current in a circuit?
    a. E
    b. C
    c. I
    d. V

22. What is one of the MOST important sources of voltage for military equipment?
    a. Batteries
    b. Converters
    c. Inverters
    d. Generators

23. Which type cathode is normally activated by heat radiation?
    a. Cold
    b. Directly heated
    c. Indirectly heated
    d. Hot

24. What is the value, in ohms, of a resistor whose color code is brown, black, and orange?
    a. 100
    b. 1,000
    c. 1,500
    d. 10,000

25. What will happen to the inductive reactance value if the frequency is doubled in an AC circuit?

a. Decrease by half
b. Remain the same
c. Increase twice
d. Increase four times

26. Why is copper a good conductor of electricity?

a. It contains many free electrons
b. It contains few free electrons
c. It has no negative charges
d. It has no positive charges

27. What BEST describes alternating current?

a. It periodically changes in magnitude and continuously changes in direction
b. It constantly changes in magnitude and direction
c. It periodically changes in direction and constantly changes in magnitude
d. It constantly changes in direction but not in magnitude

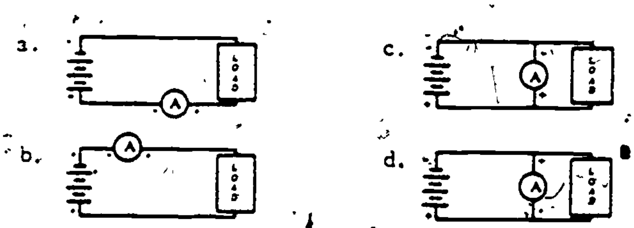
28. How many time constants constitute a fully charged capacitor?

a. 1
b. 3
c. 5
d. 7

29. Which formula is used to compute the AVERAGE VALUE of an AC voltage?

a. $E_{avg} = 0.707\ E_m$
b. $E_{avg} = 0.637\ E_m$
c. $E_{avg} = E_m : 0.637$
d. $E_{avg} = E_m : 0.707$

30. Which ammeter is connected properly to measure total current?



31. Which particles are found in the nucleus of an atom?

a. Electrons and protons
b. Electrons and neutrons
c. Protons and elements
d. Protons and neutrons

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32. What is the smallest particle into which any matter can be divided and still maintain its original characteristics?
   a. Molecule
   b. Atom
   c. Proton
   d. Electron

33. What happens a fraction of a second <u>after</u> a positive step voltage is applied to a series RL circuit?
   a. I_t is zero and E_L is increasing
   b. I_t is increasing and E_L is zero
   c. E_r is decreasing and E_L is decreasing
   d. E_r is increasing and E_L is decreasing

34. What type of electron emission is produced in a vacuum tube when light strikes a silicon surface?
   a. Photostatic
   b. Photoelectric
   c. Thermionic
   d. Nucleonic

35. What transistor design feature insures the proper socket connection?
   a. The base lead is set apart from the other leads and marked
   b. The emitter lead is placed in the center and marked
   c. The base emitter leads are adaptable to fit different shaped holes
   d. The collector hole is spaced farther from the base hole than the emitter

36. Which UNIT is negatively charged?
   a. Positron
   b. Neutron
   c. Proton
   d. Electron

37. What is ONE time constant, in percentage, of a capacitor that is being charged?
   a. 19.9
   b. 35.8
   c. 63.2
   d. 83.4

38. What type of CHARGES move in a forward biased diode?
   a. Negative
   b. Positive
   c. Minority
   d. Majority

39. Which type electron tube is normally used as a rectifier?
   a. Pentode
   b. Tetrode
   c. Triode
   d. Diode

40. A positive step voltage followed by a negative step voltage at regular intervals is what kind of a waveform?

 a. Periodic, sinusoidal
 b. Aperiodic, sinusodial
 c. Periodic, nonsinusoidal
 d. Aperiodic, nonsinusoidal

41. Which path will current normally follow?

 a. The shortest
 b. That of least resistance
 c. That of most resistance
 d. The longest

42. What limits the plate current of the triode tube that utilizes oxide-coated filaments?

 a. Plate current deterioration and cutoff
 b. Plate current saturation and cutoff
 c. Secondary emission and cathode current
 d. Secondary emission and grid current

43. Which symbols are used to compute the voltage gain of a transistor?

 a. Vbe/Vee
 b. ΔVce/ΔVbe
 c. eb/ec
 d. ec/eb

44. What change is opposed by an inductor?

 a. Current
 b. Capacitance
 c. Resistance
 d. Voltage

45. What will happen if a positive (+) signal voltage is applied to the base of an NPN common collector circuit?

 a. The output voltage will decrease
 b. The output voltage will increase
 c. The forward bias will decrease
 d. The collector current will decrease

46. Which is a CHARACTERISTIC of a parallel circuit?

 a. The combined resistance is always less than the smallest resistance in the circuit
 b. The combined resistance is always larger than the largest resistance in the circuit
 c. The same current flows in all parts of the circuit
 d. The same voltage drop is applied across each resistor

47. What is the advantage of using the junction transistor over the point contact transistor?

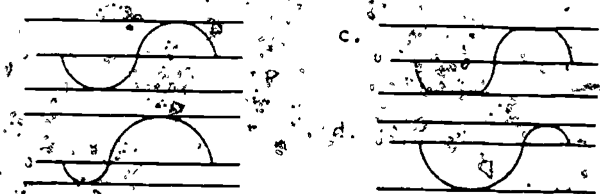
a. Greater power capability
b. Easier to install
c. Smaller shunt capacitance
d. Smaller in size

48. What represents the UNIT of power that is dissipated by a resistor?

a. Watt
b. Gauss
c. Volt
d. Joule

49. Which output waveform represents an OVERDRIVEN transistor circuit with a sine wave input signal?

a. c.
b. d.



50. What QUANTITATIVE relationship is stated by Ohm's law?

a. Current, voltage, and coulombs
b. Current, resistance, and gausses
c. Voltage, current, and resistance
d. Voltage, current, and gausses