



**NONRESIDENT  
TRAINING  
COURSE**



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# **Navy Electricity and Electronics Training Series**

## **Module 3—Introduction to Circuit Protection, Control, and Measurement**

**NAVEDTRA 14175**

## **Sailor's Creed**

"I am a United States Sailor.

I will support and defend the  
Constitution of the United States of  
America and I will obey the orders  
of those appointed over me.

I represent the fighting spirit of the  
Navy and those who have gone  
before me to defend freedom and  
democracy around the world.

I proudly serve my country's Navy  
combat team with honor, courage  
and commitment.

I am committed to excellence and  
the fair treatment of all."

# PREFACE

By enrolling in this self-study course, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this self-study course is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

**COURSE OVERVIEW:** Subjects of circuit measurement, circuit protection devices, and circuit control devices are presented to give the student background information on topics that may be encountered in daily work.

**THE COURSE:** This self-study course is organized into subject matter areas, each containing learning objectives to help you determine what you should learn along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and the occupational standards, which are listed in the *Manual of Navy Enlisted Manpower Personnel Classifications and Occupational Standards*, NAVPERS 18068, found on line at [https://buperscd.technology.navy.mil/bup\\_updt/upd\\_CD/BUPERS/enlistedManOpen.htm](https://buperscd.technology.navy.mil/bup_updt/upd_CD/BUPERS/enlistedManOpen.htm).

**THE QUESTIONS:** The questions that appear in this course are designed to help you understand the material in the text.

**VALUE:** In completing this course, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

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# NAVY ELECTRICITY AND ELECTRONICS TRAINING SERIES

The Navy Electricity and Electronics Training Series (NEETS) was developed for use by personnel in many electrical- and electronic-related Navy ratings. Written by, and with the advice of, senior technicians in these ratings, this series provides beginners with fundamental electrical and electronic concepts through self-study. The presentation of this series is not oriented to any specific rating structure, but is divided into modules containing related information organized into traditional paths of instruction.

The series is designed to give small amounts of information that can be easily digested before advancing further into the more complex material. For a student just becoming acquainted with electricity or electronics, it is highly recommended that the modules be studied in their suggested sequence. While there is a listing of NEETS by module title, the following brief descriptions give a quick overview of how the individual modules flow together.

**Module 1, *Introduction to Matter, Energy, and Direct Current***, introduces the course with a short history of electricity and electronics and proceeds into the characteristics of matter, energy, and direct current (dc). It also describes some of the general safety precautions and first-aid procedures that should be common knowledge for a person working in the field of electricity. Related safety hints are located throughout the rest of the series, as well.

**Module 2, *Introduction to Alternating Current and Transformers***, is an introduction to alternating current (ac) and transformers, including basic ac theory and fundamentals of electromagnetism, inductance, capacitance, impedance, and transformers.

**Module 3, *Introduction to Circuit Protection, Control, and Measurement***, encompasses circuit breakers, fuses, and current limiters used in circuit protection, as well as the theory and use of meters as electrical measuring devices.

**Module 4, *Introduction to Electrical Conductors, Wiring Techniques, and Schematic Reading***, presents conductor usage, insulation used as wire covering, splicing, termination of wiring, soldering, and reading electrical wiring diagrams.

**Module 5, *Introduction to Generators and Motors***, is an introduction to generators and motors, and covers the uses of ac and dc generators and motors in the conversion of electrical and mechanical energies.

**Module 6, *Introduction to Electronic Emission, Tubes, and Power Supplies***, ties the first five modules together in an introduction to vacuum tubes and vacuum-tube power supplies.

**Module 7, *Introduction to Solid-State Devices and Power Supplies***, is similar to module 6, but it is in reference to solid-state devices.

**Module 8, *Introduction to Amplifiers***, covers amplifiers.

**Module 9, *Introduction to Wave-Generation and Wave-Shaping Circuits***, discusses wave generation and wave-shaping circuits.

**Module 10, *Introduction to Wave Propagation, Transmission Lines, and Antennas***, presents the characteristics of wave propagation, transmission lines, and antennas.

**Module 11**, *Microwave Principles*, explains microwave oscillators, amplifiers, and waveguides.

**Module 12**, *Modulation Principles*, discusses the principles of modulation.

**Module 13**, *Introduction to Number Systems and Logic Circuits*, presents the fundamental concepts of number systems, Boolean algebra, and logic circuits, all of which pertain to digital computers.

**Module 14**, *Introduction to Microelectronics*, covers microelectronics technology and miniature and microminiature circuit repair.

**Module 15**, *Principles of Synchros, Servos, and Gyros*, provides the basic principles, operations, functions, and applications of synchro, servo, and gyro mechanisms.

**Module 16**, *Introduction to Test Equipment*, is an introduction to some of the more commonly used test equipments and their applications.

**Module 17**, *Radio-Frequency Communications Principles*, presents the fundamentals of a radio-frequency communications system.

**Module 18**, *Radar Principles*, covers the fundamentals of a radar system.

**Module 19**, *The Technician's Handbook*, is a handy reference of commonly used general information, such as electrical and electronic formulas, color coding, and naval supply system data.

**Module 20**, *Master Glossary*, is the glossary of terms for the series.

**Module 21**, *Test Methods and Practices*, describes basic test methods and practices.

**Module 22**, *Introduction to Digital Computers*, is an introduction to digital computers.

**Module 23**, *Magnetic Recording*, is an introduction to the use and maintenance of magnetic recorders and the concepts of recording on magnetic tape and disks.

**Module 24**, *Introduction to Fiber Optics*, is an introduction to fiber optics.

Embedded questions are inserted throughout each module, except for modules 19 and 20, which are reference books. If you have any difficulty in answering any of the questions, restudy the applicable section.

Although an attempt has been made to use simple language, various technical words and phrases have necessarily been included. Specific terms are defined in Module 20, *Master Glossary*.

Considerable emphasis has been placed on illustrations to provide a maximum amount of information. In some instances, a knowledge of basic algebra may be required.

Assignments are provided for each module, with the exceptions of Module 19, *The Technician's Handbook*; and Module 20, *Master Glossary*. Course descriptions and ordering information are in NAVEDTRA 12061, *Catalog of Nonresident Training Courses*.

Throughout the text of this course and while using technical manuals associated with the equipment you will be working on, you will find the below notations at the end of some paragraphs. The notations are used to emphasize that safety hazards exist and care must be taken or observed.

### **WARNING**

AN OPERATING PROCEDURE, PRACTICE, OR CONDITION, ETC., WHICH MAY RESULT IN INJURY OR DEATH IF NOT CAREFULLY OBSERVED OR FOLLOWED.

### **CAUTION**

AN OPERATING PROCEDURE, PRACTICE, OR CONDITION, ETC., WHICH MAY RESULT IN DAMAGE TO EQUIPMENT IF NOT CAREFULLY OBSERVED OR FOLLOWED.

### **NOTE**

An operating procedure, practice, or condition, etc., which is essential to emphasize.

# INSTRUCTIONS FOR TAKING THE COURSE

## ASSIGNMENTS

The text pages that you are to study are listed at the beginning of each assignment. Study these pages carefully before attempting to answer the questions. Pay close attention to tables and illustrations and read the learning objectives. The learning objectives state what you should be able to do after studying the material. Answering the questions correctly helps you accomplish the objectives.

## SELECTING YOUR ANSWERS

Read each question carefully, then select the BEST answer. You may refer freely to the text. The answers must be the result of your own work and decisions. You are prohibited from referring to or copying the answers of others and from giving answers to anyone else taking the course.

## SUBMITTING YOUR ASSIGNMENTS

To have your assignments graded, you must be enrolled in the course with the Nonresident Training Course Administration Branch at the Naval Education and Training Professional Development and Technology Center (NETPDTC). Following enrollment, there are two ways of having your assignments graded: (1) use the Internet to submit your assignments as you complete them, or (2) send all the assignments at one time by mail to NETPDTC.

**Grading on the Internet:** Advantages to Internet grading are:

- you may submit your answers as soon as you complete an assignment, and
- you get your results faster; usually by the next working day (approximately 24 hours).

In addition to receiving grade results for each assignment, you will receive course completion confirmation once you have completed all the

assignments. To submit your assignment answers via the Internet, go to:

**<https://courses.cnet.navy.mil>**

**Grading by Mail:** When you submit answer sheets by mail, send all of your assignments at one time. Do NOT submit individual answer sheets for grading. Mail all of your assignments in an envelope, which you either provide yourself or obtain from your nearest Educational Services Officer (ESO). Submit answer sheets to:

COMMANDING OFFICER  
NETPDTC N331  
6490 SAUFLEY FIELD ROAD  
PENSACOLA FL 32559-5000

**Answer Sheets:** All courses include one “scannable” answer sheet for each assignment. These answer sheets are preprinted with your SSN, name, assignment number, and course number. Explanations for completing the answer sheets are on the answer sheet.

**Do not use answer sheet reproductions:** Use only the original answer sheets that we provide—reproductions will not work with our scanning equipment and cannot be processed.

Follow the instructions for marking your answers on the answer sheet. Be sure that blocks 1, 2, and 3 are filled in correctly. This information is necessary for your course to be properly processed and for you to receive credit for your work.

## COMPLETION TIME

Courses must be completed within 12 months from the date of enrollment. This includes time required to resubmit failed assignments.



## PASS/FAIL ASSIGNMENT PROCEDURES

If your overall course score is 3.2 or higher, you will pass the course and will not be required to resubmit assignments. Once your assignments have been graded you will receive course completion confirmation.

If you receive less than a 3.2 on any assignment and your overall course score is below 3.2, you will be given the opportunity to resubmit failed assignments. **You may resubmit failed assignments only once.** Internet students will receive notification when they have failed an assignment—they may then resubmit failed assignments on the web site. Internet students may view and print results for failed assignments from the web site. Students who submit by mail will receive a failing result letter and a new answer sheet for resubmission of each failed assignment.

## COMPLETION CONFIRMATION

After successfully completing this course, you will receive a letter of completion.

## ERRATA

Errata are used to correct minor errors or delete obsolete information in a course. Errata may also be used to provide instructions to the student. If a course has an errata, it will be included as the first page(s) after the front cover. Errata for all courses can be accessed and viewed/downloaded at:

<https://www.advancement.cnet.navy.mil>

## STUDENT FEEDBACK QUESTIONS

We value your suggestions, questions, and criticisms on our courses. If you would like to communicate with us regarding this course, we encourage you, if possible, to use e-mail.

## For subject matter questions:

E-mail: n315.products@cnet.navy.mil  
Phone: Comm: (850) 452-1001, Ext. 1728  
DSN: 922-1001, Ext. 1728  
FAX: (850) 452-1370  
(Do not fax answer sheets.)  
Address: COMMANDING OFFICER  
NETPDTC N315  
6490 SAUFLEY FIELD ROAD  
PENSACOLA FL 32509-5237

## For enrollment, shipping, grading, or completion letter questions

E-mail: fleetservices@cnet.navy.mil  
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Comm: (850) 452-1511/1181/1859  
DSN: 922-1511/1181/1859  
FAX: (850) 452-1370  
(Do not fax answer sheets.)  
Address: COMMANDING OFFICER  
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6490 SAUFLEY FIELD ROAD  
PENSACOLA FL 32559-5000

## NAVAL RESERVE RETIREMENT CREDIT

If you are a member of the Naval Reserve, you may earn retirement points for successfully completing this course, if authorized under current directives governing retirement of Naval Reserve personnel. For Naval Reserve retirement, this course is evaluated at 5 points. (Refer to *Administrative Procedures for Naval Reservists on Inactive Duty*, BUPERSINST 1001.39, for more information about retirement points.)

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# CHAPTER 1

## CIRCUIT MEASUREMENT

### LEARNING OBJECTIVES

Learning objectives are stated at the beginning of each chapter. These learning objectives serve as a preview of the information you are expected to learn in the chapter. The comprehensive check questions are based on the objectives. By successfully completing the NRTC, you indicate that you have met the objectives and have learned the information. The learning objectives are listed below.

Upon completion of this chapter you will be able to:

1. State two ways circuit measurement is used, why in-circuit meters are used, and one advantage of out-of-circuit meters.
2. State the way in which a compass reacts to a conducting wire including the compass reaction to increasing and decreasing dc and ac high and low frequencies.
3. State how a d'Arsonval meter movement reacts to dc.
4. State the purpose of a rectifier as used in ac meters.
5. State the meaning of the term "damping" as it applies to meter movements and describe two methods by which damping is accomplished.
6. Identify average value as the value of ac measured and effective value (rms) as the ac value indicated on ac meter scales.
7. Identify three meter movements that measure dc or ac without the use of a rectifier.
8. State the electrical quantity measured by an ammeter, the way in which an ammeter is connected in a circuit, and the effect of an ammeter upon a circuit.
9. Define ammeter sensitivity.
10. State the method used to allow an ammeter to measure different ranges and the reason for using the highest range when connecting an ammeter to a circuit.
11. List the safety precautions for ammeter use.
12. State the electrical quantity measured by a voltmeter, the way in which a voltmeter is connected in a circuit, the way in which a voltmeter affects the circuit being measured, and the way in which a voltmeter is made from a current reacting meter movement.
13. Define voltmeter sensitivity.
14. State the method used to allow a voltmeter to measure different ranges and the reason for using the highest range when connecting a voltmeter to a circuit.

15. Identify the type of meter movement that reacts to voltage and the most common use of this movement.
16. List the safety precautions for voltmeter use.
17. State the electrical quantity measured by an ohmmeter, the second use of an ohmmeter, and the way in which an ohmmeter is connected to a resistance being measured.
18. State the method used to allow an ohmmeter to measure different ranges and the area of an ohmmeter scale that should be used when measuring resistance.
19. State the two types of ohmmeters and the way in which each can be identified.
20. List the safety precautions for ohmmeter use.
21. State the primary reason for using a megger and the method of using it.
22. Identify normal and abnormal indications on a megger.
23. List the safety precautions for megger use.
24. State how a multimeter differs from other meters, the reason a multimeter is preferred over separate meters, and the way in which a multimeter is changed from a voltage measuring device to a current measuring device.
25. State the reason the ac and dc scales of a multimeter differ, the reason for having a mirror on the scale of a multimeter, and the proper way of reading a multimeter using the mirror.
26. List the safety precautions for multimeter use.
27. State the purpose of a hook-on type voltmeter.
28. State the electrical quantity measured by a wattmeter and a watt-hour meter.
29. Identify the two types of frequency meters.
30. Identify the type of meter and interpret the meter reading from scale presentations of an ammeter; a voltmeter; an ohmmeter; a megger; a multimeter (current, voltage, and resistance examples); a wattmeter; a watt-hour meter; and a frequency meter (vibrating reed and moving-disk types).

## **CIRCUIT MEASUREMENT**

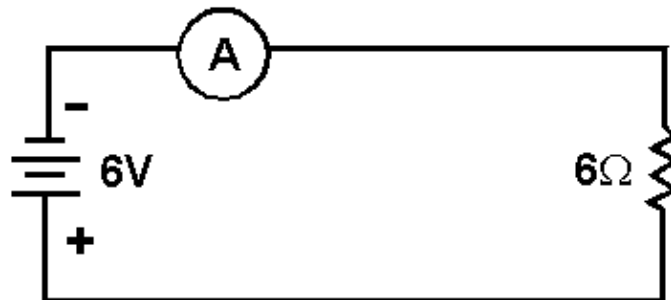
This chapter will acquaint you with the basics of circuit measurement and some of the devices used to measure voltage, current, resistance, power, and frequency. There are other quantities involved in electrical circuits, such as capacitance, inductance, impedance, true power, and effective power. It is possible to measure any circuit quantity once you are able to select and use the proper circuit measuring device. You will NOT know all there is to know about circuit measuring devices (test equipment) when you finish this chapter. That is beyond the scope of this chapter and even beyond the scope of this training series. However, more information on test equipment is provided in another portion of this training series.

A question which you might ask before starting this chapter is "Why do I need to know about circuit measurement?"

If you intend to accomplish anything in the field of electricity and electronics, you must be aware of the forces acting inside the circuits with which you work. Modules 1 and 2 of this training series introduced you to the physics involved in the study of electricity and to the fundamental concepts of direct and alternating current. The terms voltage (volts), current (amperes), and resistance (ohms) were explained, as well as the various circuit elements; e.g., resistors, capacitors, inductors, transformers, and batteries.

In explaining these terms and elements to you, schematic symbols and schematic diagrams were used. In many of these schematic diagrams, a meter was represented in the circuit, as shown in figure 1-1.

As you recall, the current in a dc circuit with 6 volts across a 6-ohm resistor is 1 ampere. The **A** in figure 1-1 is the symbol for an ammeter. An ammeter is a device that measures current. The name "ammeter" comes from the fact that it is a meter used to measure current (in amperes), and thus is called an AMPere METER, or AMMETER. The ammeter in figure 1-1 is measuring a current of 1 ampere with the voltage and resistance values given.



**Figure 1-1.—A simple representative circuit.**

In the discussion and explanation of electrical and electronic circuits, the quantities in the circuit (voltage, current, and resistance) are important. If you can measure the electrical quantities in a circuit, it is easier to understand what is happening in that circuit. This is especially true when you are troubleshooting defective circuits. By measuring the voltage, current, capacitance, inductance, impedance, and resistance in a circuit, you can determine why the circuit is not doing what it is supposed to do. For instance, you can determine why a radio is not receiving or transmitting, why your automobile will not start, or why an electric oven is not working. Measurement will also assist you in determining why an electrical component (resistor, capacitor, inductor) is not doing its job.

The measurement of the electrical parameters quantities in a circuit is an essential part of working on electrical and electronic equipment.

## **INTRODUCTION TO CIRCUIT MEASUREMENT**

Circuit measurement is used to monitor the operation of an electrical or electronic device, or to determine the reason a device is not operating properly. Since electricity is invisible, you must use some sort of device to determine what is happening in an electrical circuit. Various devices called test equipment are used to measure electrical quantities. The most common types of test equipment use some kind of metering device.

## IN-CIRCUIT METERS

Some electrical and electronic devices have meters built into them. These meters are known as in-circuit meters. An in-circuit meter is used to monitor the operation of the device in which it is installed. Some examples of in-circuit meters are the generator or alternator meter on some automobiles; the voltage, current, and frequency meters on control panels at electrical power plants; and the electrical power meter that records the amount of electricity used in a building.

It is not practical to install an in-circuit meter in every circuit. However, it is possible to install an in-circuit meter in each critical or representative circuit to monitor the operation of a piece of electrical equipment. A mere glance at or scan of the in-circuit meters on a control board is often sufficient to tell if the equipment is working properly.

While an in-circuit meter will indicate that an electrical device is not functioning properly, the cause of the malfunction is determined by troubleshooting. Troubleshooting is the process of locating and repairing faults in equipment after they have occurred. Since troubleshooting is covered elsewhere in this training series, it will be mentioned here only as it applies to circuit measurement.

## OUT-OF-CIRCUIT METERS

In troubleshooting, it is usually necessary to use a meter that can be connected to the electrical or electronic equipment at various testing points and may be moved from one piece of equipment to another. These meters are generally portable and self-contained, and are known as out-of-circuit meters.

Out-of-circuit meters are more versatile than in-circuit meters in that the out-of-circuit meter can be used wherever you wish to connect it. Therefore, the out-of-circuit meter is more valuable in locating the cause of a malfunction in a device.

*Q1. What are two ways that circuit measurement is used?*

*Q2. Why are in-circuit meters used?*

*Q3. What is one advantage of an out-of-circuit meter when it is compared with an in-circuit meter?*

## BASIC METER MOVEMENTS

The meter movement is, as the name implies, the part of a meter that moves. A meter movement converts electrical energy into mechanical energy. There are many different types of meter movements. The first one you will learn about is based upon a principle with which you are already familiar. That principle is the interaction of magnetic fields.

## COMPASS AND CONDUCTING WIRE

You know that an electrical conductor in which current flows has a magnetic field generated around it. If a compass is placed close to the conductor, the compass will react to that magnetic field (fig. 1-2).

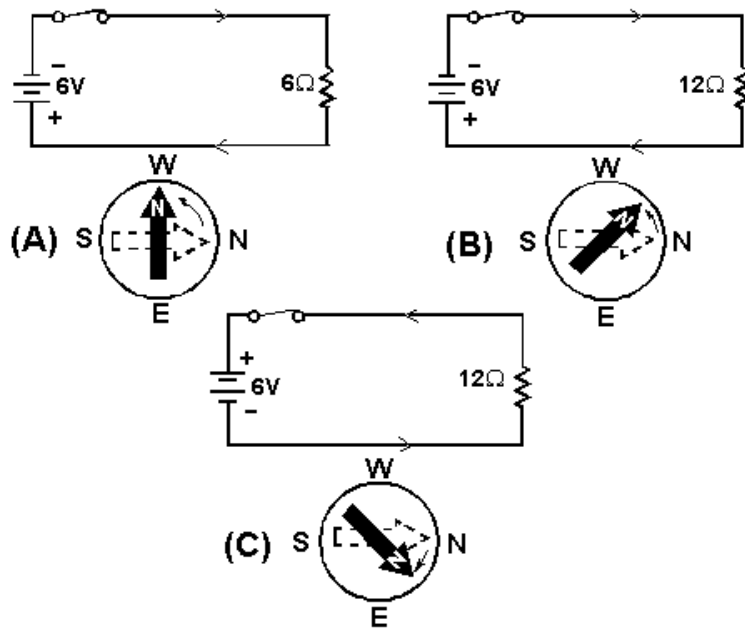


Figure 1-2.—Compass and conductor with direct current.

If the battery is disconnected, the north end of the compass needle will point to magnetic north, as illustrated in figure 1-2(A) by the broken-line compass needle pointing to the right. When the battery is connected, current flows through the circuit and the compass needle aligns itself with the magnetic field of the conductor, as indicated by the solid compass needle. The strength of the magnetic field created around the conductor is dependent upon the amount of current.

In figure 1-2(A), the resistance in the circuit is 6 ohms. With the 6-volt battery shown, current in the circuit is 1 ampere. In figure 1-2(B), the resistance has been changed to 12 ohms. With the 6-volt battery shown, current in the circuit is  $1/2$  or .5 ampere. The magnetic field around the conductor in figure 1-2(B) is weaker than the magnetic field around the conductor in figure 1-2(A). The compass needle in figure 1-2(B) does not move as far from magnetic north.

If the direction of the current is reversed, the compass needle will move in the opposite direction because the polarity of the magnetic field has reversed.

In figure 1-2(C), the battery connections are reversed and the compass needle now moves in the opposite direction.

You can construct a crude meter to measure current by using a compass and a piece of paper. By using resistors of known values, and marking the paper to indicate a numerical value, as in figure 1-3, you have a device that measures current.

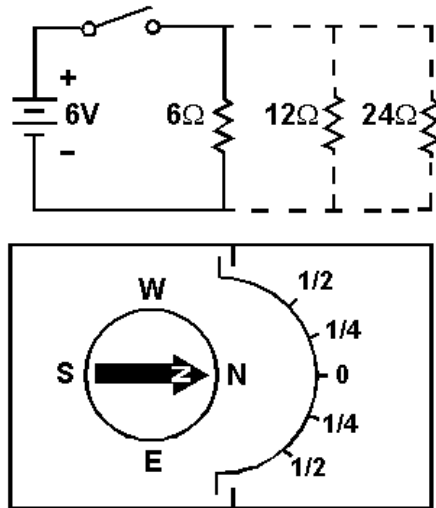


Figure 1-3.—A simple meter from a compass.

This is, in fact, the way the first GALVANOMETERS were developed. A galvanometer is an instrument that measures small amounts of current and is based on the electromagnetic principle. A galvanometer can also use the principles of electrodynamics, which will be covered later in this topic.

The meter in figure 1-3 is not very practical for electrical measurement. The amount the compass needle swings depends upon the closeness of the compass to the conductor carrying the current, the direction of the conductor in relation to magnetic north, and the influence of other magnetic fields. In addition, very small amounts of current will not overcome the magnetic field of the Earth and the needle will not move.

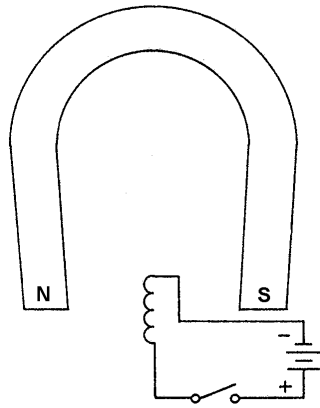
- Q4. How does a compass react when placed close to a current carrying conductor?*
- Q5. If the amount of current in the conductor changes, what happens to the magnetic field around the conductor?*
- Q6. How does the compass needle react to a decreased magnetic field?*

## PERMANENT-MAGNET MOVING-COIL MOVEMENT

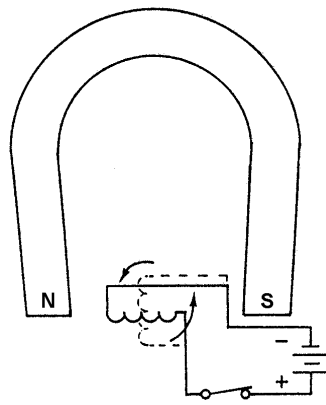
The compass and conducting wire meter can be considered a fixed-conductor moving-magnet device since the compass is, in reality, a magnet that is allowed to move. The basic principle of this device is the interaction of magnetic fields—the field of the compass (a permanent magnet) and the field around the conductor (a simple electromagnet).

A permanent-magnet moving-coil movement is based upon a fixed permanent magnet and a coil of wire which is able to move, as in figure 1-4. When the switch is closed, causing current through the coil, the coil will have a magnetic field which will react to the magnetic field of the permanent magnet. The bottom portion of the coil in figure 1-4 will be the north pole of this electromagnet. Since opposite poles attract, the coil will move to the position shown in figure 1-5.



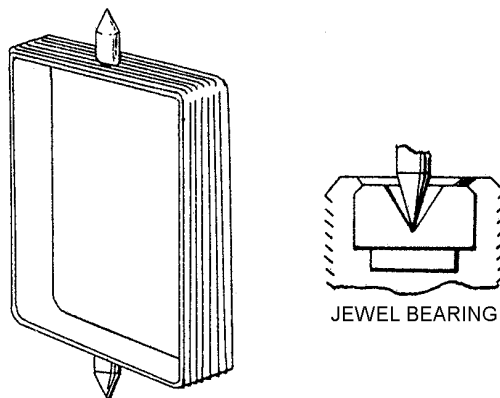


**Figure 1-4.—A movable coil in a magnetic field (no current).**



**Figure 1-5.—A movable coil in a magnetic field (current).**

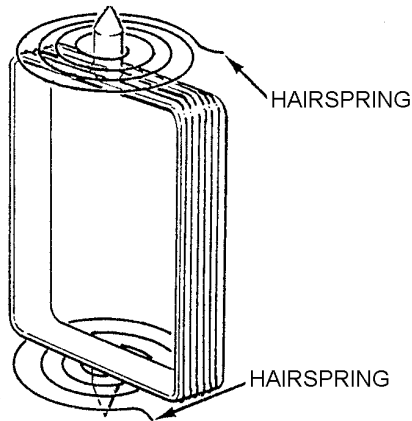
The coil of wire is wound on an aluminum frame, or bobbin, and the bobbin is supported by jeweled bearings which allow it to move freely. This is shown in figure 1-6.



**Figure 1-6.—A basic coil arrangement.**

To use this permanent-magnet moving-coil device as a meter, two problems must be solved. First, a way must be found to return the coil to its original position when there is no current through the coil. Second, a method is needed to indicate the amount of coil movement.

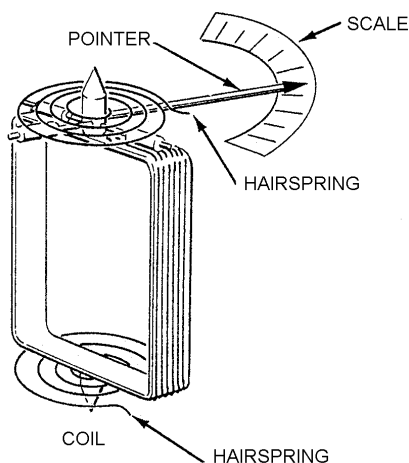
The first problem is solved by the use of hairsprings attached to each end of the coil as shown in figure 1-7. These hairsprings can also be used to make the electrical connections to the coil. With the use of hairsprings, the coil will return to its initial position when there is no current. The springs will also tend to resist the movement of the coil when there is current through the coil. When the attraction between the magnetic fields (from the permanent magnet and the coil) is exactly equal to the force of the hairsprings, the coil will stop moving toward the magnet.



**Figure 1-7.—Coil and hairsprings.**

As the current through the coil increases, the magnetic field generated around the coil increases. The stronger the magnetic field around the coil, the farther the coil will move. This is a good basis for a meter.

But, how will you know how far the coil moves? If a pointer is attached to the coil and extended out to a scale, the pointer will move as the coil moves, and the scale can be marked to indicate the amount of current through the coil. This is shown in figure 1-8.



**Figure 1-8.—A complete coil.**

Two other features are used to increase the accuracy and efficiency of this meter movement. First, an iron core is placed inside the coil to concentrate the magnetic fields. Second, curved pole pieces are

attached to the magnet to ensure that the turning force on the coil increases steadily as the current increases.

The meter movement as it appears when fully assembled is shown in figure 1-9.

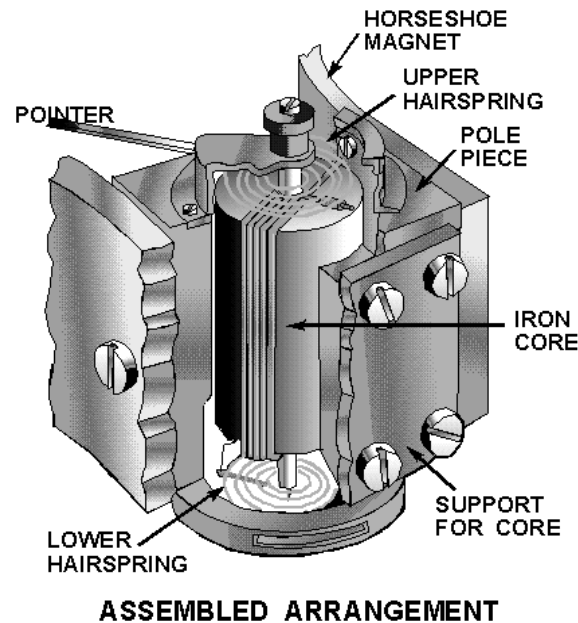


Figure 1-9.—Assembled meter movement.

This permanent-magnet moving-coil meter movement is the basic movement in most measuring instruments. It is commonly called the d'Arsonval movement because it was first employed by the Frenchman d'Arsonval in making electrical measurements. Figure 1-10 is a view of the d'Arsonval meter movement used in a meter.

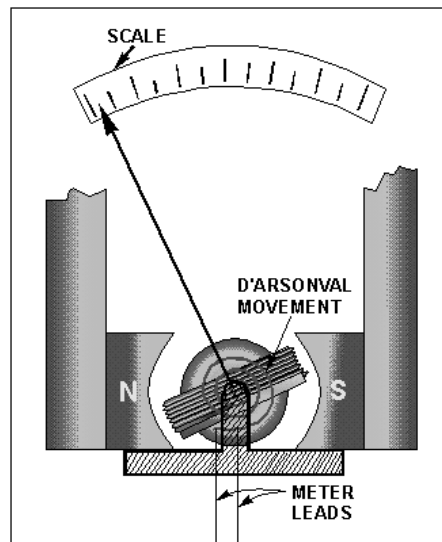


Figure 1-10.—A meter using d'Arsonval movement.

*Q7. What type of meter movement is the d'Arsonval meter movement?*

Q8. What is the effect of current flow through the coil in a d'Arsonval meter movement?

Q9. What are three functions of the hairsprings in a d'Arsonval meter movement?

## COMPASS AND ALTERNATING CURRENT

Up to this point, only direct current examples have been used. What happens with the use of alternating current? Figure 1-11 shows a magnet close to a conductor carrying alternating current at a frequency of 1 hertz.

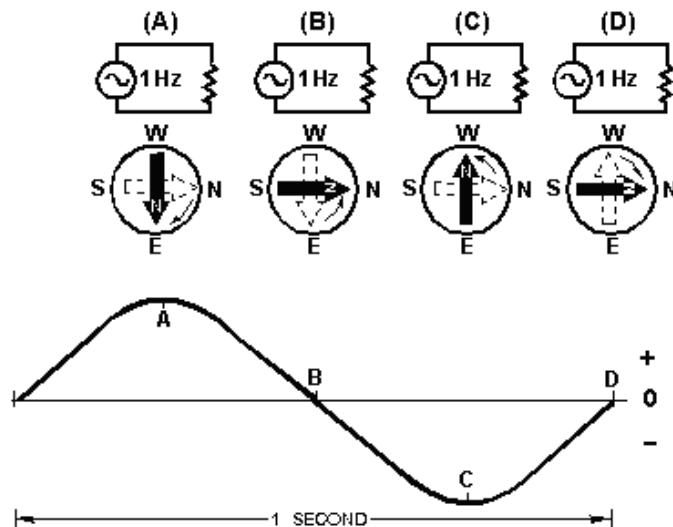


Figure 1-11.—Compass and conductor with ac.

The compass needle will swing toward the east part of the compass (down) as the current goes positive, as represented in figure 1-11(A). (The sine wave of the current is shown in the lower portion of the figure to help you visualize the current in the conductor.)

In figure 1-11(B), the current returns to zero, and the compass needle returns to magnetic north (right). As the current goes negative, as in figure 1-11(C), the compass needle swings toward the west portion of the compass (up). The compass needle returns to magnetic north as the current returns to zero as shown in figure 1-11(D).

This cycle of the current going positive and negative and the compass swinging back and forth will continue as long as there is alternating current in the conductor.

If the frequency of the alternating current is increased, the compass needle will swing back and forth at a higher rate (faster). At a high enough frequency, the compass needle will not swing back and forth, but simply vibrate around the magnetic north position. This happens because the needle cannot react fast enough to the very rapid current alternations. The compass (a simple meter) will indicate the average value of the alternating current (remember the average value of a sine wave is zero) by vibrating around the zero point on the meter (magnetic north). This is not of much use if you wish to know the value of the alternating current. Some device, such as a rectifier, is needed to allow the compass to react to the alternating current in a way that can be useful in measuring the current.

## RECTIFIER FOR AC MEASUREMENT

A rectifier is a device that changes alternating current to a form of direct current. The way in which this is done will be covered later in this training series. For now, it is necessary to know only the information presented in figure 1-12.



Figure 1-12.—Rectifier action.

Figure 1-12 shows that an alternating current passed through a rectifier will come out as a "pulsating direct current."

What happens to the compass now? Figure 1-13 answers that question.

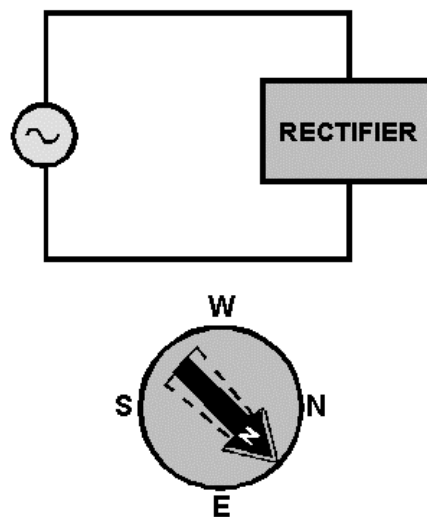


Figure 1-13.—Compass and conductor; rectified ac.

When the compass is placed close to the wire and the frequency of the alternating current is high enough, the compass will vibrate around a point that represents the average value of the pulsating direct current, as shown in figure 1-13.

- Q10. How would a compass react when placed close to a conductor carrying alternating current at a low frequency?*
- Q11. How would the compass react if the alternating current through the conductor was a high frequency?*
- Q12. What is the purpose of a rectifier in a meter?*

By connecting a rectifier to a d'Arsonval meter movement, an alternating current measuring device is created.

When ac is converted to pulsating dc, the d'Arsonval movement will react to the average value of the pulsating dc (which is the average value of one-half of the sine wave). Another characteristic of using a rectifier concerns the fact that the d'Arsonval meter movement is capable of indicating current in only one direction. If the d'Arsonval meter movement were used to indicate alternating current without a rectifier, or direct current of the wrong polarity, the movement would be severely damaged. The pulsating dc is current in a single direction, and so the d'Arsonval meter movement can be used as long as proper polarity is observed.

## DAMPING

A problem that is created by the use of a rectifier and d'Arsonval meter movement is that the pointer will vibrate (oscillate) around the average value indication. This oscillation will make the meter difficult to read.

The process of "smoothing out" the oscillation of the pointer is known as DAMPING. There are two basic techniques used to damp the pointer of a d'Arsonval meter movement.

The first method of damping comes from the d'Arsonval meter movement itself. In the d'Arsonval meter movement, current through the coil causes the coil to move in the magnetic field of the permanent magnet. This movement of the coil (conductor) through a magnetic field causes a current to be induced in the coil opposite to the current that caused the movement of the coil. This induced current will act to damp oscillations. In addition to this method of damping, which comes from the movement itself, most meters use a second method of damping.

The second method of damping used in most meter movements is an airtight chamber containing a vane (like a windmill vane) attached to the coil (fig.1-14).

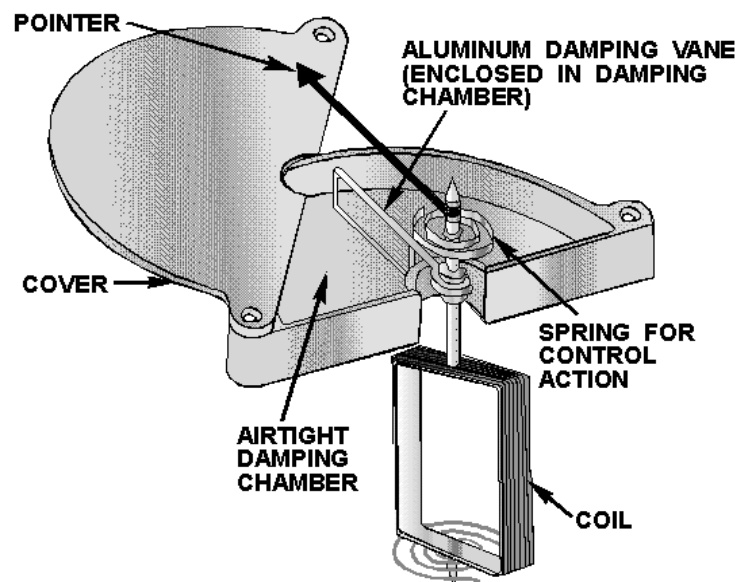


Figure 1-14.—A typical meter damping system.

As the coil moves, the vane moves within the airtight chamber. The action of the vane against the air in the chamber opposes the coil movement and damps the oscillations.

*Q13. How can a d'Arsonval meter movement be adapted for use as an ac meter?*

*Q14. What is damping?*

*Q15. What are two methods used to damp a meter movement?*

*Q16. What value does a meter movement react to (actually measure) when measuring ac?*

*Q17. What value is indicated on the scale of an ac meter?*

An additional advantage of damping a meter movement is that the damping systems will act to slow down the coil and help keep the pointer from overshooting its rest position when the current through the meter is removed.

## **INDICATING ALTERNATING CURRENT**

Another problem encountered in measuring ac is that the meter movement reacts to the average value of the ac. The value used when working with ac is the effective value (rms value). Therefore, a different scale is used on an ac meter. The scale is marked with the effective value, even though it is the average value to which the meter is reacting. That is why an ac meter will give an incorrect reading if used to measure dc.

## **OTHER METER MOVEMENTS**

The d'Arsonval meter movement (permanent-magnet moving-coil) is only one type of meter movement. Other types of meter movements can be used for either ac or dc measurement without the use of a rectifier.

When galvanometers were mentioned earlier in this topic, it was stated that they could be either electromagnetic or electrodynamic. Electrodynamic meter movements will be discussed at this point.

## **ELECTRODYNAMIC METER MOVEMENT**

An electrodynamic movement uses the same basic operating principle as the basic moving-coil meter movement, except that the permanent magnet is replaced by fixed coils (fig. 1-15). A moving coil, to which the meter pointer is attached, is suspended between two field coils and connected in series with these coils. The three coils (two field coils and the moving coil) are connected in series across the meter terminals so that the same current flows through each.

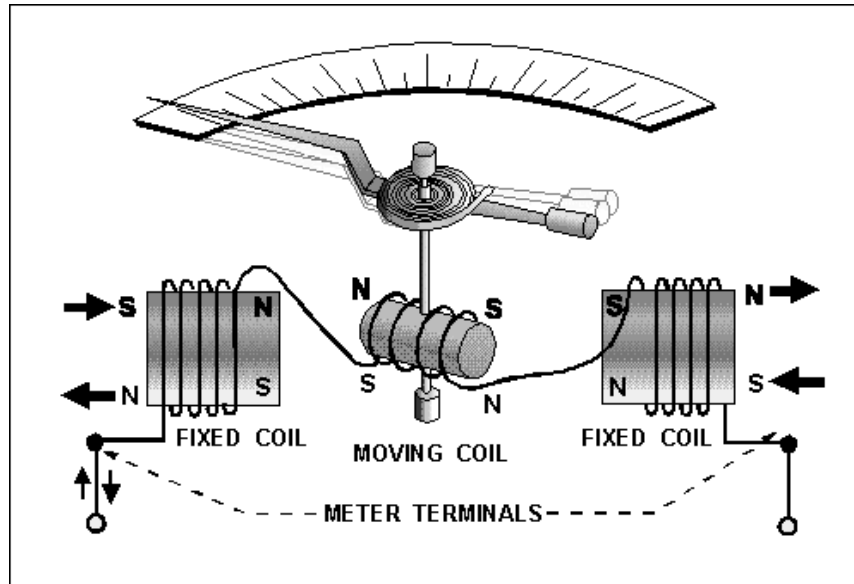


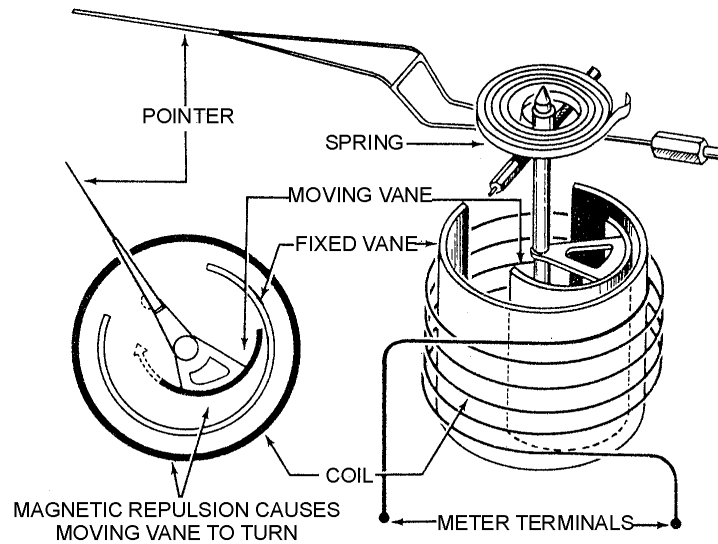
Figure 1-15.—Electrodynamic meter movement.

Current flow in either direction through the three coils causes a magnetic field to exist between the field coils. The current in the moving coil causes it to act as a magnet and exert a turning force against a spring. If the current is reversed, the field polarity and the polarity of the moving coil reverse at the same time, and the turning force continues in the original direction. Since reversing the current direction does not reverse the turning force, this type of meter can be used to measure both ac and dc if the scale is changed. While some voltmeters and ammeters use the electrodynamic principle of operation, the most important application is in the wattmeter. The wattmeter, along with the voltmeter and the ammeter, will be discussed later in this topic.

### MOVING-VANE METER MOVEMENTS

The moving-vane meter movement (sometimes called the moving-iron movement) is the most commonly used movement for ac meters. The moving-vane meter operates on the principle of magnetic repulsion between like poles (fig.1-16). The current to be measured flows through a coil, producing a magnetic field which is proportional to the strength of the current. Suspended in this field are two iron vanes. One is in a fixed position, the other, attached to the meter pointer, is movable. The magnetic field magnetizes these iron vanes with the same polarity regardless of the direction of current flow in the coil. Since like poles repel, the movable vane pulls away from the fixed vane, moving the meter pointer. This motion exerts a turning force against the spring. The distance the vane will move against the force of the spring depends on the strength of the magnetic field, which in turn depends on the coil current.





**Figure 1-16.—Moving-vane meter movement.**

These meters are generally used at 60-hertz ac, but may be used at other ac frequencies. By changing the meter scale to indicate dc values rather than ac rms values, moving-vane meters will measure dc current and dc voltage. This is not recommended due to the residual magnetism left in the vanes, which will result in an error in the instrument.

One of the major disadvantages of this type of meter movement occurs due to the high reluctance of the magnetic circuit. This causes the meter to require much more power than the D'Arsonval meter to produce a full scale deflection, thereby reducing the meters sensitivity.

### **HOT-WIRE AND THERMOCOUPLE METER MOVEMENTS**

Hot-wire and thermocouple meter movements both use the heating effect of current flowing through a resistance to cause meter deflection. Each uses this effect in a different manner. Since their operation depends only on the heating effect of current flow, they may be used to measure both direct current and alternating current of any frequency on a single scale.

The hot-wire meter movement deflection depends on the expansion of a high-resistance wire caused by the heating effect of the wire itself as current flows through it. (See fig. 1-17.) A resistance wire is stretched taut between the two meter terminals, with a thread attached at a right angle to the center of the wire. A spring connected to the opposite end of the thread exerts a constant tension on the resistance wire. Current flow heats the wire, causing it to expand. This motion is transferred to the meter pointer through the thread and a pivot.

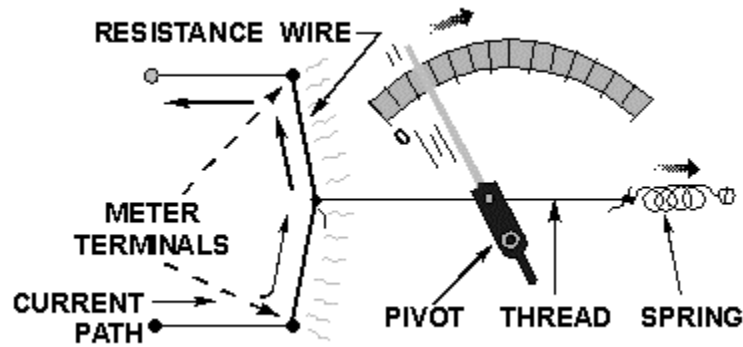


Figure 1-17.—Hot-wire meter movement.

The thermocouple meter consists of a resistance wire across the meter terminals, which heats in proportion to the amount of current. (See fig. 1-18.) Attached to this wire is a small thermocouple junction of two unlike metal wires, which connect across a very sensitive dc meter movement (usually a d'Arsonval meter movement). As the current being measured heats the heating resistor, a small current (through the thermocouple wires and the meter movement) is generated by the thermocouple junction. The current being measured flows through only the resistance wire, not through the meter movement itself. The pointer turns in proportion to the amount of heat generated by the resistance wire.

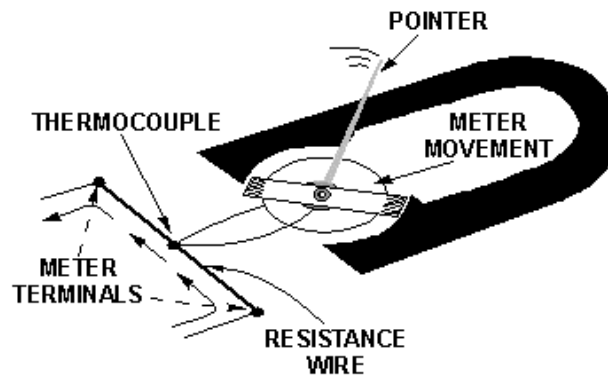


Figure 1-18.—A thermocouple meter.

Q18. List three meter movements that can measure either ac or dc without the use of a rectifier.

Q19. What electrical property is used by all the meter movements discussed so far?

## AMMETERS

An ammeter is a device that measures current. Since all meter movements have resistance, a resistor will be used to represent a meter in the following explanations. Direct current circuits will be used for simplicity of explanation.

## AMMETER CONNECTED IN SERIES

In figure 1-19(A),  $R_1$  and  $R_2$  are in series. The total circuit resistance is  $R_1 + R_2$  and total circuit current flows through both resistors. In figure 1-19(B),  $R_1$  and  $R_2$  are in parallel. The total circuit resistance is

$$\frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

and total circuit current does not flow through either resistor.

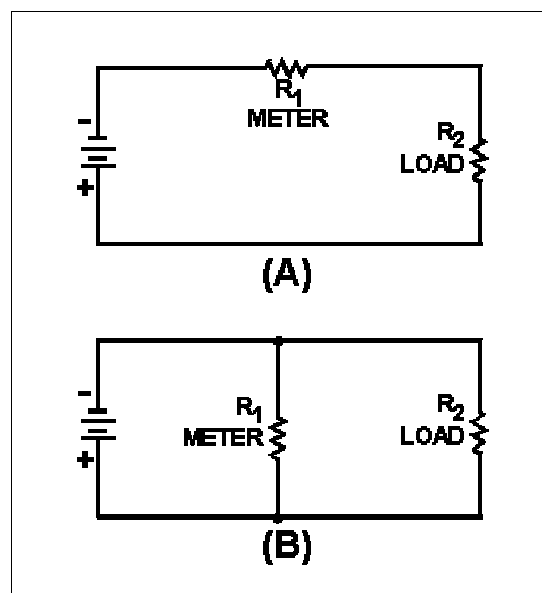


Figure 1-19.—A series and a parallel circuit.

If  $R_1$  represents an ammeter, the only way in which total circuit current will flow through the meter (and thus be measured) is to have the meter ( $R_1$ ) in series with the circuit load ( $R_2$ ), as shown in figure 1-19(A).

In complex electrical circuits, you are not always concerned with total circuit current. You may be interested in the current through a particular component or group of components. In any case, an ammeter is always connected in series with the circuit you wish to test. Figure 1-20 shows various circuit arrangements with the ammeter(s) properly connected for measuring current in various portions of the circuit.

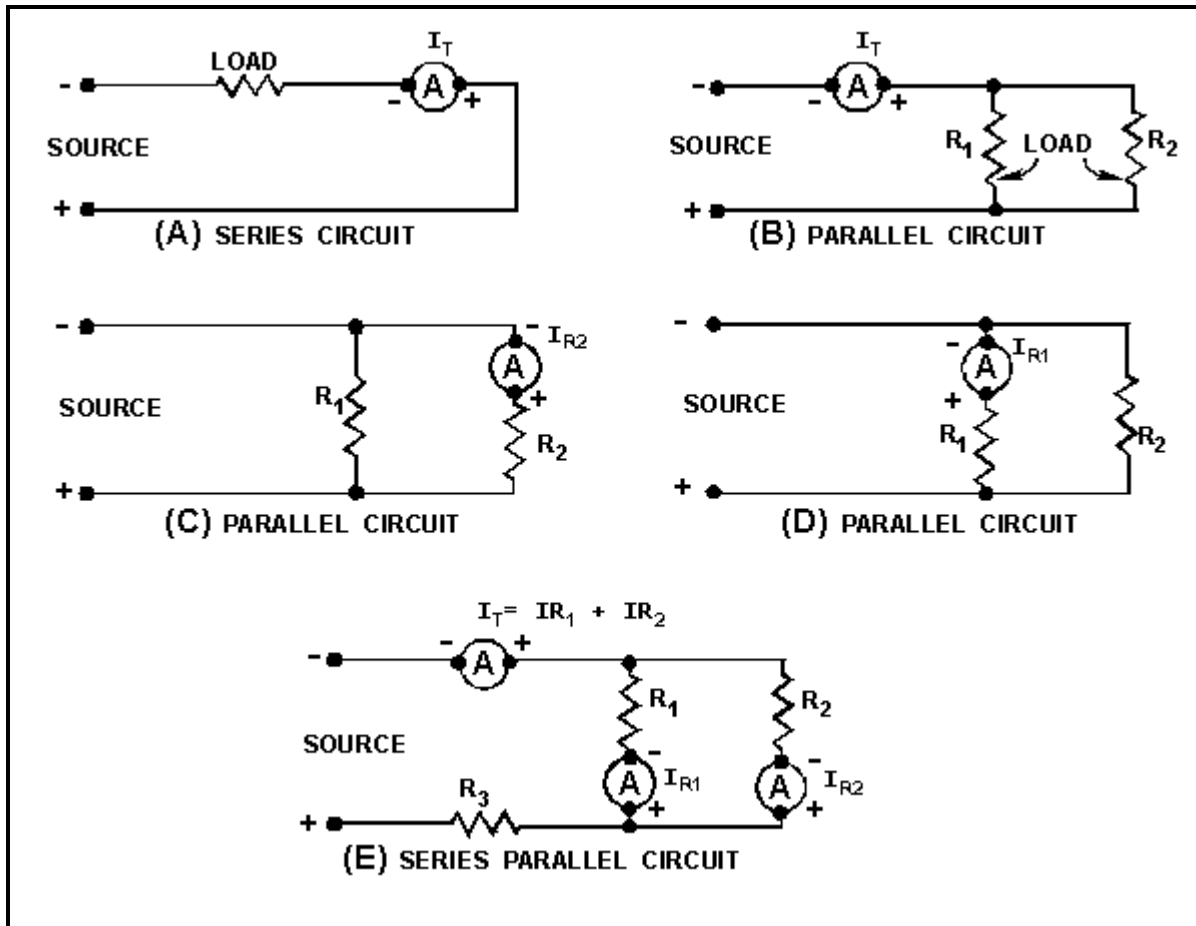


Figure 1-20.—Proper ammeter connections.

Connecting an ammeter in parallel would give you not only an incorrect measurement, it would also damage the ammeter, because too much current would pass through the meter.

### EFFECT ON CIRCUIT BEING MEASURED

The meter affects the circuit resistance and the circuit current. If  $R_1$  is removed from the circuit in figure 1-19(A), the total circuit resistance is  $R_2$ . Circuit current

$$(I) \text{ equals } \frac{E}{R_2},$$

with the meter ( $R_1$ ) in the circuit, circuit resistance is  $R_1 + R_2$  and circuit current

$$(I) \frac{E}{R_1 + R_2}.$$

The smaller the resistance of the meter ( $R_1$ ), the less it will affect the circuit being measured. ( $R_1$  represents the total resistance of the meter; not just the resistance of the meter movement.)

## AMMETER SENSITIVITY

Ammeter sensitivity is the amount of current necessary to cause full scale deflection (maximum reading) of the ammeter. The smaller the amount of current, the more "sensitive" the ammeter. For example, an ammeter with a maximum current reading of 1 milliamperere would have a sensitivity of 1 milliamperere, and be more sensitive than an ammeter with a maximum reading of 1 ampere and a sensitivity of 1 ampere. Sensitivity can be given for a meter movement, but the term "ammeter sensitivity" usually refers to the entire ammeter and not just the meter movement. An ammeter consists of more than just the meter movement.

## AMMETER RANGES

If you have a meter movement with a sensitivity of 1 milliamperere, you can connect it in series with a circuit and measure currents up to 1 milliamperere. But what do you do to measure currents over 1 milliamperere?

To answer this question, look at figure 1-21. In figure 1-21(A), 10 volts are applied to two resistors in parallel.  $R_1$  is a 10-ohm resistor and  $R_2$  is a 1.11-ohm resistor. Since voltage in parallel branches is equal-

$$I_{R1} = \frac{10V}{10\Omega} = 1A$$

$$I_{R2} = \frac{10V}{1.11\Omega} = 9A$$

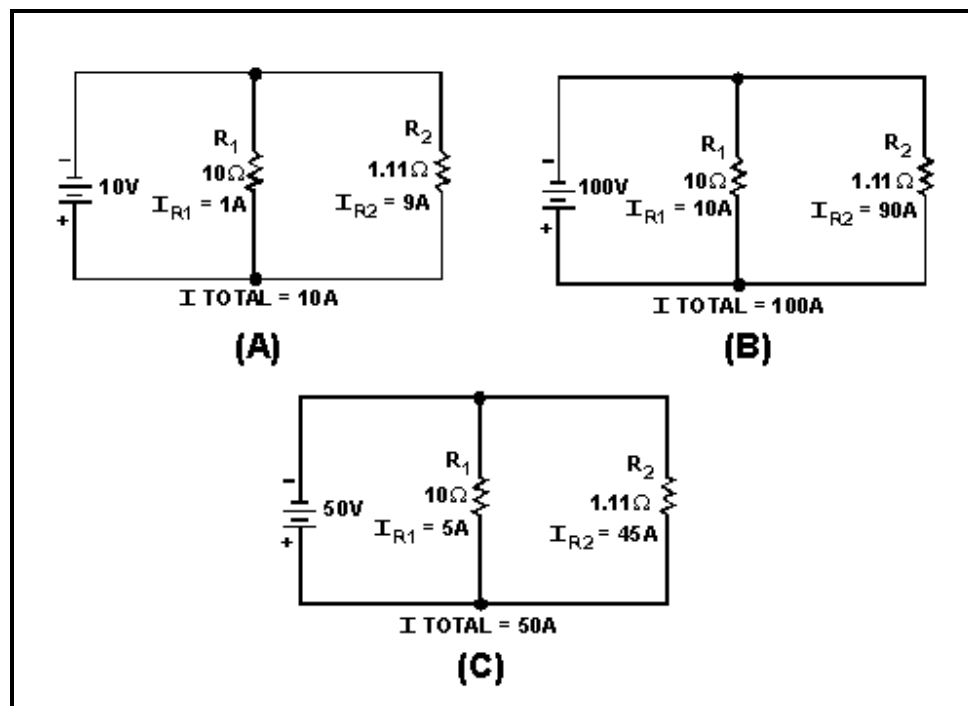


Figure 1-21.—Current in a parallel circuit.

In figure 1-21(B), the voltage is increased to 100 volts. Now,

$$I_{R1} = \frac{100V}{10\Omega} = 10A$$

$$I_{R2} = \frac{100V}{1.11\Omega} = 90A$$

In figure 1-21(C), the voltage is reduced from 100 volts to 50 volts. In this case,

$$I_{R1} = \frac{50V}{10\Omega} = 5A$$

$$I_{R2} = \frac{50V}{1.11\Omega} = 45A$$

Notice that the relationship (ratio) of  $I_{R1}$  and  $I_{R2}$  remains the same.  $I_{R2}$  is nine times greater than  $I_{R1}$  and  $I_{R1}$  has one-tenth of the total current.

If  $R_1$  is replaced by a meter movement that has 10 ohms of resistance and a sensitivity of 10 amperes, the reading of the meter will represent one-tenth of the current in the circuit and  $R_2$  will carry nine-tenths of the current.  $R_2$  is a SHUNT resistor because it diverts, or shunts, a portion of the current from the meter movement ( $R_1$ ). By this method, a 10-ampere meter movement will measure current up to 100 amperes. By adding a second scale to the face of the meter, the current can be read directly.

By adding several shunt resistors in the meter case, with a switch to select the desired resistor, the ammeter will be capable of measuring several different maximum current readings or ranges.

Most meter movements in use today have sensitivities of from 5 microamperes to 1 milliamperere. Figure 1-22 shows the circuit of meter switched to higher ranges, the shunt an ammeter that uses a meter movement with a sensitivity of 100 microamperes and shunt resistors. This ammeter has five ranges (100 microamperes; 1, 10, and 100 milliamperes; 1 ampere) selected by a switch.

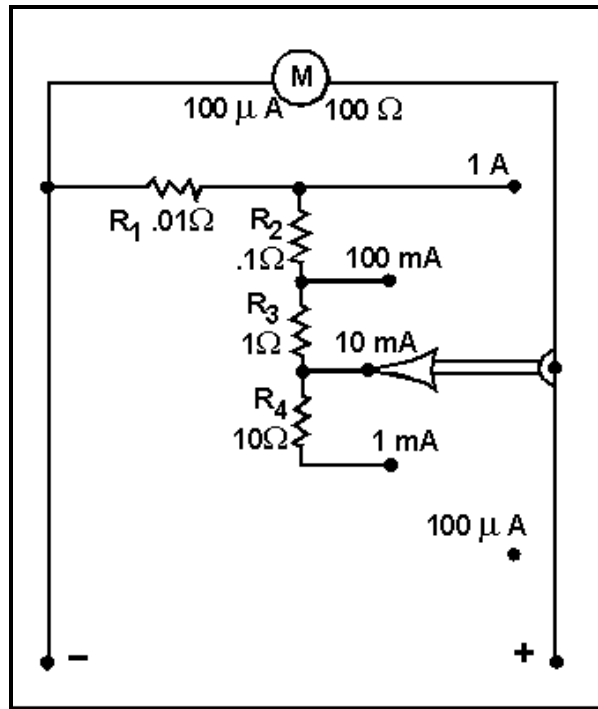


Figure 1-22.—An ammeter with internal shunt resistors.

By adding several shunt resistors in the meter case, with a switch to select the desired resistor, the ammeter will be capable of measuring several different maximum current readings or ranges.

Most meter movements in use today have sensitivities of from 5 microamperes to 1 milliampere. Figure 1-22 shows the circuit of meter switched to higher ranges, the shunt an ammeter that uses a meter movement with a sensitivity of 100 microamperes and shunt resistors. This ammeter has five ranges (100 microamperes; 1, 10, and 100 milliamperes; 1 ampere) selected by a switch.

With the switch in the 100 microampere position, all the current being measured will go through the meter movement. None of the current will go through any of the shunt resistors. If the ammeter is switched to the 1 milliampere position, the current being measured will have parallel paths of the meter movement and all the shunt resistors ( $R_1$ ,  $R_2$ ,  $R_3$ , and  $R_4$ ). Now, only a portion of the current will go through the meter movement and the rest of the current will go through the shunt resistors. When the meter is switched to the 10-milliampere position (as shown in fig. 1-22), only resistors  $R_1$ ,  $R_2$ , and  $R_3$  shunt the meter. Since the resistance of the shunting resistance is less than with  $R_4$  in the circuit (as was the case in the 1-milliampere position), more current will go through the shunt resistors and less current will go through the meter movement. As the resistance decreases and more current goes through the shunt resistors. As long as the current to be measured does not exceed the range selected, the meter movement will never have more than 100 microamperes of current through it.

Shunt resistors are made with close tolerances. That means if a shunt resistor is selected with a resistance of .01 ohms (as  $R_1$  in fig. 1-22), the actual resistance of that shunt resistor will not vary from that value by more than 1 percent. Since a shunt resistor is used to protect a meter movement and to allow accurate measurement, it is important that the resistance of the shunt resistor is known very accurately.

Figure 1-22 represents an ammeter with internal shunts. The shunt resistors are inside the meter case and selected by a switch. For limited current ranges (below 50 amperes), internal shunts are most often employed.

For higher current ranges (above 50 amperes) ammeters that use external shunts are used. The external shunt resistor serves the same purpose as the internal shunt resistor. The external shunt is connected in series with the circuit to be measured and in parallel with the ammeter. This shunt (bypasses) the ammeter so only a portion of the current goes through the meter. Each external shunt will be marked with the maximum current value that the ammeter will measure when that shunt is used. Figure 1-23 shows an ammeter that is designed to use external shunts and a d'Arsonval meter movement. Figure 1-23(A) shows the internal construction of the meter and the way in which the external shunt is connected to the meter and to the circuit being measured. Figure 1-23(C) shows some typical external shunts.

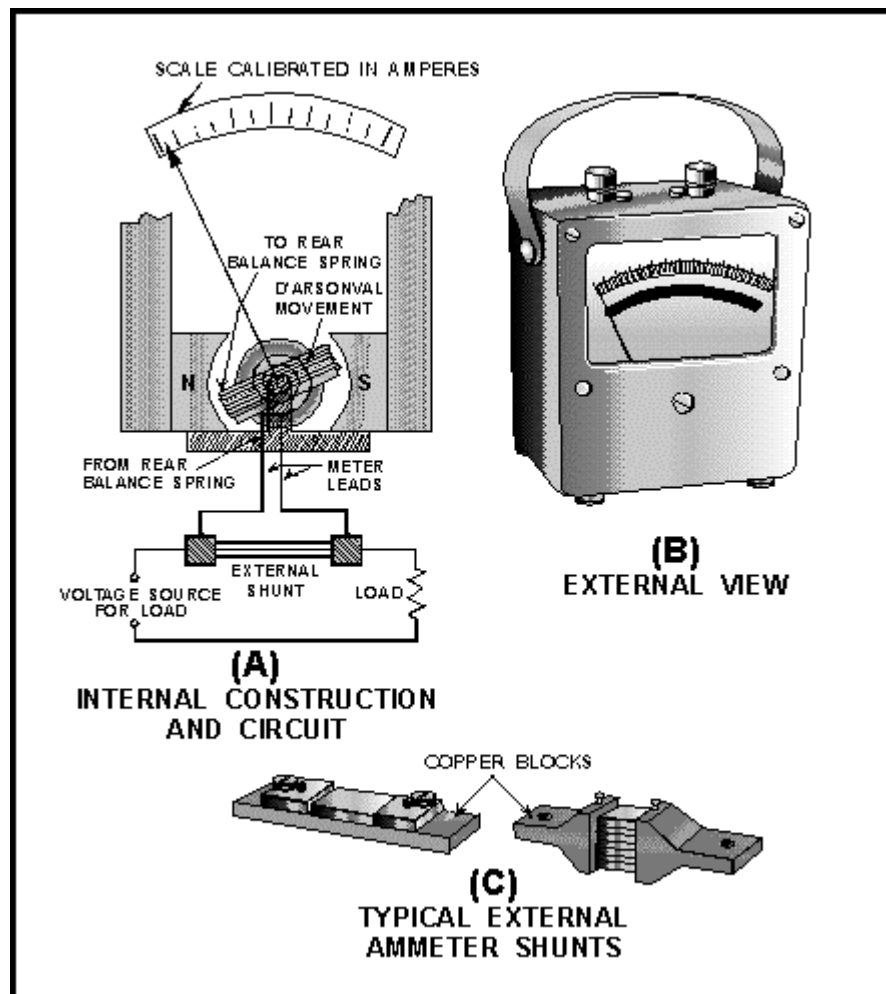


Figure 1-23.—An ammeter employing the d'Arsonval principle and external shunts.

A shunt resistor is nothing more than a resistor in parallel with the meter movement. To measure high currents, very small resistance shunts are used so the majority of the current will go through the shunt. Since the total resistance of a parallel circuit (the meter movement and shunt resistor) is always less than the resistance of the smallest resistor, as an ammeter's range is increased, its resistance decreases. This is important because the load resistance of high-current circuits is smaller than the load resistance of low-current circuits. To obtain accurate measurements, it is necessary that the ammeter resistance be much less than the load resistance, since the ammeter is connected in series with the load.

*Q20. What electrical property does an ammeter measure?*



- Q21. How is an ammeter connected to the circuit under test?
- Q22. How does an ammeter affect the circuit being measured?
- Q23. How is the ammeter's effect on the circuit being measured kept to a minimum?
- Q24. What is ammeter sensitivity?
- Q25. What is used to allow an ammeter to measure different ranges?

### Range Selection

Part of the correct use of an ammeter is the proper use of the range selection switch. If the current to be measured is larger than the scale of the meter selected, the meter movement will have excessive current and will be damaged. Therefore, it is important to always start with the highest range when you use an ammeter. If the current can be measured on several ranges, use the range that results in a reading near the middle of the scale. Figure 1-24 illustrates these points.

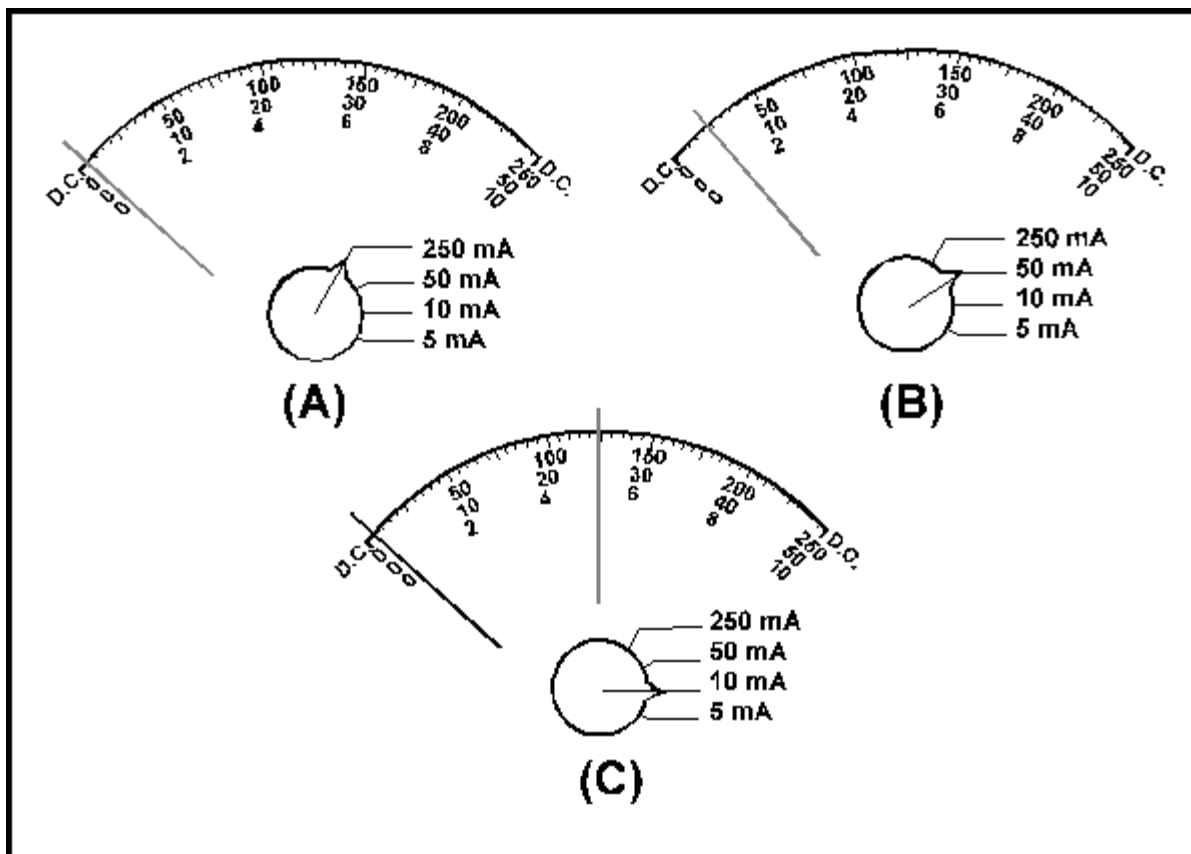


Figure 1-24.—Reading an ammeter at various ranges.

Figure 1-24(A) shows the initial reading of a circuit. The highest range (250 milliamperes) has been selected and the meter indication is very small. It would be difficult to properly interpret this reading with any degree of accuracy. Figure 1-24(B) shows the second reading, with the next largest range (50 milliamperes). The meter deflection is a little greater. It is possible to interpret this reading as 5 milliamperes. Since this approximation of the current is less than the next range, the meter is switched as

shown in figure 1-24(C). The range of the meter is now 10 milliamperes and it is possible to read the meter indication of 5 milliamperes with the greatest degree of accuracy. Since the current indicated is equal to (or greater than) the next range of the ammeter (5 milliamperes), the meter should NOT be switched to the next range.

### **AMMETER SAFETY PRECAUTIONS**

When you use an ammeter, certain precautions must be observed to prevent injury to yourself or others and to prevent damage to the ammeter or the equipment on which you are working. The following list contains the MINIMUM precautions to observe when using an ammeter.

- Ammeters must always be connected in series with the circuit under test.
- Always start with the highest range of an ammeter.
- Deenergize and discharge the circuit completely before you connect or disconnect the ammeter.
- In dc ammeters, observe the proper circuit polarity to prevent the meter from being damaged.
- Never use a dc ammeter to measure ac.
- Observe the general safety precautions of electrical and electronic devices.

*Q26. Why should you use the highest range of an ammeter for the initial measurement?*

*Q27. What range of an ammeter is selected for the final measurement?*

*Q28. List the six safety precautions for the use of ammeters.*

*Q29. Why will an ammeter be damaged if connected in parallel with the circuit to be measured?*

### **VOLTMETERS**

All the meter movements discussed so far react to current, and you have been shown how ammeters are constructed from those meter movements. It is often necessary to measure circuit properties other than current. Voltage measurement, for example, is accomplished with a **VOLTMETER**.

### **VOLTMETERS CONNECTED IN PARALLEL**

While ammeters are always connected in series, voltmeters are always connected in parallel. Figure 1-25 (and the following figures) use resistors to represent the voltmeter movement. Since a meter movement can be considered as a resistor, the concepts illustrated are true for voltmeters as well as resistors. For simplicity, dc circuits are shown, but the principles apply to both ac and dc voltmeters.

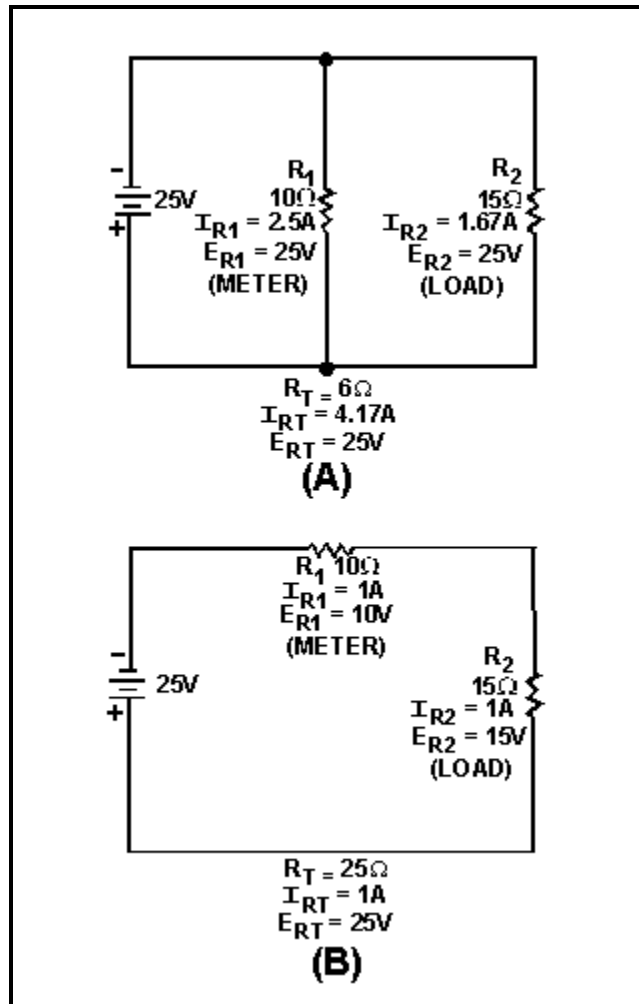


Figure 1-25.—Current and voltage in series and parallel circuits.

Figure 1-25(A) shows two resistors connected in parallel. Notice that the voltage across both resistors is equal. In figure 1-25(B) the same resistors are connected in series. In this case, the voltage across the resistors is not equal. If  $R_1$  represents a voltmeter, the only way in which it can be connected to measure the voltage of  $R_2$  is in parallel with  $R_2$ , as in figure 1-25(A).

### LOADING EFFECT

A voltmeter has an effect on the circuit being measured. This is called **LOADING** the circuit. Figure 1-26 illustrates the loading effect and the way in which the loading effect is kept to a minimum.

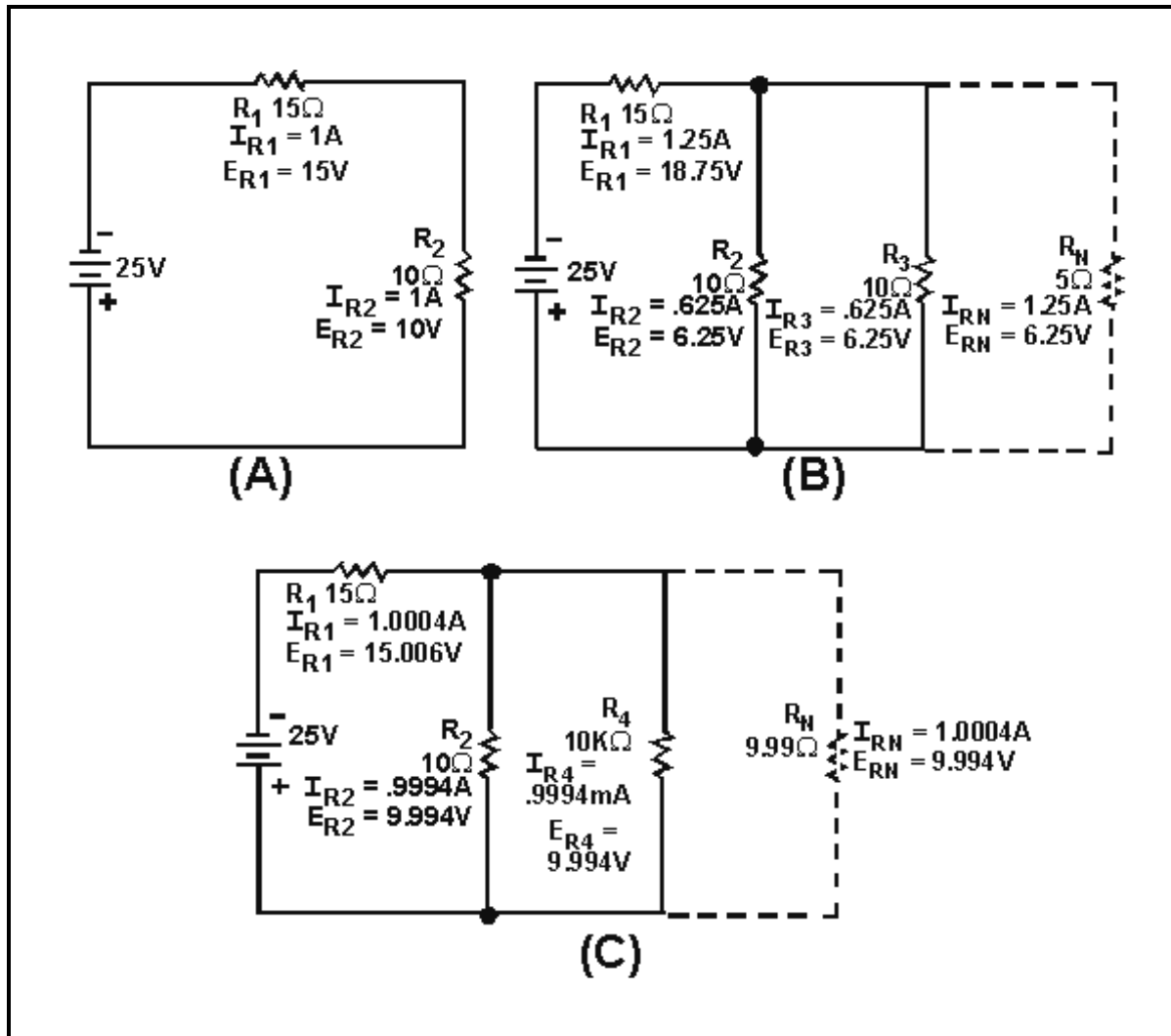


Figure 1-26.—The loading effect.

In figure 1-26(A), a series circuit is shown with  $R_1$  equaling 15 ohms and  $R_2$  equaling 10 ohms. The voltage across  $R_2$  ( $E_{R2}$ ) equals 10 volts. If a meter (represented by  $R_3$ ) with a resistance of 10 ohms is connected in parallel with  $R_2$ , as in figure 1-26(B), the combined resistance of  $R_2$  and  $R_3$  ( $R_N$ ) is equal to 5 ohms. The voltage across  $R_2$  and  $R_3$  is now 6.25 volts, and that is what the meter will indicate. Notice that the voltage across  $R_1$  and the circuit current have both increased. The addition of the meter ( $R_3$ ) has loaded the circuit.

In figure 1-26(C), the low-resistance meter ( $R_3$ ) is replaced by a higher resistance meter ( $R_4$ ) with a resistance of 10 kilohms. The combined resistance of  $R_2$  and  $R_4$  ( $R_N$ ) is equal to 9.99 ohms. The voltage across  $R_2$  and  $R_4$  is now 9.99 volts, the value that will be indicated on the meter. This is much closer to the voltage across  $R_2$ , with no meter ( $R_3$  or  $R_4$ ) in the circuit. Notice that the voltage across  $R$ , and the circuit current in figure 1-26(C) are much closer to the values in 1-26(A). The current ( $I_{R4}$ ) through the meter ( $R_4$ ) in figure 1-26(C) is also very small compared to the current ( $I_{R2}$ ) through  $R_2$ . In figure 1-26(C) the meter ( $R_4$ ) has much less effect on the circuit and does not load the circuit as much. Therefore, a voltmeter should have a high resistance compared to the circuit being measured, to minimize the loading effect.

- Q30. What electrical quantity is measured by a voltmeter?
- Q31. How is a voltmeter connected to the circuit to be measured?
- Q32. What is the loading effect of a voltmeter?
- Q33. How is the loading effect of a voltmeter kept to a minimum?

### MAKING A VOLTMETER FROM A CURRENT SENSITIVE METER MOVEMENT

The meter movements discussed earlier in this chapter have all reacted to current. Various ways have been shown in which these movements can be used in ammeters. If the current and resistance are known, the voltage can be calculated by the formula  $E = IR$ . A meter movement has a known resistance, so as the movement reacts to the current, the voltage can be indicated on the scale of the meter.

In figure 1-27(A), a voltmeter (represented by  $R_2$ ) connected across a 10-ohm resistor with 10 volts applied. The current through the voltmeter ( $R_2$ ) is .1 milliamperes. In figure 1-27(B), the voltage is increased to 100 volts. Now, the current through the voltmeter ( $R_2$ ) is 1 milliampere. The voltage has increased by a factor of 10 and so has the current. This illustrates that the current through the meter is proportional to the voltage being measured.

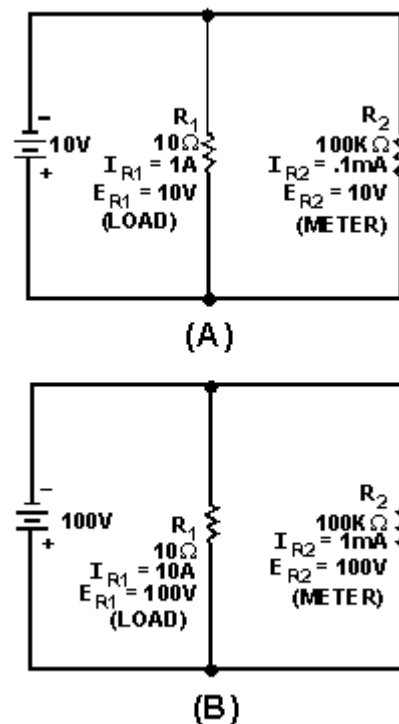


Figure 1-27.—Current and voltage in parallel circuit.

### SENSITIVITY OF VOLTMETERS

Voltmeter sensitivity is expressed in ohms per volt ( $\Omega/V$ ). It is the resistance of the voltmeter at the full-scale reading in volts. Since the voltmeter's resistance does not change with the position of the pointer, the total resistance of the meter is the sensitivity multiplied by the full-scale voltage reading. The higher the sensitivity of a voltmeter, the higher the voltmeter's resistance. Since high resistance voltmeters

have less loading effect on circuits, a high-sensitivity meter will provide a more accurate voltage measurement.

To determine the sensitivity of a meter movement, you need only to divide 1 by the amount of current needed to cause full-scale deflection of the meter movement. The manufacturer usually marks meter movements with the amount of current needed for full-scale deflection and the resistance of the meter. With these figures, you can calculate the sensitivity

$$\left( \frac{1}{\text{full - scale current}} \right)$$

and the full-scale voltage reading full-scale current (full-scale current  $\times$  resistance).

For example, if a meter has a full-scale current of 50 $\mu$ A and a resistance of 960 $\Omega$ , the sensitivity could be calculated as:

$$\text{Sensitivity} = \frac{1}{\text{full - scale current}}$$

$$\text{Sensitivity} = \frac{1}{50\mu\text{A}}$$

$$\text{Sensitivity} = 20\text{k}\Omega / \text{volt}$$

The full-scale voltage reading would be calculated as:

Full-scale voltage reading = full-scale current  $\times$  resistance

Full-scale voltage reading = 50 $\mu$ A  $\times$  960 $\Omega$

Full-scale voltage reading = 48mV

## RANGES

Table 1-1 shows the figures for most meter movements in use today.

**Table 1-1.—Meter Movement Characteristics**

CURRENT TO DEFLECT FULL SCALE	RESISTANCE	SENSITIVITY	VOLTAGE FULL SCALE
1mA	100 $\Omega$	1 k $\Omega$ /VOLT	.1 V
50 $\mu$ A	960 $\Omega$	20 k $\Omega$ /VOLT	.048 V
5 $\mu$ A	5750 $\Omega$	200 k $\Omega$ /VOLT	.029 V

Notice that the meter movements shown in table 1-1 will indicate .029 volts to .1 volt at full scale, and the sensitivity ranges from 1000 ohms per volt to 200,000 ohms per volt. The higher sensitivity

meters indicate smaller amounts of voltage. Since most voltage measurements involve voltage larger than .1 volt, a method must be used to extend the voltage reading.

Figure 1-28 illustrates the method of increasing the voltage range of a voltmeter.

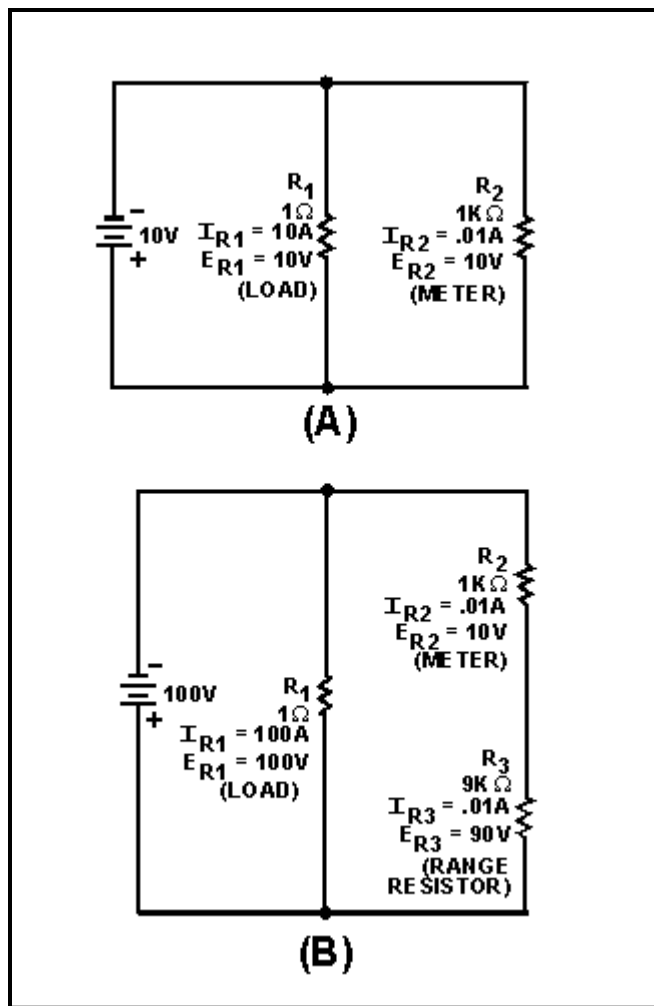


Figure 1-28.—A voltmeter and a range resistor.

In figure 1-28(A), a voltmeter with a range of 10 volts and a resistance of 1 kilohm ( $R_2$ ) is connected in parallel to resistor  $R_1$ . The meter has .01 ampere of current (full-scale deflection) and indicates 10 volts. In figure 1-28(B), the voltage has been increased to 100 volts. This is more than the meter can measure. A 9 kilohm resistor ( $R_3$ ) is connected in series with the meter ( $R_2$ ). The meter ( $R_2$ ) now has .01 ampere of current (full-scale deflection). But since  $R_3$  has increased the voltage capability of the meter, the meter indicates 100 volts.  $R_3$  has changed the range of the meter.

Voltmeters can be constructed with several ranges by the use of a switch and internal resistors. Figure 1-29 shows a voltmeter with a meter movement of 100 ohms and 1 milliampere full-scale deflection with 5 ranges of voltage through the use of a switch. In this way a voltmeter can be used to measure several different ranges of voltage.

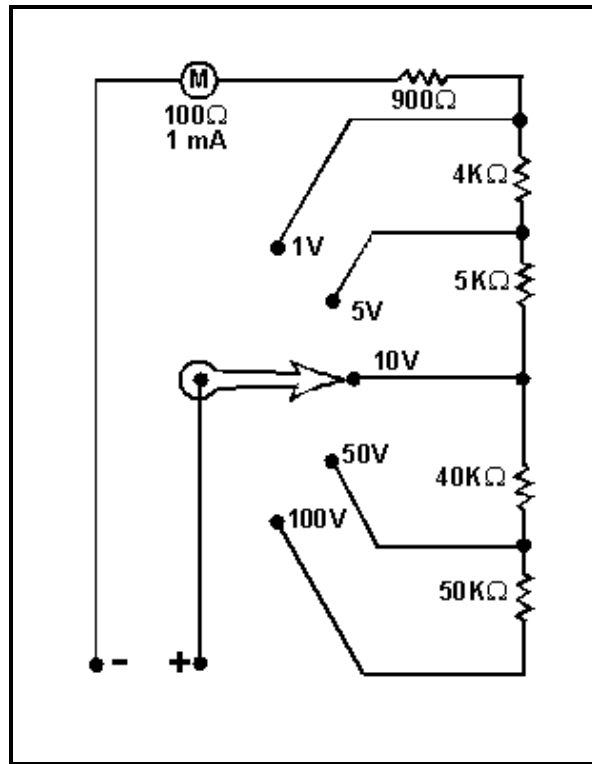


Figure 1-29.—A voltmeter with internal range resistors.

The current through the meter movement is determined by the voltage being measured. If the voltage measured is higher than the range of the voltmeter, excess current will flow through the meter movement and the meter will be damaged. Therefore, you should always start with the highest range of a voltmeter and switch the ranges until a reading is obtained near the center of the scale. Figure 1-30 illustrates these points.



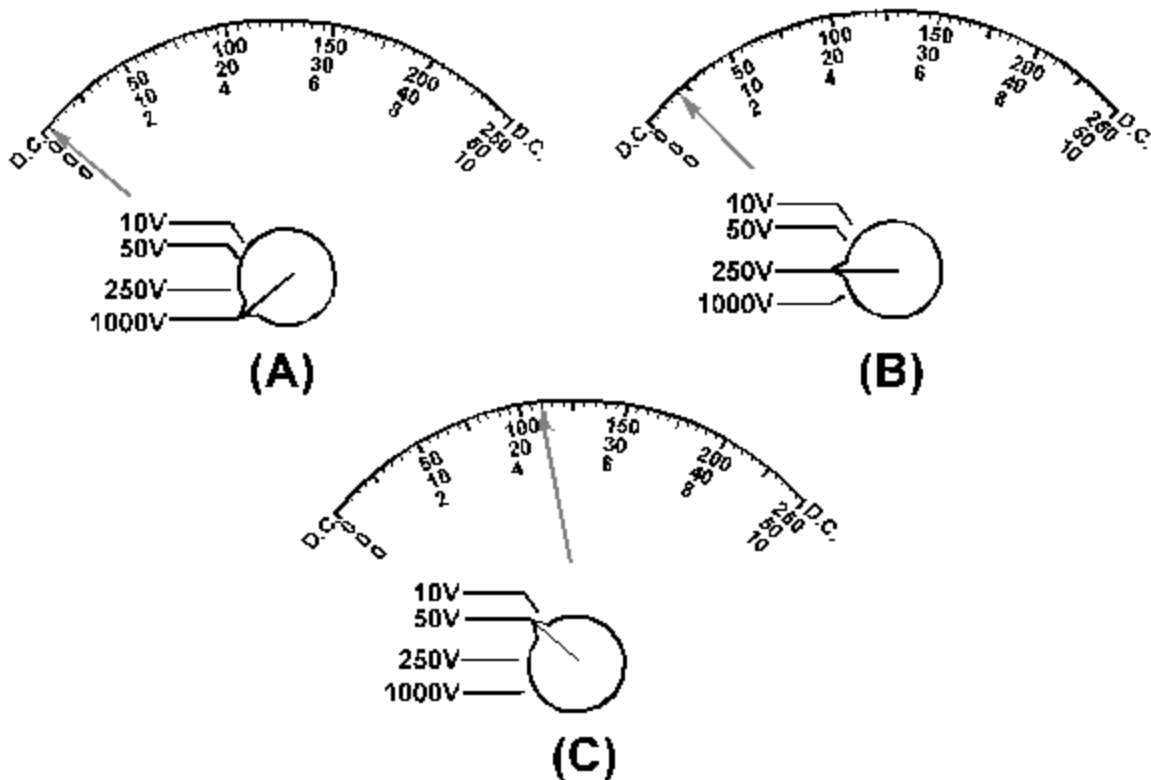


Figure 1-30.—Reading a voltmeter at various ranges.

In figure 1-30(A) the meter is in the 1000-volt range. The pointer is barely above the 0 position. It is not possible to accurately read this voltage. In figure 1-30(B) the meter is switched to the 250 volt range. From the pointer position it is possible to approximate the voltage as 20 volts. Since this is well below the next range, the meter is switched, as in figure 1-30(C). With the meter in the 50-volt range, it is possible to read the voltage as 22 volts. Since this is more than the next range of the meter (10 volts), the meter would not be switched to the next (lower) scale.

- Q34. How is it possible to use a current sensitive meter movement to measure voltage?
- Q35. What is voltmeter sensitivity?
- Q36. What method is used to allow a voltmeter to have several ranges?
- Q37. Why should you always use the highest range when connecting a voltmeter to a circuit?

## ELECTROSTATIC METER MOVEMENT

The final meter movement covered in this chapter is the ELECTROSTATIC METER MOVEMENT. The other meter movements you have studied all react to current, the electrostatic meter movement reacts to voltage.

The mechanism is based on the repulsion of like charges on the plates of a capacitor. The electrostatic meter movement is actually a large variable capacitor in which one set of plates is allowed to

move. The movement of the plates is opposed by a spring attached to the plates. A pointer that indicates the value of the voltage is attached to these movable plates. As the voltage increases, the plates develop more torque. To develop sufficient torque, the plates must be large and closely spaced. A very high voltage is necessary to provide movement, therefore, electrostatic voltmeters are used only for **HIGH VOLTAGE** measurement.

### **VOLTMETER SAFETY PRECAUTIONS**

Just as with ammeters, voltmeters require safety precautions to prevent injury to personnel and damage to the voltmeter or equipment. The following is a list of the **MINIMUM** safety precautions for using a voltmeter.

- Always connect voltmeters in parallel.
- Always start with the highest range of a voltmeter.
- Deenergize and discharge the circuit completely before connecting or disconnecting the voltmeter.
- In dc voltmeters, observe the proper circuit polarity to prevent damage to the meter.
- Never use a dc voltmeter to measure ac voltage.
- Observe the general safety precautions of electrical and electronic devices.

*Q38. What type of meter movement reacts to voltage rather than current?*

*Q39. What is the only use for the voltage sensitive meter movement?*

*Q40. List the six safety precautions for the use of voltmeters.*

### **OHMMETERS**

The two instruments most commonly used to check the continuity (a complete circuit), or to measure the resistance of a circuit or circuit element, are the **OHMMETER** and the **MEGGER** (megohm meter). The ohmmeter is widely used to measure resistance and check the continuity of electrical circuits and devices. Its range usually extends to only a few megohms. The megger is widely used for measuring insulation resistance, such as between a wire and the outer surface of the insulation, and insulation resistance of cables and insulators. The range of a megger may extend to more than 1,000 megohms.

The ohmmeter consists of a dc ammeter, with a few added features. The added features are:

1. A dc source of potential (usually a 3-volt battery)
2. One or more resistors (one of which is variable)
3. A simple ohmmeter circuit is shown in figure 1-31.

The ohmmeter's pointer deflection is controlled by the amount of battery current passing through the moving coil. Before measuring the resistance of an unknown resistor or electrical circuit, the test leads of the ohmmeter are first shorted together, as shown in figure 1-31. With the leads shorted, the meter is calibrated for proper operation on the selected range. While the leads are shorted, meter current is maximum and the pointer deflects a maximum amount, somewhere near the zero position on the ohms

scale. Because of this current through the meter with the leads shorted, it is necessary to remove the test leads when you are finished using the ohmmeter. If the leads were left connected, they could come in contact with each other and discharge the ohmmeter battery. When the variable resistor (rheostat) is adjusted properly, with the leads shorted, the pointer of the meter will come to rest exactly on the zero position. This indicates **ZERO RESISTANCE** between the test leads, which, in fact, are shorted together. The zero reading of a series-type ohmmeter is on the right-hand side of the scale, where as the zero reading for an ammeter or a voltmeter is generally to the left-hand side of the scale. (There is another type of ohmmeter which is discussed a little later on in this chapter.) When the test leads of an ohmmeter are separated, the pointer of the meter will return to the left side of the scale. The interruption of current and the spring tension act on the movable coil assembly, moving the pointer to the left side ( $\infty$ ) of the scale.

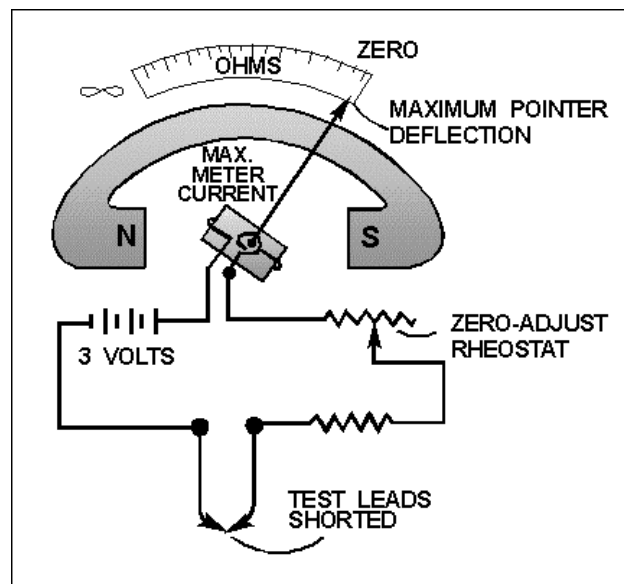


Figure 1-31.—A simple ohmmeter circuit.

## USING THE OHMMETER

After the ohmmeter is adjusted for zero reading, it is ready to be connected in a circuit to measure resistance. A typical circuit and ohmmeter arrangement is shown in figure 1-32.

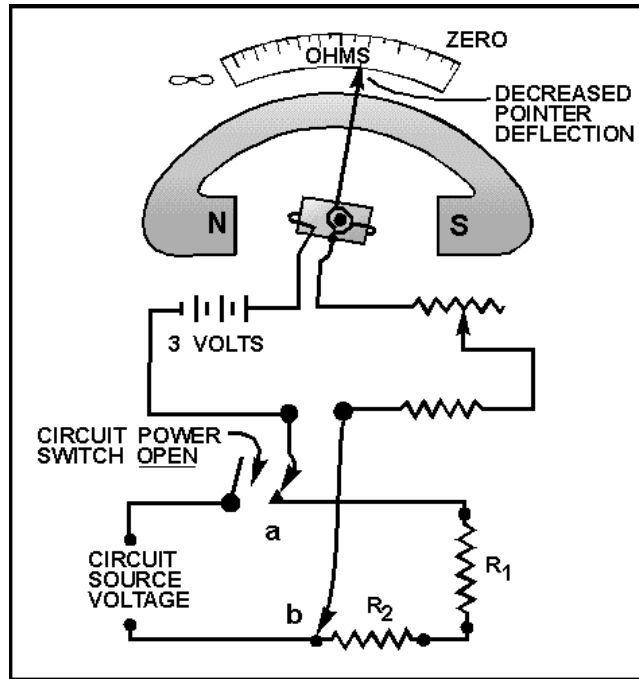


Figure 1-32.—Measuring circuit resistance with an ohmmeter.

The power switch of the circuit to be measured should always be in the **OFF** position. This prevents the source voltage of the circuit from being applied across the meter, which could cause damage to the meter movement.

The test leads of the ohmmeter are connected in series with the circuit to be measured (fig. 1-32). This causes the current produced by the 3-volt battery of the meter to flow through the circuit being tested. Assume that the meter test leads are connected at points a and b of figure 1-32. The amount of current that flows through the meter coil will depend on the total resistance of resistors  $R_1$  and  $R_2$ , and the resistance of the meter. Since the meter has been preadjusted (zeroed), the amount of coil movement now depends solely on the resistance of  $R_1$  and  $R_2$ . The inclusion of  $R_1$  and  $R_2$  raises the total series resistance, decreasing the current, and thus decreasing the pointer deflection. The pointer will now come to rest at a scale figure indicating the combined resistance of  $R_1$  and  $R_2$ . If  $R_1$  or  $R_2$ , or both, were replaced with a resistor(s) having a larger value, the current flow in the moving coil of the meter would be decreased further. The deflection would also be further decreased, and the scale indication would read a still higher circuit resistance. Movement of the moving coil is proportional to the amount of current flow.

## OHMMETER RANGES

The amount of circuit resistance to be measured may vary over a wide range. In some cases it may be only a few ohms, and in others it may be as great as 1,000,000 ohms (1 megohm). To enable the meter to indicate any value being measured, with the least error, scale multiplication features are used in most ohmmeters. For example, a typical meter will have four test lead jacks—**COMMON**,  $R \times 1$ ,  $R \times 10$ , and  $R \times 100$ . The jack marked **COMMON** is connected internally through the battery to one side of the moving coil of the ohmmeter. The jacks marked  $R \times 1$ ,  $R \times 10$ , and  $R \times 100$  are connected to three different size resistors located within the ohmmeter. This is shown in figure 1-33.

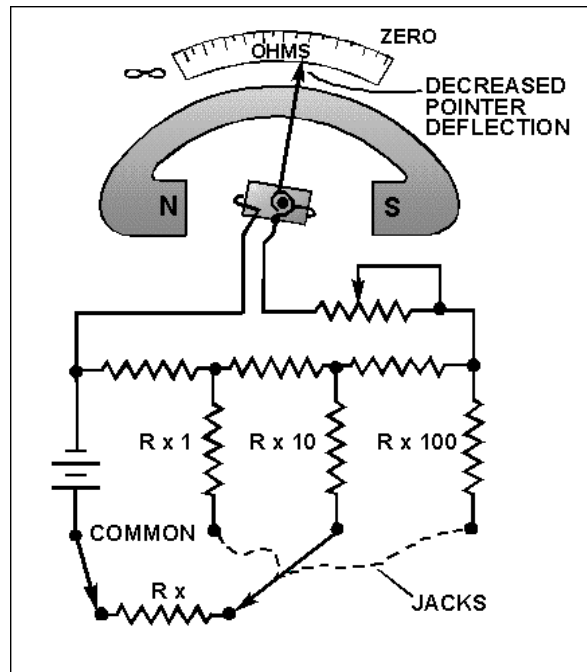


Figure 1-33.—An ohmmeter with multiplication jacks.

Some ohmmeters are equipped with a selector switch for selecting the multiplication scale desired, so only two test lead jacks are necessary. Other meters have a separate jack for each range, as shown in figure 1-33. The range to be used in measuring any particular unknown resistance ( $R_x$  in figure 1-33) depends on the approximate value of the unknown resistance. For instance, assume the ohmmeter in figure 1-33 is calibrated in divisions from 0 to 1,000. If  $R_x$  is greater than 1,000 ohms, and the  $R \times 1$  range is being used, the ohmmeter cannot measure it. This occurs because the combined series resistance of resistor  $R \times 1$  and  $R_x$  is too great to allow sufficient battery current to flow to deflect the pointer away from infinity ( $\infty$ ). (Infinity is a quantity larger than the largest quantity you can measure.) The test lead would have to be plugged into the next range,  $R \times 10$ . With this done, assume the pointer deflects to indicate 375 ohms. This would indicate that  $R_x$  has 375 ohms  $\times 10$ , or 3,750 ohms resistance. The change of range caused the deflection because resistor  $R \times 10$  has about 1/10 the resistance of resistor  $R \times 1$ . Thus, selecting the smaller series resistance permitted a battery current of sufficient amount to cause a useful pointer deflection. If the  $R \times 100$  range were used to measure the same 3,750-ohm resistor, the pointer would deflect still further, to the 37.5-ohm position. This increased deflection would occur because resistor  $R \times 100$  has about 1/10 the resistance of resistor  $R \times 10$ .

The foregoing circuit arrangement allows the same amount of current to flow through the meter's moving coil whether the meter measures 10,000 ohms on the  $R \times 10$  scale, or 100,000 ohms on the  $R \times 100$  scale.

It always takes the same amount of current to deflect the pointer to a certain position on the scale (midscale position for example), regardless of the multiplication factor being used. Since the multiplier resistors are of different values, it is necessary to **ALWAYS** "zero" adjust the meter for each multiplication factor or selected.

You should select the multiplication factor (range) that will result in the pointer coming to rest as near as possible to the midpoint of the scale. This enables you to read the resistance more accurately, because the scale readings are more easily interpreted at or near midpoint.

- Q41. What electrical quantity is measured by an ohmmeter?
- Q42. What other measurement can an ohmmeter make?
- Q43. How is a series-type ohmmeter connected to the circuit being measured?
- Q44. What is used to provide the ohmmeter with several ranges?
- Q45. What area of an ohmmeter scale should be used when measuring circuits?

## SHUNT OHMMETER

The ohmmeter described to this point is known as a series ohmmeter, because the resistance to be measured is in series with the internal resistors and the meter movement of the ohmmeter. Another type of ohmmeter is the **SHUNT OHMMETER**. In the shunt ohmmeter, the resistance to be measured shunts (is in parallel with) the meter movement of the ohmmeter. The most obvious way to tell the difference between the series and shunt ohmmeters is by the scale of the meter. Figure 1-34 shows the scale of a series ohmmeter and the scale of a shunt ohmmeter.

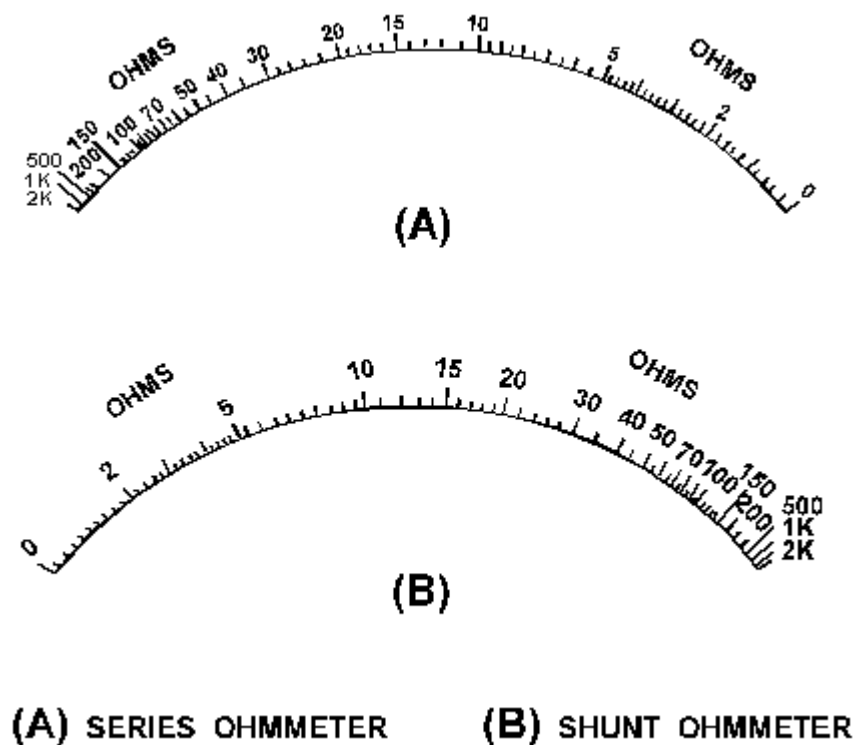


Figure 1-34.—Series and shunt ohmmeter scales.

Figure 1-34(A) is the scale of a series ohmmeter. Notice "0" is on the right and " $\infty$ " is on the left. Figure 1-34(B) is the scale of a shunt ohmmeter. In the shunt ohmmeter " $\infty$ " is on the right and "0" is on the left. A shunt ohmmeter circuit is shown in figure 1-35.

In figure 1-35,  $R_1$  is a rheostat used to adjust the  $\infty$  reading of the meter (full-scale deflection).  $R_2$ ,  $R_3$ , and  $R_4$  are used to provide the  $R \times 1$ ,  $R \times 10$ , and  $R \times 100$  ranges. Points A and B represent the meter leads. With no resistance connected between points A and B the meter has full-scale current and indicates

$\infty$ . If a resistance is connected between points A and B, it shunts some of the current from the meter movement and the meter movement reacts to this lower current. Since the scale of the meter is marked in ohms, the resistance of the shunting resistor (between points A and B) is indicated. Notice that the switch has an **OFF** position, as well as positions for  $R \times 1$ ,  $R \times 10$ , and  $R \times 100$ . This is provided to stop current flow and prevents the battery from being discharged while the meter is not being used.

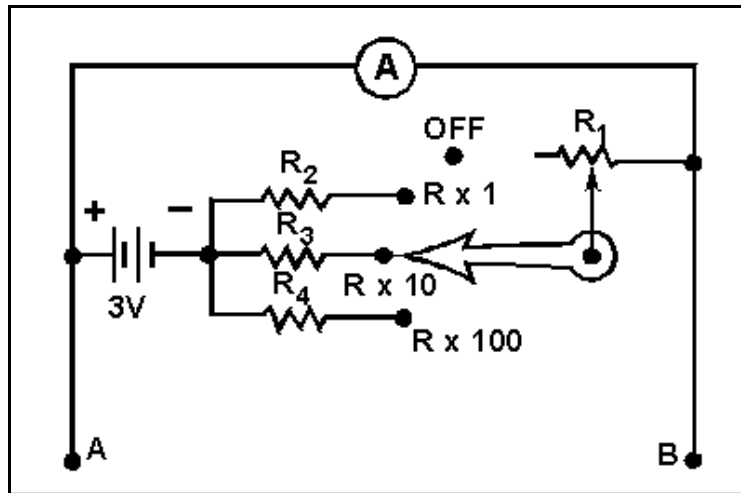


Figure 1-35.—A shunt ohmmeter with internal range resistors.

The shunt ohmmeter is connected to the circuit to be measured in the same way the series ohmmeter is connected. The only difference is that on the shunt ohmmeter the  $\infty$  reading is adjusted, while on the series ohmmeter the 0 reading is adjusted. Shunt ohmmeters are not commonly used because they are limited generally to measuring resistances from 5 ohms to 400 ohms. If you use a shunt ohmmeter, be certain to switch it to the **OFF** position when you are finished using it.

Q46. What are the two types of ohmmeters?

Q47. What is the most obvious difference between the two types of ohmmeters?

Q48. List the four safety precautions observed when using ohmmeters.

## OHMMETER SAFETY PRECAUTIONS

The following safety precautions and operating procedures for ohmmeters are the **MINIMUM** necessary to prevent injury and damage.

- Be certain the circuit is deenergized and discharged before connecting an ohmmeter.
- Do not apply power to a circuit while measuring resistance.
- When you are finished using an ohmmeter, switch it to the OFF position if one is provided and remove the leads from the meter.
- Always adjust the ohmmeter for 0 (or  $\infty$  in shunt ohmmeter) after you change ranges before making the resistance measurement.

## MEGOHMMETER

An ordinary ohmmeter cannot be used for measuring resistance of multimillions of ohms, such as in conductor insulation. To adequately test for insulation break down, it is necessary to use a much higher potential than is furnished by the battery of an ohmmeter. This potential is placed between the conductor and the outside surface of the insulation.

An instrument called a **MEGOHMMETER (MEGGER)** is used for these tests. The megger (fig. 1-36) is a portable instrument consisting of two primary elements: (1) a hand-driven dc generator, G, which supplies the high voltage for making the measurement, and (2) the instrument portion, which indicates the value of the resistance being measured. The instrument portion is of the opposed-coil type, as shown in figure 1-36(A). Coils a and b are mounted on the movable member c with a fixed relationship to each other, and are free to turn as a unit in a magnetic field. Coil b tends to move the pointer counterclockwise, and coil a tends to move the pointer clockwise.

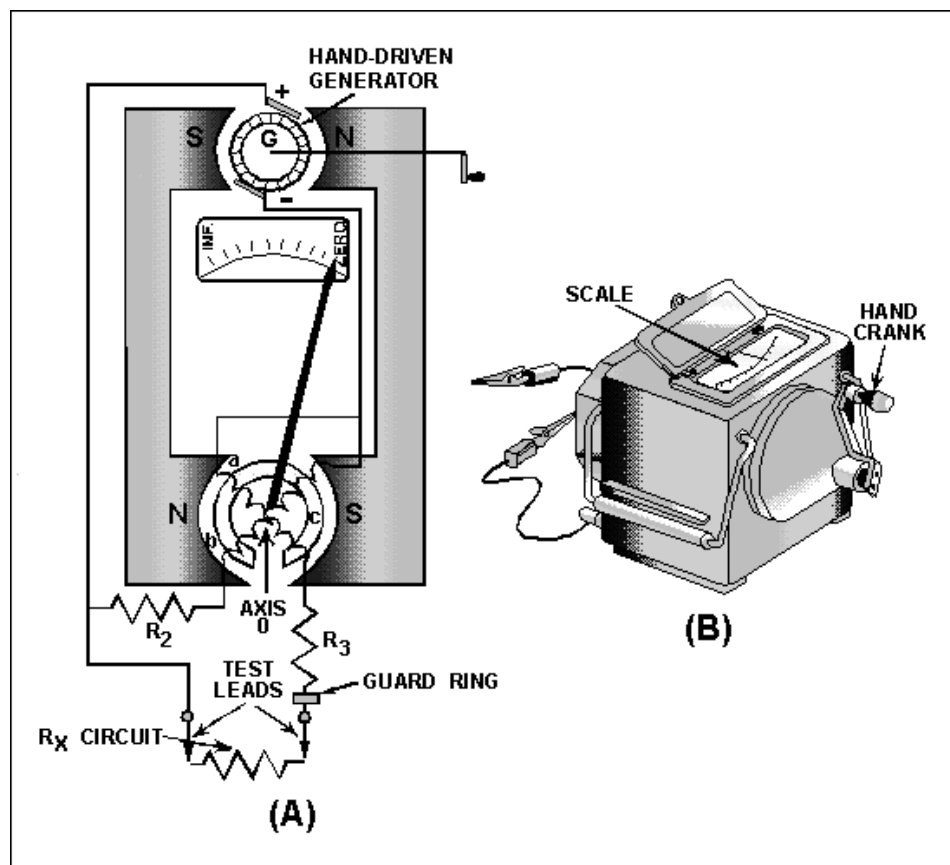


Figure 1-36.—A megger internal circuit.

Coil a is connected in series with R<sub>3</sub> and the unknown resistance, R<sub>x</sub>, to be measured. The combination of coil, R<sub>3</sub>, and R<sub>x</sub> forms a direct series path between the positive (+) and negative (–) brushes of the dc generator. Coil b is connected in series with R<sub>2</sub> and this combination is also connected across the generator. There are no restraining springs on the movable member of the instrument portion of the megger. Therefore, when the generator is not operated, the pointer floats freely and may come to rest at any position on the scale.



The guard ring intercepts leakage current. Any leakage currents intercepted are shunted to the negative side of the generator. They do not flow through coil a; therefore, they do not affect the meter reading.

If the test leads are open-circuited, no current flows in coil a. However, current flows internally through coil b, and deflects the pointer to infinity, which indicates a resistance too large to measure. When a resistance such as  $R_x$  is connected between the test leads, current also flows in coil a, tending to move the pointer clockwise. At the same time, coil b still tends to move the pointer counterclockwise. Therefore, the moving element, composed of both coils and the pointer, comes to rest in a position at which the two forces are balanced. This position depends upon the value of the external resistance, which controls the relative amount of current in coil a. Because changes in voltage affect both coil a and coil b in the same proportion, the position of the moving system is independent of the voltage. If the test leads are short-circuited, the pointer rests at zero because the current in coil a is relatively large. The instrument is not damaged under these circumstances because the current is limited by  $R_3$ .

The external view of one type of megger is shown in figure 1-36(B).

Navy meggers are usually rated at 500 volts. To avoid excessive test voltages, most meggers are equipped with friction clutches. When the generator is cranked faster than its rated speed, the clutch slips and the generator speed and output voltage are not permitted to exceed their rated values. When extremely high resistances—for example, 10,000 megohms or more—are to be measured, a high voltage is needed to cause sufficient current flow to actuate the meter movement. For extended ranges, a 1,000-volt generator is available.

When a megger is used, the generator voltage is present on the test leads. This voltage could be hazardous to you or to the equipment you are checking. Therefore, **NEVER TOUCH THE TEST LEADS WHILE THE MEGGER IS BEING USED** and isolate the item you are checking from the equipment before using the megger.

### Using the Megger

To use a megger to check wiring insulation, connect one test lead to the insulation and the other test lead to the conductor, after isolating the wiring from the equipment. Turn the hand crank until the slip clutch just begins to slip and note the meter reading. Normal insulations should read infinity. Any small resistance reading indicates the insulation is breaking down.

### Megger Safety Precautions

When you use a megger, you could be injured or damage equipment you are working on if the following **MINIMUM** safety precautions are not observed.

- Use meggers on high-resistance measurements only (such as insulation measurements or to check two separate conductors on a cable).
- Never touch the test leads while the handle is being cranked.
- Deenergize and discharge the circuit completely before connecting a megger.
- Disconnect the item being checked from other circuitry, if possible, before using a megger.

*Q49. What is the primary use of a megger?*

Q50. What is the procedure for using a megger to check the insulation of a conductor?

Q51. What is a normal indication on a megger when checking insulation?

Q52. List the four safety precautions observed when using a megger.

## MULTIMETER

A **MULTIMETER** is the most common measuring device used in the Navy. The name multimeter comes from **MULTI**ple **METER**, and that is exactly what a multimeter is. It is a dc ammeter, a dc voltmeter, an ac voltmeter, and an ohmmeter, all in one package. Figure 1-37 is a picture of a typical multimeter.

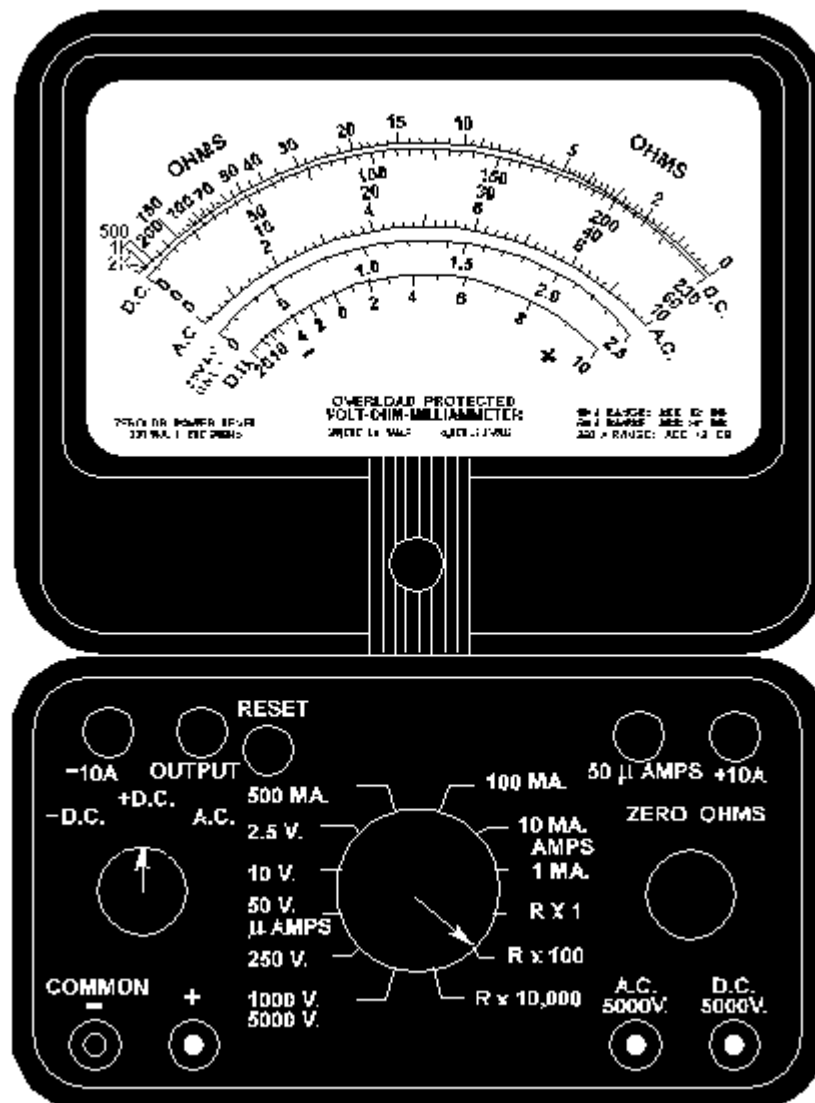


Figure 1-37.—A typical multimeter.

The multimeter shown in figure 1-37 may look complicated, but it is very easy to use. You have already learned about ammeters, voltmeters, and ohmmeters; the multimeter is simply a combination of these meters.

Most multimeters use a d'Arsonval meter movement and have a built-in rectifier for ac measurement. The lower portion of the meter shown in figure 1-37 contains the function switches and jacks (for the meter leads).

The use of the jacks will be discussed first. The **COMMON** or -jack is used in all functions is plugged into the **COMMON** jack. The +jack is used for the second meter lead for any of the functions printed in large letters beside the **FUNCTION SWITCH** (the large switch in the center). The other jacks have specific functions printed above or below them and are self-explanatory (the output jack is used with the dB scale, which will not be explained in this chapter). To use one of the special function jacks, except +10 amps, one lead is plugged into the **COMMON** jack, and the **FUNCTION SWITCH** is positioned to point to the special function (small letters). For example, to measure a very small current (20 microamperes), one meter lead would be plugged into the **COMMON** jack, the other meter lead would be plugged into the 50A AMPS jack, and the **FUNCTION SWITCH** would be placed in the 50V/IA AMPS position. To measure currents above 500 milliamperes, the +10A and -10A jacks would be used on the meter with one exception. One meter lead and the **FUNCTION SWITCH** would be placed in the 10MA/AMPS position.

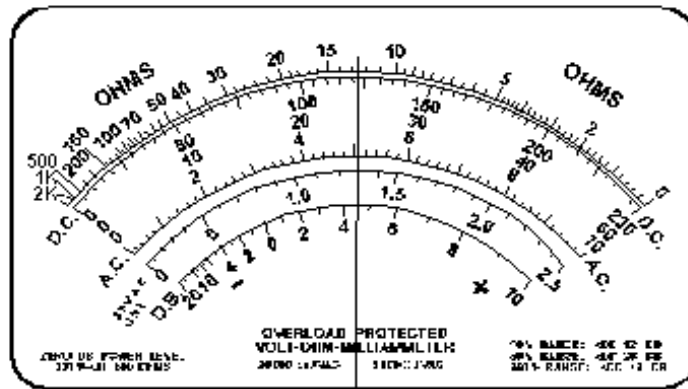
## MULTIMETER CONTROLS

As described above, the **FUNCTION SWITCH** is used to select the function desired; the -DC, +DC, AC switch selects dc or ac (the rectifier), and changes the polarity of the dc functions. To measure resistance, this switch should be in the +DC position.

The **ZERO OHMS** control is a potentiometer for adjusting the 0 reading on ohmmeter functions. Notice that this is a series ohmmeter. The **RESET** is a circuit breaker used to protect the meter movement (circuit breakers will be discussed in chapter 2 of this module). Not all multimeters have this protection but most have some sort of protection, such as a fuse. When the multimeter is not in use, it should have the leads disconnected and be switched to the highest voltage scale and AC. These switch positions are the ones most likely to prevent damage if the next person using the meter plugs in the meter leads and connects the meter leads to a circuit without checking the function switch and the dc/ac selector.

## MULTIMETER SCALES

The numbers above the uppermost scale in figure 1-38 are used for resistance measurement. If the multimeter was set to the  $R \times 1$  function, the meter reading would be approximately 12.7 ohms.



FUNCTION SWITCH	-D.C./+D.C. A.C.	INDICATION
5000 V	+ d.c.	+ 2420.00Vd.c.
1000 V	- d.c.	- 482.00Vd.c.
250 V	+ d.c.	+ 121.00Vd.c.
50 V	a.c.	24.90Va.c.
10 V	a.c.	4.99Va.c.
2.5 V	a.c.	1.28Va.c.
10 A	+ d.c.	4.82Ad.c.
500 mA	a.c.	249.00mA a.c.
100 mA	a.c.	49.90mA a.c.
10mA	+ d.c.	4.82mA d.c.
50 $\mu$ A	+ d.c.	24.20 $\mu$ A d.c.
R x 100	+ d.c.	1.27 k $\Omega$

Figure 1-38.—A multimeter scale and reading.

The numbers below the uppermost scale are used with the uppermost scale for dc voltage and direct current, and the same numbers are used with the scale just below the numbers for ac voltage and alternating current. Notice the difference in the dc and ac scales. This is because the ac scale must indicate effective ac voltage and current. The third scale from the top and the numbers just below the scale are used for the 2.5-volt ac function only. The lowest scale (labeled DB) will not be discussed. The manufacturer's technical manual will explain the use of this scale.

The table in figure 1-38 shows how the given needle position should be interpreted with various functions selected.

As you can see, a multimeter is a very versatile measuring device and is much easier to use than several separate meters.

Q53. What is a multimeter?

Q54. Why is a multimeter preferred over separate meters?

Q55. How is a multimeter changed from a voltage measuring device to a resistance measuring device?

Q56. Why is the dc scale on a multimeter different than the ac scale?

Table 1-2 illustrates an interesting point about multimeters. It was mentioned earlier in this chapter that both voltmeters and ammeters have an effect upon the circuits they measure.

**Table 1-2.—Multimeter Movements**

CURRENT TO DEFLECT FULL SCALE	METER MOVEMENT RESISTANCE	VOLTMETER SENSITIVITY	VOLTAGE FULL SCALE	SHUNT RESISTOR	OVERALL RESISTANCE
1mA	100 $\Omega$	1 k $\Omega$ /VOLT	.1 V	NA	100 $\Omega$
50 $\mu$ A	960 $\Omega$	20 k $\Omega$ /VOLT	.048 V	50.5 $\Omega$	48 $\Omega$
5 $\mu$ A	5750 $\Omega$	200 k $\Omega$ /VOLT	.029 V	29.146 $\Omega$	28.999 $\Omega$

To keep this effect to a minimum, it is necessary that the voltmeter have a high resistance (sensitivity expressed in ohms per volt) and the ammeter have a low resistance compared to the circuit being measured.

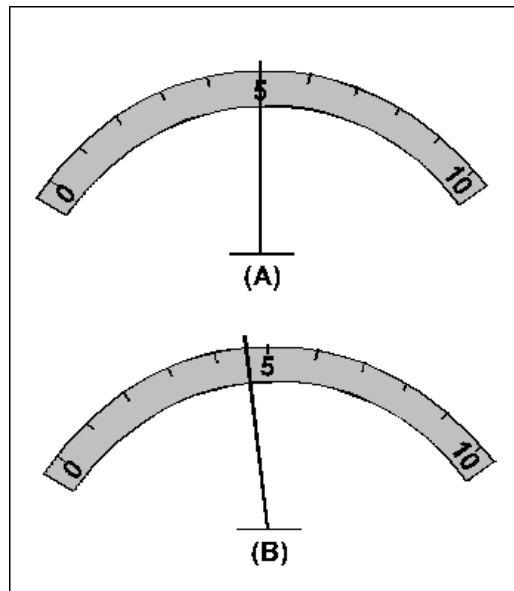
Table 1-2 shows the figures associated with three meter movements available for use in multimeters. The last two columns indicate the value of shunt resistance and the overall resistance of the shunt and meter movement necessary to compensate all three movements to an ammeter sensitivity (full-scale current) of 1 milliamper. Notice that as the voltmeter sensitivity increases, the resistance of the ammeter decreases. This shows how a meter movement used in a voltmeter will have a high effective resistance and the same meter movement used in an ammeter will have a low effective resistance because of the shunt resistors.

## PARALLAX ERROR

Most multimeters (and some other meters) have a mirror built into the scale. Figure 1-39 shows the arrangement of the scale and mirror.



Parallax can be a problem when you are reading a meter. Since the pointer is slightly above the scale (to allow the pointer to move freely), you must look straight at the pointer to have a correct meter reading. In other words, you must be in line with the pointer and the scale. Figure 1-41 shows the effect of parallax error.



**Figure 1-41.—A parallax error in a meter reading.**

Figure 1-41 (A) shows a meter viewed correctly. The meter reading is 5 units. Figure 1-41(B) shows the same meter as it would appear if you were to look at it from the right. The correct reading (5) appears to the right of the pointer because of parallax.

The mirror on the scale of a meter, shown in figure 1-39, helps get rid of parallax error. If there is any parallax, you will be able to see the image of the pointer in the mirror. If you are looking at the meter correctly (no parallax error) you will not be able to see the image of the pointer in the mirror because the image will be directly behind the pointer. Figure 1-42 shows how a mirror added to the meter in figure 1-41 shows parallax error. Figure 1-42(A) is a meter with an indication of 5 units. There is no parallax error in this reading and no image of the pointer is seen in the mirror. Figure 1-42(B) shows the same meter as viewed from the right. The parallax error is shown and the image of the pointer is shown in the mirror.

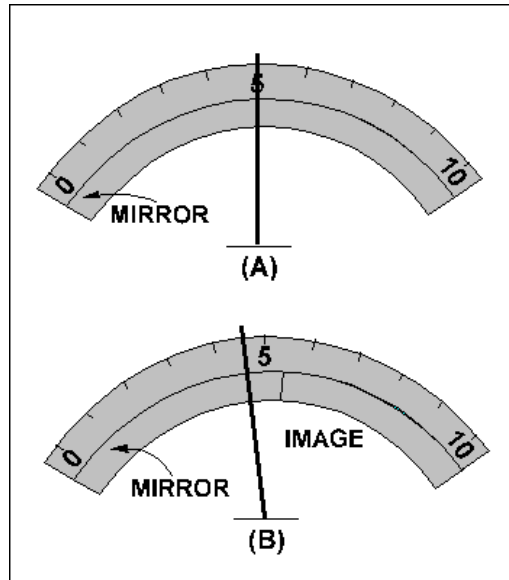


Figure 1-42.—A parallax error on a meter with a mirrored scale.

## MULTIMETER SAFETY PRECAUTIONS

As with other meters, the incorrect use of a multimeter could cause injury or damage. The following safety precautions are the **MINIMUM** for using a multimeter.

- Deenergize and discharge the circuit completely before connecting or disconnecting a multimeter.
- Never apply power to the circuit while measuring resistance with a multimeter.
- Connect the multimeter in series with the circuit for current measurements, and in parallel for voltage measurements.
- Be certain the multimeter is switched to ac before attempting to measure ac circuits.
- Observe proper dc polarity when measuring dc.
- When you are finished with a multimeter, switch it to the OFF position, if available. If there is no OFF position, switch the multimeter to the highest ac voltage position.
- Always start with the highest voltage or current range.
- Select a final range that allows a reading near the middle of the scale.
- Adjust the "0 ohms" reading after changing resistance ranges and before making a resistance measurement.
- Be certain to read ac measurements on the ac scale of a multimeter.
- Observe the general safety precautions for electrical and electronic devices.



*Q57. What is the reason for having a mirror on the scale of a multimeter?*

*Q58. How is the mirror on a multimeter used?*

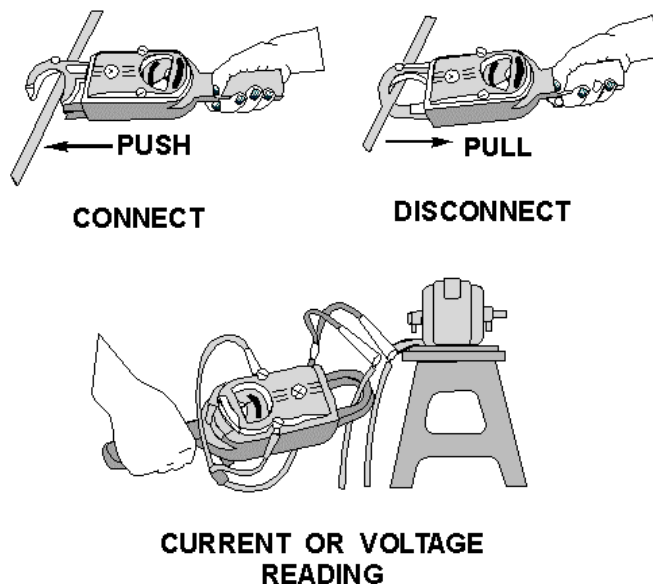
*Q59. List the 11 safety precautions for multimeters.*

## **OTHER METERS**

In addition to the ammeter, voltmeter, ohmmeter, and multimeter, you will probably use many other types of measuring devices. Many of those measuring devices (test equipment) are discussed later in this training series. The following brief discussion of a few additional meters will introduce you to some of common measuring devices you will use in working on electrical and electronic circuits.

### **HOOK-ON TYPE VOLTAMMETER**

The hook-on ac ammeter consists essentially of a current transformer with a split core and a rectifier-type instrument connected to the secondary. The primary of the current transformer is the conductor through which the current to be measured flows. The split core permits the instrument to be "hooked on" the conductor without disconnecting it. Therefore, the current flowing through the conductor may be measured safely and easily, as shown in figure 1-43.



**Figure 1-43.—A hook-on type voltammeter.**

The instrument is usually constructed so that voltages also may be measured. However, in order to read voltage, the meter switch must be set to **VOLTS**, and leads must be connected from the voltage terminals on the meter to terminals across which the voltage is to be measured.

## WATTMETER

Electric power is measured by means of a wattmeter. This instrument is of the electrodynamic type. It consists of a pair of fixed coils, known as current coils, and a movable coil known as the potential coil. (See fig. 1-44.) The fixed coils are made up of a few turns of a comparatively large conductor. The potential coil consists of many turns of fine wire. It is mounted on a shaft, carried in jeweled bearings, so that it may turn inside the stationary coils. The movable coil carries a needle which moves over a suitably marked scale. Spiral coil springs hold the needle to a zero position.

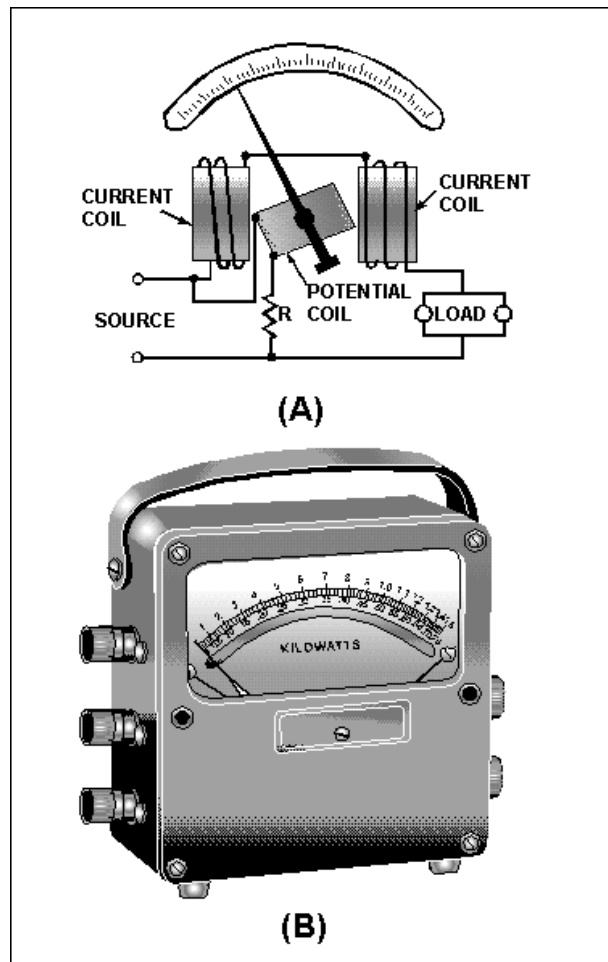


Figure 1-44.—A simplified electrodynamic wattmeter circuit.

The current coil (stationary coil) of the wattmeter is connected in series with the circuit (load), and the potential coil (movable coil) is connected across the line. When line current flows through the current coil of a wattmeter, a field is set up around the coil. The strength of this field is proportional to the line current and in phase with it. The potential coil of the wattmeter generally has a high-resistance resistor connected in series with it. This is for the purpose of making the potential-coil circuit of the meter as purely resistive as possible. As a result, current in the potential circuit is practically in phase with line voltage. Therefore, when voltage is applied to the potential circuit, current is proportional to and in phase with the line voltage.

The actuating force of a wattmeter comes from the field of its current coil and the field of its potential coil. The force acting on the movable coil at any instant (tending to turn it) is proportional to the instantaneous values of line current and voltage.

The wattmeter consists of two circuits, either of which will be damaged if too much current is passed through them. This fact is to be especially emphasized in the case of wattmeters, because the reading of the instrument does not serve to tell the user that the coils are being overheated. If an ammeter or voltmeter is overloaded, the pointer will be indicating beyond the upper limit of its scale. In the wattmeter, both the current and potential circuits may be carrying such an overload that their insulation is burning, and yet the pointer may be only part way up the scale. This is because the position of the pointer depends upon the power factor of the circuit as well as upon the voltage and current. Thus, a low power-factor circuit will give a very low reading on the wattmeter even when the current and potential circuits are loaded to the maximum safe limit. This safe rating is generally given on the face of the instrument. A wattmeter is always distinctly rated, not in watts but in volts and amperes. Figure 1-45 shows the proper way to connect a wattmeter in various circuits.

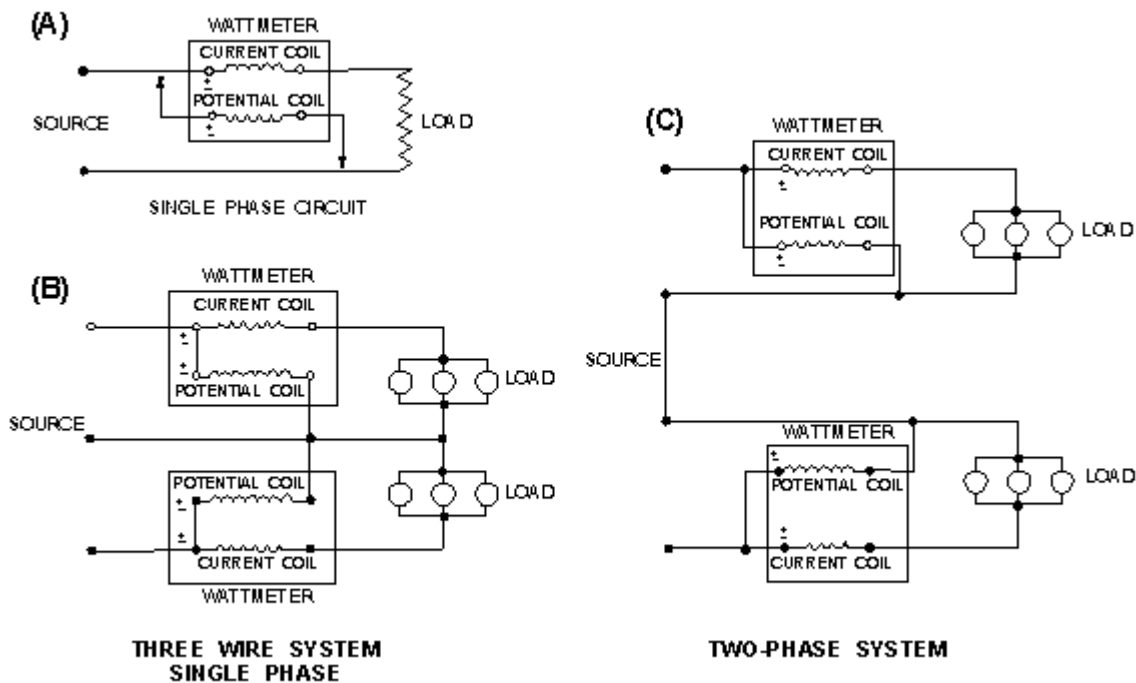


Figure 1-45.—A wattmeter connected in various circuits. TWO-PHASE SYSTEM

## WATT-HOUR METER

The watt-hour meter is an instrument for measuring energy. Since energy is the product of power and time, the watt-hour meter must take into consideration both of these factors.

In principle, the watt-hour meter is a small motor whose instantaneous speed is proportional to the **POWER** passing through it. The total revolutions in a given time are proportional to the total **ENERGY**, or watt-hours, consumed during that time.

The following directions should be followed when reading the dials of a watt-hour meter. The meter, in this case, is a four-dial type.

The pointer on the right-hand dial (fig. 1-46) registers 1 kilowatt-hour, or 1,000 watt-hours, for each division of the dial. A complete revolution of the hand on this dial will move the hand of the second dial one division and register 10 kilowatt-hours, or 10,000 watt-hours. A complete revolution of the hand of the second dial will move the third hand one division and register 100 kilowatt-hours or 100,000 watt-hours, and so on.



Figure 1-46.—Watt-hour meter.

Accordingly, you must read the hands from left to right, and add three zeros to the reading of the lowest dial to obtain the reading of the meter in watt-hours. The dial hands should always be read as indicating the figure which they have **LAST PASSED**, and not the one they are approaching.

*Q60. Why would you use a hook-on voltameter instead of a multimeter?*

*Q61. What electrical quantity is measured by a wattmeter?*

*Q62. What electrical quantity is measured by a watt-hour meter?*

*Q63. What is the quantity shown on the watt-hour meter in figure 1-46?*

## FREQUENCY METERS

All alternating voltage sources are generated at a set frequency or range of frequencies. A frequency meter provides a means of measuring this frequency. Two common types of frequency meters are the vibrating-reed frequency meter and the moving-disk frequency meter.

### Vibrating-Reed Frequency Meter

The vibrating-reed frequency meter is one of the simplest devices for indicating the frequency of an ac source. Vibrating-reed frequency meters are usually in-circuit meters. They are used on power panels

to monitor the frequency of ac. A simplified diagram of one type of vibrating-reed frequency meter is shown in figure 1-47.

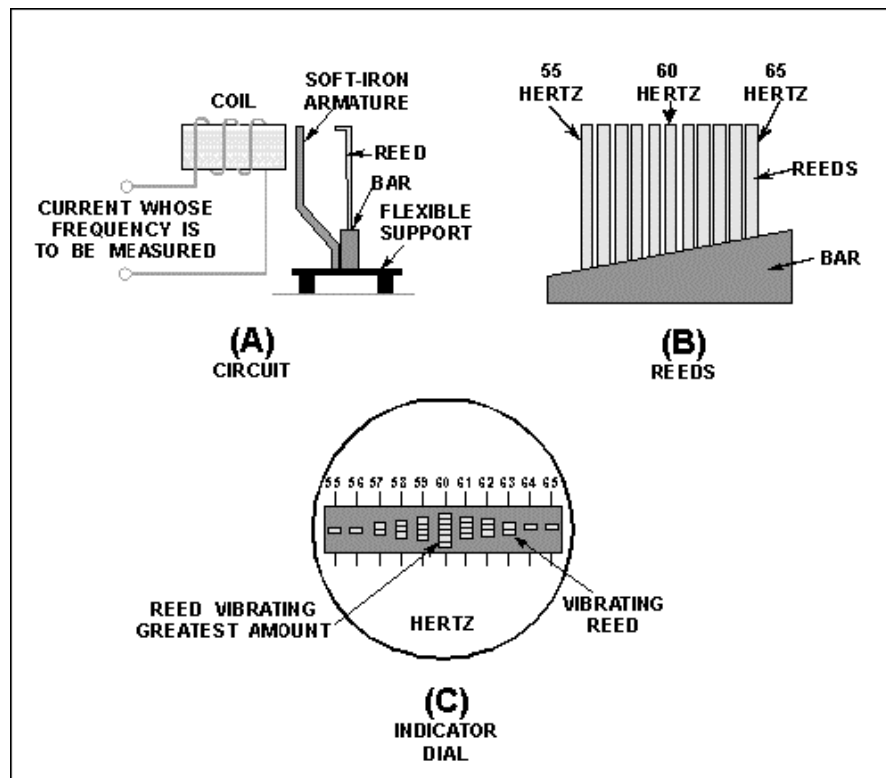


Figure 1-47.—Simplified disc of a vibrating-reed frequency meter. INDICATOR DIAL

The current whose frequency is to be measured flows through the coil and exerts maximum attraction on the soft-iron armature **TWICE** during each cycle (fig. 1-47(A)). The armature is attached to the bar, which is mounted on a flexible support. Reeds having natural vibration frequencies of 110, 112, 114, and so forth, up to 130 hertz are mounted on the bar (fig. 1-47(B)). The reed having a frequency of 110 hertz is marked 55 hertz; the one having a frequency of 112 hertz is marked 56 hertz; the one having a frequency of 120 hertz is marked 60 hertz; and so forth.

When the coil is energized with a current having a frequency between 55 and 65 hertz, all the reeds are vibrated slightly; but, the reed having a natural frequency closest to that of the energizing current (whose frequency is to be measured) vibrates more.

The frequency is read from the scale value opposite the reed having the greatest vibration.

In some instruments the reeds are the same lengths, but are weighted by different amounts at the top so that they will have different natural rates of vibration.

An end view of the reeds is shown in the indicator dial of figure 1-47(C). If the current has a frequency of 60 hertz per second, the reed marked "60" hertz will vibrate the amount, as shown.

## Moving-Disk Frequency Meter

Moving-disk frequency meters are most commonly out-of-circuit meters. They can be used to spot check the frequency of power sources or equipment signals.

A moving-disk frequency meter is shown in figure 1-48. One coil tends to turn the disk clockwise, and the other, counterclockwise. Magnetizing coil A is connected in series with a large value of resistance. Coil B is connected in series with a large inductance and the two circuits are supplied in parallel by the source.

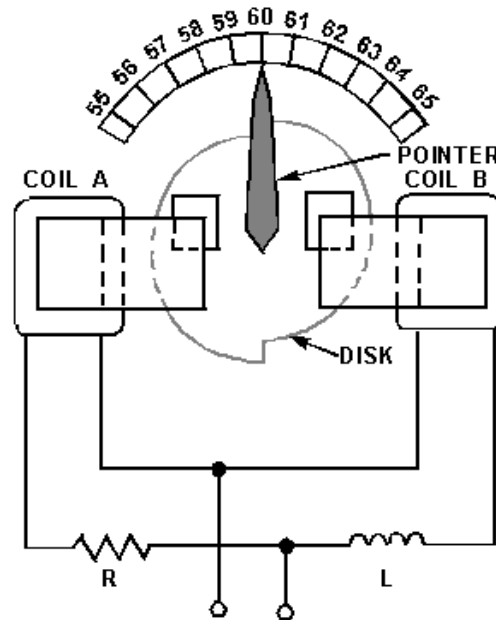


Figure 1-48.—Simplified diagram of a moving-disk frequency meter.

For a given voltage, the current through coil A is practically constant. However, the current through coil B varies with the frequency. At a higher frequency the inductive reactance is greater and the current through coil B is less; the reverse is true at a lower frequency. The disk turns in the direction determined by the stronger coil.

A perfectly circular disk would tend to turn continuously. This is not desirable, and so the disk is constructed so that it will turn only a certain amount clockwise or counterclockwise about the center position, which is commonly marked 60 hertz on commercial equipment. To prevent the disk from turning more than the desired amount, the left half of the disk is mounted so that when motion occurs, the same amount of disk area will always be between the poles of coil A. Therefore, the force produced by coil A to rotate the disk is constant for a constant applied voltage. The right half of the disk is offset, as shown in the figure. When the disk rotates clockwise, an increasing area will come between the poles of coil B; when it rotates counterclockwise, a decreasing area will come between the poles of coil B. The greater the area between the poles, the greater will be the disk current and the force tending to turn the disk.

If the frequency applied to the frequency meter should decrease, the reactance offered by L would decrease and the field produced by coil B would increase. The field produced by coil A would remain the same. Thus, the force produced by coil B would tend to move the disk and the pointer counterclockwise

until the area between the poles was reduced enough to make the two forces equal. The scale is calibrated to indicate the correct frequency.

If the frequency is constant and the voltage is changed, the currents in the two coils-and therefore the opposing forces-change by the same amount. Thus, the indication of the instrument is not affected by a change in voltage.

Q64. What are two types of frequency meters?

Q65. What type of meter is shown and what is the value of the quantity being measured for each meter in figure 1-49?

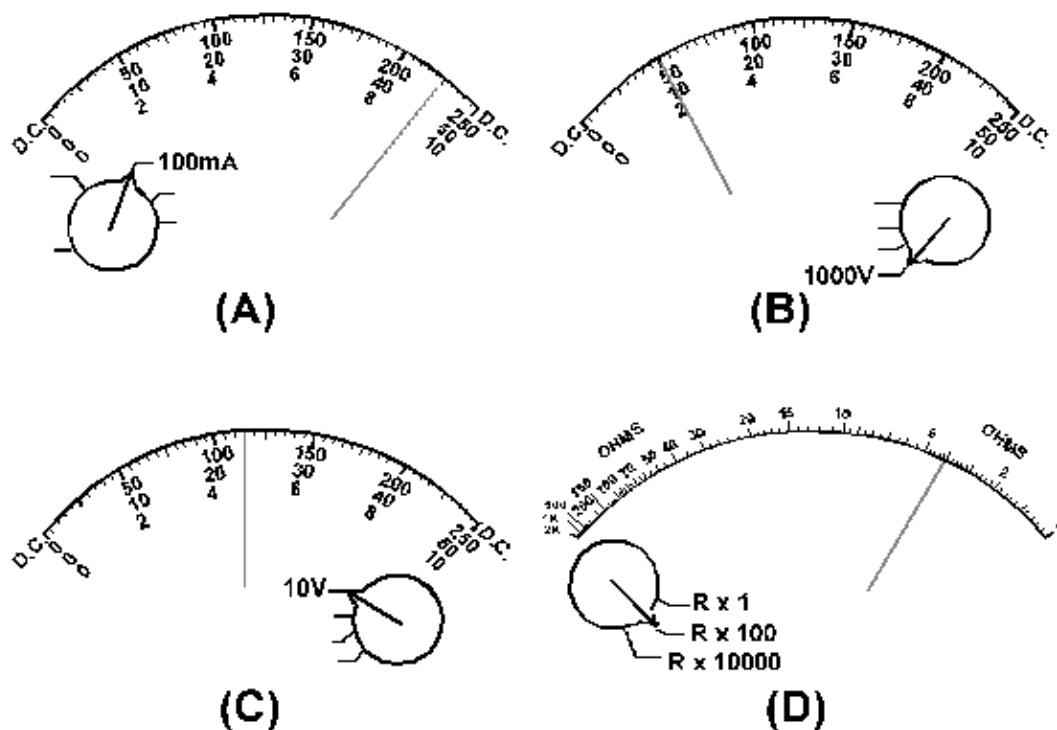


Figure 1-49.—Meter recognition.

Q66. What meter reading is shown on each multimeter in each part of figure 1-50?

Q67. Which part of figure 1-50 shows the switch positions the multimeter should be left in when the meter is secured?

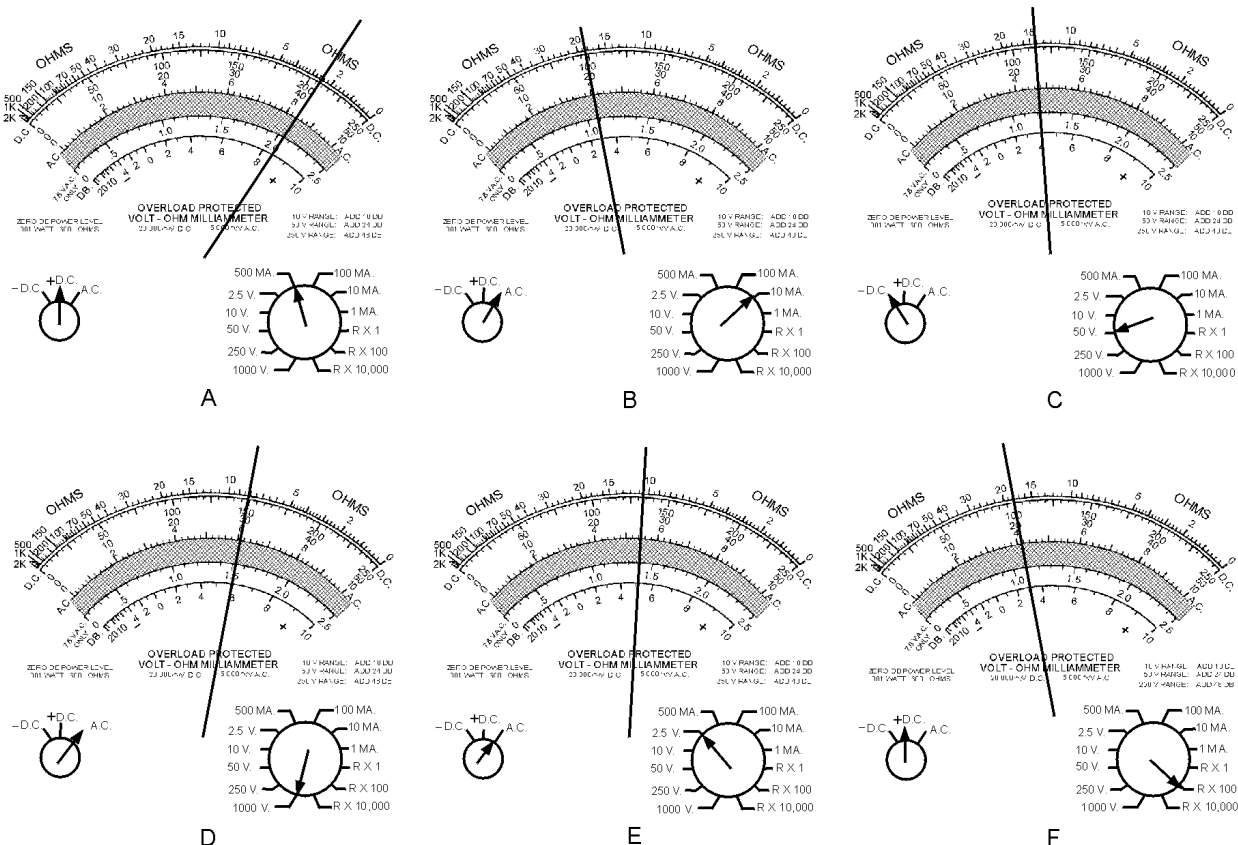


Figure 1-50.—Multimeter reading practice.

- Q68. What type of meter is shown and what is the value of the quantity being measured for each meter in figure 1-51?
- Q69. If the insulation of a conductor was being measured in figure 1-51 (A), would the reading indicate a good insulation?



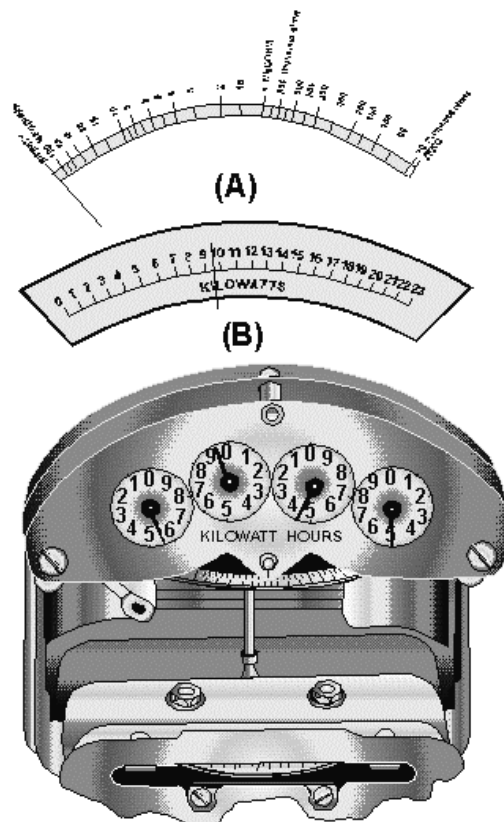


Figure 1-51.—Meter reading practice.

Q70. What type of frequency meter is shown and what is the value indicated for each meter in figure 1-52?

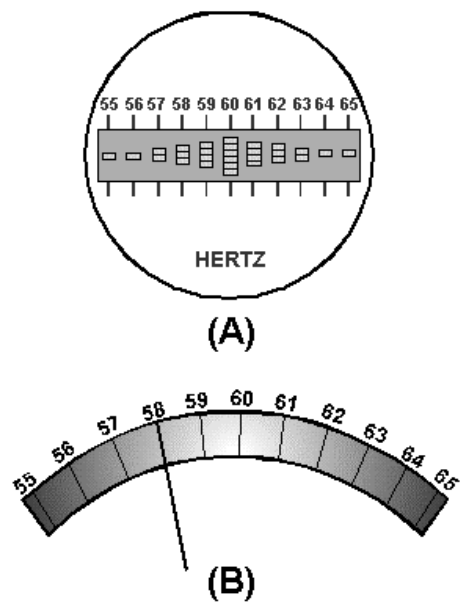


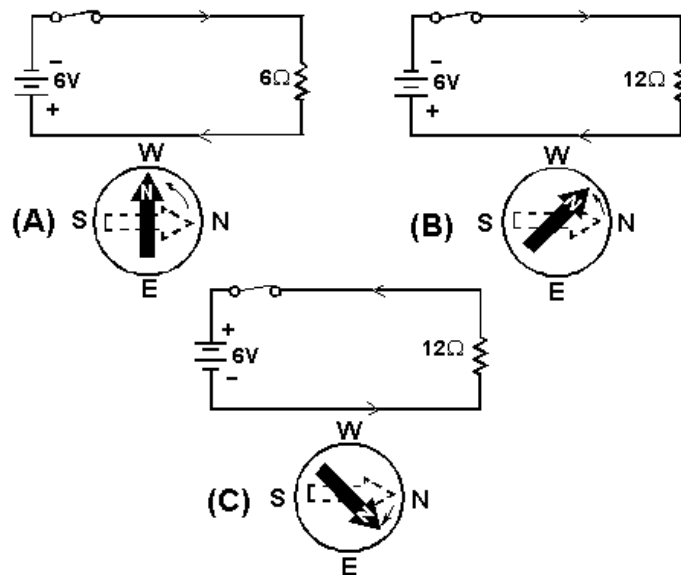
Figure 1-52.—Frequency meter reading.

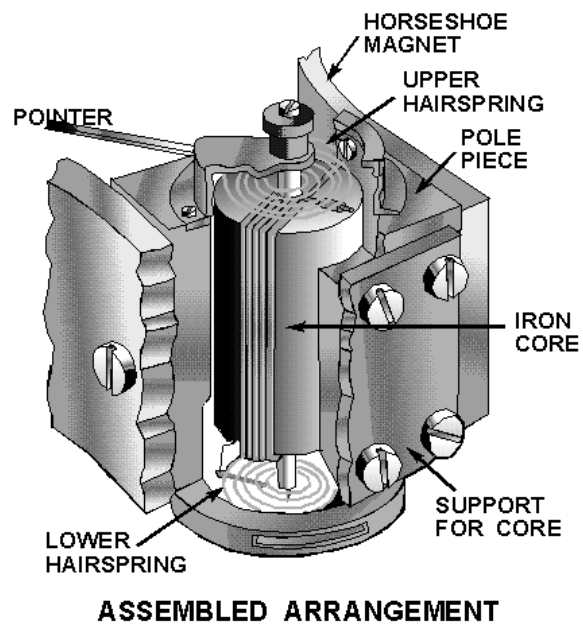
## SUMMARY

The important points of this chapter are summarized in the following summary. You should be familiar with these points before continuing with the study of electricity.

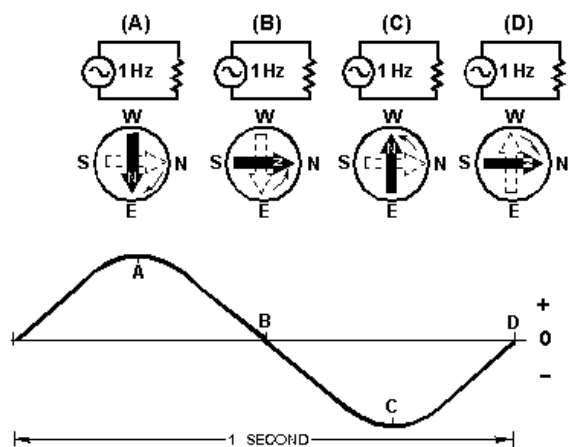
**CIRCUIT MEASUREMENT** is used to monitor the operation of a piece of electrical or electronic equipment and determine the reason the equipment is not functioning properly. In-circuit meters monitor the operation of equipment and out-of-circuit meters can be used on more than one device.

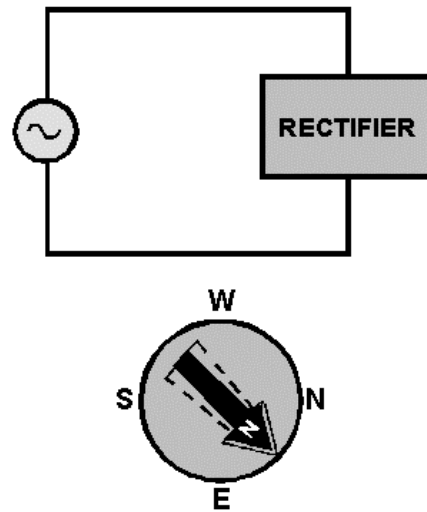
A compass will react to the magnetic field around a conducting wire. As the current increases, the compass movement increases. If the current decreases, the compass movement is less. If the current direction changes, the compass movement changes direction. **PERMANENT-MAGNET MOVING-COIL** meter movement (d'Arsonval movement) uses the interaction of magnetic fields to produce movement.



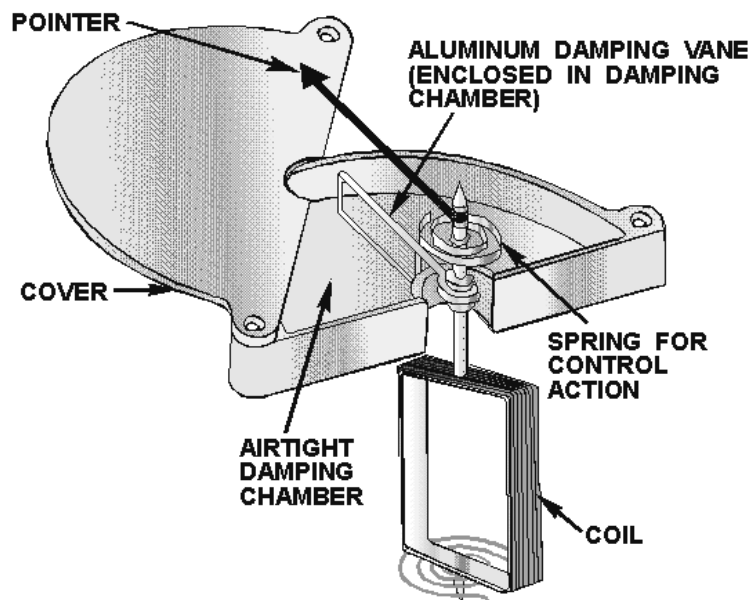


If a compass is placed close to a conductor with ac, the compass will follow the current alternations if the ac is of low frequency. A rectifier will allow the compass to react to the average value of the ac.



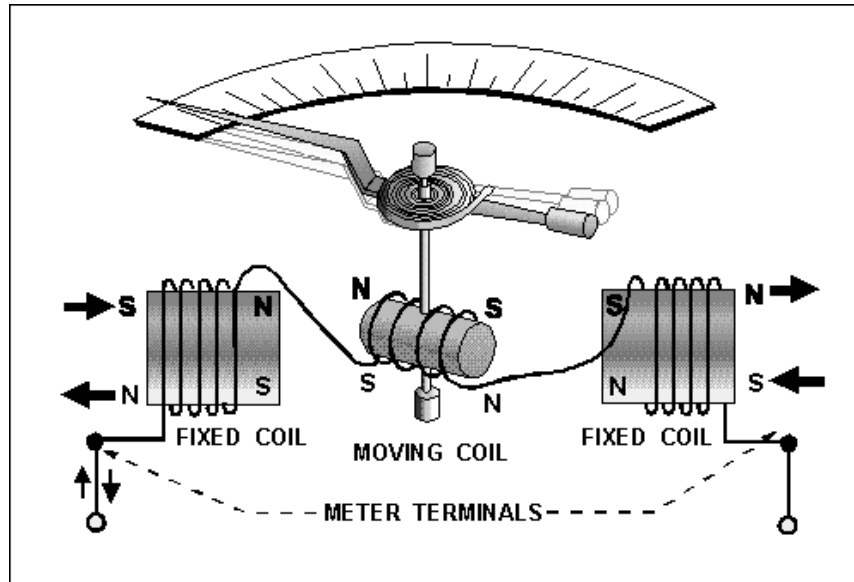


**DAMPING** is used to smooth out the vibration and to help prevent overshooting of the meter pointer. Damping in a d'Arsonval meter movement is accomplished by the emf caused by the coil movement. A second damping system uses a vane attached to the coil in an airtight chamber. A meter movement reacts to the average value of ac, but the scale is calibrated to read the effective (rms) value.

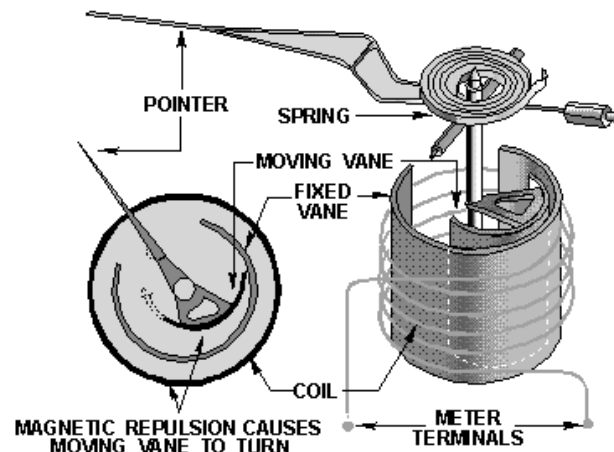


There are meter movements that will measure either ac or dc without the use of a rectifier. They are the **ELECTRODYNAMIC**, **MOVING-VANE**, and **HOT-WIRE** or **THERMOCOUPLE** movements.

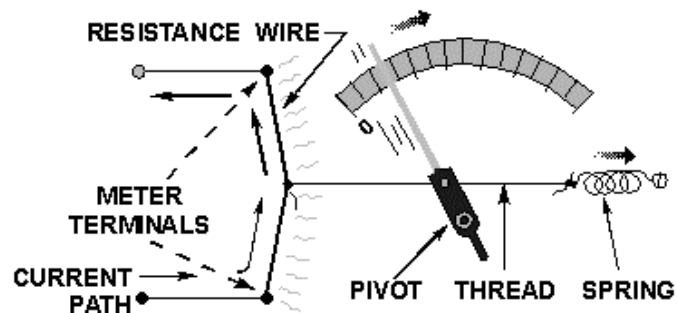
Electrodynamic meter movements are usually used in wattmeters. They operate much like a d'Arsonval meter movement, except field coils are used instead of a permanent magnet.



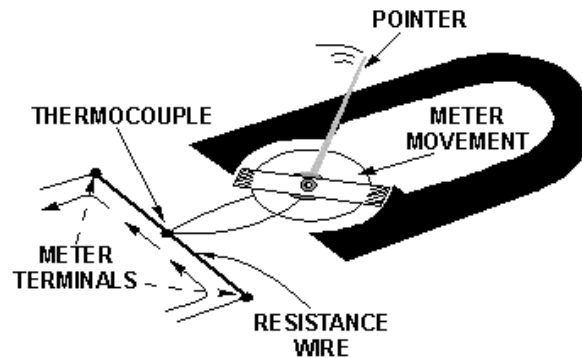
The moving-vane meter movement operates on the principle of magnetic repulsion of like poles. This movement will measure either current or voltage.



The hot-wire movement is only used to measure current. It is based on the expansion of a wire heated by current through the wire.



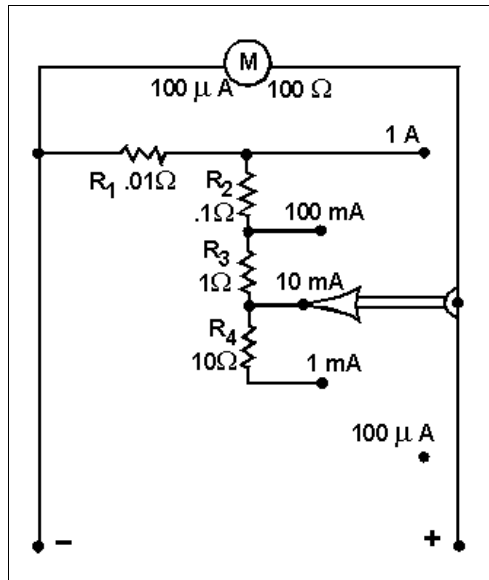
The thermocouple movement uses the current being developed in a thermocouple when the heat of a resistive wire is transferred to the thermocouple. The developed current is measured by a very sensitive dc ammeter. This movement will measure only current.



An **AMMETER** measures current. It is always connected in series with the circuit being measured. An ammeter should have a small resistance so the effect of the ammeter on the circuit will be kept to a minimum. Ammeter sensitivity is the amount of current that causes 0 full scale deflection of the ammeter. Shunt F resistors are used to provide an ammeter's ranges.

The following **SAFETY PRECAUTIONS** should be observed when using an ammeter.

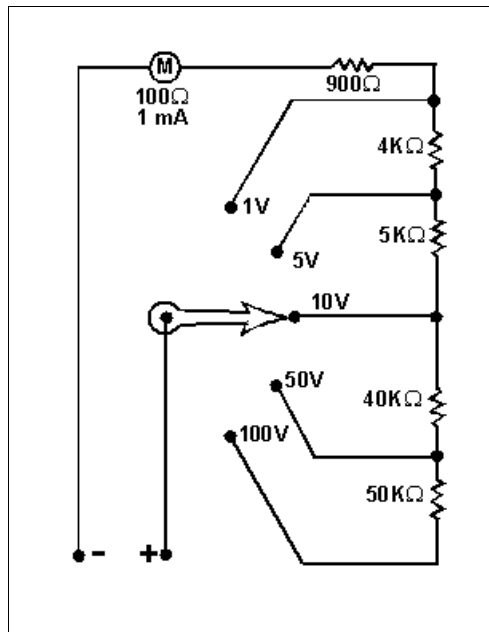
- Always connect an ammeter in series.
- Always start with the highest range.
- Deenergize and discharge the circuit before connecting or disconnecting an ammeter.
- Never use a dc ammeter to measure ac.
- In dc ammeters, observe the proper polarity.



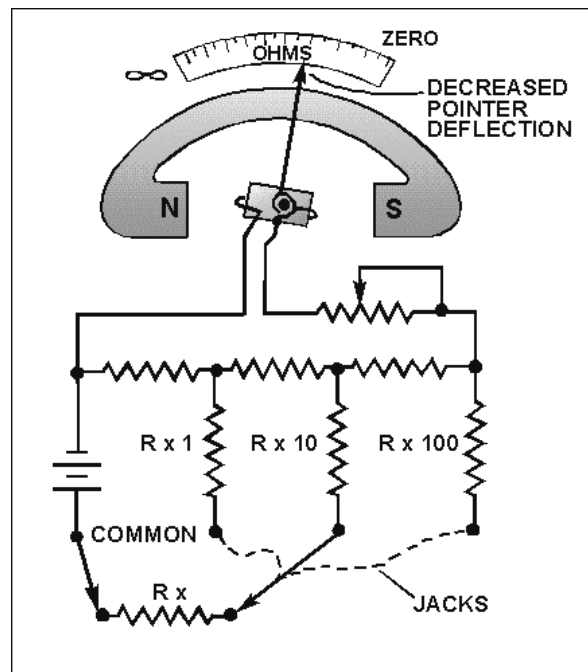
**VOLTMETERS** are used to measure voltage. They are always connected in parallel with the circuit being measured. A voltmeter should have a high resistance compared to the circuit being measured to minimize the loading effect. Since the resistance of a meter movement is constant, a voltmeter can be made from a current-sensitive meter movement by the use of range resistors and an appropriate scale. Voltmeter sensitivity is expressed in ohms per volt.

An electrostatic meter movement reacts to voltage rather than current and is used only for high-voltage measurements. The following **SAFETY PRECAUTIONS** should be observed when using a voltmeter.

- Always connect a voltmeter in parallel.
- Always start with the highest range.
- Deenergize and discharge the circuit before connecting or disconnecting the voltmeter.
- Never use a dc voltmeter to measure an ac voltage.
- On a dc voltmeter, observe the proper polarity.



**OHMMETERS** are used to measure resistance and to check continuity. An ohmmeter is connected in series with the resistance being measured. The ohmmeter range which allows a midscale indication should be selected. Resistors are used to allow an ohmmeter to have several ranges. In a **SERIES OHMMETER** the resistors are used in series with the resistance being measured. Series ohmmeters have the 0 indication on the right side of the scale.

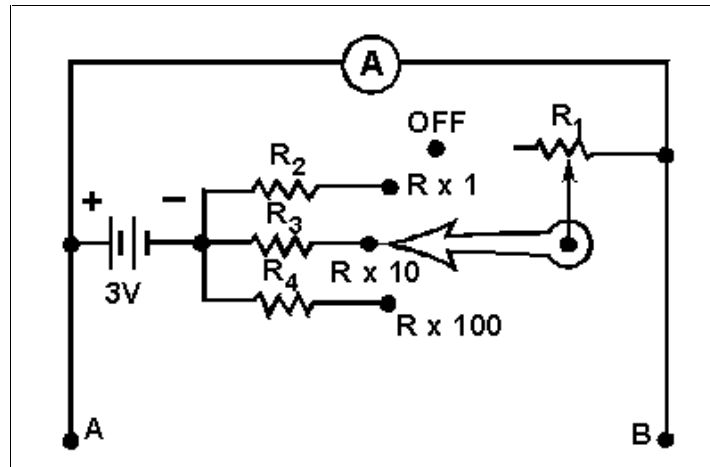


A **SHUNT OHMMETER**'s internal range resistors are in parallel with the resistance being measured. A shunt ohmmeter will have the 0 indication on the left side of the scale.



The following **SAFETY PRECAUTIONS** should be observed when using an ohmmeter.

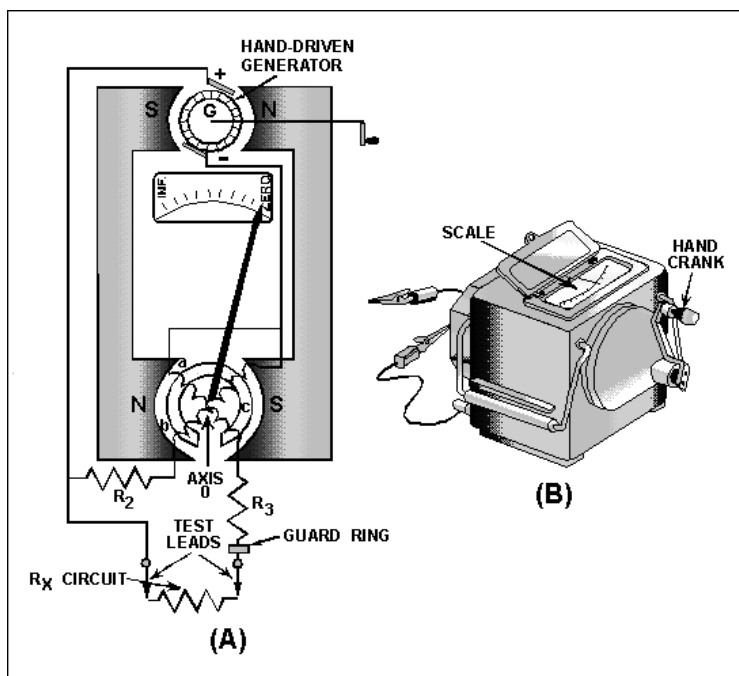
- Deenergize and discharge the circuit before connecting an ohmmeter.
- Do not apply power while measuring resistance.
- Switch ohmmeters OFF, if a setting is provided, or to the highest range and remove the meter leads from the meter when finished measuring resistance.
- Adjust the ohmmeter after changing ranges and before measuring resistance.



A **MEGOHMMETER (MEGGER)** is used to measure very large resistances, such as the insulation of wiring. To use a megger, isolate the resistance being measured from other circuits, connect the meter leads, turn the hand crank, and note the meter indication. Normal insulation will indicate infinity.

The following **SAFETY PRECAUTIONS** should be observed when using a megger. Use meggers for high-resistance measurements only.

- Never touch the test leads while the handle is being cranked.
- Deenergize and discharge the circuit completely before connecting a megger.
- Disconnect the item being checked from other circuitry, if possible, before using megger.

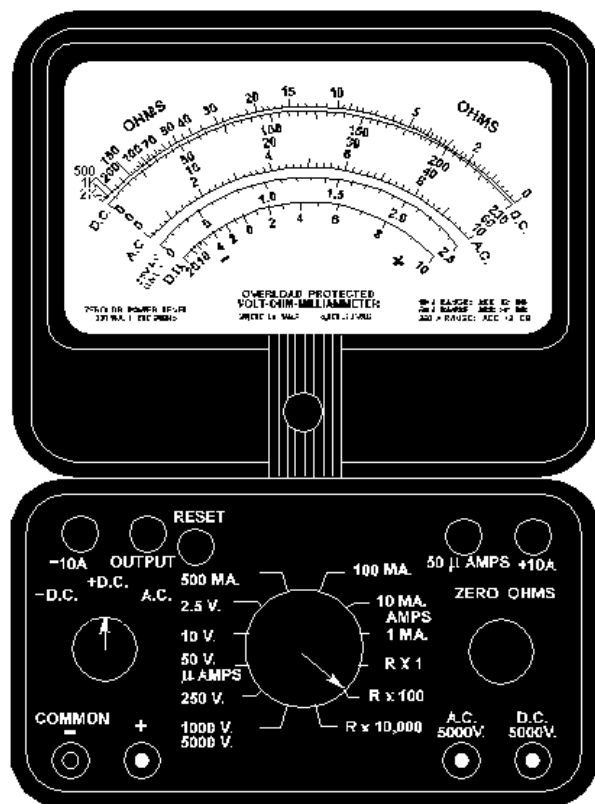


A **MULTIMETER** is a single meter that combines the functions of a dc ammeter, a dc voltmeter, an ac ammeter, an ac voltmeter, and an ohmmeter. It is more convenient to have one meter with several functions than several meters each with a single function. The various functions of a multimeter are selected by use of the appropriate function switch positions, jacks, and meter scales. A mirror may be used on the scale of a multimeter to eliminate parallax error.

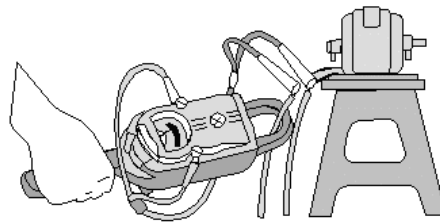
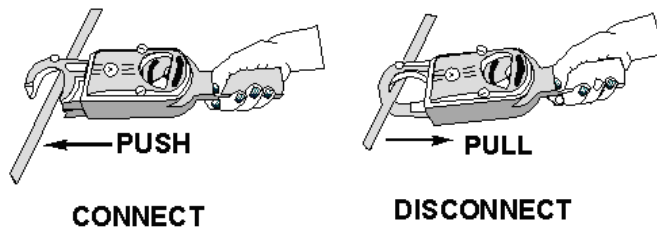
The following **SAFETY PRECAUTIONS** should be observed when using a multimeter.

- Deenergize and discharge the circuit completely before connecting a multimeter.
- Never apply power to the circuit while measuring resistance with a multimeter.
- Connect the multimeter in series with the circuit for current measurements and in parallel for voltage measurements.
- Be certain the multimeter is switched to ac before attempting to measure ac circuits.
- Observe proper dc polarity when measuring dc circuits.
- When you are finished with a multimeter, switch it to the **OFF** position, if available. If there is no **OFF** position, switch the multimeter to the highest ac voltage position.
- Always start with the highest voltage or current range.
- Select a final range that allows a reading near the middle of the scale.
- Adjust the "0 ohms" reading after changing resistance ranges and before making a resistance measurement.

- Be certain to read ac measurements on the ac scale of a multimeter.

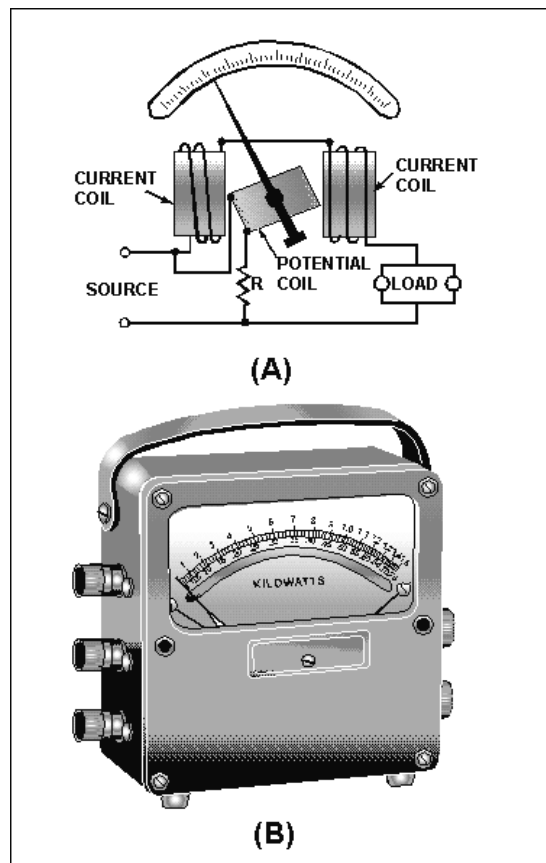


A **HOOKE-ON TYPE VOLTAMETER** allows you to measure current safely and easily (with no need to disconnect the wiring of the circuit). A hook-on type voltameter uses a split-core transformer to measure current.



**CURRENT OR VOLTAGE  
READING**

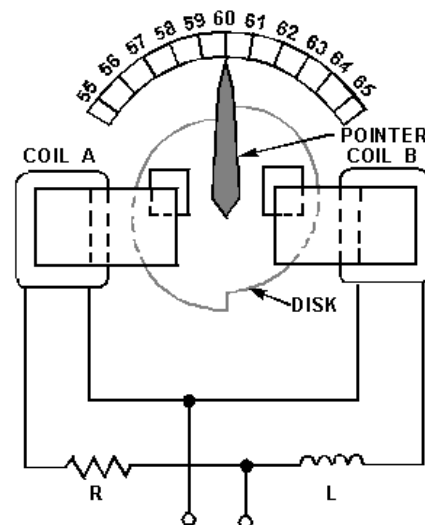
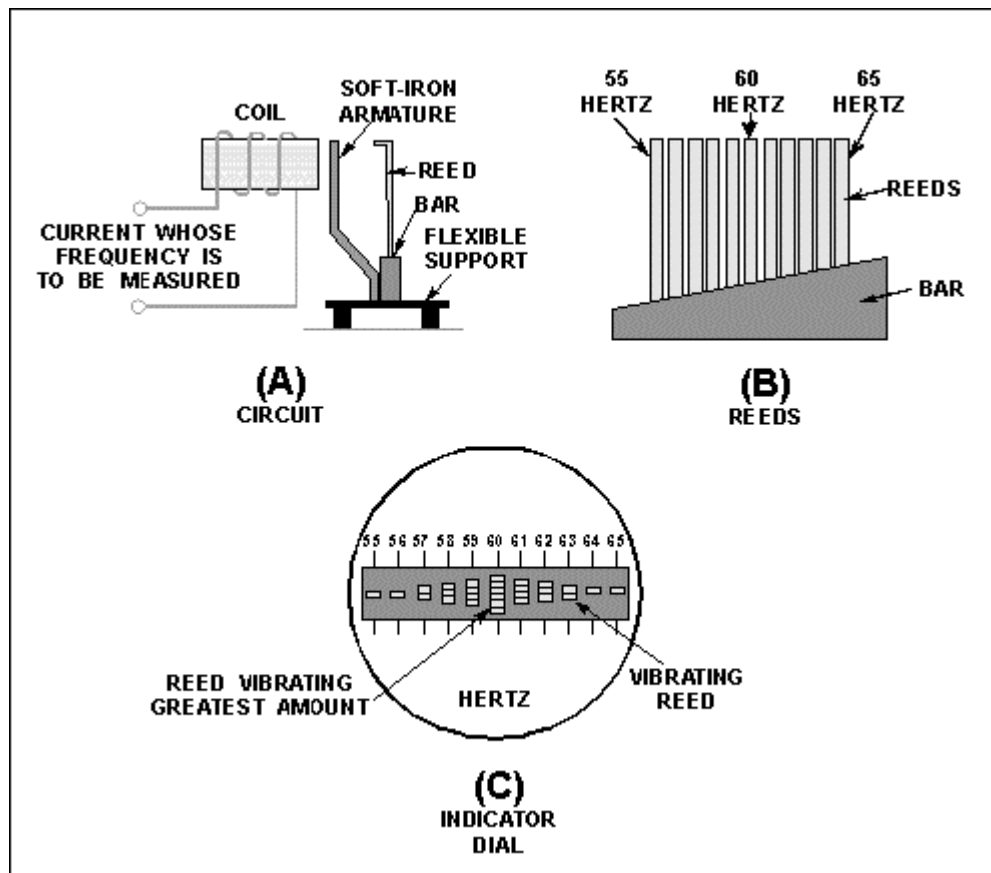
A **WATTMETER** is usually an electrodynamic meter and is used to measure power.



A **WATT-HOUR METER** is basically a small motor whose instantaneous speed is proportional to the power through the motor. The total revolutions in a given time are proportional to the total energy, or watt-hours, used during that time. Watt-hour meters measure energy.



**FREQUENCY METERS** are used to measure the frequency of an ac signal. The two basic types are the vibrating-reed frequency meter which is usually used as an in-circuit meter, and the moving-disk frequency meter which is usually used as an out-of-circuit meter.



## ANSWERS TO QUESTIONS Q1. THROUGH Q70.

- A1. *Circuit measurement is used to (1) monitor the operation of a piece of electrical or electronic equipment and (2) determine the reason a piece of electrical or electronic equipment is not functioning properly.*
- A2. *In-circuit meters are used to monitor the operation of electrical or electronic devices.*
- A3. *Out-of-circuit meters can be used on more than one electrical or electronic device.*
- A4. *The compass needle swings away from magnetic north and aligns itself with the magnetic field around the conductor.*
- A5. *If the current increases the magnetic field increases; if the current decreases the magnetic field decreases.*
- A6. *The compass needle will not be deflected as far from magnetic north.*
- A7. *A permanent-magnet moving-coil meter movement used in most electrical and electronic meters.*
- A8. *A magnetic field is generated around the coil and the attraction of this field with the permanent magnet causes the coil to move.*
- A9. *To return the pointer to its rest position when there is no current flow; to oppose the coil movement when there is current flow; to provide electrical connections for the coil.*
- A10. *The compass needle would swing back and forth as the current changed from positive to negative.*
- A11. *The compass needle would vibrate rapidly around the zero-current point ac meter (magnetic north).*
- A12. *A rectifier changes alternating current to pulsating direct current and allows a dc meter to measure ac.*
- A13. *By the use of a rectifier*
- A14. *The process of "smoothing out" the oscillation in a meter movement.*
- A15. *As the coil moves through the field of the permanent magnet, a current is induced in the coil opposing the movement of the coil; and a vane can be attached to the coil and placed in the airtight chamber so that the movement of the vane opposes the movement of the coil.*
- A16. *Average value.*
- A17. *Effective value (rms).*
- A18. *Electrodynamic, moving vane, and hot-wire or thermocouple.*
- A19. *Current.*
- A20. *Current.*
- A21. *In series.*

- A22. *Since the ammeter is a resistor in series with the load, it increases the resistance of the circuit and lowers circuit current.*
- A23. *The resistance of the ammeter must be much smaller than the circuit load.*
- A24. *The amount of current that will cause full-scale deflection.*
- A25. *Shunt resistors (internal or external).*
- A26. *To prevent damage to the meter movement from excessive current.*
- A27. *A range that allows a meter reading near the center of the scale.*
- A28.
- a. *Always connect an ammeter in series.*
  - b. *Always start with the highest range.*
  - c. *In dc ammeters, observe the proper polarity.*
  - d. *Deenergize and discharge the circuit before connecting or disconnecting the ammeter.*
  - e. *Never use a dc ammeter to measure ac current.*
  - f. *Observe the general safety precautions of electric and electronic devices.*
- A29. *Since the ammeter has a small resistance compared to the load, it will have very high current if it is connected in parallel. This high current will damage the meter.*
- A30. *Voltage.*
- A31. *In parallel.*
- A32. *The connection of a voltmeter adds a resistance in parallel with the circuit changing the total circuit resistance, and loads the circuit.*
- A33. *A voltmeter must have a high resistance compared to the circuit being measured.*
- A34. *Since the resistance of a meter movement remains the same as the pointer is deflected, the amount of current through the movement is proportional to the voltage applied. Therefore, only the scale of the movement must be changed.*
- A35. *It is an indication of the resistance of the meter expressed in ohms per volt. The total resistance of the meter is the sensitivity multiplied by the full-scale voltage.*
- A36. *The use of resistors in series with the meter movement.*
- A37. *To prevent excess current through the meter movement.*
- A38. *Electrostatic.*
- A39. *High-voltage measurement.*



A40.

- a. *Always connect a voltmeter in parallel.*
- b. *Always start with the highest range.*
- c. *Deenergize and discharge the circuit before connecting or disconnecting the voltmeter.*
- d. *In a dc voltmeter, observe the proper polarity.*
- e. *Never use a dc voltmeter to measure ac voltage.*
- f. *Observe the general safety precautions of electric and electronic devices.*

A41. *Resistance.*

A42. *Circuit continuity.*

A43. *The ohmmeter is connected in series with the resistance to be measured.*

A44. *An ohmmeter has several internal range resistors and a switch or a series of jacks to select the proper range.*

A45. *The middle of the scale.*

A46. *Series and shunt.*

A47. *Series ohmmeters have 0 on the right end of the scale and  $\infty$  on the left end of the scale. Shunt ohmmeters are the opposite.*

A48.

- a. *Deenergize and discharge the circuit before connecting an ohmmeter.*
- b. *Do not apply power to a circuit while measuring resistance.*
- c. *Switch ohmmeters to the OFF position, if provided, or to highest range and remove meter leads from the meter when finished measuring resistance.*
- d. *Adjust the ohmmeter after changing resistance range and before measuring reading indicates the resistance.*

A49. *To measure high resistance.*

A50. *Connect one lead to the insulation and one lead to the conductor. Turn the handcrank until it starts to slip. Note the reading.*

A51. *Infinity.*

A52.

- a. *Use meggers for high-resistance measurement only.*
- b. *Never touch the test leads when the handle is being cranked.*
- c. *Deenergize and discharge the circuit completely before connecting a megger.*
- d. *Disconnect the item being checked from other circuitry, if possible, before using a megger.*

A53. *A single measuring device capable of performing the functions of a dc voltmeter and ammeter, an ac voltmeter and ammeter, and an ohmmeter.*

A54. *It is much more convenient to have one meter with several functions than several meters each with a single function.*

A55. *By changing the position of the function switch.*

A56. *The meter movement reacts to average ac voltage and current and the effective value is desired.*

A57. *To stop parallax error*

A58. *Make sure no image of the pointer is visible in the mirror when reading the meter.*

A59.

- a. *Deenergize and discharge the circuit completely before connecting or disconnecting a multimeter.*
- b. *Never apply power to the circuit while measuring resistance with a multimeter.*
- c. *Connect the multimeter in series with the circuit for current measurements, and in parallel for voltage measurements.*
- d. *Be certain the multimeter is switched to ac before attempting to measure ac circuits.*
- e. *Observe proper dc polarity when measuring dc.*
- f. *When you are finished with a multimeter, switch it to the OFF position, if available. If there is no OFF position, switch the multimeter to the highest ac voltage position.*
- g. *Always start with the highest voltage or current range.*
- h. *Select a final range that allows a reading near the middle of the scale.*
- i. *Adjust the "0 ohms" reading after changing resistance ranges and before making a resistance measurement.*
- j. *Be certain to read ac measurements on the ac scale of a multimeter.*
- k. *Observe the general safety precautions for electrical and electronic devices.*

A60. *To measure current safely and easily (with no need to disconnect the wiring of the circuit).*

A61. *Power.*

A62. *Energy.*

A63. *5.945 megawatt-hours, or 5,945 kilowatt-hours, or 5,945, 000 watt-hours.*

A64. *Vibrating reed and moving disk.*

A65.

- a. A dc ammeter, 90 mA dc*
- b. A dc voltmeter, 200 V dc*
- c. An ac voltmeter, 4.6 V ac*
- d. An ohmmeter, 400 ohms*

A66. *(A) 410 mA dc; (B) 3.9 mA ac; (C) -22 V dc; (D) 600 V ac; (E) 1.4 V ac; (F) 1.9 kohms (1900  $\Omega$ ).*

A67. *Figure 1-50(D).*

A68. *(A) Megger (megohmmeter), infinity; (B) Wattmeter, 9.5 kilowatts (9,500 watts). (C) Watt-hour meter, 2.693 megawatt-hours 2,693 kilowatt-hours (2,693,000 watt-hours).*

A69. *Yes.*

A70. *(A) Vibrating-reed, 60Hz. (B) Moving-disk, 58 Hz.*



## **CHAPTER 2**

# **CIRCUIT PROTECTION DEVICES**

### **LEARNING OBJECTIVES**

Upon completion of this chapter you will be able to:

1. State the reasons circuit protection is needed and three conditions requiring circuit protection.
2. Define a direct short, an excessive current condition, and an excessive heat condition.
3. State the way in which circuit protection devices are connected in a circuit.
4. Identify two types of circuit protection devices and label the schematic symbols for each type.
5. Identify a plug-type and a cartridge-type fuse (open and not open) from illustrations.
6. List the three characteristics by which fuses are rated and state the meaning of each rating. Identify a plug-type and a cartridge-type fuse (open and not open) from illustrations.
7. List the three categories of time delay rating for fuses and state a use for each type of time-delay rated fuse.
8. List the three categories of time delay rating for fuses and state a use for each type of time-delay rated fuse. Identify fuses as to voltage, current, and time delay ratings using fuses marked with the old military, new military, old commercial, and new commercial systems. List the three categories of time delay rating for fuses and state a use for each type of time-delay rated fuse.
9. Identify a clip-type and a post-type fuse holder from illustrations and identify the connections used on a post-type fuse holder for power source and load connections.
10. List the methods of checking for an open fuse, the items to check when replacing a fuse, the safety precautions to be observed when checking and replacing fuses, and the conditions to be checked for when conducting preventive maintenance on fuses.
11. Select a proper replacement and substitute fuse from a listing of fuses.
12. List the five main components of a circuit breaker and the three types of circuit breaker trip elements.
13. Describe the way in which each type of trip element reacts to excessive current.
14. Define the circuit breaker terms trip-free and nontrip-free and state one example for the use of each of these types of circuit breakers.
15. List the three time delay ratings of circuit breakers.
16. Define selective tripping, state why it is used, and state the way in which the time delay ratings of circuit breakers are used to design a selective tripping system.
17. Identify the factors used in selecting circuit breakers.

18. List the steps to follow before starting work on a circuit breaker and the items to be checked when maintaining circuit breakers.

## **CIRCUIT PROTECTION DEVICES**

Electricity, like fire, can be either helpful or harmful to those who use it. A fire can keep people warm and comfortable when it is confined in a campfire or a furnace. It can be dangerous and destructive if it is on the loose and uncontrolled in the woods or in a building. Electricity can provide people with the light to read by or, in a blinding flash, destroy their eyesight. It can help save people's lives, or it can kill them. While we take advantage of the tremendous benefits electricity can provide, we must be careful to protect the people and systems that use it.

It is necessary then, that the mighty force of electricity be kept under control at all times. If for some reason it should get out of control, there must be a method of protecting people and equipment. Devices have been developed to protect people and electrical circuits from currents and voltages outside their normal operating ranges. Some examples of these devices are discussed in this chapter.

While you study this chapter, it should be kept in mind that a circuit protection device is used to keep an undesirably large current, voltage, or power surge out of a given part of an electrical circuit.

### **INTRODUCTION**

An electrical unit is built with great care to ensure that each separate electrical circuit is fully insulated from all the others. This is done so that the current in a circuit will follow its intended path. Once the unit is placed into service, however, many things can happen to alter the original circuitry. Some of the changes can cause serious problems if they are not detected and corrected. While circuit protection devices cannot correct an abnormal current condition, they can indicate that an abnormal condition exists and protect personnel and circuits from that condition. In this chapter, you will learn what circuit conditions require protection devices and the types of protection devices used.

### **CIRCUIT CONDITIONS REQUIRING PROTECTION DEVICES**

As has been mentioned, many things can happen to electrical and electronic circuits after they are in use. Chapter 1 of this module contains information showing you how to measure circuit characteristics to help determine the changes that can occur in them. Some of the changes in circuits can cause conditions that are dangerous to the circuit itself or to people living or working near the circuits. These potentially dangerous conditions require circuit protection. The conditions that require circuit protection are direct shorts, excessive current, and excessive heat.

#### **Direct Short**

One of the most serious troubles that can occur in a circuit is a **DIRECT SHORT**. Another term used to describe this condition is a **SHORT CIRCUIT**. The two terms mean the same thing and, in this chapter, the term direct short will be used. This term is used to describe a situation in which some point in the circuit, where full system voltage is present, comes in direct contact with the ground or return side of the circuit. This establishes a path for current flow that contains only the very small resistance present in the wires carrying the current.

According to Ohm's law, if the resistance in a circuit is extremely small, the current will be extremely large. Therefore, when a direct short occurs, there will be a very large current through the wires. Suppose, for instance, that the two leads from a battery to a motor came in contact with each other. If the leads were bare at the point of contact, there would be a direct short. The motor would stop running

because all the current would be flowing through the short and none through the motor. The battery would become discharged quickly (perhaps ruined) and there could be the danger of fire or explosion.

The battery cables in our example would be large wires capable of carrying heavy currents. Most wires used in electrical circuits are smaller and their current carrying capacity is limited. The size of wire used in any given circuit is determined by space considerations, cost factors, and the amount of current the wire is expected to carry under normal operating conditions. Any current flow greatly in excess of normal, such as there would be in the case of a direct short, would cause a rapid generation of heat in the wire.

If the excessive current flow caused by the direct short is left unchecked, the heat in the wire will continue to increase until some portion of the circuit burns. Perhaps a portion of the wire will melt and open the circuit so that nothing is damaged other than the wire involved. The probability exists, however, that much greater damage will result. The heat in the wire can char and burn the insulation of the wire and that of other wires bundled with it, which can cause more shorts. If a fuel or oil leak is near any of the hot wires, a disastrous fire might be started.

### **Excessive Current**

It is possible for the circuit current to increase without a direct short. If a resistor, capacitor, or inductor changes value, the total circuit impedance will also change in value. If a resistor decreases in ohmic value, the total circuit resistance decreases. If a capacitor has a dielectric leakage, the capacitive reactance decreases. If an inductor has a partial short of its winding, inductive reactance decreases. Any of these conditions will cause an increase in circuit current. Since the circuit wiring and components are designed to withstand normal circuit current, an increase in current would cause overheating (just as in the case of a direct short). Therefore, excessive current without a direct short will cause the same problems as a direct short.

### **Excessive Heat**

As you have read, most of the problems associated with a direct short or excessive current concern the heat generated by the higher current. The damage to circuit components, the possibility of fire, and the possibility of hazardous fumes being given off from electrical components are consequences of excessive heat. It is possible for excessive heat to occur without a direct short or excessive current. If the bearings on a motor or generator were to fail, the motor or generator would overheat. If the temperature around an electrical or electronic circuit were to rise (through failure of a cooling system for example), excessive heat would be a problem. No matter what the cause, if excessive heat is present in a circuit, the possibility of damage, fire, and hazardous fumes exists.

*Q1. Why are circuit protection devices necessary?*

*Q2. What are the three conditions that require circuit protection?*

*Q3. What is a direct short?*

*Q4. What is an excessive current condition?*

*Q5. What is an excessive heat condition?*

## **CIRCUIT PROTECTION DEVICES**

All of the conditions mentioned are potentially dangerous and require the use of circuit protection devices. Circuit protection devices are used to stop current flow or open the circuit. To do this, a circuit protection device must ALWAYS be connected in series with the circuit it is protecting. If the protection

device is connected in parallel, current will simply flow around the protection device and continue in the circuit.

A circuit protection device operates by opening and interrupting current to the circuit. The opening of a protection device shows that something is wrong in the circuit and should be corrected before the current is restored. When a problem exists and the protection device opens, the device should isolate the faulty circuit from the other unaffected circuits, and should respond in time to protect unaffected components in the faulty circuit. The protection device should NOT open during normal circuit operation.

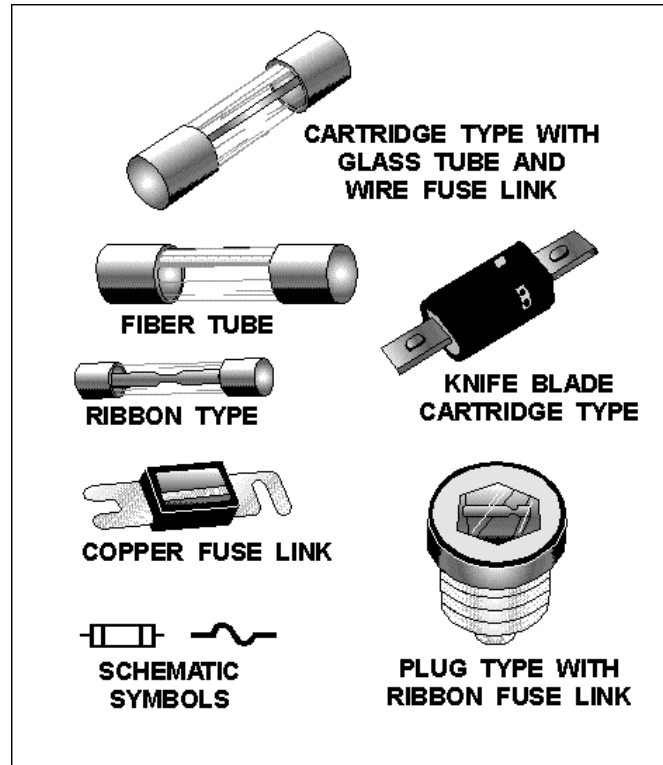
The two types of circuit protection devices discussed in this chapter are fuses and circuit breakers.

## **Fuses**

A fuse is the simplest circuit protection device. It derives its name from the Latin word "fusus," meaning "to melt." Fuses have been used almost from the beginning of the use of electricity. The earliest type of fuse was simply a bare wire between two connections. The wire was smaller than the conductor it was protecting and, therefore, would melt before the conductor it was protecting was harmed. Some "copper fuse link" types are still in use, but most fuses no longer use copper as the fuse element (the part of the fuse that melts). After changing from copper to other metals, tubes or enclosures were developed to hold the melting metal. The enclosed fuse made possible the addition of filler material, which helps to contain the arc that occurs when the element melts.

For many low power uses, the finer material is not required. A simple glass tube is used. The use of a glass tube gives the added advantage of being able to see when a fuse is open. Fuses of this type are commonly found in automobile lighting circuits.

Figure 2-1 shows several fuses and the symbols used on schematics.



**Figure 2-1.—Typical fuses and schematic symbols.**



## Circuit Breakers

While a fuse protects a circuit, it is destroyed in the process of opening the circuit. Once the problem that caused the increased current or heat is corrected, a new fuse must be placed in the circuit. A circuit protection device that can be used more than once solves the problems of replacement fuses. Such a device is safe, reliable, and tamper proof. It is also resettable, so it can be reused without replacing any parts. This device is called a **CIRCUIT BREAKER** because it breaks (opens) the circuit.

The first compact, workable circuit breaker was developed in 1923. It took 4 years to design a device that would interrupt circuits of 5000 amperes at 120 volts ac or dc. In 1928 the first circuit breaker was placed on the market. A typical circuit breaker and the appropriate schematic symbols are shown in figure 2-2.

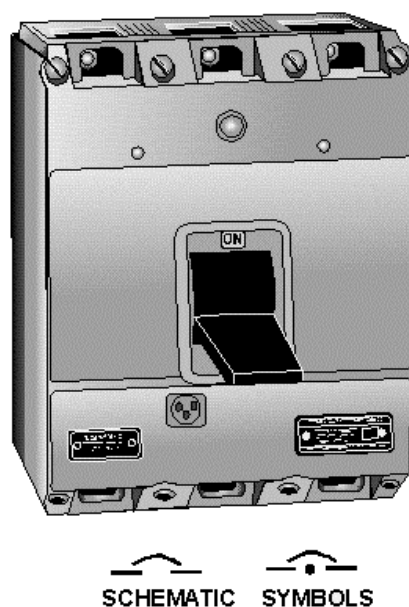


Figure 2-2.—Typical circuit breaker and schematic symbols.

- Q6. How are circuit protection devices connected to the circuit they are intended to protect and why are they connected in this way?
- Q7. What are the two types of circuit protection devices?
- Q8. Label the schematic symbols shown in figure 2-3 below.

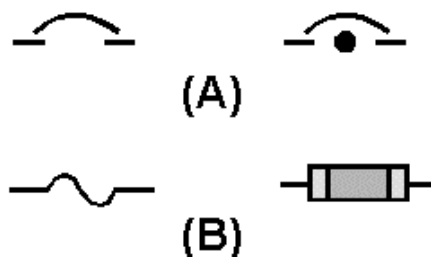


Figure 2-3.—Schematic symbols.

## FUSE TYPES

Fuses are manufactured in many shapes and sizes. In addition to the copper fuse link already described, figure 2-1 shows other fuse types. While the variety of fuses may seem confusing, there are basically only two types of fuses: plug-type fuses and cartridge fuses. Both types of fuses use either a single wire or a ribbon as the fuse element (the part of the fuse that melts). The condition (good or bad) of some fuses can be determined by visual inspection. The condition of other fuses can only be determined with a meter. In the following discussion, visual inspection will be described. The use of meters to check fuses will be discussed later in this chapter.

### PLUG-TYPE FUSE

The plug-type fuse is constructed so that it can be screwed into a socket mounted on a control panel or electrical distribution center. The fuse link is enclosed in an insulated housing of porcelain or glass. The construction is arranged so the fuse link is visible through a window of mica or glass. Figure 2-4 shows a typical plug-type fuse.

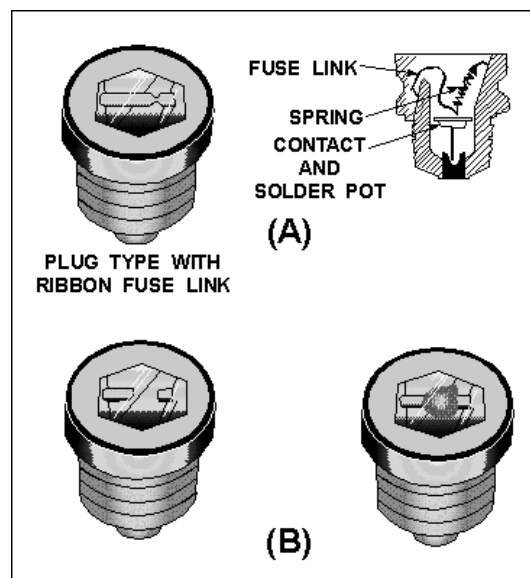


Figure 2-4.—Plug-type fuses:

Figure 2-4, view A, shows a good plug-type fuse. Notice the construction and the fuse link. In figure 2-4, view B, the same type of fuse is shown after the fuse link has melted. Notice the window showing the indication of this open fuse. The indication could be either of the ones shown in figure 2-4, view B.

The plug-type fuse is used primarily in low-voltage, low-current circuits. The operating range is usually up to 150 volts and from 0.5 ampere to 30 amperes. This type of fuse is found in older circuit protection devices and is rapidly being replaced by the circuit breaker.

### CARTRIDGE FUSE

The cartridge fuse operates exactly like the plug-type fuse. In the cartridge fuse, the fuse link is enclosed in a tube of insulating material with metal ferrules at each end (for contact with the fuse holder). Some common insulating materials are glass, bakelite, or a fiber tube filled with insulating powder.

Figure 2-5 shows a glass-tube fuse. In figure 2-5, view A, notice the fuse link and the metal ferrules. Figure 2-5, view B, shows a glass-tube fuse that is open. The open fuse link could appear either of the ways shown in figure 2-5, view B.

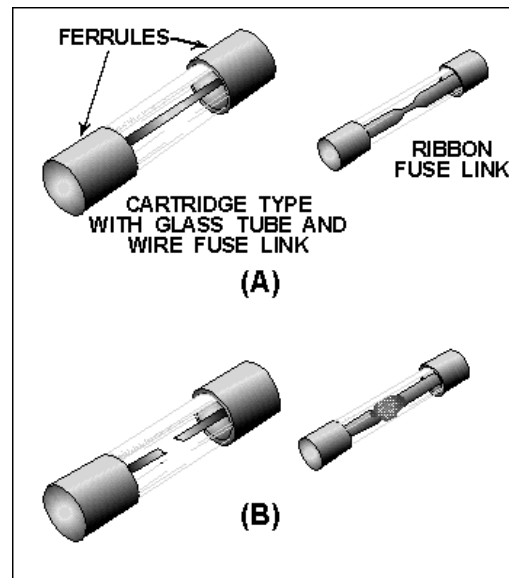


Figure 2-5.—Cartridge-tube fuse.

Cartridge fuses are available in a variety of physical sizes and are used in many different circuit applications. They can be rated at voltages up to 10,000 volts and have current ratings of from 1/500 (.002) ampere to 800 amperes. Cartridge fuses may also be used to protect against excessive heat and open at temperatures of from 165° F to 410°F (74°C to 210°C).

*Q9. Label the fuses shown in figure 2-6 according to type.*

*Q10. Identify the open fuses shown in figure 2-6.*

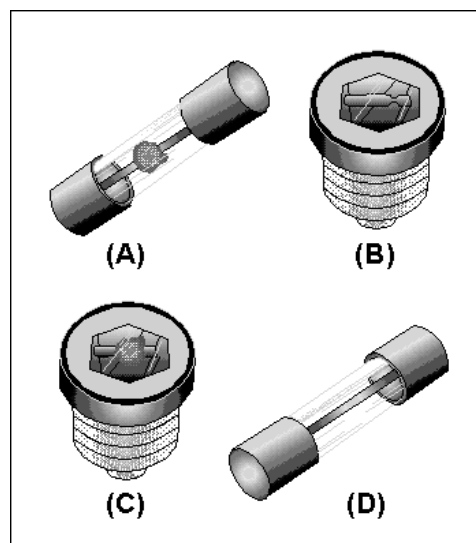


Figure 2-6.—Fuse recognition.

## **FUSE RATINGS**

You can determine the physical size and type of a fuse by looking at it, but you must know other things about a fuse to use it properly. Fuses are rated by current, voltage, and time-delay characteristics to aid in the proper use of the fuse. To select the proper fuse, you must understand the meaning of each of the fuse ratings.

### **CURRENT RATING**

The current rating of a fuse is a value expressed in amperes that represents the current the fuse will allow without opening. The current rating of a fuse is always indicated on the fuse.

To select the proper fuse, you must know the normal operating current of the circuit. If you wish to protect the circuit from overloads (excessive current), select a fuse rated at 125 percent of the normal circuit current. In other words, if a circuit has a normal current of 10 amperes, a 12.5-ampere fuse will provide overload protection. If you wish to protect against direct shorts only, select a fuse rated at 150 percent of the normal circuit current. In the case of a circuit with 10 amperes of current, a 15 ampere fuse will protect against direct shorts, but will not be adequate protection against excessive current.

### **VOLTAGE RATING**

The voltage rating of a fuse is NOT an indication of the voltage the fuse is designed to withstand while carrying current. The voltage rating indicates the ability of the fuse to quickly extinguish the arc after the fuse element melts and the maximum voltage the open fuse will block. In other words, once the fuse has opened, any voltage less than the voltage rating of the fuse will not be able to "jump" the gap of the fuse. Because of the way the voltage rating is used, it is a maximum rms voltage value. You must always select a fuse with a voltage rating equal to or higher than the voltage in the circuit you wish to protect.

### **TIME DELAY RATING**

There are many kinds of electrical and electronic circuits that require protection. In some of these circuits, it is important to protect against temporary or transient current increases. Sometimes the device being protected is very sensitive to current and cannot withstand an increase in current. In these cases, a fuse must open very quickly if the current increases.

Some other circuits and devices have a large current for short periods and a normal (smaller) current most of the time. An electric motor, for instance, will draw a large current when the motor starts, but normal operating current for the motor will be much smaller. A fuse used to protect a motor would have to allow for this large temporary current, but would open if the large current were to continue.

Fuses are time delay rated to indicate the relationship between the current through the fuse and the time it takes for the fuse to open. The three time delay ratings are delay, standard, and fast.

#### **Delay**

A delay, or slow-blowing, fuse has a built-in delay that is activated when the current through the fuse is greater than the current rating of the fuse. This fuse will allow temporary increases in current (surge) without opening. Some delay fuses have two elements; this allows a very long time delay. If the over-current condition continues, a delay fuse will open, but it will take longer to open than a standard or a fast fuse.

Delay fuses are used for circuits with high surge or starting currents, such as motors, solenoids, and transformers.

## Standard

Standard fuses have no built-in time delay. Also, they are not designed to be very fast acting. Standard fuses are sometimes used to protect against direct shorts only. They may be wired in series with a delay fuse to provide faster direct short protection. For example, in a circuit with a 1-ampere delay fuse, a 5-ampere standard fuse may be used in addition to the delay fuse to provide faster protection against a direct short.

A standard fuse can be used in any circuit where surge currents are not expected and a very fast opening of the fuse is not needed. A standard fuse opens faster than a delay fuse, but slower than a fast rated fuse.

Standard fuses can be used for automobiles, lighting circuits, or electrical power circuits.

## Fast

Fast fuses are designed to open very quickly when the current through the fuse exceeds the current rating of the fuse. Fast fuses are used to protect devices that are very sensitive to increased current. A fast fuse will open faster than a delay or standard fuse.

Fast fuses can be used to protect delicate instruments or semiconductor devices.

Figure 2-7 will help you understand the differences between delay, standard, and fast fuses. Figure 2-7 shows that, if a 1-ampere rated fuse had 2 amperes of current through it, (200% of the rated value), a fast fuse would open in about .7 second, a standard rated fuse would open in about 1.5 seconds, and a delay rated fuse would open in about 10 seconds. Notice that in each of the fuses, the time required to open the fuse decreases as the rated current increases.

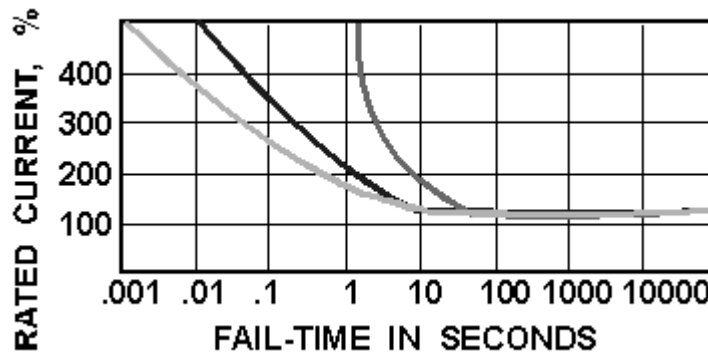


Figure 2-7.—Time required for fuse to open.

- Q11. In what three ways are fuses rated?
- Q12. What does the current rating of a fuse indicate?
- Q13. What does the voltage rating of a fuse indicate?
- Q14. What are the three time delay ratings of fuses?
- Q15. Give an example of a device you could protect with each type of time delay fuse.

## IDENTIFICATION OF FUSES

Fuses have identifications printed on them. The printing on the fuse will identify the physical size, the type of fuse, and the fuse ratings. There are four different systems used to identify fuses. The systems are the old military designation, the new military designation, the old commercial designation, and the new commercial designation. All four systems are presented here, so you will be able to identify a fuse no matter which designation is printed on the fuse.

You may have to replace an open fuse that is identified by one system with a good fuse that is identified by another system. The designation systems are fairly simple to understand and cross-reference once you are familiar with them.

### OLD MILITARY DESIGNATION

Figure 2-8 shows a fuse with the old military designation. The tables in the lower part of the figure show the voltage and current codes used in this system. The upper portion of the figure is the explanation of the old military designation. The numbers and letters in parentheses are the coding for the fuse shown in figure 2-8.

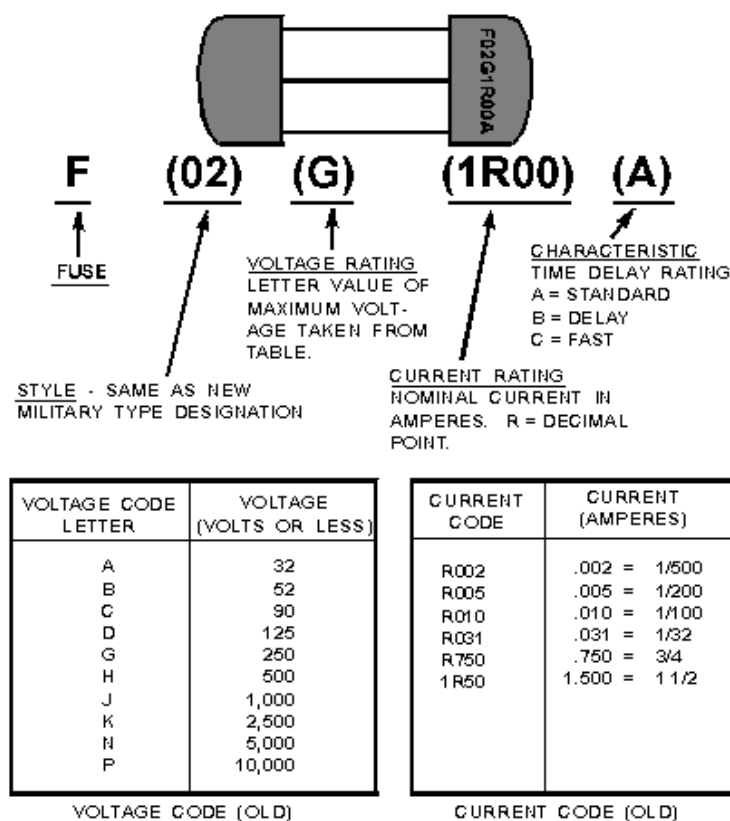


Figure 2-8.—Old type military fuse designation.

The old military designation always starts with "F," which stands for fuse. Next, the set of numbers (02) indicates the style. Style means the construction and dimensions (size) of the fuse. Following the style is a letter that represents the voltage rating of the fuse (G). The voltage code table in figure 2-8 shows each voltage rating letter and its meaning in volts. In the example shown, the voltage ratings is G,

which means the fuse should be used in a circuit where the voltage is 250 volts or less. After this is a set of three numbers and the letter "R," which represent the current rating of the fuse. The "R" indicates the decimal point. In the example shown, the current rating is 1R00 or 1.00 ampere. Some other examples of the current rating are shown in the current code table of figure 2-8. The final letter in the old military designation (A) indicates the time delay rating of the fuse.

While the old military designation is still found on some fuses, the voltage and current ratings must be "translated," since they use letters to represent numerical values. The military developed the new military designations to make fuse identification easier.

## NEW MILITARY DESIGNATION

Figure 2-9 is an example of a fuse coded in the new military designation. The fuse identified in the example in figure 2-9 is the same type as the fuse used as an example in figure 2-8.

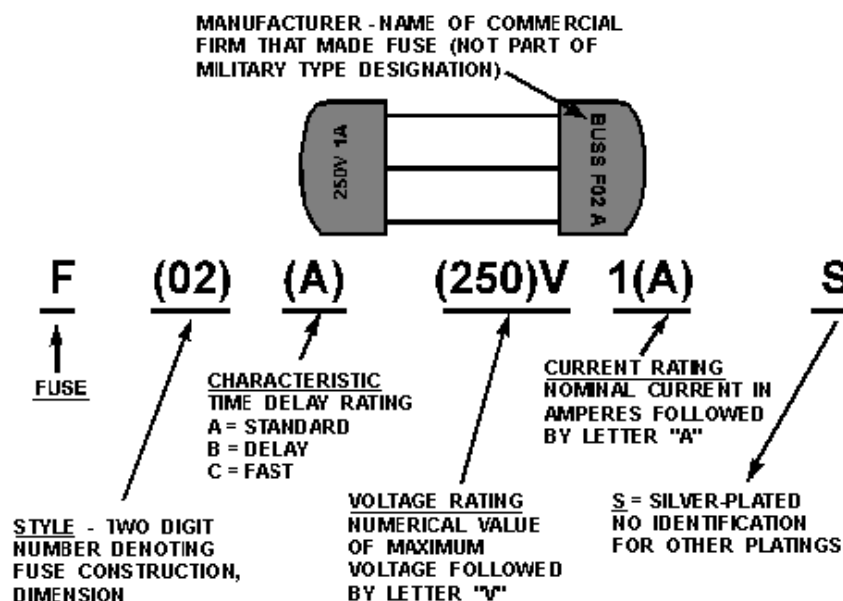


Figure 2-9.—New type military fuse designation.

The new military designation always start with the letter "F," which stands for fuse. The set of numbers (02) next to this indicates the style. The style numbers are identical to the ones used in the old military designation and indicate the construction and dimensions of the fuse. Following the style designation is a single letter (A) that indicates the time delay rating of the fuse. This is the same time delay rating code as indicated in the old military designation, but the position of this letter in the coding is changed to avoid confusing the "A" for standard time delay with the "A" for ampere. Following the time delay rating is the voltage rating of the fuse (250) V. In the old military designation, a letter was used to indicate the voltage rating. In the new military designation, the voltage is indicated by numbers followed by a "V," which stands for volts or less. After the voltage rating, the current rating is given by numbers followed by the letter "A." The current rating may be a whole number (1A), a fraction (1/500 A), a whole number and a fraction (1 1/2A), a decimal (0.250A), or a whole number and a decimal (1.50A). If the ferrules of the fuse are silver-plated, the current rating will be followed by the letter "S." If any other plating is used, the current rating will be the last part of the fuse identification.

As you can see, the new military designation is much easier to understand than the old military designation.

You may find a fuse coded in one of the commercial designations. The commercial designations are fairly easy to understand and figure 2-10 shows the old and new commercial designations for the same type of fuse that was used in figures 2-8 and 2-9.

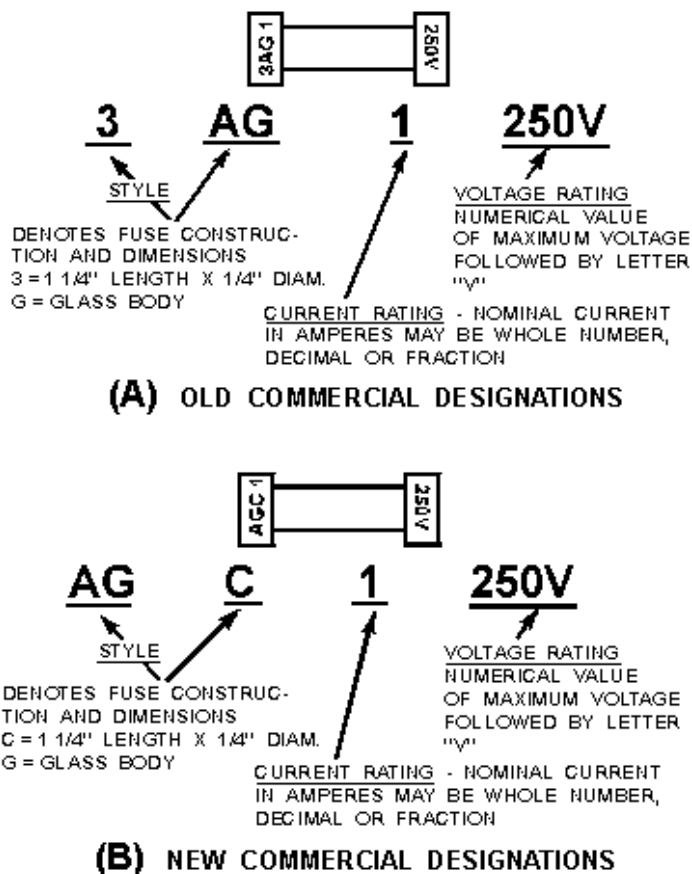


Figure 2-10.—Commercial designations for fuses:

## OLD COMMERCIAL DESIGNATION

Figure 2-10, view A, shows the old commercial designation for a fuse. The first part of the designation is a combination of letters and numbers (three in all) that indicates the style and time delay characteristics. This part of the designation (3AG) is the information contained in the style and time delay rating portions of military designations.

In the example shown, the code 3AG represents the same information as the underlined portions of F02 G 1R00 A from figure 2-8 (Old Military Designation) and F02A 250VIAS from figure 2-9 (New Military Designation). The only way to know the time delay rating of this fuse is to look it up in the manufacturer's catalog or in a cross-reference listing to find the military designation. The catalog will tell you the physical size, the material from which the fuse is constructed, and the time delay rating of the fuse. A 3AG fuse is a glass-bodied fuse, 1/4 inch  $\times$  1 1/4 inches (6.35 millimeters  $\times$  31.8 millimeters) and has a standard time delay rating.



Following the style designation is a number that is the current rating of the fuse (1). This could be a whole number, a fraction, a whole number and a fraction, a decimal, or a whole number and a decimal. Following the current rating is the voltage rating; which, in turn, is followed by the letter "V," which stands for volts or less (250V).

## NEW COMMERCIAL DESIGNATION

Figure 2-10, view B, shows the new commercial designation for fuses. It is the same as the old commercial designation except for the style portion of the coding. In the old commercial system, the style was a combination of letters and numbers. In the new commercial system, only letters are used. In the example shown, 3AG in the old system becomes AGC in the new system. Since "C" is the third letter of the alphabet, it is used instead of the "3" used in the old system. Once again, the only way to find out the time delay rating is to look up this coding in the manufacturer's catalog or to use a cross-reference listing. The remainder of the new commercial designation is exactly the same as the old commercial designation.

*Q16. What are the voltage, current, and time delay ratings for a fuse with the designation*

(a) F02DIR50B?

(b) F02A250V  $\frac{1}{8}$  A?

*Q17. What are the voltage and current ratings for a fuse designated*

(a) 3AG  $\frac{1}{16}$  125V?

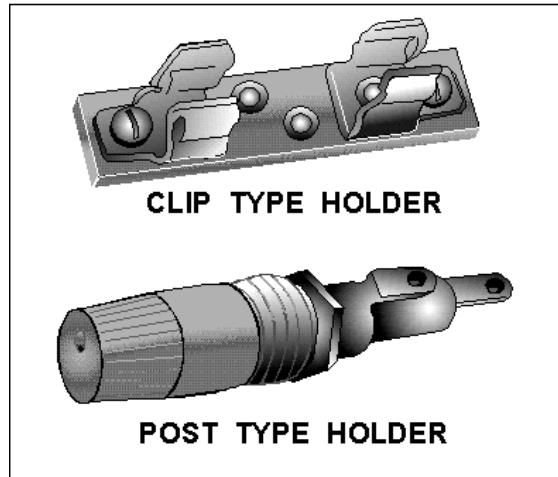
(b) FNA  $\frac{15}{100}$  250V?

*Q18. What is the new military designation for a fuse with the old military designation F05A20ROB?*

## FUSEHOLDERS

For a fuse to be useful, it must be connected to the circuit it will protect. Some fuses are "wired in" or soldered to the wiring of circuits, but most circuits make use of FUSEHOLDERS. A fuseholder is a device that is wired into the circuit and allows easy replacement of the fuse.

Fuseholders are made in many shapes and sizes, but most fuseholders are basically either clip-type or post-type. Figure 2-11 shows a typical clip-type and post-type fuseholder.



**Figure 2-11.—Typical fuseholders.**

### **CLIP-TYPE FUSEHOLDER**

The clip-type fuseholder is used for cartridge fuses. The ferrules or knife blade of the fuse are held by the spring tension of the clips. These clips provide the electrical connection between the fuse and the circuit. If a glass-bodied fuse is used, the fuse can be inspected visually for an open without removing the fuse from the fuse holder. Clip-type fuseholders are made in several sizes to hold the many styles of fuses. The clips maybe made for ferrules or knife blade cartridge fuses. While the base of a clip-type fuseholder is made from insulating material, the clips themselves are conductors. The current through the fuse goes through the clips and care must be taken to not touch the clips when there is power applied. If the clips are touched, with power applied, a severe shock or a short circuit will occur.

### **POST-TYPE FUSEHOLDERS**

Post-type fuseholders are made for cartridge fuses. The post-type fuseholder is much safer because the fuse and fuse connections are covered with insulating material. The disadvantage of the post-type fuseholder is that the fuse must be removed to visually check for an open. The post-type fuseholder has a cap that screws onto the body of the fuseholder. The fuse is held in this cap by a spring-type connector and, as the cap is screwed on, the fuse makes contact with the body of the fuseholder. When the cap and fuse are removed from the body of the fuseholder, the fuse is removed from the circuit and there is no danger of shock or short circuit from touching the fuse.

Post-type fuseholders are usually mounted on the chassis of the equipment in which they are used. After wires are connected to the fuseholder, insulating sleeves are placed over the connections to reduce the possibility of a short circuit. Notice the two connections on the post-type fuseholder of figure 2-11. The connection on the right is called the center connector. The other connector is the outside connector. The outside connector will be closer to the equipment chassis. (The threads and nut shown are used to fasten the fuseholder to the chassis.) The possibility of the outside connector coming in contact with the chassis (causing a short circuit) is much higher than the possibility of the center conductor contacting the chassis. The power source should always be connected to the center connector so the fuse will open if the outside connector contacts the chassis. If the power source were connected to the outside connector, and the outside connector contacted the chassis, there would be a direct short, but the fuse would not open.

Q19. Label the fuseholders in figure 2-12.

Q20. Which connector should you use to connect the (a) power source and (b) load to the fuseholder shown in figure 2-12(A)?

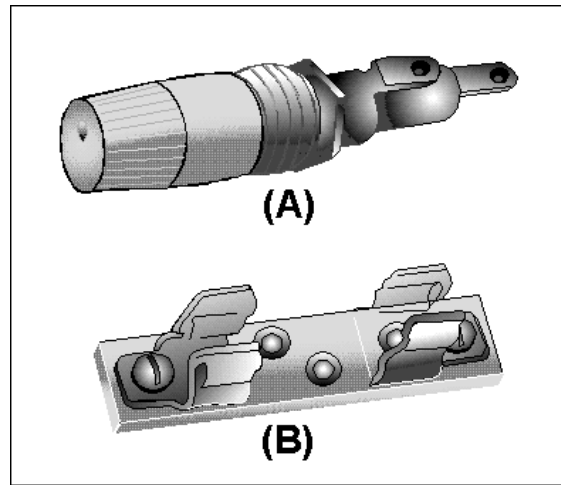


Figure 2-12.—Fuseholder identification.

## CHECKING AND REPLACEMENT OF FUSES

A fuse, if properly used, should not open unless something is wrong in the circuit the fuse is protecting. When a fuse is found to be open, you must determine the reason the fuse is open. Replacing the fuse is not enough.

Before you look for the cause of an open fuse, you must be able to determine if the fuse is open.

### CHECKING FOR AN OPEN FUSE

There are several ways of checking for an open fuse. Some fuses and fuseholders have indicators built in to help you find an open fuse; also, a multimeter can be used to check fuses. The simplest way to check glass-bodied fuses, and the method you should use first, is visual inspection.

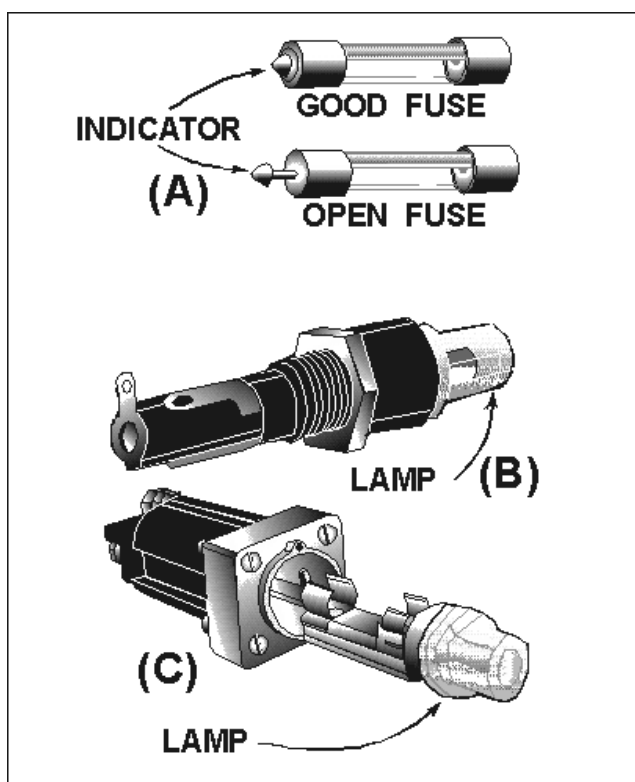
#### Visual Inspection

An open glass-bodied fuse can usually be found by visual inspection. Earlier in this chapter, figures 2-4 and 2-5 showed you how an open plug-type and an open glass-bodied cartridge-type fuse would look. If the fuse element is not complete, or if the element has been melted onto the glass tube, the fuse is open.

It is not always possible to tell if a fuse is open by visual inspection. Fuses with low current ratings have elements that are so small, it is sometimes not possible to know if the fuse link is complete simply by looking at it. If the fuse is not glass-bodied, it will not be possible to check the fuse visually. Also, sometimes a fuse will look good, but will, in fact, be open. Therefore, while it is sometimes possible to know if a fuse is open by visual inspection, it is not possible to be sure a fuse is good just by looking at it.

#### Fuse Indicators

Some fuses and fuseholders have built-in indicators to show when a fuse is open. Examples of these open-fuse indicators are shown in figure 2-13. Figure 2-13, view A, shows a cartridge-type fuse with an open-fuse indicator. The indicator is spring loaded and held by the fuse link. If the fuse link opens, the spring forces the indicator out. Some manufacturers color the indicator so it is easier to see in the open-fuse position.



**Figure 2-13.—Open fuse indicators: Clip-type fuseholder with an indicating lamp.**

Figure 2-13, view B, shows a plug-type fuseholder with an indicating lamp in the fuse cap. If the fuse opens, the lamp in the fuse cap will light. Figure 2-13, view C, shows a clip-type fuseholder with an indicating lamp.

Just as in visual checking, the indicator can show an open fuse. Since the indicator may not always work, you cannot be sure a fuse is good just because there is no open-fuse indication.

### **Checking Fuses with a Meter**

The only sure method of determining if a fuse is open is to use a meter. An ohmmeter can be used to check for an open fuse by removing the fuse from the circuit and checking for continuity through the fuse (0 ohms). If the fuse is not removed from the circuit, and the fuse is open, the ohmmeter may measure the circuit resistance. This resistance reading might lead you to think the fuse is good. You must be careful when you use an ohmmeter to check fuses with small current ratings (such as 1/32 ampere or less), because the current from the ohmmeter may be larger than the current rating of the fuse. For most practical uses, a small current capacity fuse can be checked out of the circuit through the use of a resistor. The ohmic value of the resistor is first measured and then placed in series with the fuse. The continuity reading on the ohmmeter should be of the same value, or close to it, as the original value of the resistor. This method provides protection for the fuse by dropping the voltage across the resistor. This in turn decreases the power in the form of heat at the fuse. Remember, it is heat which melts the fuse element.

A voltmeter can also be used to check for an open fuse. The measurement is taken between each end of the fuse and the common or ground side of the line. If voltage is present on both sides of the fuse (from the voltage source and to the load), the fuse is not open. Another method commonly used, is to measure across the fuse with the voltmeter. If NO voltage is indicated on the meter, the fuse is good, (not open).

Remember there is no voltage drop across a straight piece of wire. Some plug-type fuseholders have test points built in to allow you to check the voltage. To check for voltage on a clip-type fuseholder, check each of the clips. The advantage of using a voltmeter to check for an open fuse is that the circuit does not have to be deenergized and the fuse does not have to be removed.

### **WARNING**

### **PERSONNEL MAY BE EXPOSED TO HAZARDOUS VOLTAGE**

#### **Safety Precautions When Checking a Fuse**

Since a fuse has current through it, you must be very careful when checking for an open fuse to avoid being shocked or damaging the circuit. The following safety precautions will protect you and the equipment you are using.

- Turn the power off and discharge the circuit before removing a fuse.
- Use a fusepuller (an insulated tool) when you remove a fuse from a clip-type fuseholder.
- When you check a fuse with a voltmeter, be careful to avoid shocks and short circuits.
- When you use an ohmmeter to check fuses with low current ratings, be careful to avoid opening the fuse by excessive current from the ohmmeter.

*Q21. What are three methods for determining if a fuse is open?*

*Q22. You have just checked a fuse with an ohmmeter and find that the fuse is shorted. What should you do?*

*Q23. You have just checked a 1/500-ampere fuse with an ohmmeter and find it is open. Checking the replacement fuse shows the replacement fuse is open also. Why would the replacement fuse indicate open?*

*Q24. How could you check a 1/500-ampere fuse with an ohmmeter?*

*Q25. List the safety precautions to be observed when checking fuses.*

#### **REPLACEMENT OF FUSES**

After an open fuse is found and the trouble that caused the fuse to open has been corrected, the fuse must be replaced. Before you replace the fuse, you must be certain the replacement fuse is the proper type and fits correctly.

#### **Proper Type of Replacement Fuse**

To be certain a fuse is the proper type, check the technical manual for the equipment. The parts list will show you the proper fuse identification for a replacement fuse. Obtain the exact fuse specified, if possible, and check the identification number of the replacement fuse against the parts list.

If you cannot obtain a direct replacement, use the following guidelines:

- Never use a fuse with a higher current rating, a lower voltage rating, or a slower time delay rating than the specified fuse.

- The best substitution fuse is a fuse with the same current and time delay ratings and a higher voltage rating.
- If a lower current rating or a faster time delay rating is used, the fuse may open under normal circuit conditions.
- Substitute fuses must have the same style (physical dimensions) as the specified fuse.

### Proper Fit of Replacement Fuses

When you have obtained a proper replacement fuse, you must make certain it will fit correctly in the fuseholder. If the fuseholder is corroded, the fuse will not fit properly. In addition, the corrosion can cause increased resistance or heating. Clean corroded terminals with fine sandpaper so that all corrosion is removed. Do **NOT** lubricate the terminals. If the terminals are badly pitted, replace the fuseholder. Be certain the replacement fuseholder is the correct size and type by checking the parts list in the technical manual for the equipment.

After you check for and correct any corrosion problems, be certain the fuse fits tightly in the fuseholder. When you insert the fuse in the cap of a plug-type fuseholder, the fuse should fit tightly. A small amount of pressure should be needed to insert the fuse and cap into the fuseholder body.

In clip-type fuseholders, the clips can be easily bent out of shape. This causes an incorrect fit, which in time could cause an equipment malfunction. Figure 2-14 shows examples of correct and incorrect fuse contacts for clip-type fuseholders used with knifeblade and ferrule cartridge fuses. The clips shown in the left picture of each row have the correct contact. The three pictures on the right of each row show incorrect contact. Notice how the clips are not contacting completely with the knifeblade or ferrules. This incomplete contact can cause corrosion at the contacts, which in turn can create a high resistance and drop some of the circuit voltage at this point.

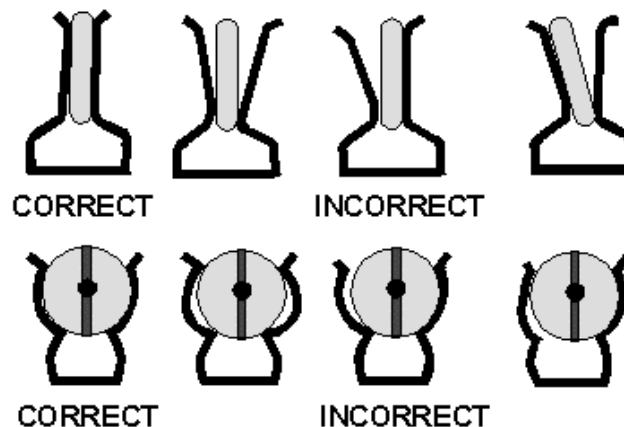


Figure 2-14.—Contact between clips and fuses.

If the fuse clips do not make complete contact with the fuse, try to bend the clips back into shape. If the clips cannot be repaired by bending, replace the fuseholder or use clip clamps. Clip clamps are shown in figure 2-15.

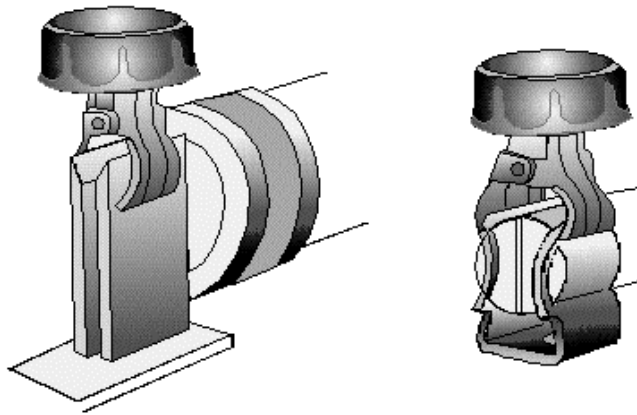


Figure 2-15.—Clip clamps.

### **Safety Precautions When Replacing Fuses**

The following safety precautions will prevent injury to personnel and damage to equipment. These are the MINIMUM safety precautions for replacing fuses.

- Be sure the power is off in the circuit and the circuit is discharged before replacing a fuse.
- Use an identical replacement fuse if possible.
- Remove any corrosion from the fuseholder before replacing the fuse.
- Be certain the fuse properly fits the fuseholder.

### **PREVENTIVE MAINTENANCE OF FUSES**

Preventive maintenance of fuses consists of checking for the following conditions and correcting any discrepancies.

1. **IMPROPER FUSE.** Check the fuse installed against that recommended in the technical manual for the equipment. If an incorrect fuse is installed, replace it with the correct fuse.
2. **CORROSION.** Check for corrosion on the fuseholder terminals or the fuse itself. If corrosion is present, remove it with fine sandpaper.
3. **IMPROPER FIT.** Check for contact between the fuse and fuseholder. If a piece of paper will fit between the fuse and the clips on a clip-type fuseholder, there is improper contact. If the fuse is not held in the cap of a plug-type fuseholder, the contacts are too loose.
4. **OPEN FUSES.** Check fuses for opens. If any fuse is open, repair the trouble that caused the open fuse and replace the fuse.

*Q26. You have removed an open fuse from a fuseholder and repaired the cause of the fuse opening. The parts list specifies a fuse coded F02BI25V $\frac{1}{2}$ A. There are no fuses available with that identification. In the following list, indicate if the fuse is a direct replacement, a good substitute, or not acceptable. For the fuses that are good substitutes, number them in order of preference and explain why they are numbered that way. If the fuse is not acceptable, explain why.*

*(a) F03BI25V $\frac{1}{2}$ A*

*(b) F02BI25V $\frac{3}{8}$ A*

*(c) F02GR500B*

*(d) F02B32V $\frac{1}{2}$ A*

*(e) F02DR500B*

*(f) F02A250V $\frac{5}{8}$ A*

*(g) F02AI25V $\frac{1}{2}$ A*

*Q27. What two things should you check before replacing a fuse?*

*Q28. List the safety precautions to be observed when replacing a fuse.*

*Q29. What conditions should you check for when conducting preventive maintenance on fuses?*

## **CIRCUIT BREAKERS**

A circuit breaker is a circuit protection device that, like a fuse, will stop current in the circuit if there is a direct short, excessive current, or excessive heat. Unlike a fuse, a circuit breaker is reusable. The circuit breaker does not have to be replaced after it has opened or broken the circuit. Instead of replacing the circuit breaker, you reset it.

Circuit breakers can also be used as circuit control devices. By manually opening and closing the contacts of a circuit breaker, you can switch the power on and off. Circuit control devices will be covered in more detail in the next chapter.

Circuit breakers are available in a great variety of sizes and types. It would not be possible to describe every type of circuit breaker in use today, but this chapter will describe the basic types of circuit breakers and their operational principles.

Circuit breakers have five main components, as shown in figure 2-16. The components are the frame, the operating mechanism, the arc extinguishers and contacts, the terminal connectors, and the trip elements.



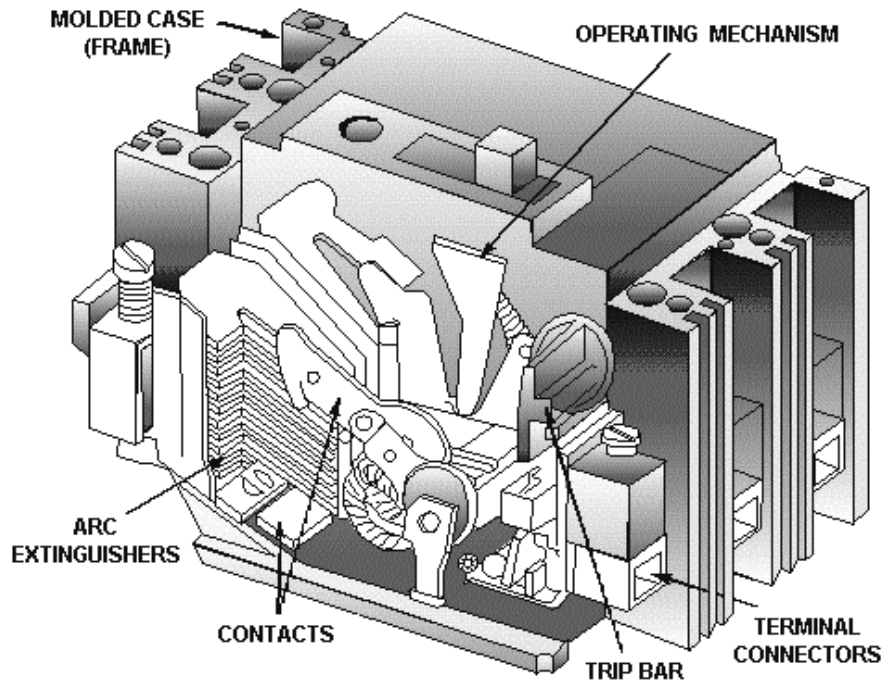
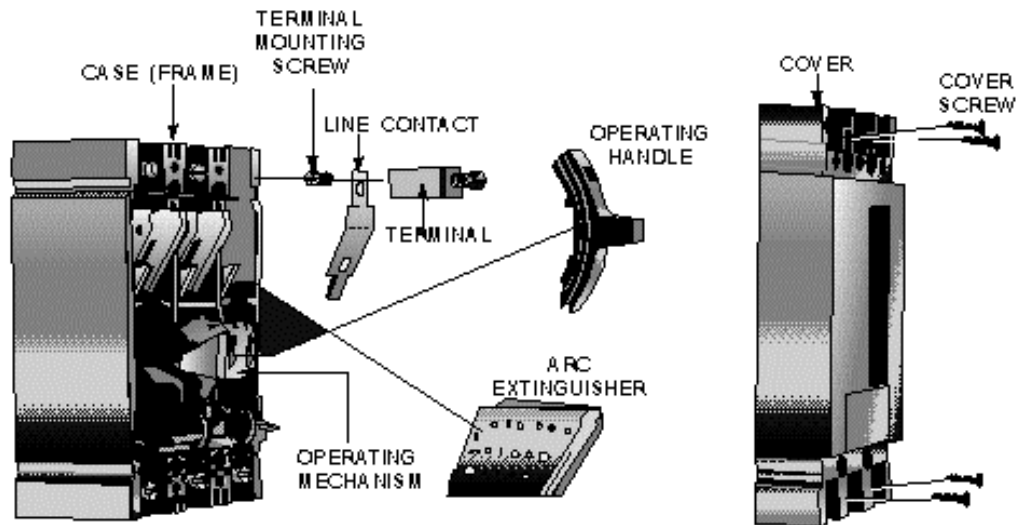


Figure 2-16.—Circuit breaker components.

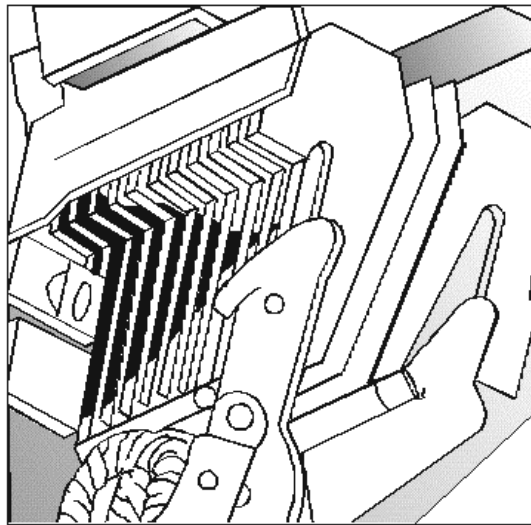
The FRAME provides an insulated housing and is used to mount the circuit breaker components (fig. 2-17). The frame determines the physical size of the circuit breaker and the maximum allowable voltage and current.

The OPERATING MECHANISM provides a means of opening and closing the breaker contacts (turning, the circuit ON and OFF). The toggle mechanism shown in figure 2-17 is the quick-make, quick-break type, which means the contacts snap open or closed quickly, regardless of how fast the handle is moved. In addition to indicating whether the breaker is ON or OFF, the operating mechanism handle indicates when the breaker has opened automatically (tripped) by moving to a position between ON and OFF. To reset the circuit breaker, the handle must first be moved to the OFF position, and then to the ON position.



**Figure 2-17.—Circuit breaker construction.**

The ARC EXTINGUISHER confines, divides, and extinguishes the arc drawn between contacts each time the circuit breaker interrupts current. The arc extinguisher is actually a series of contacts that open gradually, dividing the arc and making it easier to confine and extinguish. This is shown in figure 2-18. Arc extinguishers are generally used in circuit breakers that control a large amount of power, such as those found in power distribution panels. Small power circuit breakers (such as those found in lighting panels) may not have arc extinguishers.



**Figure 2-18.—Arc extinguisher action.**

TERMINAL CONNECTORS are used to connect the circuit breaker to the power source and the load. They are electrically connected to the contacts of the circuit breaker and provide the means of connecting the circuit breaker to the circuit.

The TRIP ELEMENT is the part of the circuit breaker that senses the overload condition and causes the circuit breaker to trip or break the circuit. This chapter will cover the thermal, magnetic, and thermal-

magnetic trip units used by most circuit breakers. (Some circuit breakers make use of solid-state trip units using current transformers and solid-state circuitry.)

### THERMAL TRIP ELEMENT

A thermal trip element circuit breaker uses a bimetallic element that is heated by the load current. The bimetallic element is made from strips of two different metals bonded together. The metals expand at different rates as they are heated. This causes the bimetallic element to bend as it is heated by the current going to the load. Figure 2-19 shows how this can be used to trip the circuit breaker.

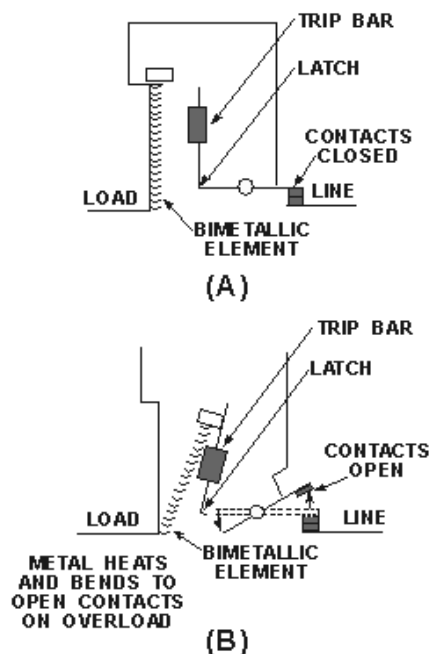


Figure 2-19.—Thermal trip element action: A. Trip element with normal current; B. Contacts open.

Figure 2-19, view A, shows the trip element with normal current. The bimetallic element is not heated excessively and does not bend. If the current increases (or the temperature around the circuit breaker increases), the bimetallic element bends, pushes against the trip bar, and releases the latch. Then, the contacts open, as shown in figure 2-19, view B.

The amount of time it takes for the bimetallic element to bend and trip the circuit breaker depends on the amount the element is heated. A large overload will heat the element quickly. A small overload will require a longer time to trip the circuit breaker.

### MAGNETIC TRIP ELEMENT

A magnetic trip element circuit breaker uses an electromagnet in series with the circuit load as in figure 2-20. With normal current, the electromagnet will not have enough attraction to the trip bar to move it, and the contacts will remain closed as shown in figure 2-20, view A. The strength of the magnetic field of the electromagnet increases as current through the coil increases. As soon as the current in the circuit becomes large enough, the trip bar is pulled toward the magnetic element (electromagnet), the contacts are opened, and the current stops, as shown in figure 2-20, view B.

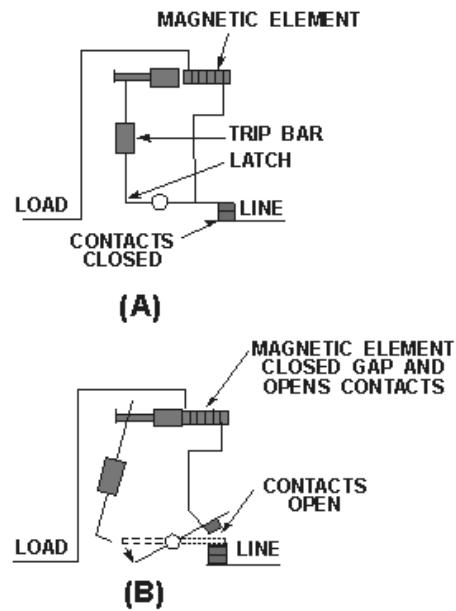
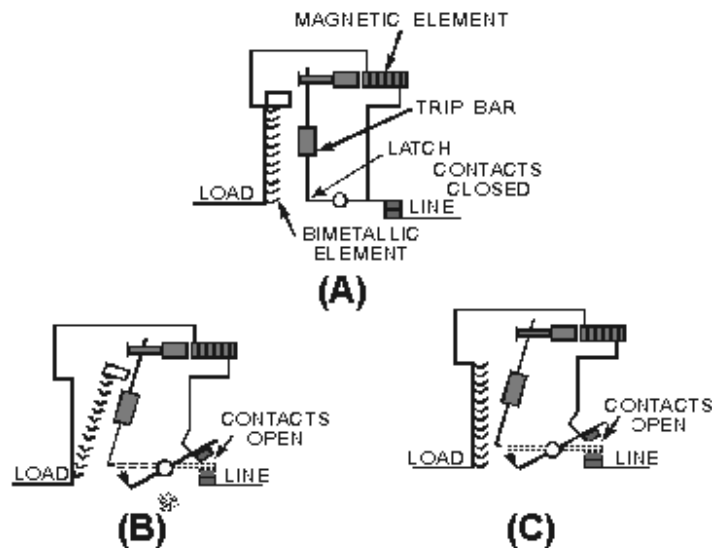


Figure 2-20.—Magnetic trip element action; Closed contacts;

The amount of current needed to trip the circuit breaker depends on the size of the gap between the trip bar and the magnetic element. On some circuit breakers, this gap (and therefore the trip current) is adjustable.

### THERMAL-MAGNETIC TRIP ELEMENT

The thermal trip element circuit breaker, like a delay fuse, will protect a circuit against a small overload that continues for a long time. The larger the overload, the faster the circuit breaker will trip. The thermal element will also protect the circuit against temperature increases. A magnetic circuit breaker will trip instantly when the preset current is present. In some applications, both types of protection are desired. Rather than use two separate circuit breakers, a single trip element combining thermal and magnetic trip elements is used. A thermal-magnetic trip element is shown in figure 2-21.



**Figure 2-21.—Thermal-magnetic element action:**

In the thermal-magnetic trip element circuit breaker, a magnetic element (electromagnet) is connected in series with the circuit load, and a bimetallic element is heated by the load current. With normal circuit current, the bimetallic element does not bend, and the magnetic element does not attract the trip bar, as shown in figure 2-21, view A.

If the temperature or current increases over a sustained period of time, the bimetallic element will bend, push the trip bar and release the latch. The circuit breaker will trip as shown in figure 2-21, view B.

If the current suddenly or rapidly increases enough, the magnetic element will attract the trip bar, release the latch, and the circuit breaker will trip, as shown in figure 2-21, view C. (This circuit breaker has tripped even though the thermal element has not had time to react to the increased current.)

*Q30. What are the five main components of a circuit breaker?*

*Q31. What are the three types of circuit breaker trip elements?*

*Q32. How does each type of trip element react to an overload?*

### **TRIP-FREE/NONTRIP-FREE CIRCUIT BREAKERS**

Circuit breakers are classified as being trip free or nontrip free. A trip-free circuit breaker is a circuit breaker that will trip (open) even if the operating mechanism (ON-OFF switch) is held in the ON position. A nontrip-free circuit breaker can be reset and/or held ON even if an overload or excessive heat condition is present. In other words, a nontrip-free circuit breaker can be bypassed by holding the operating mechanism ON.

Trip-free circuit breakers are used on circuits that cannot tolerate overloads and on nonemergency circuits. Examples of these are precision or current sensitive circuits, nonemergency lighting circuits, and nonessential equipment circuits. Nontrip-free circuit breakers are used for circuits that are essential for operations. Examples of these circuits are emergency lighting, required control circuits, and essential equipment circuits.

## TIME DELAY RATINGS

Circuit breakers, like fuses, are rated by the amount of time delay. In circuit breakers the ratings are instantaneous, short time delay, and long time delay. The delay times of circuit breakers can be used to provide for SELECTIVE TRIPPING.

Selective tripping is used to cause the circuit breaker closest to the faulty circuit to trip. This will remove power from the faulty circuit without affecting other, nonfaulty circuits. Figure 2-22 should help you understand selective tripping.

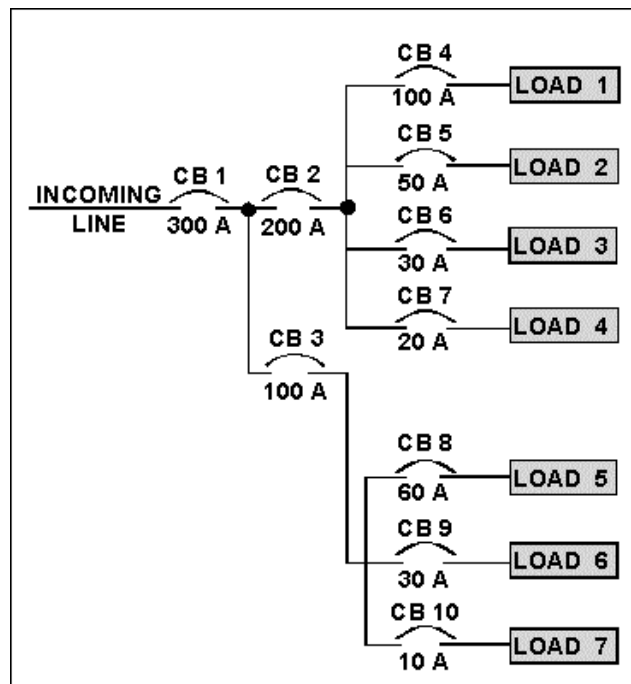


Figure 2-22.—Use of circuit breakers in a power distribution system.

Figure 2-22 shows a power distribution system using circuit breakers for protection. Circuit breaker 1 (CB1) has the entire current for all seven loads through it. CB2 feeds loads 1, 2, 3, and 4 (through CB4, CB5, CB6, and CB7), and CB3 feeds loads 5, 6, and 7 (through CB8, CB9, and CB10). If all the circuit breakers were rated with the same time delay, an overload on load 5 could cause CB1, CB3, and CB8 to trip. This would remove power from all seven loads, even though load 5 was the only circuit with an overload.

Selective tripping would have CB1 rated as long time delay, CB2 and CB3 rated as short time delay, and CB4 through CB10 rated as instantaneous. With this arrangement, if load 5 had an overload, only CB8 would trip. CB8 would remove the power from load 5 before CB1 or CB3 could react to the overload. In this way, only load 5 would be affected and the other circuits would continue to operate.

## PHYSICAL TYPES OF CIRCUIT BREAKERS

All the circuit breakers presented so far in this chapter have been physically large, designed to control large amounts of power, and used a type of toggle operating mechanism. Not all circuit breakers are of this type. The circuit breaker in figure 2-23 is physically large and controls large amounts of power; but the operating mechanism is not a toggle. Except for the difference in the operating mechanism, this circuit breaker is identical to the circuit breakers already presented.

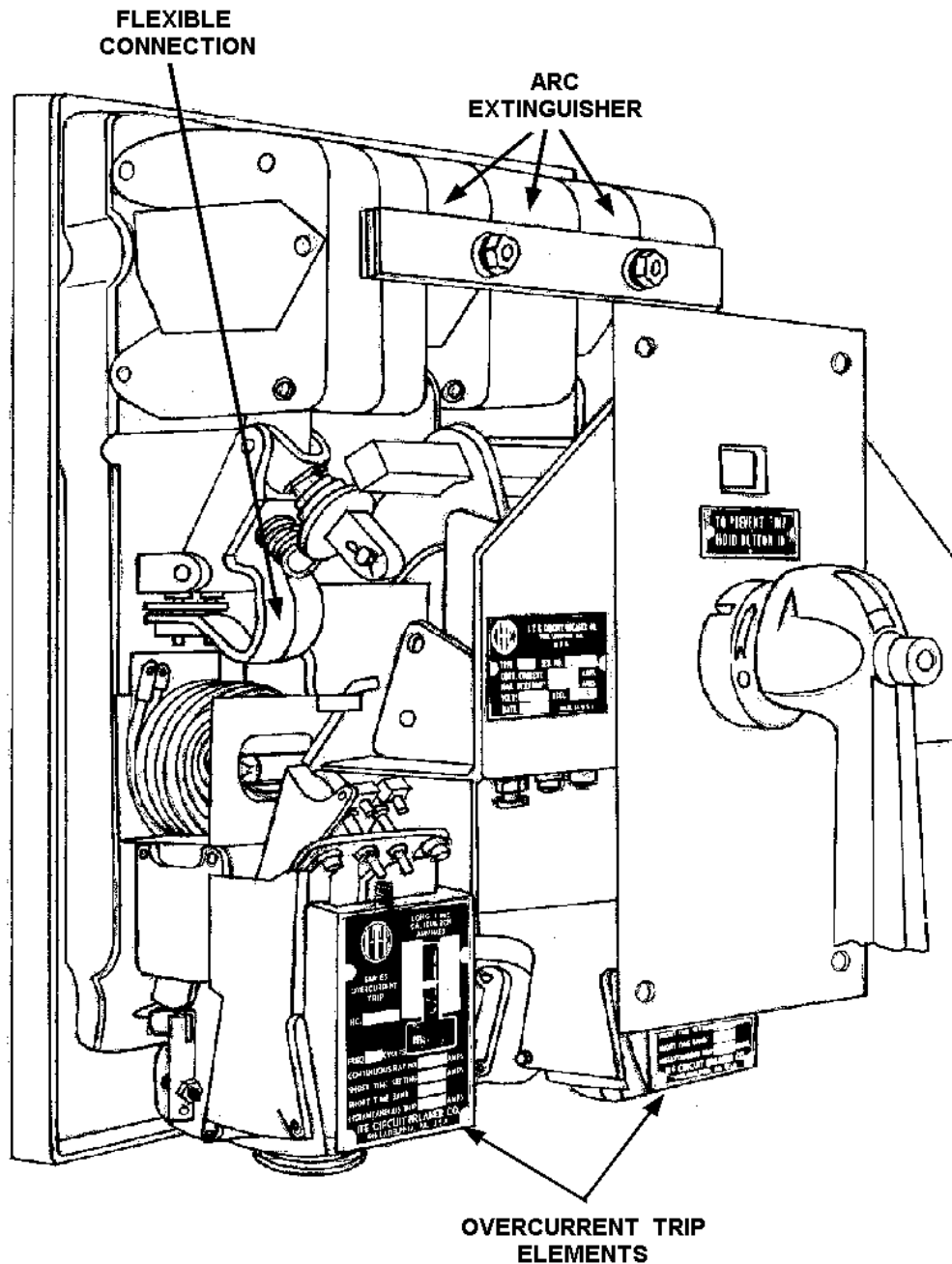
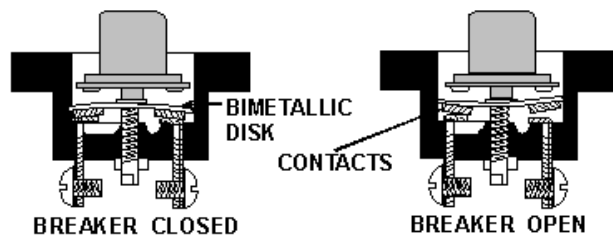


Figure 2-23.—Circuit breaker with an operating handle.

Circuit breakers used for low power protection, such as 28-volt dc, 30 amperes, can be physically small. With low power use, arc extinguishers are not required, and so are not used in the construction of these circuit breakers. Figure 2-24 shows a low power circuit breaker of the push-button or push-pull type. This circuit breaker has a thermal trip element (the bimetallic disk) and is nontrip-free. The push button is the operating mechanism of this circuit breaker.



**Figure 2-24.—Push-button circuit breaker.**

You will find other physical types of circuit breakers as you work with electrical circuits. They are found in power distribution systems, lighting panels, and even on individual pieces of equipment. Regardless of the physical size and the amount of power through the circuit breaker, the basic operating principles of circuit breakers apply.

*Q33. What is a trip-free circuit breaker?*

*Q34. What is a nontrip-free circuit breaker?*

*Q35. Where should you use a trip-free circuit breaker?*

*Q36. Where should you use a nontrip-free circuit breaker?*

The magnetic trip element makes use of a magnetic element (electromagnet). If current reaches a preset quantity, the magnetic element attracts the trip bar and releases the latch.

The thermal-magnetic trip element combines the actions of the bimetallic and magnetic elements in a single trip element. If either the bimetal element or the magnetic element reacts, the circuit breaker will trip.

*Q37. What are the three time delay ratings for circuit breakers?*

*Q38. What is selective tripping and why is it used?*

*Q39. If the power distribution system shown in figure 2-22 uses selective tripping, what is the time delay rating for each of the circuit breakers shown?*

*Q40. What factors are used to select a circuit breaker?*

*Q41. What type of circuit breaker is used on a multimeter?*

## **CIRCUIT BREAKER MAINTENANCE**

Circuit breakers require careful inspection and periodic cleaning. Before you attempt to work on circuit breakers, check the applicable technical manual carefully. When you work on shipboard circuit breakers, the approval of the electrical or engineering officer must be obtained before starting work. Be certain to remove all power to the circuit breaker before you work on it. Tag the switch that removes the power to the circuit breaker to ensure that power is not applied while you are working.

Once approval has been obtained, the incoming power has been removed, the switch tagged, and you have checked the technical manual, you may begin to check the circuit breaker. Manually operate the circuit breaker several times to be sure the operating mechanism works smoothly. Inspect the contacts for



pitting caused by arcing or corrosion. If pitting is present, smooth the contacts with a fine file or number 00 sandpaper. Be certain the contacts make proper contact when the operating mechanism is ON.

Check the connections at the terminals to be certain the terminals and wiring are tight and free from corrosion. Check all mounting hardware for tightness and wear. Check all components for wear. Clean the circuit breaker completely.

When you have finished working on the circuit breaker, restore power and remove the tag from the switch that applies power to the circuit.

*Q42. What steps are to be taken before beginning work on a circuit breaker?*

*Q43. What items are you to check when working on a circuit breaker?*

### **SUMMARY**

This chapter has provided the information to enable you to have a basic understanding of circuit protection devices. The following is a summary of the main points in this chapter.

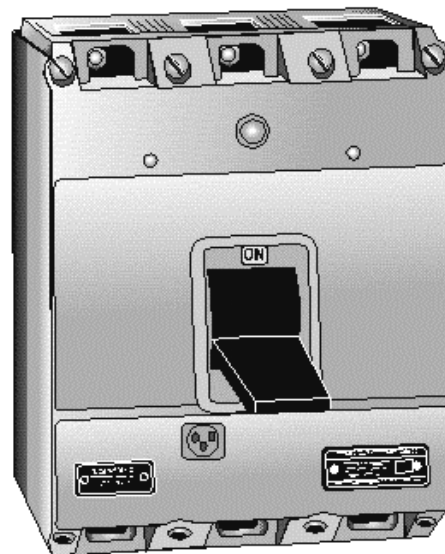
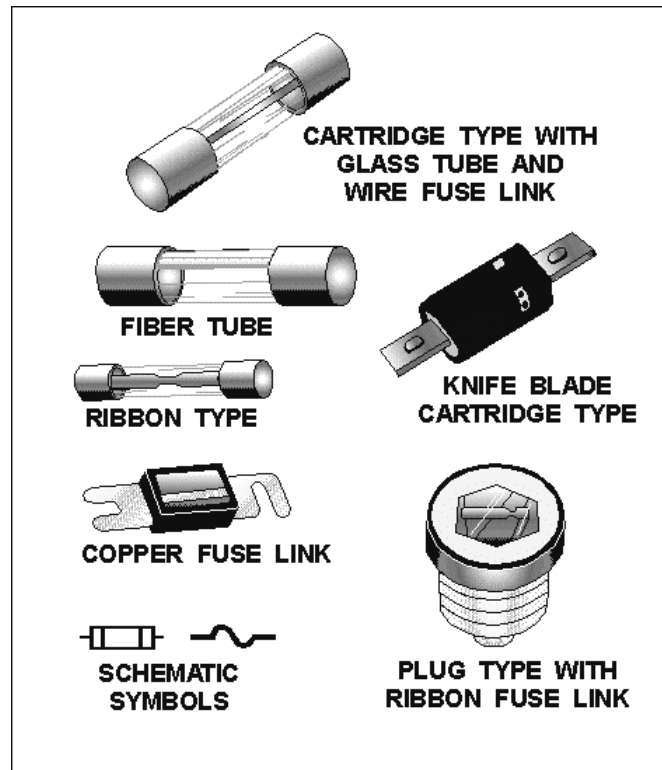
**CIRCUIT PROTECTION DEVICES** are needed to protect personnel and circuits from hazardous conditions. The hazardous conditions can be caused by a direct short, excessive current, or excessive heat. Circuit protection devices are always connected in series with the circuit being protected.

**A DIRECT SHORT** is a condition in which some point in the circuit, where full system voltage is present, comes in direct contact with the ground or return side of the circuit.

**EXCESSIVE CURRENT** describes a condition that is not a direct short but in which circuit current increases beyond the designed current carrying ability of the circuit.

**EXCESSIVE HEAT** describes a condition in which the heat in or around a circuit increases to a higher than normal level.

**FUSES** and **CIRCUIT BREAKERS** are the two types of circuit protection devices discussed in this chapter.



**SCHEMATIC SYMBOLS**

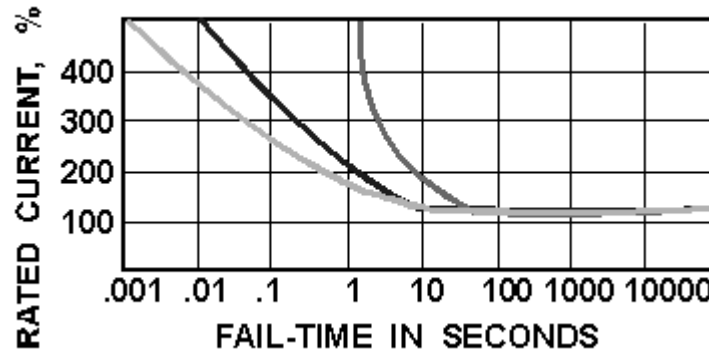
**PLUG-TYPE FUSES** are used in low-voltage, low-current circuits. This type fuse is rapidly being replaced by the circuit breaker.

**CARTRIDGE FUSES** are available in a wide range of physical sizes and voltage and current ratings. This type fuse is the most commonly used fuse.

The **CURRENT RATING** of a fuse is a value expressed in amperes that represents the amount of current the fuse will allow to flow without opening.

The **VOLTAGE RATING** of a fuse indicates the ability of the fuse to quickly extinguish the arc after the fuse element melts and the maximum voltage the open fuse will block.

The **TIME DELAY RATING** of a fuse indicates the relationship between the current through the fuse and the time it takes for the fuse to open. The three time delay ratings for fuses are DELAY, STANDARD, and FAST.

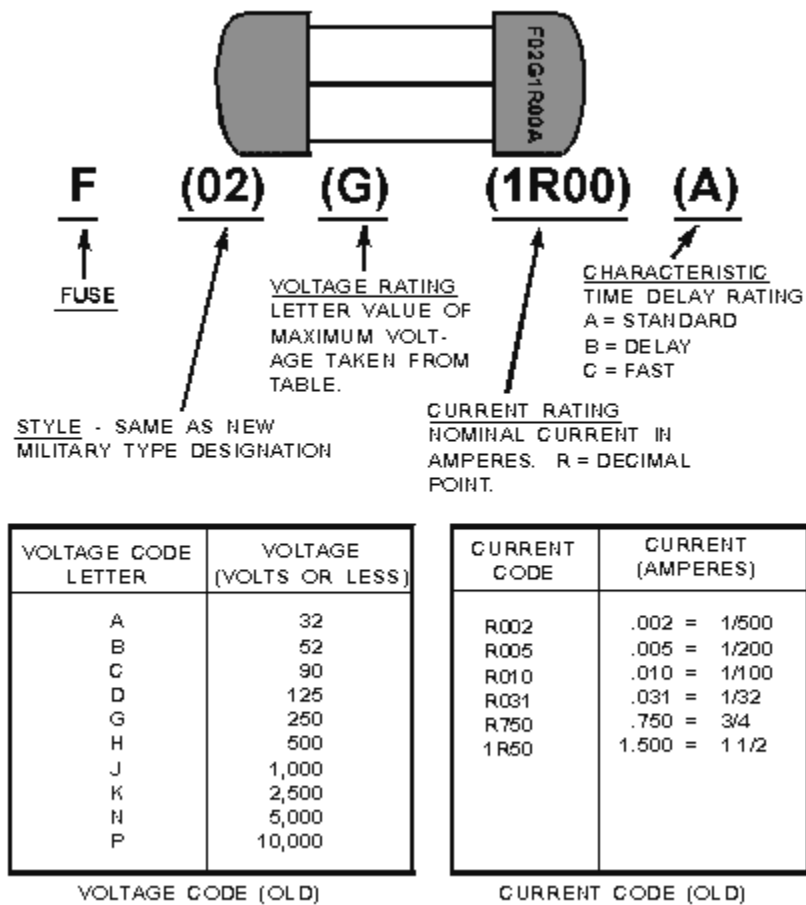


**DELAY FUSES** allow surge currents without opening. They are used to protect motors, solenoids, and transformers.

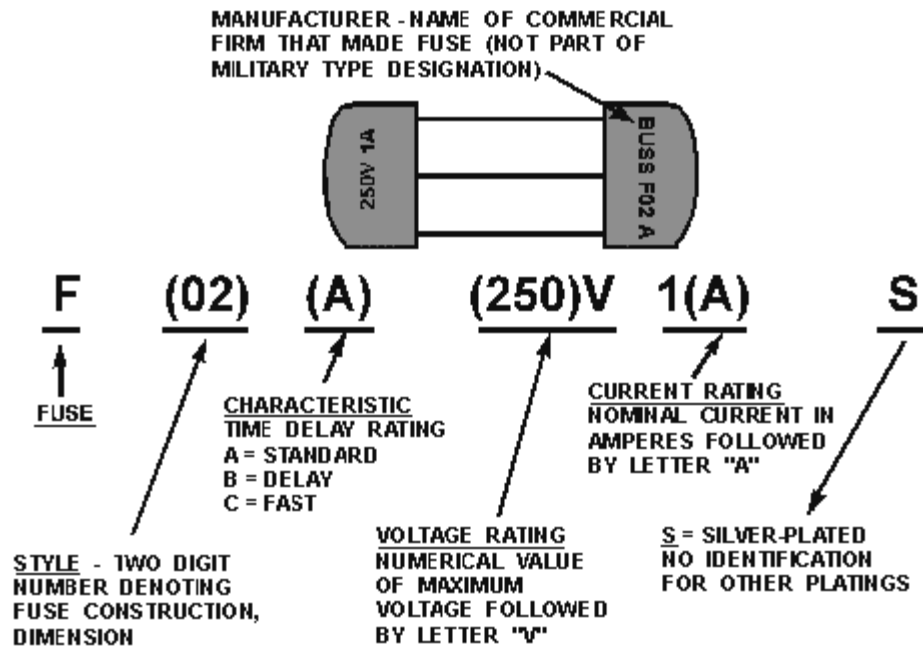
**STANDARD FUSES** have neither a time delay nor a fast acting characteristic. They are used in automobiles, lighting circuits and electrical power circuits.

**FAST FUSES** open very quickly with any current above the current rating of the fuse. They are used to protect delicate instruments or semiconductor devices.

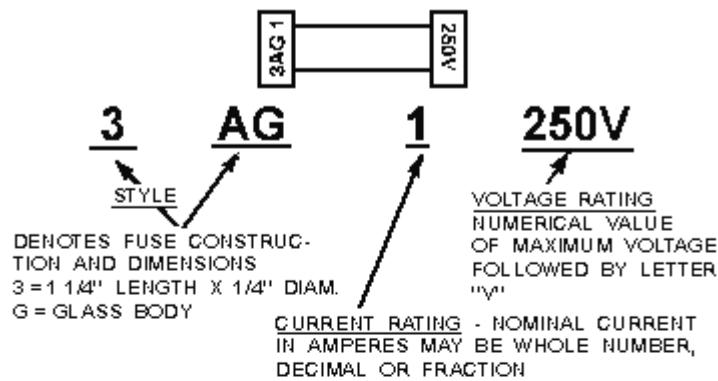
The **OLD MILITARY FUSE DESIGNATION** is a system of fuse identification that uses coding to represent the current, voltage, and time-delay rating of the fuse. New fuses purchased by the Navy will no longer use this designation.



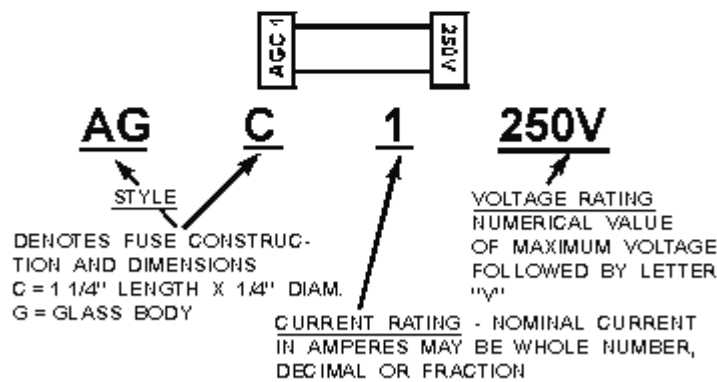
The **NEW MILITARY FUSE DESIGNATION** is the system used to identify fuses purchased by the Navy at the present time. The coding of current and voltage ratings has been replaced with direct printing of these ratings.



The **OLD COMMERCIAL FUSE DESIGNATION** was used by the fuse manufacturers to identify fuses. The current and voltage ratings are printed on the fuse, but the time delay rating is contained in the style coding of the fuse.



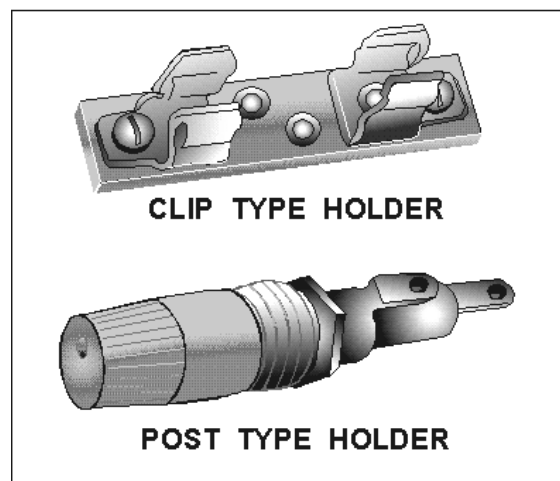
**(A) OLD COMMERCIAL DESIGNATIONS**



**(B) NEW COMMERCIAL DESIGNATIONS**

The **NEW COMMERCIAL FUSE DESIGNATION** is currently used by fuse manufacturers to identify fuses. It is similar to the old commercial fuse designation with the difference being in the style coding portion of the designation.

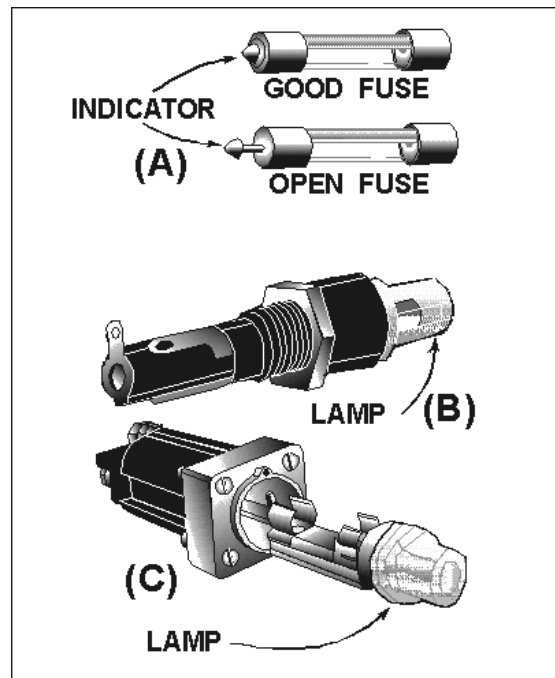
**FUSEHOLDERS** are used to allow easy replacement of fuses in a circuit.



The **CLIP-TYPE** has clips to connect the ferrules or knifeblades of the fuse to the circuit. The **POST-TYPE** is an enclosed fuseholder. The center connection of the post type should be connected to the power source and the outside connector should be connected to the load.

**OPEN FUSES** can be found by **VISUAL INSPECTION**, **FUSE INDICATORS**, or by the use of a **METER**. The following **SAFETY PRECAUTIONS** should be observed when checking a fuse:

- Turn the power off and discharge the circuit before removing a FUSE.
- Use a fusepuller when you remove a fuse from clip-type fuseholders.
- When you check a fuse with a voltmeter, be careful to avoid shocks and short circuits.
- When you use an ohmmeter to check fuses with low current ratings, be careful to avoid opening the fuse by excessive current.

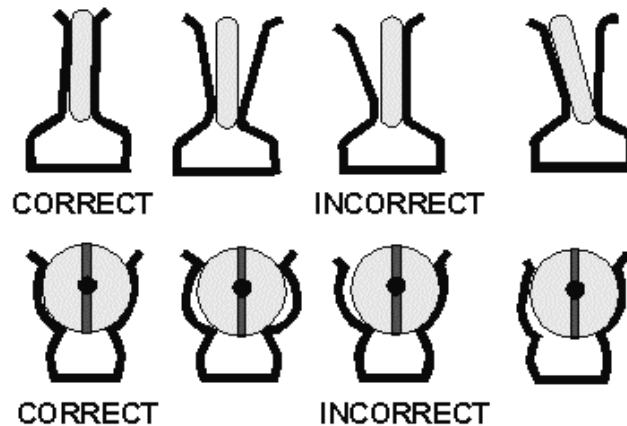


**REPLACEMENT FUSES** must be of the proper type. Check the technical manual parts list to find the identification of the proper fuse. If a substitute fuse must be used, the following guidelines should be followed:

- Never use a fuse with a higher current rating, a lower voltage rating, or a slower time delay rating than the specified fuse.
- The best substitution fuse is a fuse with the same current and time delay ratings and a higher voltage rating.

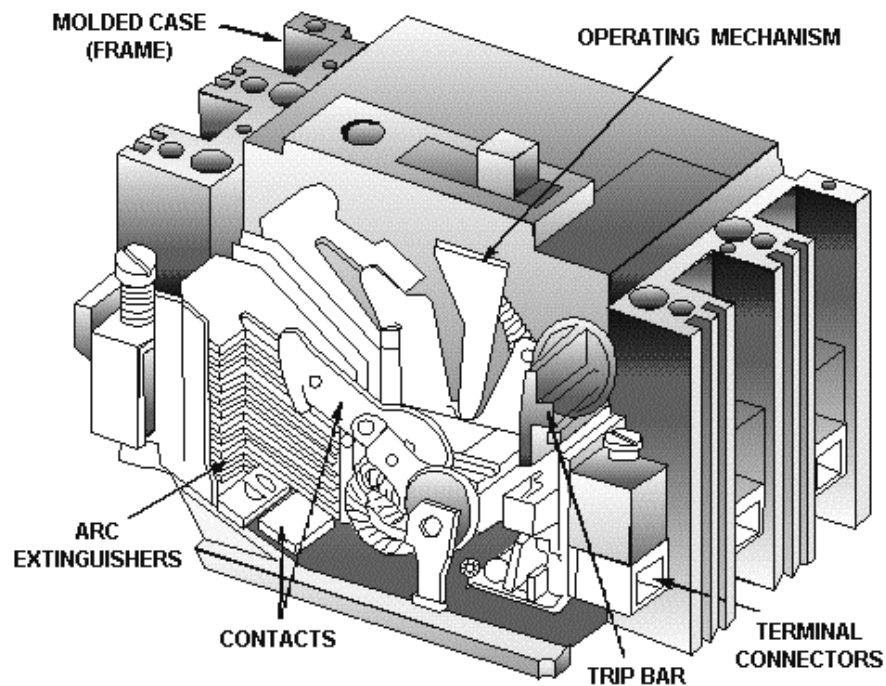
- If a lower current rating, or a lower time delay rating is used, the fuse may open under normal circuit conditions. Substitute fuses must have the same style (physical dimensions) as the specified fuse.

**PROPER FIT** between the fuse and fuseholder is essential. If the clips on clip-type fuseholders are sprung, the clips should be reformed, or clip clamps should be used. Any corrosion on fuses or fuseholders must be removed with fine sandpaper.



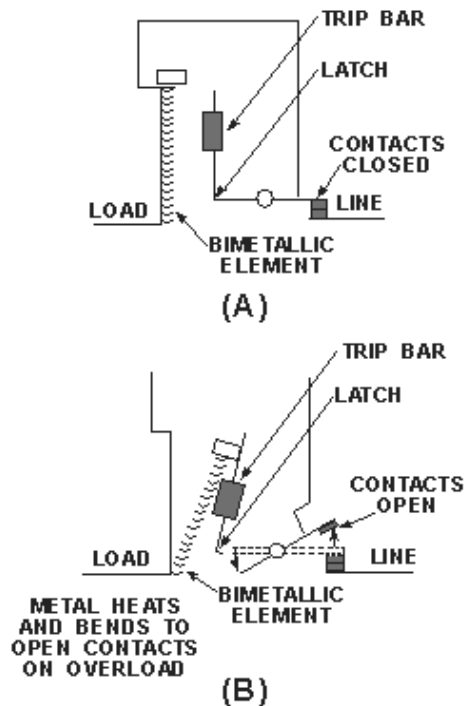
**PREVENTIVE MAINTENANCE** of fuses involves checking for the proper fuse, corrosion, proper fit, and open fuses; and correcting any discrepancies.

**CIRCUIT BREAKERS** have five main components: The frame, the operating mechanism, the arc extinguisher, the terminal connectors, and the trip element.

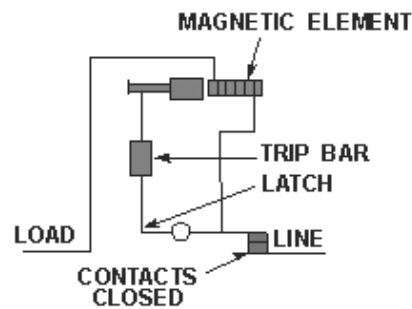




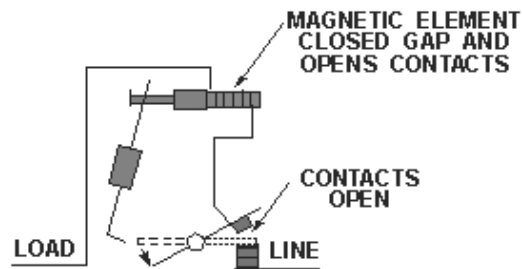
A **THERMAL TRIP ELEMENT** uses a bimetallic element that is heated by load current and bends due to this heating. If current (or temperature) increases above normal, the bimetallic element bends to push against a trip bar and opens the circuit.



A **MAGNETIC TRIP ELEMENT** uses an electromagnet in series with the load current to attract the trip bar and open the circuit if excessive current is present.

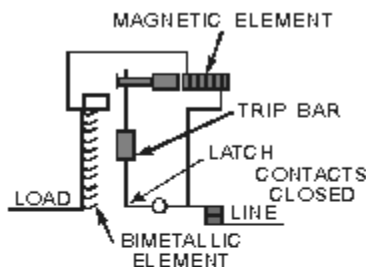


(A)

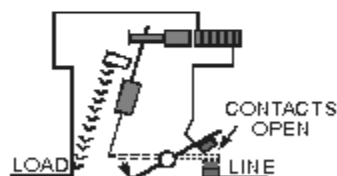


(B)

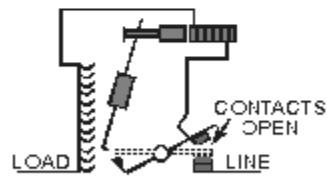
A **THERMAL-MAGNETIC TRIP ELEMENT** combines the thermal and magnetic trip elements into a single unit. A TRIP-FREE circuit breaker will trip (open) even if the operating mechanism is held in the ON position. A TRIP-FREE circuit breaker would be used on non-essential circuits.



(A)



(B)

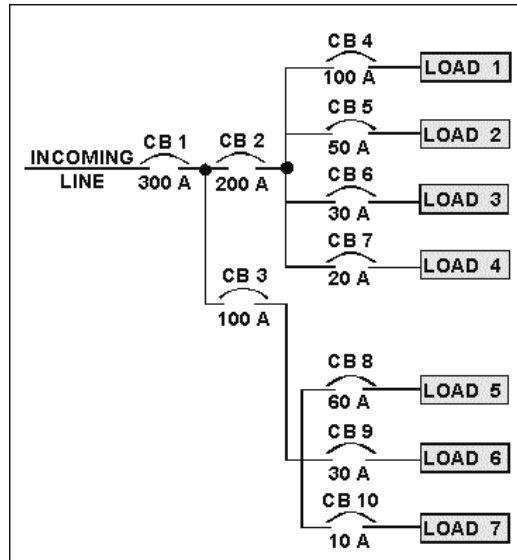


(C)

A **NONTRIP-FREE** circuit breaker can be bypassed by holding the operating mechanism ON. A NONTRIP-FREE circuit breaker would be used for emergency or essential equipment circuits.

The **TIME DELAY RATINGS** of circuit breakers are INSTANTANEOUS, SHORT TIME DELAY, and LONG TIME DELAY.

**SELECTIVE TRIPPING** is used to cause the circuit breaker closest to the faulty circuit to trip, isolating the faulty circuit without affecting other nonfaulty circuits. This is accomplished by using an instantaneous circuit breaker close to the load, a short time delay circuit breaker at the next junction, and a long time delay circuit breaker at the main junction box.



The **FACTORS** used to select a circuit breaker are the power requirements of the circuit and the physical space available.

When **WORKING ON CIRCUIT BREAKERS**, the following items should be done **BEFORE** working on the circuit breaker: Check the applicable technical manual, obtain the approval of the electrical or engineering officer (for shipboard circuit breakers), remove power from the circuit breaker, and tag the switch that removes power from the circuit breaker. The following items should be checked and discrepancies corrected when working on circuit breakers: Check the operating mechanism for smooth operation, check the contacts for pitting, check the terminals for tightness and corrosion, check the mounting hardware for tightness and wear, check all components for wear, and check the entire circuit breaker for cleanliness.

#### ANSWERS TO QUESTIONS Q1. THROUGH Q43.

- A1. *To protect people and circuits from possible hazardous conditions.*
- A2. *A direct short, excessive current, and excessive heat.*
- A3. *A condition in which some point in the circuit where full system voltage is present comes in contact with the ground or return side of the circuit.*
- A4. *A condition that is not a direct short but in which circuit current increases beyond the designed current carrying ability of the circuit.*
- A5. *A condition in which the heat in or around the circuit increases to a higher than normal level*

A6. *In series, so total current will be stopped when the device opens.*

A7. *Fuses and circuit breakers.*

A8.

- a. *circuit breaker*
- b. *fuse.*

A9.

- a. *cartridge*
- b. *plug*
- c. *plug*
- d. *cartridge.*

A10. *A, C.*

A11. *Current, voltage, and time delay.*

A12. *The amount of current the fuse will allow without opening.*

A13. *The ability of the fuse to quickly extinguish the arc after the fuse element melts and the maximum voltage that cannot jump across the gap of the fuse after the fuse opens.*

A14. *Delay, standard, and fast.*

A15. *Delay-Motors, solenoids, or transformers. Standard-Automobiles, lighting or electrical power circuits. Fast-Delicate instruments or semiconductor devices.*

A16.

- a. *125 volts or less, 1.5 amperes, delay*
- b. *250 volts or less, 1/8 ampere standard*

A17.

- a. *125 volts or less, 1/16 ampere*
- b. *250 volts or less, .15 ampere*

A18. *F05B32V20A.*

A19.

- a. *Post-type fuseholder*
- b. *Clip-type fuseholder*

A20.

- a. *Center connector*
- b. *Outside connector*

A21. *Visual inspection, indicators, and using a meter.*

A22. *Put it back in the circuit. A good fuse will have zero ohms of resistance.*

A23. *The ohmmeter causes more than 1/500 ampere through the fuse when you check the fuse, thus it opens the fuse.*

A24. *Use a resistor in series with the fuse when you check it with the ohmmeter.*

A25. *Turn the power off and discharge the circuit before you remove fuses. Use a fuse puller (an insulated tool) when you remove fuses from clip-type fuse holders. When you check fuses with a voltmeter, be careful to avoid shocks and short circuits.*

A26.

- a. *Not acceptable-wrong style*
- b. *Substitute #3-smaller current rating*
- c. *Substitute #1-identical, except higher voltage rating*
- d. *Not acceptable-lower voltage rating*
- e. *Direct replacement*
- f. *Not acceptable-higher current rating*
- g. *Substitute #2-Faster time delay rating*

A27. *Check for the proper type of replacement fuse and proper fit.*

A28. *Be sure the power is off in the circuit and the circuit is discharged before replacing a fuse. Use an identical replacement fuse if possible. Remove any corrosion from the fuseholders before replacing the fuses.*

A29. *Improper fuse, corrosion, improper fit, and open fuse.*

A30. *Frame, operating mechanism, arc extinguishers, terminal connectors, and trip element.*

A31. *Thermal, magnetic, and thermal-magnetic.*

A32. *The thermal trip element makes use of a bimetallic element that bends with an increase in temperature or current. The bending causes the trip bar to be moved releasing the latch.*

A33. *A circuit breaker that will trip even if the operating mechanism is held ON.*

A34. *A circuit breaker that can be overridden if the operating mechanism is held ON.*

A35. *In current sensitive or nonemergency systems.*

- A36. In emergency or essential circuits.*
- A37. Instantaneous, short time delay, and long time delay.*
- A38. It is the use of time delay ratings to cause the circuit breaker closest to the faulty circuit to trip. This isolates the faulty circuit without affecting other circuits.*
- A39. CB1-long time delay; CB2, CB3-short time delay; CB4 through CB10-instantaneous.*
- A40. The power requirements of the circuit and the physical space available.*
- A41. A push button or push-pull circuit breaker (small size, low power).*
- A42. Check the applicable technical manual, obtain the approval of the electrical or engineering officer (for shipboard circuit breakers), remove power from the circuit breaker, and tag the switch that supplies power to the circuit breaker.*
- A43. Check the operating mechanism for smooth operation, check the contacts for pitting, check the terminals for tightness and corrosion, check the mounting hardware for tightness and wear, check all components for wear, and check the entire circuit breaker for cleanliness.*

## **CHAPTER 3**

# **CIRCUIT CONTROL DEVICES**

### **LEARNING OBJECTIVES**

Upon completion of this chapter you will be able to:

1. State three reasons circuit control devices are used and list three general types of circuit control devices.
2. Identify the schematic symbols for a switch, a solenoid, and a relay.
3. State the difference between a manual and an automatic switch and give an example of each.
4. State the reason multicontact switches are used.
5. Identify the schematic symbols for the following switches:
  - Single-pole, double-throw
  - Double-pole, single-throw
  - Double-pole, double-throw
  - Single-break
  - Double-break
  - Rotary
  - Wafer
6. State the characteristics of a switch described as a rocker switch.
7. State the possible number of positions for a single-pole, double-throw switch.
8. Identify a type of momentary switch.
9. State the type of switch used to prevent the accidental energizing or deenergizing of a circuit.
10. State the common name for an accurate snap-acting switch.
11. State the meaning of the current and voltage rating of a switch.
12. State the two types of meters you can use to check a switch.
13. Select the proper substitute switch from a list.
14. State the conditions checked for in preventive maintenance of switches.

15. State the operating principle and one example of a solenoid.
16. State the ways in which a solenoid can be checked for proper operation.
17. State the operating principle of a relay and how it differs from a solenoid.
18. State the two types of relays according to use.
19. State the ways in which a relay can be checked for proper operation and the procedure for servicing it.

## **CIRCUIT CONTROL DEVICES**

Circuit control devices are used everywhere that electrical or electronic circuits are used. They are found in submarines, computers, aircraft, televisions, ships, space vehicles, medical instruments, and many other places. In this chapter you will learn what circuit control devices are, how they are used, and some of their characteristics.

### **INTRODUCTION**

Electricity existed well before the beginning of recorded history. Lightning was a known and feared force to early man, but the practical uses of electricity were not recognized until the late 18th century. The early experimenters in electricity controlled power to their experiments by disconnecting a wire from a battery or by the use of a clutch between a generator and a steam engine. As practical uses were found for electricity, a convenient means for turning power on and off was needed.

Telegraph systems, tried as early as the late 1700s and perfected by Morse in the 1830s, used a mechanically operated contact lever for opening and closing the signal circuit. This was later replaced by the hand-operated contact lever or "key."

Early power switches were simple hinged beams, arranged to close or open a circuit. The blade-and-jaw knife switch with a wooden, slate, or porcelain base and an insulated handle, was developed a short time later. This was the beginning of circuit control devices.

Modern circuit control devices can change their resistance from a few milliohms (when closed) to well over 100,000 megaohms (when open) in a couple of milliseconds. In some circuit control devices, the movement necessary to cause the device to open or close is only .001 inch (.025 millimeters).

### **NEED FOR CIRCUIT CONTROL**

Circuit control, in its simplest form, is the application and removal of power. This can also be expressed as turning a circuit on and off or opening and closing a circuit. Before you learn about the types of circuit control devices, you should know why circuit control is needed.

If a circuit develops problems that could damage the equipment or endanger personnel, it should be possible to remove the power from that circuit. The circuit protection devices discussed in the last chapter will remove power automatically if current or temperature increase enough to cause the circuit protection device to act. Even with this protection, a manual means of control is needed to allow you to remove power from the circuit before the protection device acts.

When you work on a circuit, you often need to remove power from it to connect test equipment or to remove and replace components. When you remove power from a circuit so that you can work on it, be



sure to "tag out" the switch to ensure that power is not applied to the circuit while you are working. When work has been completed, power must be restored to the circuit. This will allow you to check the proper operation of the circuit and place it back in service. After the circuit has been checked for proper operation, remove the tag from the power switch.

Many electrical devices are used some of the time and not needed at other times. Circuit control devices allow you to turn the device on when it is needed and off when it is not needed.

Some devices, like multimeters or televisions, require the selection of a specific function or circuit. A circuit control device makes possible the selection of the particular circuit you wish to use.

## TYPES OF CIRCUIT CONTROL DEVICES

Circuit control devices have many different shapes and sizes, but most circuit control devices are either SWITCHES, SOLENOIDS, or RELAYS.

Figure 3-1 shows an example of each of these types of circuit control devices and their schematic symbols.

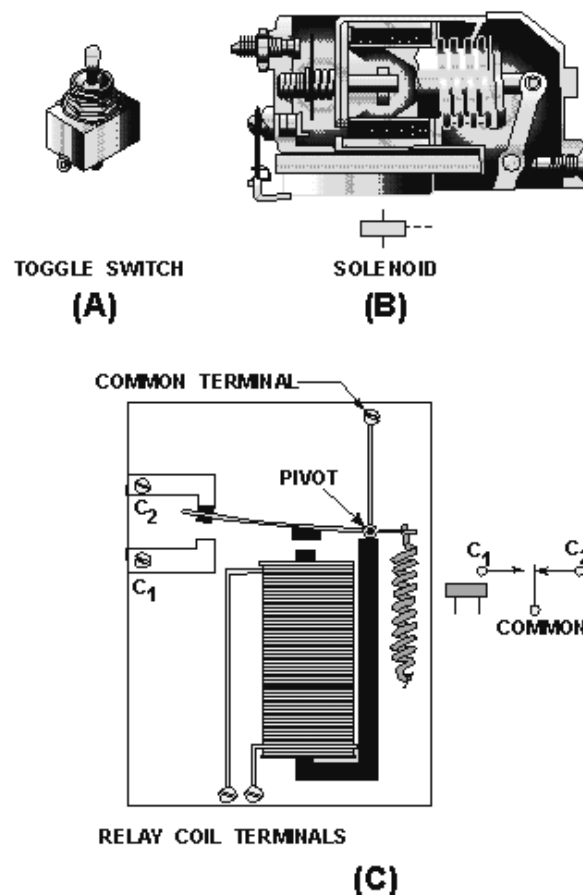


Figure 3-1.—Typical circuit control devices: RELAY COIL TERMINALS

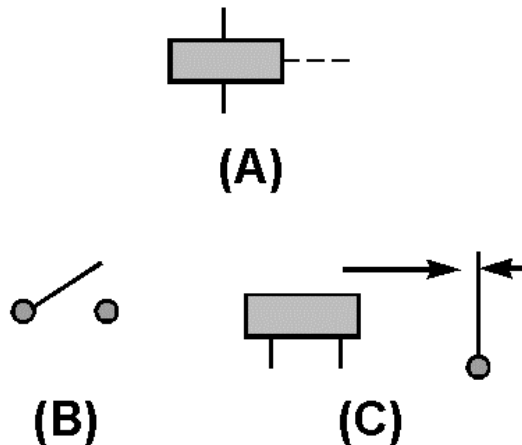
Figure 3-1, view A, is a simple toggle switch and the schematic symbol for this switch is shown below it. Figure 3-1, view B, is a cutaway view of a solenoid. The schematic symbol below the solenoid

is one of the schematic symbols used for this solenoid. Figure 3-1, view C, shows a simple relay. One of the schematic symbols for this relay is shown next to the relay.

*Q1. What are three reasons circuit control is needed?*

*Q2. What are the three types of circuit control devices?*

*Q3. Label the schematic symbols shown in figure 3-2.*



**Figure 3-2.—Schematic symbol recognition.**

## **SWITCH TYPES**

There are thousands and thousands of switch applications found in home, industry, and the Navy. Hundreds of electrical switches work for you everyday to perform functions you take for granted. Some switches operate by the touch of a finger and many others are operated automatically.

Switches are used in the home to turn off the alarm clock, to control the stove, to turn on the refrigerator light, to turn on and control radios and televisions, hair dryers, dishwashers, garbage disposals, washers and dryers, as well as to control heating and air conditioning. A typical luxury automobile with power seats and windows might have as many as 45 switches.

Industry uses switches in a wide variety of ways. They are found in the business office on computers, copy machines, electric typewriters, and other equipment. A factory or shop may use thousands of switches and they are found on almost every piece of machinery. Switches are used on woodworking machinery, metal working machinery, conveyors, automation devices, elevators, hoists, and lift trucks.

The Navy uses switches in a number of ways. A typical aircraft could have over 250 switches to control lights, electronic systems, and to indicate whether the landing gear is up or down. Ships, fire control systems, and missile launchers are also controlled by electrical switches. In fact, almost all electrical or electronic devices will have at least one switch.

Switches are designed to work in many different environments from extreme high pressure, as in a submarine, to extreme low pressure, as in a spacecraft. Other environmental conditions to consider are high or low temperature, rapid temperature changes, humidity, liquid splashing or immersion, ice, corrosion, sand or dust, fungus, shock or vibration, and an explosive atmosphere.

It would not be possible to describe all the different switches used. This chapter will describe the most common types of switches.

## **MANUAL SWITCHES**

A manual switch is a switch that is controlled by a person. In other words, a manual switch is a switch that you turn on or off. Examples of common manual switches are a light switch, the ignition switch on a motor vehicle, or the channel selector on a television. You may not think of the channel selector as a switch that you use to turn something on or off, but that is what it does. The channel selector is used to turn on the proper circuit and allows the television to receive the channel you have selected.

## **AUTOMATIC SWITCH**

An automatic switch is a switch that is controlled by a mechanical or electrical device. You do not have to turn an automatic switch on or off. Two examples of automatic switches are a thermostat and the distributor in a motor vehicle. The thermostat will turn a furnace or air conditioner on or off by responding to the temperature in a room. The distributor electrically turns on the spark plug circuit at the proper time by responding to the mechanical rotation of a shaft. Even the switch that turns on the light in a refrigerator when the door is opened is an automatic switch.

Automatic switches are not always as simple as the examples given above. Limit switches, which sense some limit such as fluid level, mechanical movement, pressure (altitude or depth under water), or an electrical quantity, are automatic switches. Computers use and control automatic switches that are sometimes quite complicated.

Basically, any switch that will turn a circuit on or off without human action is an automatic switch.

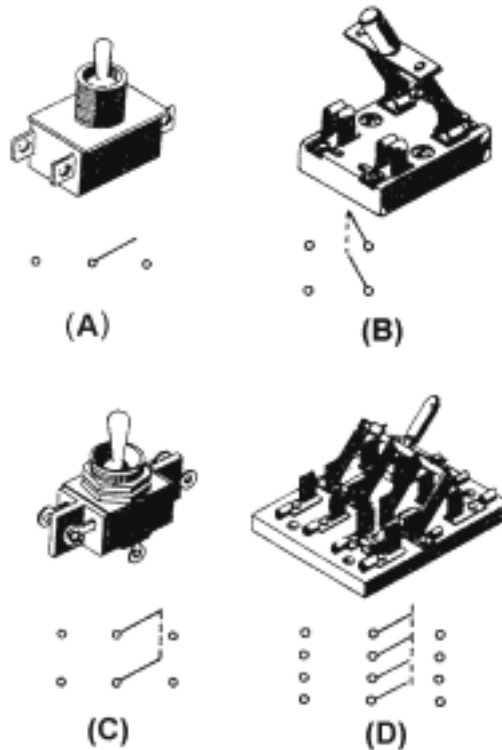
## **MULTICONTACT SWITCHES**

Switches are sometimes used to control more than one circuit or to select one of several possible circuits. An example of a switch controlling more than one circuit is the AM/FM selector on a radio. This switch enables you to control either the AM or FM portion of the radio with a single switch. An example of a switch that selects one of several circuits is the channel selector of a television set. These switches are called MULTICONTACT switches because they have more than one contact or MULTI(ple) CONTACTS.

### **Number of Poles and Number of Throws**

Multicontact switches (other than rotary switches, which will be covered later) are usually classified by the number of POLES and number of THROWS. Poles are shown in schematics as those contacts through which current enters the switch; they are connected to the movable contacts. Each pole may be connected to another part of the circuit through the switch by "throwing" the switch (movable contacts) to another position. This action provides an individual conduction path through the switch for each pole connection. The number of THROWS indicates the number of different circuits that can be controlled by each pole. By counting the number of points where current enters the switch (from the schematic symbol or the switch itself), you can determine the number of poles. By counting the number of different points each pole can connect with, you can determine the number of throws.

Figure 3-3 will help you understand this concept by showing illustrations of various multicontact switches and their schematic symbols.



**Figure 3-3.—Multicontact switches.**

Figure 3-3(A) shows a single-pole, double-throw switch. The illustration shows three terminals (connections) on this switch. The schematic symbol for the switch is also shown.

The center connection of the schematic symbol represents the point at which current enters the switch. The left and right connections represent the two different points to which this current can be switched. From the schematic symbol, it is easy to determine that this is a single-pole, double-throw switch.

Now look at figure 3-3(B). The switch is shown with its schematic symbol. The schematic symbol has two points at which current can enter the switch, so this is a double-pole switch. Each of the poles is mechanically connected (still electrically separate) to one point, so this is a single-throw switch. Only one throw is required to route two separate circuit paths through the switch.

Figure 3-3(C) shows a double-pole, double-throw switch and its schematic symbol. Figure 3-3(D) shows a four-pole, double-throw switch and its schematic symbol.

It might help you to think of switches with more than one pole as several switches connected together mechanically. For example, the knife switch shown in figure 3-3(D) could be thought of as four single-pole, double-throw switches mechanically connected together.

*Q4. What is the difference between a manual and an automatic switch?*

*Q5. What is one example of a manual switch?*

*Q6. What is one example of an automatic switch?*

*Q7. Why are multicontact switches used?*

Q8. Label the schematic symbols shown in figure 3-4 as to number of poles and number of throws.

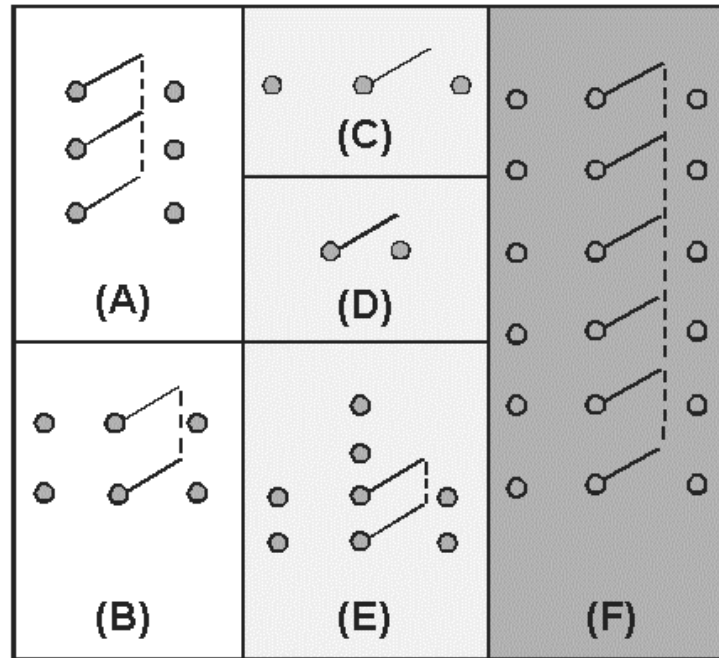


Figure 3-4.—Schematic symbols of switches.

### Single-Break and Double-Break Switches

Switches can also be classified as SINGLE-BREAK or DOUBLE-BREAK switches. This refers to the number of places in which the switch opens or breaks the circuit. All of the switches shown so far have been single-break switches. A double-break switch is shown in figure 3-5. The schematic symbol shown in figure 3-5(A) shows that this switch breaks the circuit in two places (at both terminals). The upper part of the schematic symbol indicates that these contacts are in the open position and the circuit will close when the switch is acted upon (manually or automatically). The lower symbol shows closed contacts. These contacts will open the circuit when the switch is acted upon.

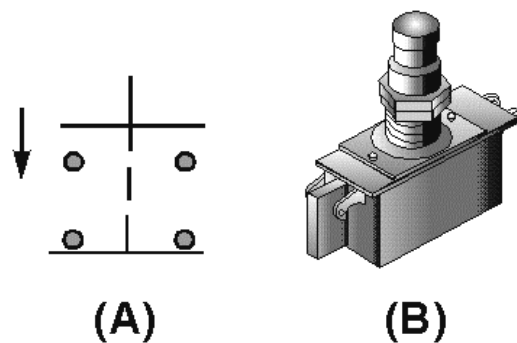


Figure 3-5.—Double-break pushbutton switch.

Figure 3-5(B) is a picture of the switch. This switch is called a pushbutton switch because it has a button that must be pushed to change the switch contact connections. Notice that the switch has four terminals. The schematic symbol in figure 3-5(A) shows that when one set of contacts is open, the other set of contacts is closed. This switch is a double-pole, single-throw, double-break switch.

The number of poles in a switch is independent of the number of throws and whether it is a single or double break switch. The number of throws in a switch is independent of the number of poles and whether it is a single or double break switch. In other words, each characteristic of a switch (poles, throws, break) is not determined by either of the other characteristics. Figure 3-6 shows the schematic symbols for several different switch configurations.

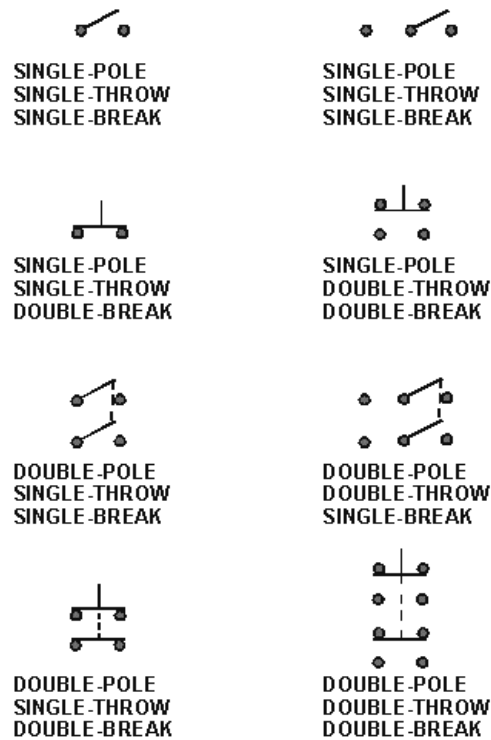
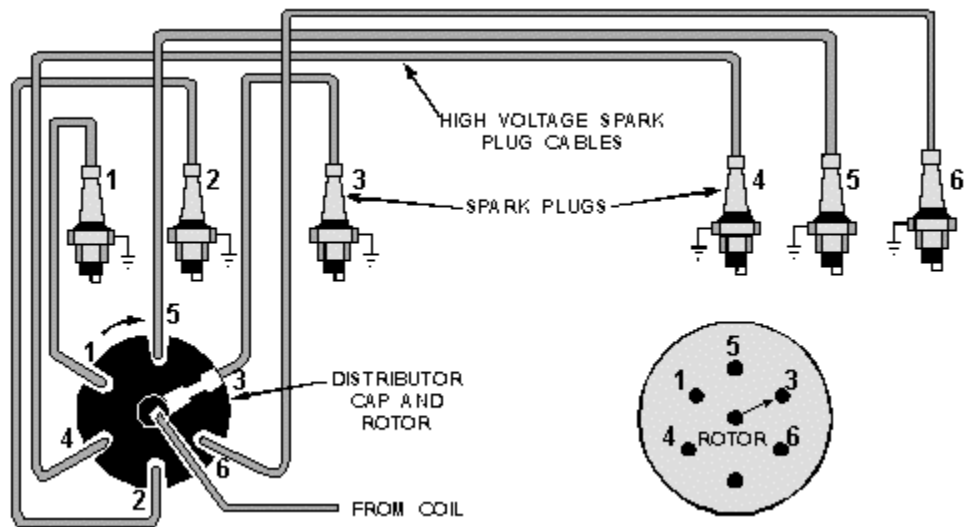


Figure 3-6.—Schematic symbols of switch configurations.

## Rotary Switches

A rotary switch is a midcontact switch part of the schematic with the contacts arranged in a full or partial circle. Instead of a pushbutton or toggle, the mechanism used to select the contact moves in a circular motion and must be turned. Rotary switches can be manual or automatic switches. An automobile distributor, the ignition switch on a motor vehicle, and the channel selector on some television sets are rotary switches.

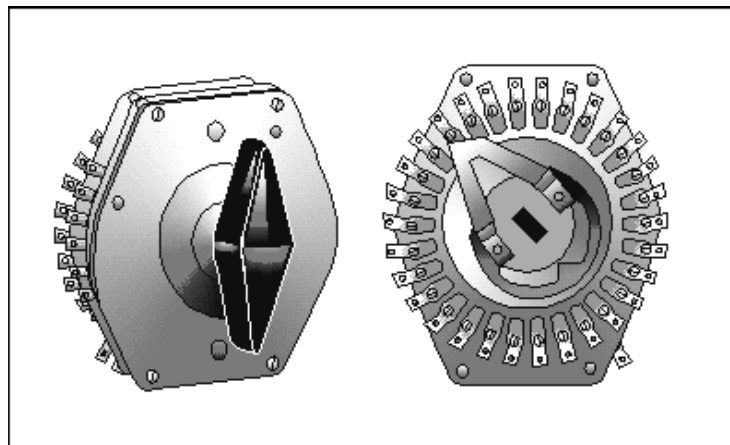
The automobile distributor cap and rotor are an example of the simplest form of an automatic rotary switch. Figure 3-7 shows a portion of an automobile ignition system with the distributor cap and rotor shown. The rotor is the portion of this switch that moves (rotates) and selects the circuit (spark plug). The rotor does not actually touch the contacts going to the spark plugs, but the signal (spark) jumps the gap between the rotor and the contacts. This switch has one input (the rotor) and six positions (one for each spark plug). The schematic diagram for this rotary switch is shown below the illustration of the distributor cap.



**Figure 3-7.—Rotary switch in automobile ignition system.**

The rotor in the distributor rotates continually (when in use) in one direction and makes a complete circle. This is not true for all rotary switches. The ignition switch in an automobile is also a rotary switch. It usually has four positions (accessory, off, on, start). Unlike the rotor, it does not rotate continually when in use, can be turned in either direction, and does not move through a complete circle.

Some rotary switches are made with several layers or levels. The arrangement makes possible the control of several circuits with a single switch. Figure 3-8 is an illustration of a rotary switch with two layers. Each layer has a selector and 20 contacts. As this switch is rotated, both layers select a single circuit (contact) of the 20.

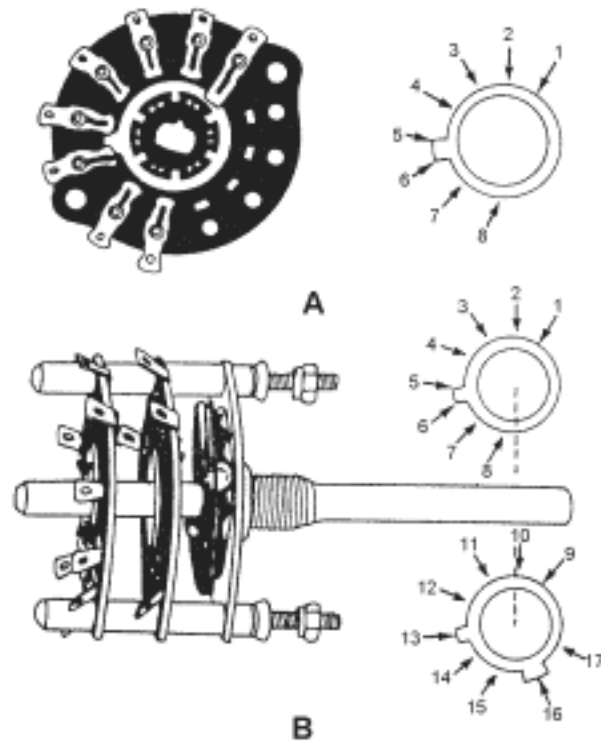


**Figure 3-8.—Two-layer rotary switch.**

The channel selector on some television sets is a multilayer rotary switch. It is also called a WAFER SWITCH. In a wafer switch, each layer is known as a wafer.

The schematic of the wafer is always drawn to represent the wafer as it would look if viewed from opposite the operating handle or mechanism. If the wafer has contacts on both sides, two drawings are used to show the two sides of the wafer. The two drawings are labeled "front" and "rear." The drawing labeled "front" represents the side of the wafer closest to the operating mechanism.

Figure 3-9(A) shows one wafer of a wafer switch and its schematic symbol. Contact 1 is the point at which current enters the wafer. It is always connected to the movable portion of the wafer. With the wafer in the position shown, contact 1 is connected to both contact 5 and 6 through the movable portion. If the movable portion was rotated slightly clockwise, contact 1 would only be connected to contact 5. This arrangement is known as MAKE BEFORE BREAK because the switch makes a contact before breaking the old contact.



**Figure 3-9.—Wafer switch.**

Figure 3-9(B) is an illustration of the entire switch and its schematic symbol. Since the switch has two wafers mechanically connected by the shaft of the switch, the shaft rotates the movable portion of both wafers at the same time. This is represented on the schematic symbol by the dotted line connecting the two wafers.

The upper wafer of the schematic symbol is the wafer closest to the control mechanism, and is identical to the wafer shown in figure 3-9(A). When switches have more than one wafer, the first wafer shown is always the wafer closest to the operating mechanism. The lower wafer on the schematic diagram is the wafer farthest away from the operating mechanism. Contact 9 of this wafer is connected to the movable portion and is the point at which current enters the wafer. In the position shown, contact 9 is connected to both contact 13 and 16. If the switch is rotated slightly clockwise, contact 9 would no longer be connected to contact 13. A further clockwise movement would connect contact 9 to contact 12. This arrangement is called BREAK BEFORE MAKE. Contact 9 will also be connected to contact 15 at the same time as it is connected to contact 12.

*Q9. Label the switch schematics shown in figure 3-10A through 3-10G.*



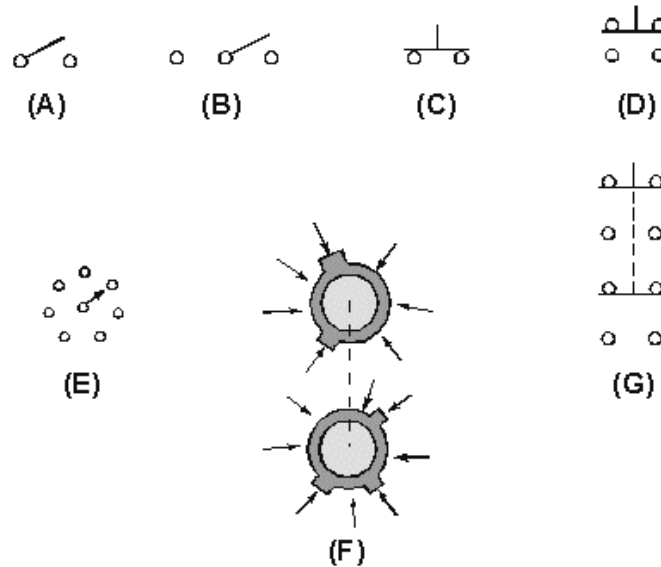


Figure 3-10.—Switch schematic symbols.

## OTHER TYPES OF SWITCHES

You have learned that switches are classified by the number of poles, throws, and breaks. There are other factors used to describe a switch such as the type of actuator and the number of positions. In addition, switches are classified by whether the switch has momentary contacts or is locked into or out of position and whether or not the switch is snap-acting.

### Type of Actuator

In addition to the pushbutton, toggle, and knife actuated switches already described, switches can have other actuators. There are rocker switches, paddle switches, keyboard switches and mercury switches (in which a small amount of mercury makes the electrical contact between two conductors).

### Number of Positions

Switches are also classified by the number of positions of the actuating device. Figure 3-11 shows three toggle switches, the toggle positions, and schematic diagrams of the switch. Figure 3-11(A) is a single-pole, single-throw, two-position switch. The switch is marked to indicate the ON position (when the switch is closed) and the OFF position (when the switch is open). Figure 3-11(B) is a single-pole, double-throw, three-position switch. The switch markings show two ON positions and an OFF position. When this switch is OFF, no connection is made between any of the terminals. In either of the ON positions, the center terminal is connected to one of the outside terminals. (The outside terminals are not connected together in any position of the switch.) Figure 3-11(C) is a single-pole, double-throw, two-position switch. There is no OFF position. In either position of this switch, the center terminal is connected to one of the outside terminals.

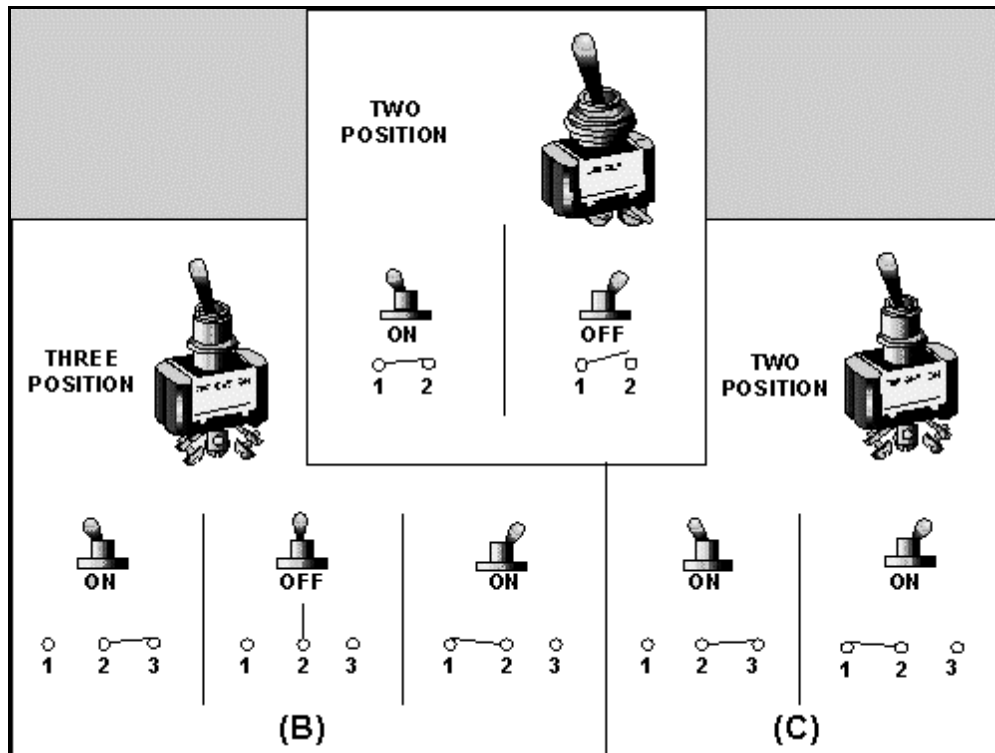


Figure 3-11.—Two- and three-position switches.

### Momentary and Locked Position Switches

In some switches, one or more of the switch positions are **MOMENTARY**. This means that the switch will only remain in the momentary position as long as the actuator is held in that position. As soon as you let go of the actuator, the switch will return to a non-momentary position. The starter switch on an automobile is an example of a momentary switch. As soon as you release the switch, it no longer applies power to the starter.

Another type of switch can be **LOCKED IN** or **OUT** of some of the switch positions. This locking prevents the accidental movement of the switch. If a switch has locked-in positions, the switch cannot be moved from those positions accidentally (by the switch being bumped or mistaken for an unlocked switch). If the switch has locked-out positions, the switch cannot be moved into those positions accidentally. Figure 3-12 shows a three-position, locking switch.

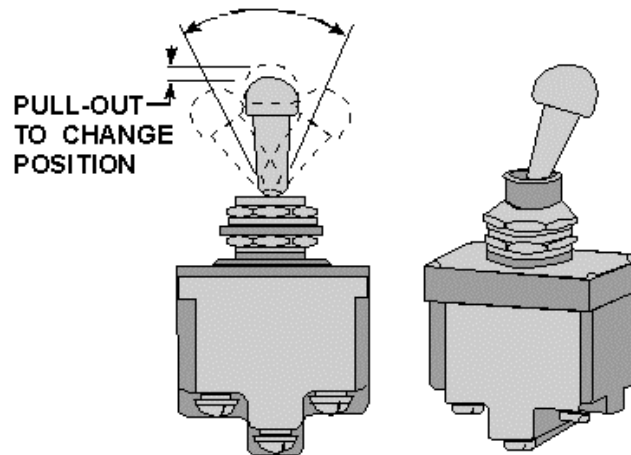


Figure 3-12.—Three-position locking switch.

### Snap-Acting Switches

A SNAP-ACTING switch is a switch in which the movement of the switch mechanism (contacts) is relatively independent of the activating mechanism movement. In other words, in a toggle switch, no matter how fast or slow you move the toggle, the actual switching of the circuit takes place at a fixed speed. The snap-acting switch is constructed by making the switch mechanism a leaf spring so that it "snaps" between positions. A snap-acting switch will always be in one of the positions designed for that switch. The switch cannot be "between" positions. A two-position, single-pole, double-throw, snap-acting switch could not be left in an OFF position.

### Accurate Snap-Acting Switches

An ACCURATE SNAP-ACTING SWITCH is a snap-acting switch in which the operating point is pre-set and very accurately known. The operating point is the point at which the plunger causes the switch to "switch." The accurate snap-acting switch is commonly called a MICROSWITCH. A microswitch is shown in figure 3-13.

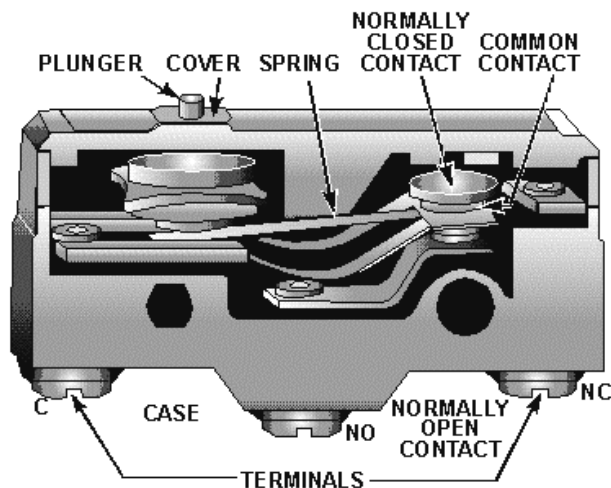


Figure 3-13.—Accurate snap-acting switch (microswitch).

The full description of the microswitch shown in figure 3-13 is a two-position, single-pole, double-throw, single-break, momentary-contact, accurate, snap-acting switch. Notice the terminals

marked C, NO, and NC. These letters stand for common, normally open, and normally closed. The common terminal is connected to the normally closed terminal until the plunger is depressed. When the plunger is depressed, the spring will "snap" into the momentary position and the common terminal will be connected to the normally open terminal. As soon as the plunger is released, the spring will "snap" back to the original condition.

This basic accurate snap-acting switch is used in many applications as an automatic switch. Several different methods are used to actuate this type of switch. Some of the more common actuators and their uses are shown in figure 3-14.

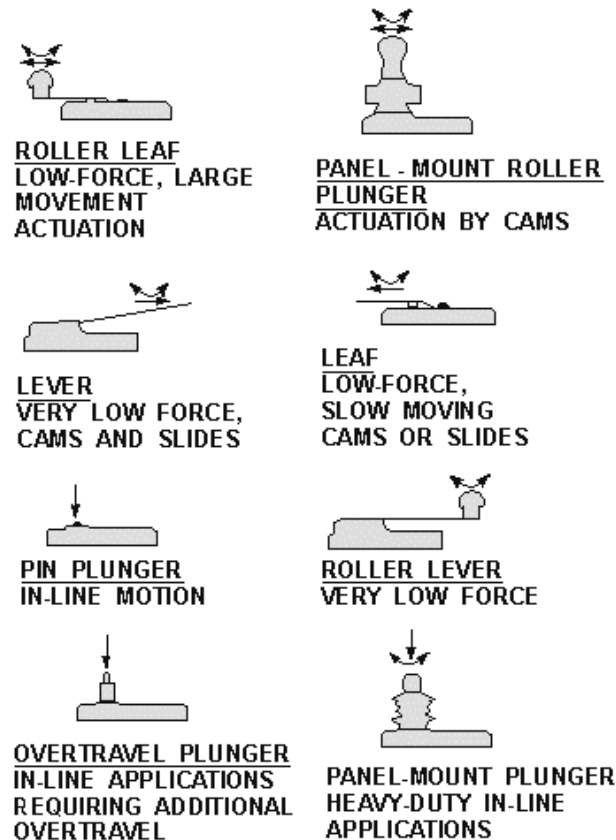


Figure 3-14.—Common actuators and their uses for accurate snap-acting switches.

- Q10. What classification of a switch is used when you describe it as a rocker switch?
- Q11. In describing a switch by the number of positions of the actuator, what are the two possible configurations for a single-pole, double-throw switch?
- Q12. What type of switch should be used to control a circuit that requires a temporary actuation signal?
- Q13. What type of switch is used if it is necessary to guard against a circuit being accidentally turned on or off?
- Q14. What is the common name used for an accurate snap-acting switch?

## SWITCH RATING

Switches are rated according to their electrical characteristics. The rating of a switch is determined by such factors as contact size, contact material, and contact spacing. There are two basic parts to a switch rating-the current and voltage rating. For example, a switch may be rated at 250 volts dc, 10 amperes. Some switches have more than one rating. For example, a single switch may be rated at 250 volts dc, 10 amperes; 500 volts ac, 10 amperes; and 28 volts dc, 20 amperes. This rating indicates a current rating that depends upon the voltage applied.

### CURRENT RATING OF A SWITCH

The current rating of a switch refers to the maximum current the switch is designed to carry. This rating is dependent on the voltage of the circuit in which the switch is used. This is shown in the example given above. The current rating of a switch should never be exceeded. If the current rating of a switch is exceeded, the contacts may "weld" together making it impossible to open the circuit.

### VOLTAGE RATING OF A SWITCH

The voltage rating of a switch refers to the maximum voltage allowable in the circuit in which the switch is used. The voltage rating may be given as an ac voltage, a dc voltage, or both. The voltage rating of a switch should never be exceeded. If a voltage higher than the voltage rating of the switch is applied to the switch, the voltage may be able to "jump" the open contacts of the switch. This would make it impossible to control the circuit in which the switch was used.

*Q15. What is the current rating of a switch?*

*Q16. What is the voltage rating of a switch?*

## MAINTENANCE AND REPLACEMENT OF SWITCHES

Switches are usually a very reliable electrical component. This means, they don't fail very often. Most switches are designed to operate 100,000 times or more without failure if the voltage and current ratings are not exceeded. Even so, switches do fail. The following information will help you in maintaining and changing switches.

### CHECKING SWITCHES

There are two basic methods used to check a switch. You can use an ohmmeter or a voltmeter. Each of these methods will be explained using a single-pole, double-throw, single-break, three-position, snap-acting, toggle switch.

Figure 3-15 is used to explain the method of using an ohmmeter to check a switch. Figure 3-15(A) shows the toggle positions and schematic diagrams for the three switch positions. Figure 3-15(B) shows the ohmmeter connections used to check the switch while the toggle is in position 1. Figure 3-15(C) is a table showing the switch position, ohmmeter connection, and correct ohmmeter reading for those conditions.

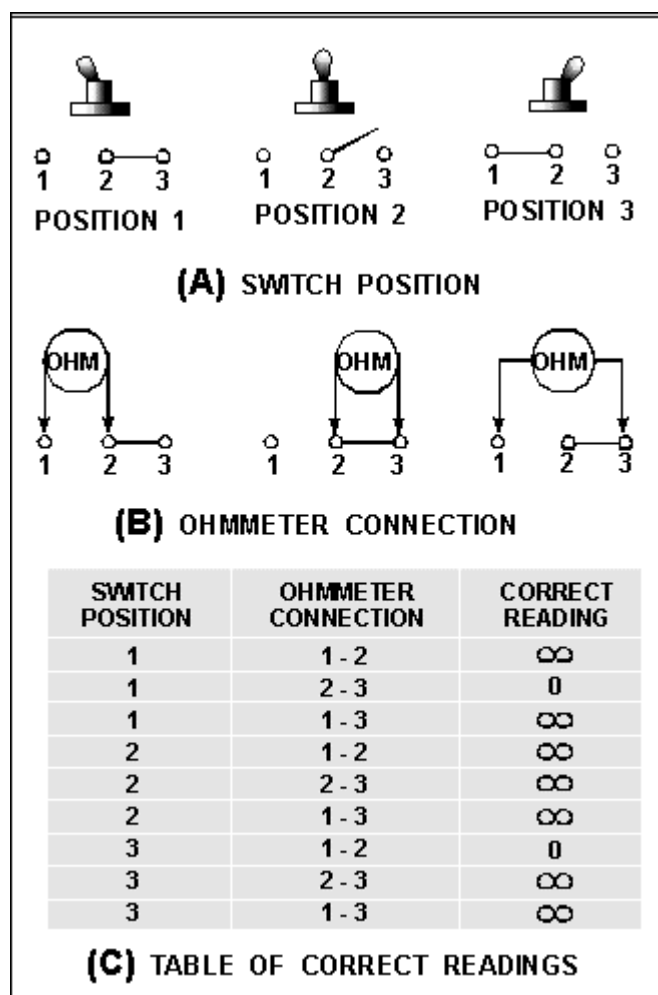


Figure 3-15.—Table of correct readings.

With the switch in position 1 and the ohmmeter connected to terminals 1 and 2 of the switch, the ohmmeter should indicate ( $\infty$ ). When the ohmmeter is moved to terminals 2 and 3, the ohmmeter should indicate zero ohms. With the ohmmeter connected to terminals 1 and 3, the indication should be ( $\infty$ ).

As you remember from chapter 1, before the ohmmeter is used, power must be removed from the circuit and the component being checked should be isolated from the circuit. The best way to isolate the switch is to remove it from the circuit completely. This is not always practical, and it is sometimes necessary to check a switch while there is power applied to it. In these cases, you would not be able to use an ohmmeter to check the switch, but you can check the switch by the use of a voltmeter.

Figure 3-16(A) shows a switch connected between a power source (battery) and two loads. In figure 3-16(B), a voltmeter is shown connected between ground and each of the three switch terminals while the switch is in position 1. Figure 3-16(C) is a table showing the switch position, voltmeter connection, and the correct voltmeter reading.

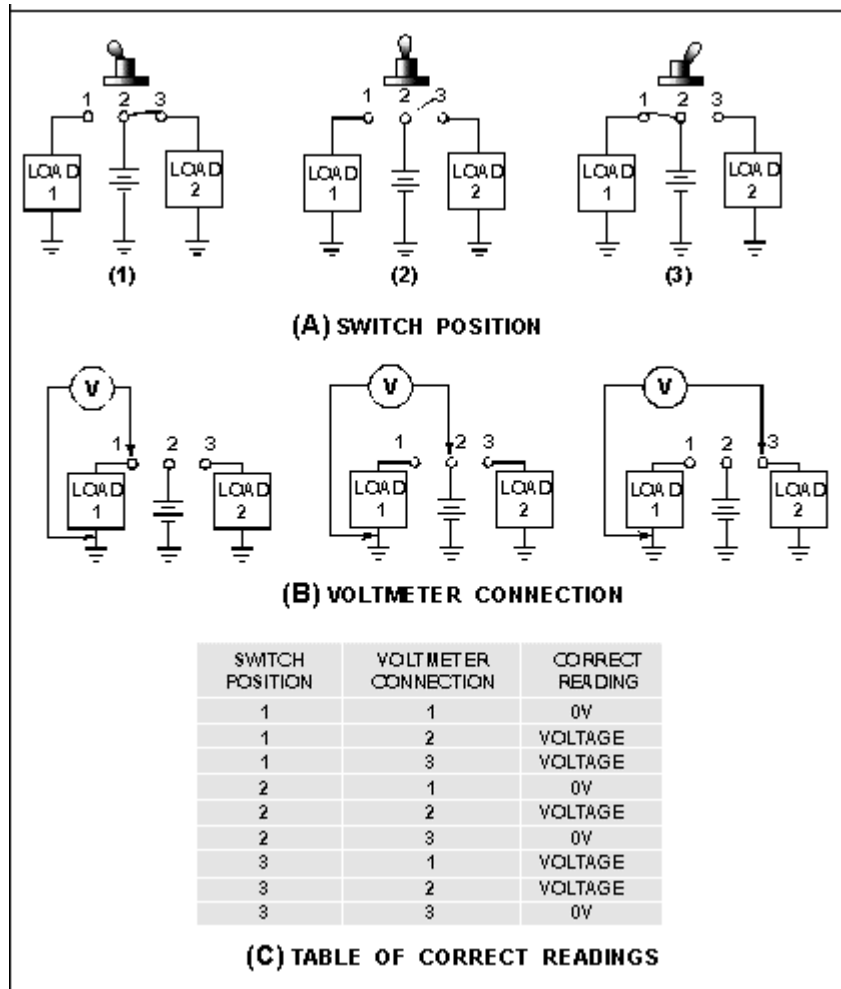


Figure 3-16.—Table of correct readings.

With the switch in position 1 and the voltmeter connected between ground and terminal 1, the voltmeter should indicate no voltage (0V). When the voltmeter is connected to terminal 2, the voltmeter should indicate the source voltage. With the voltmeter connected to terminal 3, the source voltage should also be indicated. The table in figure 3-16(C) will show you the correct readings with the switch in position 2 or 3.

## REPLACEMENT OF SWITCHES

When a switch is faulty, it must be replaced. The technical manual for the equipment will specify the exact replacement switch. If it is necessary to use a substitute switch, the following guidelines should be used. The substitute switch must have all of the following characteristics.

- At least the same number of poles.
- At least the same number of throws.
- The same number of breaks.
- At least the same number of positions.

- The same configuration in regard to momentary or locked positions.
- A voltage rating equal to or higher than the original switch.
- A current rating equal to or higher than the original switch.
- A physical size compatible with the mounting.

In addition, the type of actuator (toggle, pushbutton, rocker, etc.) should be the same as the original switch. (This is desirable but not necessary. For example, a toggle switch could be used to replace a rocker switch if it were acceptable in all other ways.)

The number of poles and throws of a switch can be determined from markings on the switch itself. The switch case will be marked with a schematic diagram of the switch or letters such as SPST for single-pole, single-throw. The voltage and current ratings will also be marked on the switch. The number of breaks can be determined from the schematic marked on the switch or by counting the terminals after you have determined the number of poles and throws. The type of actuator, number of positions, the momentary and locked positions of the switch can all be determined by looking at the switch and switching it to all the positions.

## **PREVENTIVE MAINTENANCE OF SWITCHES**

As already mentioned, switches do not fail very often. However, there is a need for preventive maintenance of switches. Periodically switches should be checked for corrosion at the terminals, smooth and correct operation, and physical damage. Any problems found should be corrected immediately. Most switches can be inspected visually for corrosion or damage. The operation of the switch may be checked by moving the actuator. When the actuator is moved, you can feel whether the switch operation is smooth or seems to have a great deal of friction. To check the actual switching, you can observe the operation of the equipment or check the switch with a meter.

*Q17. What two types of meters can be used to check a switch?*

*Q18. If a switch must be checked with power applied, what type of meter is used?*

*Q19. A double-pole, double-throw, single-break, three-position, toggle switch is faulty. This switch has a momentary position 1 and is locked out opposition 3. The voltage and current ratings for the switch are 115 volt dc, 5 amperes. No direct replacement is available. From switches A through I, in table 3-1, indicate if the switch is acceptable or not acceptable as a substitute. Of the acceptable switches, rank them in order of choice. If the switch is unacceptable, give the reason.*

*Q20. What should you check when performing preventive maintenance on a switch?*



**Table 3-1.—Replacement Switches and Their Characteristics**

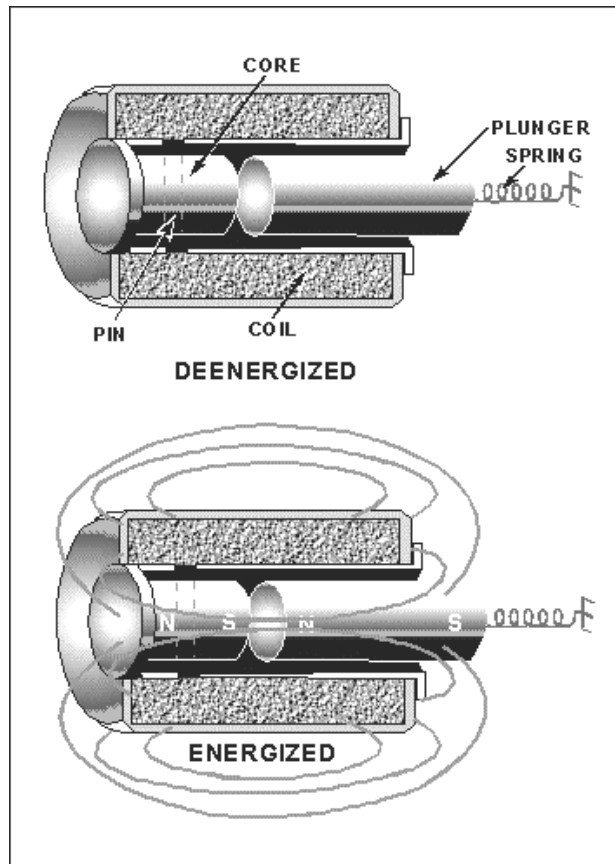
	POLES	THROWS	BREAKS	NUMBER OF POSITIONS	MOMENTARY POSITIONS	LOCKED POSITIONS	ACTUATOR	RATING
A	2	1	1	2	—	—	PUSH BUTTON	115Vdc 5A
B	2	2	2	3	1	OUT-3	TOGGLE	150Vdc 5A
C	2	2	1	3	1	OUT-3	ROCKER	115Vdc 10A
D	1	2	1	3	1	OUT-3	TOGGLE	115Vdc 5A
E	2	2	1	3	—	OUT-3	ROCKER	150Vdc 10A
F	2	2	1	3	1	OUT-3	TOGGLE	150Vdc 10A
G	2	2	1	3	1	IN-3	TOGGLE	115Vdc 10A
H	2	2	1	3	1	OUT-3	ROCKER	115Vdc 3A
I	2	2	1	3	1	OUT-3	ROCKER	28Vdc 5A

## SOLENOIDS

A SOLENOID is a control device that uses electromagnetism to convert electrical energy into mechanical motion. The movement of the solenoid may be used to close a set of electrical contacts, cause the movement of a mechanical device, or both at the same time.

Figure 3-17 is a cutaway view of a solenoid showing the solenoid action. A solenoid is an electromagnet formed by a conductor wound in a series of loops in the shape of a spiral. Inserted within this coil is a soft-iron core and a movable plunger. The soft-iron core is pinned or held in an immovable position. The movable plunger (also soft iron) is held away from the core by a spring when the solenoid is deenergized.

When current flows through the conductor, it produces a magnetic field. The magnetic flux produced by the coil results in establishing north and south poles in both the core and the plunger. The plunger is attracted along the lines of force to a position at the center of the coil. As shown in figure 3-17, the deenergized position of the plunger is partially out of the coil due to the action of the spring. When voltage is applied, the current through the coil produces a magnetic field. This magnetic field draws the plunger within the coil, resulting in mechanical motion. When the coil is deenergized, the plunger returns to its normal position because of spring action. The effective strength of the magnetic field on the plunger varies according to the distance between the plunger and the core. For short distances, the strength of the field is strong; and as distances increase, the strength of the field drops off quite rapidly.



**Figure 3-17.—Solenoid action.**

While a solenoid is a control device, the solenoid itself is energized by some other control device such as a switch or a relay. One of the distinct advantages in the use of solenoids is that a mechanical movement can be accomplished at a considerable distance from the control device. The only link necessary between the control device and the solenoid is the electrical wiring for the coil current. The solenoid can have large contacts for the control of high current. Therefore, the solenoid also provides a means of controlling high current with a low current switch. For example, the ignition switch on an automobile controls the large current of a starter motor by the use of a solenoid. Figure 3-18 shows a cutaway view of a starter motor-solenoid combination and a section of the wiring for the solenoid. Notice that the solenoid provides all electrical contact for current to the starter motor as well as a mechanical movement of the shift lever.

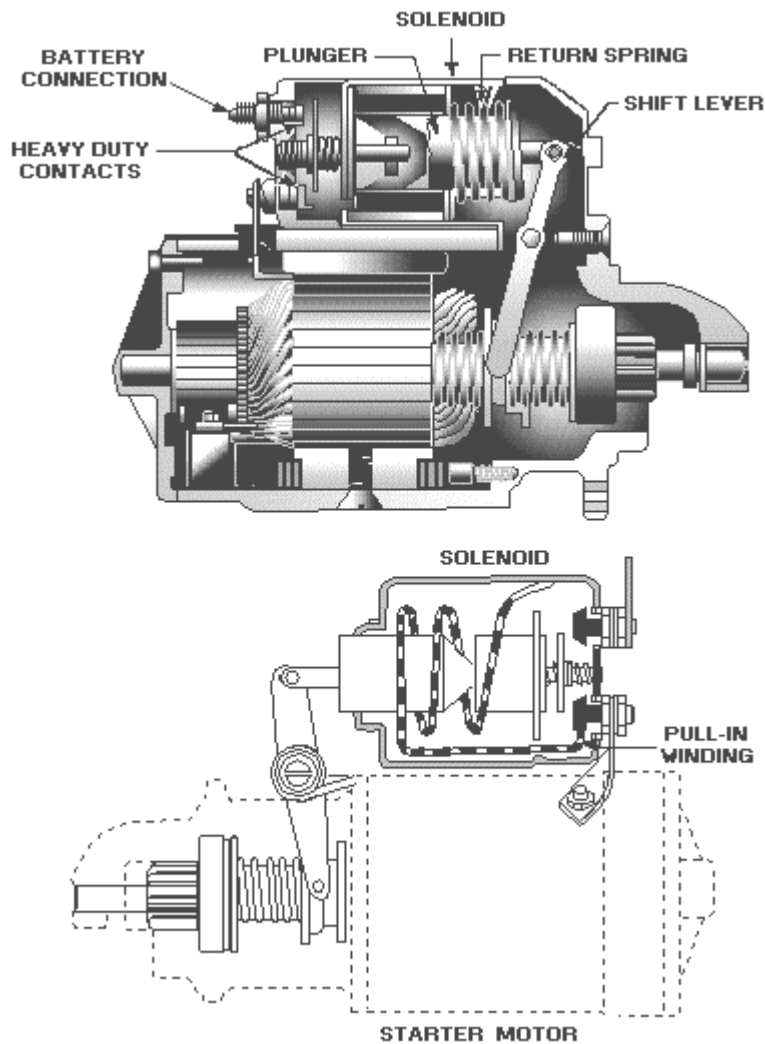


Figure 3-18.—Starter motor and solenoid.

## MAINTENANCE OF SOLENOIDS

If you suspect that a solenoid is not working properly, the first step in troubleshooting it is a good visual inspection. Check the connections for poor soldering, loose connections, or broken wires. The plunger should be checked for cleanliness, binding, mechanical failure, and improper alignment. The mechanism that the solenoid is connected to (actuates) should also be checked for proper operation.

The second step is to check the energizing voltage with a voltmeter. If the voltage is too low, the result is less current flowing through the coil and a weak magnetic field. A weak magnetic field can result in slow or poor operation. Low voltage could also result in chatter or no operation at all. If the energizing voltage is too high, it could damage the solenoid by causing overheating or arcing. In either case, the voltage should be reset to the proper value so that further damage or failure of the solenoid will not result.

The solenoid coil should then be checked for opens, shorts, and proper resistance with an ohmmeter. If the solenoid coil is open, current cannot flow through it and the magnetic field is lost. A short results in fewer turns and higher current in the coil. The net result of a short is a weak magnetic field. A high-resistance coil will reduce coil current and also result in a weak magnetic field. A weak magnetic field

will cause less attraction between the plunger and the core of the coil. This will result in improper operation similar to that caused by low voltage. If the coil is open, shorted, or has changed in resistance, the solenoid should be replaced.

Finally, you should check the solenoid to determine if the coil is shorted to ground. If a short to ground is found, the short should be removed to restore the solenoid to proper operation.

*Q21. What is the operating principle of a solenoid?*

*Q22. What is one example of the use of a solenoid?*

*Q23. If a solenoid is not operating properly, what items should be checked?*

## **RELAYS**

The RELAY is a device that acts upon the same fundamental principle as the solenoid. The difference between a relay and a solenoid is that a relay does not have a movable core (plunger) while the solenoid does. Where multipole relays are used, several circuits may be controlled at once.

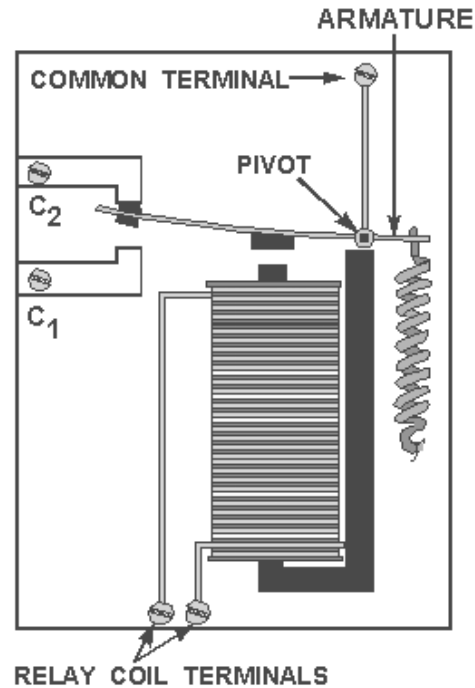
Relays are electrically operated control switches, and are classified according to their use as POWER RELAYS or CONTROL RELAYS. Power relays are called CONTACTORS; control relays are usually known simply as relays.

The function of a contactor is to use a relatively small amount of electrical power to control the switching of a large amount of power. The contactor permits you to control power at other locations in the equipment, and the heavy power cables need be run only through the power relay contacts.

Only lightweight control wires are connected from the control switches to the relay coil. Safety is also an important reason for using power relays, since high power circuits can be switched remotely without danger to the operator.

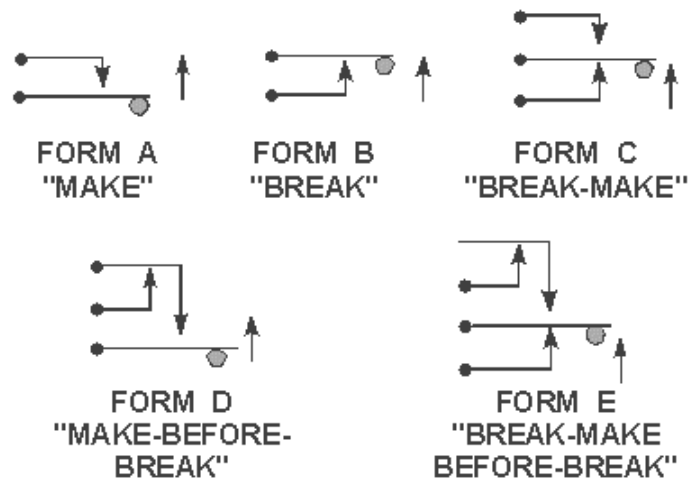
Control relays, as their name implies, are frequently used in the control of low power circuits or other relays, although they also have many other uses. In automatic relay circuits, a small electric signal may set off a chain reaction of successively acting relays, which then perform various functions.

In general, a relay consists of a magnetic core and its associated coil, contacts, springs, armature, and the mounting. Figure 3-19 illustrates the construction of a relay. When the coil is energized, the flow of current through the coil creates a strong magnetic field which pulls the armature downward to contact C1, completing the circuit from the common terminal to C1. At the same time, the circuit to contact C2, is opened.



**Figure 3-19.—Relay construction.**

A relay can have many different types of contacts. The relay shown in figure 3-19 has contacts known as "break-make" contacts because they break one circuit and make another when the relay is energized. Figure 3-20 shows five different combinations of relay contacts and the names given to each.



**Figure 3-20.—Contact combinations.**

A single relay can have several different types of contact combinations. Figure 3-21 is the contact arrangement on a single relay that has four different contact combinations. (The letters next to the contacts are the "forms" shown in figure 3-20.)

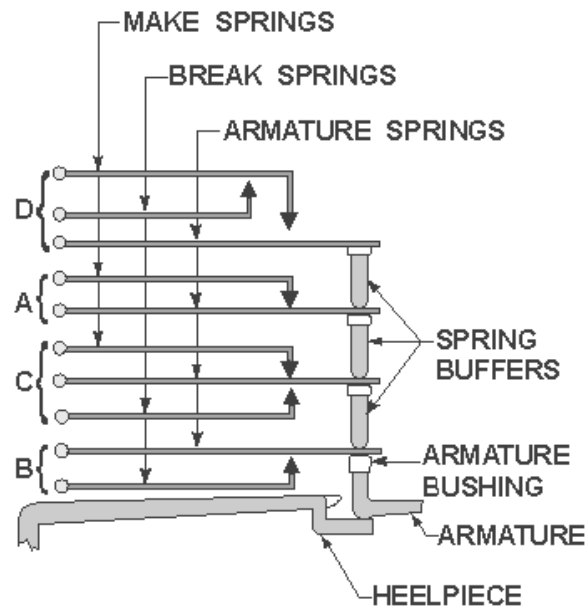


Figure 3-21.—Relay contact arrangement.

One type of relay with multiple sets of contacts is the clapper relay shown in figure 3-22. As the circuit is energized, the clapper is pulled to the magnetic coil. This physical movement of the armature of the clapper forces the pushrod and movable contacts upward. Any number of sets of contacts may be built onto the relay; thus, it is possible to control many different circuits at the same time. This type of relay can be a source of trouble because the motion of the clapper armature does not necessarily assure movement of all the movable contacts. Referring to figure 3-22, if the pushrod were broken, the clapper armature might push the lower movable contact upward but not move the upper movable contact.

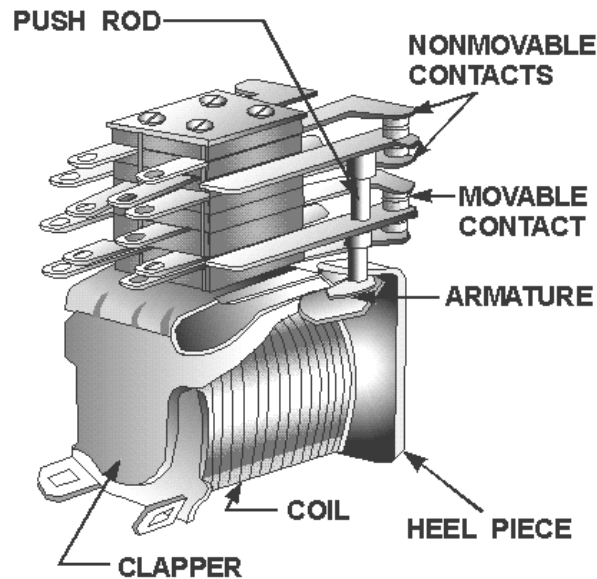
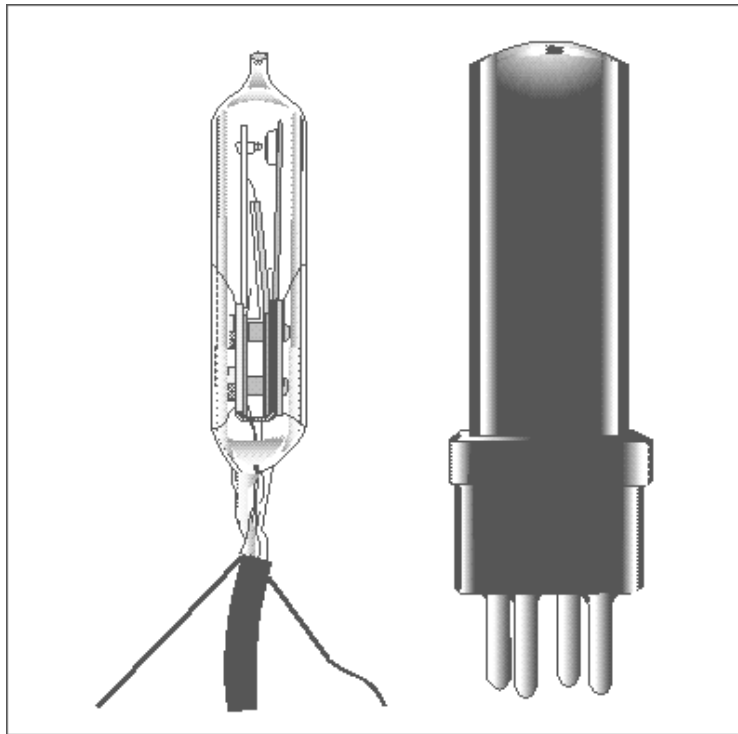


Figure 3-22.—Clapper-type relay.

Some equipment requires a "warm-up" period between the application of power and some other action. For example, vacuum tubes (covered later in this training series) require a delay between the application of filament power and high voltage. A time-delay relay will provide this required delay.

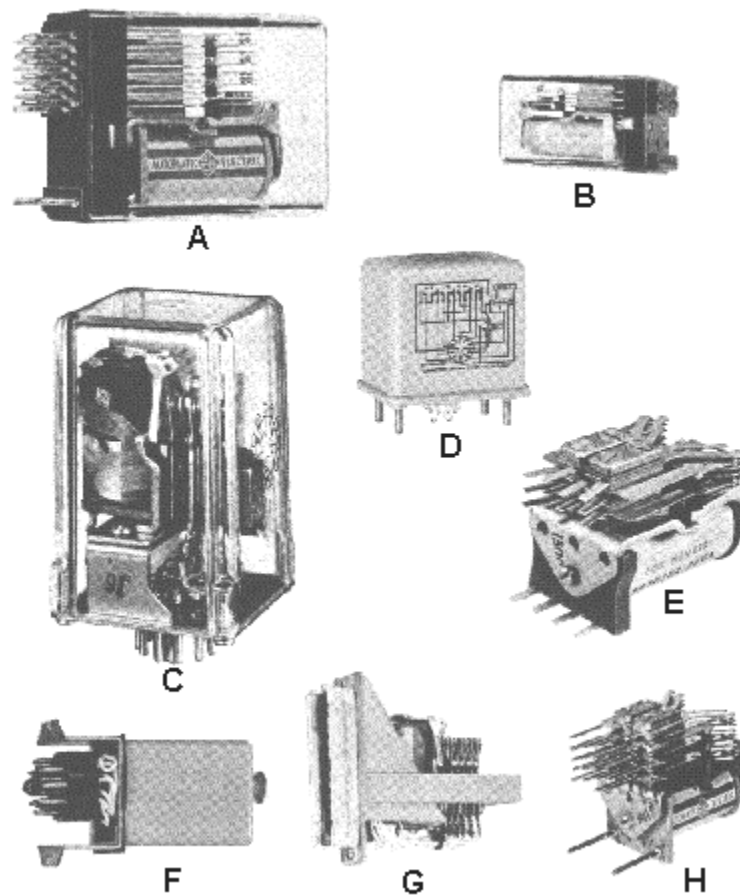
A thermal time-delay relay (fig. 3-23) is constructed to produce a delayed action when energized. Its operation depends on the thermal action of a bimetallic element similar to that used in a thermal circuit breaker. A heater is mounted around or near the element. The movable contact is mounted on the element itself. As the heat causes the element to bend (because of the different thermal expansion rates), the contacts close.



**Figure 3-23.—A thermal time-delay relay.**

Relays can be described by the method of packaging; open, semisealed, and sealed. Figure 3-24 shows several different relays and illustrates these three types of packaging.

Figure 3-24 (E), (G) and (H) are open relays. The mechanical motion of the contacts can be observed and the relays are easily available for maintenance. Figure 3-24 (A), (B) and (C) are semisealed relays. The covers provide protection from dust, moisture, and other foreign material but can be removed for maintenance.



**Figure 3-24.—Relay enclosures.**

The clear plastic or glass covers provide a means of observing the operation of the relay without removal of the cover. Figure 3-24 (D) and (F) are examples of a hermetically sealed relay. These relays are protected from temperature or humidity changes as well as dust and other foreign material. Since the covers cannot be removed, the relays are also considered to be tamper-proof. With metal or other opaque covers, the operation of the relay can be "felt" by placing your finger on the cover and activating the relay.

*Q24. What is the operating principle of a relay?*

*Q25. How does a relay differ from a solenoid?*

*Q26. What are the two classifications of relays?*



## MAINTENANCE OF RELAYS

The relay is one of the most dependable electromechanical devices in use, but like any other mechanical or electrical device, relays occasionally wear out or become inoperative. Should an inspection determine that a relay is defective, the relay should be removed immediately and replaced with another of the same type. You should be sure to obtain the same type relay as a replacement. Relays are rated in voltage, amperage, type of service, number of contacts, and similar characteristics.

Relay coils usually consist of a single coil. If a relay fails to operate, the coil should be tested for open circuit, short circuit, or short to ground. An open coil is a common cause of relay failure.

During preventive maintenance you should check for charred or burned insulation on the relay and for darkened or charred terminal leads. Both of these indicate overheating, and the likelihood of relay breakdown. One possible cause for overheating is that the power terminal connectors are not tight. This would allow arcing at the connection.

The build-up of film on the contact surfaces of a relay is another cause of relay trouble. Although film will form on the contacts by the action of atmospheric and other gases, grease film is responsible for a lot of contact trouble. Carbon build-up which is caused by the burning of a grease film or other substance (during arcing), also can be troublesome. Carbon forms rings on the contact surfaces and as the carbon rings build-up, the relay contacts are held open.

When current flows in one direction through a relay, a problem called "cone and crater" may be created at the contacts. The crater is formed by transfer of metal from one contact to the other contact, the deposit being in the shape of a cone. This condition is shown in figure 3-25(A).

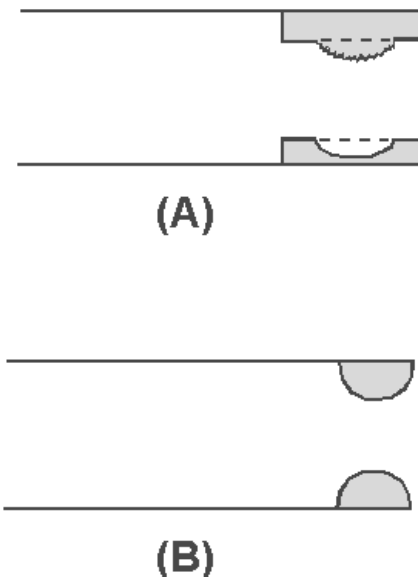
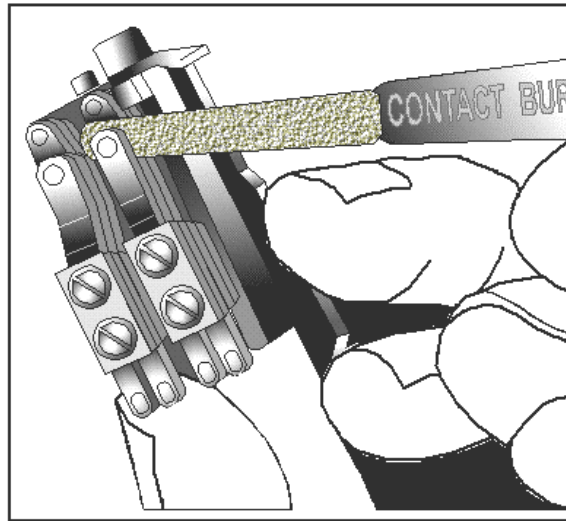


Figure 3-25.—Relay contacts.

Some relays are equipped with ball-shaped contacts and, in many applications, this type of contact is considered superior to a flat surface. Figure 3-25(B) shows a set of ball-shaped contacts. Dust or other substances are not as readily deposited on a ball-shaped surface. In addition, a ball-shaped contact penetrates film more easily than a flat contact. When you clean or service ball-shaped relay contacts, be careful to avoid flattening or otherwise altering the rounded surfaces of the contacts, YOU could damage

a relay if you used sandpaper or emery cloth to clean the contacts. Only a burnishing tool, shown in figure 3-26 should be used for this purpose.



**Figure 3-26.—Burnishing tool.**

You should not touch the surfaces of the burnishing tool that are used to clean the relay contacts. After the burnishing, tool is used, it should be cleaned with alcohol.

Contact clearances or gap settings must be maintained in accordance with the operational specifications of the relay. When a relay has bent contacts, you should use a point bender (shown in figure 3-27) to straighten the contacts. The use of any other tool could cause further damage and the entire relay would have to be replaced.



**Figure 3-27.—Point bender.**

Cleanliness must be emphasized in the removal and replacement of covers on semi sealed relays. The entry of dust or other foreign material can cause poor contact connection. When the relay is installed in a position where there is a possibility of contact with explosive fumes, extra care should be taken with the cover gasket. Any damage to, or incorrect seating of the gasket increases the possibility of igniting the vapors.

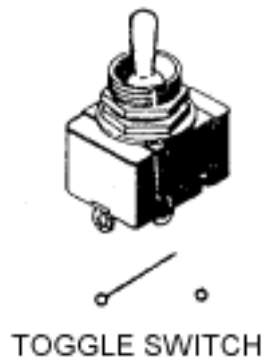
- Q27. How can you determine if a relay is operating (changing from one position to the other)?
- Q28. What items should be checked on a relay that is not operating properly?
- Q29. What is used to clean the contacts of a relay?
- Q30. What tool is used to set contact clearances on a relay?

## SUMMARY

This chapter has provided you with basic information on circuit control devices. The following is a summary of the main points in this chapter.

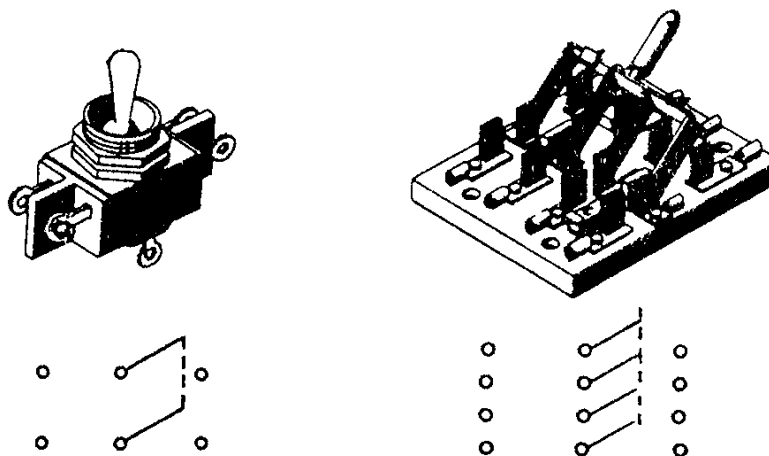
**CIRCUIT CONTROL DEVICES** are used to apply or remove power and to select a function or circuit within a device.

A **SWITCH** is one type of circuit control device. Switches are classified in many different ways.



A **MANUAL SWITCH** must be turned ON or OFF by a person. An **AUTOMATIC SWITCH** will turn a circuit ON or OFF without the action of a person by using mechanical or electrical devices.

**MULTICONTACT SWITCHES** make possible the control of more than one circuit or the selection of one of several possible circuits with a single switch.



The **POLES** of a switch are the points at which current can enter the switch. The number of **THROWS** is the number of possible circuits that can be connected to each pole. The number of **BREAKS** is the number of points at which the switch breaks the circuit.




SINGLE-POLE  
SINGLE-THROW  
SINGLE-BREAK



SINGLE-POLE  
SINGLE-THROW  
SINGLE-BREAK



SINGLE-POLE  
SINGLE-THROW  
DOUBLE-BREAK




SINGLE-POLE  
DOUBLE-THROW  
DOUBLE-BREAK



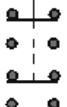
DOUBLE-POLE  
SINGLE-THROW  
SINGLE-BREAK



DOUBLE-POLE  
DOUBLE-THROW  
SINGLE-BREAK

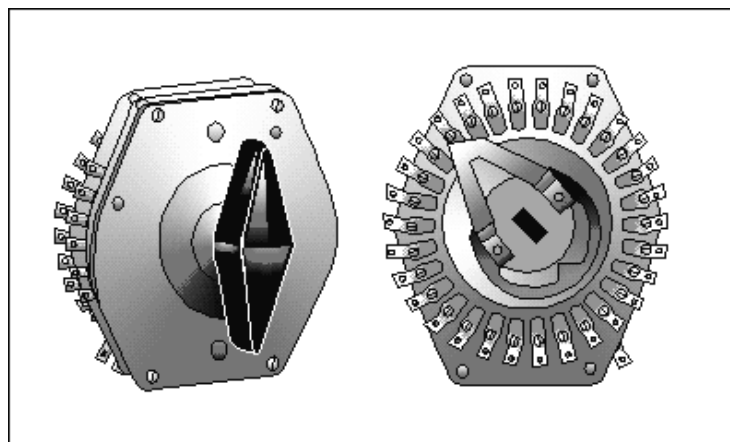


DOUBLE-POLE  
SINGLE-THROW  
DOUBLE-BREAK

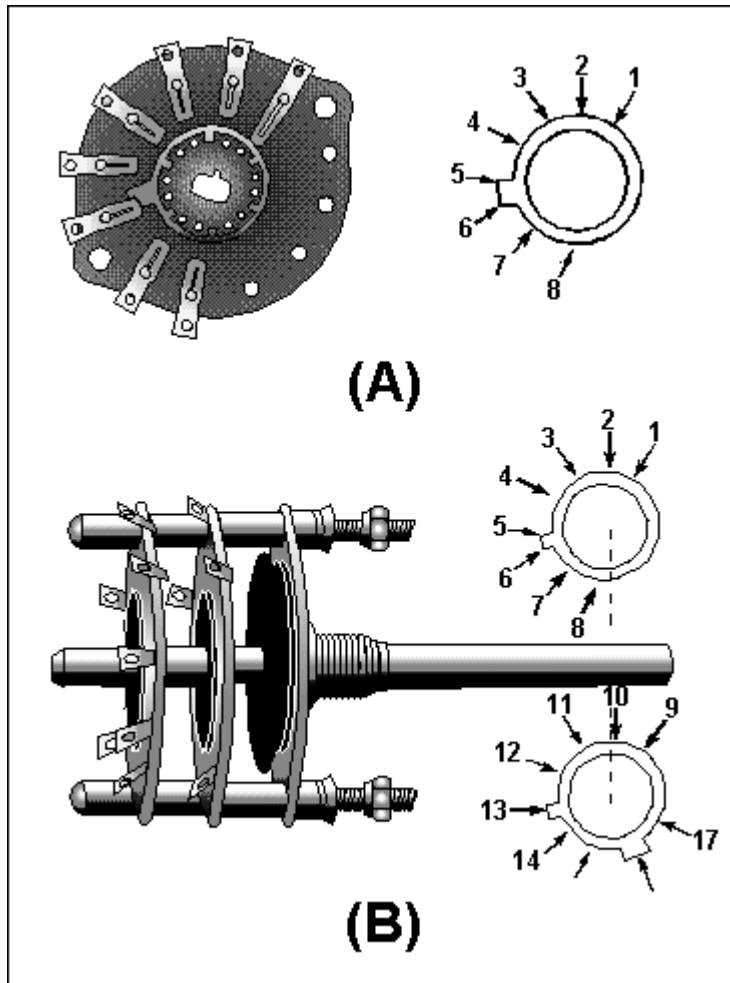


DOUBLE-POLE  
DOUBLE-THROW  
DOUBLE-BREAK

A **ROTARY SWITCH** is a multicontact switch with contacts arranged in a circular or semicircular manner.

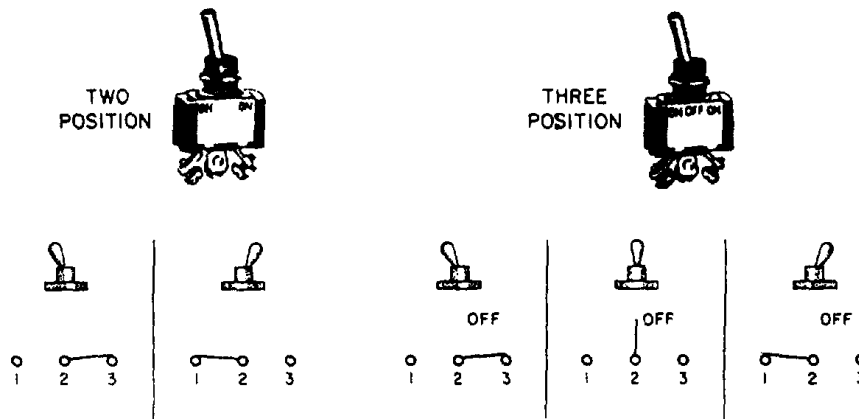


A **WAFER SWITCH** is a rotary switch in which the contacts are on wafers. The wafers are mechanically connected by the shaft of the switch.



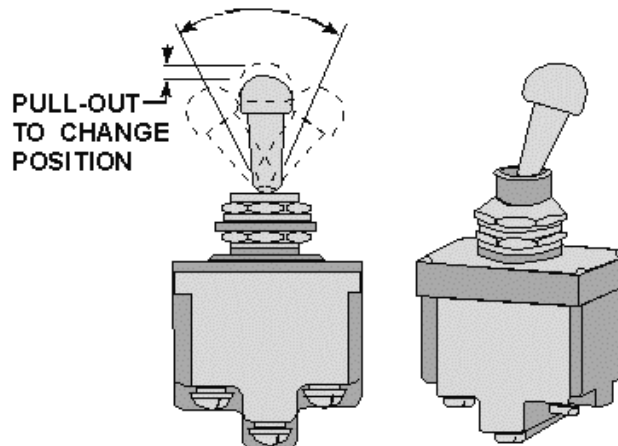
The **ACTUATOR** of a switch is the portion of the switch which is moved to cause the switch to change contact positions. The actuator could be a toggle, a pushbutton, a rocker, or, in the case of a rotary switch, a shaft and handle.

The **NUMBER OF POSITIONS** of a switch refers to the number of points at which the actuator can select a contact configuration.



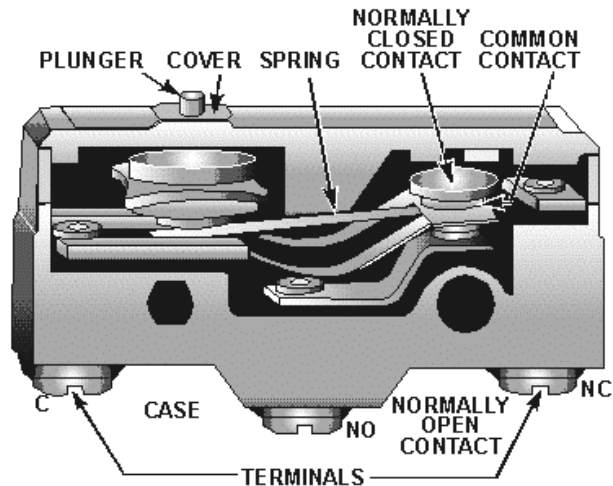
A **MOMENTARY POSITION** of a switch is one in which the actuator will only stay as long as force is applied to the actuator. When the force is removed, the actuator (and switch) will return to a non-momentary position.

A **LOCKED POSITION** of a switch is used to prevent the accidental movement of the actuator to or from a specific position.



A **SNAP-ACTING SWITCH** is one in which the movement of the switch contacts is relatively independent of the actuator movement. This is accomplished by using a leaf spring for the common contact of the switch.

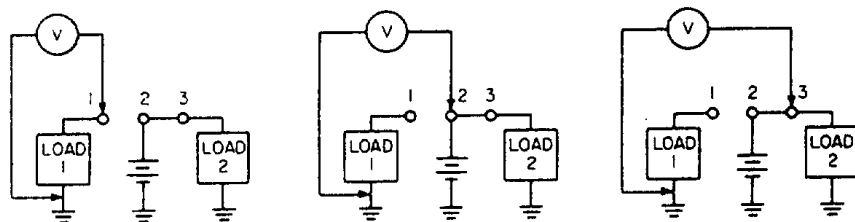
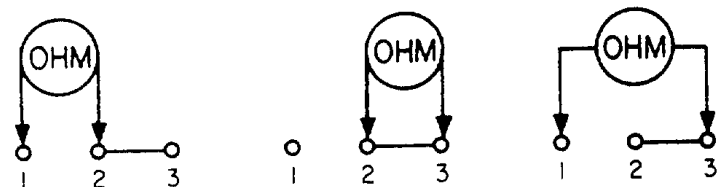
A **MICROSWITCH** is an accurate snap-acting switch and the operating point is preset and very accurately known.



The **VOLTAGE RATING** of a switch is the maximum voltage the switch is designed to control. A voltage higher than the voltage rating may be able to "jump" the open contacts of the switch.

The **CURRENT RATING** of a switch is the maximum current the switch is designed to carry; it is dependent on the voltage rating. Any current higher than the current rating may cause the contacts of the switch to melt and "weld" together.

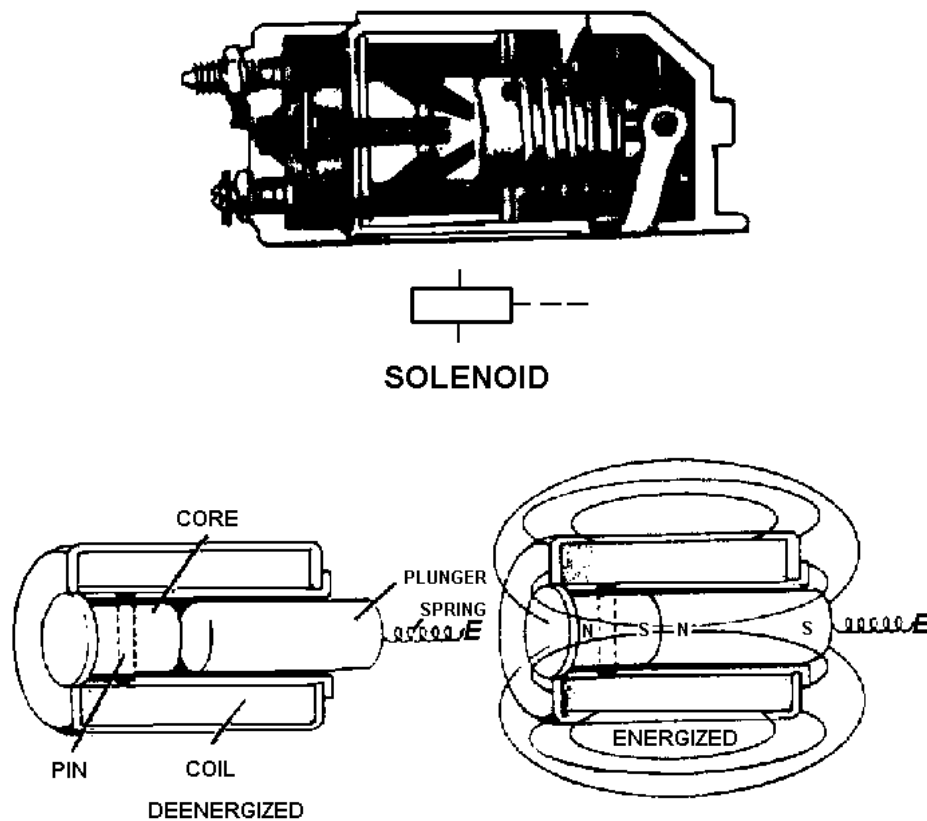
The contacts of a switch can be checked with an ohmmeter if power is removed or with a voltmeter if power is applied to the switch. To check a switch, the actuator should be checked for smooth and correct operation, the terminals should be checked for evidence of corrosion, and the physical condition of the switch should be determined. If a substitute switch must be used to replace a faulty switch, the substitute must have all of the following:



At least the same number of poles, throws, and positions; the same number of breaks and an identical configuration in regard to momentary and locked positions; and a voltage and current rating equal to or higher than the original switch. In addition, the substitute must be of a physical size compatible with the mounting, and must have the same type actuator as the original switch.

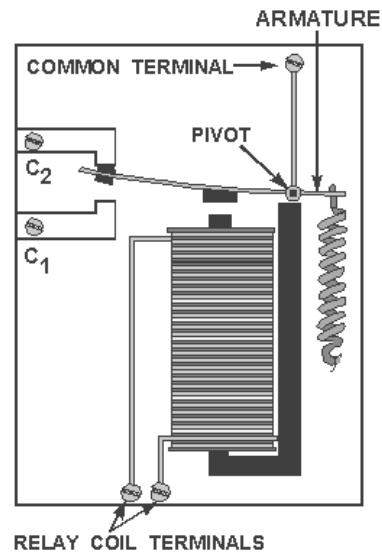
A **SOLENOID** is a control device that uses electromagnetism to convert electrical energy into a mechanical motion. The magnetic field of the coil and core will attract the plunger of a solenoid when current flows through the coil. When current is removed, the spring attached to the plunger will cause the plunger to return to its original position.

If a solenoid fails to operate, check the terminal connections, the plunger and attached mechanism for smooth operation, the energizing voltage, and the coil of the solenoid.

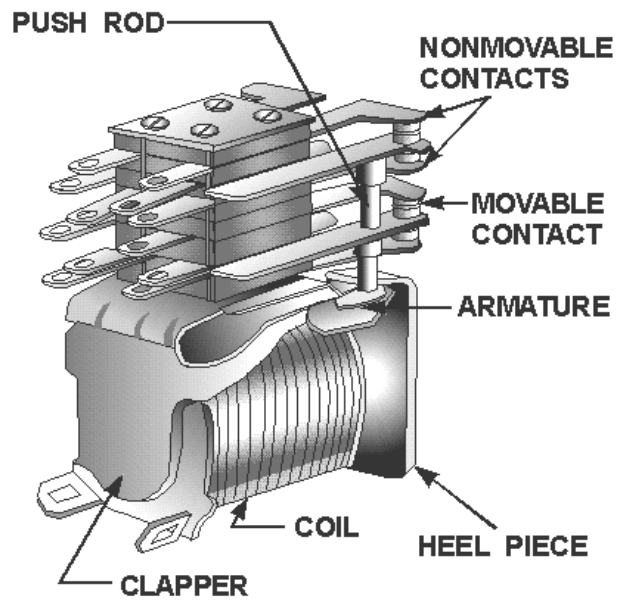


A **RELAY** is an electromagnetic control device that differs from the solenoid in that the solenoid uses a movable core (plunger) while the relay has fixed core. Relays are classified as **CONTROL RELAYS**, which control low power **COMMON** circuits and **POWER RELAYS** or **CONTACTORS** which control high power circuits.

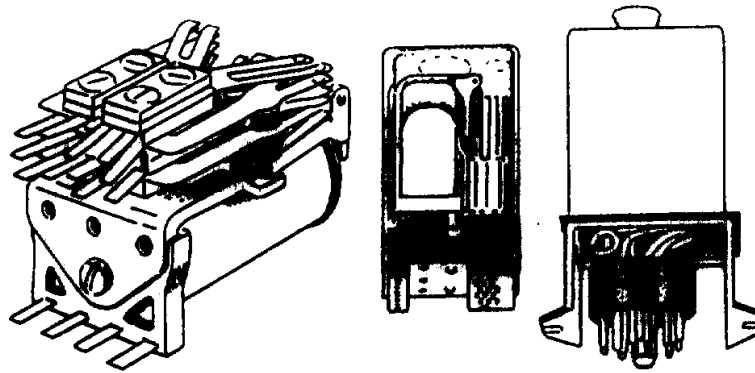




**CLAPPER RELAYS** use a clapper (armature) to move contact positions and accomplish the switching of circuits.

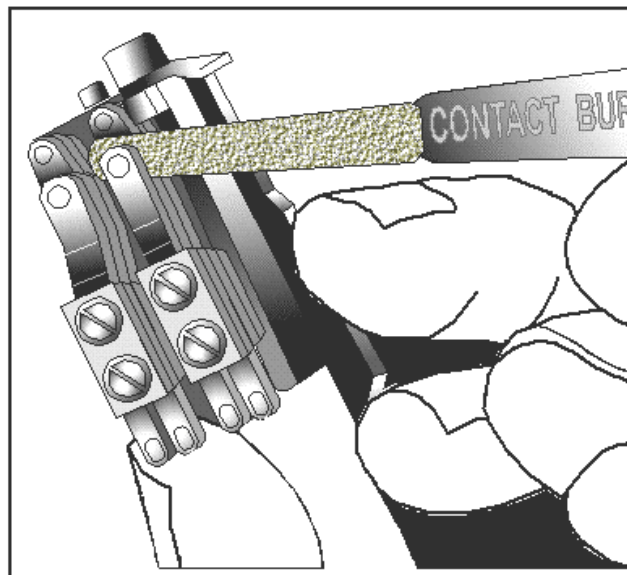


Relays are described by the type of enclosure. A relay may be OPEN, SEMISEALED, or SEALED.



If a relay fails to function, the movement of the contacts should be observed; the coil should be checked for opens or shorts; the terminal leads should be checked for burned or charred insulation; and the contact surfaces should be checked for carbon, arcing, and contact spacing.

A **BURNISHING TOOL** is used to clean the contacts of a relay. Files, sandpaper, and emery cloth should NOT be used.



A **POINT BENDER** is used to adjust contact spacing of a relay. No other tool should be used.



#### **ANSWERS TO QUESTIONS Q1. THROUGH Q30.**

- A1. *To remove power from a malfunctioning device; to remove power from a device you wish to work on and restore power when the work is completed; to turn devices on and off as the device is needed; to select the function or circuit desired within a device.*
- A2. *Switches, solenoids, and relays.*
- A3.
- a. *Solenoid.*
  - b. *Switch.*
  - c. *Relay.*
- A4. *A manual switch must be turned on or off by a person. An automatic switch turns a circuit on or off without the action of a person (by using mechanical or electrical devices).*
- A5. *A light switch, an ignition switch, television channel selector, etc.*
- A6. *A thermostat, an automobile distributor, a limit switch, etc.*
- A7. *Multicontact switches make possible the control of more than one circuit or the selection of one of several possible circuits with a single switch.*

A8.

- a. *Three-pole, single-throw (triple-pole, single-throw)*
- b. *Double-pole, double-throw*
- c. *Single-pole, double-throw*
- d. *Single-pole, single-throw*
- e. *Double-pole, triple-throw*
- f. *Six-pole, double-throw*

A9.

- a. *Single-pole, single-throw, single-break*
- b. *Single-pole, double-throw, single-break*
- c. *Single-pole, single-throw, double-break*
- d. *Single-pole, double-throw, double-break*
- e. *Rotary*
- f. *Wafer*
- g. *Double-pole, double-throw, double-break*

A10. *The type of actuator.*

A11. *Two-position and three-position.*

A12. *A momentary switch.*

A13. *A locked-position switch.*

A14. *A microswitch.*

A15. *The maximum current a switch is designed to carry.*

A16. *The maximum voltage allowable in the circuit in which the switch is installed.*

A17. *An ohmmeter and a voltmeter.*

A18. *A voltmeter.*

A19.

- a. *Not acceptable-single throw.*
- b. *Not acceptable-double break.*
- c. *Acceptable-choice #2 (different actuator).*
- d. *Not acceptable-single pole.*
- e. *Not acceptable-no momentary position.*
- f. *Acceptable-choice #1 (higher rating).*
- g. *Not acceptable-locked position incorrect.*
- h. *Not acceptable-current rating too low.*
- i. *Not acceptable-voltage rating too low.*

A20. *The switch operation for smooth and correct operation, the terminals for corrosion, and the physical condition of the switch.*

A21. *The magnetic field created in a coil of wire and core will attract a soft iron plunger when current flows through the coil.*

A22. *A starter motor and solenoid.*

A23. *The connections, the plunger, the mechanism that the solenoid actuates, the energizing voltage, and the coil of the solenoid.*

A24. *The magnetic field created in a coil of wire will attract a soft armature causing a movement in sets of contacts.*

A25. *The solenoid provides a mechanical movement of a plunger (a moveable core) while the core of a relay is fixed.*

A26. *Control relays and power relays (contactors).*

A27. *By observing the movement of the contacts if the relay is open or sealed with a transparent cover. If the relay has an opaque cover, you can "feel" the operation of the relay by placing your finger on the cover.*

A28. *The coil should be checked for opens, shorts, or a short to ground; terminal leads should be checked for charred or burned insulation; the contact surfaces should be checked for film, carbon, arcing, and contact spacing.*

A29. *A burnishing tool.*

A30. *A point bender*



## APPENDIX I

# GLOSSARY

**ACTUATOR**—The part of a switch that is acted upon to cause the switch to change contact connections; e.g., toggle, pushbutton, and rocker.

**AMMETER**—A meter used to measure current.

**ARC EXTINGUISHER**—The part of a circuit breaker that confines and divides the arc that occurs when the contacts of the circuit breaker open.

**ARMATURE**—In a relay, the movable portion of the relay.

**BREAK**—In a switch, the number of breaks refers to the number of points at which the switch opens the circuit; e.g., single break and double break.

**BURNISHING TOOL**—A tool used to clean and polish contacts on a relay.

**CONTINUITY**—An uninterrupted, complete path for current.

**DAMPING**—The process of smoothing out oscillations. In a meter, damping is used to keep the pointer of the meter from overshooting the correct reading.

**D'ARSONVAL METER MOVEMENT**—A name used for the permanent-magnet moving-coil movement used in most meters.

**DIRECT SHORT**—A connection between two points in a circuit, such as between a component and ground.

**ELECTRODYNAMIC METER MOVEMENT**—A meter movement using fixed field coils and a moving coil; usually used in wattmeters.

**ELECTROMAGNETISM**—The relationship between magnetism and electricity.

**ELECTROSTATIC METER MOVEMENT**—A meter movement that uses the electrostatic repulsion of two sets of charged plates (one fixed and the other movable). This meter movement reacts to voltage rather than to current and is used to measure high voltage.

**FERRULES**—The cylindrical metallic ends of a cartridge fuse.

**FREQUENCY METER**—A meter used to measure the frequency of an ac signal.

**GALVANOMETER**—A meter used to measure small values of current by electromagnetic or electrodynamic means.

**HOT WIRE METER MOVEMENT**—A meter movement that uses the expansion of a heated wire to move the pointer of a meter; measures dc or ac.

**IN-CIRCUIT METER**—A meter permanently installed in a circuit; used to monitor circuit operation.

**LOADING EFFECT**—The effect of a voltmeter upon the circuit being measured which results in an inaccurate measurement. Loading effect is minimized by using a voltmeter with an internal resistance many times higher than the resistance of the circuit being measured.

**MAGNETIC TRIP ELEMENT**—A circuit breaker trip element that uses the increasing magnetic attraction of a coil with increased current to open the circuit.

**MEGGER**—Common name for a megohmmeter.

**MEGOHMMETER**—A meter that measures very large values of resistance; usually used to check for insulation breakdown in wires.

**METER**—A device used to measure an electrical quantity; e.g., current, voltage, and frequency.

**METER MOVEMENT**—The part of a meter that moves.

**MOVING-IRON METER MOVEMENT**—Same as moving-vane meter movement.

**MOVING-VANE METER MOVEMENT**—A meter movement that uses the magnetic repulsion of the like poles created in iron vanes by current through a coil of wire; most commonly used movement for ac meters.

**MULTIMETER**—A single meter combining the functions of an ammeter, a voltmeter, and an ohmmeter.

**NONTRIP-FREE CIRCUIT BREAKER**—A circuit breaker that can be held ON during an overcurrent condition.

**OHMMETER**—A meter used to measure resistance.

**OUT-OF-CIRCUIT METER**—A meter which is not permanently installed in a circuit. Usually portable and self-contained, these meters are used to check the operation of a circuit or to isolate troubles within a circuit.

**PARALLAX ERROR**—The error in meter readings that results when you look at a meter from some position other than directly in line with the pointer and meter face. A mirror mounted on the meter face aids in eliminating parallax error.

**POINT BENDER**—A tool used to adjust the contact spacing on a relay.

**POLE**—(1) One end of a magnet. (2) The number of points at which current can enter a switch; e.g., single pole, double pole, and three pole.

**POLE PIECE**—A piece of ferromagnetic material used to control the distribution of magnetic lines of force; i.e., concentrate the lines of force in a particular place or evenly distribute the lines of force over a wide area.

**RANGES**—The several upper limits a meter will measure as selectable by a switch or by jacks; e.g., a voltmeter may have ranges of 1 volt, 2.5 volts, 10 volts, 25 volts, and 100 volts.

**RECTIFIER**—A device used to convert ac to pulsating dc.

**RELAY**—An electromagnetic device with one or more sets of contacts which changes position by the magnetic attraction of a coil to an armature.



**RELUCTANCE**—The resistance of a magnetic path to the flow of magnetic lines of force through it.

**ROTARY SWITCH**—A multicontact switch with contacts arranged in a circular or semi-circular manner.

**SENSITIVITY**—(1) For an ammeter: the amount of current that will cause full-scale deflection of the meter. (2) For a voltmeter: the ratio of the voltmeter resistance divided by the full-scale reading of the meter, expressed in ohms-per-volt.

**SHORT CIRCUIT**—An unintentional current path between two components in a circuit or between a component and ground which is usually caused by a malfunction in the circuit.

**SHUNT RESISTOR**—A resistor in parallel. In an ammeter, shunt resistors are used to provide range capability.

**SNAP-ACTING**—Changing position quickly with the aid of a spring.

**SOLENOID**—An electromagnetic device that changes electrical energy into mechanical motion; based upon the attraction of a movable iron plunger to the core of an electromagnet.

**SWITCH**—A device used to open or close a circuit.

**TEST EQUIPMENT**—A general term applied to devices used to test electrical and electronic circuits.

**THERMAL TRIP ELEMENT**—A circuit breaker trip element that uses the increased bending of a bimetallic strip caused by increased current to open a circuit.

**THERMAL-MAGNETIC TRIP ELEMENT**—A single circuit breaker trip element that combines the action of a thermal and a magnetic trip element.

**THERMOCOUPLE METER MOVEMENT**—A meter movement that uses the current induced in a thermocouple by the heating of a resistive element to measure the current in a circuit; used to measure ac or dc.

**THROW**—In a switch, the number of different circuits each pole can control; e.g., single throw and double throw.

**TRIP-ELEMENT**—The part of a circuit breaker that senses any overload condition and causes the circuit breaker to open the circuit.

**TRIP-FREE CIRCUIT BREAKER**—A circuit breaker that will open a circuit even if the operating mechanism is held in the ON position.

**TROUBLESHOOTING**—The process of locating and repairing faults in electrical or electronic equipment.

**VOLTMETER**—A meter used to measure voltage.

**WAFER SWITCH**—A rotary switch in which the contacts are arranged on levels. Each level is electrically independent but mechanically connected by the shaft of the switch.

**WATT-HOUR METER**—A meter used to measure electrical energy.

**WATTMETER**—A meter used to measure electrical power.



## APPENDIX II

# LAWS OF EXPONENTS

The International Symbols Committee has adopted prefixes for denoting decimal multiples of units. The National Bureau of Standards has followed the recommendations of this committee, and has adopted the following list of prefixes:

Numbers	Powers of ten	Prefixes	Symbols
1,000,000,000,000	10 <sup>12</sup>	tera	T
1,000,000,000	10 <sup>9</sup>	giga	G
1,000,000	10 <sup>6</sup>	mega	M
1,000	10 <sup>3</sup>	kilo	k
100	10 <sup>2</sup>	hecto	h
10	10	deka	da
.1	10 <sup>-1</sup>	deci	d
.01	10 <sup>-2</sup>	centi	c
.001	10 <sup>-3</sup>	milli	m
.000001	10 <sup>-6</sup>	micro	u
.000000001	10 <sup>-9</sup>	nano	n
.000000000001	10 <sup>-12</sup>	Pico	p
.000000000000001	10 <sup>-15</sup>	femto	f
.000000000000000001	10 <sup>-18</sup>	Atto	a

To multiply like (with same base) exponential quantities, add the exponents. In the language of algebra the rule is  $a^m \times a^n = a^{m+n}$

$$10^4 \times 10^2 = 10^{4+2} = 10^6$$

$$0.003 \times 825.2 = 3 \times 10^3 \times 8.252 \times 10^2$$

$$= 24.756 \times 10^1 = 2.4756$$

To divide exponential quantities, subtract the exponents. In the language of algebra the rule is

$$\frac{a^m}{a^n} = a^{m-n} \quad \text{or} \quad \frac{10^8}{10^2} = 10^6$$

$$\frac{3,000}{0.015} = \frac{(3 \times 10^3)}{(1.5 \times 10^{-2})} = 2 \times 10^5 = 200,000$$

To raise an exponential quantity to a power, multiply the exponents. In the language of algebra  $(x^m)^n = x^{mn}$ .

$$(10^3)^4 = 10^{3 \times 4} = 10^{12}$$

$$2,500^2 = (2.5 \times 10^3)^2 = 6.25 \times 10^6 = 6,250,00$$

Any number (except zero) raised to the zero power is one. In the language of algebra  $x^0 = 1$

$$\frac{x^3}{x^3} = 1$$

$$\frac{10^4}{10^4} = 1$$

Any base with a negative exponent is equal to 1 divided by the base with an equal positive exponent. In the language of algebra  $x^{-a} = 1/x^a$

$$10^{-2} = \frac{1}{10^2} = \frac{1}{100}$$

$$5a^{-3} = \frac{5}{a^3}$$

$$(6a)^{-1} = \frac{1}{6a}$$

To raise a product to a power, raise each factor of the product to that power.

$$(2 \times 10)^2 = 2^2 \times 10^2$$

$$3,000 = (3 \times 10^3)^3 = 27 \times 10^9$$

To find the nth root of an exponential quantity, divide the exponent by the index of the root. Thus, the nth root of  $a^m = a^{\frac{m}{n}}$ .






























$$\sqrt[6]{x^6} = x^{\frac{6}{2}} = x^3$$

$$\sqrt[3]{64 \times 10^3} = 4 \times 10 = 40$$

**APPENDIX III**

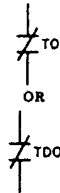
**SCHEMATIC SYMBOLS**

## Contacts, Switches, Contactors, and Relays

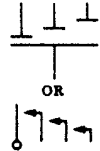
<p><b>Switching Function</b></p> <p>(break) Conducting, closed contact</p>  <p>(make) Nonconducting, open contact</p>  <p>Application: transfer</p>  <p>OR</p>  <p><b>Electrical Contact</b></p> <p><b>Fixed contact</b></p> <p>Fixed contact for jack, key, relay, switch, etc</p>  <p>OR</p>  <p>Fixed contact with momentary contact (automatic return)</p> <p>NOTE When this symbol (representing a contact with automatic return) is used on a diagram for international use, the convention should be so noted on the diagram or associated documentation. <u>IEC</u></p>  <p>† Sleeve</p>  <p>OR</p>  <p><b>Moving Contact</b></p> <p>† The broken line --- indicates where line connection to a symbol is made and is not part of the symbol.</p>	<p>Adjustable or sliding contact for resistor, inductor, etc</p> <p>OR</p>  <p>Locking</p>  <p>Nonlocking</p>  <p>Segment; bridging contact</p>  <p>OR</p>  <p>Vibrator reed</p>  <p>Vibrator split reed</p>  <p>Rotating contact (slip ring) and brush</p>  <p><b>Basic Contact Assemblies</b></p> <p>The standard method of showing a contact is by a symbol indicating the circuit condition it produces when the actuating device is in the deenergized or nonoperated position. The actuating device may be of a mechanical, electrical, or other nature, and a clarifying note may be necessary with the symbol to explain the proper point at which the contact functions; for example, the point where a contact closes or opens as a function of changing pressure, level, flow, voltage, current, etc. In cases where it is desirable to show contacts in the energized or operated condition and where confusion may result, a clarifying note shall be added to the drawing.</p> <p>Auxiliary switches or contacts for circuit breakers, etc, may be designated as follows:</p> <p>(a) Closed when device is energized or operated position.</p> <p>(b) Closed when device is in deenergized or nonoperated position.</p> <p>(aa) Closed when operating mechanism of main device is in energized or operated position.</p> <p>(bb) Closed when operated mechanism of main device is in deenergized or nonoperated position.</p> <p>See American National Standard Manual and Automatic Station Control, Supervisory, and Associated Telemetering</p>	<p>Equipment, C37.2-1970, for further details.</p> <p>In the parallel-line contact symbols shown below, the length of the parallel lines shall be approximately 1½ times the width of the gap</p> <p><b>Closed contact (make)</b></p>  <p>OR</p>  <p>OR</p>  <p><b>Open contact (break)</b></p>  <p>OR</p>  <p>OR</p>  <p><b>Transfer</b></p>  <p>OR</p>  <p>OR</p>  <p><b>Make-before-break</b></p>  <p>Application: open contact with time closing (TC) or time-delay closing (TDC) feature</p>  <p>OR</p> 
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## Contacts, Switches, Contactors, and Relays

Application: closed contact with time opening (TO) or time-delay opening (TDO) feature



Time sequential closing



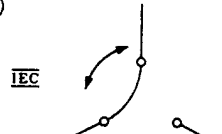
Multiway transfer switch

Two-position switch (90° step)

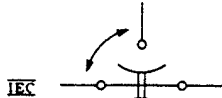


step)

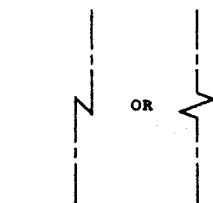
Three-position switch (120°



Four-position switch (45° step)



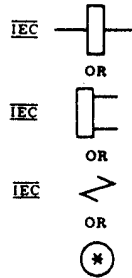
† Magnetic Blowout Coil



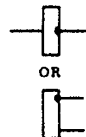
Operating Coil  
Relay Coil

† The broken line --- indicates where line connection to a symbol is made and is not part of the symbol.

NOTE The asterisk is not part of the symbol. Always replace the asterisk by a device designation.

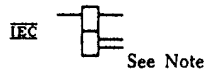


Semicircular dot indicates inner end of winding



Application: multiwinding coil (2 windings shown)

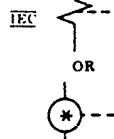
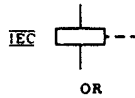
NOTE The ends of a given winding shall be shown directly opposite each other on opposite sides of the core, or adjacent to each other on the same side of the core.



See Note

Electromagnetic actuator (solenoid), with mechanical linkage shown

NOTE The mechanical linkage may be omitted if the intent is clear.



\* See Notes

Switch

See also FUSE

Fundamental symbols for contacts; mechanical connections, etc., may be used for switch symbols.

The standard method of showing switches is in a position with no operating force applied. For switches that may be in any of two or more positions with no operating force applied, and for switches actuated by some mechanical device (as in air-pressure, liquid-level, rate-of-flow, etc., switches), a clarifying note may be necessary to explain the point at which the switch functions.

When the basic switch symbols are shown in the closed position on a diagram, terminals must be added for clarity.

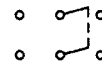
Single-throw, general



Double-throw, general



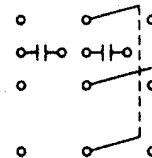
Application: 2-pole double-throw switch with terminals shown



Knife switch, general

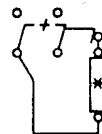


Application: 3-pole double-throw knife switch with auxiliary contacts and terminals



Application: 2-pole field-discharge knife switch with terminals and discharge resistor

NOTE The asterisk is not part of the symbol. Always add identification within or adjacent to the rectangle.

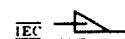


\* See Note




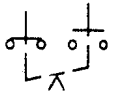
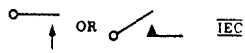
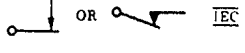

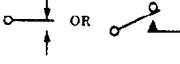

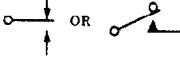

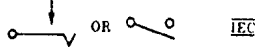
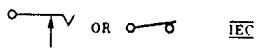




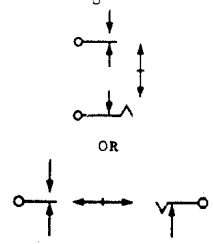
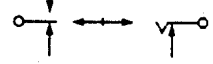
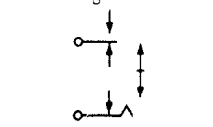

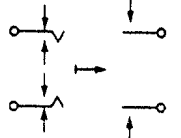
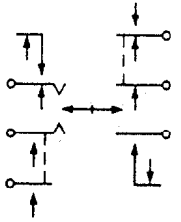
Switch with horn gap



Sector switch



## Contacts, Switches, Contactors, and Relays

<p><b>Pushbutton Spring-Return</b></p> <p>Circuit closing (make)</p>  <p>Circuit opening (break)</p>  <p>Two-circuit</p>  <p><b>Two-Circuit, Maintained or Not Spring-Return</b></p>  <p><b>Nonlocking Switch, Momentary or Spring-Return</b></p> <p>The symbols to the left are commonly used for spring buildups in key switches, relays, and jacks.</p> <p>The symbols to the right are commonly used for toggle switches.</p> <p>Circuit closing (make)</p>  <p>Circuit opening (break)</p>  <p>Two-circuit</p>  <p>Transfer</p> 	<p><b>Make-before-break</b></p>  <p><b>Locking Switch</b></p> <p>The symbols to the left are commonly used for spring buildups in key switches and jacks.</p> <p>The symbols to the right are commonly used for toggle switches.</p> <p>Circuit closing (make)</p>  <p>Circuit opening (break)</p>  <p>Transfer, 2-position</p>  <p>Transfer, 3-position</p>  <p><b>Make-before-break</b></p>  <p><b>Combination Locking and Nonlocking Switch</b></p> <p>Commonly used for toggle switches</p> <p>3-position, 1-pole: circuit closing (make), off, momentary circuit closing (make)</p>  <p>3-position, 2-pole: circuit closing (make), off, momentary circuit closing (make)</p>  <p><b>Key-Type Switch Lever Switch</b></p> <p>2-position with locking transfer and break contacts</p> 	<p>3-position with nonlocking transfer and locking break contacts</p>  <p>OR</p>  <p>3-position, multicontact combination</p>  <p>OR</p>  <p>2-position, half of key switch normally operated, multicontact combination</p>  <p><b>Selector or Multiposition Switch</b></p> <p>The position in which the switch is shown may be indicated by a note or designation of switch position.</p> <p>General (for power and control diagrams)</p> <p>Any number of transmission paths may be shown.</p> 
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## Contacts, Switches, Contactors, and Relays

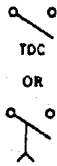
If specific type identification is required: circuit closing



### Switches with Time-Delay Feature

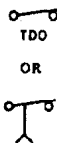
**NOTE** The point of the arrow indicates the direction of switch operation in which contact action is delayed.

Open switch with time-delay closing (TDC) feature



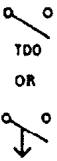
See Note

Closed switch with time-delay opening (TDO) feature



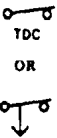
See Note

Open switch with time-delay opening (TDO) feature



See Note

Closed switch with time-delay closing (TDC) feature



See Note

### Flow-Actuated Switch

Closes on increase in flow



Opens on increase in flow



### Liquid-Level-Actuated Switch

Closes on rising level



Opens on rising level



### Pressure- or Vacuum-Actuated Switch

Closes on rising pressure

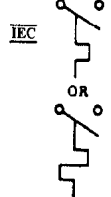


Opens on rising pressure

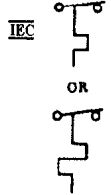


### Temperature-Actuated Switch

Closes on rising temperature



Opens on rising temperature



### Thermostat

**NOTE** The  $t^*$  symbol shall be shown or be replaced by data giving the nominal or specific operating temperature of the device.

**NOTE** If clarification of direction of contact operation is needed, a directional arrow may be added. The arrowhead shall point in the direction of rising temperature operation. A directional arrow shall always be shown for central-off (neutral) position devices.

Closes on rising temperature



See Note

With contact-motion direction clarified



See Note

Opens on rising temperature



See Note

Transfers on rising temperature



See Note

Transfer, with intended central-off (neutral) position



See Notes

Application: multifunction, typical



See Notes

With integral heater and transfer contacts

Use only if essential to indicate integral heater details.



See Notes

Application: with operating temperatures indicated



See Notes

### Flasher Self-Interrupting Switch



## Contacts, Switches, Contactors, and Relays

### Foot-Operated Switch Foot Switch

Opens by foot pressure



Closes by foot pressure



### Switch Operated by Shaft Rotation and Responsive to Speed or Direction

Speed



Plugging: to stop drive after it has come practically to rest



Anti-plugging: to prevent plugging of drive



Centrifugal switch (opening on increasing speed)



### Switches with Specific Features

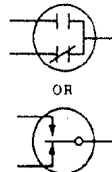
Hook switch



Telephone dial (switch)



Switch in evacuated envelope,  
1-pole double-throw



Mushroom-head safety feature

Application to 2-circuit pushbutton switch.



Key-operated lock switch

Use appropriate standard symbol and add key designation or other information in note.

### Telegraph Key

Simple



Simple with shorting switch



Open-circuit or pole-changing



### Governor (Contact-making) Speed Regulator

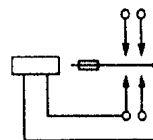
Contacts open or closed as required (shown here as closed).



### Vibrator, Interrupter

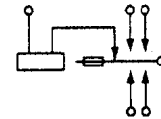
Typical shunt drive (with terminals shown)

Show contacts as required.



Typical separate drive (with terminals shown)

Show contacts as required.

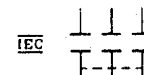


### Contactors

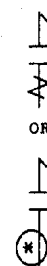
See also CIRCUIT BREAKER

Fundamental symbols for contacts, coils, mechanical connections, etc., are the basis of contactor symbols and should be used to represent contactors on complete diagrams. Complete diagrams of contactors consist of combinations of fundamental symbols for control coils, mechanical connections, etc., in such configurations as to represent the actual device. Mechanical interlocking should be indicated by notes.

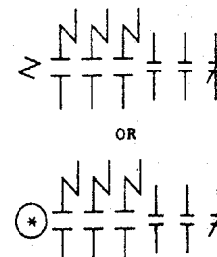
Manually operated 3-pole contactor



Electrically operated 1-pole contactor with series blowout coil

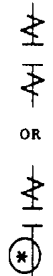


Electrically operated 3-pole contactor with series blowout coils; 2 open and 1 closed auxiliary contacts (shown smaller than the main contacts)



## Contacts, Switches, Contactors, and Relays

Electrically operated 1-pole  
contactor with shunt blowout coil



Relay

See OPERATING COIL; RELAY COIL

Fundamental symbols for contacts, mechanical connections, coils, etc., are the basis of relay symbols and should be used to represent relays on complete diagrams.

The following letter combinations or symbol elements may be used with relay symbols. The requisite number of these letters or symbol elements may be used to show what special features a relay possesses.

The terms "slow" and "fast" are relative, and the degree is not to be noted by a multiplicity of the same relay symbol on a diagram. Relays that are direct-current operated are not marked to indicate dc operation.

IEC		AC Alternating-current or ringing relay
	D	Differential
	DB	Double-biased (biased in both directions)
	DP	Dashpot
	EP	Electrically polarized
	FO	Fast-operate
	FR	Fast-release
	L	Latching
	MG	Marginal
	ML	Magnetic-latching (remanent)
	NB	No bias
	NR	Nonreactive
	P	Magnetically polarized using biasing spring, or having magnet bias
	SA	Slow-operate and slow-release
IEC		SO Slow-operate
	SR	Slow-release
	SW	Sandwich-wound to improve balance to longitudinal currents

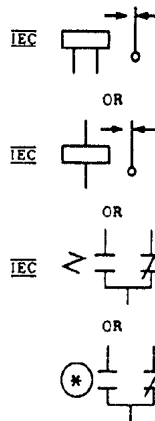
The proper poling for a polarized relay shall be shown by the use of + and - designations applied to the winding leads. The interpretation of this shall be

that a voltage applied with the polarity as indicated shall cause the armature to move toward the contact shown nearer the coil on the diagram. If the relay is equipped with numbered terminals, the proper terminal numbers shall also be shown.

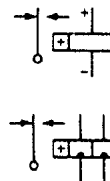
Basic



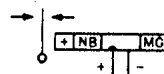
Application: relay with transfer contacts



Application: polarized relay with transfer contacts (two typical types shown)



Application: polarized (no bias) marginal relay with transfer contacts

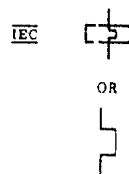


Relay, thermally operated

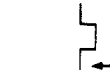
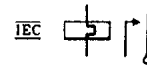
Activating device for thermally operated relay

Time of delay may be shown.

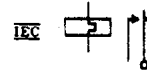
Contacts may be shown separately from the operating device.



With normally open contacts shown (two typical types)

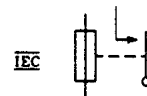


With transfer contacts shown

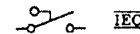


Thermal relay, one-time type, not reusable

Normally open contact type shown.



Inertia Switch (operated by sudden deceleration)

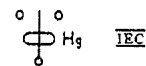


NOTE This symbol is commonly used on diagrams for aerospace applications.

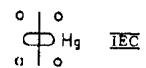
Mercury Switch

Leveling

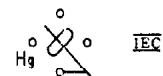
Three terminal



Four terminal



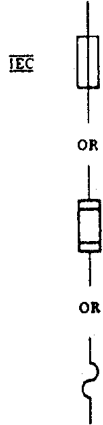
With acceleration cutoff (four terminal)



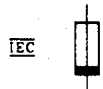
## Circuit Protectors

**Fuse (one-time thermal current-over-load device)**

General

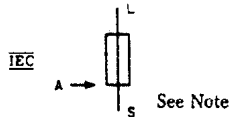


Fuse, supply side indicated by a thick line

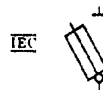


Fuse with alarm contact

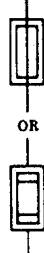
**NOTE** When fuse blows, alarm bus A is connected to power supply bus S. The letters S (supply), L (load), and A (alarm circuit) are for explanation only, and are not part of the symbol.



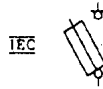
Isolating fuse-switch; high-voltage primary fuse cutout, dry



High-voltage primary fuse cut-out, oil



Isolating fuse-switch for on-load switching



**Current Limiter (for power cable)**  
The arrowheads in this case are filled.

**NOTE** Use appropriate number of single-line diagram symbols.



See Note

**Lightning Arrester**  
Arrester (electric surge, etc)  
Gap

General



Carbon block; telephone protector block

The sides of the rectangle shall be approximately in the ratio of 1 to 2 and the space between rectangles shall be approximately equal to the width of a rectangle.



Electrolytic or aluminum cell

This symbol is not composed of arrowheads.



Horn gap



Protective gap

These triangles shall not be filled.



Sphere gap



Valve or film element



Multigap, general



Application: gap plus valve plus ground, 2-pole



**Circuit Breaker**

If it is desired to show the condition causing the breaker to trip, the relay protective-function symbols in item 9.5.1 may be used alongside the breaker symbol.

General



Air circuit breaker, if distinction is needed; for alternating-current circuit breakers rated at 1,500 volts or less and for all direct-current circuit breakers



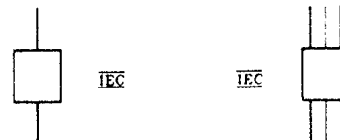
Network protector



Circuit breaker

The symbol in the right column is for a 3-pole breaker.

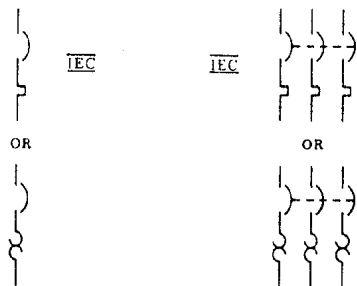
**NOTE** On a power diagram, the symbol may be used without other identification. On a composite drawing where confusion with the general circuit element symbol (item 16.1) may result, add the identifying letters CB inside or adjacent to the square.



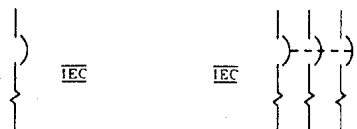
See Note

## Circuit Protectors

Application: 3-pole circuit breaker with thermal-overload device in all 3 poles



Application: 3-pole circuit breaker with magnetic-overload device in all 3 poles



Application: 3-pole circuit breaker, drawout type



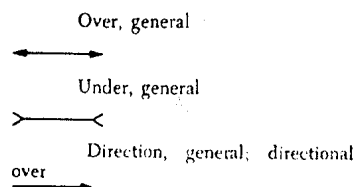
### Protective Relay

Fundamental symbols for contacts, coils, mechanical connections, etc., are the basis of relay symbols and should be used to represent relays on complete diagrams.

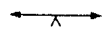
See RELAY COIL, OPERATING COIL and RELAY

### Relay protective functions

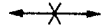
The following symbols may be used to indicate protective functions, or device-function numbers may be placed in the circle or adjacent to the basic symbol (see American National Standard for Manual and Automatic Station Control, Supervisory, and Associated Telemetering Equipments, C37.2-1970).



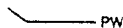
### Balance, general



### Differential, general



### Pilot wire, general



### Carrier current, general




### Operating quantity

The operating quantity is indicated by the following letters or symbols placed either on or immediately above the relay protective-function symbols shown above.

C	*Current
Z	Distance
F	Frequency
GP	Gas pressure
$\phi$	Phase
W	Power
S	Synchronism
T	Temperature
V	Voltage

\* The use of the letter may be omitted in the case of current, and the absence of such letter presupposes that the relay operates on current.

### Ground relays

Relays operative on residual current only are so designated by attaching the ground symbol  to the relay protective-function symbol. Note that the zero phase-sequence designation given below may be used instead when desirable.

### Phase-sequence quantities

Operations on phase-sequence quantities may be indicated by the use of the conventional subscripts 0, 1, and 2 after the letter indicating the operating quantity.

### Applications

#### Overcurrent



#### Directional overcurrent



#### Directional residual overcurrent



#### Undervoltage



### Power directional



### Balanced current



### Differential current



### Distance



### Directional distance



### Overfrequency



### Overtemperature



### Phase balance



### Phase sequence



### Pilot wire, differential-current



### Pilot wire, directional-comparison



### Carrier pilot



### Positive phase-sequence undervoltage



### Negative phase-sequence overcurrent



### Gas-pressure (Buchholz)



### Out-of-step



## Meter Instrument

NOTE The asterisk is not part of the symbol. Always replace the asterisk by one of the following letter combinations, depending on the function of the meter or instrument, unless some other identification is provided in the circle and explained on the diagram.

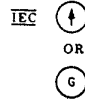


\* See Note

A	Ammeter	IEC
AH	Ampere-hour meter	
C	Coulombmeter	
CMA	Contact-making (or breaking) ammeter	
CMC	Contact-making (or breaking) clock	
CMV	Contact-making (or breaking) voltmeter	
CRO	Oscilloscope	
DB	DB (decibel) meter	
DBM	DBM (decibels referred to 1 milliwatt) meter	
DM	Demand meter	
DTF	Demand-totalizing relay	
F	Frequency meter	
GD	Ground detector	
I	Indicating meter	
INT	Integrating meter	
μA or UA	Microammeter	
MA	Milliammeter	
NM	Noise meter	
OHM	Ohmmeter	
OP	Oil pressure meter	
OSCG	Oscillograph, string	
PF	Power factor meter	
PH	Phasemeter	
PI	Position indicator	
RD	Recording demand meter	
REC	Recording meter	
RF	Reactive factor meter	
SY	Synchroscope	
t°	Temperature meter	
THC	Thermal converter	
TLM	Telemeter	
TT	Total time meter	
	Elapsed time meter	
V	Voltmeter	IEC
VA	Volt-ammeter	
VAR	Varmeter	
VARH	Varhour meter	
VI	Volume indicator	
	Audio-level meter	
VU	Standard volume indicator	
	Audio-level meter	
W	Wattmeter	IEC
WH	Watt-hour meter	

## Readout Devices

### Galvanometer



### Electromagnetically Operated Counter Message Register

#### General



#### With make contact



# APPENDIX IV

## CROSS REFERENCE OF MILITARY AND COMMERCIAL FUSE DESIGNATIONS

OLD MILITARY	NEW MILITARY	OLD COMMERCIAL	NEW COMMERCIAL
F02GR010A	F02A 250V 1/100A	3AG 1/100 250V	AGC 1/100 250V
F02GR031A	F02A 250V 1/32A	3AG 1/32 250V	AGC 1/32 250V
F02GR062A	F02A 250V 1/16A	3AG 1/16 250V	AGC 1/16 250V
F02G1R50A	F02A 250V 1 1/2A	3AG 1 1/2 250V	AGC 1 1/2 250V
F02G2R00A	F02A 250V 2A	3AG 2 250V	AGC 2 250V
F02GR010B	F02B 250V 1/100A	3AG 1/100 250V	MDL 1/100 250V
F02GR031B	F02B 250V 1/32A	3AG 1/32 250V	MDL 1/32 250V
F02GR375B	F02B 250V 3/8A	3AG 3/8 250V	MDL 3/8 250V
F02D1R50B	F02B 125V 1 1/2A	3AG 1 1/2 125V	MDL 1 1/2 125V
F02D2R00B	F02B 125V 2A	3AG 2 125V	MDL 2 125V
F03G1R00A	F03A 250V 1A	3AB 1 250V	ABC 1 250V
F03G3R00A	F03A 250V 3A	3AB 3 250V	ABC 3 250V
F03G10R0A	F03A 250V 10A	3AB 10 250V	ABC 10 250V
F03G12R0A	F03A 250V 12A	3AB 12 250V	ABC 12 250V
F03D20R0A	F03A 125V 20A	3AB 20 125V	ABC 20 125V
F03D30R0A	F03A 125V 30A	3AB 30 125V	ABC 30 125V
F04A10R0A	F02A 32V 10A	3AG 10 32V	AGC 10 32V
F04A15R0A	F02A 32V 15A	3AG 15 32V	AGC 15 32V
F04A5R00B	F02B 32V 5A	3AG 5 32V	MDL 5 32V
F04A10R0B	F02B 32V 10A	3AG 10 32V	MDL 10 32V
F05A10R0A	F05A 32V 10A	4AG 10 32V	AGS 10 32V
F05A15R0A	F05A 32V 15A	4AG 15 32V	AGS 15 32V
F05A10R0B	F05B 32V 10A	4AG 10 32V	MDM 10 32V
F05A15R0B	F05B 32V 15A	4AG 15 32V	MDM 15 32V
F06G1R00A	F06A 250V 1A	4AB 1 250V	ABS 1 250V
F06G2R00A	F06A 250V 2A	4AB 2 250V	ABS 2 250V
F07A5R00A	F07A 32V 5A	5AG 5 32V	AGU 5 32V
F07A10R0A	F07A 32V 10A	5AG 10 32V	AGU 10 32V
F07A5R00B	F07B 32V 5A	5AG 5 32V	MDR 5 32V
F07A10R0B	F07B 32V 10A	5AG 10 32V	MDR 10 32V
F08G1R00A	F07A 250V 1A	5AG 1 250V	AGU 1 250V
F08G2R00A	F07A 250V 2A	5AG 2 250V	AGU 2 250V
F08G1R00B	F09B 250V 1A	5AG 1 250V	FNM 1 250V
F08G2R00B	F09B 250V 2A	5AG 2 250V	FNM 2 250V





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# *Assignment Questions*

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**Information:** The text pages that you are to study are provided at the beginning of the assignment questions.



# ASSIGNMENT 1

Textbook assignment: Chapter 1, "Circuit Protection Devices," pages 1-1 through 1-73.

- 1-1. Circuit measurement is used for which of the following purposes?
1. To find the weight of a circuit
  2. To increase the power used in a circuit
  3. To discover the length and width of a circuit
  4. To determine the reason a circuit is not functioning properly
- 1-2. An in-circuit meter is used for which of the following purposes?
1. To reduce circuit losses
  2. To monitor circuit operation
  3. To control power to a circuit
  4. To prevent circuit overload conditions
- 1-3. Out-of-circuit meters have which of the following advantages over in circuit meters?
1. They can be used on more than one device
  2. They are lighter weight
  3. They are more rugged
  4. All of the above

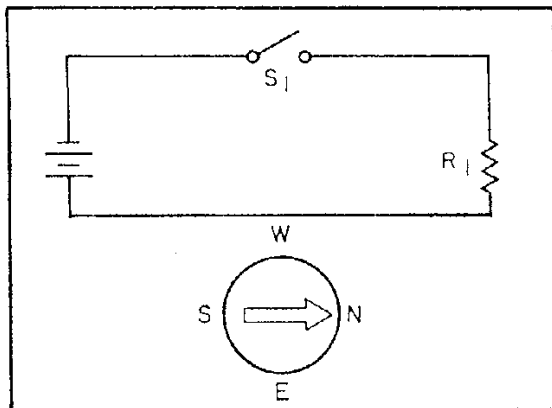


Figure 1-A.—Compass and wire (dc).

IN ANSWERING QUESTIONS 1-4 THROUGH 1-6, REFER TO FIGURE 1-A.

- 1-4. When  $S_1$  is closed, the compass needle will align itself in which of the following manners?
1. With magnetic north
  2. With geographic north
  3. Parallel to the conductor
  4. With the magnetic field around the wire
- 1-5. If the current through the conductor is decreased, what happens to the magnetic field around the conductor?
1. It reverses
  2. It decreases
  3. It increases
  4. It oscillates
- 1-6. When the current through the conductor decreases, the compass needle will react in which of the following manners?
1. Point more to magnetic north
  2. Move farther away from magnetic north
  3. Swing back and forth from east to west
  4. Vibrate rapidly back and forth around magnetic north
- 1-7. The d'Arsonval meter movement is based on which of the following principles?
1. Moving vane
  2. Electrostatic
  3. Electrodynamic
  4. Permanent-magnet moving-coil

1-8. Current through a meter results in the pointer. In d'Arsonval meter movement, what force produces this deflection?

1. Thermocouple action
2. Electrostatic repulsion
3. Mechanical spring tension
4. The interaction of magnetic fields

1-9. The hairsprings in a d'Arsonval meter movement perform which of the following functions?

1. They keep the pointer in the position of the last indication when current is removed
2. They aid the movement of the pointer when there is current through the meter
3. They make electrical connections to the meter movement
4. All of the above

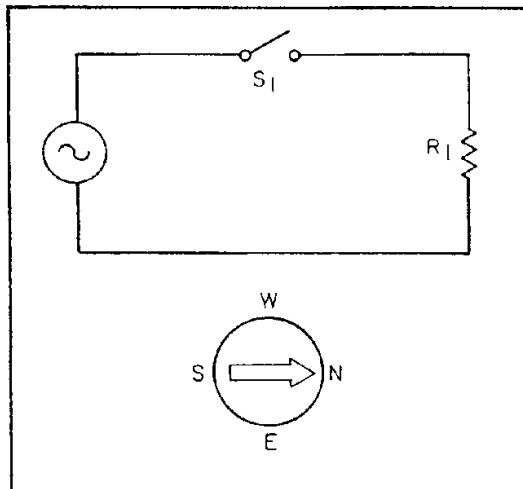


Figure 1-B.—Compass and wire (ac).

IN ANSWERING QUESTIONS 1-10 AND 1-11, REFER TO FIGURE 1-B.

1-10. If the frequency of the ac source is 5 Hz, how will the compass needle react when S1 is closed?

1. It will swing back and forth
2. It will point directly at the wire
3. It will point directly away from the wire
4. It will vibrate rapidly around magnetic north

1-11. If the frequency of the ac source is 200 Hz, how will the compass needle react when S1 is closed?

1. It will swing back and forth
2. It will point directly at the wire
3. It will point directly away from the wire
4. It will vibrate rapidly around magnetic north

1-12. What device allows a d'Arsonval meter movement to measure ac by converting ac to pulsating dc?

1. A pulsator
2. A modulator
3. A rectifier
4. A converter

1-13. What is meant by the term "meter damping"?

1. Moistening the felt pads
2. Smoothing the oscillations of the pointer
3. Preventing excessive current through the coil
4. Compensating for electromagnetic induced interference

1-14. Which of the following methods is used to dampen a meter?

1. Mount the meter in a mu-metal case
2. Install a fuse in one of the input leads
3. Incorporate an airtight chamber containing a van
4. Provide a fluid reservoir and sponge arrangement next to the pads

1-15. A d'Arsonval meter movement reacts to which of the following values of voltage?

1. Peak
2. Average
3. Effective
4. Peak-to-peak

1-16. What value of ac is indicated by a meter scale?

1. Peak
2. Average
3. Effective
4. Peak-to-peak

1-17. Which of the following meter movements will measure either ac or dc without the use of a rectifier?

1. GMS
2. d'Arsonval
3. Electrostatic
4. Electrodynamic

1-18. What electrical property is reacted to by the electrodynamic, d'Arsonval, moving-vane, and thermocouple meter movements?

1. Power
2. Current
3. Voltage
4. Resistance

1-19. What electrical property is measured by an ammeter?

1. Power
2. Current
3. Voltage
4. Resistance

1-20. How are ammeters connected in an electrical circuit?

1. In series with the load
2. In parallel with the load
3. In accordance with Lenz's Law
4. In series-parallel with the load

1-21. How does an ammeter affect the circuit being measured?

1. It acts as a resistances in series and lowers the circuit current
2. It acts as a resistance in series and raises the circuit current
3. It acts as a resistance in parallel and lowers the circuit current
4. It acts as a resistance in parallel and raises the circuit current

1-22. How is the effect that an ammeter produces in a circuit kept to a minimum?

1. By using a large resistor in series with the ammeter
2. By using a large capacitor in parallel with the ammeter
3. By ensuring that the meter resistance is low compared to circuit resistance
4. By ensuring that the meter resistance is high compared to circuit resistance

1-23. The ammeter with the greatest sensitivity has which of the following characteristics?

1. The lowest amount of current for full-scale deflection indication
2. The highest amount of current for full-scale deflection indication
3. A low ratio of internal resistance to full-scale deflection indication
4. A high ratio of internal resistance to full-scale deflection indication

1-24. Ammeters measure various ranges through the addition of which of the following components?

1. Shunt resistors in series with the meter movement
2. Shunt resistors in parallel with the meter movement
3. Capacitors in series with the meter movement
4. Capacitors in parallel with the meter movement

1-25. What range of an ammeter should you use for an initial measurement?

1. The lowest range
2. The highest range
3. The mid-scale range

1-26. What portion of the ammeter scale should be used to take a final reading?

1. The upper half
2. The lower half
3. The mid-scale portion
4. Anywhere on the meter face

1-27. When, if ever, can you use a dc ammeter to measure ac values?

1. When the ac is high frequency
2. For low values
3. Always
4. Never

1-28. Which of the following safety precautions should be observed prior to connecting an ammeter into a circuit?

1. Switch to the highest range
2. Observe proper dc polarity
3. Deenergize the circuit
4. All of the above

1-29. What electrical property is measured by a voltmeter?

1. Power
2. Current
3. Voltage
4. Resistance

1-30. A voltmeter should be connected in an electrical circuit in what manner?

1. In series with the load
2. In parallel with the load
3. In accordance with Lenz's Law
4. In series-parallel with the load

1-31. A voltmeter has an effect on the circuit being measured; what is this effect called?

1. Loading
2. Damping
3. Rectification
4. Eddy-current drag

1-32. To keep the effect of a voltmeter on a circuit to a minimum, the internal resistance of the voltmeter must have which of the following relationships to the circuit load?

1. Equal to
2. Lower than
3. Higher than
4. In proportion to

1-33. Which of the following types of meters can be made from a current sensitive meter movement?

1. Ammeter
2. Ohmmeter
3. Voltmeter
4. Each of the above

1-34. A voltmeter has a high sensitivity when it has which of the following characteristics?

1. Low deflection indication
2. High deflection indication
3. Low ratio of internal resistance to full-scale deflection indication
4. High ratio of internal resistance to full-scale deflection indication

1-35. Which of the following configurations extends the range of a voltmeter?

1. A resistor in series with the meter movement
2. A resistor in parallel with the meter movement
3. A capacitor in series with the meter movement
4. A capacitor in parallel with the meter movement

1-36. What voltmeter range should be used for initial measurements?

1. The lowest
2. The highest
3. The mid-scale

1-37. The electrostatic meter movement reacts to which of the following electrical properties?

1. Power
2. Current
3. Voltage
4. Resistance

1-38. Electrostatic meter movements are used to measure which of the following current/voltage values?

1. Low voltage
2. Low current
3. High voltage
4. High current

1-39. Which of the following safety precautions should be observed when a voltmeter is used?

1. Deenergize the circuit before connecting the meter
2. Start with the lowest range of the meter
3. Connect the meter in series with the circuit
4. All of the above

1-40. What electrical property is measured with an ohmmeter?

1. Power
2. Current
3. Voltage
4. Resistance

1-41. An ohmmeter is used to check for which of the following conditions?

1. Continuity
2. Overheating
3. Overcurrent
4. Undercurrent

1-42. How should an ohmmeter be connected in an electrical circuit?

1. In series with the load
2. In parallel with the load
3. In parallel with the source
4. In series-parallel with the load

1-43. An ohmmeter can measure different ranges because of the use of which of the following components?

1. Range coils
2. Range resistors
3. Range capacitors
4. Range potentiometers

1-44. What area of an ohmmeter scale should be used when a measurement is taken?

1. Upper half
2. Lower half
3. Mid-scale portion
4. Anywhere on the meter face

1-45. Ohmmeter are classified by type. What are the two types of ohmmeters?

1. Series and shunt
2. Normal and reverse
3. Full- and half-scale

1-46. What is the most obvious differences in the two types of ohmmeters?

1. The ranges of the meters
2. The scales of the meters
3. The power sources of the meters
4. The size of the test leads of the meters

1-47. Which of the following safety precautions should be observed when an ohmmeter is used?

1. Always start with the highest scale of the meter
2. Deenergize the circuit before connecting the meter
3. Observe proper polarity
4. All of the above

1-48. Meggers (megohmmeters) are used to measure which of the following quantities?

1. Low voltage
2. High voltage
3. Low resistance
4. High resistance

1-49. When a megger is used to check the insulation of a wire, which of the following indications should be considered normal?

1.  $\infty$
2. 0
3. 500 V
4. 1000 V

1-50. Which of the following safety precautions should be observed when a megger is used?

1. Do not use a dc megger to measure circuits that are powered by ac
2. Always start with the highest scale selection of the meter
3. Do not touch the meter leads when a measurement is being taken
4. All of the above

1-51. A multimeter can be used to measure which of the following electrical properties?

1. Voltage
2. Current
3. Resistance
4. Each of the above

1-52. The function switch on a multimeter does NOT perform which of the following functions?

1. Selection of the meter range
2. Determination of the proper scale
3. Selection of ac or dc capability
4. Changing of the multimeter from an ammeter to a voltmeter

1-53. One of the problems encountered in building a multimeter is that the meter movement gives different readings for the same values of ac and dc. Which of the following features of a multimeter will solve this problem?

1. A rectifier
2. An ac/dc switch
3. Separate scales for ac and dc
4. A mirror on the face of the meter

1-54. Why is there a mirror on the face of a multimeter?

1. To illuminate the meter face
2. To aid in reducing parallax error
3. To reduce the friction between the pointer and the meter face
4. To compensate for the difference in ac and dc measurements

1-55. If the mirror on the face of a multimeter is used properly, where will the image of the pointer appear?

1. Hidden behind the pointer
2. Barely visible on either side of the pointer
3. Clearly visible to the left of the pointer
4. Clearly visible to the right of the pointer



1-56. Which of the following safety precautions does NOT apply to a multimeter?

1. Observe proper dc polarity when measuring dc
2. Deenergize the circuit before connecting the meter
3. Be sure the meter is switched to ac for ac measurements
4. Never apply power to the circuit when measuring voltage with the meter

1-57. If a multimeter has no OFF position, and it is returned to storage, on which of the following positions should the meter be set?

1. +dc; highest voltage range
2. -dc; higher resistance range
3. Ac; highest voltage range
4. Ac; highest current range

1-58. When the current in a conductor is measured without the conductor being disconnected, which of the following meters could be used?

1. Multimeter
2. Hook-on voltameter
3. Induction wattmeter
4. Transformer voltmeter

1-59. Which of the following electrical quantities is measured by a wattmeter?

1. Power
2. Energy
3. Voltage
4. Current

1-60. Which of the following electrical quantities is measured by a watt hour meter?

1. Power
2. Energy
3. Voltage
4. Current

## ASSIGNMENT 2

Textbook assignment: Chapter 2, "Circuit Protection Devices," pages 2-1 through 2-42.

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- 2-1. Circuit protection devices are used for which of the following purposes?
1. To protect people
  2. To protect circuits
  3. To guard against hazardous conditions
  4. All of the above
- 2-2. Which of the following conditions does NOT require the use of a circuit protection device?
1. Direct short
  2. High resistance
  3. Excessive current
  4. Abnormal heating
- 2-3. When a point in a circuit, where full system voltage is present, comes in direct contact with the ground or return side of the circuit, which of the following terms applies?
1. Direct short
  2. High resistance
  3. Excessive current
  4. Abnormal heating
- 2-4. When circuit current increases beyond the designed current carrying capability of the circuit, which of the following terms applies?
1. Direct short
  2. High resistance
  3. Excessive current
  4. Abnormal heating
- 2-5. If the bearings of a generator were to fail, which of the following circuit conditions would probably occur?
1. Direct short
  2. High resistance
  3. Excessive current
  4. Abnormal heating
- 2-6. How are circuit protection devices connected to the circuit they are protecting?
1. Alongside
  2. In series
  3. In parallel
  4. In series-parallel
- 2-7. Which of the following two are circuit protection devices?
1. Electrical plugs and CO<sub>2</sub> cartridges
  2. CO<sub>2</sub> cartridges and circuit breakers
  3. Fuses and circuit breakers
  4. Fuses and electrical plugs

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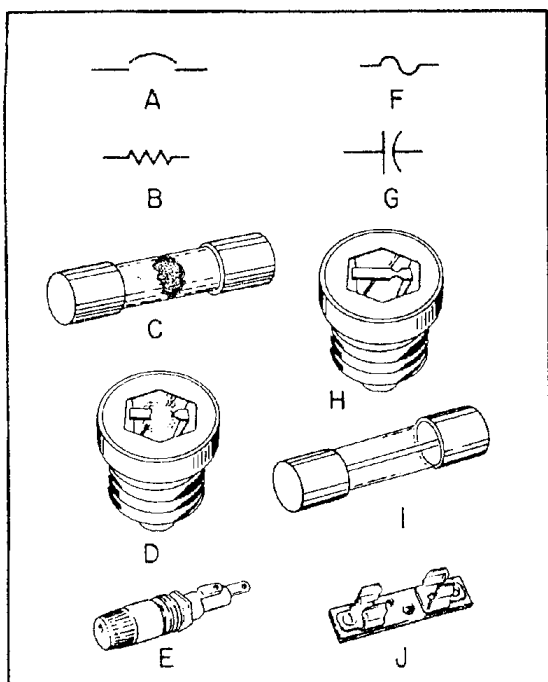


Figure 2-A.—Recognition practice.

IN ANSWERING QUESTIONS 2-8  
THROUGH 2-13, REFER TO FIGURE 2-A.

- 2-8. Which of the following is the schematic symbol for a fuse?
1. A
  2. B
  3. F
  4. G
- 2-9. Which of the following is the schematic symbol for a circuit breaker?
1. A
  2. B
  3. F
  4. G
- 2-10. Which of the following is an illustration of an open cartridge fuse?
1. C
  2. D
  3. E
  4. I
- 2-11. Which of the following is an illustration of a good cartridge fuse?
1. C
  2. D
  3. E
  4. I
- 2-12. Which of the following is an illustration of a good plug-type fuse?
1. C
  2. D
  3. E
  4. H
- 2-13. Which of the following is an illustration of an open plug-type fuse?
1. C
  2. D
  3. E
  4. H
- 2-14. Which of the following factors is NOT used to rate fuses?
1. Size
  2. Current
  3. Voltage
  4. Time delay
- 2-15. A fuse current rating has which of the following definitions?
1. The maximum current that can flow through a circuit without causing the circuit to overheat
  2. The maximum current that will flow through a circuit if there is a direct short
  3. The maximum current that will flow through a fuse without opening the fuse
  4. The maximum current that will not "jump" an open fuse

- 2-16. A fuse voltage rating has which of the following definitions?
1. The maximum voltage that can exist in a circuit without causing the circuit to overheat
  2. The maximum voltage that can exist in a circuit if there is a direct short
  3. The maximum voltage across a fuse that will not cause the fuse to open
  4. The maximum voltage across a fuse that will not jump the open fuse

---

IN ANSWERING QUESTIONS 2-17 THROUGH 2-19, MATCH THE TIME-DELAY RATING LISTED IN COLUMN B TO THE ELECTRICAL DEVICE LISTED IN COLUMN A. NOT ALL ITEMS IN COLUMN B WILL BE USED.

A. ELECTRICAL DEVICES	B. TIME-DELAY RATINGS
2-17. Electric motor	1. Fast
2-18. Lighting circuit	2. Delay
2-19. Meter Movement	3. Standard
	4. Intermediate

---

- 2-20. What is the voltage rating for a fuse with the designation F03D1R00B?
1. 32 V or less
  2. 125 V or less
  3. 250 V or less
  4. 500 V or less
- 2-21. What is the current rating for a fuse with the designation F03B0R50B?
1. 1/2 amp
  2. 1.5 amp
  3. 3 amp
  4. 50 amp

- 2-22. What is the time-delay rating for a fuse with the designation F03A20R0C?
1. Fast
  2. Delay
  3. Standard
  4. Intermediate
- 2-23. What is the voltage rating for a fuse with the designation F02B250V10AS?
1. 10 V or less
  2. 32 V or less
  3. 52 V or less
  4. 250 V or less
- 2-24. What is the current rating for a fuse with the designation F03A125V5A?
1. 125 amp
  2. 5 amp
  3. 3 amp
  4. 1/8 amp
- 2-25. What is the time-delay rating for a fuse with the designation F04C125V2AS?
1. Fast
  2. Delay
  3. Standard
  4. Intermediate
- 2-26. What is the voltage rating for a fuse with the designation 3AG20125V?
1. 20 V or less
  2. 90 V or less
  3. 125 V or less
  4. 250 V or less
- 2-27. What is the current rating for a fuse with the designation 3AG1032V?
1. 1 amp
  2. 2 amp
  3. 3 amp
  4. 10 amp

2-28. What is the voltage rating for a fuse with the designation AGC5125V?

1. 12 V or less
2. 25 V or less
3. 51 V or less
4. 125 V or less

2-29. What is the current rating for a fuse with the designation AGC2125V?

1. 1 amp
2. 2 amp
3. 3 amp
4. 25 amp

2-30. What is the new military designation for a fuse with the old, military designation F03D1R50B?

1. F03A125V1.5A
2. F02B125V1.5A
3. F03A250V11/2A
4. F03B125V1.5A

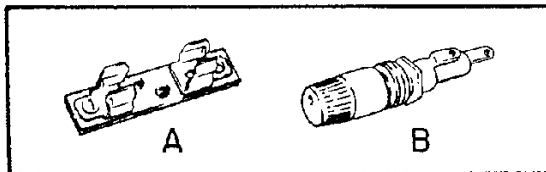


Figure 2-B.—Fuseholder identification.

IN ANSWERING QUESTIONS 2-31 THROUGH 2-34, REFER TO FIGURE 2-B.

2-31. What type of fuseholder is shown in figure 2-B(A)?

1. Clip
2. Post
3. Bayonet
4. Spring-loaded

2-32. What type of fuseholder is shown in figure 2-B(B)?

1. Clip
2. Post
3. Bayonet
4. Spring-loaded

2-33. When you use the fuseholder shown in figure 2-B(B), which connector should be connected to the power source?

1. Ground
2. Center
3. Inside
4. Outside

2-34. When you use the fuseholder shown in figure 2-B(B), which connector should be connected to the load?

1. Ground
2. Center
3. Inside
4. Outside

2-35. Which of the following methods will provide an ABSOLUTE determination as to whether or not a fuse is open?

1. A visual inspection
2. A check of the fuse indicator
3. A voltmeter check of the fuse
4. A thermometer check of the temperature of the fuse

2-36. A fuse is removed from a circuit, checked with an ohmmeter, and found to be shorted. What action should be taken?

1. Discard the fuse
2. Check the fuse with a voltmeter
3. Put the fuse back in the circuit
4. Return the fuse to the supply department

2-37. Which of the following methods should be used to check a .002 ampere fuse?

1. Use a megger and place a capacitor in parallel with the fuse
2. Use a megger and place a capacitor in series with the fuse
3. Use an ohmmeter and place a resistor in parallel with the fuse
4. Use an ohmmeter and place a resistor in series with the fuse

2-38. What should you use to remove a fuse from a clip-type fuseholder?

1. A scribe
2. A fusepuller
3. A screwdriver
4. A pair of pliers

2-39. Which of the following is a safety precaution to be observed when a fuse is checked?

1. Turn the power off and discharge the circuit before the fuse is removed
2. When you check a fuse with an ohmmeter, be careful to avoid short circuits
3. When you use a voltmeter to check a low current fuse, be careful to avoid opening the fuse by excessive current from the voltmeter
4. All of the above

YOU HAVE FOUND AN OPEN FUSE IN A PIECE OF EQUIPMENT AND HAVE REPAIRED THE CASUALTY. THE TECHNICAL MANUAL FOR THE EQUIPMENT SPECIFIES A FUSE CODED F02A125V3A. NO FUSES WITH THAT DESIGNATION ARE AVAILABLE. THE FOLLOWING FUSES ARE CARRIED BY THE SUPPLY SYSTEM.

- A. F03D3R00A
- B. 3AG3250V
- C. F02A3R00B
- D. AGC3125V
- E. F02D3R00C
- F. AGC5250V

**Figure 2-C.—Fuse replacement problem.**

IN ANSWERING QUESTIONS 2-40 THROUGH 2-46, USE THE INFORMATION IN FIGURE 2-C.

2-40. What fuse is a direct replacement?

1. A
2. C
3. D
4. E

2-41. What fuse is the best substitute?

1. A
2. B
3. C
4. F

2-42. What fuse is the second best in the fuseholder substitute?

1. A
2. C
3. E
4. F

2-43. What fuse is unacceptable because the physical size is incorrect?

1. A
2. C
3. E
4. F

2-44. What fuse is unacceptable because of the current rating?

1. B
2. D
3. E
4. F

2-45. What fuse is unacceptable because of the voltage rating?

1. A
2. B
3. C
4. D

2-46. What fuse is unacceptable because of the time-delay rating?

1. A
2. C
3. D
4. E

2-47. Before replacing a fuse, you should check for which of the following conditions?

1. Proper fit
2. Proper fuse
3. Both 1 and 2 above
4. Proper input voltage

2-48. Which of the following is NOT a safety precaution to be observed when a fuse is changed?

1. Be sure to "tag out" the fuseholder when you remove the fuse
2. Remove the power from a circuit before removing and replacing a fuse
3. Remove any corrosion from the fuseholder before replacing a fuse
4. Be sure the fuse fits properly in the fuseholder

2-49. When you perform preventive maintenance on fuses, which of the following is NOT a condition you should check?

1. Corrosion
2. Shorted fuse
3. Improper fit
4. Improper fuse

2-50. What is the total number of main components in a circuit breaker?

1. Five
2. Two
3. Three
4. Four

2-51. Which of the following is NOT a type of trip element for a circuit breaker?

1. Thermal
2. Magnetic
3. Mechanical
4. Thermal-magnetic

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IN ANSWERING QUESTIONS 2-52 THROUGH 2-54, SELECT FROM COLUMN B THE TRIP ELEMENT THAT IS DESCRIBED BY THE ACTION LISTED IN COLUMN A. NOT ALL ITEMS IN COLUMN B WILL BE USED.

	A. ACTIONS	B. TRIP ELEMENTS
2-52.	An electromagnet is connected in series with the load	1. Thermal
2-53.	A bimetallic strip is heated by the load current	2. Magnetic
2-54.	A bimetallic strip is heated by the load current and electromagnet is connected in series with the load	3. Mechanical
		4. Thermal-magnetic

---

2-55. A circuit breaker that will trip even if the operating mechanism is held ON is known as what type of circuit breaker?

1. Standard
2. Emergency
3. Trip free
4. Nontrip free

2-56. What type of circuit breaker can be overridden if the operating mechanism is held ON?

1. Standard
2. Emergency
3. Trip free
4. Nontrip free

2-57. Which of the following is NOT a time-delay rating for a circuit breaker?

1. Long
2. Short
3. Standard
4. Instantaneous

2-58. Selective tripping is used to cause which of the following circuit breakers to trip when there is an overload?

1. The least expensive
2. The most accessible
3. The smallest current rating
4. The closest to the fault

2-59. Selective tripping is used to accomplish which of the following purposes?

1. To reduce wear and tear on circuit breakers
2. To isolate a faulty circuit without affecting other circuits
3. To simplify the task of resetting the circuit breaker
4. To enable the application of power to emergency circuits during an overload

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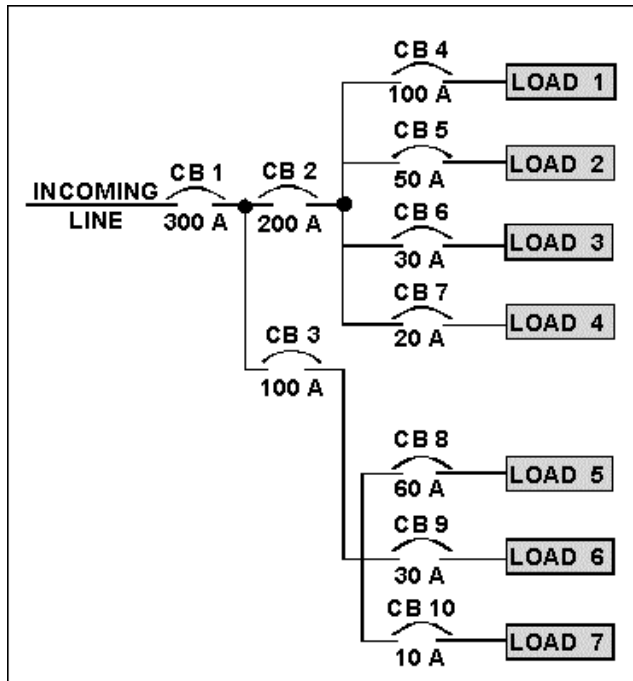


Figure 2-D.—Use of circuit breakers in a power distribution system.

IN ANSWERING QUESTIONS 2-60 THROUGH 2-62, REFER TO FIGURE 2-D.

2-60. Which of the following circuit breakers should have a long time delay?

1. CB1
2. CB2
3. CB3
4. CB4

2-61. Which of the following circuit breakers should have a short time delay?

1. CB1
2. CB2
3. CB5
4. CB4

2-62. Which of the following circuit breakers should have an instantaneous time delay?

1. CB1
2. CB2
3. CB3
4. CB4

2-63. The following actions must be taken prior to working on a circuit breaker. Arrange these items in the proper sequence, then select the choice below that lists the events in the proper sequence.

- A. Tag the power switch
- B. Obtain the approval of the electrical officer
- C. Remove power to the circuit breaker
- D. Check the applicable technical manual

1. A, B, C, D
2. C, B, D, A
3. D, B, C, A
4. B, A, D, C

2-64. Which of the following items is NOT checked during maintenance on a circuit breaker?

1. Input power voltage
2. Operating mechanism smoothness
3. Terminal tightness and corrosion
4. Contact surfaces for pitting

## ASSIGNMENT 3

Textbook assignment: Chapter 3, "Circuit Control Devices," pages 3-1 through 3-39.

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3-1. Circuit control devices should NOT be used for which of the following reasons?

1. To adjust the power level of a device
2. To remove power from a malfunctioning device
3. To apply power to a device when work is completed on it
4. To select the function or circuit desired within a device

3-2. Which of the following are types of circuit control devices?

1. Relays
2. Switches
3. Solenoids
4. All of the above

3-6. Which of the following is a manual switch?

1. A light switch
2. A limit switch
3. A thermostat
4. A distributor

3-7. Which of the following is an automatic switch?

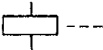


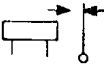
1. An ignition switch on a motor vehicle
2. A switch that turns on a light in a refrigerator
3. A channel selector on a television
4. A dial or push button on a telephone

3-8. Control or selection of one or more circuits is a function of which of the following switches?

1. A manual switch
2. An automatic switch
3. A multicontact switch
4. A single contact switch

---

IN ANSWERING QUESTIONS 3-3 THROUGH 3-5, MATCH THE SCHEMATIC SYMBOL SHOWN IN COLUMN B TO THE DEVICE LISTED IN COLUMN A.

A. DEVICES	B. SCHEMATIC SYMBOLS
3-3. A switch	1. 
3-4. A relay	2. 
3-5. A solenoid	3. 
	4. 

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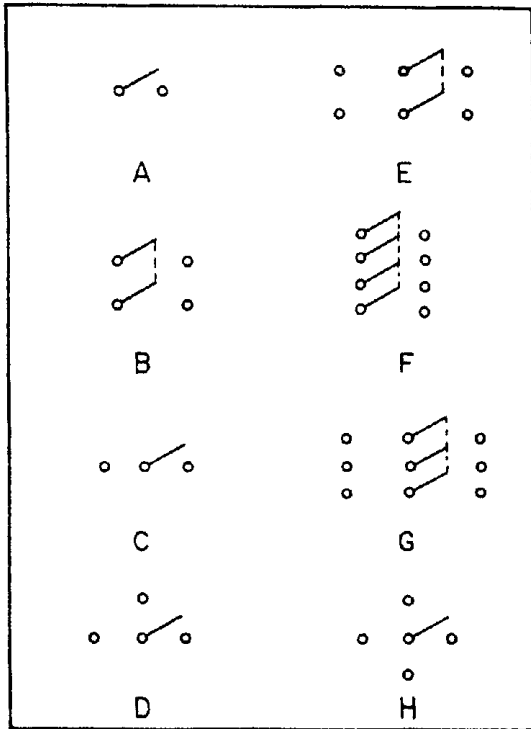


Figure 3-A.—Switch schematics.

IN ANSWERING QUESTIONS 3-9  
THROUGH 3-15, REFER TO FIGURE 3-A.  
SELECT THE SYMBOL THAT REPRESENTS  
THE TYPE OF SWITCH STATED IN EACH  
QUESTION.

3-9. A single-pole, double-throw switch.

1. A
2. B
3. C
4. D

3-10. A double-pole, double-throw switch.

1. B
2. E
3. G
4. H

3-11. A single-pole, four-throw switch.

1. B
2. D
3. F
4. H

3-12. A double-pole, single-throw switch.

1. B
2. C
3. E
4. H

3-13. A single-pole, single-throw switch.

1. A
2. B
3. C
4. D

3-14. A three-pole, double-throw switch.

1. E
2. F
3. G
4. H

3-15. A single-pole, triple-throw switch.

1. B
2. D
3. E
4. G

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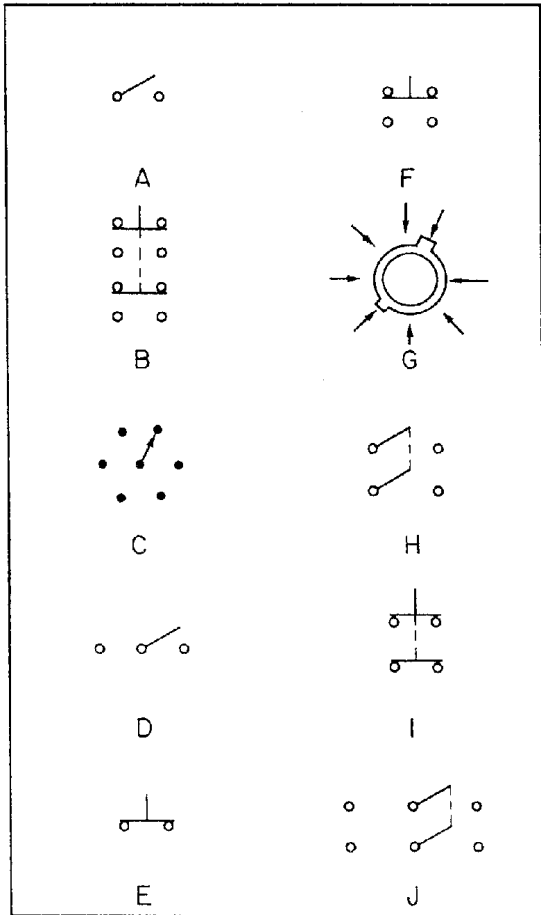


Figure 3-B.—Switch schematics.

IN ANSWERING QUESTIONS 3-16 THROUGH 3-24, REFER TO FIGURE 3-B. SELECT THE SYMBOL THAT REPRESENTS THE TYPE OF SWITCH STATED IN EACH QUESTION.

3-16. A single-pole, single-throw, double-break switch.

1. A
2. C
3. D
4. E

3-17. A double-pole, single-throw, double-break switch.

1. F
2. H
3. I
4. J

3-18. A single-pole, double-throw, single-break switch.

1. A
2. D
3. E
4. F

3-19. A single-pole, double-throw, double-break switch.

1. E
2. F
3. H
4. I

3-20. A double-pole, single-throw, single-break switch.

1. E
2. H
3. I
4. J

3-21. A double-pole, double-throw, double-break switch.

1. B
2. F
3. H
4. I

3-22. A double-pole, double-throw, single-break switch.

1. F
2. H
3. I
4. J

3-23. A rotary switch.

1. C
2. D
3. H
4. I

- 3-24. A wafer switch.
1. D
  2. E
  3. G
  4. H
- 3-25. A switch actuator is described by which of the following terms?
1. Momentary
  2. Two-position
  3. Toggle
  4. Four-position
- 3-26. What is the maximum number of different single-pole, single throw switch positions possible?
1. One
  2. Two
  3. Three
  4. Four
- 3-27. What is the maximum number of different single-pole, double throw switch positions possible?
1. One
  2. Two
  3. Three
  4. Four
- 3-28. Control of a circuit requiring a temporary actuation signal is provided by which of the following switches?
1. Momentary
  2. Locked-in
  3. Locked-out
  4. Rotary
- 3-29. To guard against the accidental actuation of a circuit, which of the following types of switches are used?
1. Momentary
  2. Locked-in
  3. Locked-out
  4. Rotary
- 3-30. To guard against the accidental turning off of a circuit, which of the following types of switches are used?
1. Momentary
  2. Locked-in
  3. Locked-out
  4. Rotary
- 3-31. What is the common name for a accurate snap-acting switch?
1. Maxiswitch
  2. Multiswitch
  3. Miniswitch
  4. Microswitch
- 3-32. Designation of switch current rating is based on which of the following current values?
1. Maximum
  2. Minimum
  3. Nominal
  4. Average
- 3-33. Designation of switch voltage rating is based on which of the following voltage values?
1. Maximum
  2. Minimum
  3. Nominal
  4. Average
- 3-34. Checking a switch with the circuit power NOT applied is accomplished by using which of the following meters?
1. Wattmeter
  2. Frequency meter
  3. Temperature meter
  4. Ohmmeter

3-35. Checking a switch with the power applied is accomplished by using which of the following meters?

1. Megger
2. Ohmmeter
3. Wattmeter
4. Voltmeter

A THREE-POLE, DOUBLE-THROW, SINGLE-BREAK, THREE POSITION, ROCKER SWITCH IS FAULTY. THIS SWITCH HAS A MOMENTARY POSITION 3 AND IS LOCKED INTO POSITION 1. THE VOLTAGE AND CURRENT RATING FOR THE SWITCH ARE 230 VOLTS, 3 AMPERES. THE FOLLOWING SWITCHES ARE AVAILABLE.

	POLES	THROWS	BREAKS	NUMBER OF POSITIONS	MOMENTARY POSITION	LOCKED POSITION	ACTUATOR	RATING
A	4	1	1	2	---	---	TOGGLE	115V 3A
B	2	2	2	3	2	OUT 1	ROCKER	400V 1A
C	4	1	1	2	3	OUT 1	ROCKER	230V 3A
D	2	2	2	3	2	IN 1	ROCKER	115V 6A
E	3	3	2	3	1	IN 2	TOGGLE	400V 3A
F	3	2	1	3	3	IN 1	ROCKER	230V 5A
G	3	2	1	3	3	IN 1	TOGGLE	230V 3A
H	3	2	1	3	1	IN 2	ROCKER	230V 10A

Figure 3-C.—Switch replacement problem.

IN ANSWERING QUESTIONS 3-36 THROUGH 3-45, REFER TO FIGURE 3-C.

3-36. What switch is the best substitute?

1. C
2. F
3. G
4. H

3-37. What switch is the second best substitute?

1. C
2. F
3. G
4. H

3-38. Which of the following switches is unacceptable because of the number of poles?

1. A
2. D
3. F
4. G

3-39. Which of the following switches is unacceptable because of the number of throws?

1. A
2. B
3. D
4. E

3-40. Which of the following switches is unacceptable because of the number of breaks?

1. A
2. C
3. E
4. G

3-41. Which of the following switches is unacceptable because of the number of positions?

1. C
2. D
3. E
4. F

3-42. Which of the following switches is unacceptable because of the momentary position?

1. C
2. F
3. G
4. H

3-43. Which of the following switches has the wrong locked position?

1. B
2. D
3. F
4. G

3-44. Which of the following switches has an unacceptable voltage rating?

1. B
2. D
3. E
4. F

3-45. Which of the following switches has an unacceptable current rating?

1. B
2. C
3. D
4. F

3-46. When you perform preventive maintenance on a switch, which of the following items should be checked?

1. The terminals for corrosion
2. The physical condition of the switch
3. The switch operation for smooth and correct operation
4. All of the above

3-47. A solenoid is based upon which of the following principles?

1. A bimetallic strip bends when it is heated
2. A thermocouple produces a current when heated
3. A coil attracts a soft iron core when current flows in the coil
4. A soft iron core moving in a magnetic field creates a current

3-48. A solenoid is commonly used in which of the following devices?

1. A fuel quantity indicating system
2. A shipboard lighting system
3. A sound-powered telephone system
4. A starter for a motor vehicle

3-49. If a solenoid is not operating properly, which of the following items need NOT be checked?

1. Coil
2. Armature
3. Plunger
4. Energizing voltage

---

IN ANSWERING QUESTIONS 3-50 THROUGH 3-54, MATCH THE DEVICE(S) LISTED IN COLUMN B TO THE STATEMENTS IN COLUMN A. THE DEVICES IN COLUMN B MAY BE USED MORE THAN ONCE.

	A. STATEMENTS	B. DEVICES
3-50.	An electromagnetic device	1. A switch only
3-51.	A device with a movable plunger	2. A solenoid only
3-52.	A device with a fixed core	3. A relay only
3-53.	A device classified as power or control	4. A relay and a solenoid
3-54.	A device containing an armature	

---

- 3-55. If a relay is hermetically sealed with an opaque cover, which of the following methods should be used to determine whether the relay is operating?
1. Shake the relay and listen for loose parts
  2. Place your finger on the cover and feel the relay contact movement
  3. Remove the cover and visually observe the relay contacts when the relay is activated
  4. Activate the relay and observe whether a metal object is attracted by the magnetic field
- 3-56. If a relay is NOT operating properly, which of the following items need NOT be checked?
1. The armature resistance
  2. The terminal leads
  3. The contact surfaces
  4. The contact spacing

- 3-57. What should be used to clean the contacts of a relay?
1. Sandpaper
  2. Emery cloth
  3. A jeweler's file
  4. A burnishing tool
- 3-58. What should be used to adjust contact clearances on a relay?
1. A point bender
  2. A burnishing tool
  3. A pair of pliers
  4. A pair of hemostats