Circuit Measurement

Course No: E04-007
Credit: 4 PDH

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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 voltameter.

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 @(UPPERCASE 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.
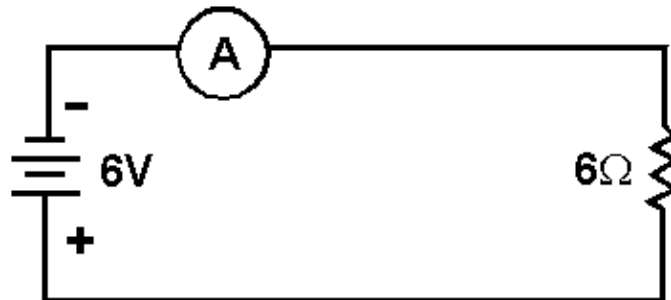

Figure 1-1.—A simple representative circuit.

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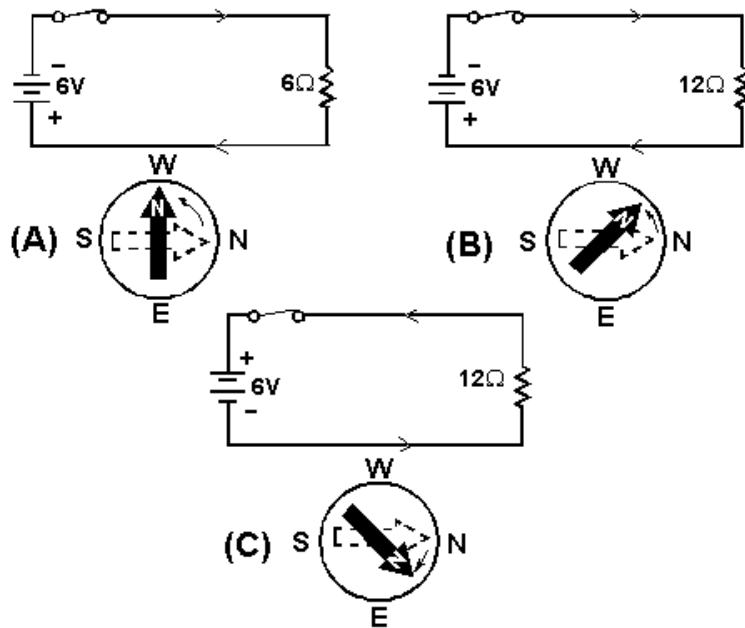
Figure 1-2.—Compass and conductor with direct current.

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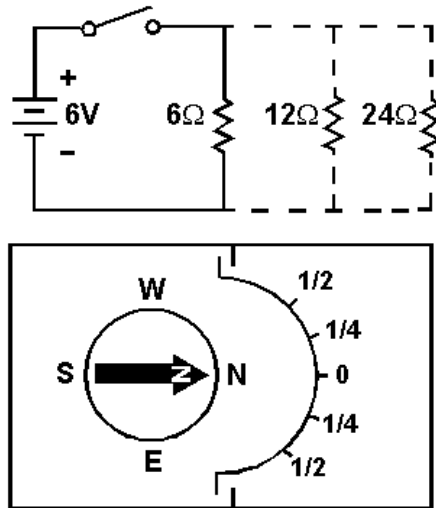
Figure 1-3.—A simple meter from a compass.

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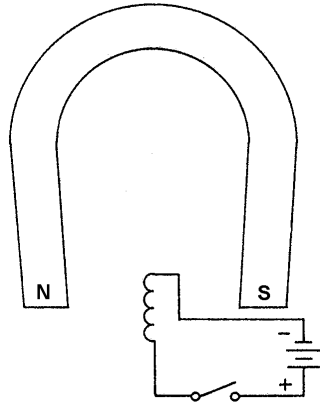
Figure 1-4.—A movable coil in a magnetic field (no current).
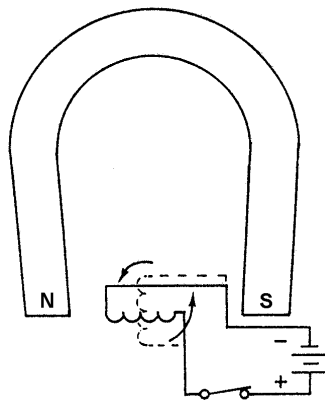

Figure 1-5.—A movable coil in a magnetic field (current).

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.
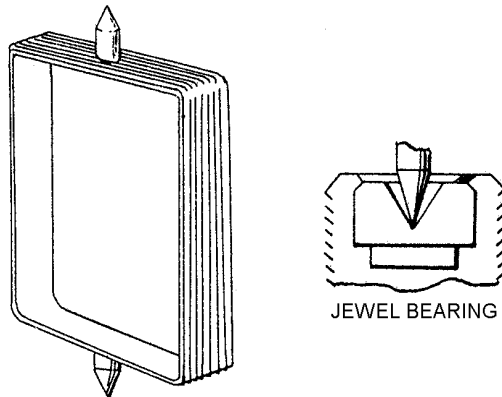

JEWEL BEARING

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.
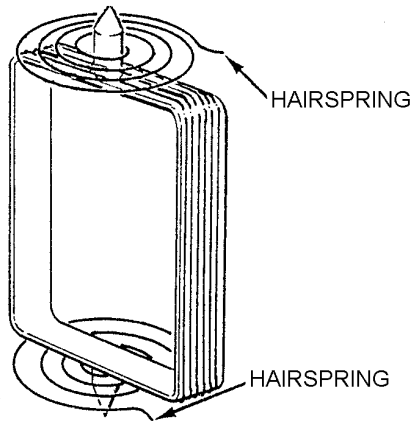

Figure 1-7.—Coil and hairsprings.

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.
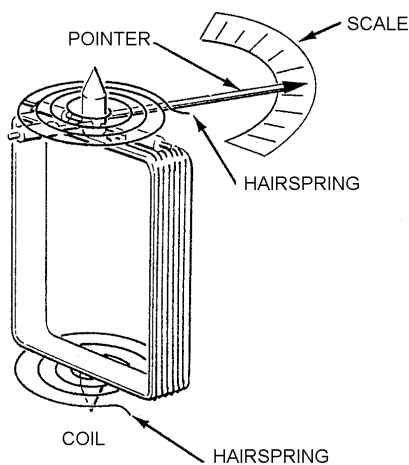

Figure 1-8.—A complete coil.

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.

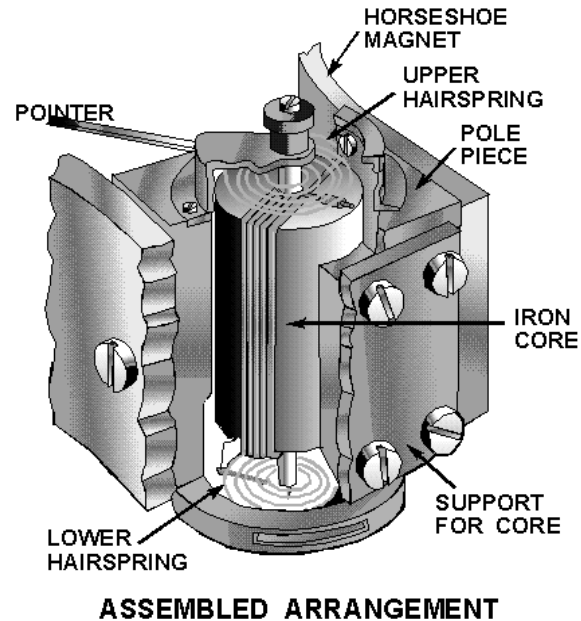The meter movement as it appears when fully assembled is shown in figure 1-9.

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.
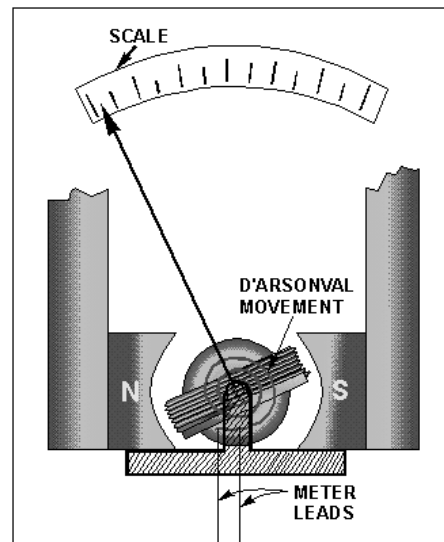

Figure 1-10.—A meter using d'Arsonval movement.

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.
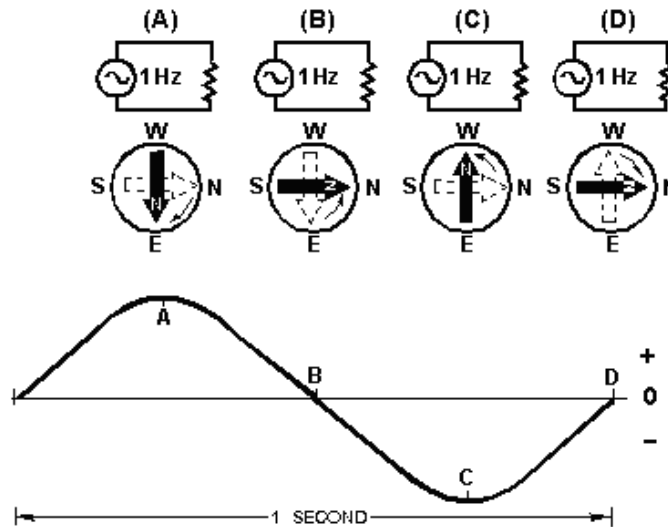

Figure 1-11.—Compass and conductor with ac.

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.
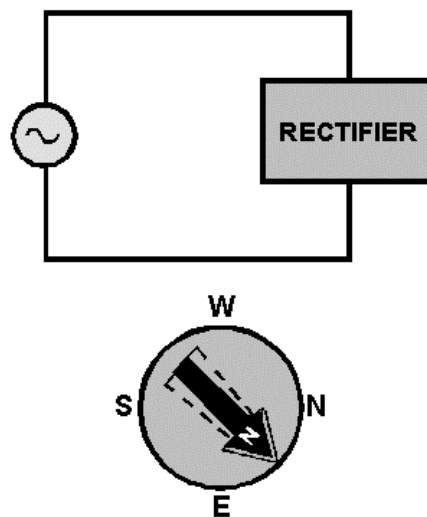

Figure 1-13.—Compass and conductor; rectified ac.

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).
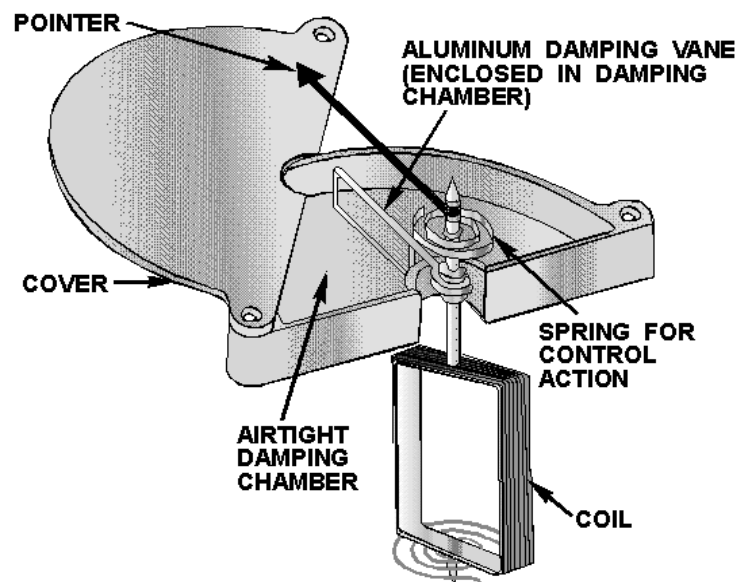

Figure 1-14.—A typical meter damping system.

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.
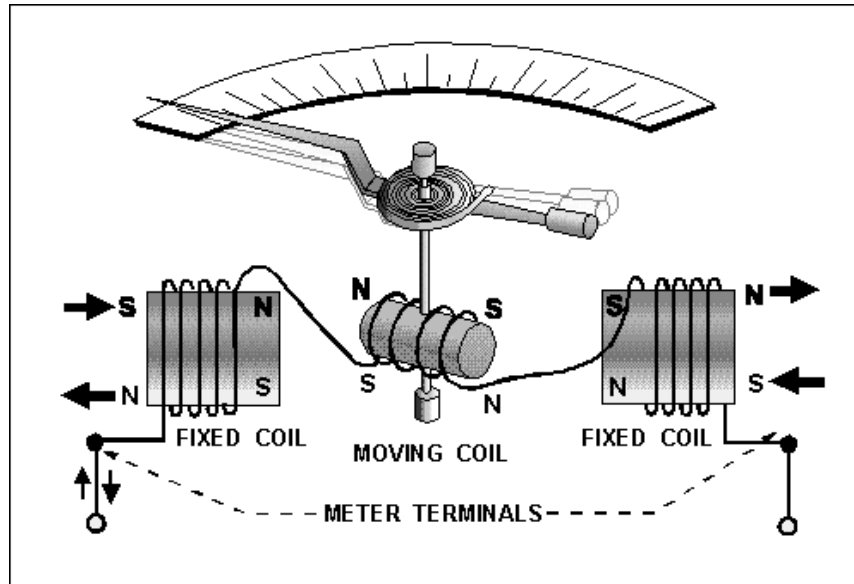
Figure 1-15.—Electrodynamic meter movement.

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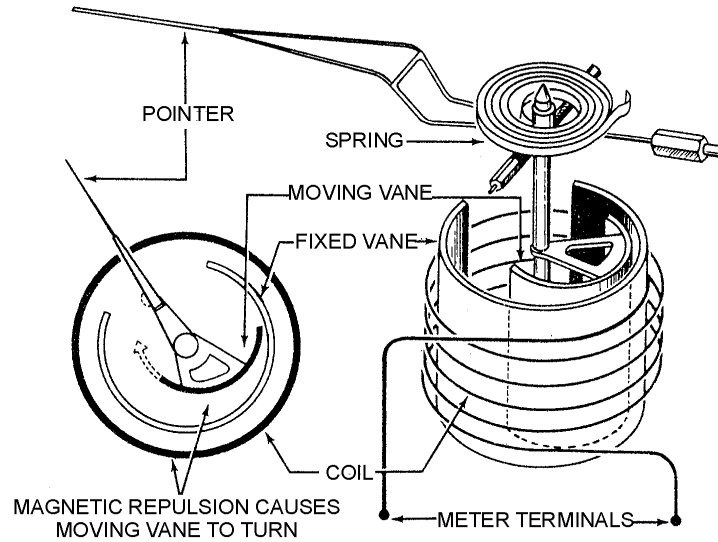
Figure 1-16.—Moving-vane meter movement.

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.
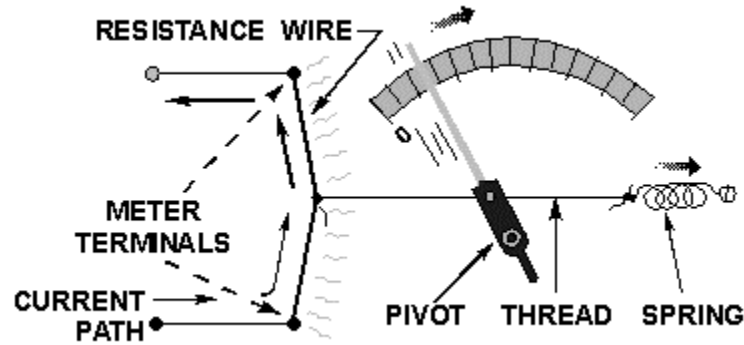
Figure 1-17.—Hot-wire meter movement.

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.
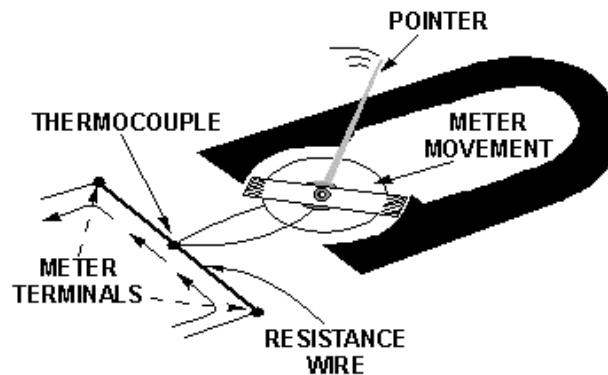

Figure 1-18.—A thermocouple meter.

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 $R_2 + R_2$ 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

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

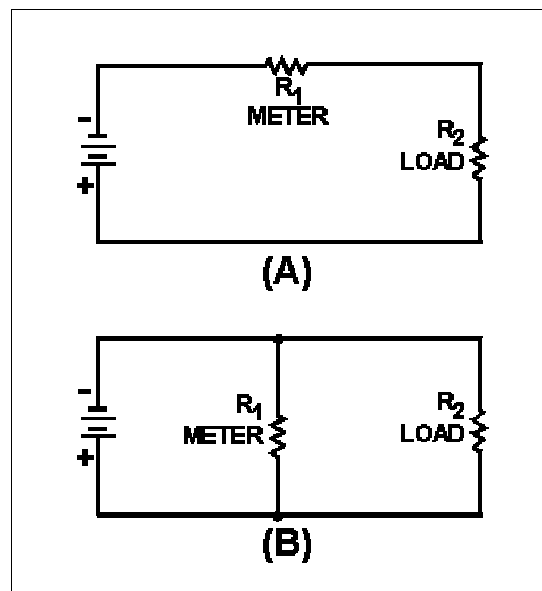and total circuit current does not flow through either resistor.

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.
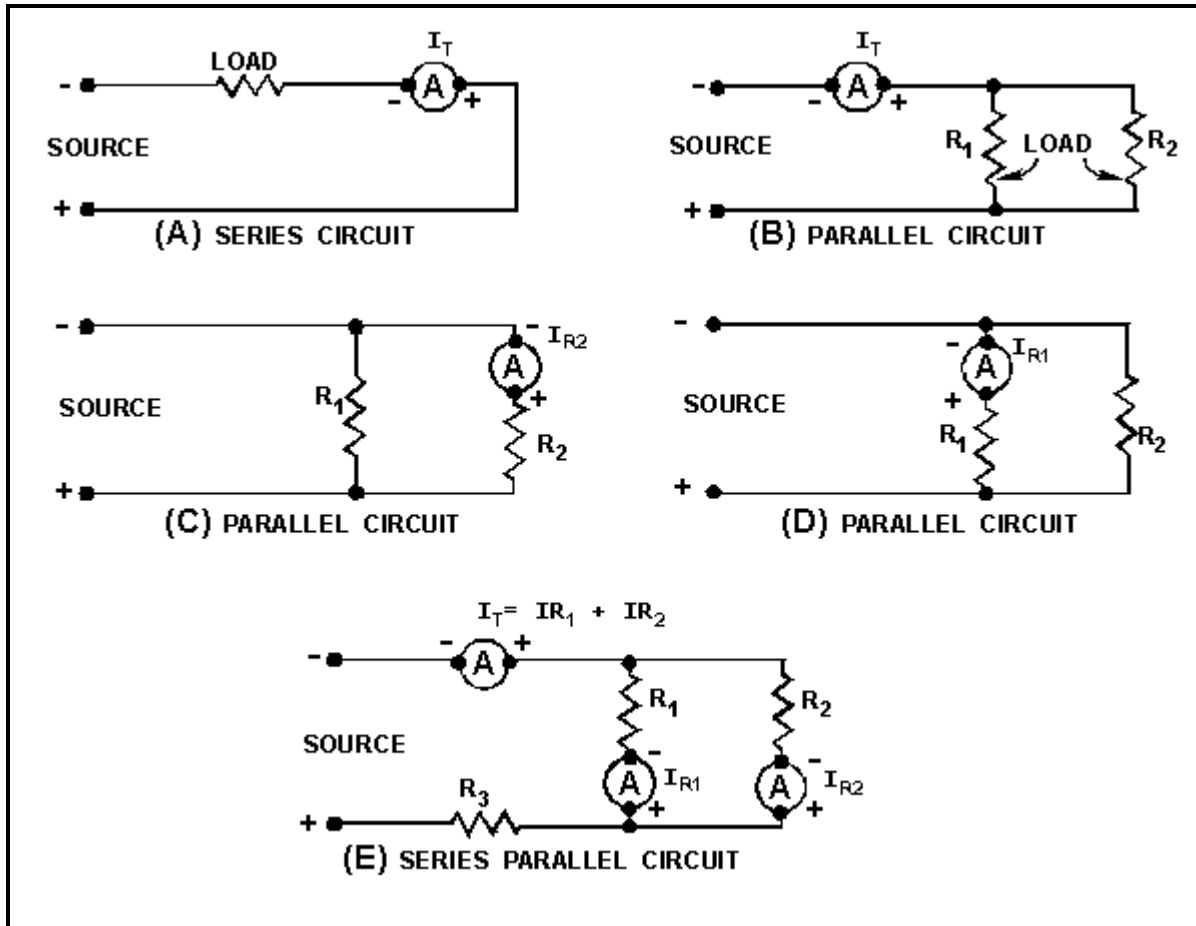
Figure 1-20.—Proper ammeter connections.

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

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

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

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-

$$I_{R1} = \frac{10V}{10\Omega} = 1A$$
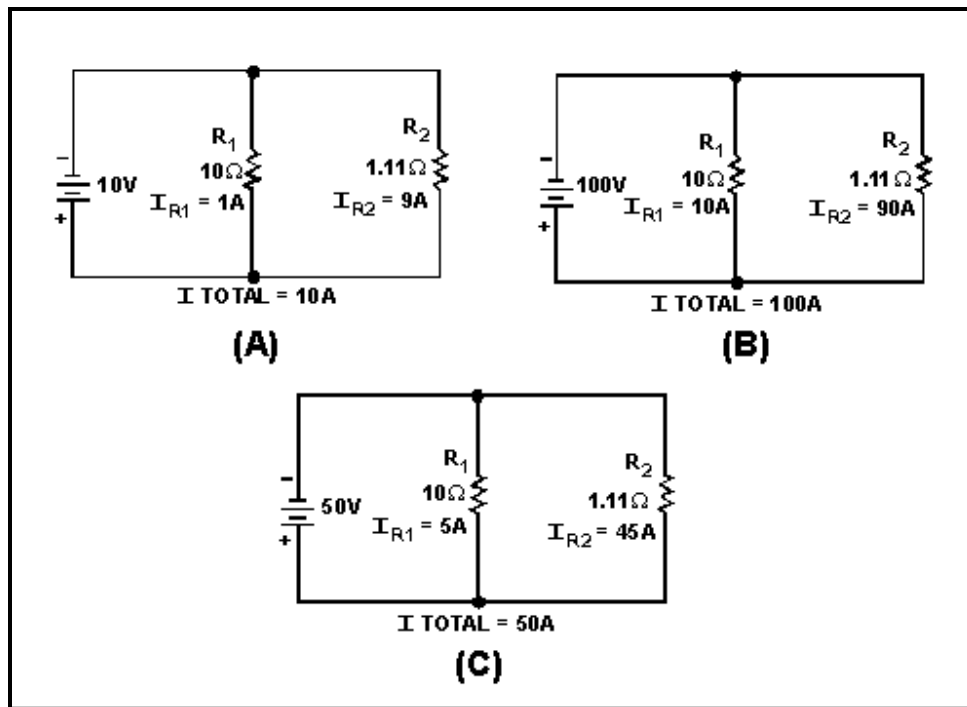
$$I_{R2} = \frac{10V}{1.11\Omega} = 9A$$

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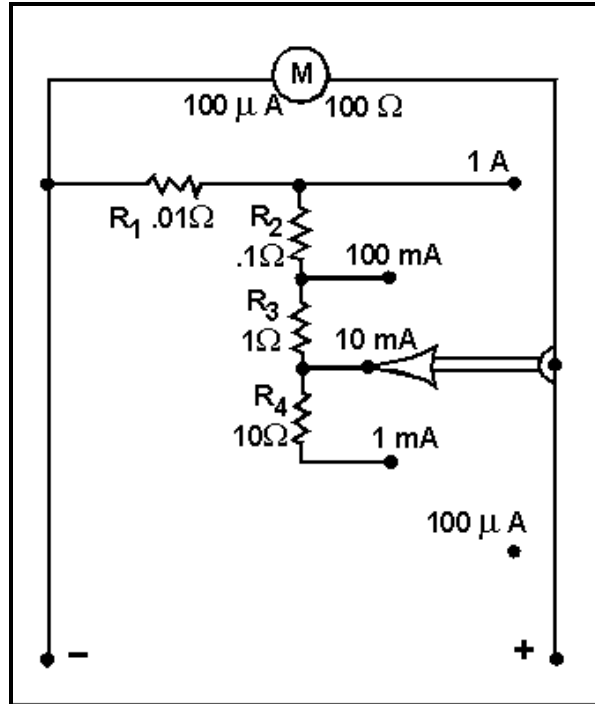
Figure 1-22.—An ammeter with internal shunt resistors.

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 shunts (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.
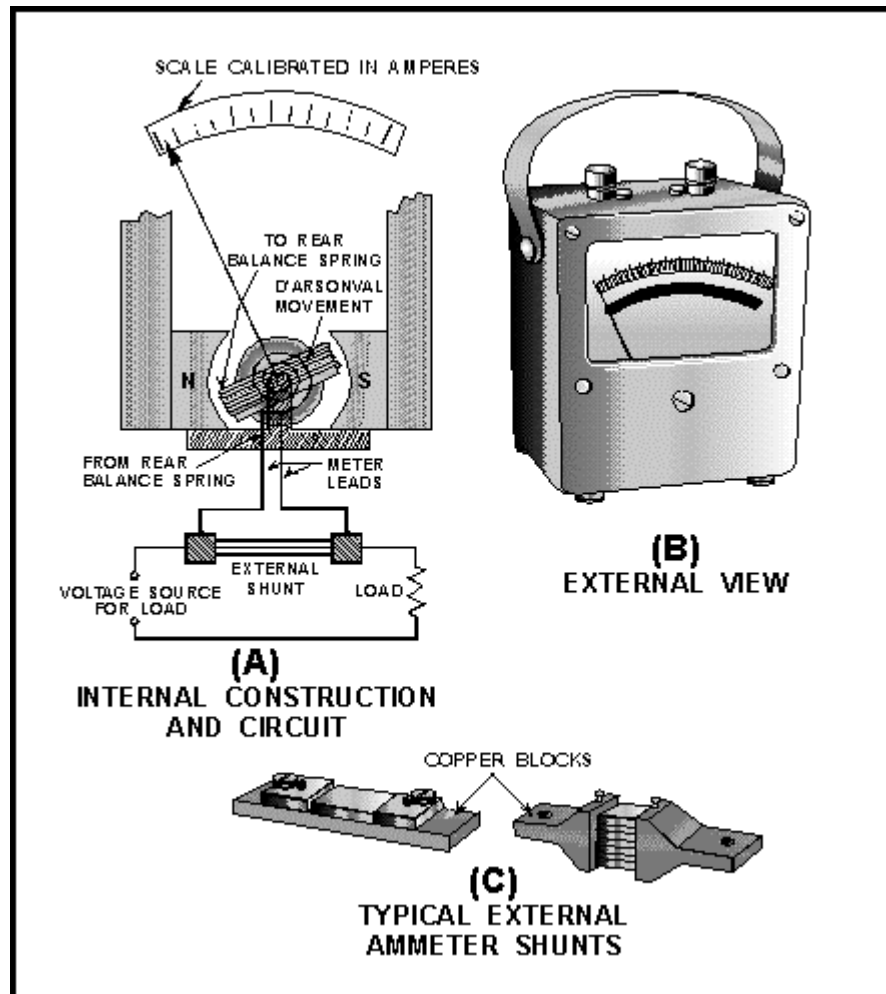

Figure 1-23.—An ammeter employing the d'Arsonval principle and external shunts.

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 <u>middle of the scale</u>. Figure 1-24 illustrates these points.
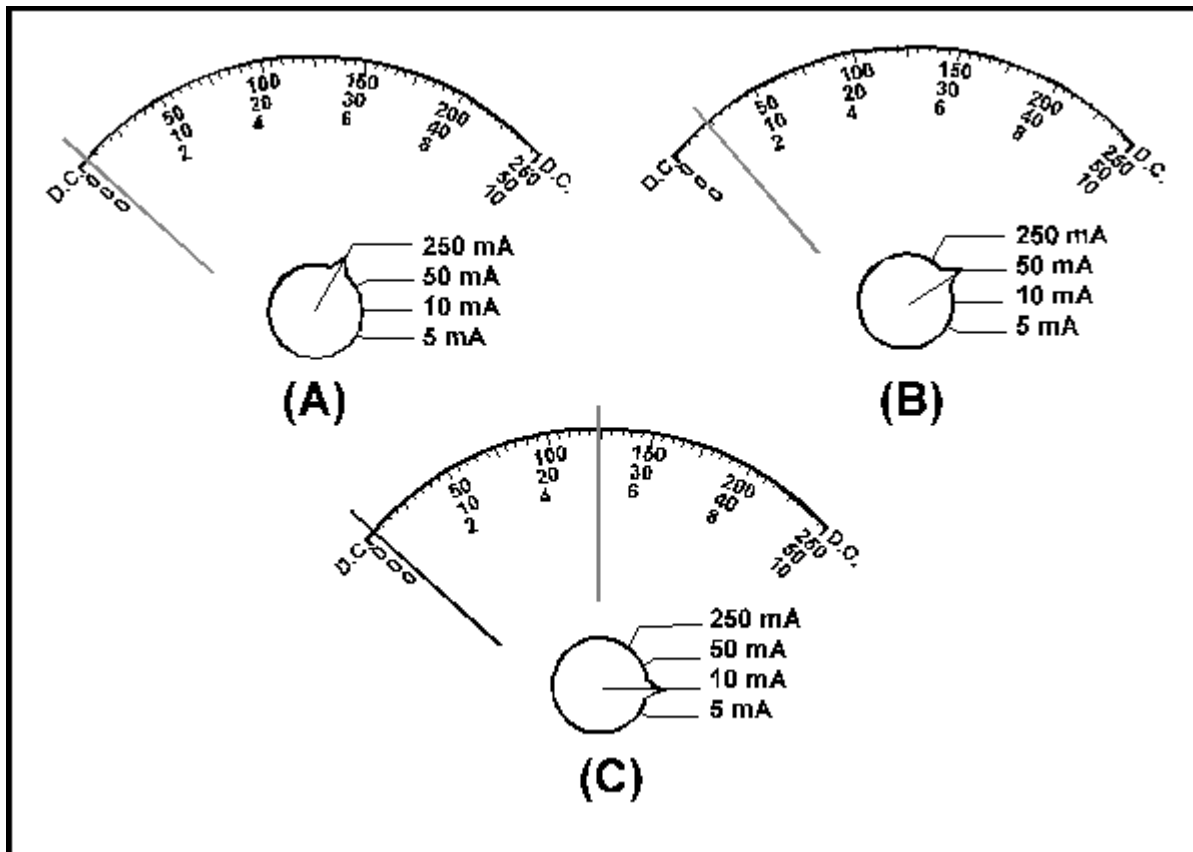

Figure 1-24.—Reading an ammeter at various ranges.

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 <u>are always connected in parallel</u>. 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.
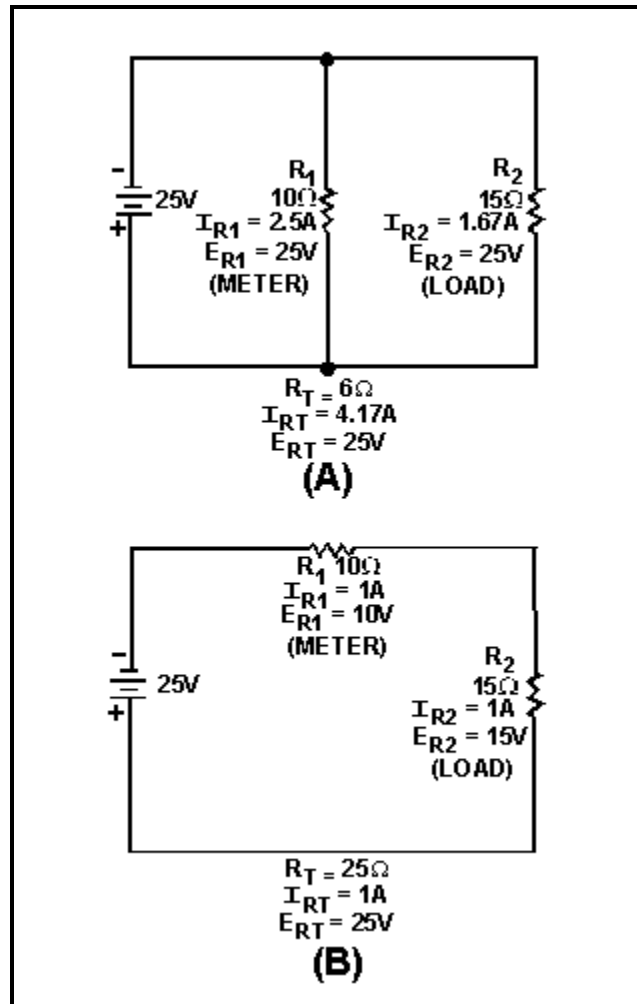
Figure 1-25.—Current and voltage in series and parallel circuits.

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.
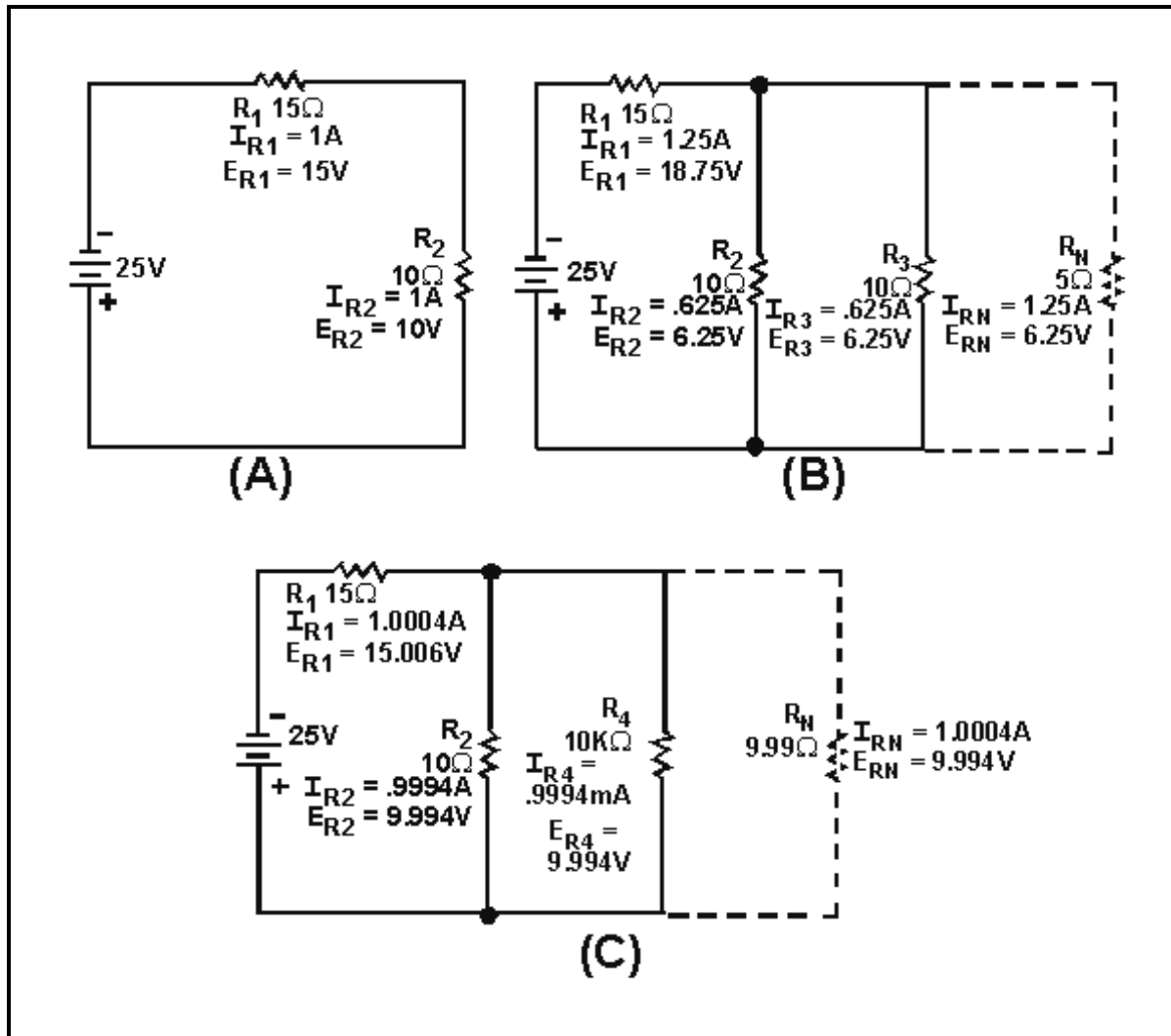
Figure 1-26.—The loading effect.

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, <u>a voltmeter should have a high resistance compared to the circuit being measured, to minimize the loading effect</u>.

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.
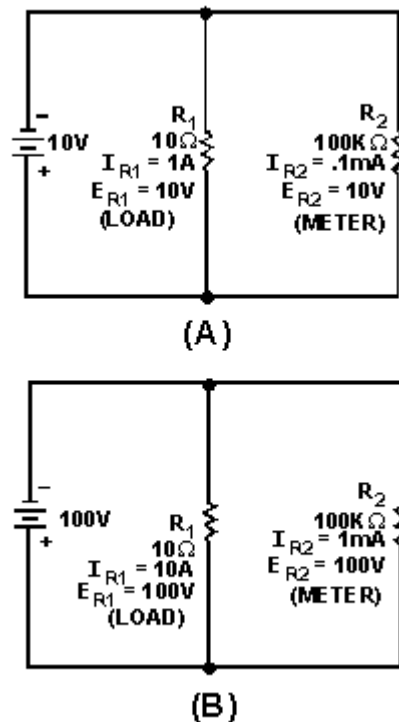

Figure 1-27.—Current and voltage in parallel circuit.

SENSITIVITY OF VOLTMETERS

Voltmeter sensitivity is expressed in ohms per volt (Ω/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 × resistance).

For example, if a meter has a full-scale current of 50μA and a resistance of 960Ω, the sensitivity could be calculated as:

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

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

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

The full-scale voltage reading would be calculated as:

Full-scale voltage reading = full-scale current × resistance

Full-scale voltage reading = 50μA × 960Ω

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 Ω	1 k Ω/VOLT	.1 V
50 μA	960 Ω	20 k Ω/VOLT	.048 V
5 μA	5750 Ω	200 k Ω/VOLT	.029 V

Notice that the meter movements shown in table 1-1 will indicate .029 volts to .I 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.

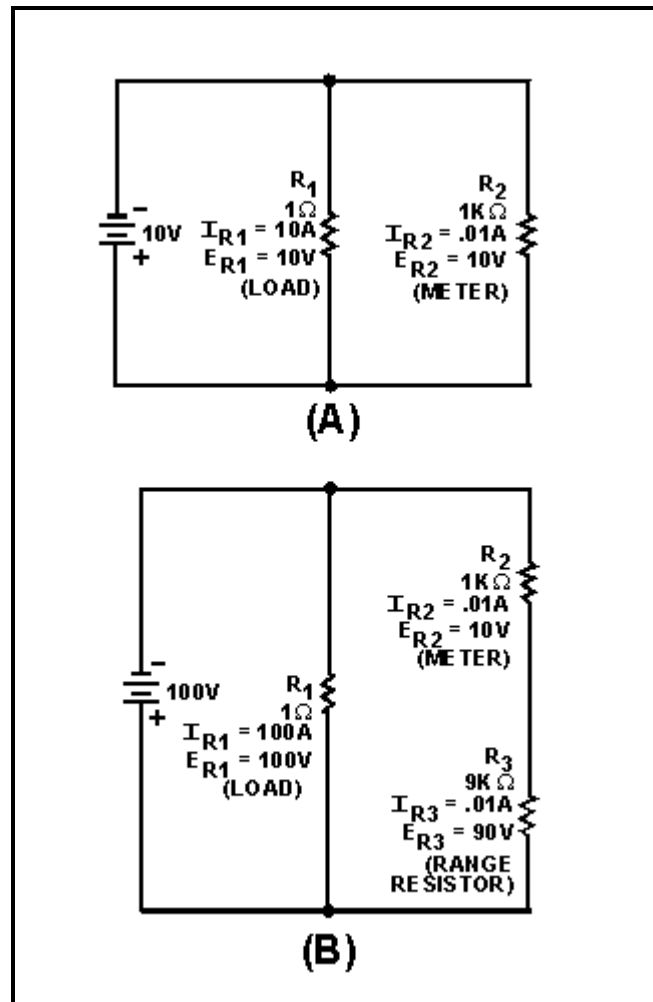Figure 1-28 illustrates the method of increasing the voltage range of a voltmeter.

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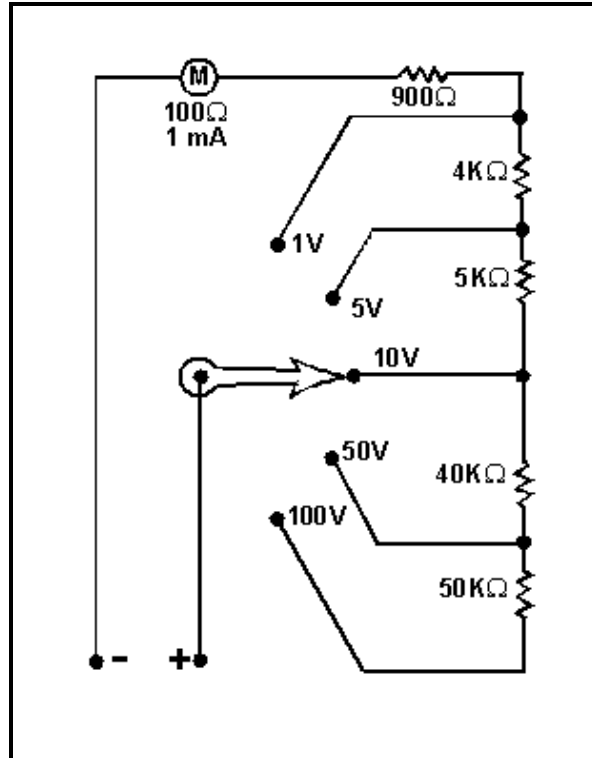
Figure 1-29.—A voltmeter with internal range resistors.

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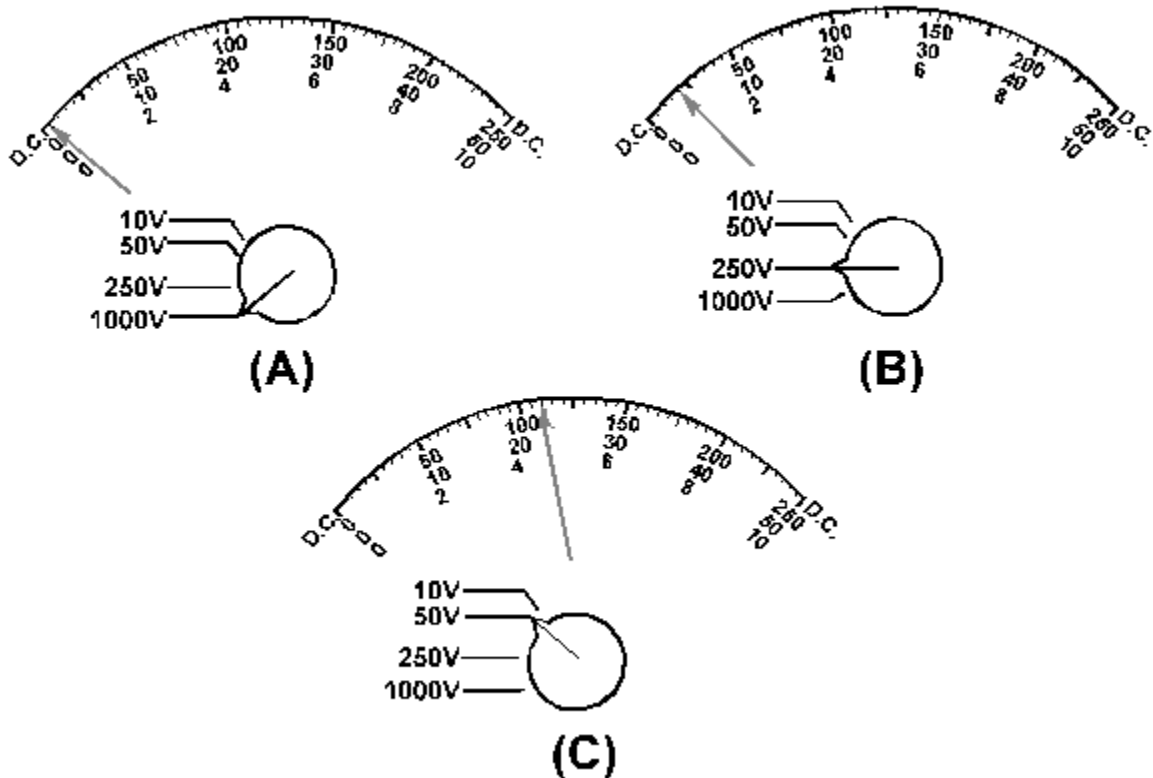
Figure 1-30.—Reading a voltmeter at various ranges.

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 <u>current</u>, the electrostatic meter movement reacts to <u>voltage</u>.

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 <u>series-type</u> ohmmeter is on the <u>right-hand</u> 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 (∞) of the scale.
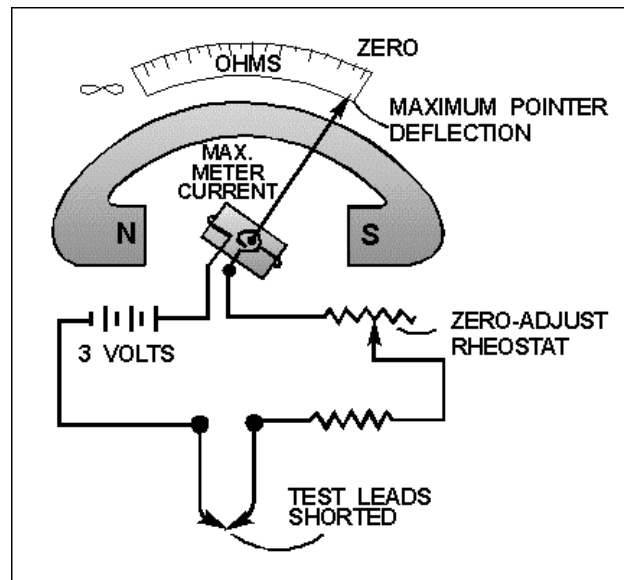

Figure 1-31.—A simple ohmmeter circuit.

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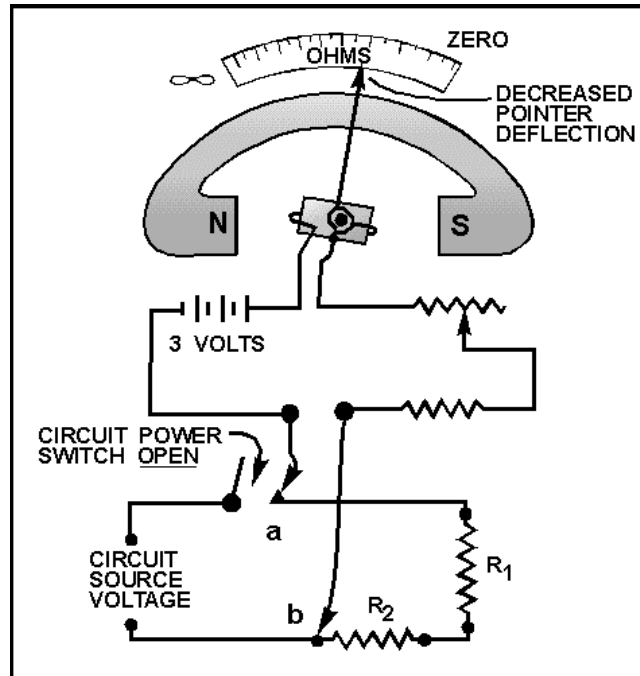
Figure 1-32.—Measuring circuit resistance with an ohmmeter.

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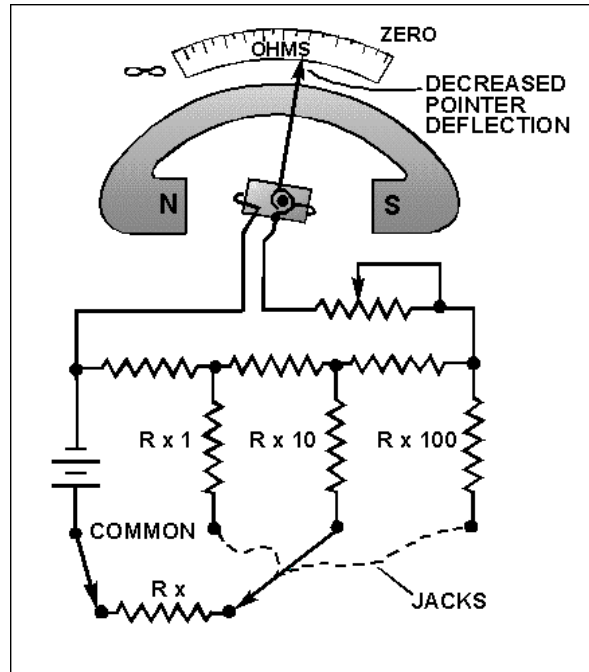
Figure 1-33.—An ohmmeter with multiplication jacks.

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 x 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 (∞). (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 fact 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.
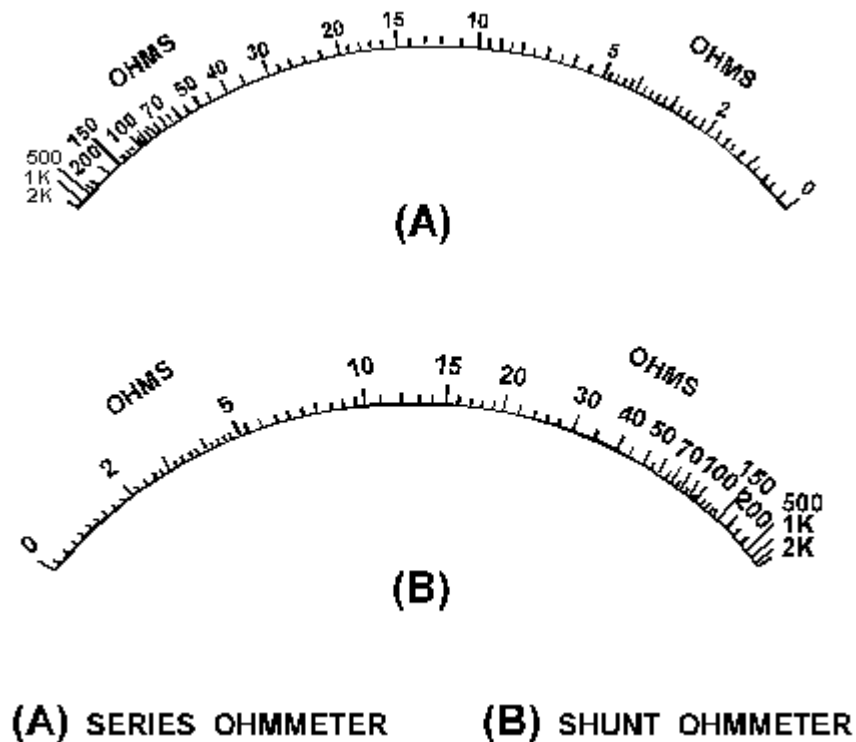
Figure 1-34.—Series and shunt ohmmeter scales.

Figure 1-34(A) is the scale of a series ohmmeter. Notice "0" is on the right and "∞" is on the left. Figure 1-34(B) is the scale of a shunt ohmmeter. In the shunt ohmmeter "∞" 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 ∞ reading of the meter (full-scale deflection). R_2, R_3, and R_4 are used to provide the R × 1, R × 10, and R × 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

∞. 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 × 1, R × 10, and R × 100. This is provided to stop current flow and prevents the battery from being discharged while the meter is not being used.
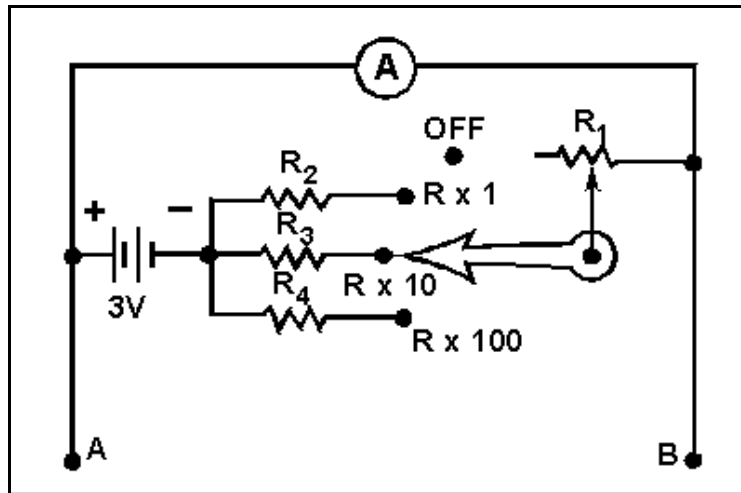
Figure 1-35.—A shunt ohmmeter with internal range resistors.

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 ∞ 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 ∞ 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.
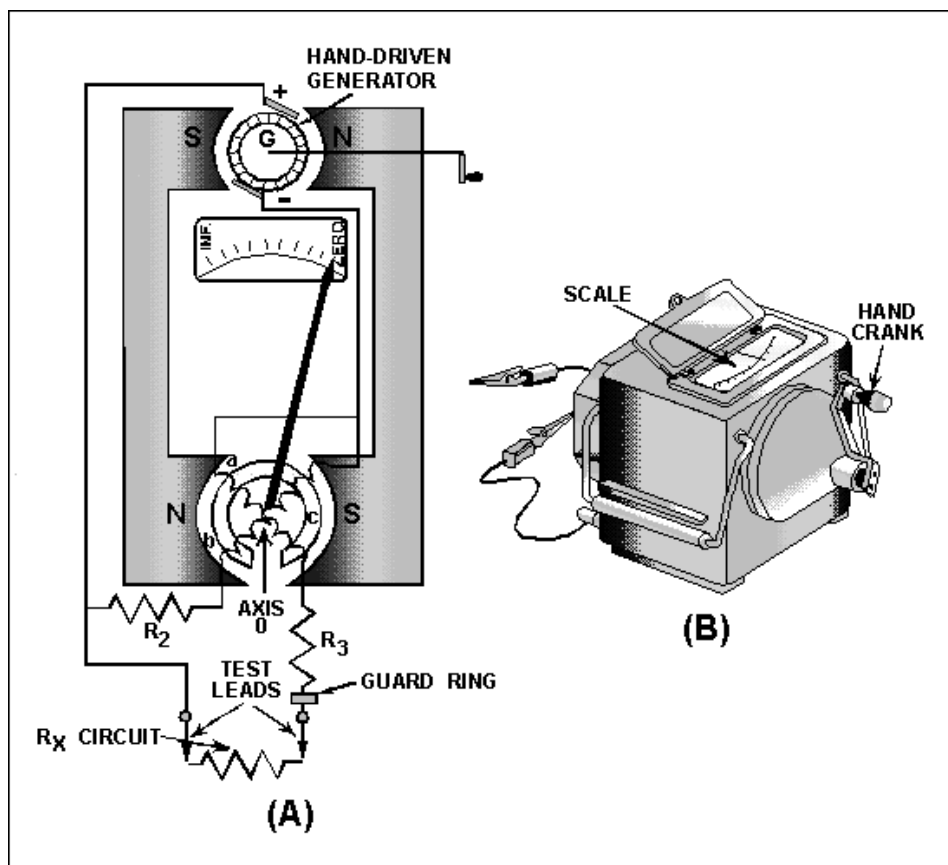

Figure 1-36.—A megger internal circuit.

Coil a is connected in series with R_3 and the unknown resistance, R_x, to be measured. The combination of coil, R_3, and R_x forms a direct series path between the positive (+) and negative (−) brushes of the dc generator. Coil b is connected in series with R_2 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.
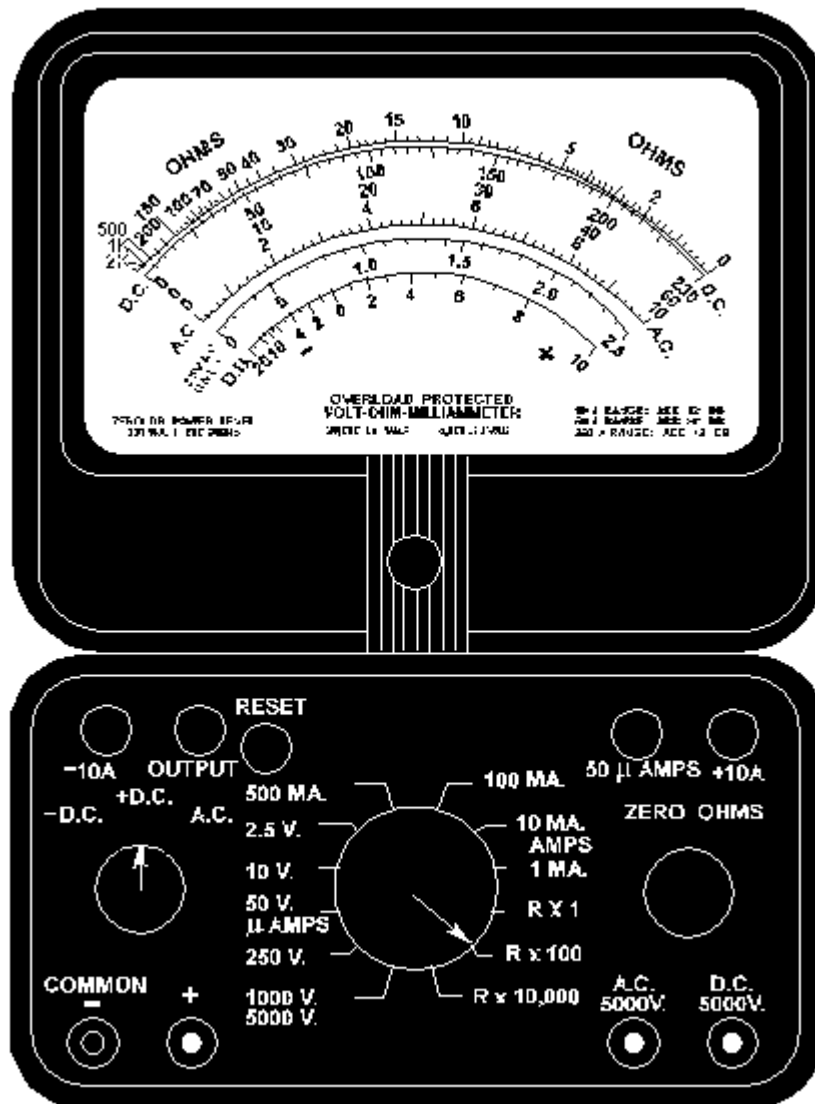
Figure 1-37.—A typical multimeter.

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 x 1 function, the meter reading would be approximately 12.7 ohms.
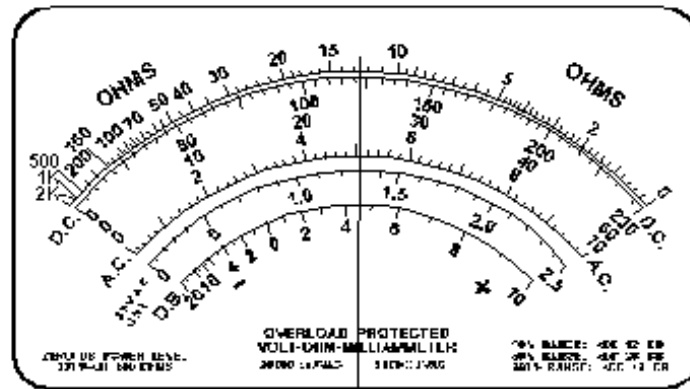
FUNCTION SWITCH	-D.C./+D.C. A.C.	INDICATION
5000 V	+ d.c.	+ 2420.00Vd.c.
1000 V	- d.c.	- 482.00Vd.c.
250 V	+ d.c.	+ 121.00Vd.c.
50 V	a.c.	24.90Va.c.
10 V	a.c.	4.99Va.c.
2.5 V	a.c.	1.28Va.c.
10 A	+ d.c.	4.82Ad.c.
500 mA	a.c.	249.00mAa.c.
100 mA	a.c.	49.90mAa.c.
10mA	+ d.c.	4.82mAd.c.
50μA	+ d.c.	24.20μAd.c.
R x 100	+ d.c.	1.27kΩ

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 Ω	1 k Ω/VOLT	.1 V	NA	100 Ω
50 цA	960 Ω	20 k Ω/VOLT	.048 V	50.5 Ω	48 Ω
5 цA	5750 Ω	200 k Ω/VOLT	.029 V	29.146Ω	28.999 Ω

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 milliampere. 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.
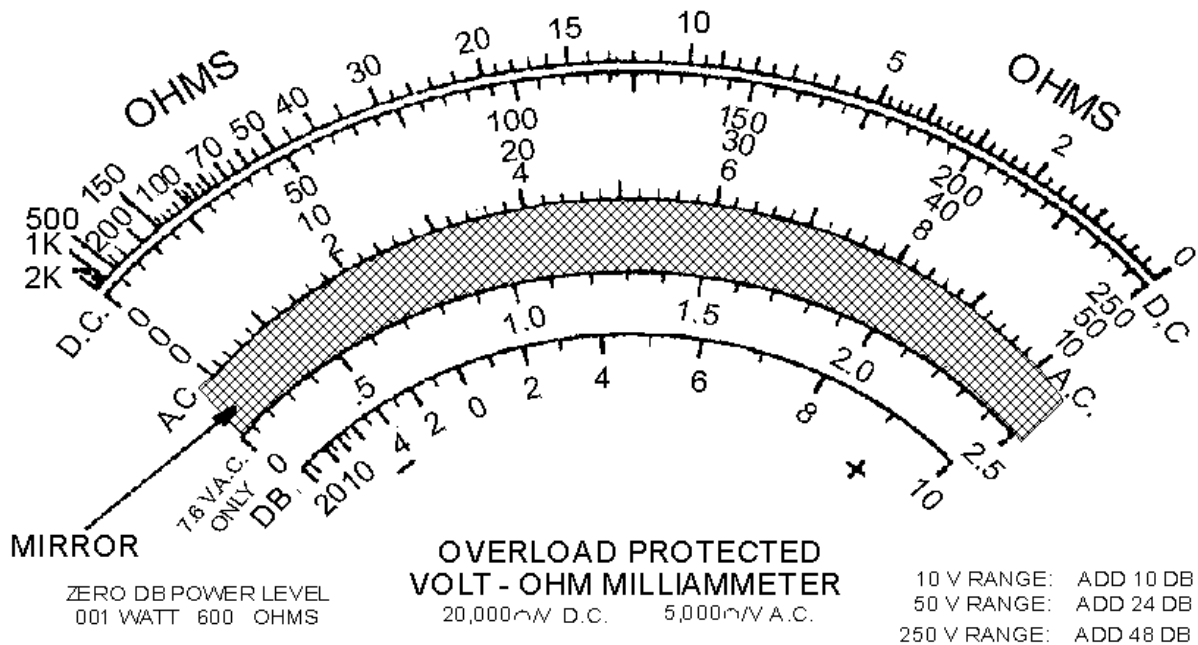
Figure 1-39.—A multimeter scale with mirror.

The purpose of the mirror on the scale of a meter is to aid in reducing **PARALLAX ERROR**. Figure 1-40 will help you understand the idea of parallax.

Figure 1-40(A) shows a section of barbed wire fence as you would see it from one side of the fence. Figure 1-40(B) shows the fence as it would appear if you were to look down the fine of fence posts and were directly in line with the posts. You see only one post because the other posts, being in line, are hidden behind the post you can see. Figure 1-40(C) shows the way the fence would appear if you moved to the right of the line of posts. Now the fence posts appear to the right of the post closest to you. Figure 1-40(D) shows the line of fence posts as you would see them if you moved to the left of the front post. This apparent change in position of the fence posts is called **PARALLAX**.
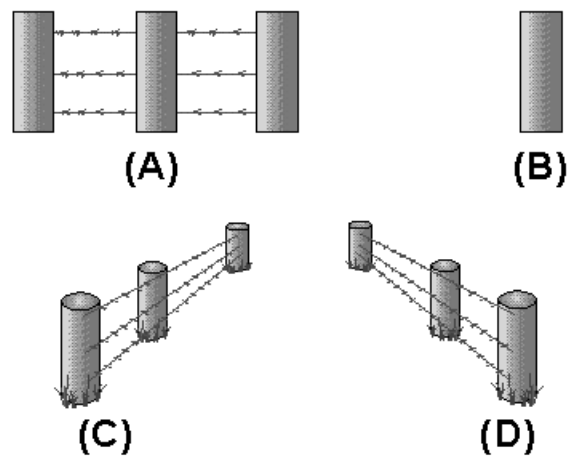
Figure 1-40.—Parallax illustration (barbed-wire fence).

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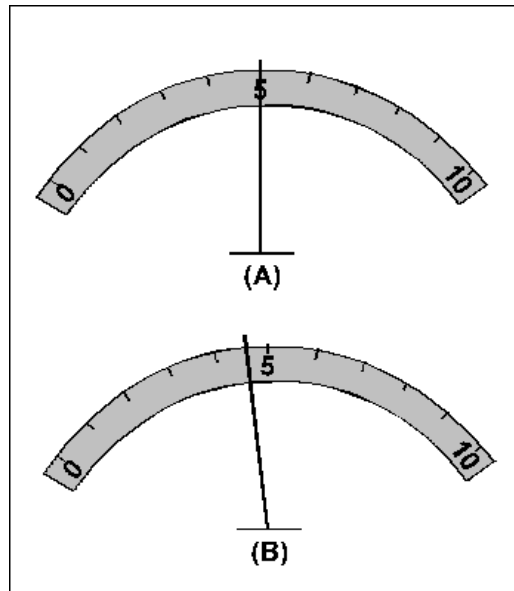
Figure 1-41.—A parallax error in a meter reading.

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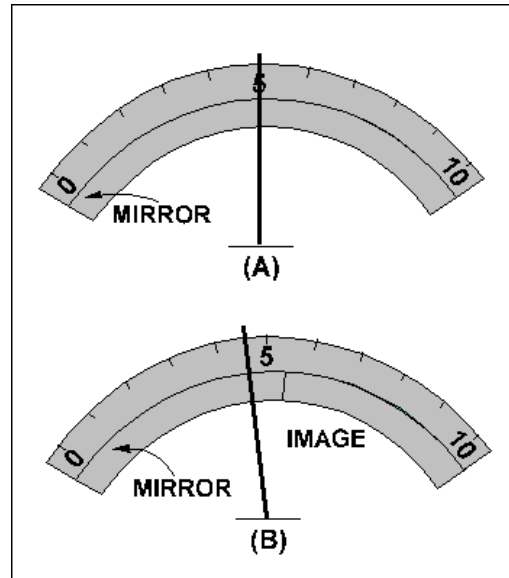
Figure 1-42.—A parallax error on a meter with a mirrored scale.

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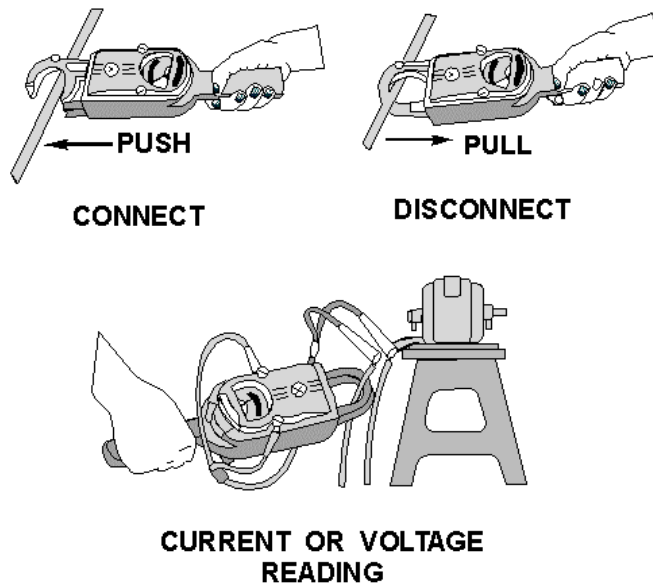
Figure 1-43.—A hook-on type voltammeter.

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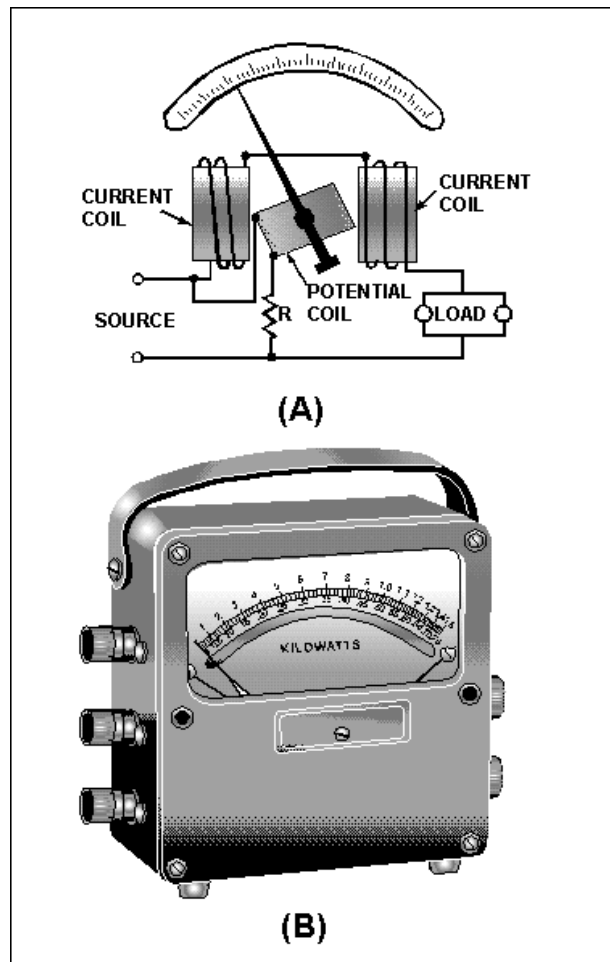
Figure 1-44.—A simplified electrodynamic wattmeter circuit.

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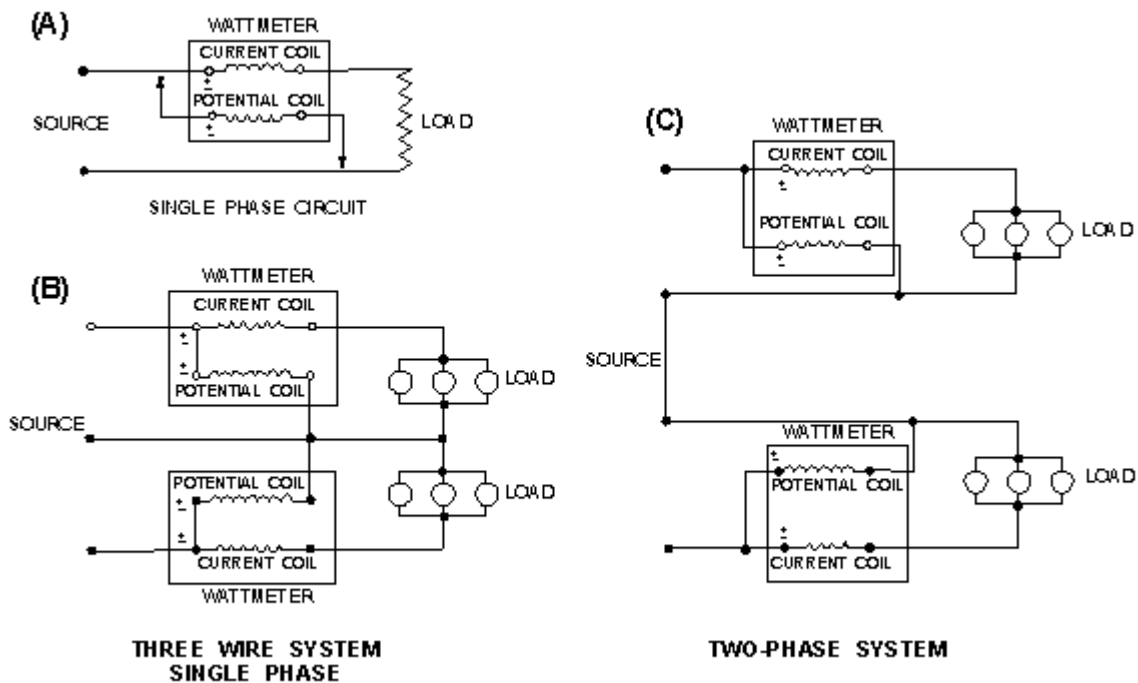
Figure 1-45.—A wattmeter connected in various circuits. TWO-PHASE SYSTEM

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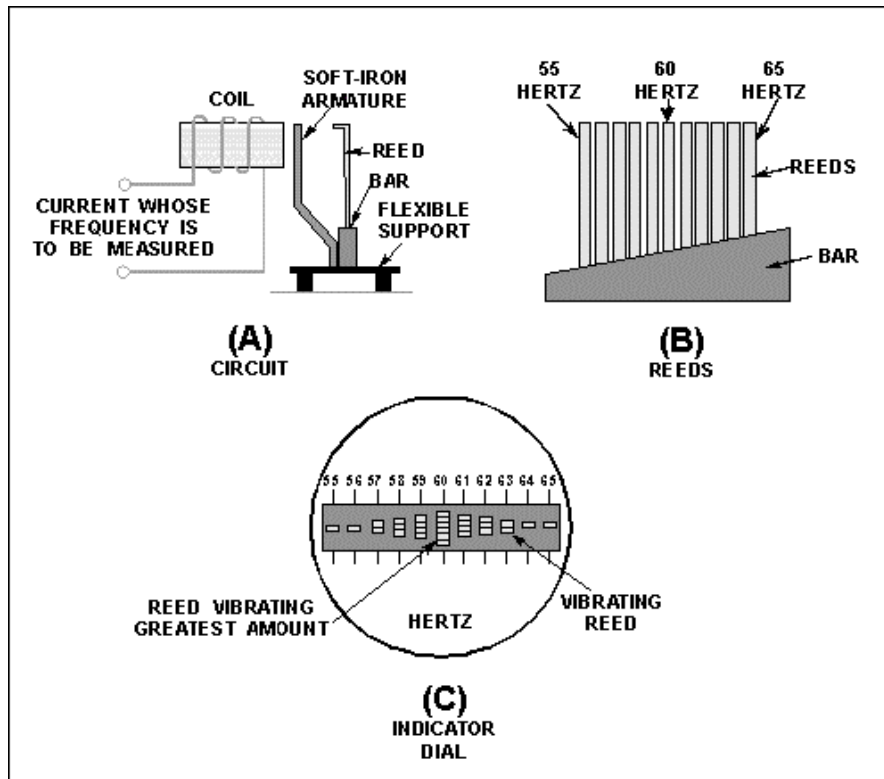
Figure 1-47.—Simplified disc of a vibrating-reed frequency meter. INDICATOR DIAL

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.
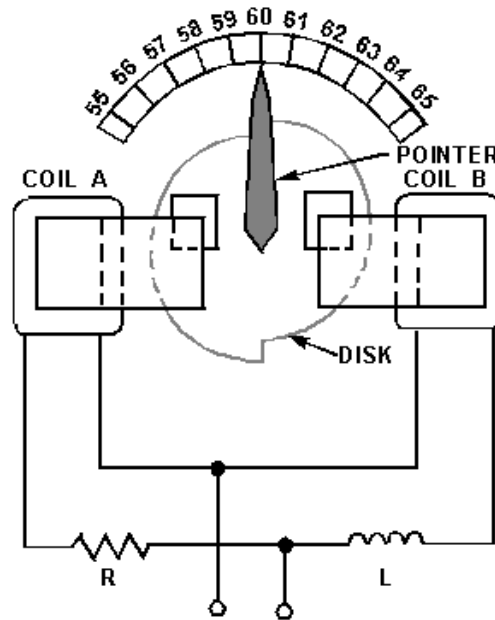

Figure 1-48.—Simplified diagram of a moving-disk frequency meter.

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 figure1-49?
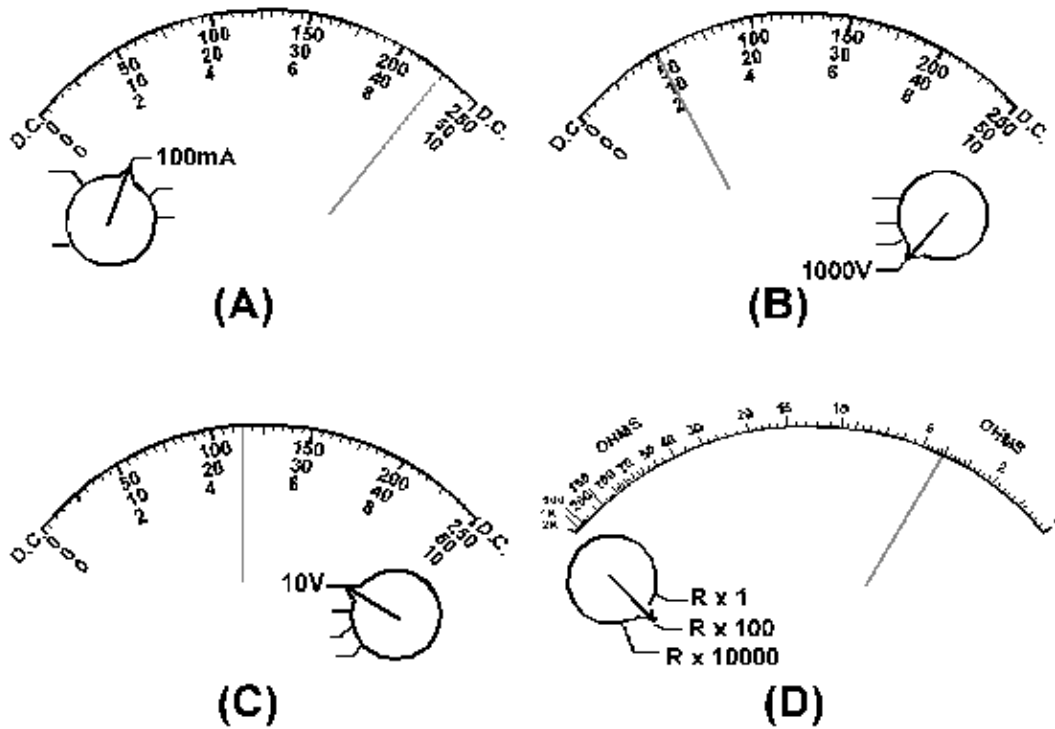
Figure 1-49.—Meter recognition.

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

Q67.   Which part of figure1-50 shows the switch positions the multimeter should be left in when the meter is secured?
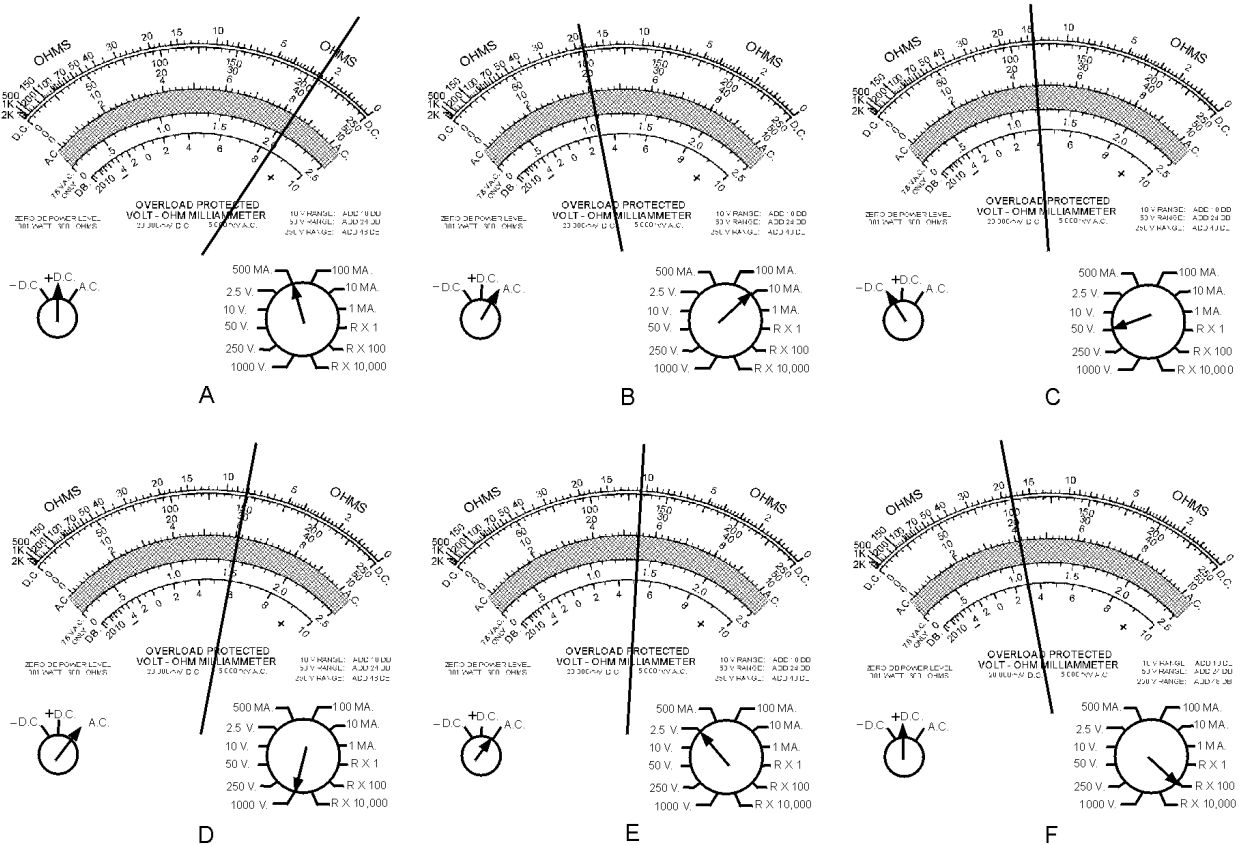
Figure 1-50.—Multimeter reading practice.

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 figure1-51 (A), would the reading indicate a good insulation?*
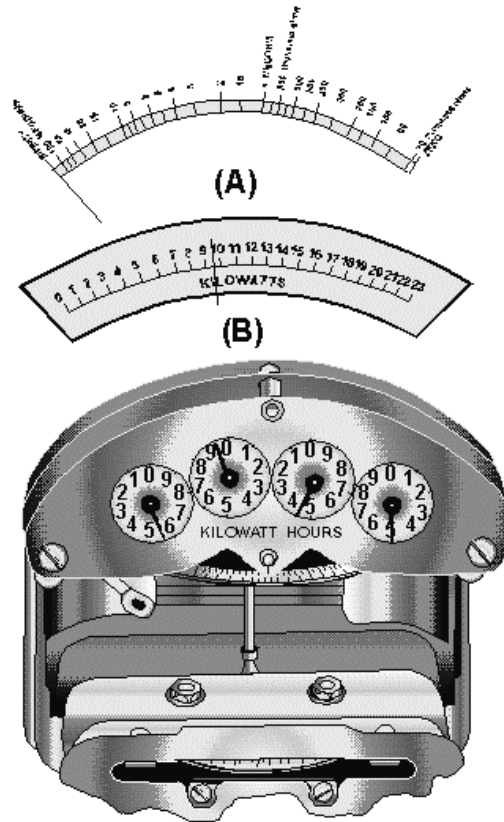
Figure 1-51.—Meter reading practice.

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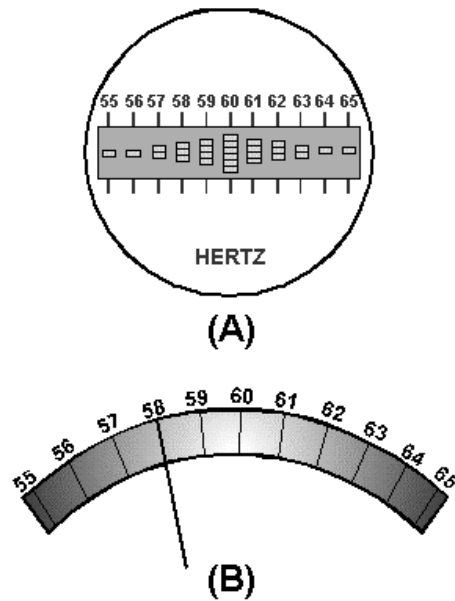

Figure 1-52.—Frequency meter reading.

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.
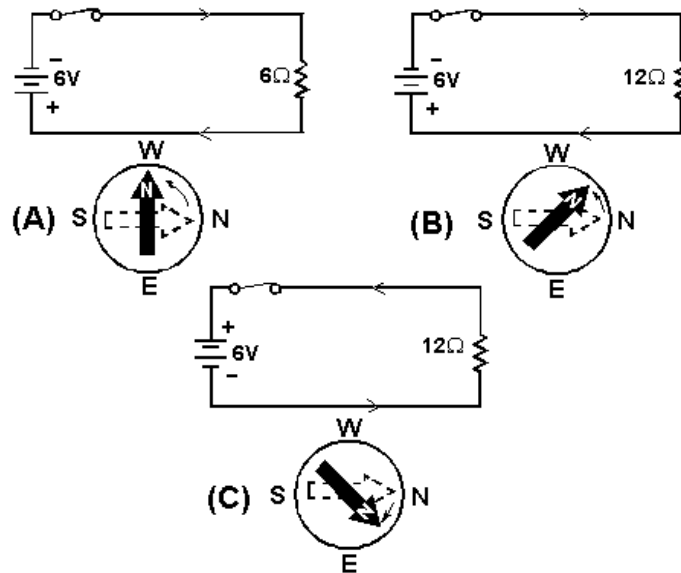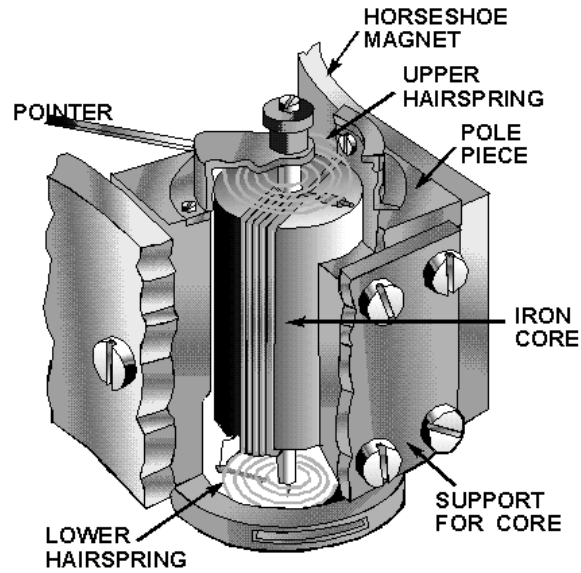
ASSEMBLED ARRANGEMENT

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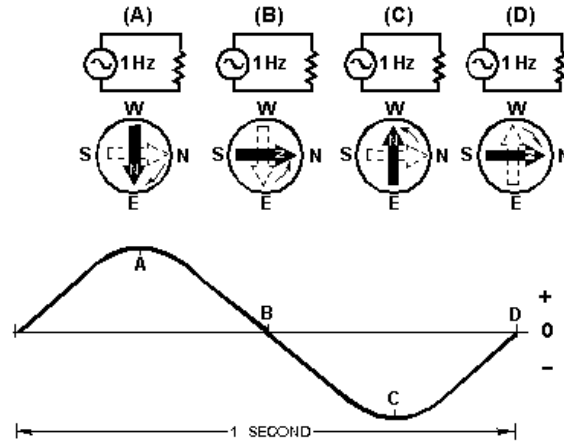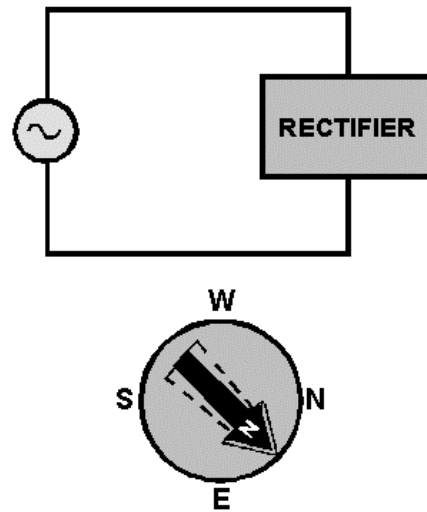
DAMPING is used to smooth out the vibration and to help prevent overshooting of the meter pointer. Damping in a d'Arsonval meter movement is accomplished by the emf caused by the coil movement. A second damping system uses a vane attached to the coil in an airtight chamber. A meter movement reacts to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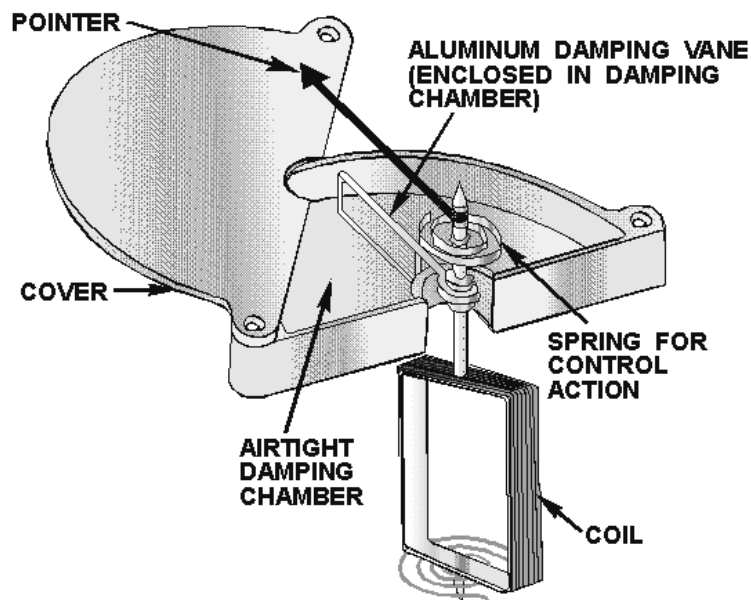

There are meter movements that will measure either ac or dc without the use of a rectifier. They are the **ELECTRODYNAMIC**, **MOVING-VANE**, and **HOT-WIRE** or **THERMOCOUPLE** movements.

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.
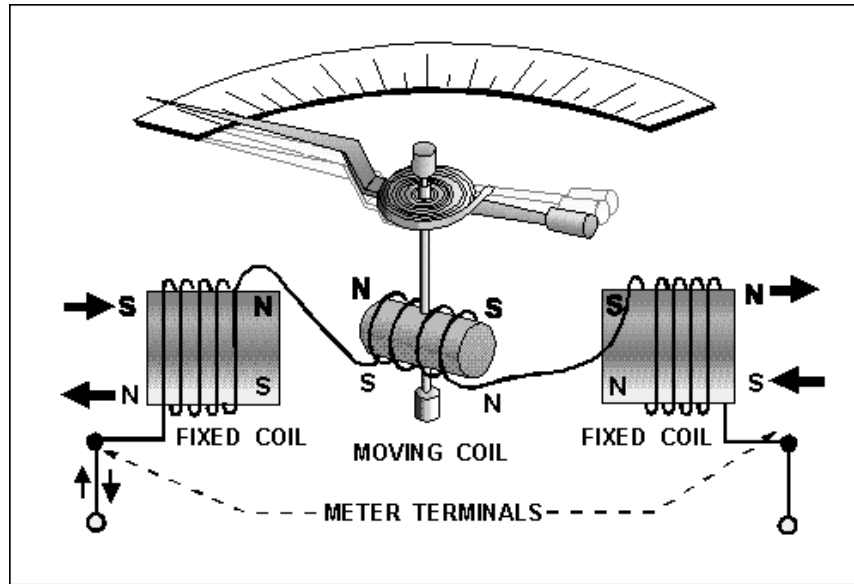
The moving-vane meter movement operates on the principle of magnetic repulsion of like poles. This movement will measure either current or voltage.
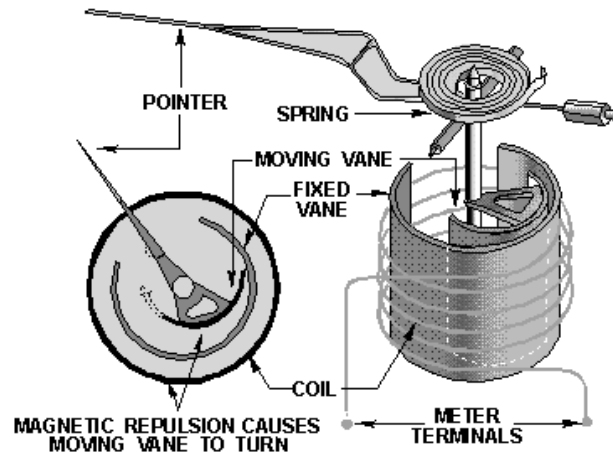
The hot-wire movement is only used to measure current. It is based on the expansion of a wire heated by current through the wire.
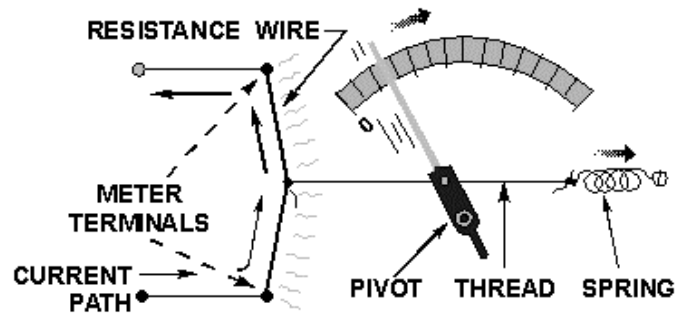
The thermocouple movement uses the current being developed in a thermocouple when the heat of a resistive wire is transferred to the thermocouple. The developed current is measured by a very sensitive dc ammeter. This movement will measure only current.
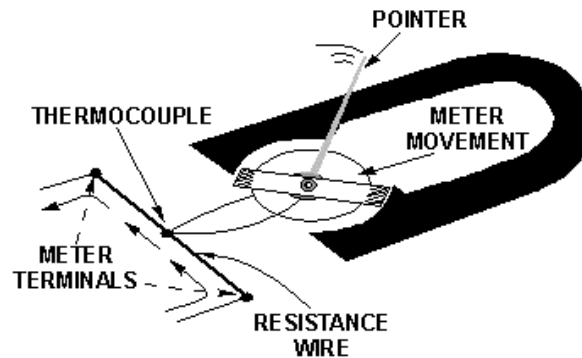
An **AMMETER** measures current. It is always connected in series with the circuit being measured. An ammeter should have a small resistance so the effect of the ammeter on the circuit will be kept to a minimum. Ammeter sensitivity is the amount of current that causes 0 full scale deflection of the ammeter. 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.
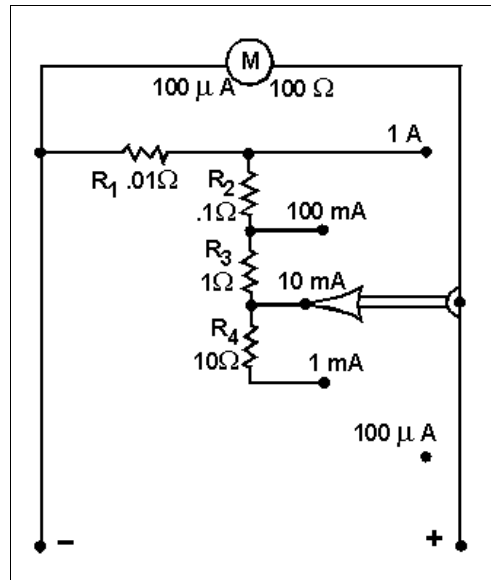
VOLTMETERS are used to measure voltage. They are always connected in parallel with the circuit being measured. A voltmeter should have a high resistance compared to the circuit being measured to minimize the loading effect. Since the resistance of a meter movement is constant, a voltmeter can be made 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.
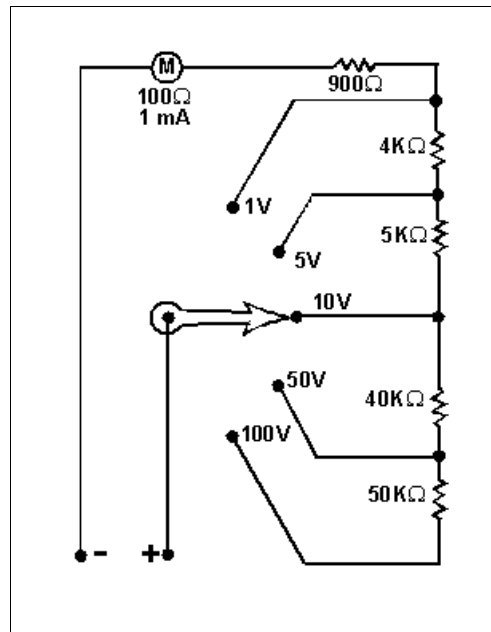
OHMMETERS are used to measure resistance and to check continuity. An ohmmeter is connected in series with the resistance being measured. The ohmmeter range which allows a midscale indication should be selected. Resistors are used to allow an ohmmeter to have several ranges. In a **SERIES OHMMETER** the resistors are used in series with the resistance being measured. Series ohmmeters have the 0 indication on the right side of the scale.
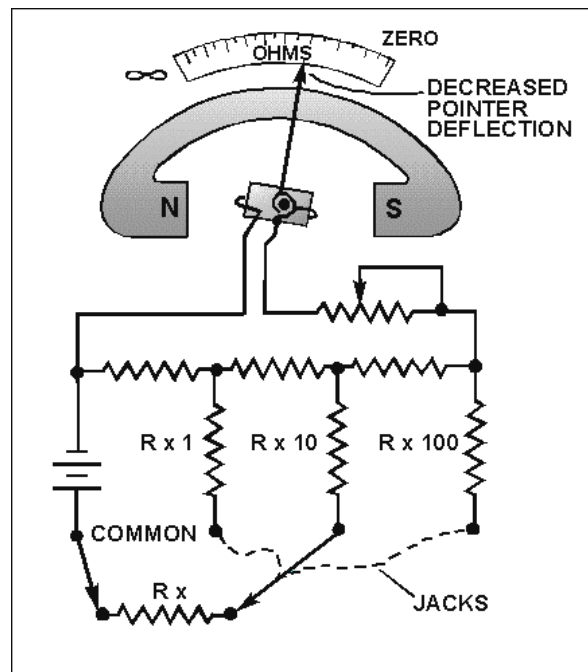
A **SHUNT OHMMETER's** internal range resistors are in parallel with the resistance being measured. A shunt ohmmeter will have the 0 indication on the left side of the scale.

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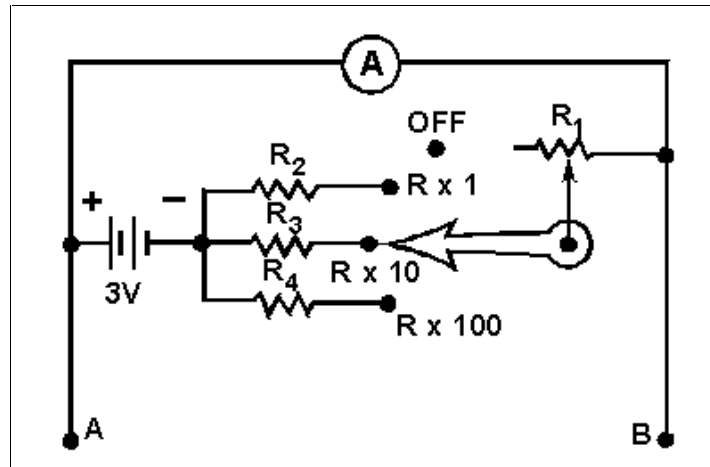
A **MEGOHMMETER (MEGGER)** is used to measure very large resistances, such as the insulation of wiring. To use a megger, isolate the resistance being measured from other circuits, connect the meter leads, turn the hand crank, and note the meter indication. Normal insulation will indicate infinity.

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.
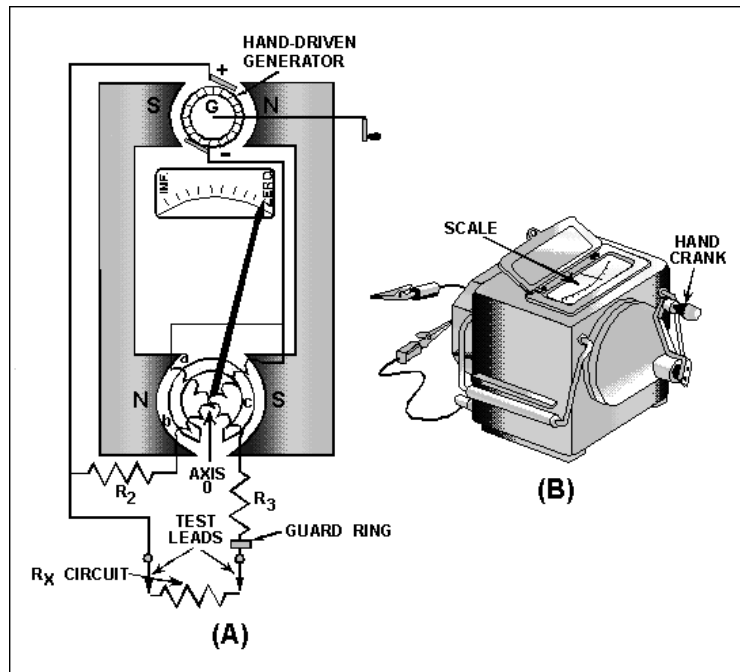
A **MULTIMETER** is a single meter that combines the functions of a dc ammeter, a dc voltmeter, an ac ammeter, an ac voltmeter, and an ohmmeter. It is more convenient to have one meter with several functions than several meters each with a single function. The various functions of a multimeter are selected 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.
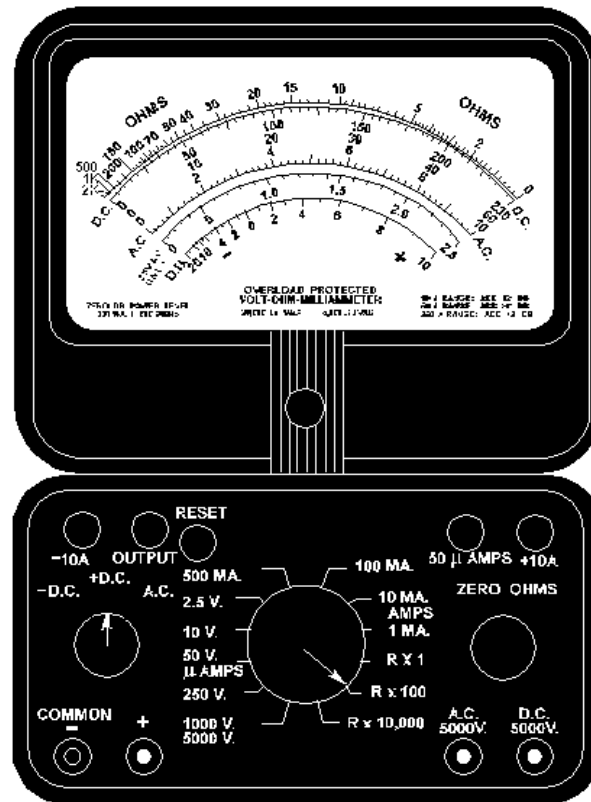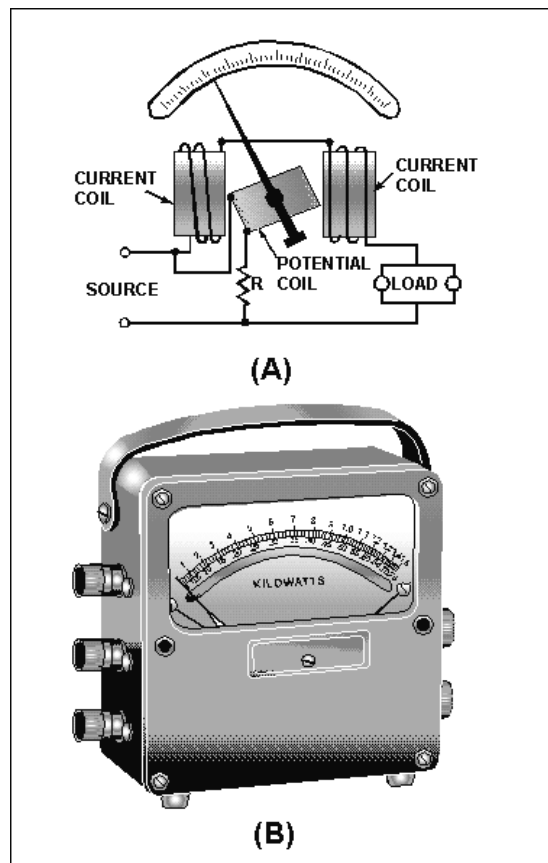

A **HOOK-ON TYPE VOLTAMETER** allows you to measure current safely and easily (with no need to disconnect the wiring of the circuit). A hook-on type voltameter uses a split-core transformer to measure current.

PUSH ← CONNECT

PULL → DISCONNECT
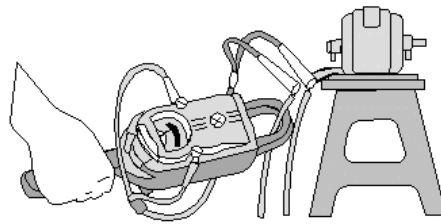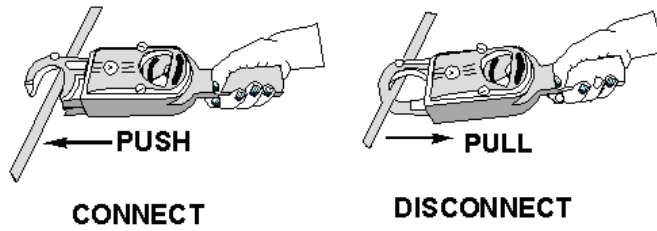
CURRENT OR VOLTAGE
READING

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

(A)

(B)

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.
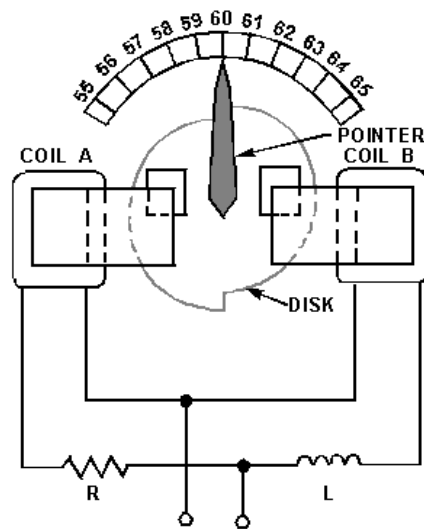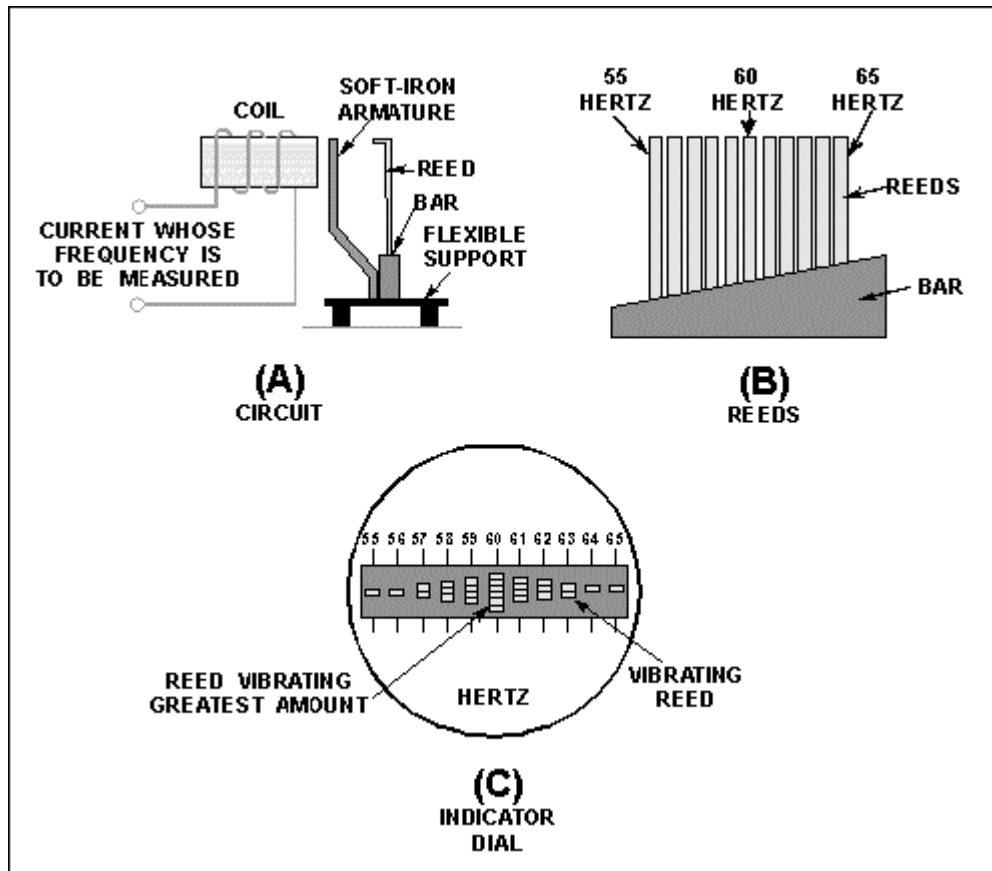
ANSWERS TO QUESTIONS Q1. THROUGH Q70.

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 ∞ 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 "O 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 Ω).

A67. Figure1-50(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.