COMPILATION
OF
USEFUL FACTS AND INFORMATION

FOR THE
ELECTRICITY SECTION

OF THE
IDAHO STATE FFA
CAREER DEVELOPMENT EVENTS

Prepared By

Edwin Dowding
Biological and Agricultural Engineering Department
University of Idaho
Moscow, Idaho 83844-2060

July 1996

INTRODUCTION TO ELECTRICAL POWER

We live in a world of ***electronics***. We use E-Mail, Internet, and micro processor controls. However, our dependence on ***ELECTRICITY*** is much broader than our need for electronic gadgets. Electricity provides us with a source of light, heat, cooling, energy to provide rotary motion as in electric motors, and for transportation. I do not believe anyone would be willing to go back to the good old days before electrical energy was available on a broad commercial scale. We are dependent on electricity for food, clothing, shelter, entertainment, and recreation.

The agricultural industry uses electricity to provide lighting which allows workers to perform tasks with improved safety and efficiency. Electric motors drive a variety of equipment and machines that help the agricultural industry operate efficiently, providing food and fiber to the people of the United States at the most reasonable prices in the world.

There is an almost endless array of electrical applications for the home, farm, agribusiness and the recreational activity we all enjoy.

Electricity is considered to be almost magical by many people, which promotes a certain amount of fear because of a lack of knowledge concerning its use and control. In the early days of electrical energy use, many people's fear of electricity in general far exceeded the fear many people have for nuclear power plants today. As instructors, we need to provide the basic knowledge that will allow the student to understand the process of electrical power distribution and application, thus reducing the fear of electricity, while instilling a healthy respect for electricity as an energy source that can be destructive if used improperly.

If used improperly, electricity can be dangerous. The power of electricity commonly found in our homes is more than enough to cause death from electrical shock. Therefore, the safe use of electricity should be a major portion of any educational program proposed. If the fundamental principles of wiring, installing circuits, and proper fusing are known and if dangerous situations are recognized, there is better chance of not receiving a shock, causing a fire, or having a problem that results in the loss of electrical service.

When a device as simple as a fuse blows, and we are without electrical service, panic occurs. How do we handle the problem? How do we go about restoring the electrical system to its operational state? Do we call the electrician, or do we attempt to determine the condition that caused the fuse to blow and restore the electrical system ourselves? With a basic understanding of electrical principles, we can determine whether to make the necessary repairs and correct the problem or to call a qualified electrician.

In the future we will find that there will be an increase in the number of electrical power consuming appliances and equipment used in the home, on the farm and in the agribusiness environment. There has been an ever increasing need for the use of electrical energy in the environmental control of plant and animal structures. This trend will likely continue into the next century.

You have a limited amount of time to help your students understand the practical aspects of electricity. Your major goal should be to motivate the student to seek additional information leading to a working knowledge of advanced electrical theories and applications. You may also influence a student or two to seek careers in the electrical power area and work in an agriculture related position.

Electricity is Powerful. Under control, electricity safely performs an endless variety of work. But uncontrolled, it can be destructive. Electricity can be controlled if the correct types of wiring and equipment are installed in the correct manner. It can be dangerous if the wrong types of wiring and equipment are used, or even if the right types of equipment are improperly installed. Properly installed wiring and equipment can become dangerous if not properly maintained.

Electrical Terms and Facts

For the student to understand the basic concepts of electric power, practice wiring, circuits, and safety they will have to know some facts relating to electricity.

Common Electrical Terms

VOLTAGE (E) — The volt is a unit of electrical force or pressure. Electricity comes to the home or farmstead at 120 and 240 volts. It may be compared to water pressure.

AMPERE (I) — A unit for measuring the rate of current flow (electron flow) through wires. It can be compared to the flow of water in pipes.

OHM (R) — Measure of the resistance to current flow through a wire or other current carrying material.

OHM'S LAW — A pressure of one volt (E) will force a current (I) of one ampere through a resistance (R) of one ohm.

$$I = \frac{E}{R}$$

WATT (P) — A unit of measure for electrical power. It is equal to the product of volts times the current flowing in amperes. One volt multiplied by one ampere is equal to one watt. One kilowatt is equal to 1000 watts.

$$P = E \times I$$

KILOWATT HOUR — A unit to measure quantities of electrical energy. It is equal to a thousand watts used for one hour. The average cost of electricity in Idaho is about 5 cents per kilowatt-hour.

SWITCH	A device for opening and closing an electrical circuit.
FUSE	A protective device used in an electrical circuit to limit the current flow in a wire. It is the safety valve of an electrical system.
CIRCUIT BREAKER	A mechanical device that opens the electrical circuit when the current flow gets too high. It serves the same purpose as a fuse, except it can be reset after the overload is removed.
BRANCH CIRCUIT	The wiring from the service entrance box to the electrical equipment and return. It will be protected by a separate fuse or circuit breaker in the service entrance box.
ELECTRICAL GROUND	A connection between the neutral wire of an electrical system and the earth.
HOT WIRE	An electrical wire carrying a voltage with respect to ground.
GROUNDED WIRE	The return wire for a 2-wire circuit. It carries current but no voltage with respect to ground.
NEUTRAL WIRE	The wire in a 3-wire, 120/230 volt system that carries current but no voltage with respect to ground. The neutral wire is grounded at the service entrance box.
GROUNDING WIRE	A wire running from the frame of the equipment to the electrical system ground.
G.F.C.I	Ground Fault Circuit Interrupter. This device will instantly trip the circuit breaker if the equipment has leakage current which might give a person a shock. Leakage currents as low as 5 milliamps will trip the breaker.

Electrical Shock:

An electrical shock is felt when an electrical current flows through the body. This happens whenever part of the body is allowed to become part of an electrical circuit. Electrical shock can be fatal depending on the amount of current, shock duration, and path of the current through the body. The shock hazard is greatest when the current is allowed to flow through the heart and chest region. The effects on the human body are:

Less than 1 milliamp	-	no shock sensation.
2 to 8 milliamps	-	sensation of shock.
10.5 milliamps	-	average let-go current for women (current above this level will "freeze" victim to the circuit).

16 milliamps	-	average let-go current for men.
20 milliamps	-	breathing ceases during the duration of the shock, very painful, loss of muscular control.
50 to 100 milliamps	-	possible ventricular fibrillation-rhythmic heart contractions cease, pumping action stops. Death ensues within a few minutes without defibrillation treatment.
Above 250 milliamps	-	may cause cardiac arrest, respiratory inhibition, damage to the nervous system and serious burns.

Both body weight and shock duration affect the magnitude of the current which will cause fibrillation. A lesser current is required for either a lighter person or a longer shock duration. Fibrillation current can be estimated from:

$$I = \frac{1.7 \times W}{\sqrt{T}}$$

Where: I is the current that will cause fibrillation, W is the body weight in pounds and T is the shock duration in seconds.

Current Flow Through the Body:

Ohm's Law may be used to determine how much current will flow through the body if we can estimate the resistance and know the value of the applied voltage. A high voltage and low body resistance will cause a high current flow. Applying Ohm's Law to a 120 volt shock will result in the following currents:

Body Resistance, Ohms	Current, Milliamps
1,000	120
2,000	60
4,000	30
8,000	15
15,000	8
30,000	4
60,000	2

The average body resistance for DRY skin will be grater than 15,000 ohms. However, when the skin is WET the resistance may drop as low as 2,500 ohms.

Dampness:

Dampness is an enemy of electrical safety. Avoid handling live cords, wires, and other "hot" parts with wet hands without rubber gloves or other equivalent protection. Damp skin and the body itself have very low resistance and afford little or no protection, while dry skin may have resistance as high as 60,000 to 100,000 ohms. Therefore, dry skin is the only protection against severe shock offered by a person's body. When changing fuses, for example, stand on a dry board or other insulation unless the fuse box is of the "dead-front" type or the power can be turned off with a switch; a practice advisable in most cases but sometimes difficult. Outside wiring and extension cords over damp floors or earth may be especially dangerous. Keep outside wires well insulated from the earth and at proper height to prevent accidental contact by cars, trucks and machinery.

Severe Shock:

If a person being shocked has grasped the live parts with his hands, it may be impossible for him to release them, though he is conscious. Since all arm muscles are tensed by the current beyond voluntary control, the person cannot open his hands and escape. If he is helpless, and the voltage is not more than 240 volts, drag him away from the live circuit by his (dry) clothing or move the wire with a dry, non-conducting object. Apply artificial respiration and/or CPR, if necessary, and call for a doctor and resuscitator at once.

Some persons can touch a 115 volt circuit without severe shock if their hands are dry. These persons are sometimes tempted to test for a "live circuit" or possible shock with the fingers. This procedure is not advisable. If testing must be done in this manner, instead of using a test lamp or other safe type of tester, it is better to touch with the back of the hand rather than the palm. If a shock is felt, the natural reaction of the muscles will quickly jerk the hand away, breaking contact. Use the fingers of one hand only, so current will not pass through a vital part of the body. Any voltage above 115 volts should be considered very dangerous and should be strictly avoided. Persons with certain nervous disorders should not receive a shock at any time.

Fibrillation Treatment:

Ventricular fibrillation is considered the most dangerous electric shock hazard. Once fibrillation occurs in a person, it rarely stops spontaneously. Death ensures within a few minutes, since the brain begins to die two to four minutes after it is deprived of its oxygenated blood supply. Resuscitation techniques must be applied immediately, if the victim is to be saved.

The usual treatment consists of prompt release of the victim from the circuit and immediate and continuous application of artificial respiration, preferably the mouth-to-mouth method. If the rescuer has been trained, artificial respiration should be combined with Cardiopulmonary Resuscitation (CPR), if the heart has stopped functioning. Resuscitation should be continued until the trained paramedics have arrived at the scene or the victim is transported to a hospital. If the victim is being transported to a hospital, the hospital authorities should be notified so that they may be ready to apply defibrillation immediately upon arrival. Victims of accidental electrical shock are now being saved by these procedures.

Safe Grounding:

Often a dangerous shock can be obtained from an appliance which appears to be in good operating condition. This is a result of an internal short in the equipment which results in the frame of the equipment being "hot". Anybody touching such equipment while they are in contact with an electrical ground may receive a fatal shock. Such electrical grounds might be plumbing fixtures, pipes, grounded electrical appliances, or heat ducts.

An additional conductor running from the electrical system ground to the frame of the appliance will provide a path for current flow through the short to the ground. If the circuit is properly fused, the fuse will blow instantly thus protecting the operator.

Grounding is accomplished by using a 3-prong grounding plug on portable appliances that are not double insulated. When the appliance is plugged into a grounded outlet, no shock hazard will exist. Of course, no protection is provided when the appliance is plugged into an ungrounded outlet using an improper adapter.

Stationary equipment should be grounded by running an additional conductor from the frame of the equipment to the electrical system ground.

Outlets in garages, bathrooms, outside the residence and near swimming pools must be protected by a ground-fault-circuit-interrupter (G.F.C.I.). The fault detector can sense a fault current as low as 5 milliamps and provide excellent shock protection.

A FEW RULES FOR ELECTRICAL SAFETY:

1. Provide proper fuse protection for all circuits. Motors require special fuse protection.

2. Use 3-prong grounding plugs whenever possible.

3. Do not allow electricity to pass through your body.

4. Do not remove an electrical cord by jerking or pulling on the cord. Pull on the plug itself.

5. Do not use worn appliance cords.

6. Use heavy duty extension cords where needed. Light cords are for lights only.

7. Do not turn on or work with electrical appliances if your hands are wet or while you are standing in water. Wet surfaces are good conductors of electricity.

8. Do not try to repair a cord or electrical circuit without disconnecting the power supply. Be sure the line is DEAD.

9. If you get a shock from an appliance, lamp fixture, or switch, something is wrong. Find the trouble and have it repaired immediately.

10. Keep irrigation pipe and farm machinery away from power lines.

11. Avoid working on hot wires or appliances that are connected to an electrical source.

12. Avoid touching electric wires, switches, drop cords, or appliances while standing in water or on damp surfaces.

13. Before cutting an electric wire, make certain that it is disconnected from the power source.

14. In all phases of farm and home wiring, follow the National Electrical Code.

15. Check the present electrical load on all circuits before adding other devices to it. Do not overload the circuit!

16. Check the cause of a circuit breaker tripping or a fuse blowing before resetting the breaker or replacing the fuse.

17. Check the cause of blackened overheated wires. Also, investigate smoking appliances or overheated electric motors. Electric motors should feel comfortable to the hand after continued operation.

18. In purchasing electric appliances and materials, insist on quality products.

19. Employ a certified electrician for all major wiring jobs; at least until you have obtained wiring experience.

UNDERSTAND AND KNOW WHAT TO DO FOR A PERSON THAT HAS RECEIVED AN ELECTRIC SHOCK:

Do not act on impulse; if you are electrocuted also, you cannot help.

The muscles of a person receiving electric shock become paralyzed, causing him to freeze to the hot wire. Sometimes the victim is not able to free himself. Getting him loose may be accomplished in the following manner:

a. Look for a "live" wire or source of the electric circuit which is causing shock, but do not take hold of the person with your bare hands.

b. Decide immediately whether to move the person or the conductor. Move the conductor with a dry stick; move the person with twelve to fifteen thicknesses of dry newspaper or clothing as an insulator.

c. Have someone call for emergency medical assistance.

After the victim is disconnected from the circuit, do the following:

a. The effect of electric shock may stop the heart and breathing. Begin artificial respiration immediately and continue until the victim is breathing normally or professional medical assistance is available.

b. Burns on various parts of the body often occur as side effects; these may be serious of themselves. Use approved first aid treatments.

Measurement of Electrical Values
Using
TEST METERS

The use of test meters is an invaluable and essential aid in diagnosing troubles in an electrical circuit. If values of voltage, current and resistance are not measured with suitable test meters, only a guess can be made as to what type of defect exists in the circuit.

To effectively determine the relationship between the components of an electric circuit, one must understand the mathematical relationship between the voltage, amperage, and resistance of the circuit. Ohm's Law is the relationship between the three qualities of the circuit. In addition to understanding the quantities to be measured, the operation of the three meters normally used must be understood. To become familiar with the use of electrical meters and to understand the relationship between voltage, current, and resistance, we should study the construction of the multimeter.

Understanding the volt - ohm - milliammeter (V.O.M. meter):

The meter is an extremely delicate instrument which may burn out instantly if it is not used properly. Follow instructions carefully. The indicating mechanism is so delicate it may show a full scale deflection when a current as small as 1/10,000 ampere (0.1 milliamp or 100 microamps) flows through it.

The pointer on the meter is activated by the current flow through a small coil. The coil is wound around a small iron core connected to the pointer. The coil is between the poles of a permanent or electromagnet; therefore, as the current increases, a torque is produced which activates the needle. Small spiral springs restrain the motion of the indicator. The current flow through the coil to produce full scale deflection is very low, generally being from 0.05 ma to 10 ma.

The meter actually measures the flow of current regardless of what measurement is being taken. Since both voltage and resistance are proportional to current, it is possible to make voltage and resistance readings with the meter. Various voltage, current, and resistance ranges can be measured using a selector switch to change the value of the resistance in the measuring circuit.

VOLTMETERS

To use the meter as a voltmeter, the current through the coil must be limited to safe values. To accomplish this, voltmeters are constructed with an internal resistor, in series with the coil, to limit the current to a safe value. The voltmeter scale is calibrated accordingly, to indicate the true voltage.

The voltmeter resistance is often printed on the face of the meter, and usually is specified in ohms per volt. If the voltmeter resistance is 1,000 ohms per volt, and if the 20-volt scale on the meter is being used, the voltmeter internal resistance is 1,000 ohms/volt x 20 volts = 20,000 ohms.

Voltmeters having a choice of scales, have a selector knob to insert different resistor values in series with the moving coil. The selector knob would choose an internal resistance of 10,000 ohms for a 10-volt scale, thus adhering to the 1,000 ohms per volt specification. In general, the higher the ohms per volt rating, the more sensitive the volt-meter.

Voltmeters are connected across (in parallel with) the voltage to be measured. Since the voltmeter has a high resistance, adding this component to the circuit will change the total circuit current very little, and the voltage reading obtained indicates the true voltage present without the meter in the circuit.

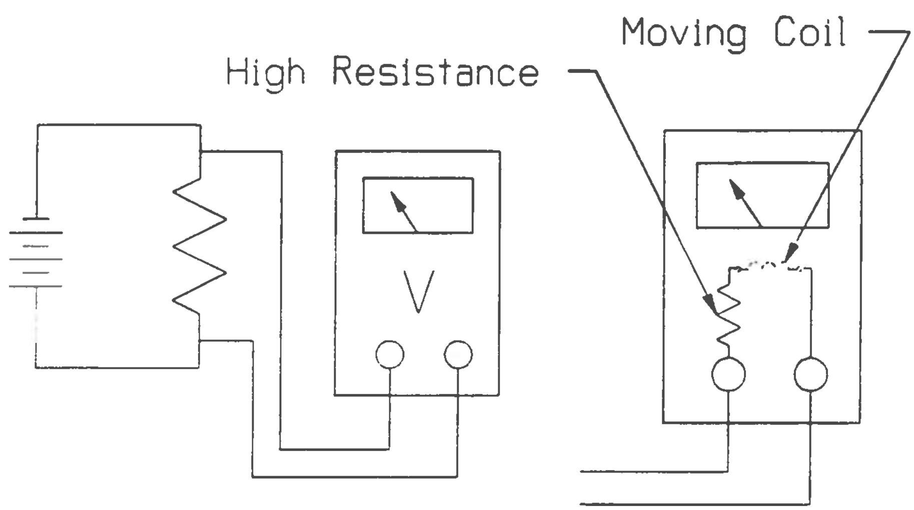

Fig. 1. Voltmeter Connections

OHMMETERS

An ohmmeter may also be of the moving coil type, and contains a resistor and dry cell battery connected internally to the moving coil. When the ohmmeter is connected to a resistor, the current flow through the moving coil is directly related to the value of the resistor, and the scale is calibrated accordingly to indicate the resistor value in ohms. Ohmmeters should never be connected to an external source of voltage, as the meter movement may be damaged.

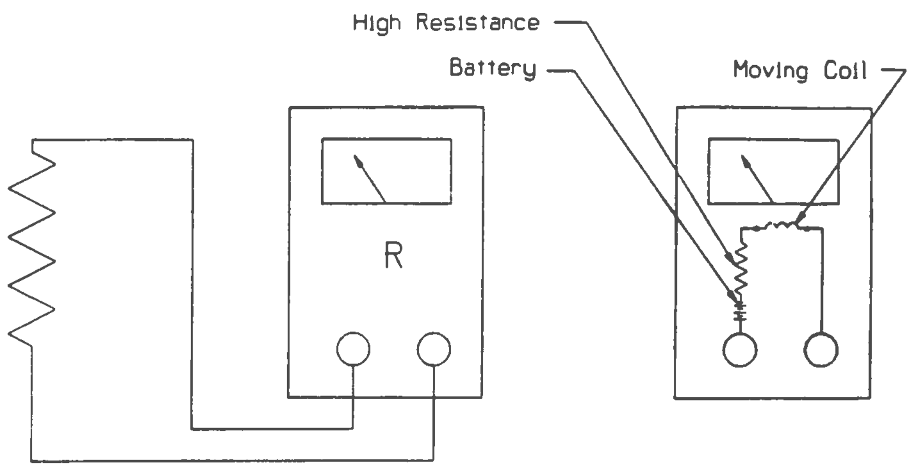

Fig. 2. Ohm Meter Connection

WARNING NOTICE

TO MEASURE RESISTANCE, THE UNKNOWN RESISTANCE MUST BE REMOVED FROM THE CIRCUIT.

AMMETERS

Ammeters may also be of the moving coil type, and differ from voltmeters, in that a low resistance shunt is used internally or externally in place of a high resistance. The shunt is connected in parallel with the moving coil, and conducts the major part of the current being measured, leaving only a small portion to flow through the moving coil. The ammeter scale is calibrated in amperes to indicate the total circuit current, since the pointer deflection is directly proportional to the total current flow in the circuit.

Since the ammeter has a very low resistance, it must be connected in series in the circuit, and **never** across the voltage source. If connected across the voltage source, such as a battery, the meter may be instantly damaged. Having a very low resistance, connecting the ammeter in series does not introduce any appreciable added resistance to the circuit that would alter the true current flow.

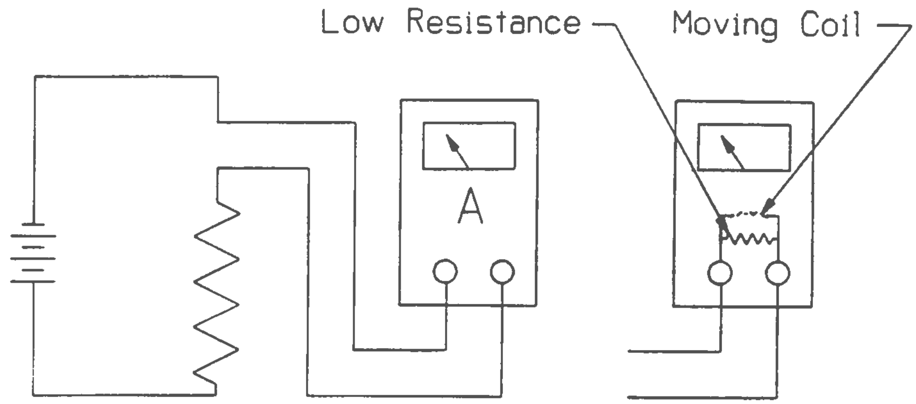

Fig. 3. Ammeter Connection

WARNING NOTICE

CONNECTING AN AMMETER ACROSS THE LOAD WILL RESULT IN ITS DESTRUCTION.

READING THE MULTIMETER

The following section applies to the Model 260 Volt-ohm-milliammeter manufactured by the Simpson Electric Company, 853 Dundee Avenue, Elgin, Illinois 60120. You should be able to find similar information concerning your meter in the operators instructions that come with your meter.

MAKING DC VOLTAGE MEASUREMENT

(Range 0 to 2.5 volts through 0 to 500 volts)

A. Set the function switch at + DC.

B. Plug the BLACK test lead into the - COMMON jack and the RED test lead into the + jack.

C. Set the range switch at one of the five voltage range positions marked 2.5V, 10V, 50V, 250V, or 500V.

NOTE: When in doubt as to the voltage percent, always use the highest voltage range as a protection to the instrument. If the voltage range is within a lower range, the switch may be set for the lower range to obtain a more accurate reading. Be sure the power is off in the circuit being measured and all capacitors are discharged before moving range switch.

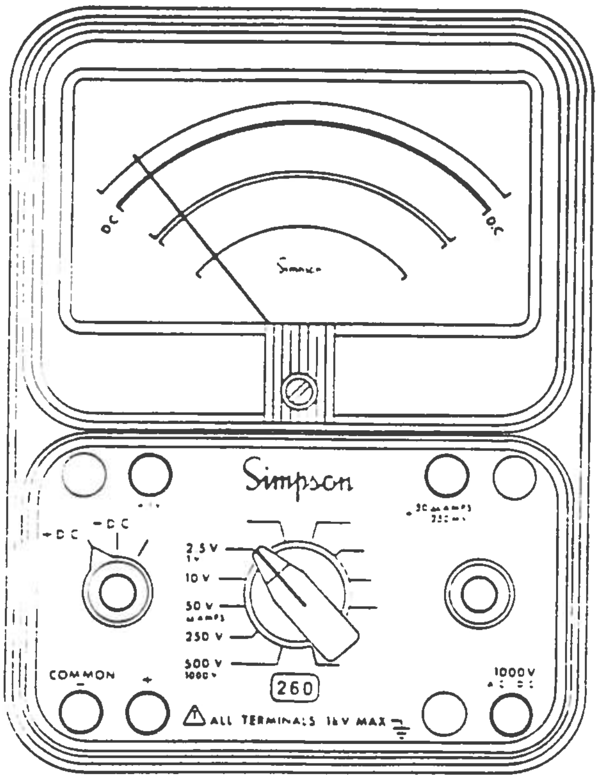

Fig. 4. Jacks and switch positions for measuring DC Voltage.

D. Connect the Black test lead to the negative side of the circuit being measured and the RED test lead to the positive side of the circuit.

E. Turn on the power in the circuit being measured.

F. Read the voltage on the black scale marked DC. For the 2.5V range, use the 0-250 figures and divide by 100. For the 10V, 50, and 250V ranges, read the figures directly. For the 500Vrange, use the 0 - 50 figures and multiply by 10.

G. <u>DO NOT</u> use the 0 to 1000 volt range without special high voltage leads and special training.

<u>NOTE</u>. Turn off power to the circuit and wait until the meter indicates zero before disconnecting the test leads.

MAKING AC VOLTAGE MEASUREMENT
(Range 0 to 2.5 volts through 0 to 500 volts)

The Model 260 meter responds to the average value of an AC waveform. It is calibrated in terms of the rms (root mean square) value of a pure sine wave.

A. Set the function switch at AC.

B. Set the range switch at one of the five voltage range positions marked 2.5V, 10V, 250V, or 500V. (When in doubt as to the actual voltage present, always use the highest voltage range as a protection to the instrument. If the voltage is within the lower range, the switch may be set for the lower range to obtain a more accurate reading. Make sure the power is OFF when moving the range switch).

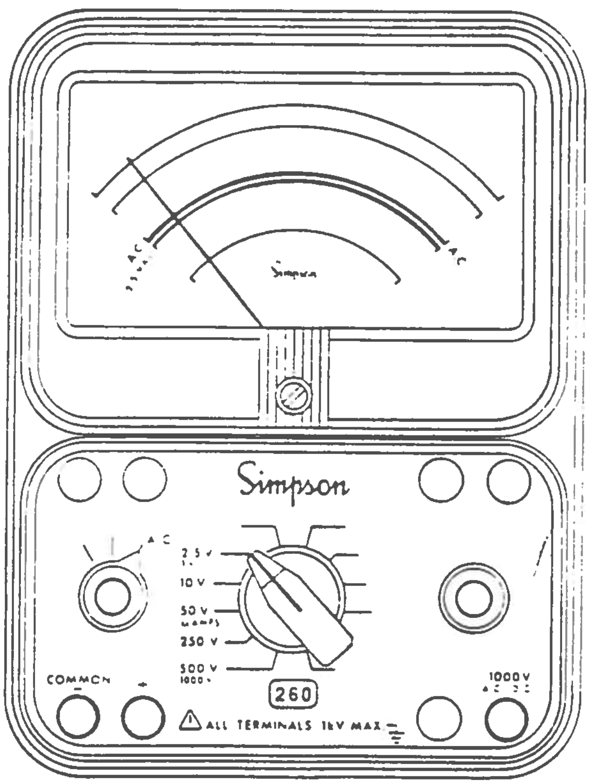

Fig 5. Jacks and switch positions for measuring AC voltage.

C. Plug the BLACK test lead into the - COMMON jack and the RED test lead into the + jack.

D. Turn off the power to the circuit to be measured and discharge any capacitors.

E. Connect the test leads across the circuit voltage to be measured with the black lead to the grounded side.

F. For the 2.5V range, read the valuedirectly on the scaled marked 2.5 VAC. For the 10V, 50V, and 250V ranges, read the red scale marked AC and use the black figures immediately above the scale. For the 500V range, read the red scale marked AC and use the 0 - 50 figures. Multiply the reading by 10.

AC VOLTAGE MEASUREMENT 0-1000 VOLT RANGE

WARNING NOTICE

BE EXTREMELY CAREFUL WHEN WORKING WITH HIGH VOLTAGE CIRCUITS. DO NOT HANDLE THE INSTRUMENT OR TEST LEADS WHILE THE CIRCUIT BEING MEASURED IS ENERGIZED.

OBSERVE ALL SAFETY PRECAUTIONS WHEN WORKING WITH HIGH VOLTAGE.

A. Set the function switch to AC.

B. Set the range switch at 500/1000V position.

C. Plug the BLACK test lead into the - COMMON jack and the RED test lead into the 1000V jack.

D. Be sure the power is off in the circuit being measured and that all its capacitors are discharged. Connect the test leads to the circuit.

E. Connect the test leads across the circuit voltage to be measured with the BLACK lead to the grounded side, if any

F. Turn on the power in the circuit being measured.

G. Read the voltage on the red scale marked AC. Use the 0-10 figures and multiply by 100.

MAKING RESISTANCE MEASUREMENTS

WARNING NOTICE

VOLTAGE APPLIED TO A RESISTANCE RANGE WILL CAUSE READING ERRORS IF LOW, OR DAMAGE THE INSTRUMENT IF HIGH. WHEN MAKING IN-CIRCUIT MEASUREMENTS, MAKE CERTAIN THAT THE CIRCUIT IS COMPLETELY DEENERGIZED BEFORE MAKING CONNECTIONS TO IT.

WHEN MAKING IN-CIRCUIT MEASUREMENTS, CIRCUIT PATHS IN PARALLEL WITH THE RESISTANCE BEING MEASURED MAY CAUSE READING ERRORS. CHECK CIRCUIT DIAGRAMS FOR THE PRESENCE OF SUCH COMPONENTS BEFORE ASSUMING THE READING OBTAINED IS CORRECT.

NOTE: When resistance is measured, the INTERNAL batteries furnish power for the circuit. Since batteries are subject to variation in voltage and internal resistance, the instrument must be adjusted to zero before measuring a resistance, as follows:

A. Turn the range switch to desired ohms range.

B. Plug the BLACK test lead into the - COMMON jack and the RED test lead into the + jack.

C. Connect the ends of the test leads together to short the VOM resistance circuit.

D. Rotate the ZERO OHMS control until the pointer indicates zero ohms. If the pointer cannot be adjusted to zero, one or both of the batteries must be replaced.

E. Disconnect shorted end of test leads.

MEASURING RESISTANCE

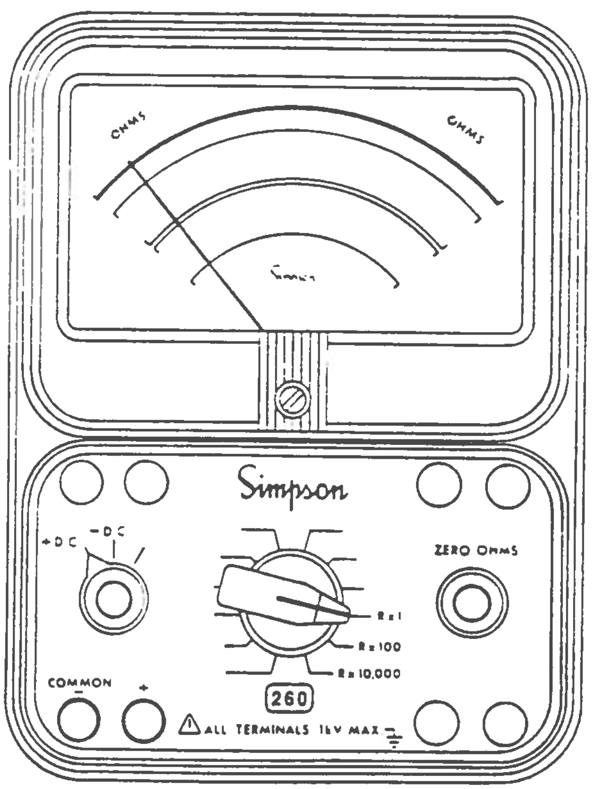

Fig. 6. Jacks and switch positions for measuring resistance.

A. Before measuring resistance in the circuit, make sure the power is off to the circuit being tested and all capacitors are discharged. Disconnect shunted component from the circuit before measuring its resistance.

B. Set the range switch to one of the resistance range positions as follows:

1. Use R x 1 for resistance readings from 0 to 200 ohms.
2. Use R x 100 for resistance readings from 200 to 20,000 ohms.
3. Use R x 10,000 for resistance readings above 20,000 ohms.

C. Set the function switch at either - DC or + DC position: operation is the same in either position except if there are semiconductors in the same circuit. Adjust the ZERO OHMS control for each resistance range.

D. Observe the reading on the OHMS scale at the top of the dial. *Note: The OHMS scale reads from right to left for increasing values of resistance.*

E. To determine the actual resistance value, multiply the reading by the factor at the switch position. (K on the OHMS scale equals one thousand).

MAKING DIRECT CURRENT MEASUREMENTS

WARNING NOTICE

DO NOT CHANGE THE RANGE SETTING OR THE FUNCTION SWITCHES WHILE CIRCUIT IS ENERGIZED.

NEVER DISCONNECT THE TEST LEADS FROM THE CIRCUIT UNDER MEASUREMENT WHILE THE CIRCUIT IS ENERGIZED.

ALWAYS CONNECT THE INSTRUMENT IN SERIES WITH THE GROUND SIDE OF THE CIRCUIT.

IN ALL DIRECT CURRENT MEASUREMENTS, MAKE CERTAIN THE POWER TO THE CIRCUIT BEING TESTED HAS BEEN TURNED OFF BEFORE CONNECTING AND DISCONNECTING THE TEST LEADS OR RESTORING CIRCUIT CONTINUITY.

DIRECT CURRENT MEASUREMENT
(0 - 50µA RANGE)

A. Set the function at + DC.

B. Plug the BLACK test lead into the - COMMON jack and the RED test lead into the + 50µAMPS/250V jack.

C. Set the range switch at 50µAMPS (dual position with 50V).

D. Open the ground side of the circuit in which the current is being measured. Connect the VOM in SERIES with the circuit. Connect the RED test lead to the positive side and the BLACK test lead to the negative side.

E. Read the current on the black DC scale. Use the 0 - 50 figures to read directly in microamperes.

DIRECT CURRENT MEASUREMENT
(0 - 1mA through 0 - 500mA RANGE)

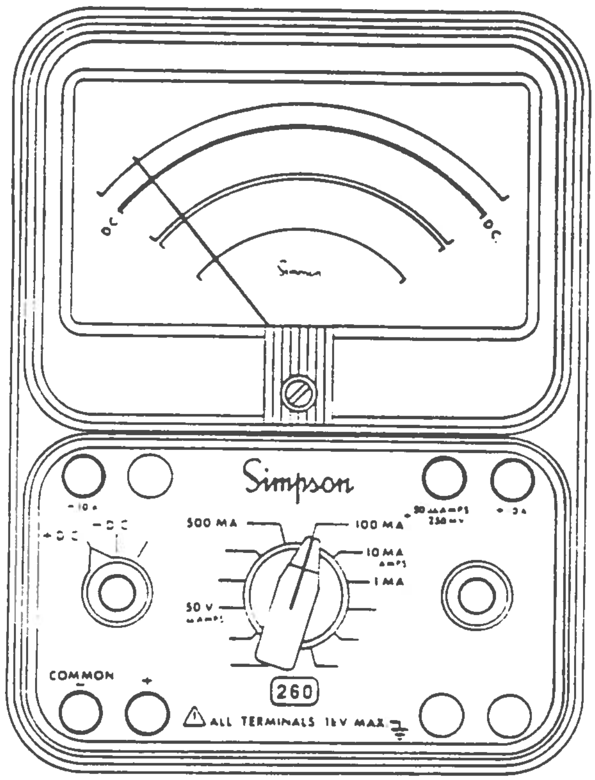

Fig. 7. Jacks and switch positions for measuring direct current.

A. Set the function switch at + DC.

B. Plug the BLACK test lead into the - COMMON jack and the RED test lead into the + jack.

C. Set the range switch at one of the four range positions marked 1mA, 10mA, 100mA, or 500mA.

D. Open the grounded side of the circuit in which the current is to be measured. Connect the VOM in **SERIES** with the circuit. Connect the RED test lead to the positive side and the BLACK test lead to the negative side.

E. Turn the power on. Read the current in milliamperes on the black DC scale. For the 1mA range, use the 0 - 10 figures and divide by 10. For the 10mA range, use the 0 - 10 figures directly. For the 100mA range, use the 0 - 10 figures and multiply by 10. For the 500mA range, use the 0 - 50 figures and multiply by 10.

F. Turn off the power and disconnect the test leads.

DIRECT CURRENT MEASUREMENT
(0 - 10 A RANGE)

A. Plug the BLACK test lead into the - 10A jack and the RED test lead into the + 10A jack.

B. Set the range switch at 10 AMPS (dual position with 10mA).

C. Open the ground side of circuit in which the current is being measured. Connect the VOM in **SERIES** with the circuit. Connect the RED test lead to the positive side and the BLACK test lead to the negative side.

NOTE: The function switch has no effect on the polarity for the 10 AMPS range.

D. Turn the power on. Read the current directly on the black scale. Use the 0 - 10 figures to read directly in amperes.

E. Turn the power off and disconnect the test leads.

WARNING NOTICE

THE 10A RANGE IS NOT INTERNALLY FUSED IN THE MODEL 260 METER.

WHEN USING THE 10A RANGE, NEVER DISCONNECT A TEST LEAD FROM A JACK OR FROM THE CIRCUIT WHILE THE CIRCUIT IS ENERGIZED. DOING SO MAY DAMAGE THE TEST JACKS OR LEADS AND THE ARCING MAY BE HAZARDOUS TO THE OPERATOR. TURN OFF THE CIRCUIT POWER AND WAIT FOR THE METER READING TO DROP TO ZERO.

DETERMINATION OF VOLTAGE DROP IN A CONDUCTOR

The voltage available at the point of actual use (end of an extension cord or branch circuit) is related to the current flowing through the conductor, the size of the conductor, the total length of the conductor, and the material (resistance per foot of length) used to make the conductor. The mathematical relationship is expressed in the following equations:

The voltage drop for copper conductors used in single phase circuits is found by:

$$ED = 22 \times I \times L \div CM \qquad \{\text{Equation No. 1}\}$$

Where: ED is the voltage drop in volts
I is the current flow in amperes
L is the total conductor length in feet
CM is the conductor size in circular mills
22 is a constant that includes the corrections for units and the value of the resistance of the copper.

The voltage drop for aluminum conductors used in a single phase circuit is found by:

$$ED = 22 \times I \times L \times 1.6 \div CM \qquad \{\text{Equation No. 2}\}$$

Where: All symbols are as stated above
1.6 is a constant that corrects for the difference between the resistance of aluminum and copper

Table 1 below, indicates the weight in pounds and the resistance in ohms per 1000 feet for various sizes of copper and aluminum conductors commonly used in agricultural electrical power applications. The size of conductors used in electrical power applications may be expressed in either American Wire Gauge (AWG) or Thousands of Circular Mills (MCM).

A circular mill is an indication of a wire size that is calculated by squaring the diameter of the wire measured in thousands of an inch (mill). That is, if a wire were 1/8 inch in diameter its diameter would be 125 thousands of an inch. Therefore, its size in circular mills would be 125 mills squared or 15625 circular mills. The abbreviation for the unit circular mills varies, but is usually stated as CM.

Table 1. Conductor Data (for 20^0 C).

Size AWG or MCM	Circular Mills	Copper		Aluminum	
		Pounds per 1000 feet	Resistance ohms per 1000 feet	Pounds per 1000 feet	Resistance ohms per 1000 feet
12	6530	19.8	1.59	6.01	2.57
10	10380	31.43	0.9988	9.556	1.62
8	16510	49.98	0.6281	15.2	1.02
6	26240	79.44	0.3952	24.15	0.6395
4	41740	126.3	0.2485	38.41	0.4021
3	52620	159.3	0.1971	48.43	0.3189
2	66360	205	0.1594	62.3	0.2580
1	83690	259	0.1264	78.6	0.2045
0	105600	326	0.1002	99.1	0.1622
00	133100	411	0.07949	125	0.1286
000	167800	518	0.06306	157	0.1020
0000	211600	653	0.04999	199	0.0809
250	250000	772	0.04232	235	0.06847
300	300000	925	0.03526	282	0.05706
350	350000	1080	0.03022	328	0.04891
400	400000	1236	0.02645	375	0.04280
500	500000	1542	0.02115	469	0.03423
600	600000	1850	0.01764	563	0.02853
700	700000	2160	0.01512	657	0.02445
750	750000	2316	0.01411	704	0.02283
800	800000	2469	0.01322	751	0.02140
900	900000	2780	0.01175	845	0.01902
1000	1000000	3086	0.01058	938	0.01712

EXAMPLE ONE

Generally, we would like to maintain voltage drop at less than two to three percent of line voltage. If the line voltage is 120 volts and the allowable voltage drop is two percent, then the allowable voltage drop is:

Allowable voltage drop (volt) = 120 volts x 0.02 = 2.4 volt

EXAMPLE TWO

If we have an air compressor which draws 15 amperes at 120 volts, what size conductors are required for a 25 foot long extension cord, if the voltage drop in the cord is to be less than 2 percent? Assume copper conductors.

Rearranging equation 1:

$CM = 22 \times I \times L \div ED$

$CM = 22 \times 15 \text{ amp} \times 2 \times 25 \text{ feet} \div 2.4 \text{ volt}$

The 2 in the above equation is necessary to account for the total conductor length, 25 feet out and 25 feet back.

$CM = 6875 \text{ CM}$

From Table 1, the minimum cord size would be AWG No. 10 (10380 CM). The smallest standard size above the minimum.

The required value of 6875 CM is very close to the value for AWG No. 12 (6530CM). If an AWG No. 12 conductor were used, the voltage drop would be slightly greater than 2 percent.

The actual voltage drop value could be found using Equation No. 1.

$ED = 22 \times I \times L \div CM$

$ED = 22 \times 15 \text{ amp} \times 2 \times 25 \text{ feet} \div 6530 \text{ CM}$

$ED = 2.53 \text{ volt}$

To determine the actual percent voltage drop:

Percent Voltage Drop (%) = 2.53 volt ÷ 120 volt x 100

Percent Voltage Drop = 2.1 percent

This is close enough to a 2 percent voltage drop, therefore, we could get by with the AWG No. 12 copper conductor without unnecessary loss of efficiency of our air compressor.

These calculations require time to make and may lead to calculation errors. Tables are available to determine conductor size for design purposes. An example of such a table is shown in Table 2 below.

Table 2 is used to select conductor size based on voltage drop as calculated from Equations 1 and 2 above. Note: Table 2 is only one of the thirty one voltage drop tables available in the listed publication. There are tables for copper and aluminum conductors, tables for 2 percent, 3 percent and 4 percent voltage drops, as well as tables for 120 volt, 240 volt single phase, 240 volt three-phase, and 480 volt three-phase.

Explanation of Table 2. The far left column is the circuit load in amperes, and the seven columns to the right of column 1 relate to the minimum conductor size, its insulation type, and location (cable, conduit, direct burial , or overhead in air) based on the NATIONAL ELECTRIC CODE. Note: the values for types UF and USE are the same for direct burial, cable or conduit. The column values to the right of the double vertical lines indicate the minimum conductor size for the ONE-WAY distance indicated at the top of each column.

To use the table, find the load in amperes in the far left column, and read horizontally to the right of the double vertical lines. Find the ONE WAY distance in feet in the upper row numbers (30 to 700). The number at the intersection of the row of the load in amps and the one-way distance in feet is the minimum size conductor to select. Be sure to compare the value read at this intersection with the value in the seven columns directly to the left of the vertical double line. Always use the larger of the two sizes.

EXAMPLE THREE

To use the compressor of example two:

Select 15 amps in column one, move to the first column to the right of the double vertical line (one-way distance of 30 feet) and read AWG No. 12. This is the same value obtained by the calculations. Note: if you were selecting conductors for a permanent overhead installation between buildings (outside and exposed to the weather) the conductors would need to be larger, (as indicated in columns seven or eight) depending on conditions, to meet the minimum mechanical strength as required by the NEC.

EXAMPLE FOUR

You are asked to select the conductor to serve an 80 amp load on a 120 volt, single phase circuit that has a one-way distance of 50 feet. The voltage drop should be no more than 2 percent and the conductor used should be a direct burial underground feeder.

Read down column one to 80 amps, move horizontally to the right to the 50 foot column. Read AWG No. 4. Compare with column five from left (Direct Burial UF) which required an AWG No. 3. Therefore, recommend the larger AWG No. 3 copper conductor with UF insulation.

Table 2. Conductor Size For Copper Conductors Operating On A 120 Volt Single Phase System, Based On 2 Percent Voltage Drop. Taken from Agricultural Wiring Handbook, Tenth Edition, 1993. Published by the National Food and Energy Council, Columbia, MO.

10 Minimum Allowable Size of Conductor

Copper up to 200 Amperes, 115-120 Volts, Single Phase, Based on 2% Voltage Drop

Load in Amps	In Air Cable or Conduit			Direct Burial		Overhead in Air*	
	UF**	RH, RHW, THW, THWN, USE, RM, SE	THHN	UF**	USE	Single	Triplex
5	14	14	14	14	14	10	8
7	14	14	14	14	14	10	8
10	14	14	14	14	14	10	8
15	14	14	14	14	14	10	8
20	12	12	12	12	12	10	8
25	10	10	10	10	10	10	8
30	10	10	10	10	10	10	8
35	8	8	8	8	8	8	8
40	8	8	8	8	8	8	8
45	6	6	6	6	6	6	8
50	6	6	6	6	6	6	6
60	4	6	6	4	6	6	6
70	4	4	6	4	4	6	6
80	3	4	4	3	4	6	4
90	2	3	4	2	3	4	4
100	1	3	3	1	3	4	4
115	0	2	2	0	2	3	3
130	00	1	2	00	1	2	2
150	000	0	1	000	0	1	1
175	4/0	00	00	4/0	00	0	0
200		000	000		000	00	00

Length of Run in Feet

Compare size shown below with size shown to left of double line. Use the larger size.

Load in Amps	30	40	50	60	75	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700
5	14	14	14	14	14	12	12	10	10	10	10	8	8	8	8	6	6	6	6	[illegible]	4	4
7	14	14	14	14	12	12	10	10	8	8	8	8	6	6	6	6	4	4	4	4	4	3
10	14	14	12	12	10	10	8	8	8	6	6	6	6	4	4	4	4	3	3	2	2	2
15	12	12	10	10	10	8	6	6	6	4	4	4	4	4	3	2	2	1	1	1	0	0
20	12	10	10	8	8	6	6	4	4	4	4	3	3	2	2	1	1	0	0	00	00	00
25	10	10	8	8	6	6	4	4	4	3	3	2	2	1	1	0	0	00	00	000	000	000
30	10	8	8	8	6	4	4	4	3	2	2	1	1	1	0	00	00	000	000	000	4/0	4/0
35	10	8	8	6	6	4	4	3	2	2	1	1	0	0	00	00	000	000	4/0	4/0	4/0	250
40	8	8	6	6	4	4	3	2	2	1	1	0	0	00	00	000	000	4/0	4/0	250	250	300
45	8	8	6	6	4	4	3	2	1	1	0	0	00	00	000	000	4/0	4/0	250	250	300	300
50	8	6	6	4	4	3	2	1	1	0	0	00	00	000	000	4/0	4/0	250	250	300	300	350
60	8	6	4	4	4	2	1	1	0	00	00	000	000	000	4/0	250	250	300	300	350	400	400
70	6	6	4	4	3	2	1	0	00	00	000	000	4/0	4/0	250	300	300	350	400	400	500	500
80	6	4	4	3	2	1	0	00	00	000	000	4/0	4/0	250	300	300	350	400	400	500	500	600
90	6	4	4	3	2	1	0	00	000	000	4/0	4/0	250	250	300	350	400	500	500	500	600	600
100	4	4	3	2	1	0	00	000	000	4/0	4/0	250	250	300	350	400	500	500	500	600	600	700
115	4	4	3	2	1	0	00	000	4/0	4/0	250	300	300	350	400	500	500	600	600	700	700	750
130	4	3	2	1	0	00	000	4/0	4/0	250	300	300	350	400	500	500	600	600	700	750	800	900
150	4	2	1	1	0	000	4/0	4/0	250	300	350	350	400	500	500	600	700	700	800	900	900	1M
175	3	2	1	0	00	000	4/0	250	300	350	400	400	500	500	600	700	750	800	900	1M		
200	2	1	0	00	000	4/0	250	300	350	400	500	500	500	600	700	750	900	1M				