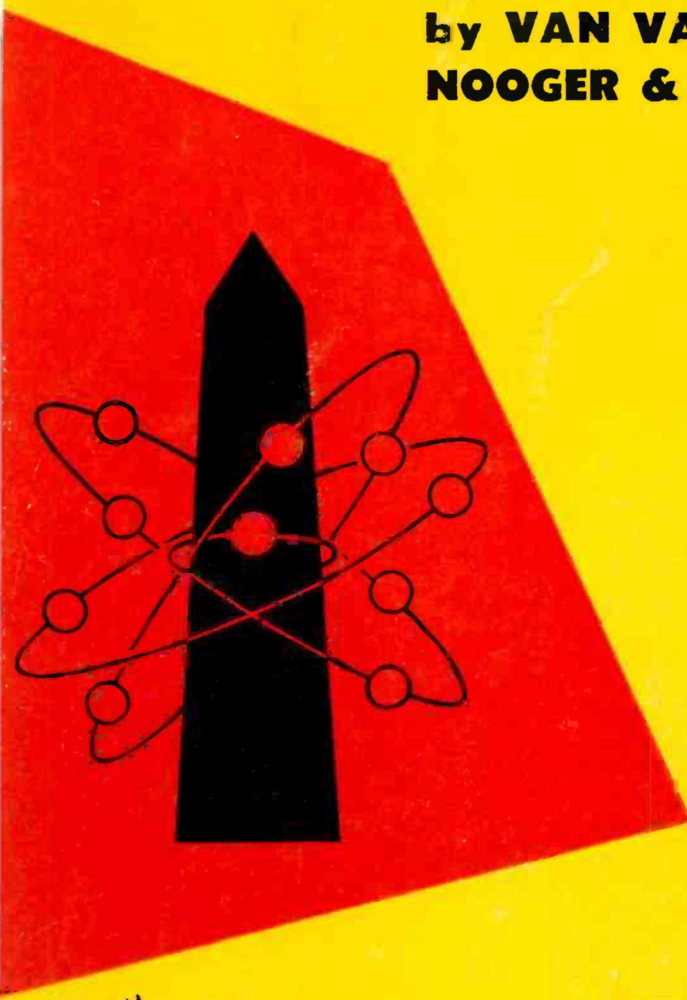
0035

basic electricity

by VAN VALKENBURGH, NOOGER & NEVILLE, INC.



VOL. 2

DIRECT CURRENT CIRCUITS

OHM'S & KIRCHHOFF'S LAWS

ELECTRIC POWER

RIDER

basic electricity

by VAN VALKENBURGH,
NOOGER & NEVILLE, INC.

VOL. 2

JOHN F. RIDER PUBLISHER, INC., NEW YORK
a division of HAYDEN PUBLISHING COMPANY, INC.

First Edition

Library of Congress Catalog Card No. 54-12946

Printed in the United States of America

PREFACE

The texts of the entire Basic Electricity and Basic Electronics courses, as currently taught at Navy specialty schools, have now been released by the Navy for civilian use. This educational program has been an unqualified success. Since April, 1953, when it was first installed, over 25,000 Navy trainees have benefited by this instruction and the results have been outstanding.

The unique simplification of an ordinarily complex subject, the exceptional clarity of illustrations and text, and the plan of presenting one basic concept at a time, without involving complicated mathematics, all combine in making this course a better and quicker way to teach and learn basic electricity and electronics. The Basic Electronics portion of this course will be available as a separate series of volumes.

In releasing this material to the general public, the Navy hopes to provide the means for creating a nation-wide pool of pre-trained technicians, upon whom the Armed Forces could call in time of national emergency, without the need for precious weeks and months of schooling.

Perhaps of greater importance is the Navy's hope that through the release of this course, a direct contribution will be made toward increasing the technical knowledge of men and women throughout the country, as a step in making and keeping America strong.

Van Valkenburgh, Nooger and Neville, Inc.

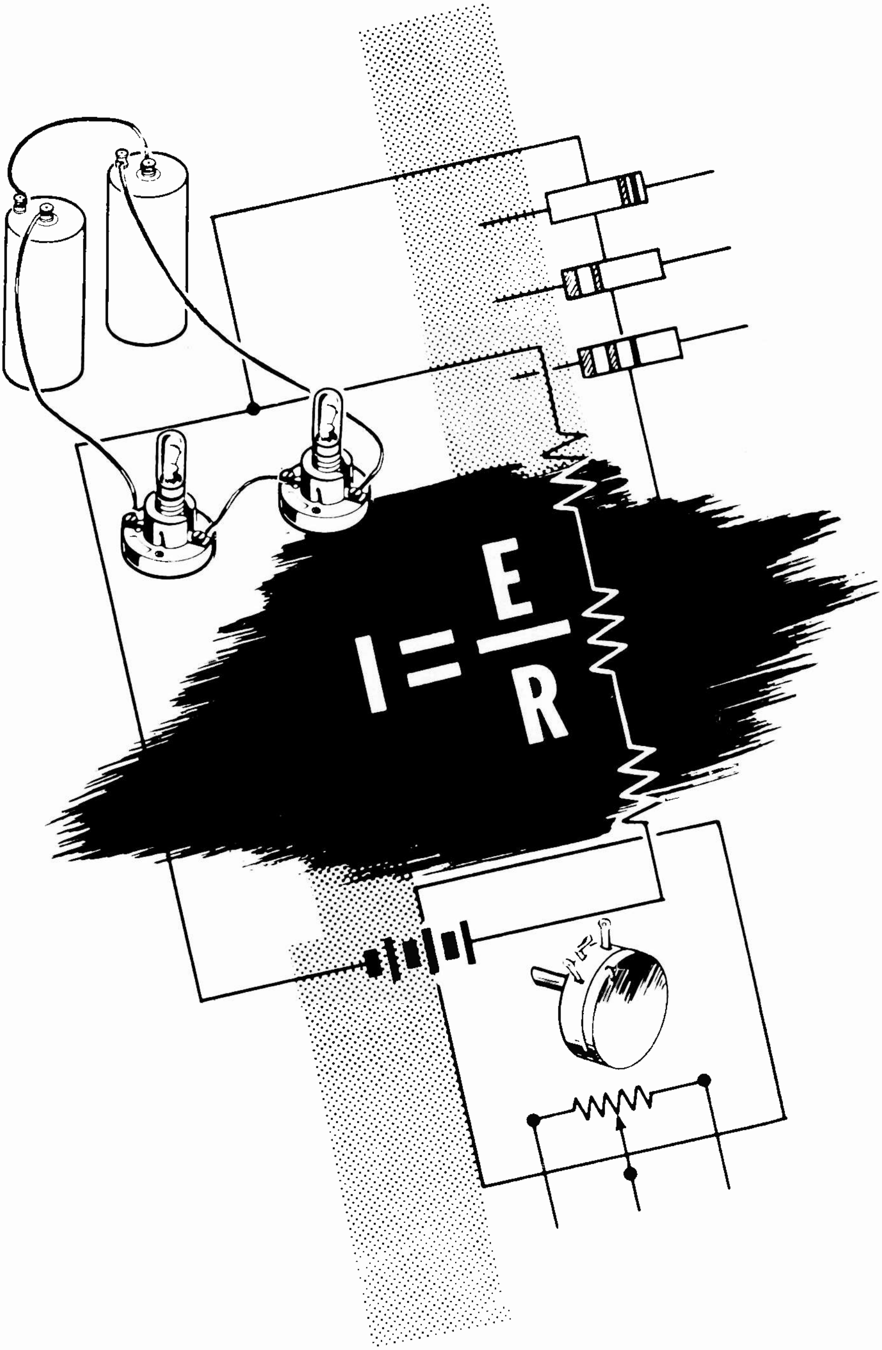
New York, N. Y.
October, 1954

TABLE OF CONTENTS

VOL. 2 — BASIC ELECTRICITY

BASIC ELECTRICITY

Vol. 2

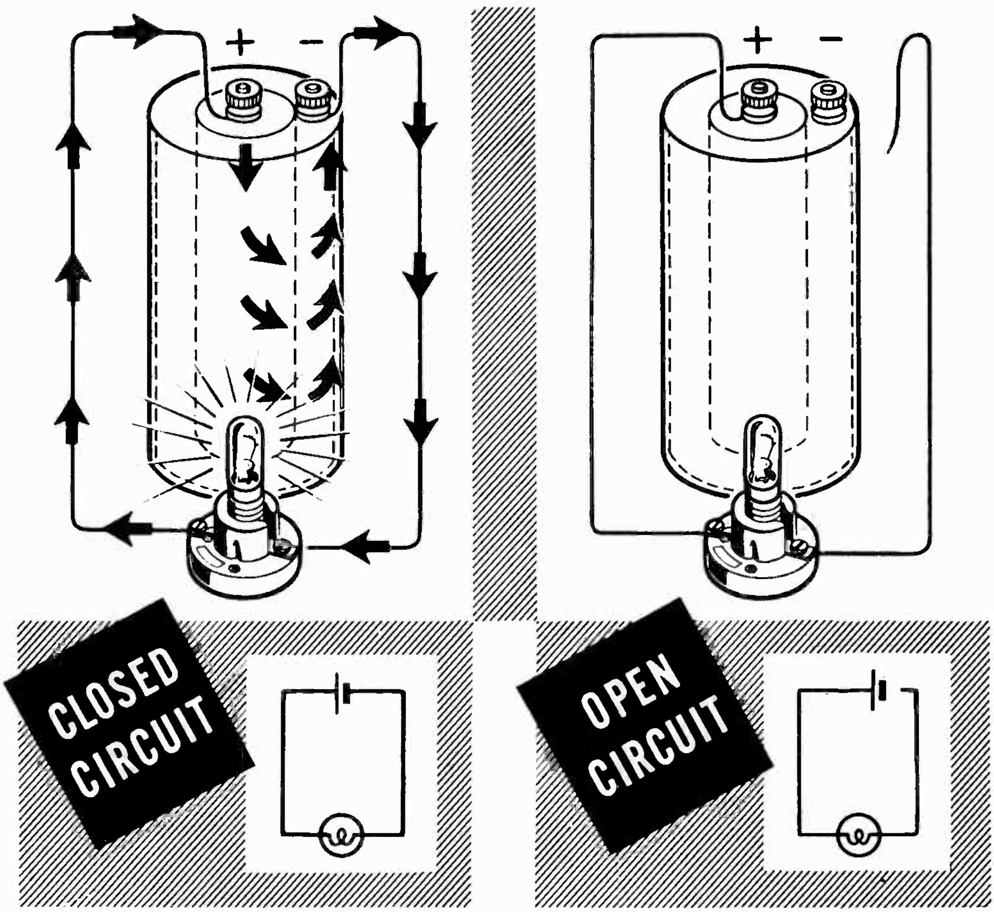


Direct current circuits

Electric Circuits

Wherever two charges are connected by a conductor, a pathway for current flow exists; and if the charges are unequal, current flows from the negative to the positive charge. The amount of current flow depends on the voltage difference of the charges and the resistance of the conductor. If two charged bars are connected by a copper wire, for example, current will flow from the more negative to the more positive bar, but only long enough to cause each bar to have an equal charge. Although current flows briefly, this kind of connection is not an electrical circuit.

An electric circuit is a completed electrical pathway, consisting not only of the conductor in which the current flows from the negative to the positive charge, but also of a path through a voltage source from the positive charge back to the negative charge. As an example, a lamp connected across a dry cell forms a simple electric circuit. Current flows from the (-) terminal of the battery through the lamp to the (+) battery terminal, and continues by going through the battery from the (+) to the (-) terminal. As long as this pathway is unbroken, it is a closed circuit and current flows; but, if the path is broken at any point, it is an open circuit and no current flows.

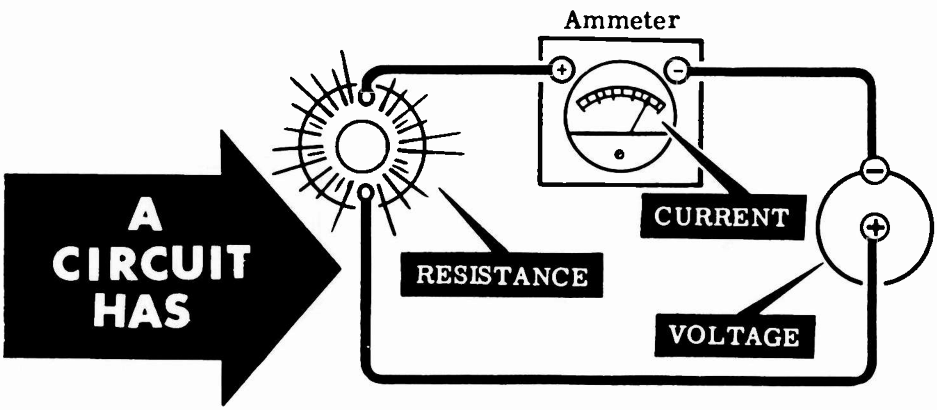


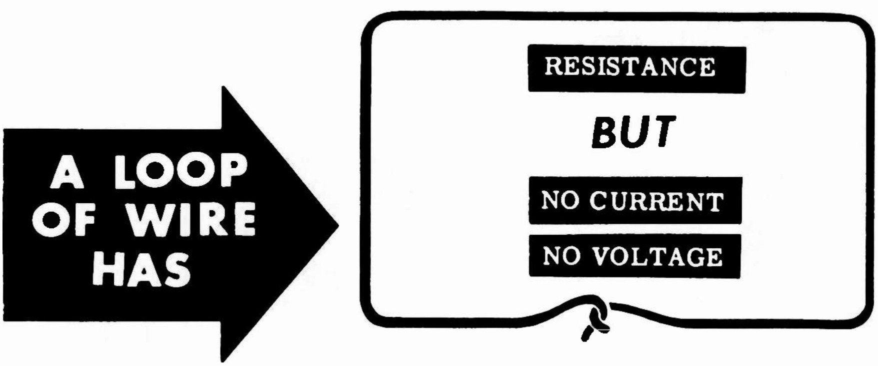
Electric Circuits (continued)

A closed loop of wire is not always a circuit. Only if a source of emf is part of the loop do you have an electric circuit. In any electric circuit where electrons move around a closed loop, current, voltage and resistance are present. The pathway for current flow is actually the circuit, and its resistance controls the amount of current flow around the circuit.

Direct current circuits consist of a source of DC voltage, such as batteries, plus the combined resistance of the electrical equipment connected across this voltage. While working with DC circuits, you will find out how the total resistance of a circuit is changed by using various combinations of resistances, how these combinations control the circuit current and affect the voltage.

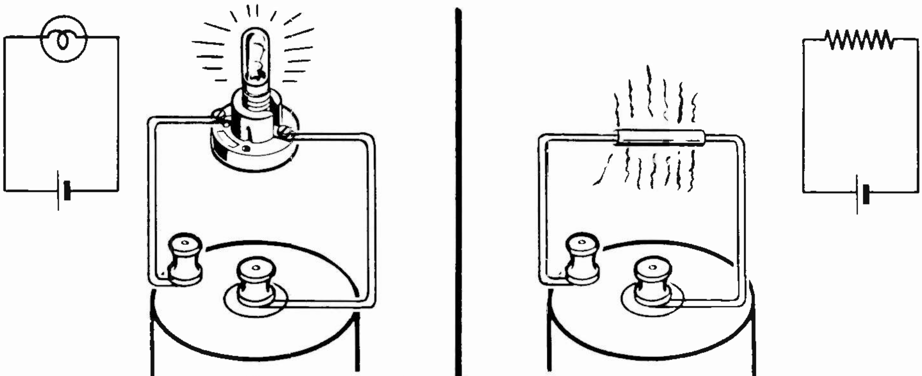
You have found out how cells are connected in series or parallel, and now you will find that resistances are connected in the same manner to form the two basic types of circuits, series and parallel circuits. No matter how complex a circuit you may work with, it can always be broken down into either a series circuit connection or a parallel circuit connection.





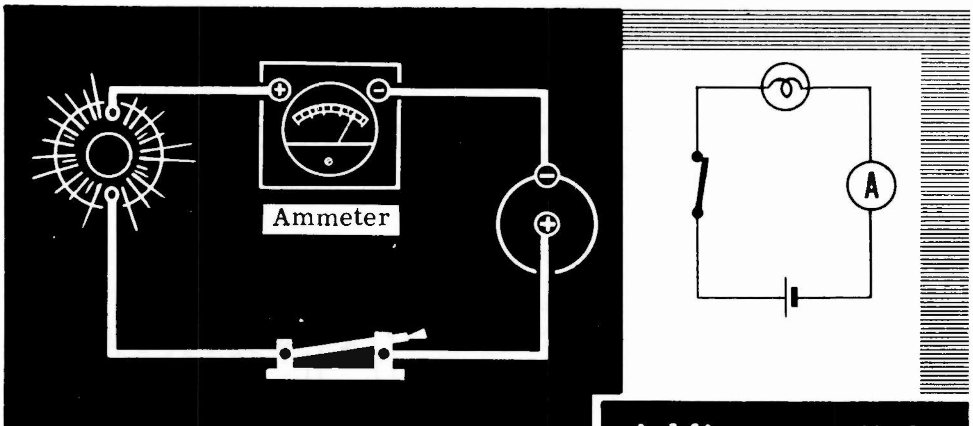
Simple Circuit Connections

Only the resistances in the external circuit, between the terminals of the voltage source, are used to determine the type of circuit. When you have a circuit consisting of only one device having resistance, a voltage source and the connecting wires, it is called a SIMPLE circuit. For example, a lamp connected directly across the terminals of a dry cell forms a simple circuit. Similarly, if you connect a resistor directly across the terminals of a dry cell, you have a simple circuit since only one device having resistance is being used.



SIMPLE CIRCUITS

Simple circuits may have other devices connected in series with a lamp but the nature of the circuit does not change unless more than one resistance is used. A switch and a meter inserted in series with the lamp do not change the type of circuit since they have negligible resistance.



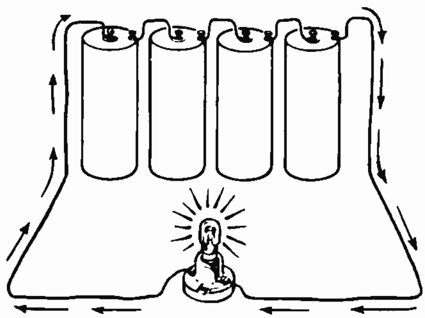
Adding a switch and a meter to a simple circuit

Whenever you use more than one device having resistance in the same circuit, they will be connected to form either a SERIES or PARALLEL circuit, or a combination SERIES-PARALLEL circuit.

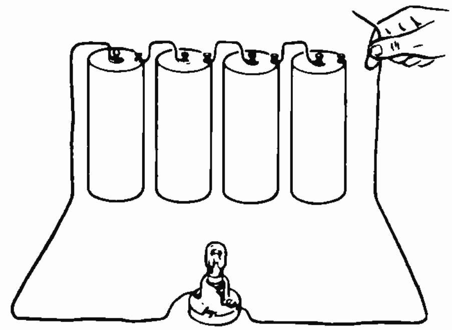
Switches

You already know that, in order for current to flow through a circuit, a closed path must be provided between the + and - terminals of the voltage source. Any break in the closed path opens the circuit and stops the flow of current.

CURRENT FLOW REQUIRES A CLOSED PATH



Current flow through a closed path

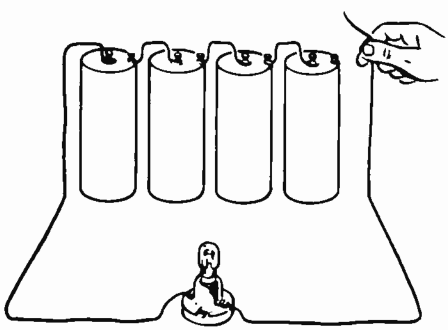


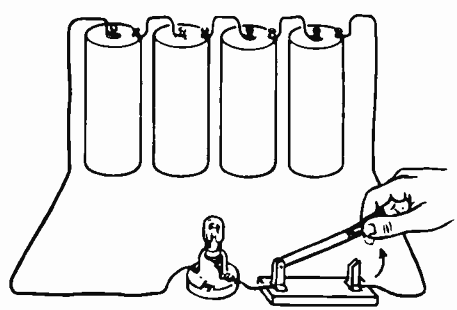
No closed path– no current flow

Until now we have stopped current flow by removing a battery lead. Since this is not a suitable method for opening a practical circuit, switches are actually used.

A CIRCUIT MAY BE OPENED BY:

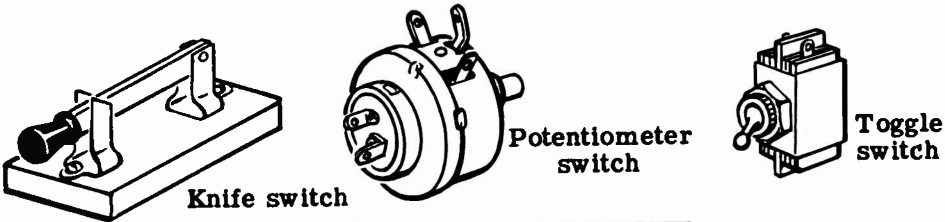
Removing a battery lead or . . . . opening a switch



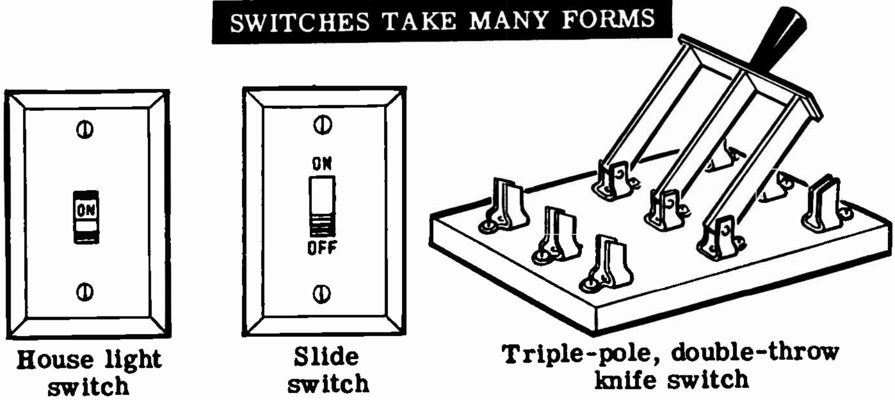


Switches (continued)

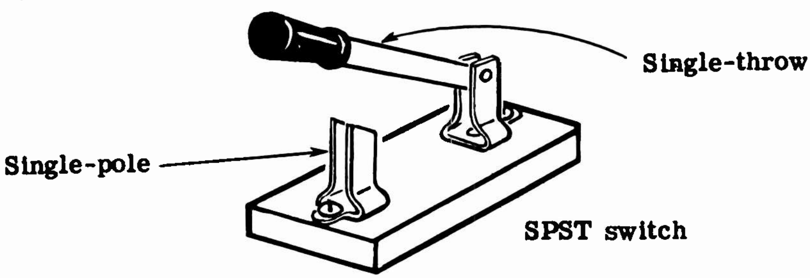
A switch is a device used to open and close a circuit or part of a circuit when desired. You have been using switches all your life—in lamps, flash-lights, radio, car ignition, etc. You will meet many other kinds of switches while working with equipment.



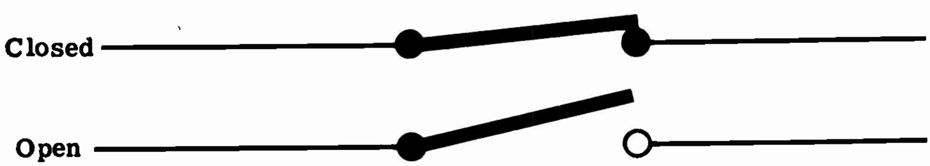
SWITCHES TAKE MANY FORMS



In the demonstrations and experiments to follow, a switch will be inserted in one of the battery leads. You will use a "single-pole, single-throw knife switch," which looks like this:



and is represented symbolically like this:



Circuit Symbols

Electrical circuit connections are usually shown in symbol form in the same manner as the dry cell and battery symbols which you have used previously. You will find that symbols are not only used to represent various types of equipment and show circuit connections, but are also used to express current, voltage and resistance.

To express the amounts of current, voltage, resistance and power, the following symbols are commonly used:

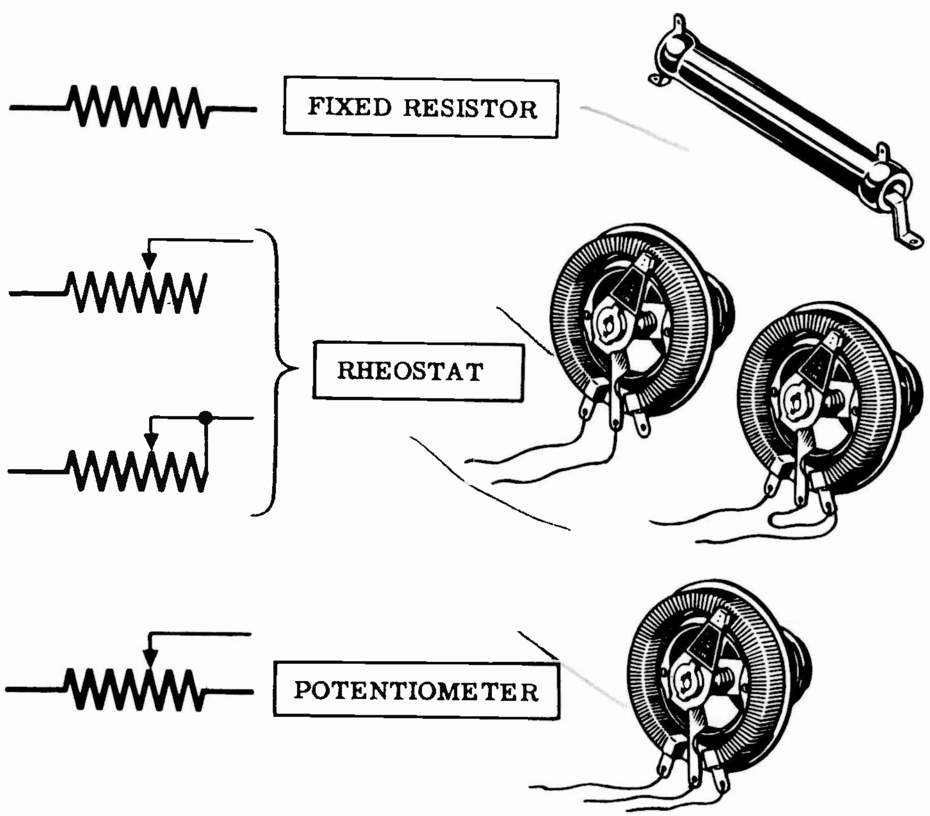
E = voltage **I** = current **R** = resistance **P** = power

V = volts **A** = amperes **Ω** = ohms **W** = watts

For example, in a simple circuit consisting of a lamp connected across a dry cell the voltage, current and resistance would be expressed as shown:

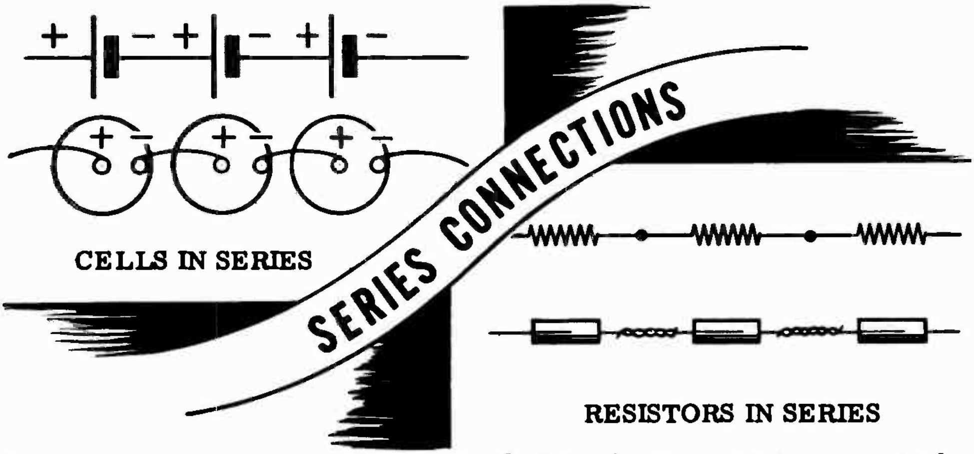
E=1.5 V (volts) **I=0.3 A** (ampere) **R=5Ω** (ohms) **P=0.45 W** (watt)

Circuit Symbols for Resistors



Series Circuit Connections

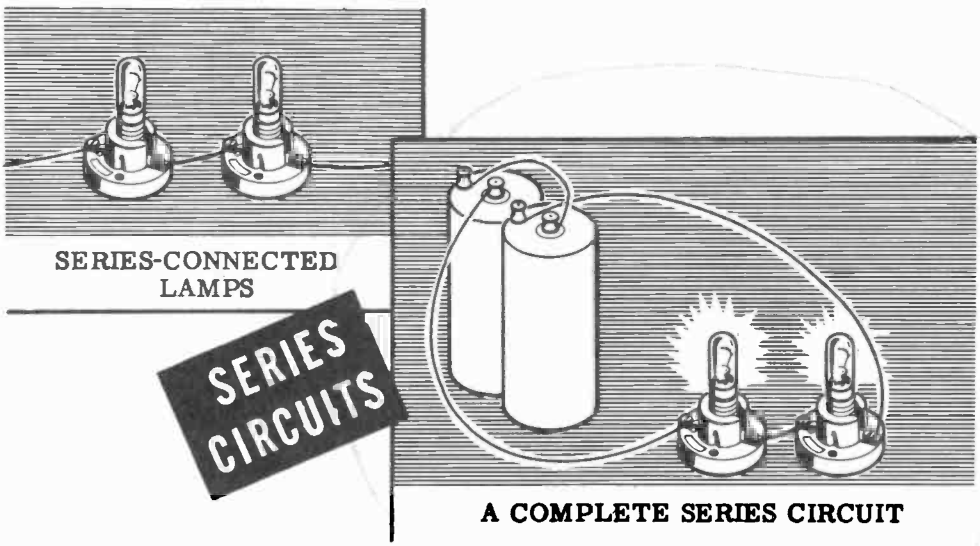
Whenever you connect resistances end to end, they are said to be series-connected. If all the resistances around a circuit are connected end to end so that there is only one path for current flow, they form a series circuit. You have already found out how to connect cells in series to form a battery. An important difference between cells and resistances connected in series is that cells must be connected with the proper polarity but resistances are not polarized.



CELLS IN SERIES

RESISTORS IN SERIES

Suppose you should connect a terminal of one lamp socket to a terminal on another socket, leaving one terminal on each socket unconnected. Lamps placed in these sockets would be series-connected, but you would not have a series circuit. To complete your series circuit, you would have to connect the lamps across a voltage source, such as a battery, using the unconnected terminals to complete the circuit. Any number of lamps, resistors or other devices having resistance can be used to form a series circuit, provided they are connected end to end across the terminals of a voltage source with only one path for current flow between these terminals.



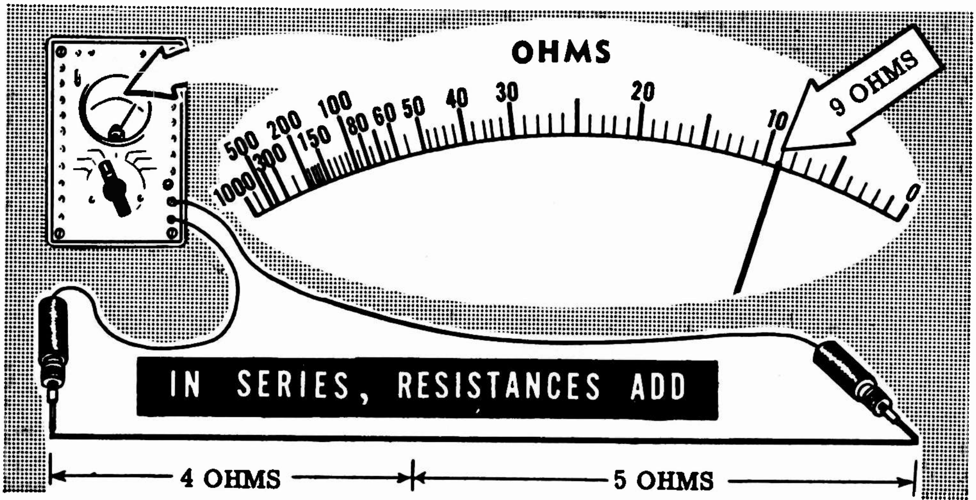
SERIES-CONNECTED LAMPS

A COMPLETE SERIES CIRCUIT

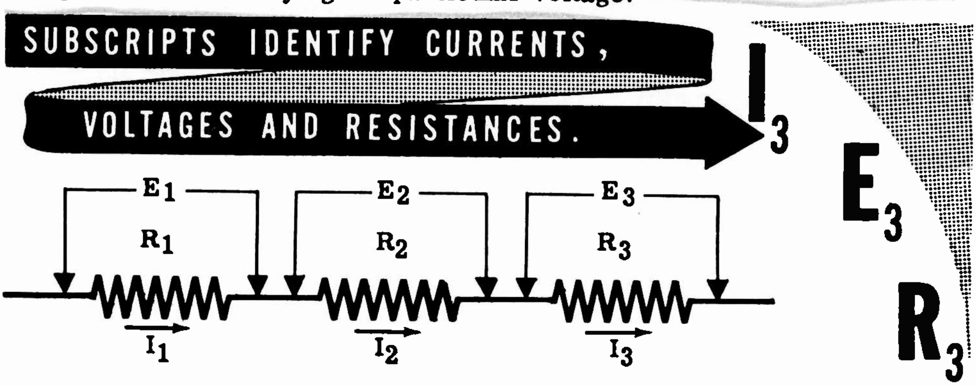
Resistances in Series

One of the factors of resistance is length, with the resistance of a conductor increasing as the conductor length increases.

If you add one length of wire to another, the resistance of the entire length of wire is equal to the sum of the resistances of the original lengths. For example, if two lengths of wire—one having a resistance of 4 ohms and the other of 5 ohms—are connected together, the total resistance between the unconnected ends is 9 ohms. Similarly, when other types of resistances are connected in series, the total resistance equals the sum of the individual resistances.

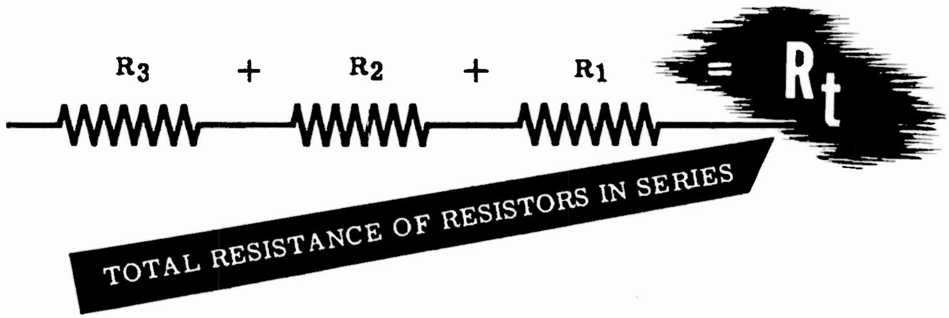


Whenever you use more than one of the same device or quantity in an electrical circuit, some method of identifying each individual device or quantity is necessary. For example, if three resistors of different values are used in a series circuit, something other than just R is needed to distinguish each resistor. A system of identification called "subscripts" is used and consists of following the symbol of the device or quantity by a very small identification number. R_1, R_2 and R_3 are all symbols for resistors but each identifies a particular resistor. Similarly E_1, E_2 and E_3 are all different values of voltage used in the same circuit, with the small subscript number identifying the particular voltage.



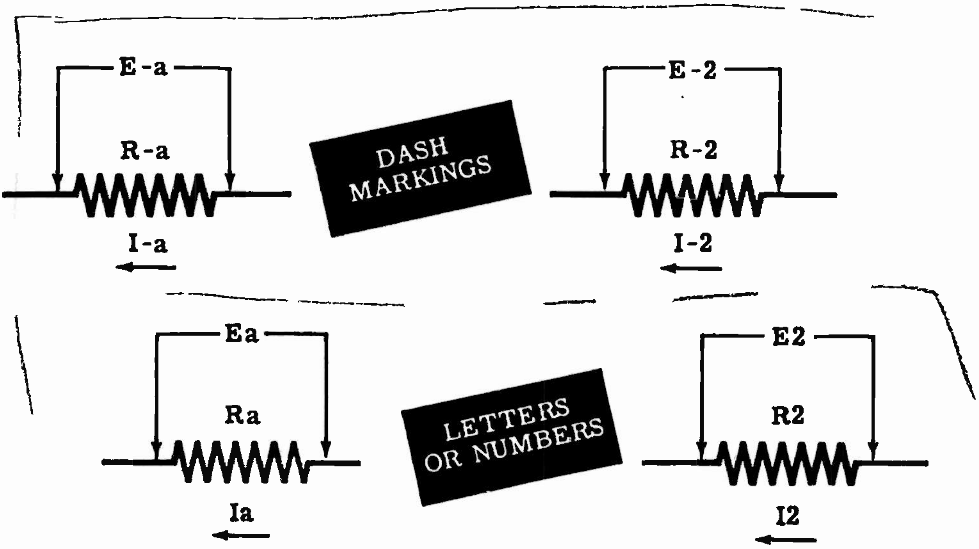
Resistances in Series (continued)

While numbers are used to identify individual electrical devices or quantities, a small letter "t" following the symbol indicates the total amount. You have found that when resistances are connected in series the total resistance equals the sum of the individual resistances. This might be expressed as $R_t = R_1 + R_2 + R_3$ where R_1, R_2 and R_3 represent resistors. The symbol R is also used to represent the resistance of other electrical devices.



You will find that, although subscripts are one method of identifying individual devices or quantities, other methods are also used. Some of these other methods are shown below and compared to the subscript method of marking. Regardless of the method used, the marking serves only one purpose—identification of individual devices or quantities—and does not indicate a value.

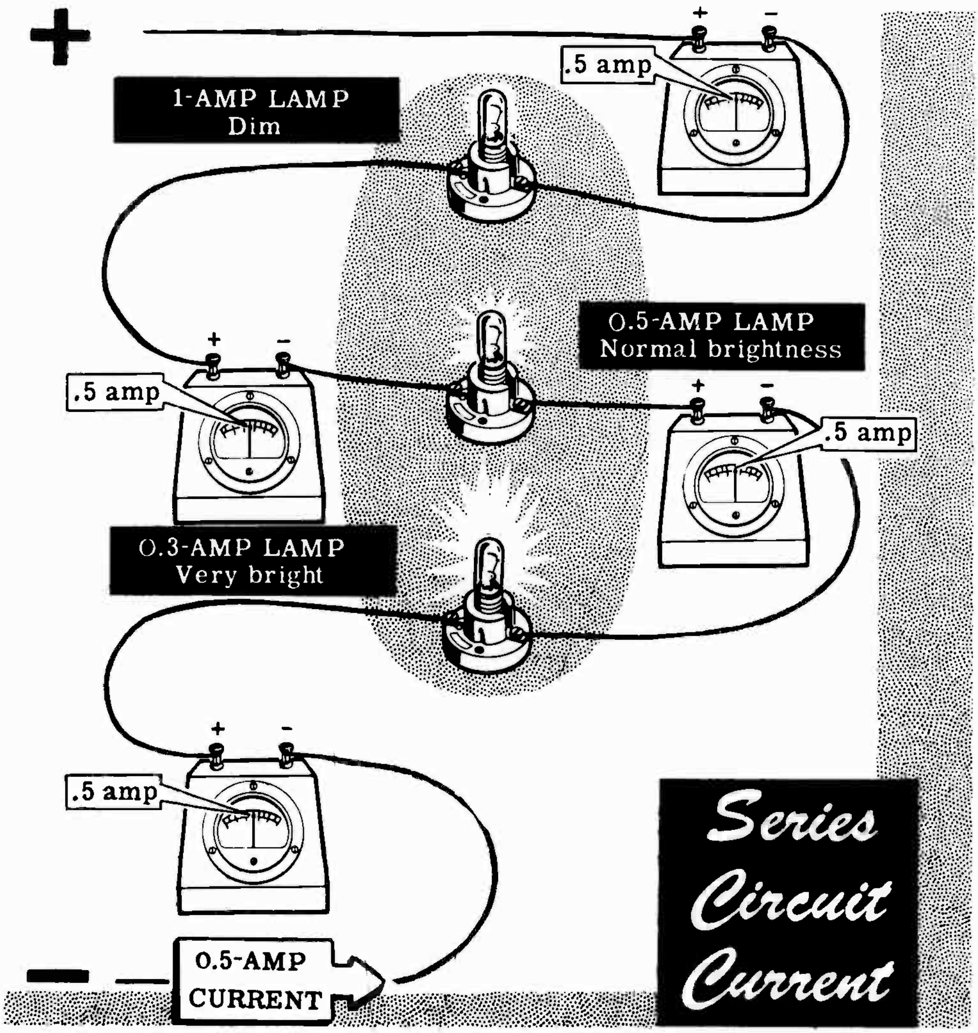
OTHER MARKINGS USED FOR IDENTIFICATION



Current Flow in Series Circuits

In a series circuit there is only one path for current flow. This means that all the current must flow through each resistance in the circuit. All parts of the circuit then must be able to pass the maximum current which flows, and the total resistance of the circuit must be large enough to reduce the amount of current to a value which can be safely passed by all the circuit resistances.

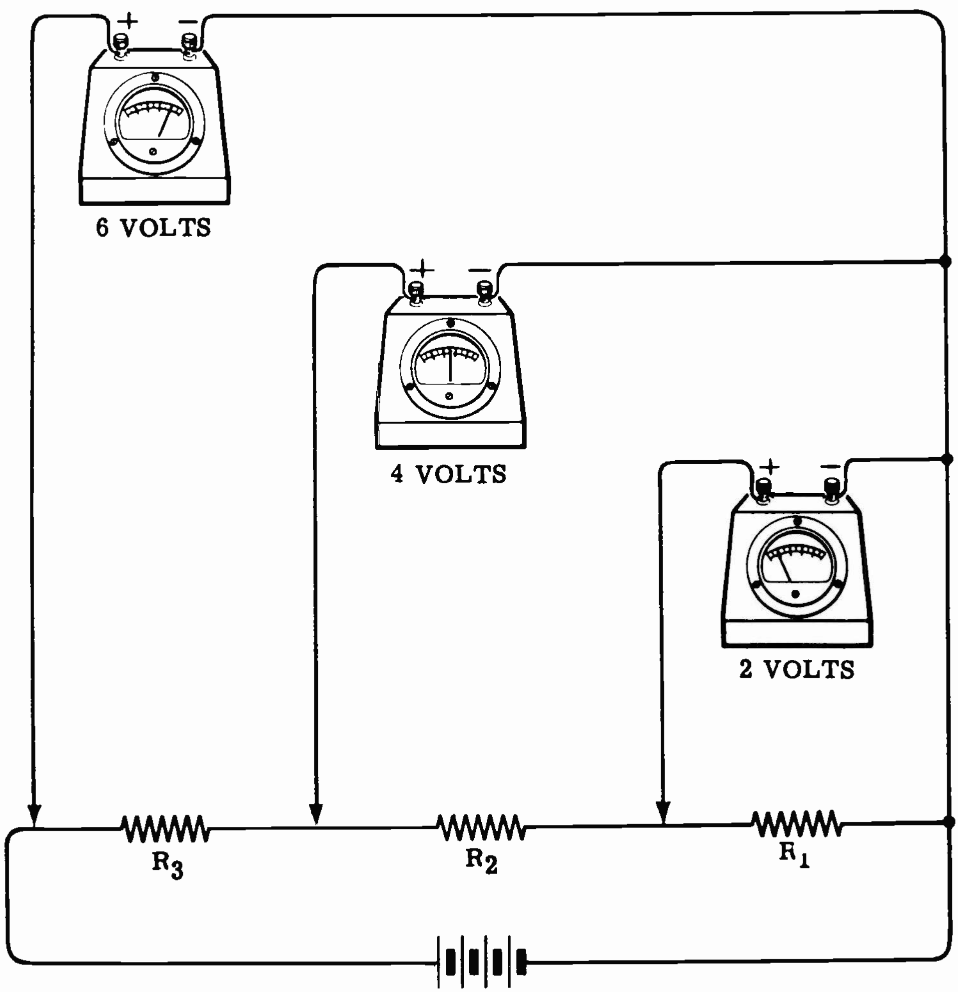
Ammeters placed at each end of all the resistances of a series circuit would read the same amount of current flow through each resistance. In a circuit containing devices such as lamps in series, each lamp for proper operation should be rated with the same amount of current. Lamps rated to operate at higher currents than the circuit current will light only dimly, while lamps rated for less than the circuit current will light very brightly, and perhaps even burn out due to the excess current. The same effect would be noticed if the circuit contained other types of resistances.



Voltage in Series Circuits

Whenever a force is exerted to move something against some form of opposition, the force is expended. For example, a hammer striking a nail exerts a force which moves the nail against the opposition offered by the wood, and as the nail moves, the force exerted is expended. Similarly, as emf moves electrons through a resistor, the force is expended, resulting in a loss of emf called "voltage drop."

Starting at one end of a series circuit consisting of three resistors of equal value connected across a six-volt battery, the potential drops will be two volts across resistor R_1, four volts across R_1 and R_2, and six volts across R_1, R_2, and R_3, the entire circuit. The voltage across each resistor is two volts, and adding the voltages across the three resistors results in the original total voltage of six volts.

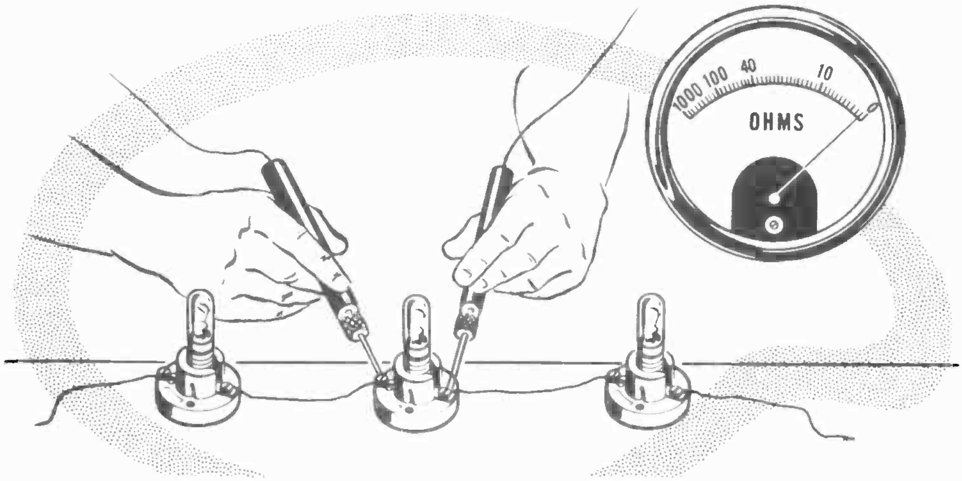


This drop in voltage occurs because the current flow in a series circuit is always the same throughout the circuit.

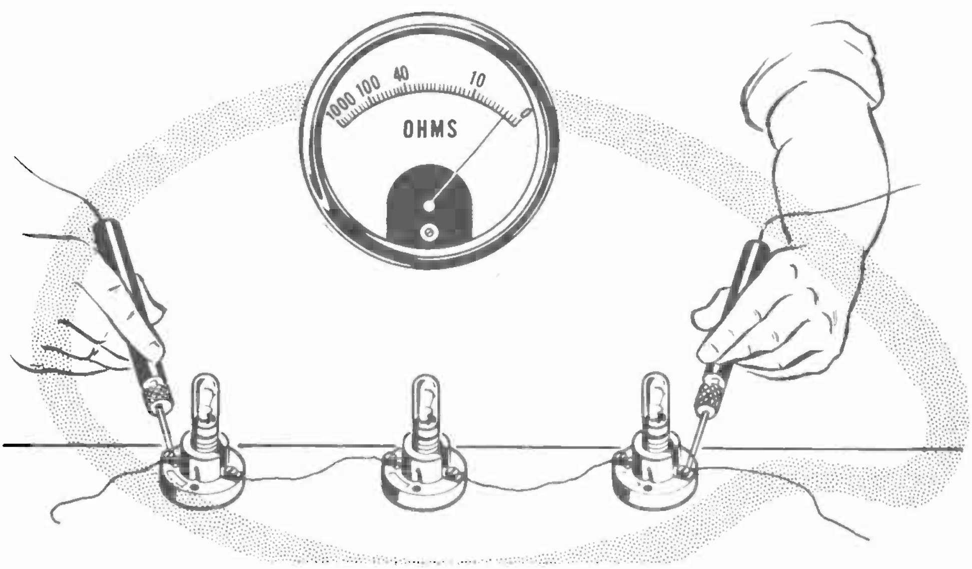
Demonstration—Series Circuit Resistance

To demonstrate the effect of connecting resistances in series, the instructor will measure the resistance of three lamps individually and then measure their resistance in series.

First the instructor connects three lamp sockets in series and inserts 6-volt lamps in the sockets. He then uses the ohmmeter to measure the resistance of each lamp, and you see that each lamp measures about one ohm.

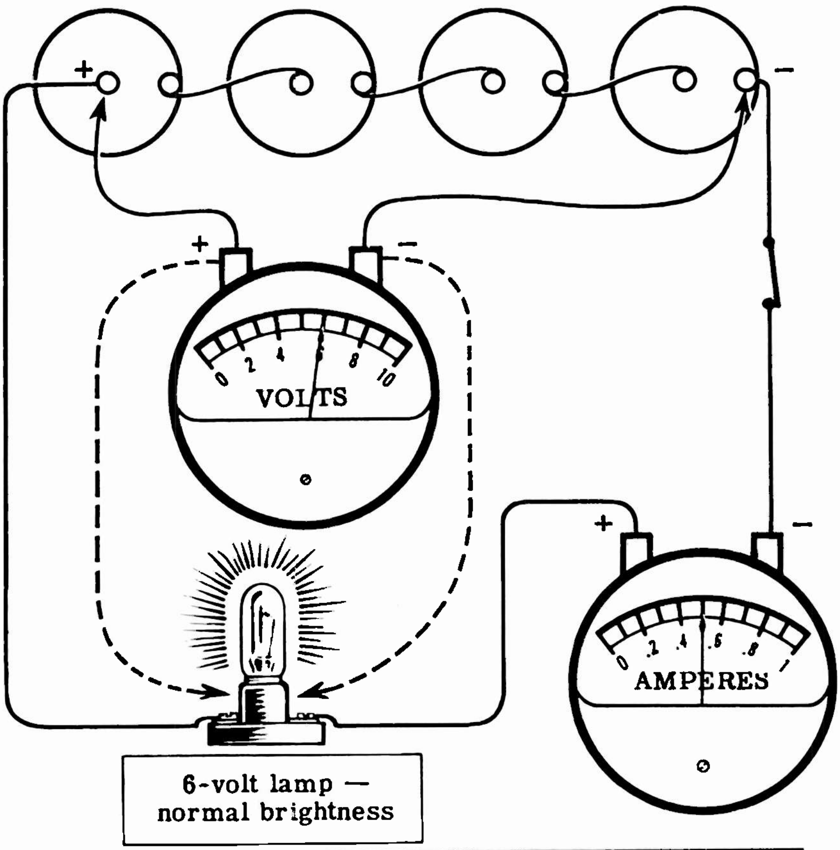


Then the instructor measures the resistance of the three lamps in series, and you see that the total resistance is about 3 ohms. Thus the total resistance of series-connected resistances is seen to be equal to the sum of all the individual resistances.



Demonstration—Series Circuit Resistance (continued)

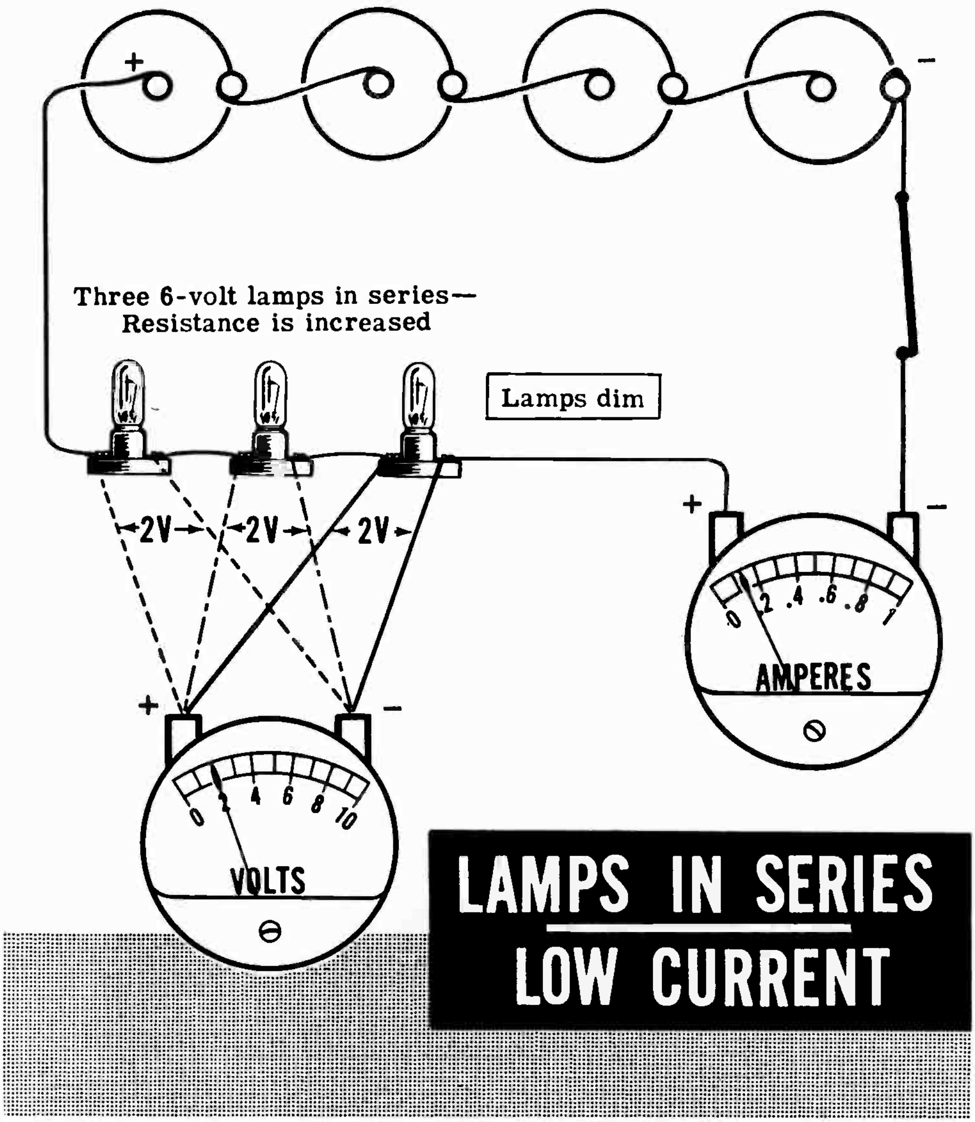
Using four dry cells connected in series to form a six-volt battery as a voltage source, the instructor demonstrates the effect of adding resistance in series. The voltmeter is connected across the battery and reads six volts, while the ammeter is connected in series with the negative lead of the battery to show the amount of current flow from the battery. With the ammeter in series, a single lamp socket is connected across the battery and a 6-volt lamp is inserted in the socket. You see that the lamp lights to normal brilliancy and that the ammeter reading is about 0.5 ampere. As the instructor moves the voltmeter to connect it directly across the lamp, you see that the voltage across the lamp is 6 volts.



SINGLE LAMP—
NORMAL CURRENT

Demonstration—Series Circuit Resistance (continued)

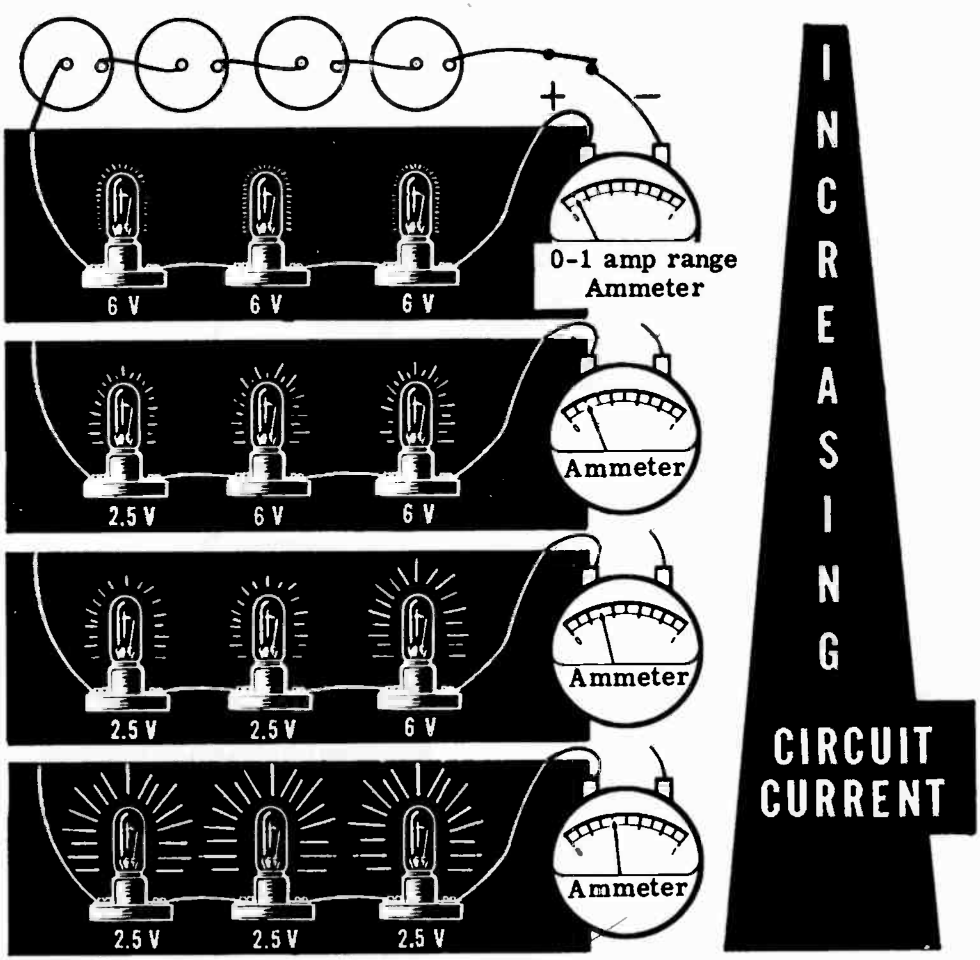
Next, the single lamp socket is replaced by three sockets in series and 6-volt lamps are inserted in the sockets. The lamps now light at well below normal brilliance, and the ammeter reading is about one-third its previous value. A voltmeter reading taken across the total circuit reads 6 volts and across each lamp the voltage is 2 volts. Since the voltage from the battery is not changed but the current decreased, the resistance must be greater. Adding the voltage across each lamp shows that the sum of the voltages across the individual resistances equals the total voltage.



Demonstration—Series Circuit Current

To show the effect of changing resistances on the amount of current flow and how different equipment requires different amounts of current for proper operation, one of the 6-volt lamps is replaced by a 2.5-volt lamp of less resistance. You see that the two 6-volt lamps increase to almost half of normal brilliancy while the 2.5-volt lamp is dim. The ammeter reading shows that the current increases, indicating that decreasing the resistance of one part of the circuit decreases the total opposition to current flow. Replacing another of the 6-volt lamps with a 2.5-volt lamp further decreases the total resistance and increases the total circuit current.

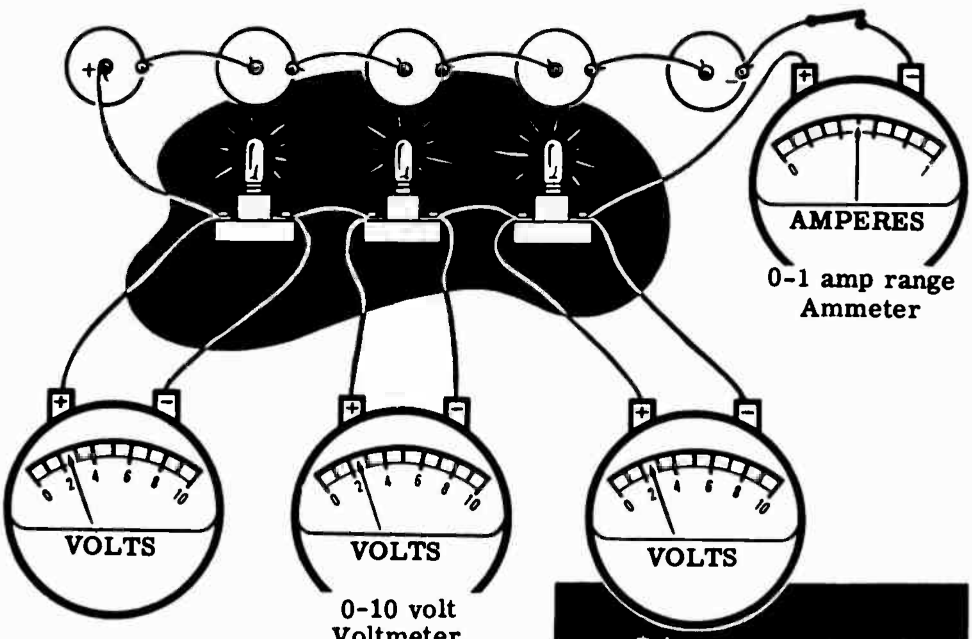
The brilliance of the lamps increases as the current flow increases, and with the last 6-volt lamp replaced by a lower resistance 2.5-volt lamp, you see that the circuit current for the three 2.5-volt lamps is approximately the same as that of a single 6-volt lamp. Also, the three lamps light at about normal brilliancy because the current is only slightly less than the rated value of these lamps, as is the voltage measured across each lamp.

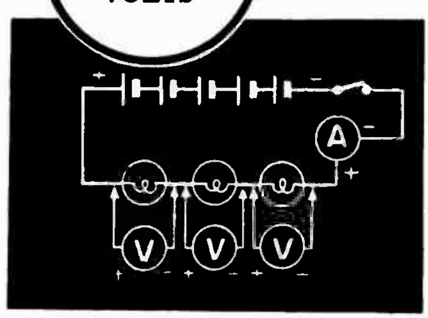


Demonstration—Series Circuit Voltage

The rated voltage of three 2.5-volt lamps in series is 7.5 volts so that the 6-volt battery does not cause the rated current to flow. By adding one more dry cell, the instructor shows how increasing the circuit voltage without changing the resistance will cause a greater current flow as you can see by the increased brilliancy of the lamps and the increased current reading. Voltage readings taken across the lamps show that the voltage across each lamp is the rated voltage of 2.5 volts. Removing one cell of the battery at a time and taking voltage readings across the lamps, the instructor shows that the voltages across the lamps equal each other and always add to equal the total battery voltage.

Now using five cells to form a 7.5-volt battery, the instructor replaces one of the 2.5-volt lamps with a 6-volt lamp having greater resistance. Voltmeter readings across the lamps still total 7.5 volts when added, but are not all equal. The voltages across the lower resistance 2.5-volt lamps are equal but less than 2.5 volts, while the voltage across the higher resistance 6-volt lamp is greater than 2.5 volts. You can see that for resistors in series the voltage divides in proportion across the various resistances connected in series, with more voltage drop across the larger resistance and less voltage drop across the smaller resistance.





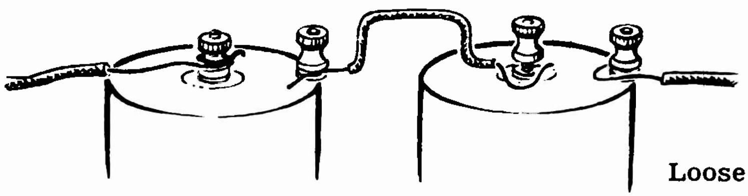
SERIES CIRCUITS... VOLTAGES DIVIDE

Demonstration—Open Circuits

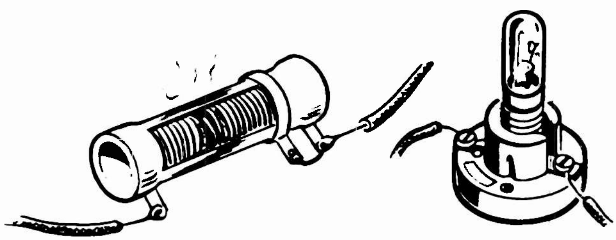
You already know that in order for a current to pass through a circuit a closed path is required. Any break in the closed path causes an "open" circuit, and stops current flow. Each time you open a switch, you are causing an open circuit.

Anything which causes an "open" other than actually opening a switch interferes with the proper operation of the circuit, and must be corrected. An open circuit may be caused by a loose connection, a burned-out resistor or lamp filament, poor joints or loose contacts, or broken wire.

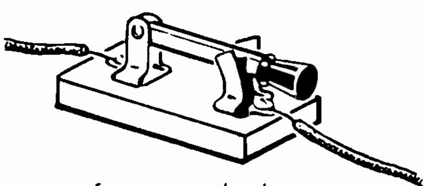
OPEN CIRCUITS can be caused by.....



Loose connections



Burned-out resistors
or lamp filament



Loose contacts

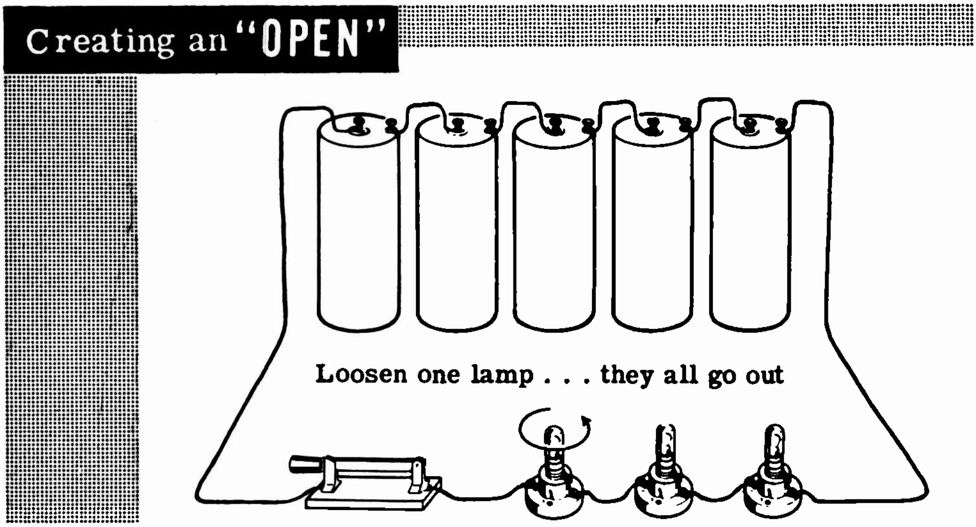
Broken wire

These faults can often be detected visually, and you may find that, in performing the experiments to follow, you will encounter one or more of these "opens."

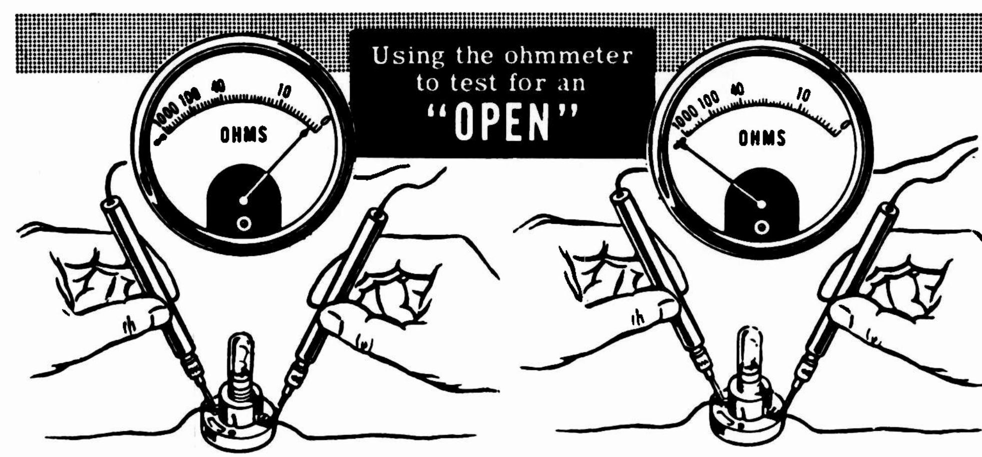
In some cases it is not possible to visually detect the cause of an open circuit. The instructor will demonstrate how to use the ohmmeter or a test lamp to find the cause of trouble.

Demonstration—Open Circuits (continued)

The instructor connects five dry cells, a knife switch and three lamp sockets in series. He then inserts 2.5-volt lamps in the sockets. When he closes the switch the lamps light with normal brilliancy. He then loosens one of the lamps and they all go out, indicating an open circuit. (A loosened lamp simulates a burned-out filament or other open.)



To locate the open with the ohmmeter the instructor first opens the knife switch to remove the voltage source, since an ohmmeter must never be used on a circuit with the power connected. He then touches the ohmmeter test leads across each unit in the circuit—the three lamps in this case. You see that for two of the lamps the ohmmeter indicates a resistance under 10 ohms, but for the loosened lamp the ohmmeter indicates infinity. Since an open does not allow any current to flow, its resistance must be infinite. The ohmmeter check for an open, then, is to find the series-connected element in the circuit which measures infinite resistance on the ohmmeter.

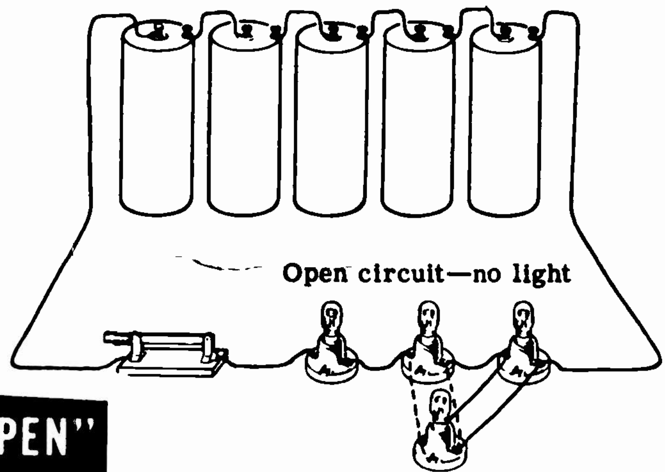


Good bulb – resistance less than 10 Ω "Open"– infinite resistance

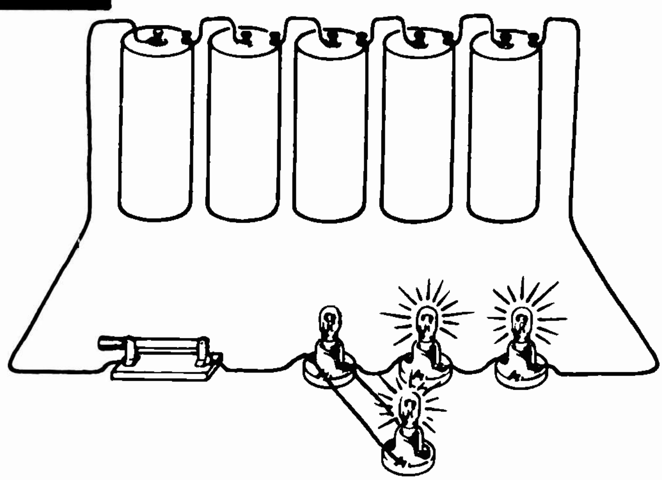
Demonstration—Open Circuits (continued)

The second method used to locate an open is to test the circuit by means of a test lamp. The instructor attaches leads to the terminals of a lamp socket and inserts a 2.5-volt lamp. He closes the circuit switch and touches the test lamp leads across each lamp in the circuit. The lamp does not light until he touches the terminals of the loosened lamp. The test lamp then lights, indicating he has found the open.

Finding an "OPEN" with a test lamp



Test lamp doesn't light across good lamps



Test lamp lights across loosened lamp

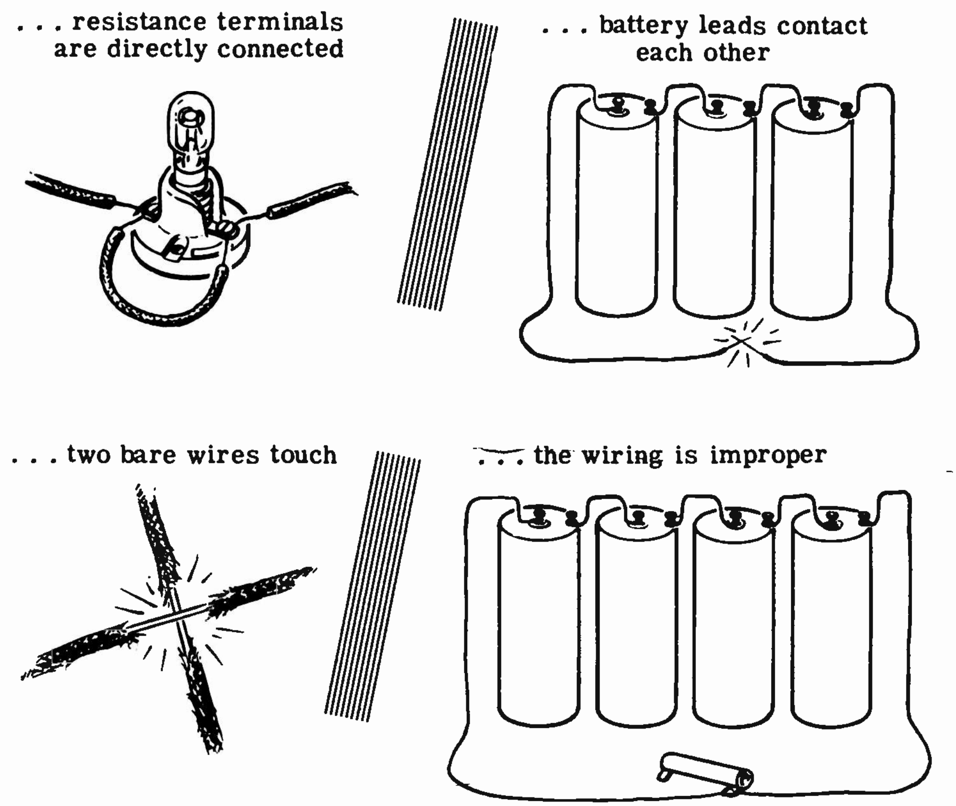
The test lamp completes the circuit and allows current to flow, bypassing the open. You will use this method often to detect opens which cannot be seen.

Demonstration—Short Circuits

You have seen how an open prevents current flow by breaking the closed path between terminals of the voltage source. Now you will see how a "short" produces just the opposite effect, creating a "short circuit" path of low resistance through which a larger than normal current flows.

A short occurs whenever the resistance of a circuit or part of a circuit drops from its normal value to zero resistance. This happens if the two terminals of a resistance in a circuit are directly connected; the voltage source leads contact each other, two current-carrying uninsulated wires touch, or the circuit is improperly wired.

A "Short" OCCURS WHEN . . .

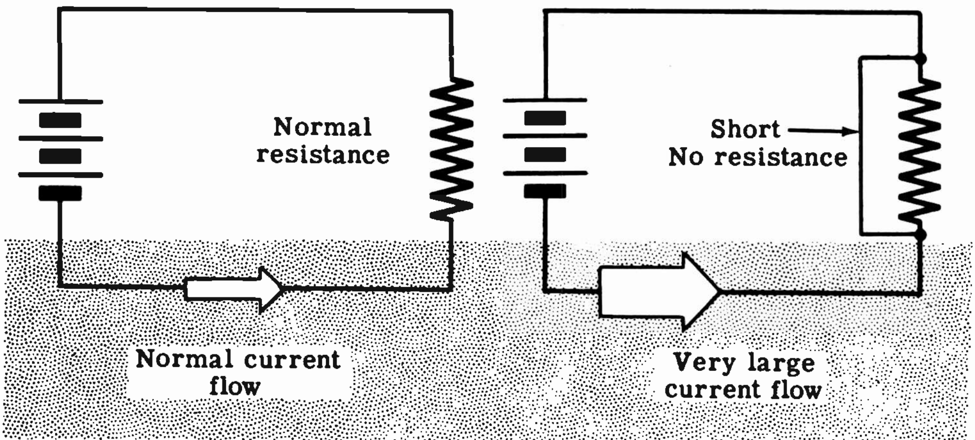


These shorts are called "external shorts" and can usually be detected by visual inspection.

Demonstration—Short Circuits (continued)

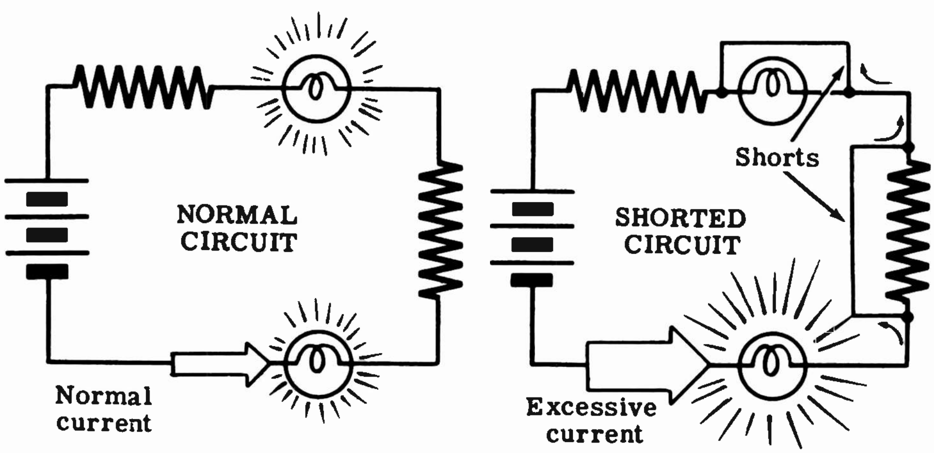
When a short occurs in a simple circuit, the resistance of the circuit to current flow becomes zero, so that a very large current flows.

The effect of a "SHORT" on current flow



In a series circuit, a short across one or more parts of the circuit results in reduction of the total resistance of the circuit and corresponding increased current, which may damage the other equipment in the circuit.

A *Shorted Circuit* RESULTS IN GREATER THAN NORMAL CURRENT

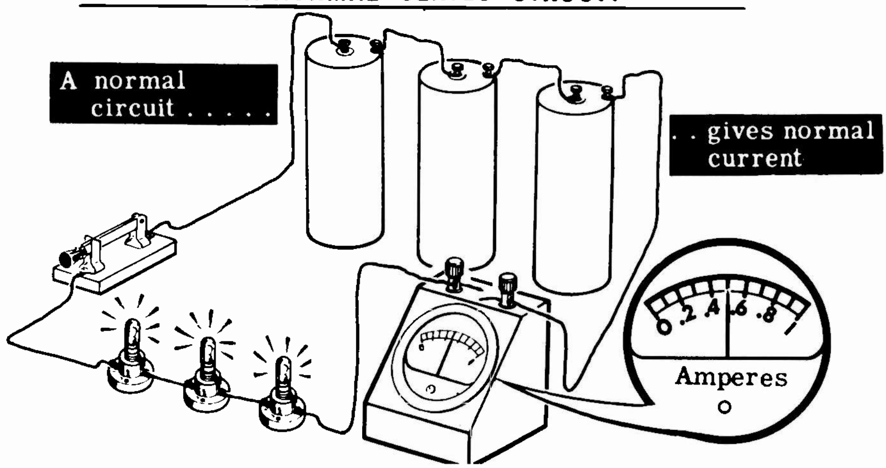


Circuits are usually protected against excessive current flow by the use of fuses, which you will learn about later. But it is important that you understand the reasons for and results of shorts so that you can avoid accidentally shorting your circuits and causing damage to meters or other equipment.

Demonstration—Short Circuits (continued)

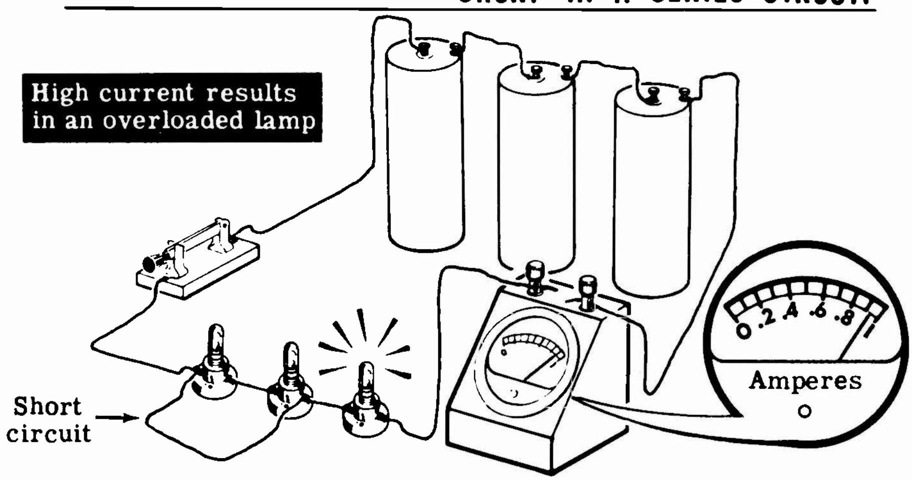
The instructor connects three dry cells in series with a 0-1 amp range ammeter and three lamp sockets. He inserts 2.5-volt lamps in the sockets and closes the switch. You see that the lamps light equally but are dim, and the ammeter indicates a current flow of about 0.5 amp.

A NORMAL SERIES CIRCUIT



The instructor then touches the ends of an insulated lead to the terminals of one of the lamps,"short-circuiting" the current around that lamp. You see that the lamp goes out, the other two lamps become brighter, and the ammeter shows that the current has increased to about 0.6 amp. When he moves the lead to short out two of the lamps, you see that they both go out, the third lamp becomes very bright, and the current increases to about 0.9 amp. Since the lamp is rated at only 0.5 amp, this excessive current would soon burn out the lamp filament.

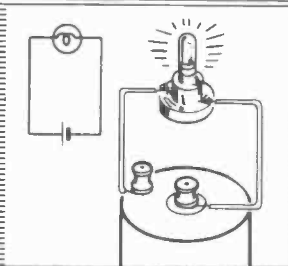
SEEING THE EFFECT OF A SHORT IN A SERIES CIRCUIT

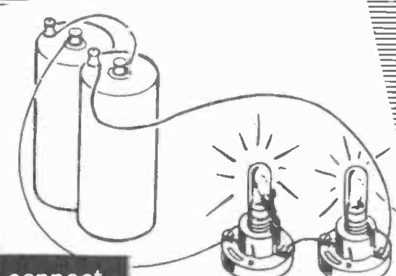


If the instructor were to short out all three lamps, the lack of resistance of the circuit would cause a very great current to flow which would damage the ammeter.

Review of Series Circuit Connections

Consider now what you have found out so far about electric circuits and particularly series circuits. While a complete electric circuit always consists of a complete path for current flow through the voltage source and across the terminals of the voltage source, you have discovered that—for all practical purposes—the path through the voltage source is disregarded in considering a circuit. Only the connections and effect of the resistances connected across the terminals of the voltage source are considered.

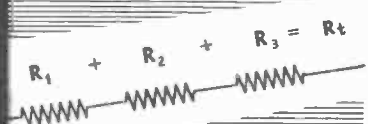




Simple Circuit—A single resistance connected across a voltage source.

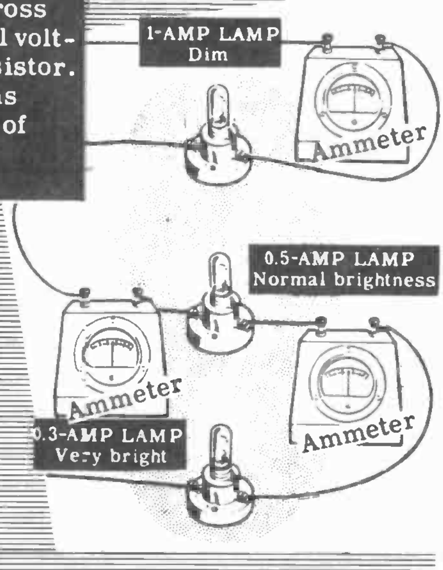
Series Circuit—Resistances connected end to end across a voltage source.

Series Circuit Resistance—The total resistance equals the sum of the individual resistances.



Series Circuit Current—The current is the same through all parts of the circuit.

Series Circuit Voltage—The voltage across each resistance is only a part of the total voltage and depends on the value of each resistor. Each of these parts of the total voltage is called IR or VOLTAGE DROP, the sum of which equal the total or applied voltage.



Ohm's Law in Simple Circuits

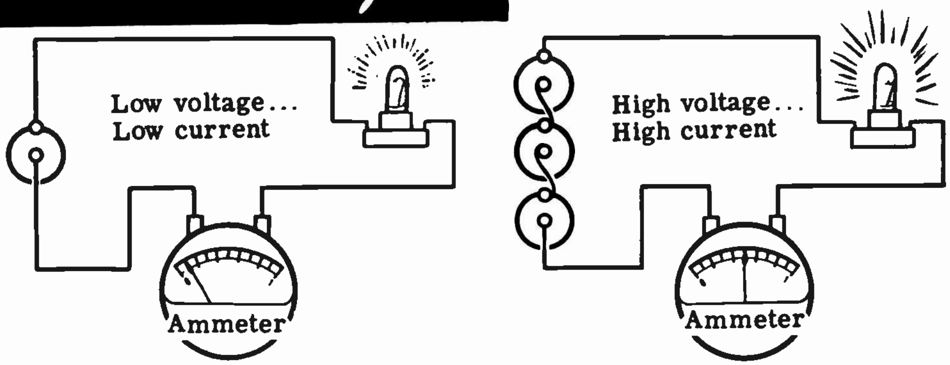
You have found out that voltage and resistance affect the current flow in a circuit, and that voltage drops across a resistance. The basic relationships of current, voltage and resistance are as follows:

1. Current in a circuit increases when the voltage is increased for the same resistance.
2. Current in a circuit decreases when the resistance is increased for the same voltage.

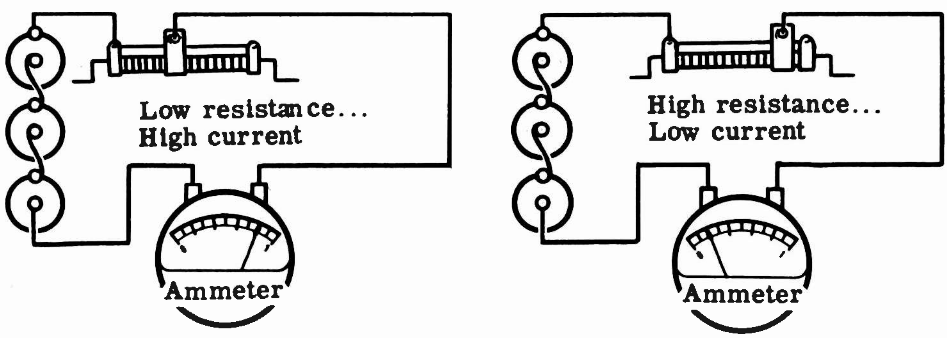
These two relationships combined are Ohm's Law, ~~the most~~ basic law of electric circuits, usually stated as follows:

THE CURRENT FLOWING IN A CIRCUIT CHANGES IN THE SAME DIRECTION THAT THE VOLTAGE CHANGES, AND IN THE OPPOSITE DIRECTION THAT THE RESISTANCE CHANGES.

Current changes...



...IN THE SAME DIRECTION THAT THE VOLTAGE CHANGES...



. . IN THE OPPOSITE DIRECTION THAT THE RESISTANCE CHANGES

Ohm's Law in Simple Circuits (continued)

You have seen that if a certain current of electricity flows in a circuit, it flows because a certain electromotive force, or voltage, forces it to flow, and that the amount of current is limited by the resistance of the circuit. In fact, the amount of current depends upon the amount of electrical pressure, or voltage, and the amount of resistance. This fact was discovered by a man named George S. Ohm and is expressed by the now famous Ohm's Law which is the fundamental equation of all electrical science. Since it was first stated in 1827, this law has been of outstanding importance in electrical calculation. One of the most common ways of expressing Ohm's Law is that THE CURRENT FLOWING IN A CIRCUIT IS DIRECTLY PROPORTIONAL TO THE APPLIED VOLTAGE, AND INVERSELY PROPORTIONAL TO THE RESISTANCE. When you put this word statement into a mathematical relationship you get

$$\text{CURRENT} = \frac{\text{ELECTROMOTIVE FORCE (or VOLTAGE)}}{\text{RESISTANCE}}$$

or

$$\text{AMPERES} = \frac{\text{VOLTS}}{\text{OHMS}}$$

Ohm's Law can also be written in two other forms.

$$\text{VOLTAGE} = \text{CURRENT} \times \text{RESISTANCE}$$

or

$$\text{VOLTS} = \text{AMPERES} \times \text{OHMS}$$

This enables you to find the voltage when you know the current and resistance.

If you know the voltage and the current, you can find the resistance then by simply applying the following form of Ohm's Law.

$$\text{RESISTANCE} = \frac{\text{VOLTAGE}}{\text{CURRENT}}$$

or

$$\text{OHMS} = \frac{\text{VOLTS}}{\text{AMPERES}}$$

Ohm's Law in Simple Circuits (continued)

Ohm's law is used in electric circuits and parts of circuits to find the unknown quantity of current, voltage or resistance when any two of these quantities are known. In its basic form Ohm's law is used to find the current in a circuit if the voltage and resistance are known. To find the current through a resistance, the voltage across the resistance is divided by the resistance.

$$\text{Current (amperes)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms)}}$$

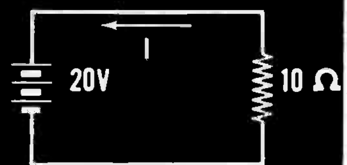
In symbol form: $I = \frac{E}{R}$

As you know, the current in a circuit increases if the voltage increases and the resistance remains the same. By giving values to E and R, you can see how this works. Suppose that R is 10 ohms and E is 20 volts. Since the current equals 20 divided by 10, the current is 2 amperes as shown:

$$\text{Current} = \frac{\text{voltage}}{\text{resistance}}$$

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

$$I = \frac{20}{10} = 2 \text{ amperes}$$



Now if E is increased to 40 volts without changing the resistance, the current increases to 4 amperes.

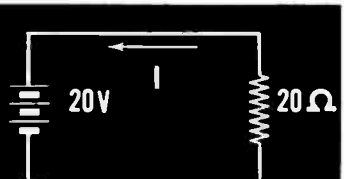
$$I = \frac{E}{R}$$

$$I = \frac{40}{10} = 4 \text{ amperes}$$

Similarly, if the voltage remains the same and the resistance is increased, the current decreases. Using the original values where E is 20 volts and R is 10 ohms, you found that the current is 2 amperes. If R is increased to 20 ohms without changing the voltage, the current decreases to 1 ampere.

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

$$I = \frac{20}{20} = 1 \text{ ampere}$$



Ohm's Law in Simple Circuits (continued)

While $I = \frac{E}{R}$ is the basic form of Ohm's law and is used to find current, by expressing the law in other forms, it may be used to obtain either E or R.

To use Ohm's law to find the resistance when voltage and current are known, the voltage is divided by the current.

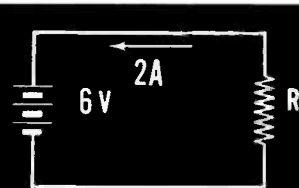
$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

In symbol form: $R = \frac{E}{I}$

As an example, if the current through a lamp connected across a 6-volt battery is 2 amperes, the resistance of the lamp is 3 ohms.

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

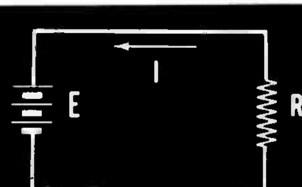
$$R = \frac{6}{2} = 3 \text{ ohms}$$



A third use for Ohm's law is to find the voltage when the current and resistance are known. To find the voltage across a resistance, the current is multiplied by the resistance.

Voltage = Current x Resistance

$$E = I \times R$$

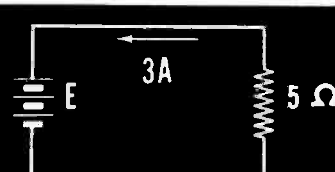


In writing electrical laws as formulas, the multiplication sign is not normally used, so that Ohm's law for voltage is expressed as: $E = IR$

To find the voltage across a 5-ohm resistor when 3 amperes of current are flowing, you must multiply I times R, so that the voltage equals 15 volts.

$$E = IR$$

$$E = 3 \times 5 = 15 \text{ volts}$$



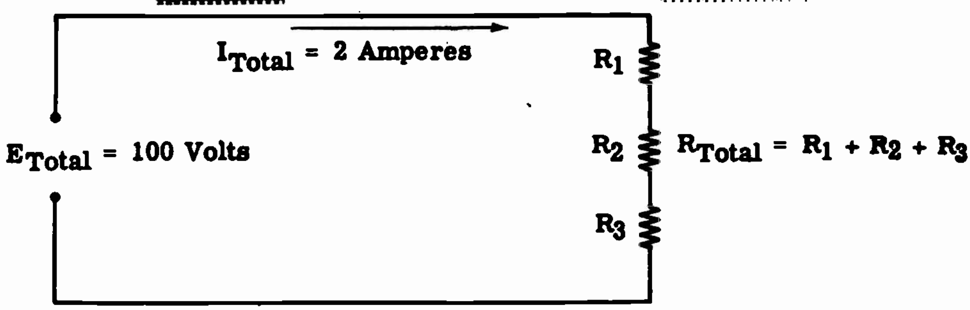
In using Ohm's law, the quantities must always be expressed in the basic units of current, voltage and resistance. If a quantity is given in larger or smaller units, it must first be changed so that it is expressed in amperes, volts or ohms.

Establishing Total Resistance in Series Circuits

In the previous topic you learned that the total resistance in a series circuit is equal to the sum of the individual resistances in that circuit. Total resistance in a series circuit, called R_T, may be established by using Ohm's Law if the amount of current in the circuit and the impressed voltage are known.

Consider the schematic diagram below. Note that the total impressed voltage, E_T, is 100 volts, and that the total current in the circuit, I_T, is two amperes. Note also, that there are three resistors in series. This fact will not cause any difficulty in solving the problem if you remember that the total current flowing in a circuit is the result when the total voltage is applied across the total resistance in the circuit. Using Ohm's Law, then, the total resistance is equal to the total voltage divided by the total current.

Applying Ohm's Law To A Series Circuit



$$R_{Total} = R_1 + R_2 + R_3$$

$$R_{Total} = \frac{E_{Total}}{I_{Total}}$$

$$R_T = \frac{100 \text{ Volts}}{2 \text{ Amperes}}$$

$$R_T = 50 \text{ Ohms}$$

In the previous topic you also learned that when the voltage drops in a series circuit are added together, the total value is equal to the total impressed voltage, or

$$E_{Total} = E_1 + E_2 + E_3$$

You learned, too, that the current flowing in a series circuit is everywhere the same, or

$$I_{Total} = I_1 = I_2 = I_3$$

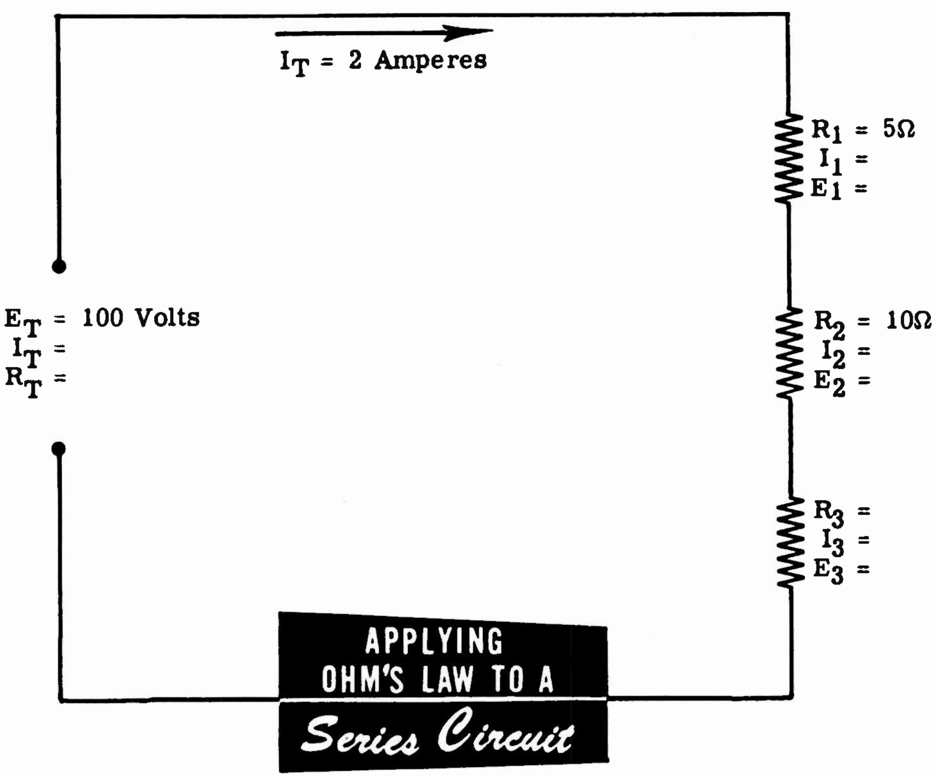
This is true even though the various resistors in the series circuit may all be of different values.

Ohm's Law in Series Circuits

You can use Ohm's law in working with series circuits, either as applied to the entire circuit or to only a part of the circuit. It can only be used to find an unknown quantity for a certain part of the circuit when two factors are known. Consider a circuit consisting of three resistors connected in series across 100 volts, with a circuit current flow of 2 amperes. If two of the resistor values, R_1 and R_2, are known to be 5 ohms and 10 ohms respectively, but the third resistor value R_3 is not known, the value of R_3 and the current and voltage for each resistor may be determined by applying Ohm's law to each part of the circuit.

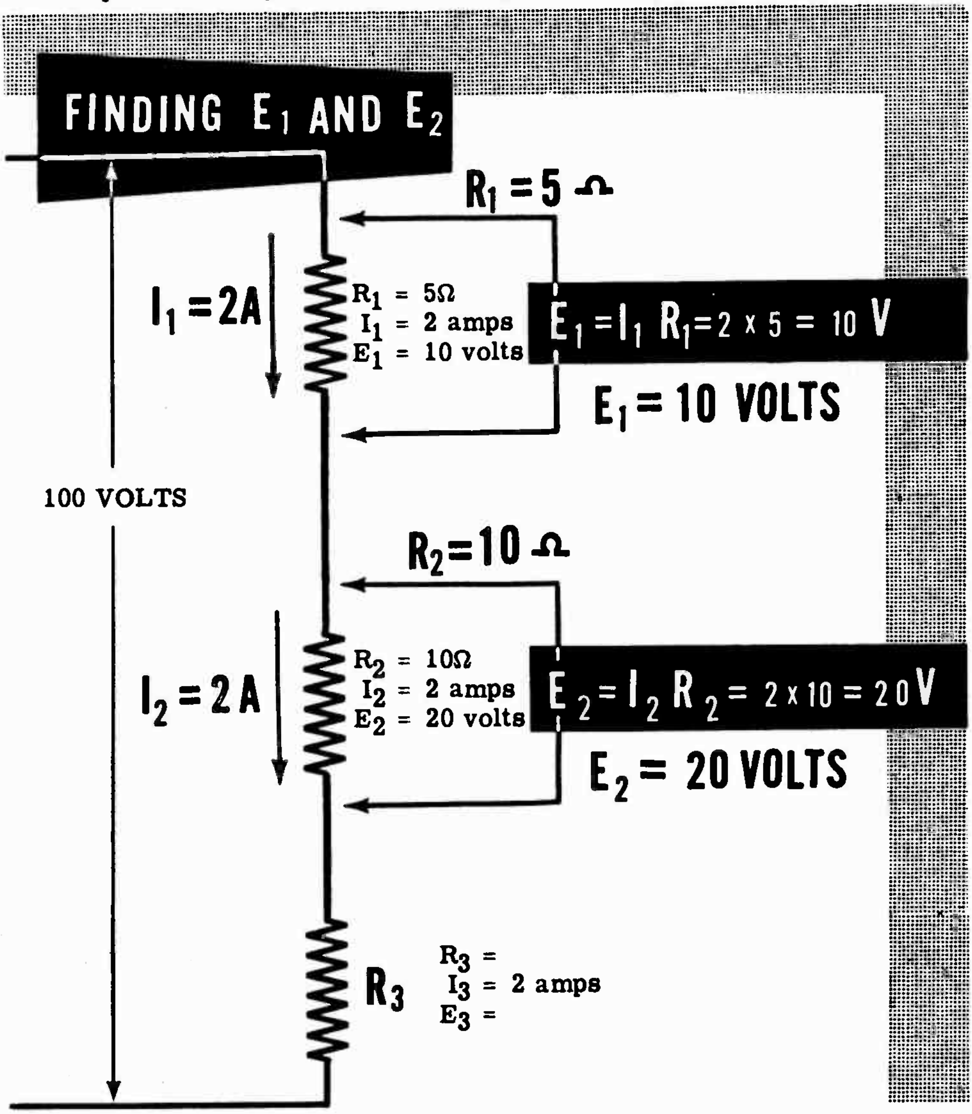
To find the unknown values, you should first make a simple sketch, see the diagram below, for recording the information which you already have and that which you will obtain as you use Ohm's Law for various parts of the circuit. This sketch will enable you to visualize the various components of the circuit and their relationships with one another.

Next you should record all of the known factors concerning each resistor. You know that R_1 equals 5 ohms and R_2 equals 10 ohms and also that the circuit current is 2 amperes. Since there is only one path for current in a series circuit, the current is the same in every part of the circuit and is equal to 2 amperes.



Ohm's Law in Series Circuits (continued)

For R_1 and R_2 you have two known quantities—resistances and currents—and can therefore find the voltages. Using Ohm's law to find the voltage across R_1, for example, the current—2 amperes—is multiplied by the resistance—5 ohms—resulting in a voltage of 10 volts across R_1. Similarly the voltage across R_2 is found by multiplying the current by the resistance—2 amperes times 10 ohms—resulting in a voltage of 20 volts across R_2.

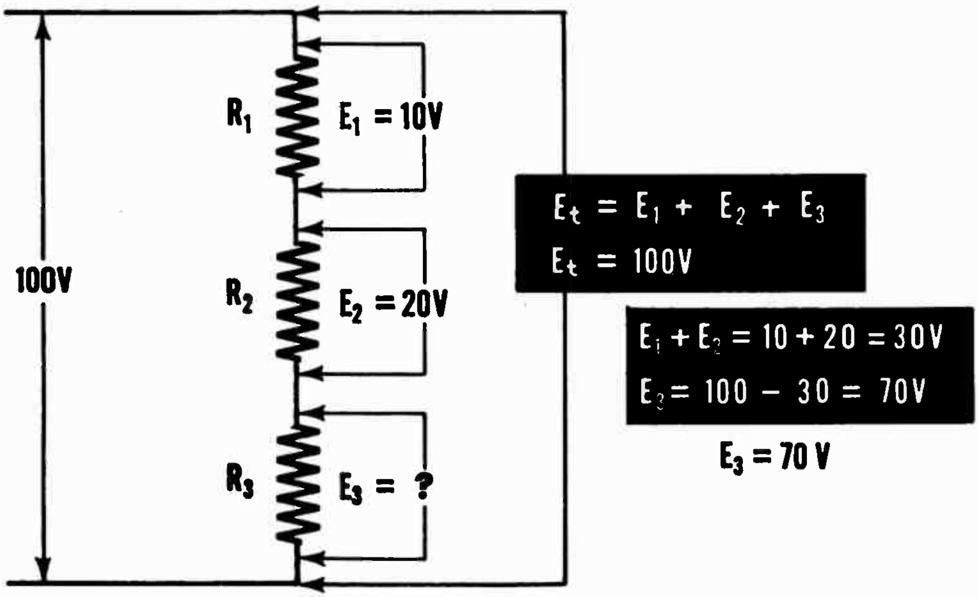


Your sketch now is complete except for the resistance value and voltage across R_3. If you can obtain the correct value of either the resistance or the voltage for R_3, the other quantity can easily be found by applying Ohm's law to R_3.

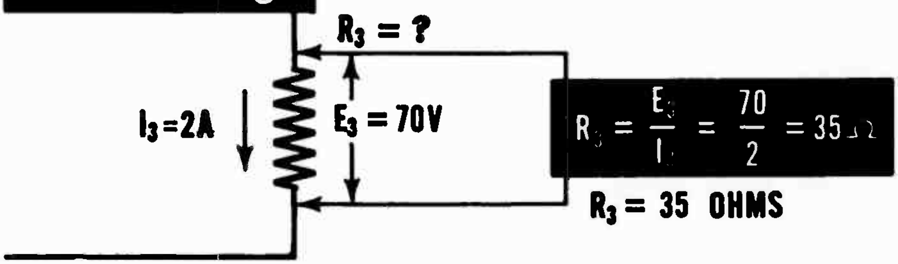
Ohm's Law in Series Circuits (continued)

Since the three resistors are connected across 100 volts, the voltages across the three resistors must equal 100 volts when added together. If the voltages across R_1 and R_2 are equal to 10 volts and 20 volts respectively, the total voltage across the two equals 30 volts. Then the voltage across R_3 must equal the difference between the total 100 volts and the 30-volt total across R_1 and R_2, or 70 volts. Ohm's law can be used to find the resistance of R_3 by dividing the voltage—70 volts—by the current —2 amperes—so that R_3 equals 35 ohms.

FINDING E_3



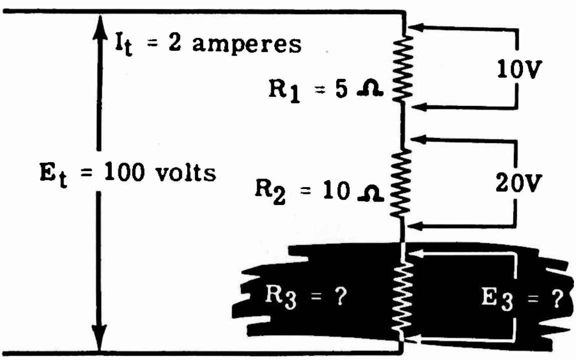
FINDING R_3



Ohm's Law in Series Circuits (continued)

You can also use another method of finding the unknown quantities for R_3. Since the total circuit voltage and current is known, the total circuit resistance can be found by dividing the voltage—100 volts—by the current—2 amperes. The total resistance then is 50 ohms and, since this total must equal the sum of R_1, R_2 and R_3, the value of R_3 is equal to the difference between 50 ohms and R_1 plus R_2. The sum of R_1 and R_2 equals 15 ohms, leaving a difference of 35 ohms as the resistance value of R_3. With the resistance value and current for R_3 known, the voltage is found by multiplying the two known quantities. Multiplying the resistance—35 ohms—by the current—2 amperes—results in a voltage of 70 volts across R_3. The results are the same as those previously obtained.

ANOTHER WAY TO FIND R_3 AND E_3



$R_t = \frac{E_t}{I_t} = \frac{100}{2} = 50\,\Omega$

$R_t = 50\,\Omega$

Also

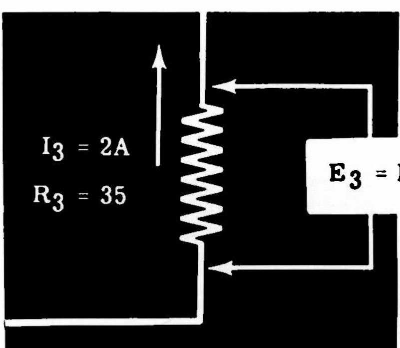
$R_t = R_1 + R_2 + R_3$

To find R_3

$R_1 + R_2 = 5 + 10 = 15\,\Omega$

$R_3 = 50 - 15 = 35\,\Omega$

R_3 = 35 OHMS



$E_3 = I_3 R_3 = 2 \times 35 = 70V$

E_3 = 70 VOLTS

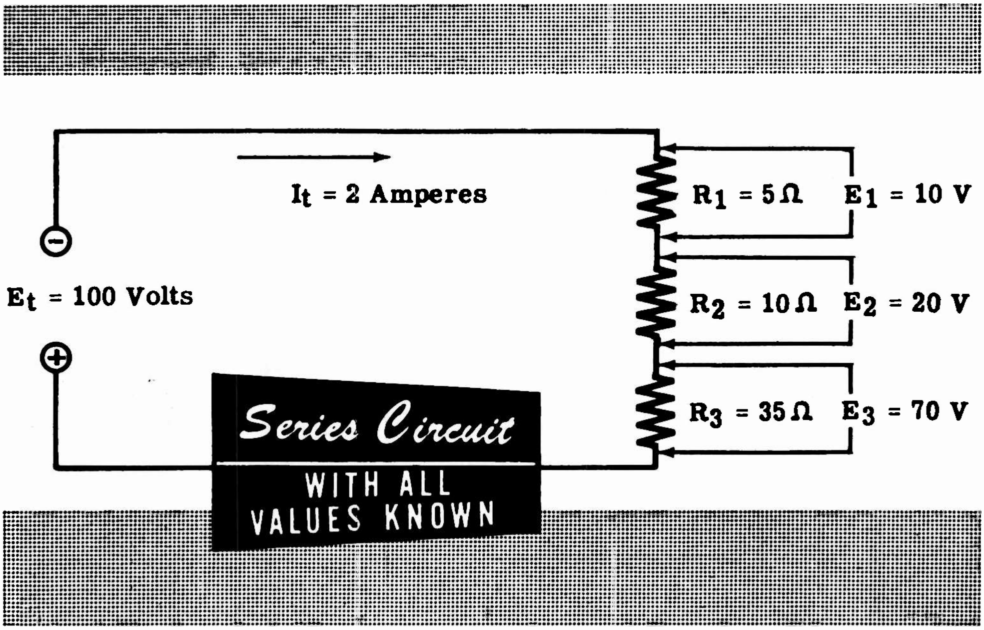
Ohm's Law in Series Circuits (continued)

With the values of R_3 and E_3 known, your table is now complete, giving all the values of resistance, voltage and current for each of the three resistors in the circuit. From the completed table of values you can find the total circuit resistance, voltage and current. Since the circuit is series-connected, the current for the total circuit is the same as that for any part of the circuit, while the total voltage and the total resistance are found by adding the individual voltages and resistances.

Completed Table of Values

Part of Circuit	Resistance	Voltage	Current
R_1	5 Ohms	10 Volts	2 Amperes
R_2	10 Ohms	20 Volts	2 Amperes
R_3	35 Ohms	70 Volts	2 Amperes

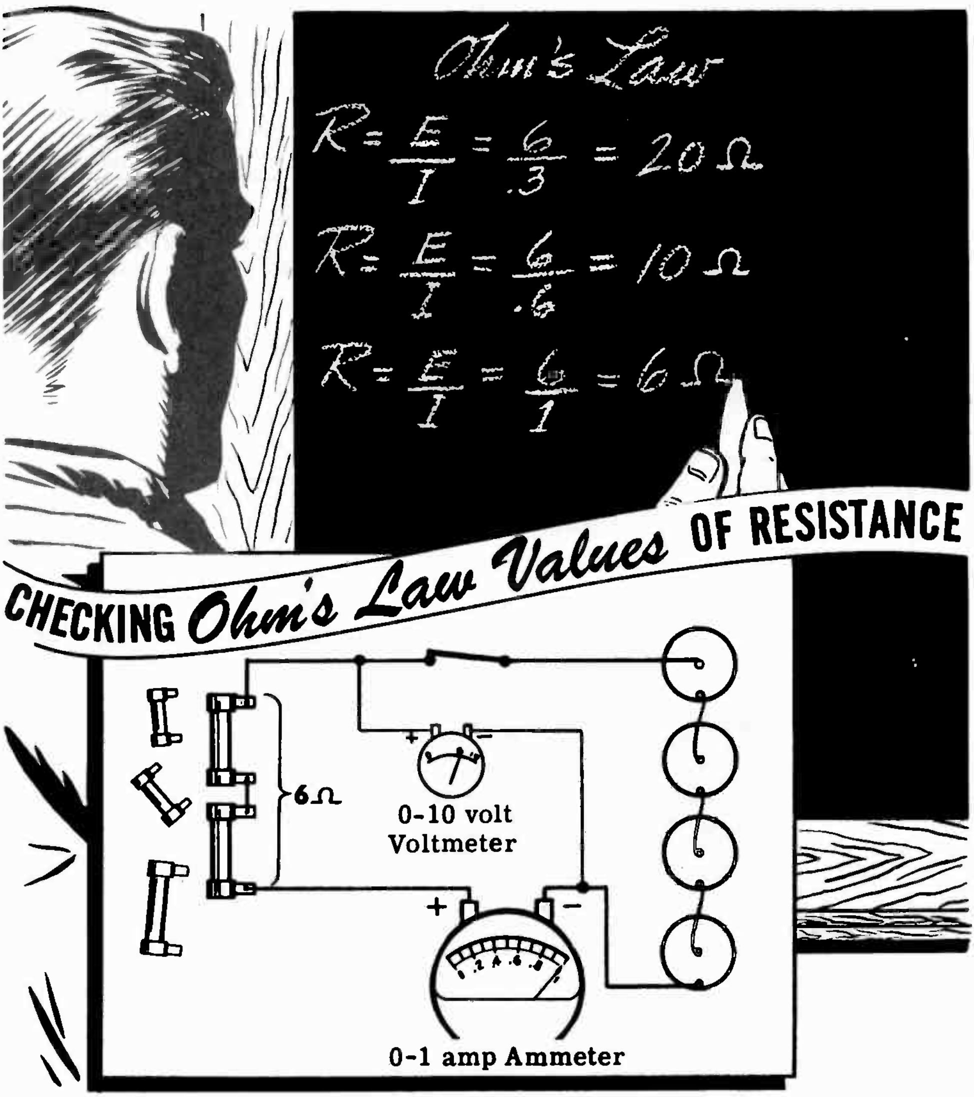
The total resistance (R_t) is equal to 50 ohms, the total current (I_t) is 2 amperes, and the total voltage (E_t) is 100 volts. Now you know all of the circuit values.



To find unknown circuit quantities always solve completely those parts of the circuit for which you know two quantities, by applying Ohm's law to that part of the circuit. Apply the rules for current, voltage and resistance in series circuits to find other unknown quantities which cannot be found by means of Ohm's law.

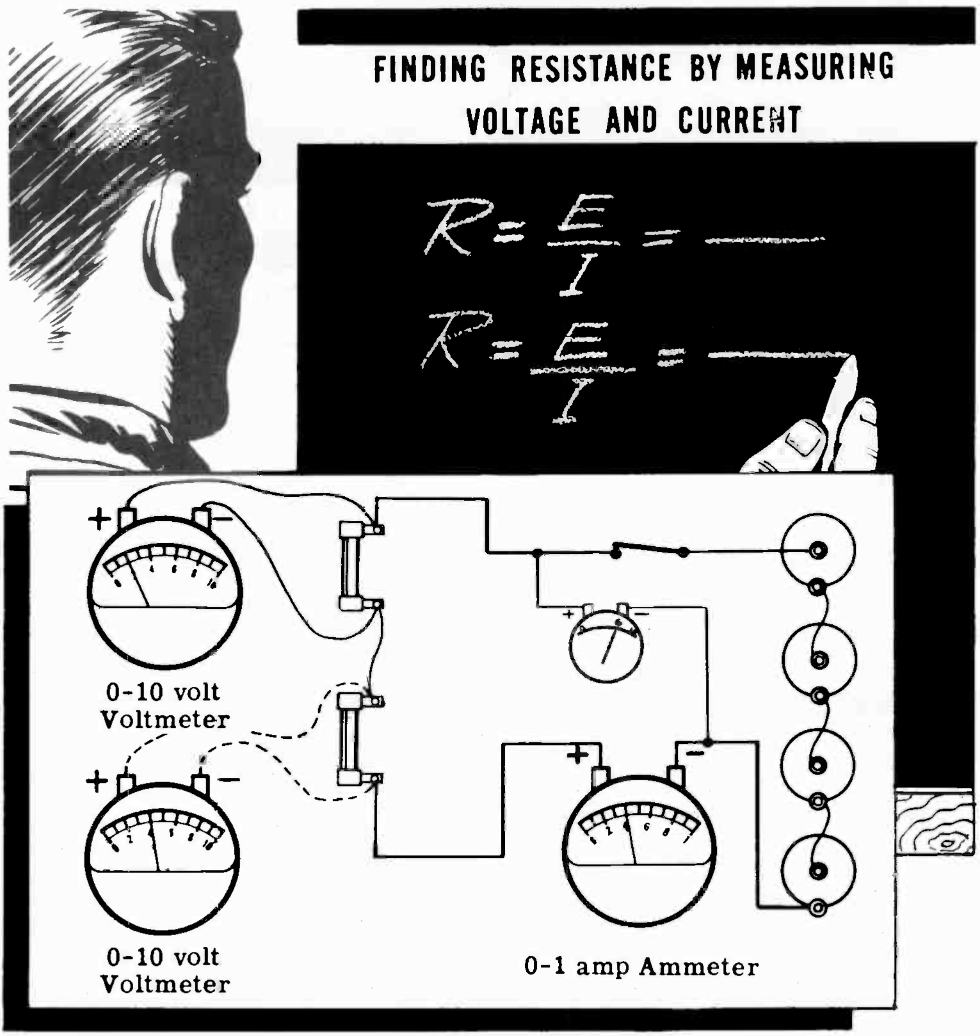
Demonstration of Ohm's Law

To show how Ohm's law may be used to find the resistance needed, the instructor connects four dry cells to form a 6-volt battery. Then choosing desired values of current such as .3, .6 and 1 amperes, he determines the resistances which will give these currents when connected across the 6-volt battery. Using Ohm's law, the voltage—6 volts—is divided by the desired currents—.3, .6 and 1 amperes—giving required resistances of 20, 10 and 6 ohms. To check these values, he connects two 3-ohm resistors in series to form a 6-ohm resistance and connects it in series with an ammeter across the 6-volt battery. You can see that the resulting current is approximately 1 ampere. By adding more resistors in series to form 10- and 20-ohm resistances, the instructor shows that these resistance values also result in the desired currents.



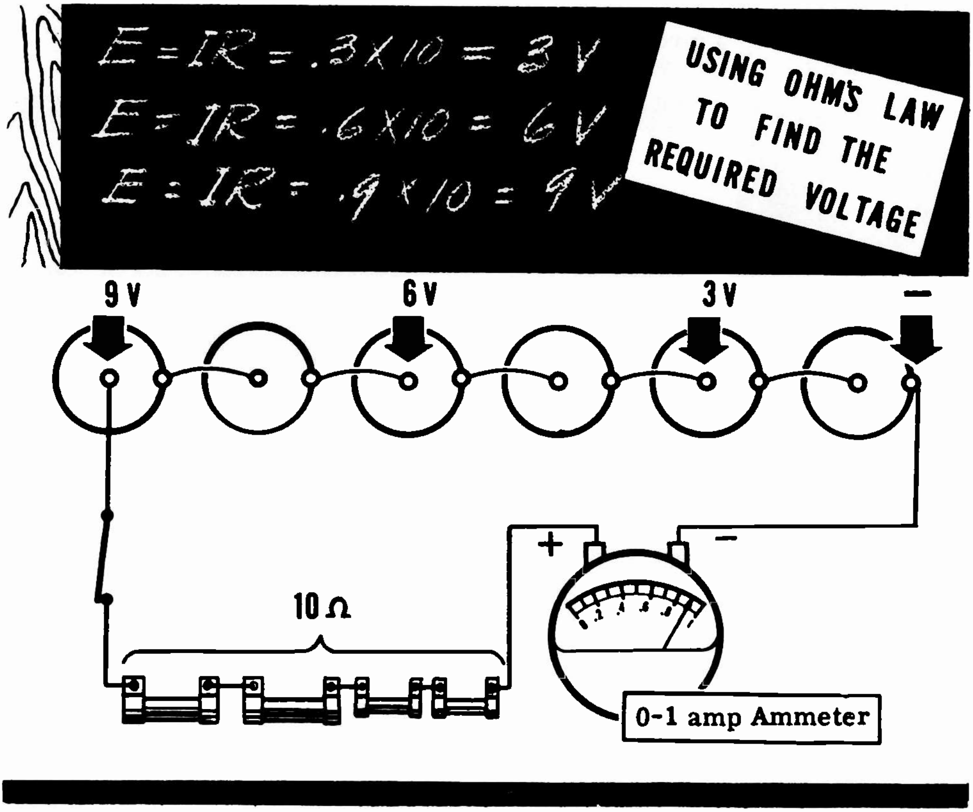
Demonstration of Ohm's Law (continued)

Current and voltage may also be used to find the value of a resistance in a circuit when the resistance is unknown. To demonstrate this use of Ohm's law, the instructor connects two resistors, having no resistance marking, to form a series circuit across a six-volt battery with an ammeter connected to measure the current flow. The voltage across each resistor is read and you see that these two voltages, added, equal the battery voltage. By dividing the voltages across the resistors by the circuit current, the instructor obtains the resistance value of the resistors. To show that the answers are correct, the resistances are measured with an ohmmeter and you see that the values obtained by Ohm's law equal those indicated on the ohmmeter. As several such problems are worked, you see that rated current and voltage can be used to find the value of resistance needed in a circuit, and the measured values of current and voltage can be used to find the value of an unknown resistance in a circuit.



Demonstration of Ohm's Law (continued)

How to use Ohm's law to find the voltage required to give the correct current flow through a known resistance will now be demonstrated. Using a 10-ohm resistance consisting of two 2-ohm resistors and two 3-ohm resistors in series, the instructor determines the voltages needed to obtain .3, .6 and .9 ampere of current flow by multiplying 10 ohms by each current in turn. The voltage values obtained are 3, 6 and 9 volts respectively. To check these values the 10-ohm resistance in series with an ammeter is connected across cells connected to give these voltages. With the 3-volt battery of cells, you see that the current is .3 amperes, for the 6-volt battery it is .6 amperes, and for the 9-volt battery it is .9 amperes, showing that the Ohm's law values are correct.



Next the instructor shows how Ohm's law may be used to measure current in a series circuit. Using a 9-volt battery of dry cells connected across six 3-ohm resistors in series, the instructor determines the total circuit resistance to be 18 ohms by adding the resistance values. By dividing the 9 volts by 18 ohms he determines that the circuit current is .5 amperes. Measuring the voltage across each individual resistor and dividing by the resistor value also results in a current value of .5 amperes for the circuit. The instructor then connects an ammeter to check the current and you see that the current value checks. Several similar demonstrations all show that, when two values are known for any part of a circuit, the unknown value can be determined directly by using Ohm's law.

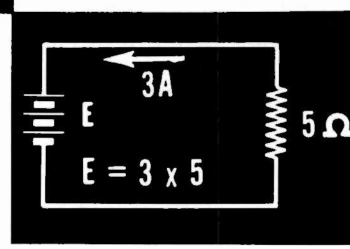
Review of Ohm's Law

Ohm's law is a tool used in electricity in place of a meter to find an unknown factor concerning a circuit or part of a circuit when two of the factors are known. You can use it in place of an ohmmeter, voltmeter or ammeter to find resistance, voltage or current provided that you know two of the quantities and desire to find the third. Like any tool, Ohm's law becomes easier to use with practice, and the more often you use it, the more skilled you will become in its use. You have read about it, discussed it and seen it demonstrated; now suppose you review its use in finding unknown circuit quantities. Remember that all quantities must be expressed in basic units—volts, amperes and ohms.

Voltage equals current multiplied by resistance

VOLTS = AMPERES x OHMS

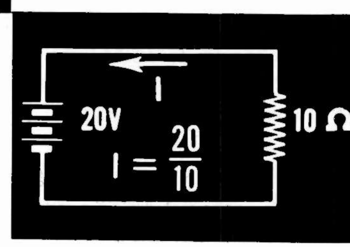
$$E = IR$$



Current equals voltage divided by resistance

AMPERES = VOLTS ÷ OHMS

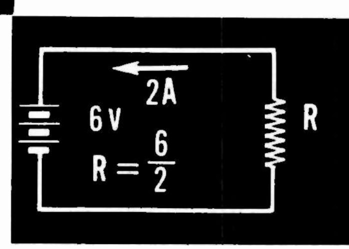
$$I = \frac{E}{R}$$



Resistance equals voltage divided by current

OHMS = VOLTS ÷ AMPERES

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



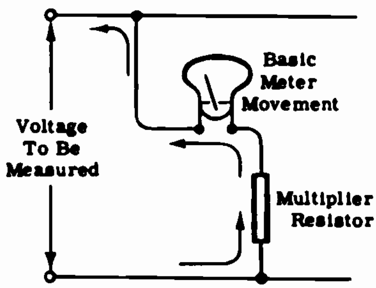
While it is not necessary to memorize many of the formulas you will use in electricity, Ohm's law should be memorized since you will use it more frequently than any other.

Extending the Range of Voltmeters

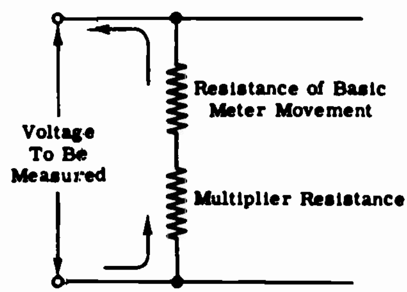
The following is a practical application of Ohm's Law in series circuits.

In the diagram below, note that the meter is in series with the multiplier resistor and that both these components are placed across the voltage source which is being measured. The equivalent circuit shows the basic meter movement as a resistance which is placed in series with the multiplier resistor. The current through both the multiplier resistor and the meter movement is the same since the components are in series with each other. For any given type of meter movement a high resistance series multiplier will limit the current to a very small value (by Ohm's Law). For the same meter movement a low resistance series multiplier will permit a comparatively large amount of current to flow through the circuit. The resistance value of series multipliers is always chosen, however, so as to limit the current enough to prevent damage to the meter but at the same time provide the required indications.

As you learned in Volume I of this course, a voltmeter is simply an ammeter which measures the current flow through a given material called a series multiplier resistor. The "voltmeter" movement with which you will come in contact most frequently is the very familiar 0-1 ma. milliammeter. You can see why the series multiplier is such a necessary factor in measuring voltages. If no multiplier were incorporated in the unit, the low resistance of the one-milliamp meter movement would act like a short circuit, causing high currents to flow for all but the smallest voltages being measured. The series multiplier then, limits the current through the meter to a maximum of 1 milliamp and provides a standard by which the voltmeter range can be determined. For a given multiplier, the meter will indicate a large current if the voltage being measured is high, or a small current if the voltage being measured is low. The meter may be equipped with scales of different ranges or a multiplication factor may be used to establish accurate readings.



VOLTMETER



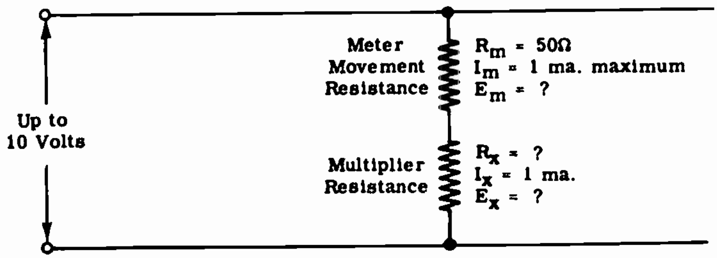
Equivalent Circuit of Voltmeter

Extending the Range of Voltmeters (continued)

Certain factors regarding the use of series multipliers in extending the ranges of voltmeters were described on the previous sheet. You will now learn how to use the familiar Ohm's Law in calculating the resistance value of series multipliers.

Suppose that you wish to use a 0-1 ma. milliammeter as a 0-10 volt voltmeter. Assume, for this problem, that the meter movement resistance is 50 ohms.

Calculate the resistance value of the multiplier which will permit measurements of ten volts (or less) without damage to the meter. See the diagram below.



Recall that the total voltage in a series circuit is equal to the sum of the individual voltage drops in the circuit or, as in this case

$$E_{Total} = E_m + E_x$$

You know that the total voltage to be measured will be ten volts. You also know that the total allowable current through the meter movement I_m, must not exceed a maximum of one milliampere. Since the current (I_m) and resistance (R_m) of the meter movement are known, you can find the IR drop across the meter. Using Ohm's Law, then,

$$E_m = I_m R_m$$

or, by substituting,

$$E_m = .001 \times 50$$

$$E_m = .05 \text{ volts}$$

In order to find the multiplier resistance R_x, you must first find E_x, the voltage across the multiplier. Recall the formula given above for total voltage in a series circuit.

$$E_{total} = E_m + E_x$$

Solving for E_x you find that $E_{total} - E_m = E_x$

$$E_x = 10 - .05$$

$$E_x = 9.95 \text{ volts}$$

Using Ohm's Law, it is a simple matter to find R_x since I_x is known to be one milliampere ($I_m = I_x$).

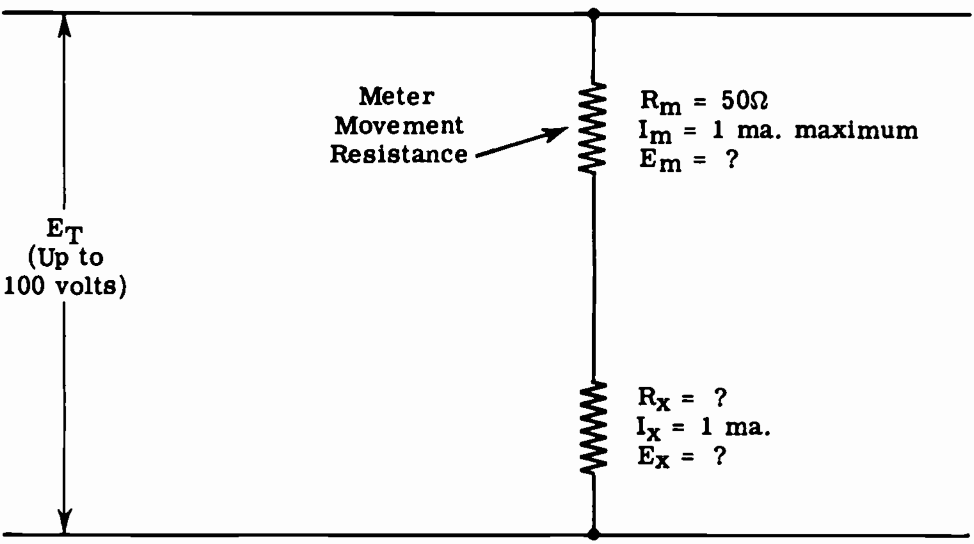
$$R_x = \frac{E_x}{I_x} = \frac{9.95}{.001}$$

$$R_x = 9,950 \text{ ohms}$$

Extending the Range of Voltmeters (continued)

You have just learned how to calculate the resistance value of a multiplier which permits measurement of voltages not higher than ten volts. This example was used for the purposes of illustration only, because you will probably be provided with a 0-10 volt voltmeter. The examples which follow however, are concerned with much higher voltages, and are similar to problems involving series multipliers which you may have to solve in the future.

Suppose that you wish to extend the range of your meter so that it will measure voltages up to 100 volts, DC. Assume that the meter movement is the very familiar 0-1 milliamp, 50-ohm Weston movement. What value of resistance must be used as a series multiplier to limit the current through the meter to a maximum of one milliampere even when the voltage being measured is as high as 100 volts? See the diagram below.



Recall that $I_m = I_x$, since the multiplier and meter form a series circuit across the line. Recall also, that the sum of E_m and E_x must equal the total voltage E_T. Solving for E_m

$$E_m = I_m \times R_m = .001 \times 50 = .05 \text{ volts}$$

Since you now have the value for E_m find the value of E_x by substituting in the formula

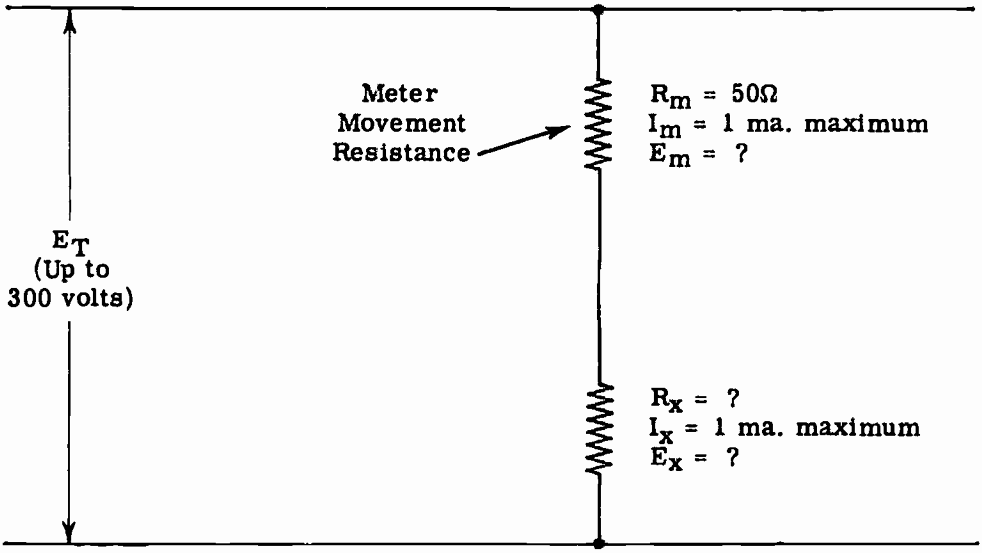
$$E_T = E_m + E_x$$
$$E_x = E_T - E_m = 100 - .05$$
$$E_x = 99.95 \text{ volts}$$

Using Ohm's Law, solve for R_x

$$R_x = \frac{E_x}{I_x} = \frac{99.95}{.001} = 99{,}950 \text{ ohms}$$

Extending the Range of Voltmeters (continued)

In another problem, find the value of multiplier necessary to extend the range of the meter movement (same as above) to 300 volts.



As before, solve for E_m

$$E_m = I_m R_m = .001 \times 50$$
$$E_m = .05 \text{ volts}$$

Substitute in formula, below, to find E_x

$$E_T = E_m + E_x$$
$$E_x = E_T - E_m$$
$$E_x = 300 - .05$$
$$E_x = 299.95 \text{ volts}$$

Using Ohm's Law, solve for R_x

$$R_x = \frac{E_x}{I_x} = \frac{299.95}{.001}$$

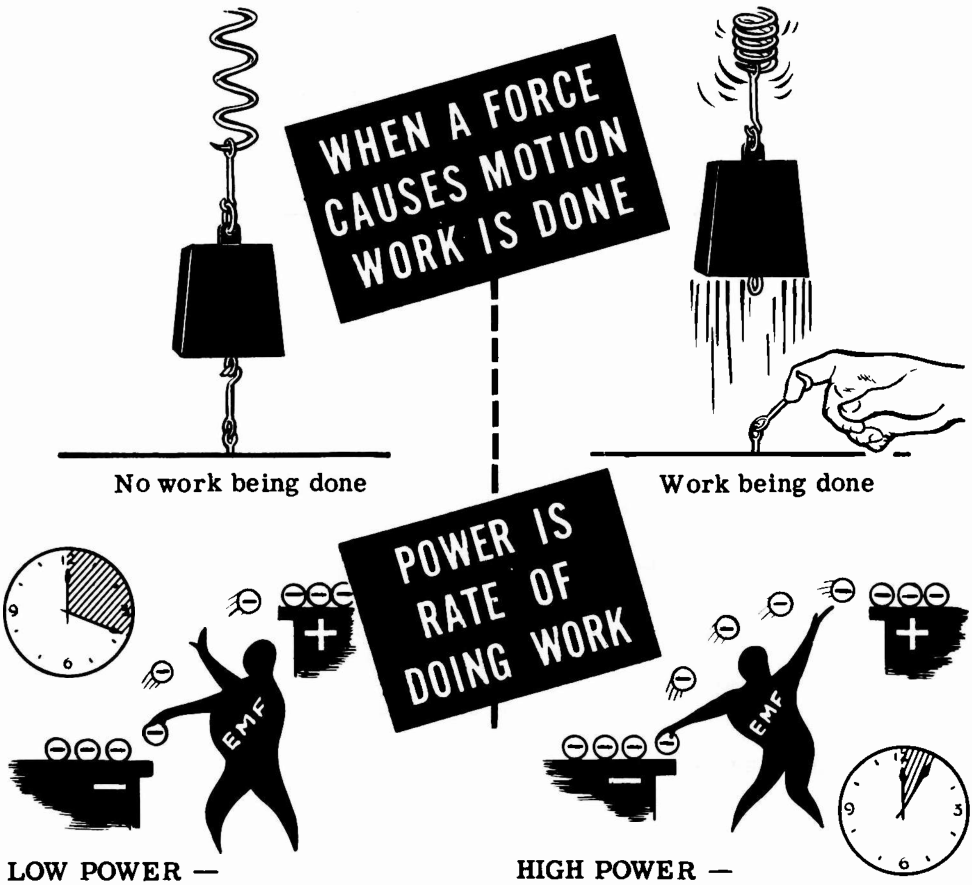
$$R_x = 299,950 \text{ ohms}$$

What Power Is

Power—whether electrical or mechanical—means the rate of doing work. Work is done whenever a force causes motion. If a mechanical force is used to lift or move a weight, work is done. However, force exerted without causing motion—such as the force of a spring under tension between two objects which do not move—is not work.

Previously you found that electrical force is voltage and that voltage causes current flow—movement of electrons. Voltage existing between two points without causing current flow is similar to the spring under tension without moving, and is not doing work. Whenever voltage causes electron movement, work is done in moving electrons from one point to another. The rate at which this work is done is called electric power.

The same total amount of work may be done in different amounts of time. For example, a given number of electrons may be moved from one point to another in one second or in one hour, depending on the rate at which they are moved; and the total work done will be the same in each case. If all the work is done in one second, more electrical energy will be changed to heat or light per second than if the total amount of work is done in an hour.



No work being done

Work being done

LOW POWER —
fewer electrons per minute

HIGH POWER —
more electrons per minute

Units of Electric Power

The basic unit of power is the watt, which equals the voltage multiplied by the current—electrical force times coulombs of electrons moved past a point per second. This represents the rate at which work is being done in moving electrons through a material. The symbol P indicates electrical power. To find the power used in a resistance—

POWER FORMULA

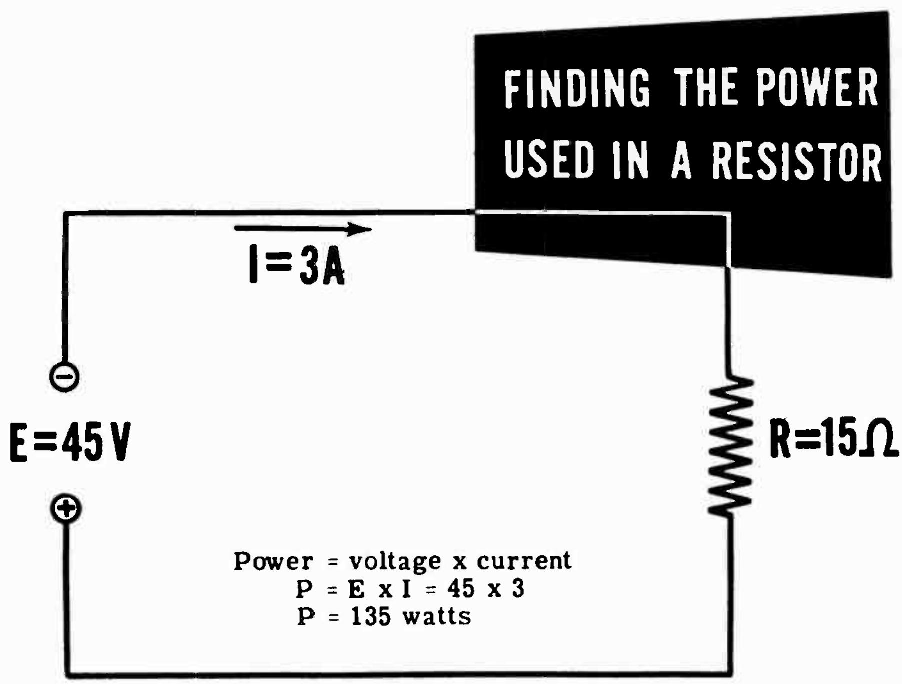
Power = Voltage x Current

Watts = Volts x Amperes

$P = E \times I$

or $P = EI$

In a circuit consisting of a 15-ohm resistor across a voltage source of 45 volts, 3 amperes of current flow through the resistor. The power used can be found by multiplying the voltage and current.



CIRCUIT POWER USED IS 135 WATTS

Units of Electric Power (continued)

By substituting Ohm's law expressions in the formula for watts, the formula may be expressed in terms of current and resistance or voltage and resistance. According to Ohm's law, $E = IR$. By replacing E in the power formula with its equal value (IR), power can be determined without knowing the voltage.

VARIATION OF THE POWER FORMULA

$$P = EI$$

SUBSTITUTING (IR) FOR E: $P = (IR)I$ OR $I \times R \times I$

SINCE I x I IS I^2: $P = I^2R$

Similarly, $I = \frac{E}{R}$ and, if $\frac{E}{R}$ is substituted for I in the power formula, power can be found with only the voltage and current known.

ANOTHER VARIATION

$$P = EI$$

SUBSTITUTING $\frac{E}{R}$ FOR I: $P = E\left(\frac{E}{R}\right)$ OR $\frac{E \times E}{R}$

SINCE E x E IS E^2: $P = \frac{E^2}{R}$

For quantities of power beyond 1,000 watts the unit used is the kilowatt, while quantities smaller than a watt are expressed in milliwatts.

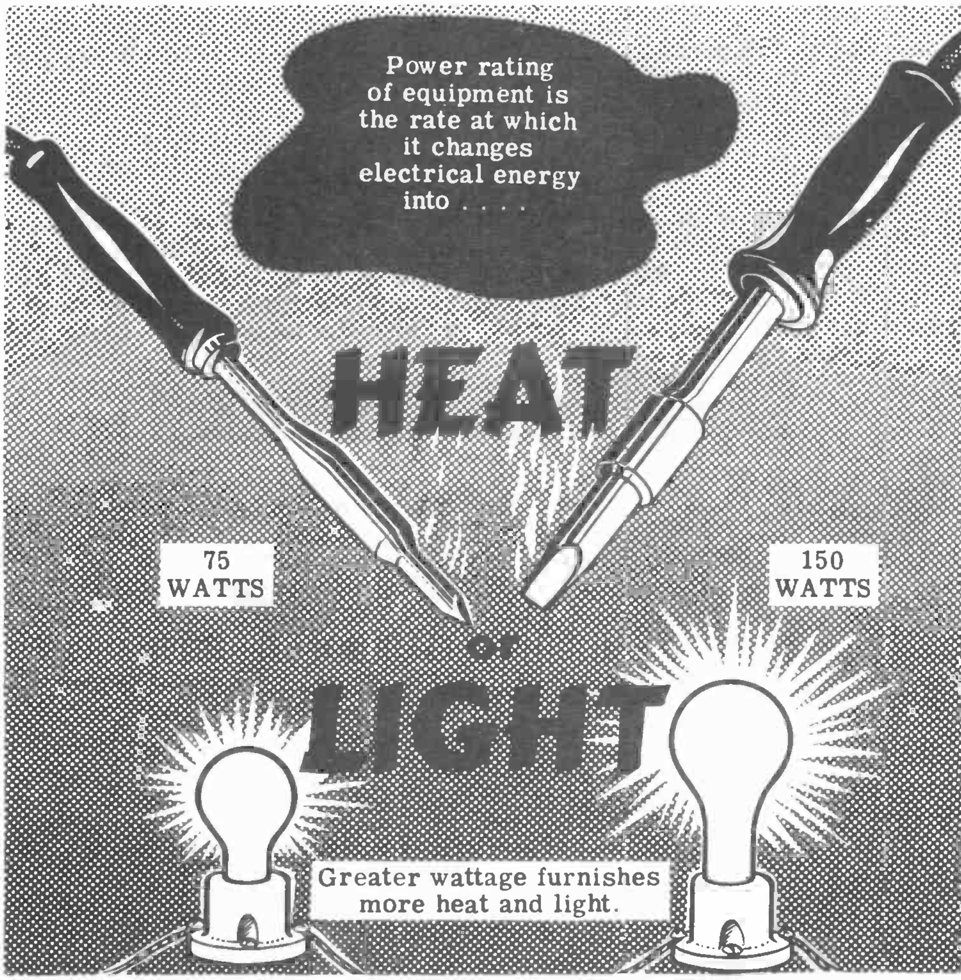
LARGE AND SMALL UNITS OF POWER

1 kilowatt = 1000 watts
1 kw = 1000 w

1 milliwatt = $\frac{1}{1000}$ watt

1 mw = $\frac{1}{1000}$ w

Power Rating of Equipment



From your own experience you have probably found that most electrical equipment is rated for both voltage and power—volts and watts. Electric lamps rated at 117 volts for use on a 117-volt power line are also rated in watts, and are usually identified by wattage rather than volts.

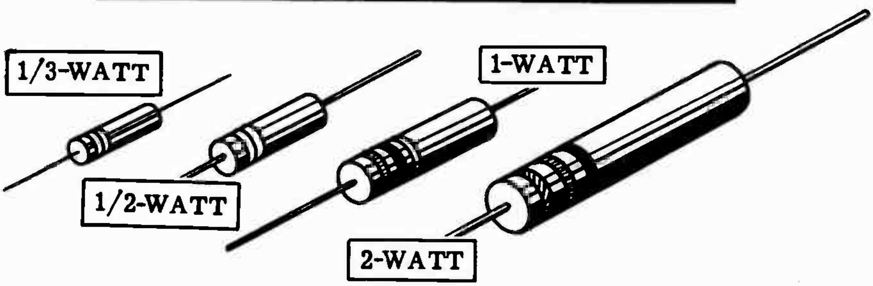
Perhaps you have wondered what this rating in watts means and indicates. The wattage rating of an electric lamp or other electrical equipment indicates the rate at which electrical energy is changed into another form of energy, such as heat or light. The faster a lamp changes electrical energy to light, the brighter the lamp will be; thus, a 100-watt lamp furnishes more light than a 75-watt lamp. Electric soldering irons are made in various wattage ratings with the higher wattage irons changing electrical energy to heat faster than those of a low wattage rating. Similarly the wattage rating of motors, resistors and other electrical devices indicates the rate at which they are designed to change electrical energy into some other form of energy. If the normal wattage rating is exceeded, the equipment or device will overheat and perhaps be damaged.

Power Rating of Equipment (continued)

When more power is used in a resistance, the rate at which electrical energy is changed to heat increases and the temperature of the resistance rises. If the temperature rises too high the material of the resistance may change its composition, expand, contract or burn due to the heat. For that reason all types of electrical equipment are rated for a maximum wattage. This rating may be in terms of watts or often in terms of maximum voltage and current, which effectively give the rating in watts.

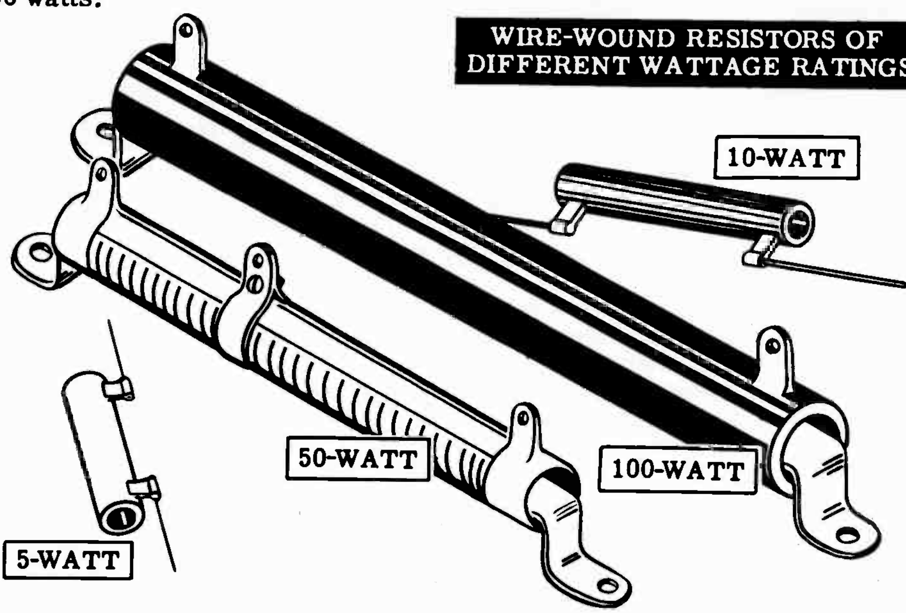
Resistors are rated in watts in addition to ohms of resistance. Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage ratings of 1/3, 1/2, 1 and 2 watts. The larger the size of carbon resistor the higher its wattage rating, since a larger amount of material will absorb and give up heat more easily.

COMPARATIVE SIZE OF CARBON RESISTORS OF DIFFERENT WATTAGE RATINGS



When resistors of wattage ratings greater than 2 watts are needed, wire-wound resistors are used. Such resistors are made in ranges between 5 and 200 watts, with special types being used for power in excess of 200 watts.

WIRE-WOUND RESISTORS OF DIFFERENT WATTAGE RATINGS

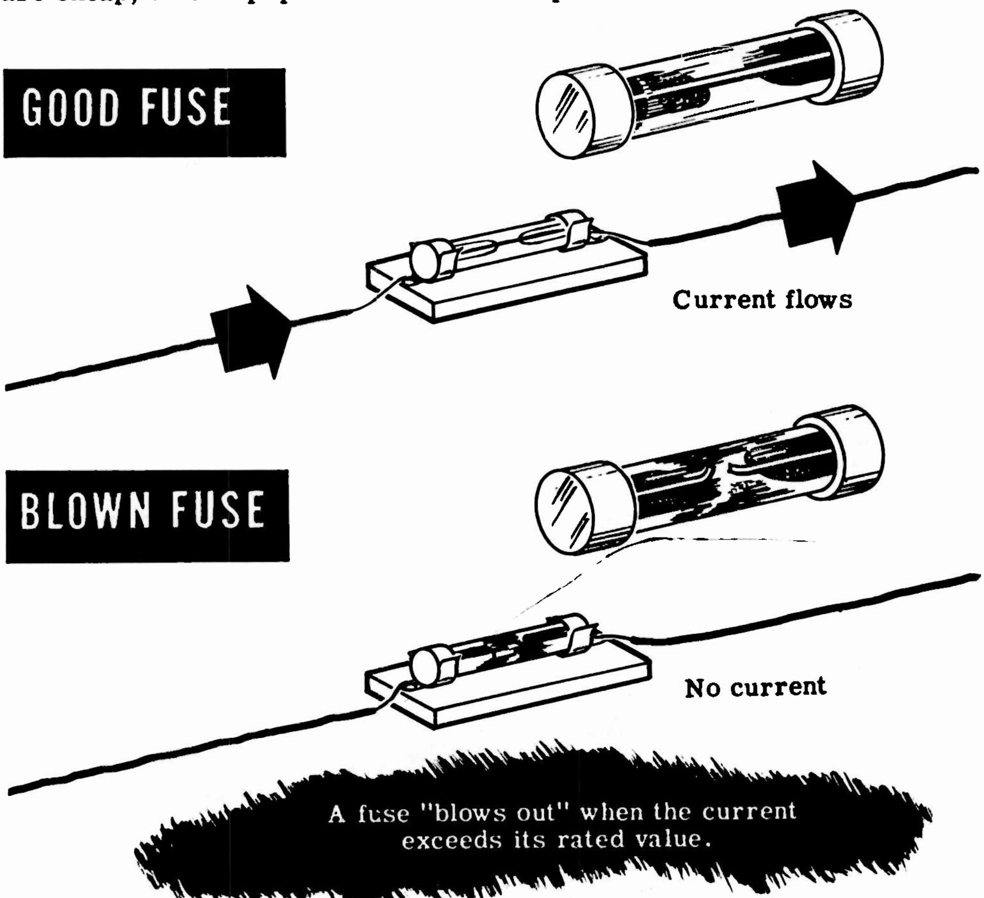


Fuses

When current passes through a resistor, electric energy is transformed into heat, which raises the temperature of the resistor. If the temperature rises too high, the resistor may be damaged. The metal wire in a wound resistor may melt, opening the circuit and interrupting current flow. This effect is used to advantage in fuses.

Fuses are metal resistors with very low resistance values, which are designed to "blow out" and thus open the circuit when the current exceeds the fuse's rated value. When the power consumed by the fuse raises the temperature of the metal too high, the metal melts and the fuse "blows." Blown fuses can be identified by a broken filament and darkened glass.

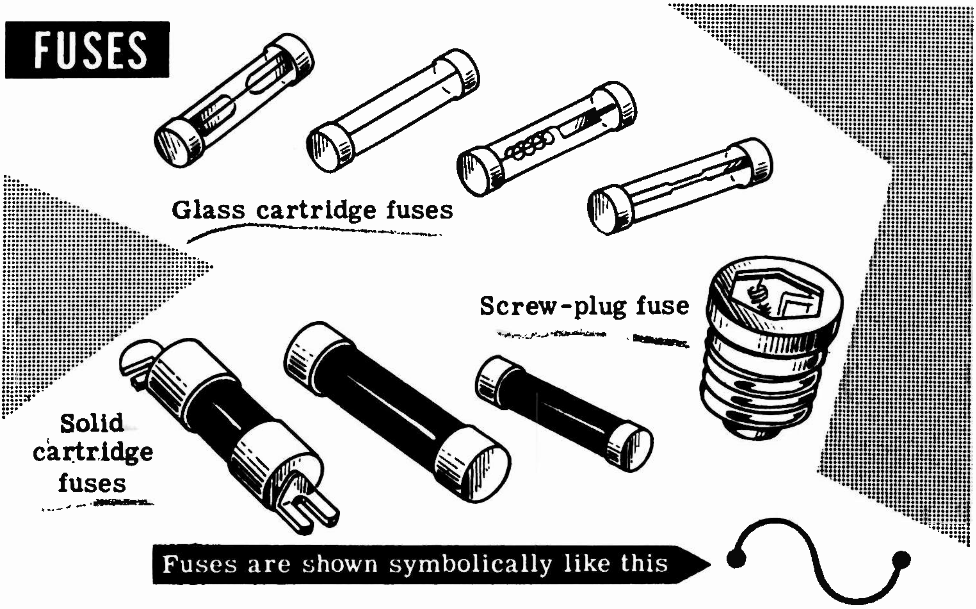
You have already learned that excessive current may seriously damage electrical equipment—motors, instruments, radio receivers, etc. The purpose of the fuse is to protect such equipment from excessive current. It is connected in series with the equipment, so that the fuse will open the circuit before the excessive current does damage to the equipment. Fuses are cheap, other equipment much more expensive.



A fuse "blows out" when the current exceeds its rated value.

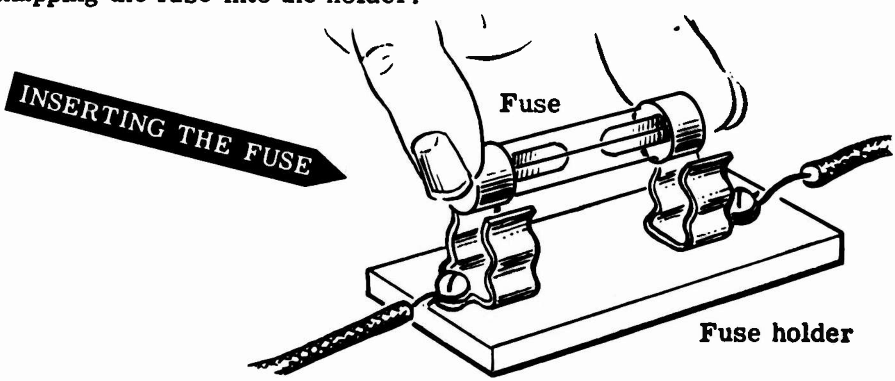
Fuses (continued)

Although it is the power used by a fuse which causes it to blow, fuses are rated by the current which they will conduct without burning out, since it is high current which damages equipment. Since various types of equipment use different currents, fuses are made in many sizes, shapes and current ratings.



It is important that you always use fuses with the proper current rating—slightly higher than the greatest current you expect in the circuit. Too low a rating will result in unnecessary blow-outs, while too high a rating may allow dangerously high currents to pass. In the demonstrations to follow, the circuits will be "fused" to protect the ammeter. Since the range of the ammeter is 0 to 1 ampere, a 1.5-amp fuse will be used.

The fuse is inserted in the circuit by connecting the fuse holder in series and snapping the fuse into the holder.

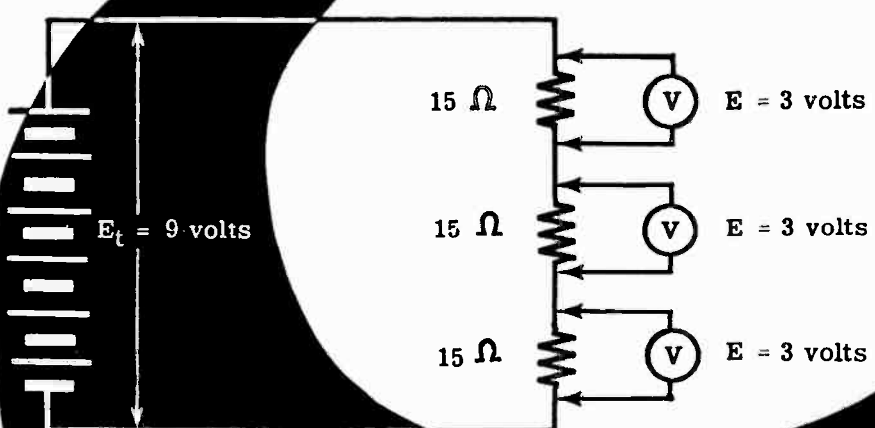


Demonstration of Power in Series Circuits

To show that power can be determined when any two of the circuit variables—current, voltage and resistance—are known, the instructor connects three 15-ohm, 10-watt resistors in series across a 9-volt dry cell battery.

After measuring the voltage across each resistor, he applies the power formula $P = \frac{E^2}{R}$ to find the power for each resistor. You see that the power used by each resistor is about 0.6 watt and that the total power is about 1.8 watts.

FINDING POWER WHEN VOLTAGE AND RESISTANCE ARE KNOWN



For each resistor: $P = \frac{E^2}{R} = \frac{3 \times 3}{15} = \frac{9}{15} = 0.6$

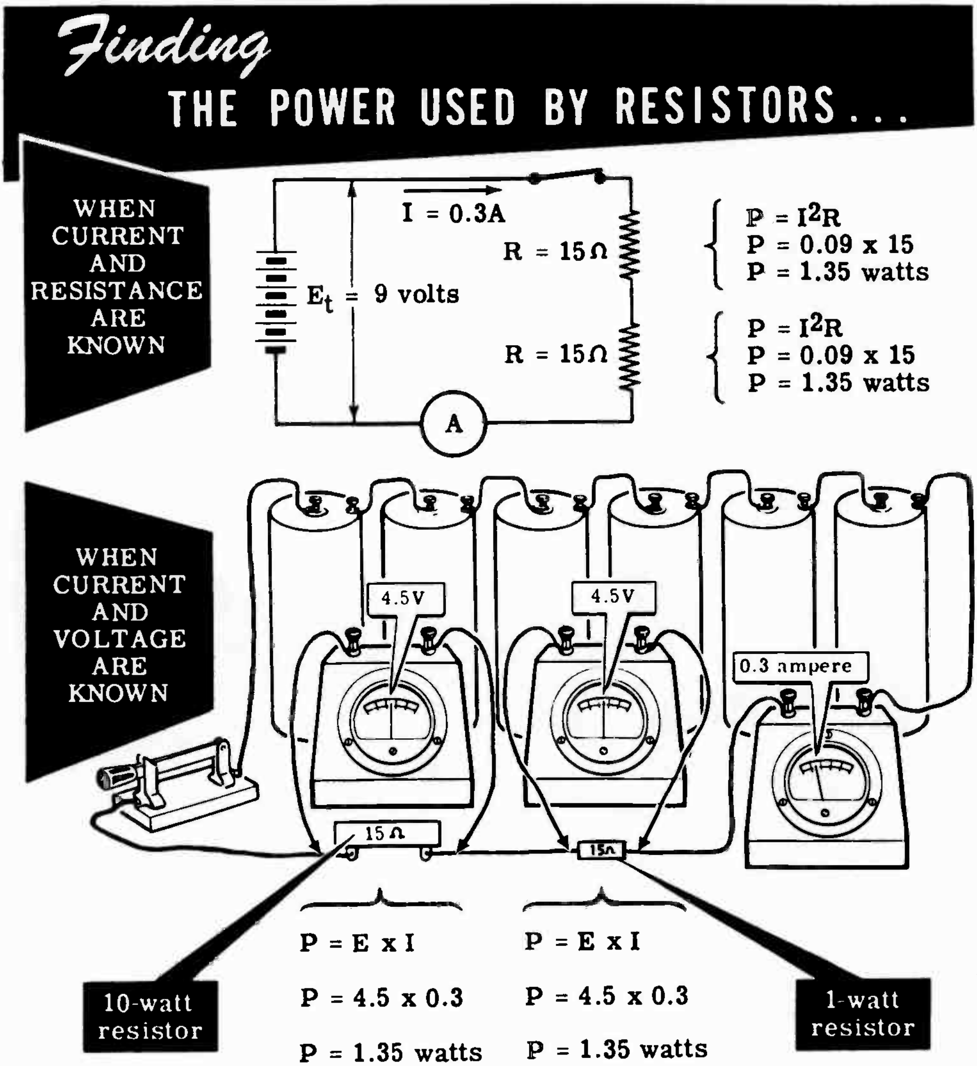
For three resistors $P = 0.6 \times 3 = 1.8$

Total circuit power is 1.8 watts

To show that the same results are obtained using current and resistance or current and voltage, the instructor connects an ammeter in the circuit to measure current. The power used by each resistor is then found by using the power formula in two ways: $P = I^2R$ and $P = EI$. Notice that the power in watts is very nearly the same for each variation of the power formula used, with the negligible difference being due to meter inaccuracies and slight errors in meter readings.

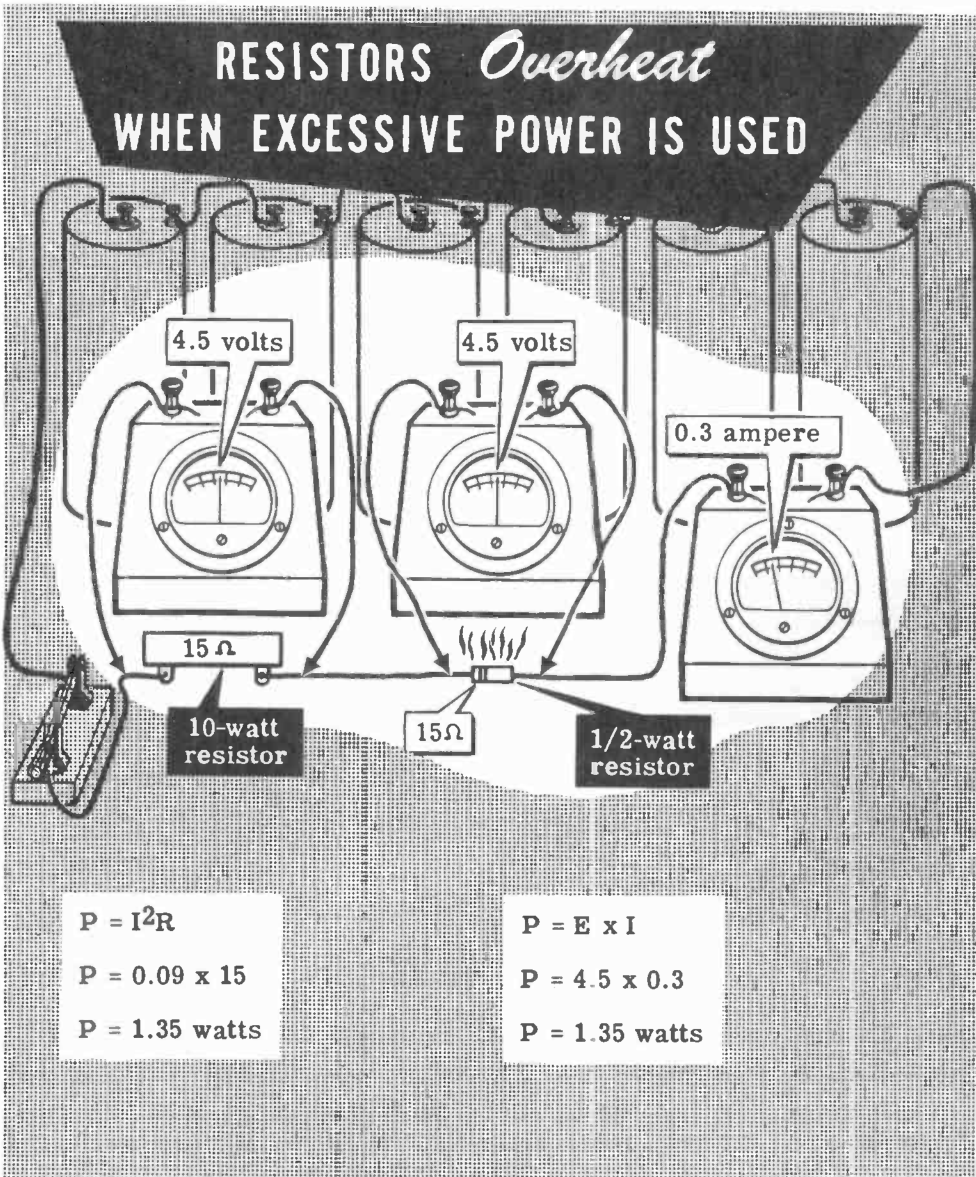
Demonstration of Power in Series Circuits (continued)

To show the effect of the power rating of a resistor on its operation in a circuit, the instructor connects two 15-ohm resistors—one 10-watt and one 1-watt resistor—in a series circuit as shown below. The ammeter reads the circuit current and, using the power formula $P = I^2R$, you find that the power used in each resistor is approximately 1.35 watts. As this is slightly more than the power rating of the 1-watt resistor you see that it heats rapidly, while the 10-watt resistor remains relatively cool. To check the power used in each resistor, the voltages across them are measured with a voltmeter and multiplied by the current. Notice that the power is the same as that previously obtained, and that the power used by each resistor is exactly equal.



Demonstration of Power in Series Circuits (continued)

Next, the 1-watt resistor is replaced by one rated at 1/2 watt. Observe that it heats more rapidly than the 1-watt resistor and becomes very hot, indicating that the power rating has been exceeded. As the power for each resistor is found (using current and resistance, then voltage and current as a check), you see that each resistor is using the same amount of power. This shows that the power rating of a resistor does not determine the amount of power used in a resistor. Instead the power rating only indicates the maximum amount of power that may be without damaging the resistor.

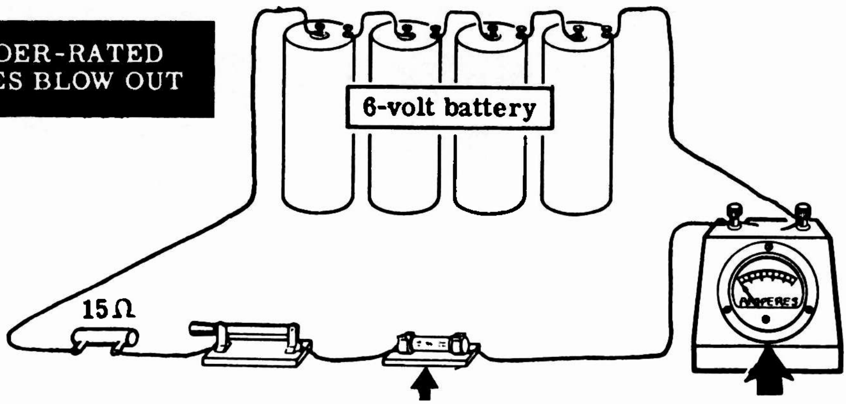


Demonstration on the Use of Fuses

You have seen how a resistor overheats when it uses more power than its power rating. Now you will see how this effect is put to use to protect electrical equipment from damage due to excessive currents.

The instructor connects four dry cells in series to form a 6-volt battery. He then connects a 15-ohm 10-watt resistor, a knife switch, a fuse holder and the ammeter in series across the battery, and inserts a 1/8-amp fuse in the fuse holder. When he closes the switch, you see that the fuse "blows." This opens the circuit so that no current can flow, as you see by the zero reading of the ammeter.

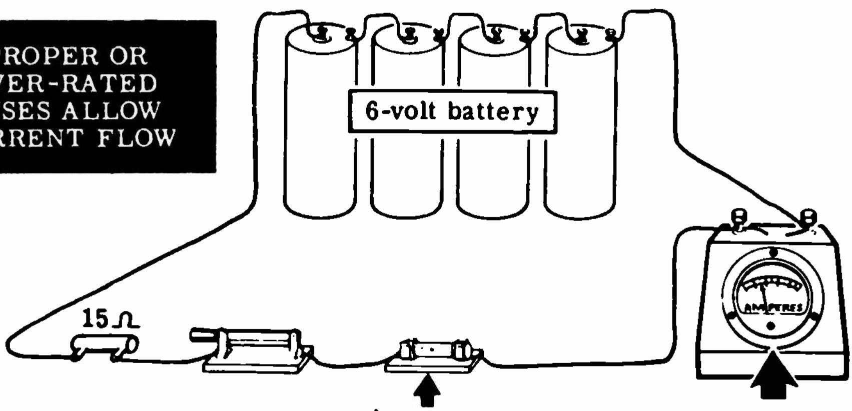
UNDER-RATED FUSES BLOW OUT



1/8-amp fuse blows out . . . . . .no current

However, when the instructor inserts a 1/2-amp fuse in the fuse holder, you see that it does not blow, and the ammeter shows a current flow.

PROPER OR OVER-RATED FUSES ALLOW CURRENT FLOW

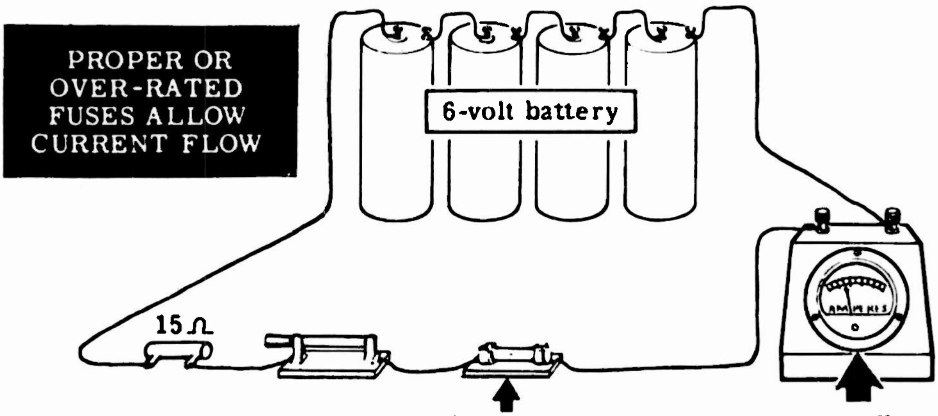


1/2-amp fuse . . . . .current flows

Since the resistance of the circuit is 15 ohms and the voltage is 6 volts, the current flow by Ohm's law is about 0.4 amp $\left(\frac{6 \text{ volts}}{15 \text{ ohms}}\right)$. Since the 1/8 amp (0.125 amp) fuse "blows out" when the current exceeds its rating, it will not carry 0.4 amp. However, the 1/2 amp (0.5 amp) fuse carries the current without blowing, since its rating exceeds the actual current flow.

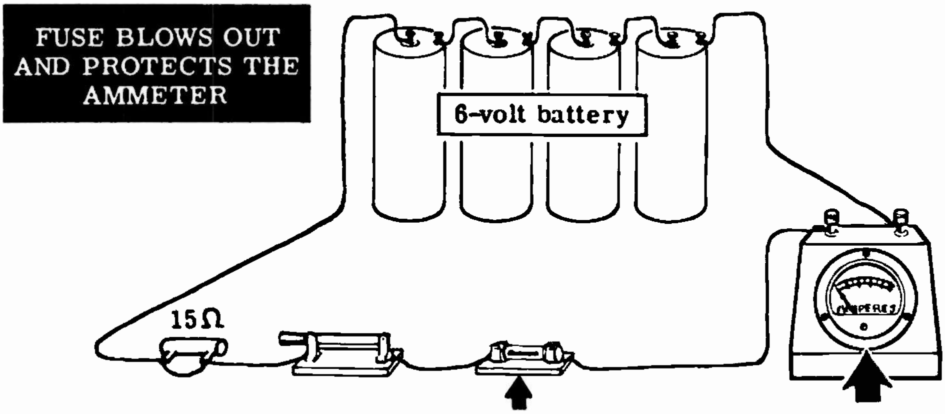
Demonstration of How Fuses Protect Equipment

Using the circuit as shown, immediately below, note that a 15-ohm resistor limits the current through the circuit sufficiently to keep a half-ampere fuse from burning out. The circuit operates without damage to the ammeter.



1/2-amp fuse . . . . current flows

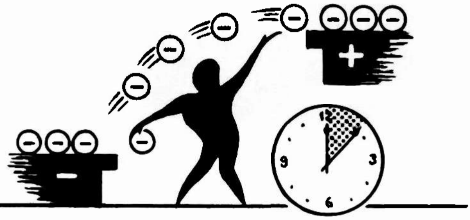
If you were to short-circuit the resistor, see the diagram below, the fuse would burn out and open the circuit without damage to the ammeter or line wire. Because the fuse serves as the predetermined weakest link in this circuit, it is an electrical safety device. In choosing fuses be sure not to choose one whose rating is too high for the expected current flow. If trouble occurs, the highly over-rated fuse may not burn out before the meter does so that all protection is lost for the meter.



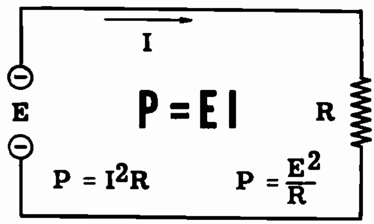
1/8-amp fuse blows out . . . . . . no current

Review of Electric Power

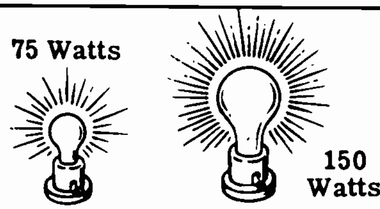
Whenever an electric current flows, work is done in moving electrons through the conductor. The work may be done slowly or rapidly. All of the electrons to be moved may be moved in either a short or long period of time, and the rate at which the work ~~is done~~ is called electric power. Now let's review electric power, the power formula and power rating of equipment.



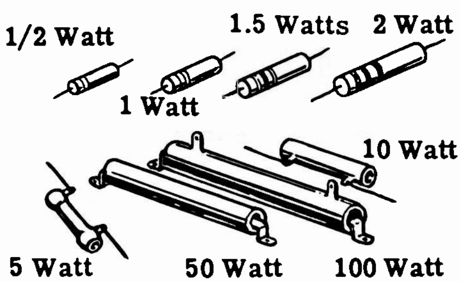
ELECTRIC POWER — The rate of doing work in moving electrons through a material. The basic unit of power is the watt represented by the letter P.



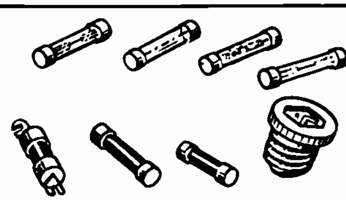
POWER FORMULA — Electric power used in a resistance equals the voltage across the resistance terminals times the current flow through the resistance. It is also equal to the current squared times the resistance or, the voltage squared divided by the resistance.



POWER RATING — Electrical equipment is rated according to the rate at which it uses electric power The power used is converted from electrical energy into heat or light.



RESISTOR POWER RATINGS — Resistors are rated both in ohms of resistance and the maximum power which can safely be used in the resistor. High wattage resistors are constructed larger than low wattage resistors to provide a greater surface for dissipating heat.



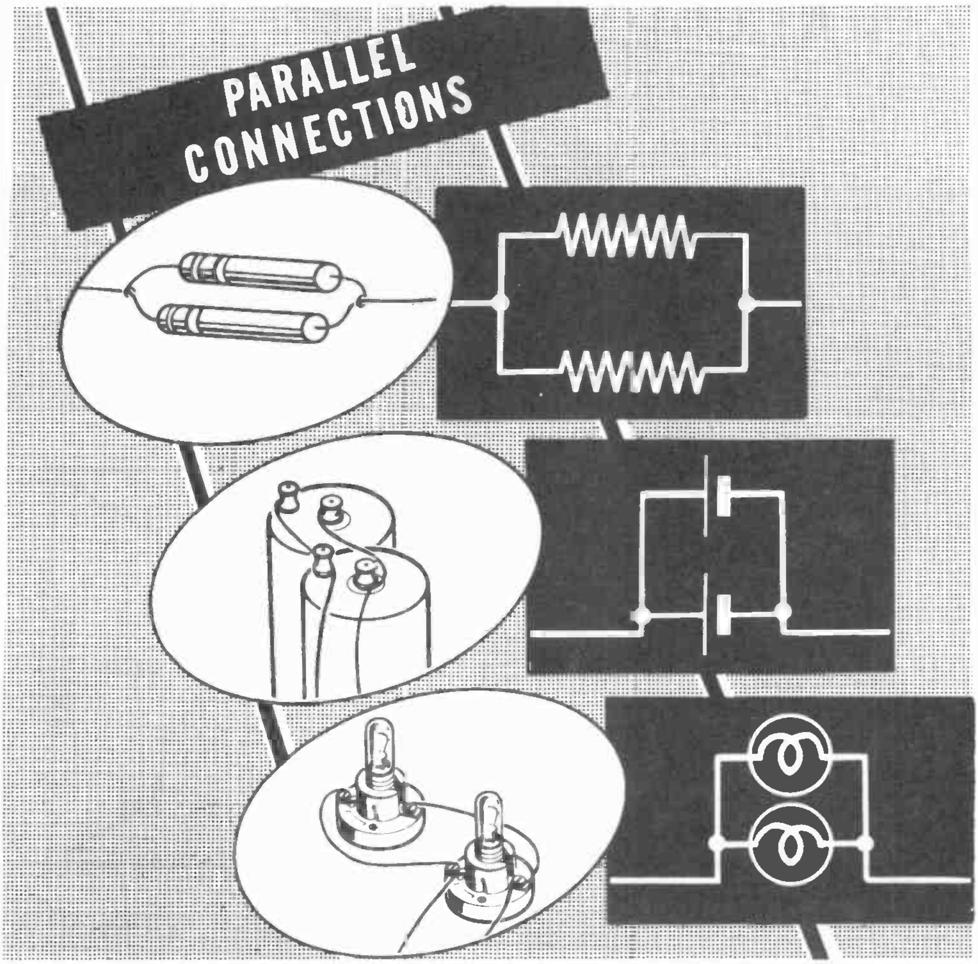
FUSES — Fuses are metal resistors of low resistance values designed to open an electric circuit if the current through the resistor exceeds the fuse's rated value.

Parallel Circuit Connections

When you connect resistances side by side with the ends connected, they are parallel-connected. For such a connection there is more than one path for current flow and, if the resistances in a circuit are so connected, the circuit is a parallel circuit. Similarly, cells connected in parallel to form a battery provide more than one current path through the battery, with each cell furnishing only a part of the total battery current.

If two lamp sockets are placed side by side, with adjacent terminals of the sockets connected together, the lamps are parallel-connected but do not form a parallel circuit. If the two points at which the sockets are connected together are used as terminals and placed across a voltage source, they form a complete parallel circuit.

Most electric power lines form parallel circuits, with each lamp, motor or other type of resistance being connected in parallel across the power line. Each of these devices provides a different path for current flow between the terminals of the line voltage source.

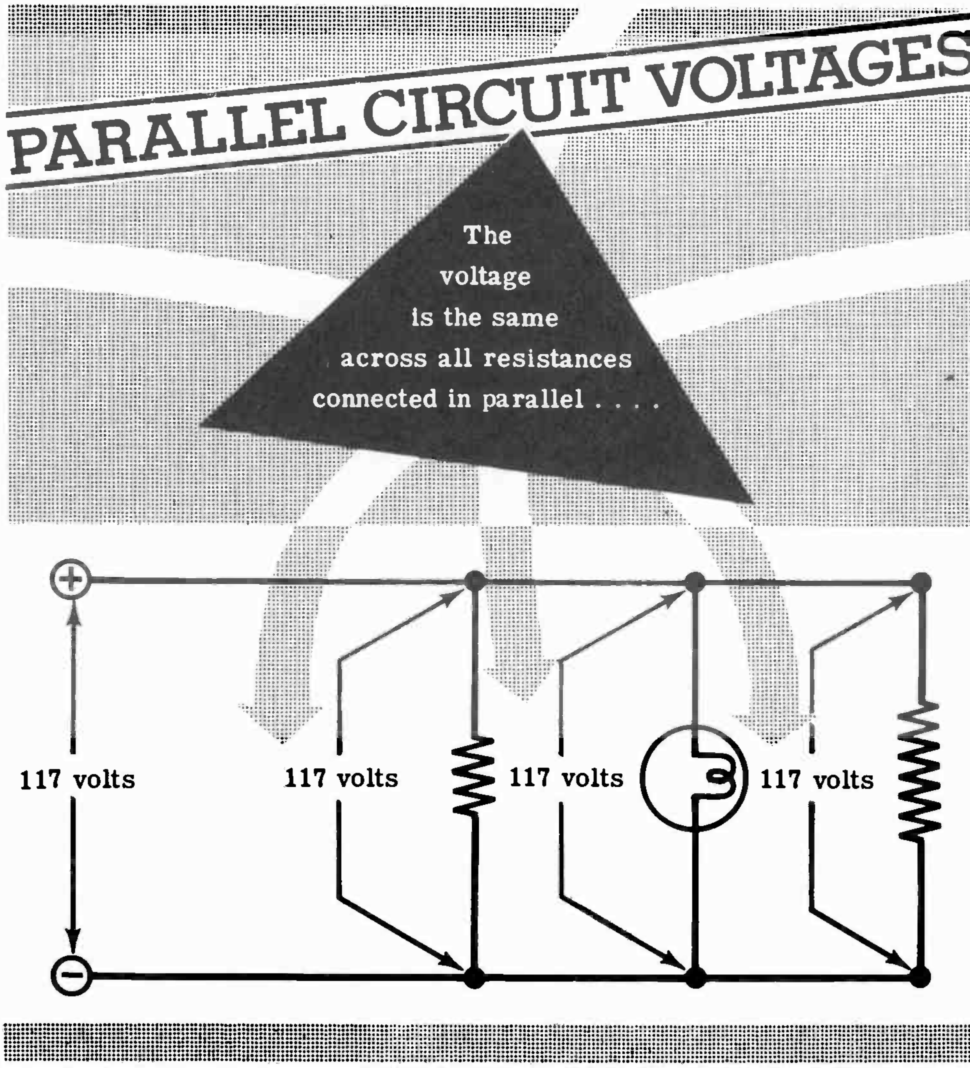


Voltage in Parallel Circuits

Parallel resistances connected across a voltage source have the same voltage applied to each resistance, although the currents may differ depending on the values of resistance. All resistances which are to be connected in parallel must have the same voltage rating for proper operation, though each may pass a different amount of current.

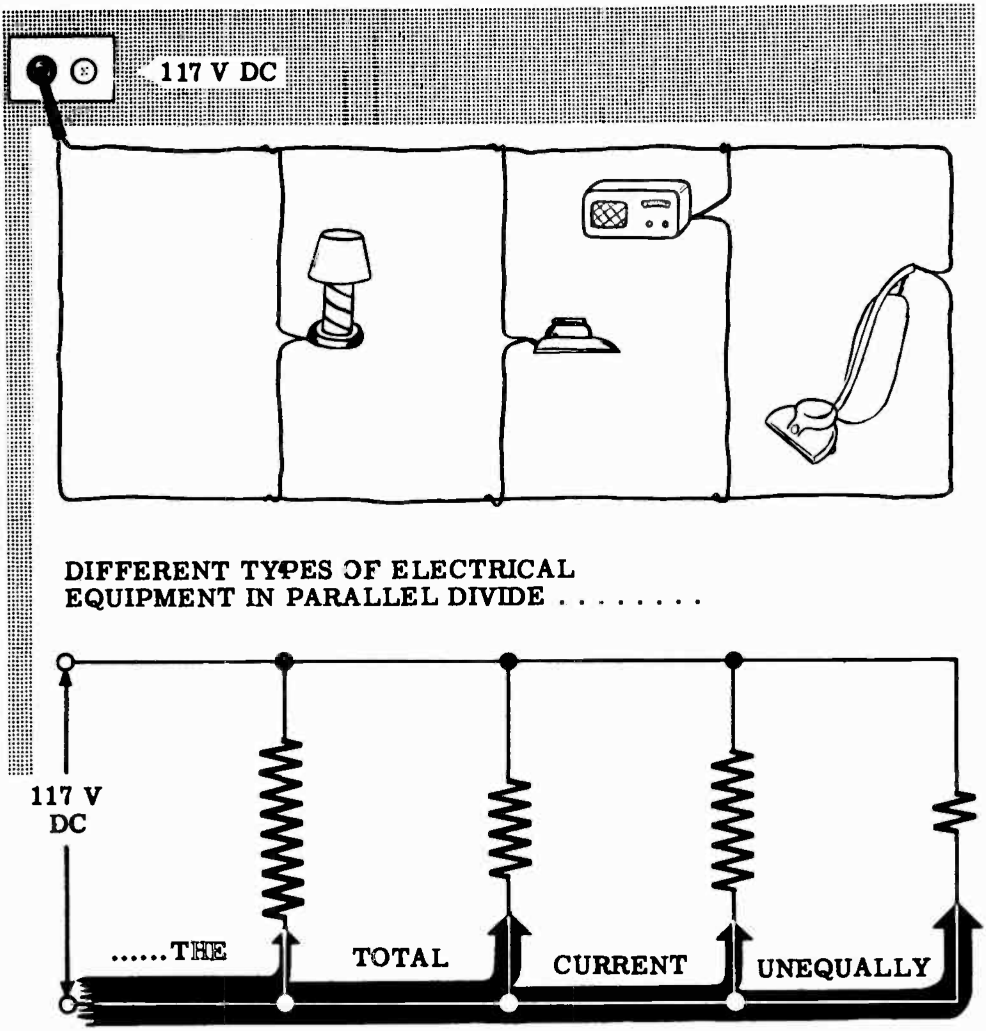
You have used lamps and electric appliances on electric power lines, and have found that they are rated for normal operation on a 117-volt power line. In use, they are connected in parallel across the power line which is the voltage source.

The voltage across each is the same since they are all connected across the same voltage source.



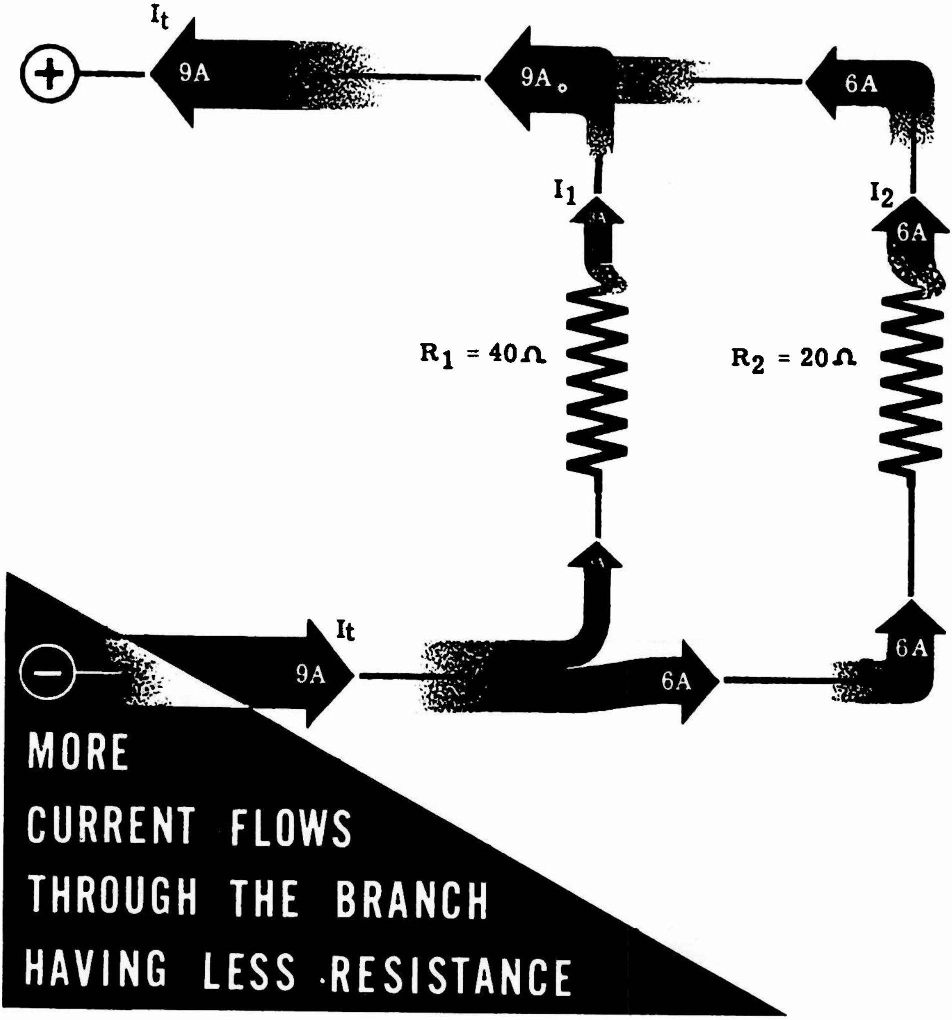
Current Flow in Parallel Circuits

Current divides among the various branches of a parallel circuit in a manner depending on the resistance of each branch. If an electric lamp, an iron, a radio and a vacuum cleaner are connected in parallel, the current through each branch will vary since each piece of equipment offers different resistance to current flow.



In the following demonstration and experiment on parallel circuits, resistors and lamps will be used to show division of current. Resistors of various values will be used to represent different types of electrical equipment. Regardless of the form the resistance may take, the rule is the same: Branches in a parallel circuit with low resistance draw more current than branches with high resistance.

Current Flow in Parallel Circuits (continued)



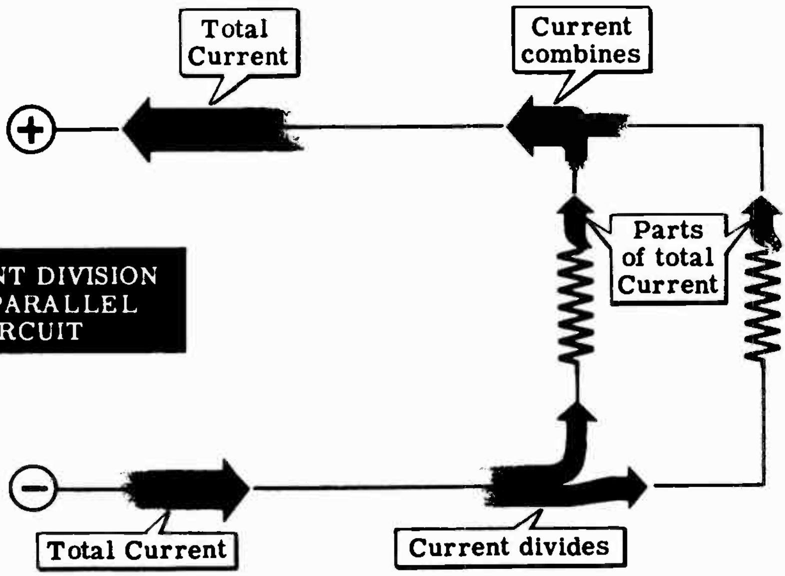
When unequal resistances are connected in parallel, the opposition to current flow is not the same for each branch of the circuit. A small value of resistance offers less opposition, and thus the smaller resistances in parallel circuits pass more current than the larger resistances. If two resistances—R_1 and R_2—are connected in parallel and R_1 has only half the resistance of R_2, the current through R_1 will be twice that of R_2. Also, if R_1 has one-third the resistance of R_2, the current through R_1 will be three times as great as that through R_2, etc.

Current is always greatest through the path of least opposition. As an example, suppose your parallel circuit consists of two resistors, R_1 and R_2, where R_1 equals 40 ohms and R_2 equals 20 ohms. Through this circuit the total current—regardless of its value—will divide, with twice as much current flowing through R_2 as flows through R_1.

Current Flow in Parallel Circuits

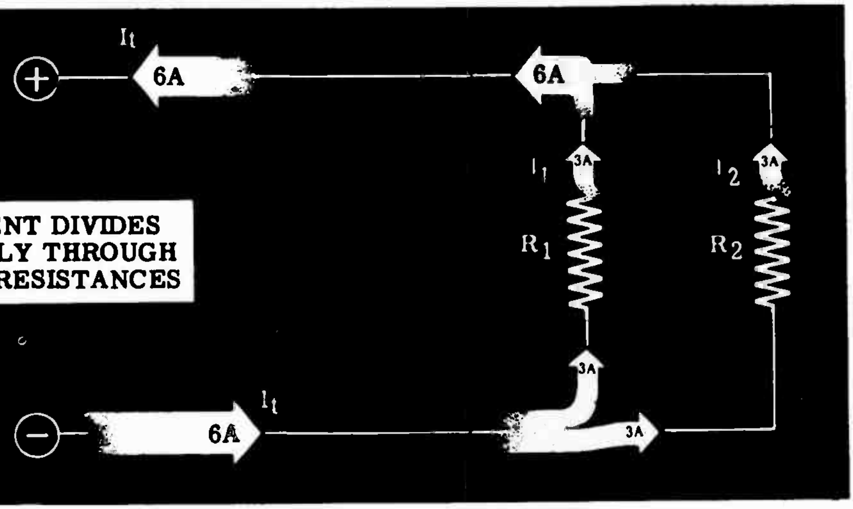
Resistances connected side by side—parallel connection—provide alternate paths for current flow between the terminals of the voltage source. The total circuit current divides, with part of the total current flowing through each possible path. Each resistance is rated to pass a certain maximum current, but the total circuit current can be greater than this individual rated value, if the current divides and flows through more than one path.

CURRENT DIVISION IN A PARALLEL CIRCUIT



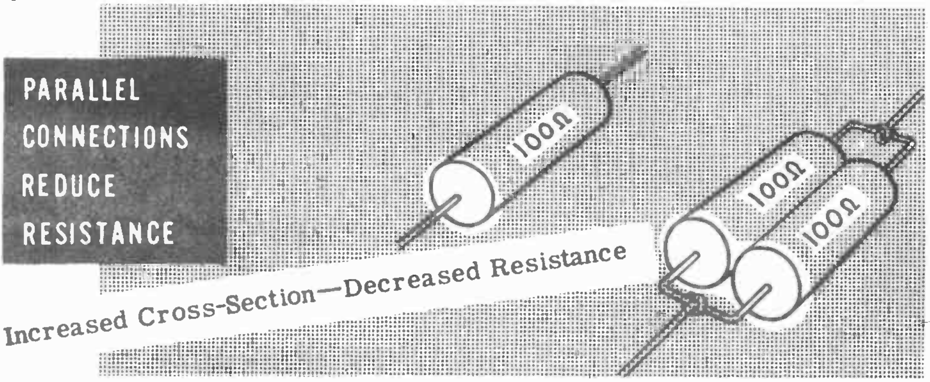
For parallel circuits consisting of equal resistances in parallel the currents through each resistor will be equal, since each path offers an equal amount of opposition to current flow. In such a circuit the current through each resistance is equal to the total current divided by the number of resistances connected in parallel.

CURRENT DIVIDES EQUALLY THROUGH EQUAL RESISTANCES

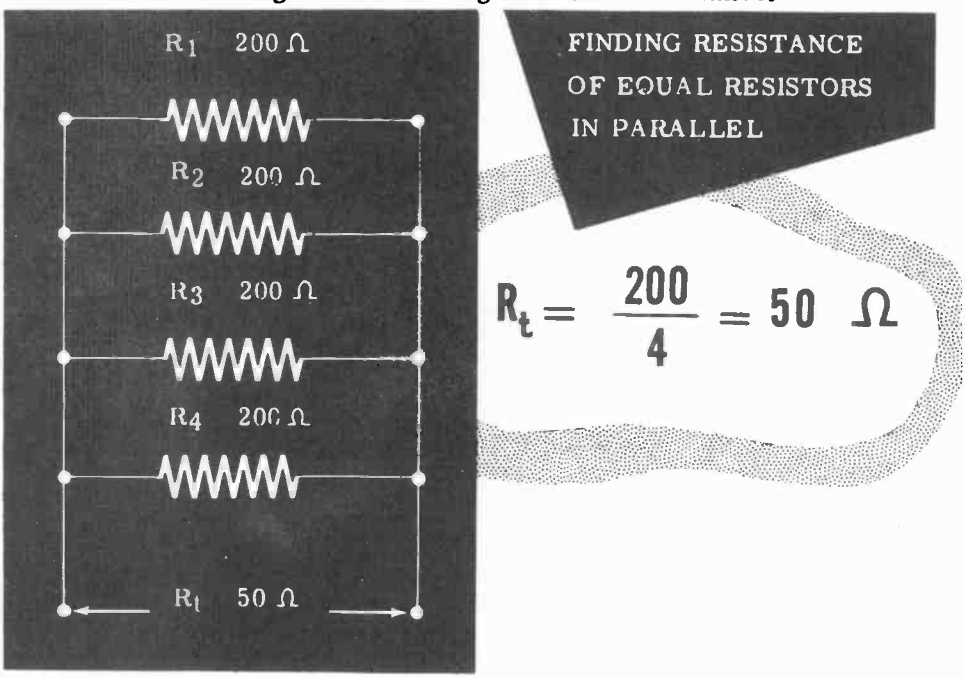


Resistances in Parallel

Resistances in parallel are like water pipes in parallel. In each case, the total cross-section is increased and the opposition to current flow—resistance—is decreased. Two water pipes of the same size placed side by side carry twice as much water as a single pipe; and equal resistances connected side by side—parallel connection—pass twice as much current as a single resistance. This greater current flow indicates that the total resistance of the parallel-connected resistances is less than that of a single resistance.



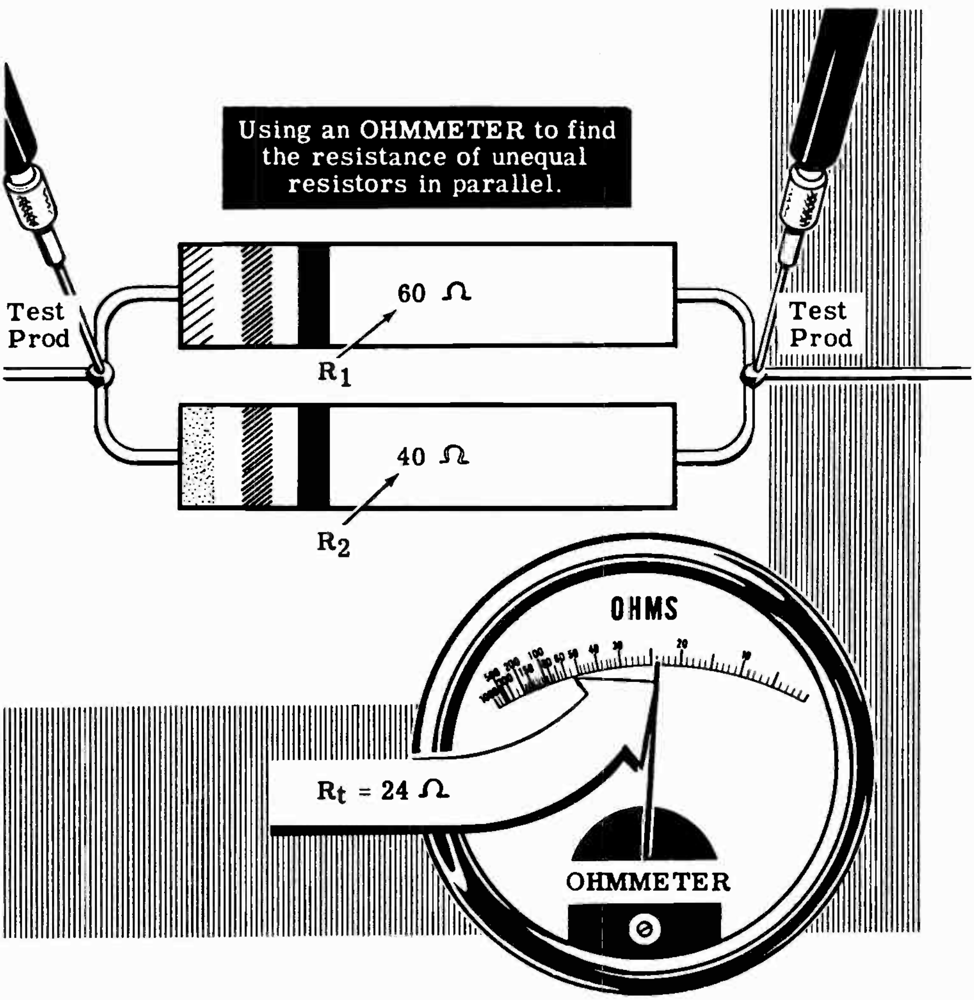
To find the resistance of equal resistances connected in parallel, you need only to divide the value of one resistance by the number of resistances. Suppose that your circuit consists of four 200-ohm resistances in parallel. The total resistance of the parallel connection is one-fourth that of a single 200-ohm resistance or equal to 50 ohms. This parallel connection will act in the circuit as though it were a single 50-ohm resistance.



Resistances in Parallel (continued)

If the circuit you are working with consists of unequal resistances in parallel, you cannot find the total resistance quite as easily as if they were of equal value. Two water pipes—one large and one small—will carry more water than either pipe alone, and two resistors of unequal value will pass more current than either resistor alone. Although the total opposition to current flow offered by the parallel resistances is less than that of either resistance alone, it cannot be found by dividing either of the known values by two.

For a parallel circuit consisting of two resistors, R_1 and R_2, where R_1 equals 60 ohms and R_2 equals 40 ohms, the total resistance is less than 40 ohms but does not equal 20 ohms. You could find the total resistance by using an ohmmeter and would find that the measured total resistance is 24 ohms. However, it may not always be possible to use an ohmmeter, and instead you will need to use another method to find the total resistance.



Resistances in Parallel—Two Unequal Resistors

When resistors are connected in parallel, the effect on the circuit is the same as having one resistor with a resistance value that is less than that of the smaller of the two parallel components. You may refer to this "one" resistor as a single or equivalent resistor. You will now see what happens to the total resistance of two resistors of unequal value, when the components are connected in parallel.

On the previous sheet you were told that it is often impossible to use an ohmmeter for measuring values of resistance. In such cases another tool must be used to ascertain total resistance. The tool referred to is derived from the very familiar Ohm's Law. You have already learned that in parallel circuits

$$E_t = E_1 = E_2$$

and that

$$I_t = I_1 + I_2$$

The resistance is found by first substituting the Ohm's Law formula for current in each part of the I_t equation, above. As you know

1 $$I_t = \frac{E}{R_t}$$

and since

2 $$I_t = I_1 + I_2$$

then (by substitution)

3 $$\frac{E}{R_t} = \frac{E}{R_1} + \frac{E}{R_2}$$

Now, recall that the voltage is the same in each part of the circuit, as illustrated in formula number three. By dividing both sides of equation number three by the voltage "E," we find that

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

and in simplifying find the following:

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

$$R_1 R_2 = R_T (R_2 + R_1)$$

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

The formula states, in effect, that total resistance in a parallel circuit composed of two resistors of unequal value, is found by multiplying the value of one resistor by the value of the second, adding the value of one resistor to the value of the second, and then dividing the first figure by the second figure.

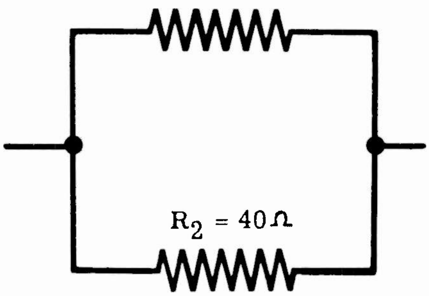
Resistances in Parallel (continued)

If the values of two resistances connected in parallel are known, you can find the total resistance of the parallel combination by using a formula and solving for the total resistance. The solution involves three steps—multiplication, addition and division. For example, to find the total resistance of the 60-ohm and 40-ohm resistors in parallel, you use the following steps.

1. Multiply the two resistance values.
   $60 \times 40 = 2400$

2. Add the two resistance values.
   $60 + 40 = 100$

3. Divide the product by the sum.
   $2400 \div 100 = 24$



The total resistance of the parallel combination of the 60-ohm and 40-ohm resistor then is 24 ohms, and the combination will act as though it were a single resistance of that value.

This formula is expressed as follows:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

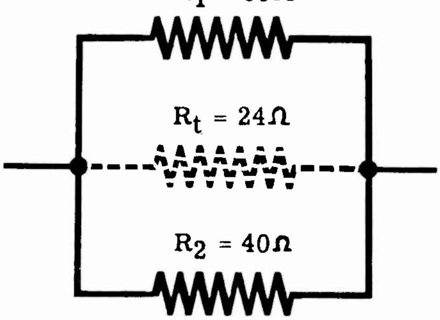
The formula shows that R_t equals the product of R_1 and R_2 divided by their sum. To find R_t the numerical values of R_1 and R_2 are used and the three steps to the solution are performed.

$$R_t = \frac{60 \times 40}{60 + 40}$$

1. Multiply — $R_t = \frac{60 \times 40}{60 + 40} = \frac{2400}{60 + 40}$

2. Add — $R_t = \frac{2400}{60 + 40} = \frac{2400}{100}$

3. Divide — $R_t = \frac{2400}{100} = 24$ ohms



Resistances in Parallel—Three or More Unequal Resistors

Combinations of three or more unequal resistances in parallel are sometimes used. To find the resistance of such combinations, you first find the total resistance of any two of the resistances. Combine this total in the same way with another of the resistance values and you have the total for three resistances. Continue to combine the total with additional resistances until all of the resistances have been combined to give the total resistance of all the parallel resistances.

For example, if three resistors—R_1, R_2 and R_3—are connected in parallel, you would first find the total resistance of R_1 and R_2 in parallel. Next you combine this value with R_3 and obtain the total resistance of R_1, R_2 and R_3. This total is the total resistance of the three resistors in parallel.

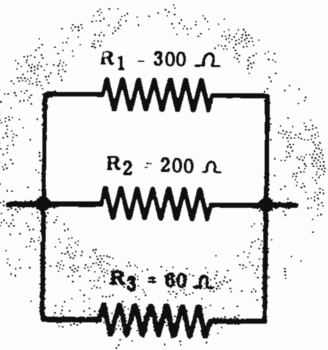
If R_1 equals 300 ohms, R_2 equals 200 ohms and R_3 equals 60 ohms, the total resistance is found by combining 300 ohms and 200 ohms and then combining this result with 60 ohms.

Combining R_1 and R_2

$$R_a = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_a = \frac{300 \times 200}{300 + 200} = \frac{60{,}000}{500} = 120$$

$$R_a = 120\ \Omega$$

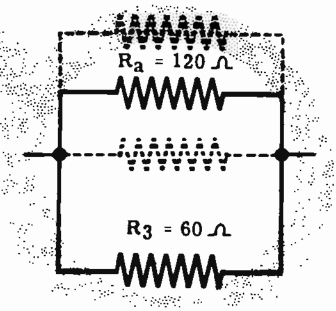


Combining R_a and R_3

$$R_t = \frac{R_a \times R_3}{R_a + R_3}$$

$$R_t = \frac{120 \times 60}{120 + 60} = \frac{7200}{180} = 40$$

$$R_t = 40\ \Omega$$



The total resistance of the three resistors connected in parallel is 40 ohms, and the combination will act as a single 40-ohm resistor in the circuit. You can easily see that this method for finding total resistance becomes very cumbersome as the number of resistors in parallel increases. On the next sheet you will use another, fairly simple method for finding the total resistance of three resistors in parallel. This new method, however, may be applied to finding the total resistance of any number of resistors in parallel, with comparative ease.

Resistance in Parallel—Three or More Unequal Resistors (continued)

Finding the total resistance in parallel circuits which are composed of three or more resistors may be accomplished by using the "reciprocal" method. Refer to the development of the formula for finding total resistance of two resistors in parallel.

You already know that in parallel circuits

$$E_t = E_1 = E_2 = E_3 = \text{etc.}$$

and that

$$I_t = I_1 + I_2 + I_3 + \text{etc.}$$

The resistance of the parallel circuit is found by first substituting the Ohm's Law formula for current in each part of the equation for I_t, above. As you know

$$① \quad I_t = \frac{E}{R_t}$$

and since

$$② \quad I_t = I_1 + I_2 + I_3 + \text{etc.}$$

you find (by substitution) that

$$③ \quad \frac{E}{R_t} = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} + \text{etc.}$$

Now, recall that the voltage is the same across each parallel component. By dividing both sides of equation number three by the voltage "E," you find that the reciprocal equation is

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{etc.}$$

Consider the parallel circuit on the previous sheet. This time you will find the total resistance by using the reciprocal formula just derived. Note that R_1 = 300 ohms, R_2 = 200 ohms, and R_3 = 60 ohms.

By substituting these resistance values in the reciprocal equation you find that

$$\frac{1}{R_t} = \frac{1}{60} + \frac{1}{200} + \frac{1}{300}$$

In order to add these resistances you must find the least common denominator; in this case 600. Then

$$\frac{1}{R_t} = \frac{10}{600} + \frac{3}{600} + \frac{2}{600}$$

Resistance in Parallel—Three or More Unequal Resistors (continued)

$$\frac{1}{R_t} = \frac{15}{600} = .025$$

$$\frac{1}{R_t} = \frac{.025}{1}$$

$$R_t = \frac{1}{.025} = 40 \text{ ohms}$$

You can see that if the parallel circuit under analysis is composed of six or eight resistors of unequal value, it will be a simple matter to find the total resistance by using the reciprocal formula. However, suppose the resistance values are such that no suitable least common denominator can be found. How would you solve the problem then?

The answer is simple. Recall the equation, above,

$$\frac{1}{R_t} = \frac{1}{60} + \frac{1}{200} + \frac{1}{300}$$

and take the reciprocal of both sides. You then have

$$R_t = \frac{1}{\frac{1}{60} + \frac{1}{200} + \frac{1}{300}}$$

In simplifying, you see that

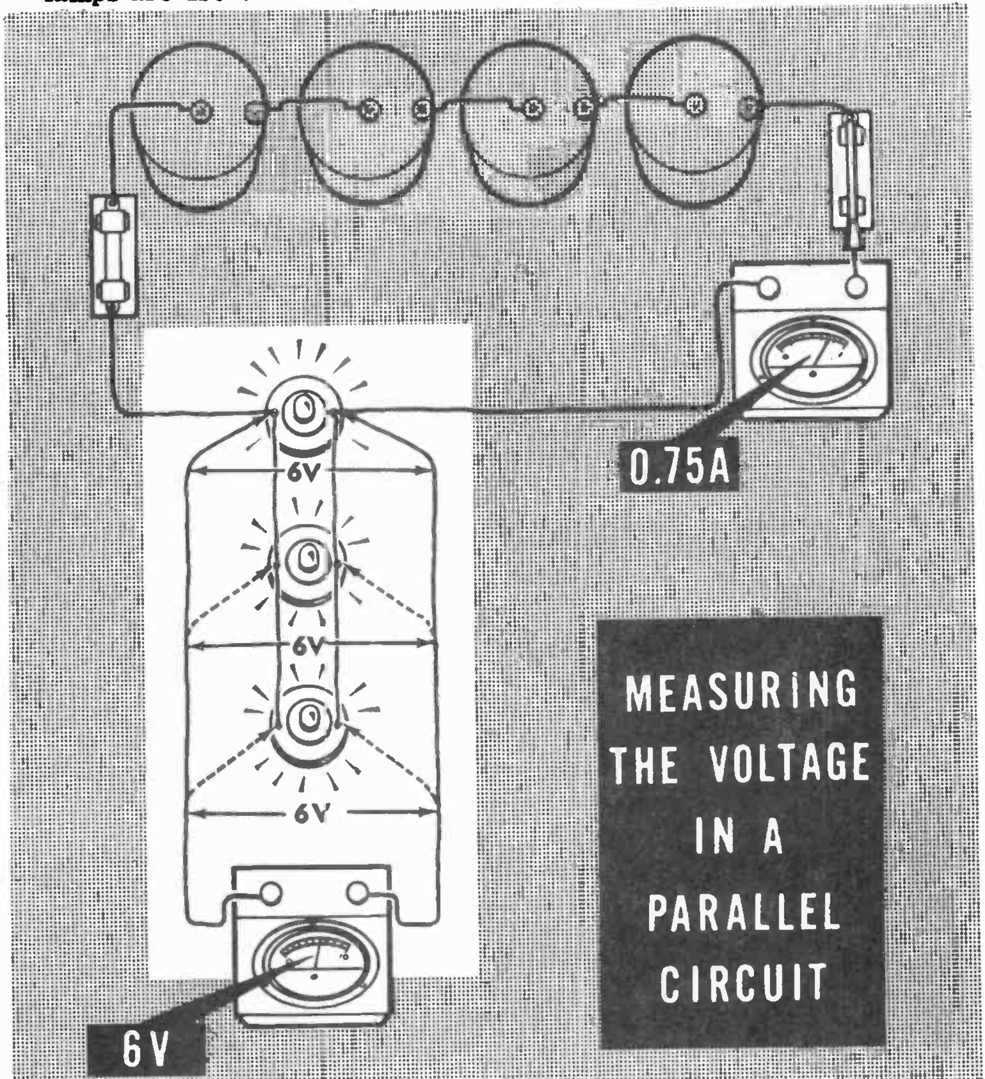
$$R_t = \frac{1}{.0167 + .005 + .0033} = \frac{1}{.0250}$$

$$R_t = 40 \text{ ohms}$$

If the parallel circuit is composed of a number of resistors (2, 3, 4, 5, etc.) of equal value the total current flowing in the circuit will divide equally for all of the parallel branches. The combined resistance of all the branches is considered to be equal to the value of a single resistor divided by the number of resistors in the circuit. For example, if six resistors of 36 ohms resistance each are connected in parallel, the combined resistance of the circuit is 36 divided by 6, or 6 ohms, since six paths are being presented to the flow of current instead of just one.

Demonstration—Parallel Circuit Voltages

1. While the current through the various branches of a parallel circuit is not always the same, the voltage across each branch resistance is equal to that across the others. The instructor connects three lamp sockets in parallel and inserts 250-ma. lamps in each of the three parallel-connected sockets. You see that each lamp lights with the same brilliance as when only a single lamp is used, and that for three lamps the circuit current is 750 ma. Also you can see that the voltmeter reading across the battery terminals is the same whether one, two or three lamps are used.

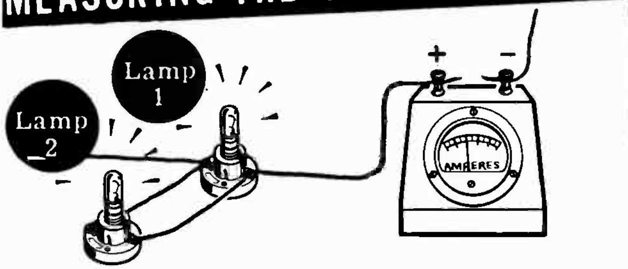


Removing the voltmeter leads from the battery terminals, the instructor connects the voltmeter across the terminals of each lamp socket in turn. You see that the voltage is the same across each of the lamps and is equal to that of the voltage source—the battery.

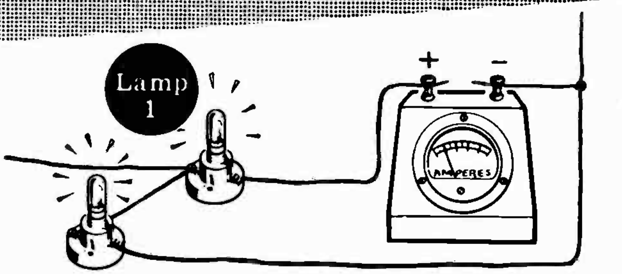
Demonstration—Parallel Circuit Current

2. To demonstrate the division of current the instructor places a 250-ma. lamp with a 150-ma. lamp as shown. The ammeter now shows that the total circuit current is 400 ma. The instructor connects the ammeter first in series with one lamp, then in series with the other and you see that the 400-ma. total current divides, with 250 ma. flowing through one lamp and 150 ma. through the other. The ammeter is then connected to read the total circuit current at that end of the parallel combination opposite the end at which it was originally connected. You can see that the total circuit current is the same at each end of the parallel circuit, the current dividing to flow through the parallel branches of the circuit and combining again after passing through these branches.

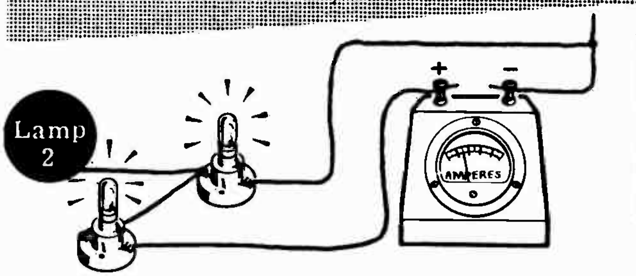
MEASURING THE CURRENTS IN A PARALLEL CIRCUIT



0.4 ampere —Total circuit current for both lamps.



0.15 ampere —The current through Lamp 1 only.

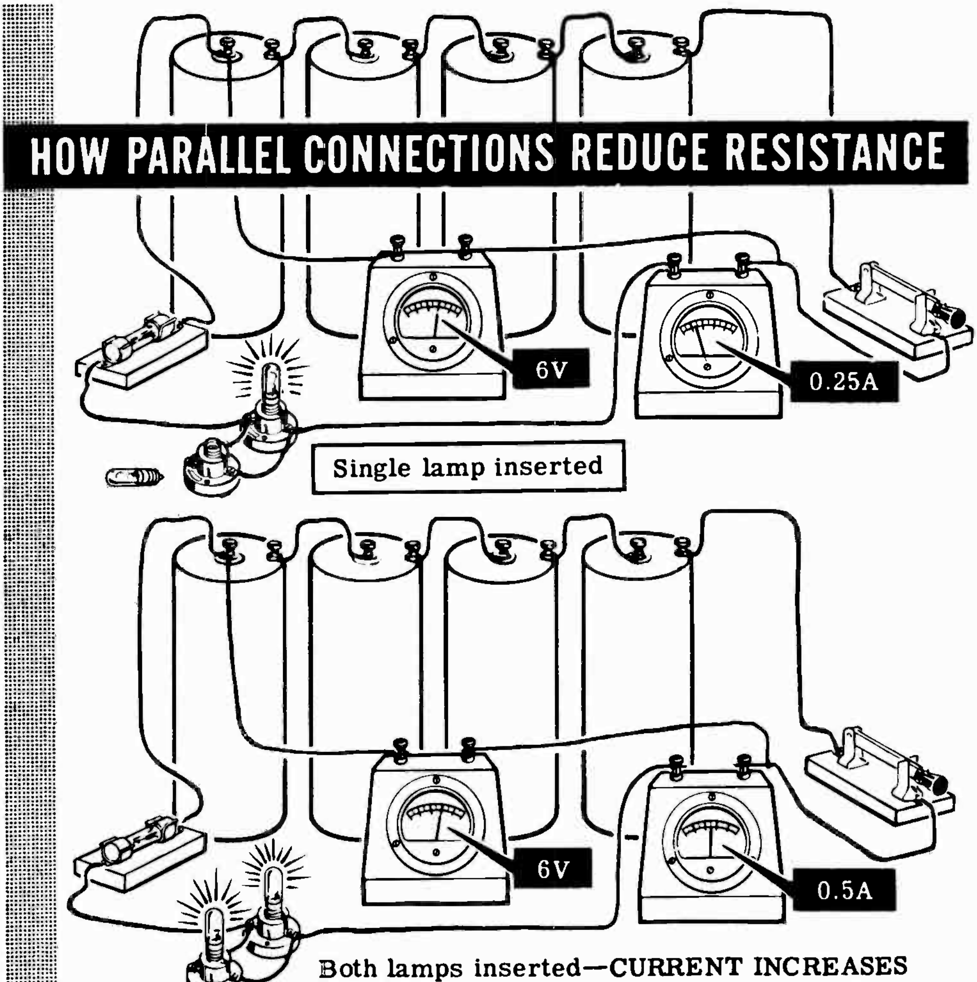


0.25 ampere —The current through Lamp 2 only.

Demonstration—Parallel Circuit Resistance

3. When the total current flow in a circuit increases with no change in the voltage, a decrease in total resistance is indicated. To show this effect, the instructor connects two lamp sockets in parallel. This parallel combination is connected across the terminals of a 6-volt battery of dry cells with an ammeter inserted in one battery lead to measure the total circuit current. As a voltmeter is connected across the battery terminals you see that the voltage is 6 volts. When only one lamp is inserted, the ammeter indicates a current flow of approximately 250 ma. and the voltmeter reads 6 volts. With both lamps inserted, the current reading increases but the voltage remains at 6 volts—indicating that the parallel circuit offers less resistance than a single lamp.

HOW PARALLEL CONNECTIONS REDUCE RESISTANCE



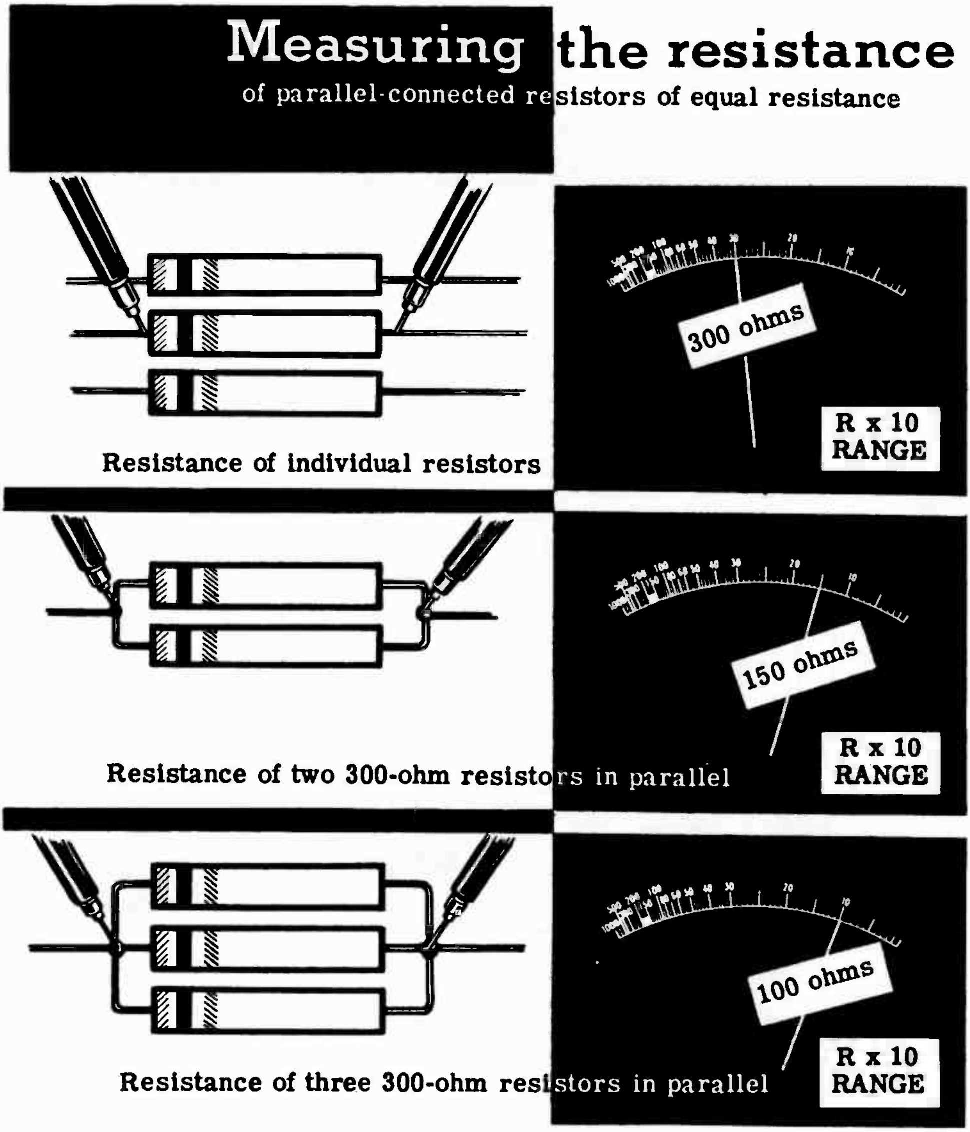
Single lamp inserted

Both lamps inserted—CURRENT INCREASES

4. As each of the lamps is inserted in turn, you see that the ammeter reading for each lamp alone is 250 ma., but with both lamps inserted the total current indicated is 500 ma. This shows that the circuit current of 500 ma. divides into two 250-ma. currents, with each flowing through a separate lamp.

Demonstration—Parallel Resistances

To show how parallel connection of resistances decreases the total resistance, the instructor measures the resistance of three 300-ohm resistors individually with the ohmmeter. When two of the 300-ohm resistors are paralleled, the total resistance should be 150 ohms; this is shown by so connecting them and measuring the parallel resistance with the ohmmeter. As another 300-ohm resistor is connected in parallel, you see that the resistance is lowered to a value of 100 ohms. This shows that connecting <u>equal</u> resistances in parallel not only reduces the total resistance, but also shows that the total resistance can be found by dividing the value of a single resistance by the number of resistances used.



Resistance of individual resistors

Resistance of two 300-ohm resistors in parallel

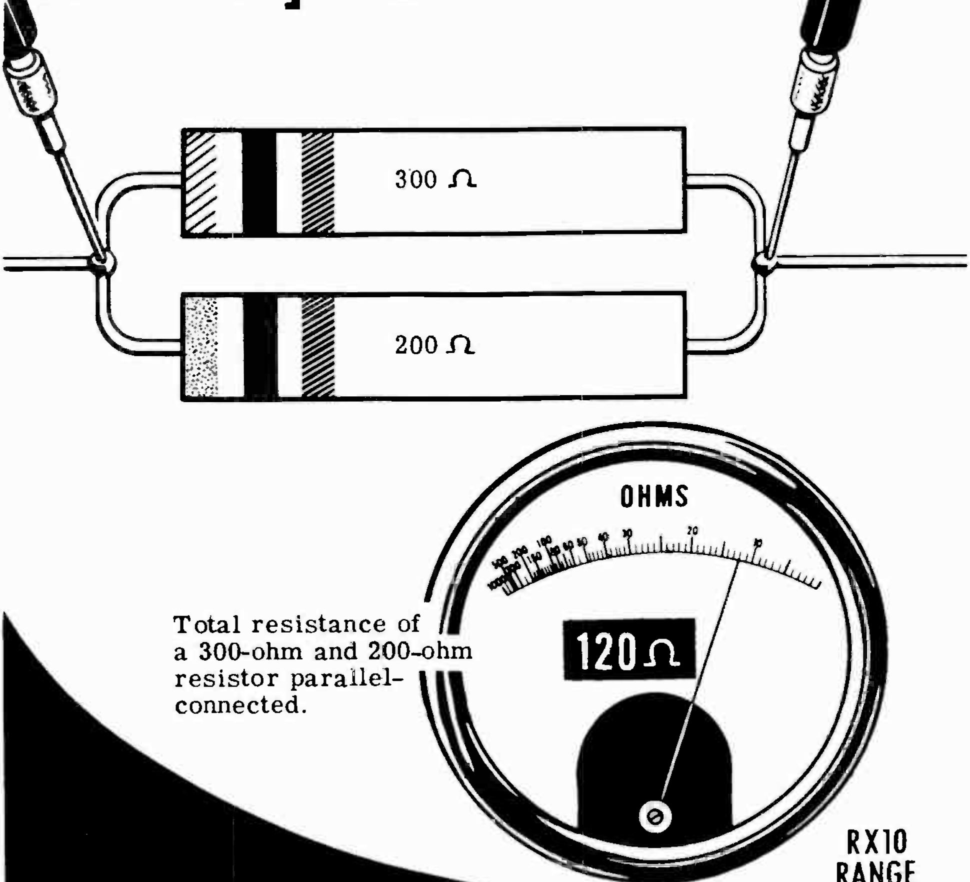
Resistance of three 300-ohm resistors in parallel

Demonstration—Parallel Resistances (continued)

Next, a 200-ohm resistor is connected in parallel with a 300-ohm resistor. Solving the formula for parallel resistance shows that the total resistance should be 120 ohms. An ohmmeter reading shows that this value is correct.

Measuring the resistance of parallel-connected resistors

# of unequal resistance



Total resistance of a 300-ohm and 200-ohm resistor parallel-connected.

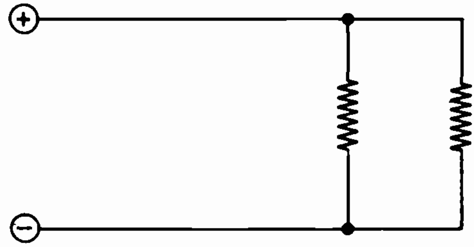
$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_t = \frac{300 \times 200}{300 + 200} = \frac{60000}{500} = 120$$

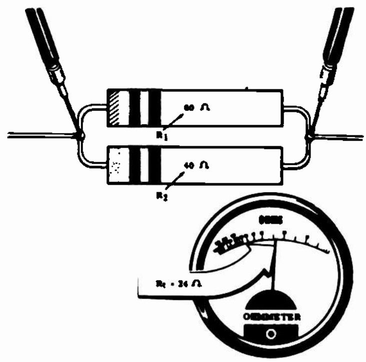
$$R_t = 120\,\Omega$$

Review of Parallel Circuits

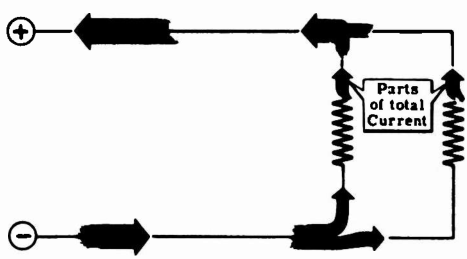
Now review what you have found out and seen concerning parallel circuits and their effect on resistance, voltage and current, before you work with these circuits yourself. Observe that parallel circuits are the opposite of series circuits—with voltages being equal and currents dividing in parallel circuits, while currents are equal and voltage divides for a series circuit.



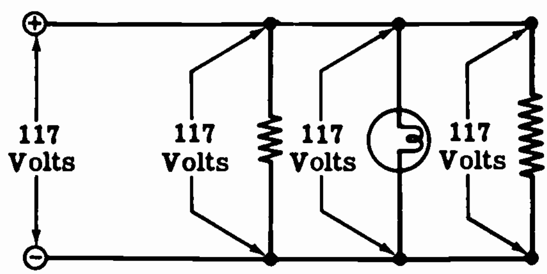
PARALLEL CIRCUIT — Resistances connected side by side across a voltage source.



PARALLEL CIRCUIT RESISTANCE — The total resistance is less than that of the smallest individual resistance.



PARALLEL CIRCUIT CURRENT — The current divides to flow through the parallel branches of the circuit.



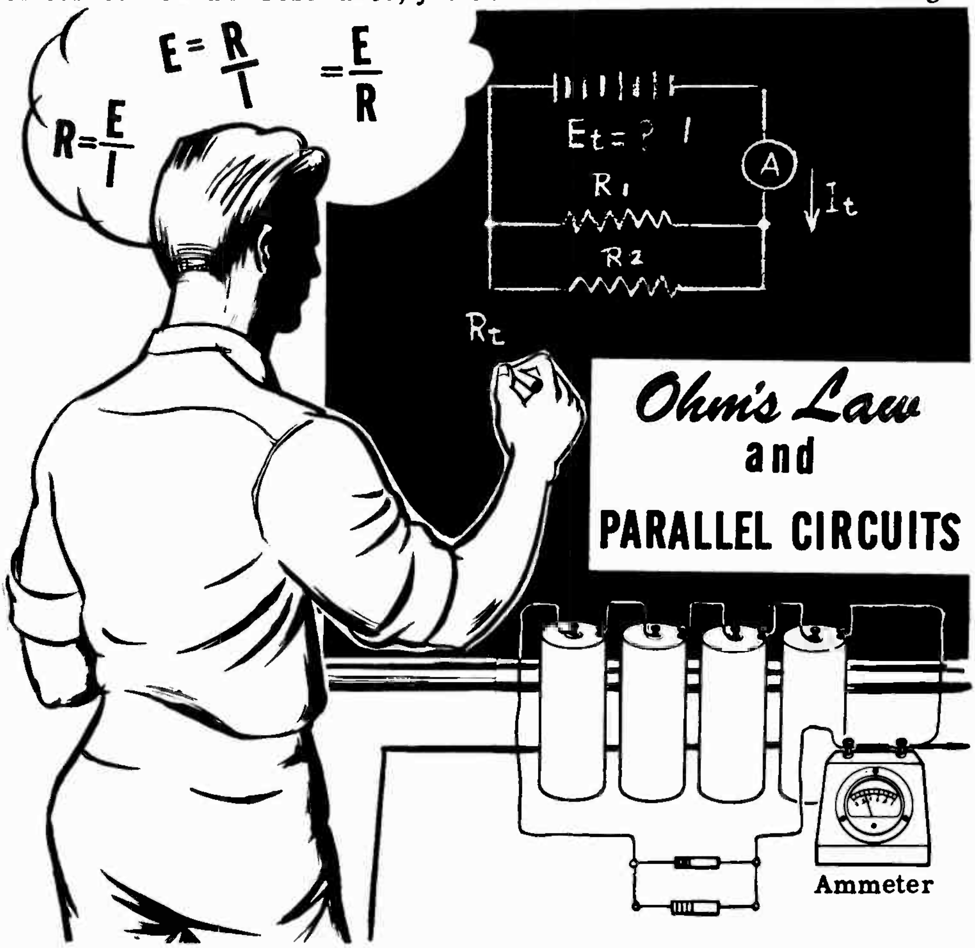
PARALLEL CIRCUIT VOLTAGE — The voltage across each resistance is the same and equals that of the voltage source.

Applying Ohm's Law to Parallel Circuits

Unknown quantities of resistance, current and voltage in parallel circuits may be found by using Ohm's law. Suppose you want to use an ohmmeter to measure the resistance of a resistor connected in parallel with one or more other resistances. You must disconnect the resistor to be measured from the circuit; otherwise the ohmmeter will read the total resistance of the parallel combination of resistors. In such cases, you will find that it is usually easier to use Ohm's law than the ohmmeter.

To measure the current flow through one particular resistance of a combination of parallel resistances, you will have to disconnect the circuit and insert an ammeter to read only the current flow through that particular resistance. Again you will save time and effort by using Ohm's law.

Without disconnecting the circuit you can read the voltage across each resistance of a parallel circuit by connecting a voltmeter across the entire circuit, since the voltage across each resistance equals that across the parallel combination. The voltage across a resistor can be divided by the resistance to obtain the current. If you have no voltmeter, but can obtain the circuit current and resistance, you can use Ohm's law to find the voltage.



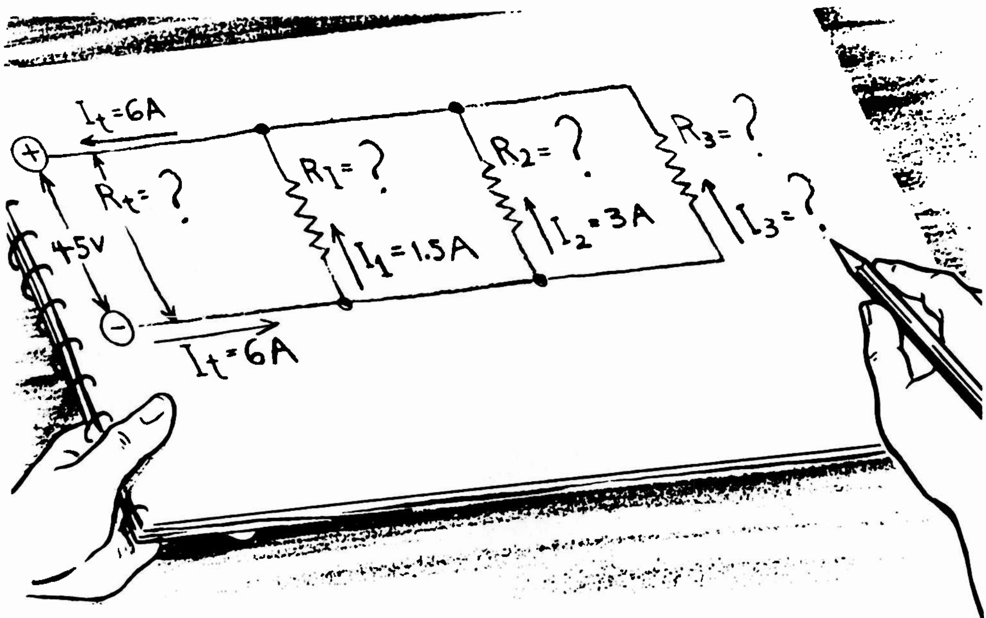
Finding Resistances in Parallel Circuits

This is how you use Ohm's law to find resistances in parallel circuits—

Suppose a parallel circuit consists of three resistors—R_1, R_2 and R_3—of unknown values connected across 45 volts. The total circuit current is 6 amperes and the current flowing through R_1 is 1.5 amperes; the current flowing through R_2 is 3 amperes, and the current flowing through R_3 is unknown.

To find the unknown resistance values, first sketch the circuit and fill in all of the known values of resistance, voltage and current; then make up a table of these values and the unknown values for each resistance. For those circuit branches where any two quantities are known you solve for the unknown quantity, using either Ohm's law or the rules regarding total resistance, current and voltage in a parallel circuit.

1. Sketch the circuit and the known values.



2. Tabulate all the known quantities.

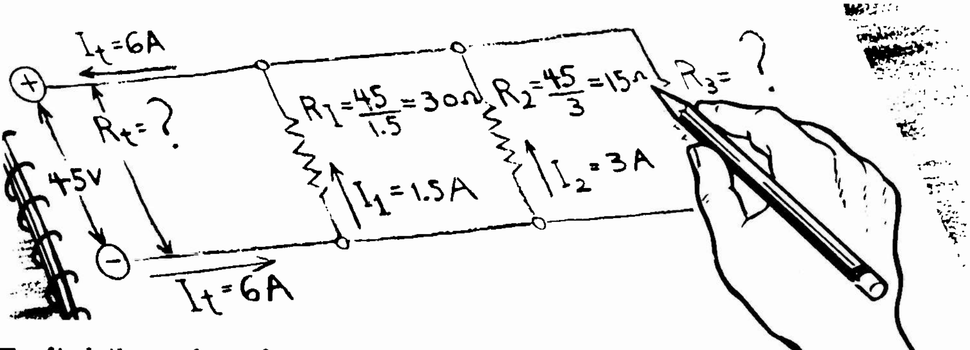
	R_1	R_2	R_3	R_t
Resistance				
Current	1.5	3		6
Voltage	45	45	45	45

Finding Resistances in Parallel Circuits (continued)

Since both the current and voltage are known for R_1 and R_2, you can find their resistance values.

3. Find R_1 and R_2, using Ohm's law.

$$R_1 = \frac{45}{1.5} = 30 \text{ ohms} \qquad R_2 = \frac{45}{3} = 15 \text{ ohms}$$



To find the value of R_3, you must first determine the current through it. The total circuit current is 6 amperes and equals the sum of the three branch currents. The sum of the currents through R_1 and R_2 is 4.5 amperes, with the remainder of the total circuit current flowing through R_3.

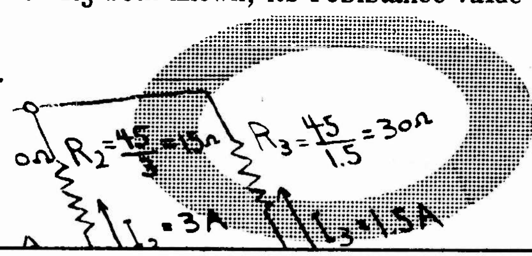
4. Find the current through R_3 by subtraction.

$$I_3 = 6 - 4.5 = 1.5 \text{ amperes}$$

With the voltage and current for R_3 both known, its resistance value may be obtained.

5. Find R_3, using Ohm's law.

$$R_3 = \frac{45}{1.5} = 30 \text{ ohms}$$



	R_1	R_2	R_3	R_t
Resistance	30	15	30	
Current	1.5	3	1.5	6
Voltage	45	45	45	45

Finding Resistances in Parallel Circuits (continued)

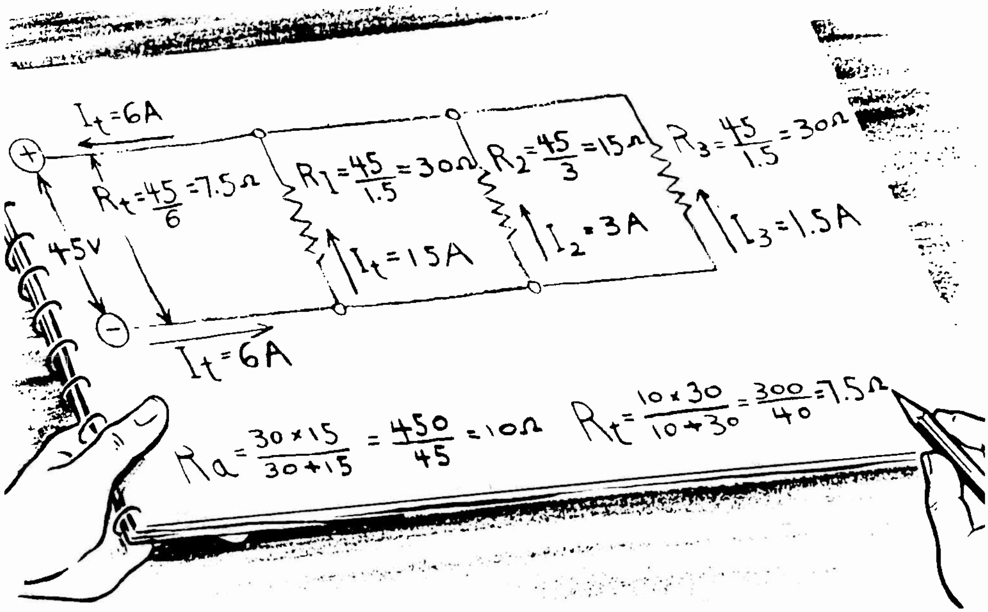
The total circuit resistance (R_t) can be obtained either by using the formula for the total resistance of parallel resistances or applying Ohm's law to the total circuit current and voltage.

6. Find R_t, using Ohm's law: $R_t = \frac{45}{6} = 7.5$ ohms
7. Find R_t, using the formula for parallel resistances.

$$R_a = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{30 \times 15}{30 + 15} = \frac{450}{45} = 10 \text{ ohms}$$

$$R_t = \frac{R_a \times R_3}{R_a + R_3} = \frac{10 \times 30}{10 + 30} = \frac{300}{40} = 7.5 \text{ ohms}$$

The two results obtained are equal and are used as a check on the accuracy of the solution.



Your table is now complete with all circuit values known—

	R_1	R_2	R_3	R_t
Resistance	30	15	30	7.5
Current	1.5	3	1.5	6
Voltage	45	45	45	45

Finding Currents in Parallel Circuits

This is how you use Ohm's law to find currents in parallel circuits—

To solve for currents in parallel circuits you use the same procedure as that used in solving for resistances, except that the unknown quantities are currents. For example, a parallel circuit consists of four resistors—R_1, R_2, R_3 and R_4—connected across 120 volts. If the resistance of R_1 is 80 ohms, R_2 is 48 ohms, R_3 is 30 ohms, and R_4 is 60 ohms, the individual resistor currents can be obtained by applying Ohm's law; and the total circuit current will equal the sum of these currents. Knowing the circuit voltage and total current, you can find the total circuit resistance.

KNOWN VALUES OF THE CIRCUIT

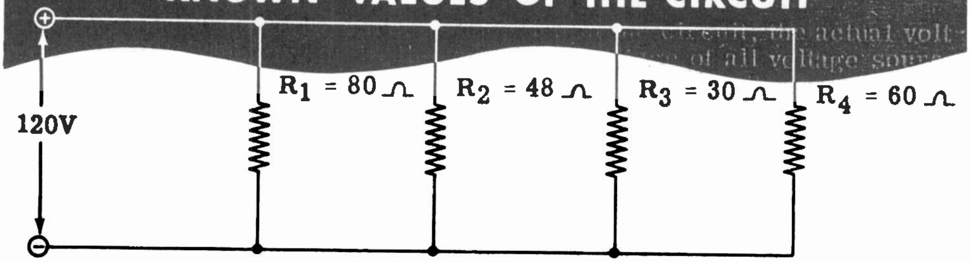


TABLE OF KNOWN VALUES

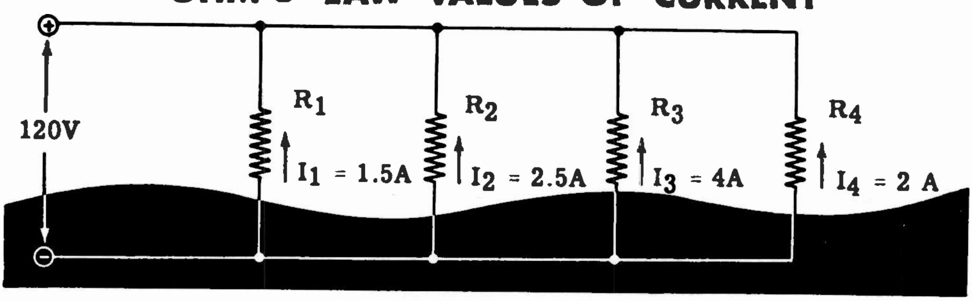
	R_1	R_2	R_3	R_4	R_t
Resistance	80	48	30	60	-
Current	-	-	-	-	-
Voltage	120	120	120	120	120

1. Find the resistor currents, using Ohm's law.

$$I_1 = \frac{120}{80} = 1.5 \text{ amperes} \qquad I_3 = \frac{120}{30} = 4 \text{ amperes}$$

$$I_2 = \frac{120}{48} = 2.5 \text{ amperes} \qquad I_4 = \frac{120}{60} = 2 \text{ amperes}$$

OHM'S LAW VALUES OF CURRENT

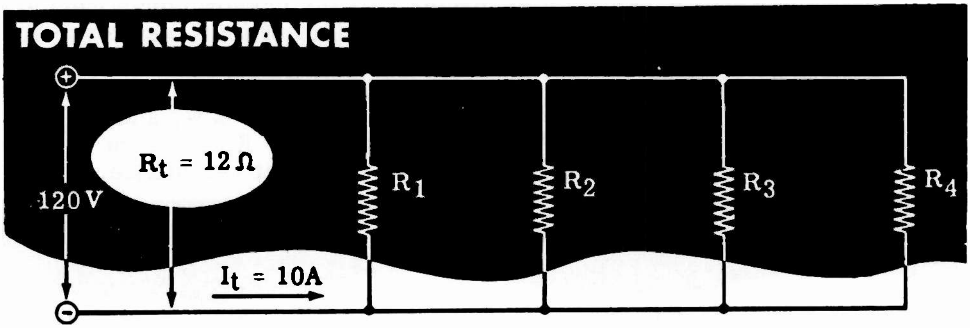


2. The total circuit current equals the sum of the branch currents.

$$I_t = I_1 + I_2 + I_3 + I_4 = 1.5 + 2.5 + 4 + 2 = 10 \text{ amperes}$$

Finding Currents in Parallel Circuits (continued)

3. Find the total resistance, using Ohm's law: $R_t = \dfrac{E_t}{I_t} = \dfrac{120}{10} = 12$ ohms



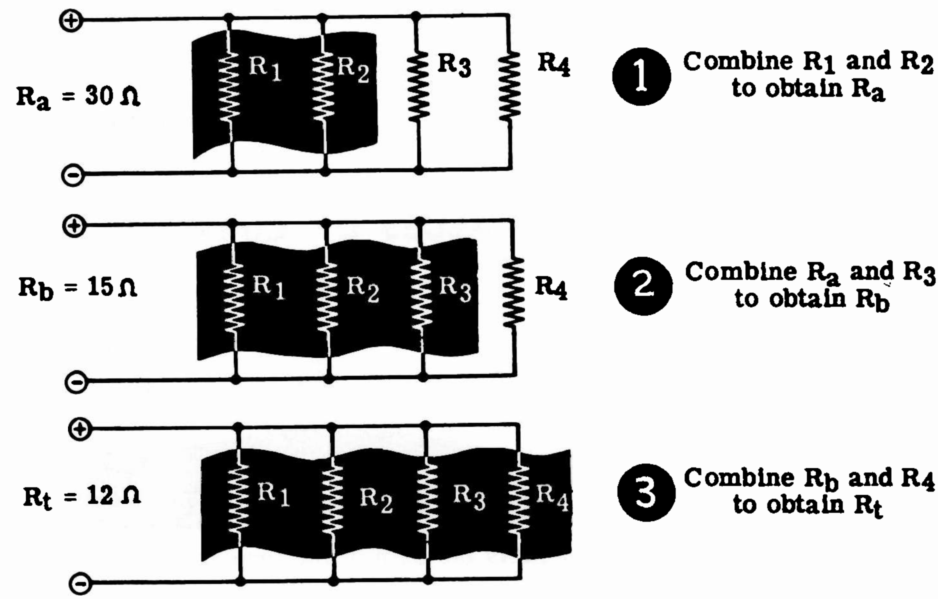
4. Check the total resistance, using the parallel resistance formula.

1 $$R_a = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{80 \times 48}{80 + 48} = \frac{3840}{128} = 30 \text{ ohms}$$

2 $$R_b = \frac{R_a \times R_3}{R_a + R_3} = \frac{30 \times 30}{30 + 30} = \frac{900}{60} = 15 \text{ ohms}$$

3 $$R_t = \frac{R_b \times R_4}{R_b + R_4} = \frac{15 \times 60}{15 + 60} = \frac{900}{75} = 12 \text{ ohms}$$

CHECKING TOTAL RESISTANCE



Finding Currents in Parallel Circuits (continued)

5. With all of the voltage, current and resistance values known, your table of values can be completed.

COMPLETE TABLE OF VALUES

	R_1	R_2	R_3	R_4	R_t
Resistance	80	48	30	60	12
Current	1.5	2.5	4	2	10
Voltage	120	120	120	120	120

Parallel circuit voltage may also be found by using Ohm's law. Since the voltage across each resistor is equal in a parallel circuit, the circuit voltage can be found if the values of resistance and current are both known for any of the circuit resistors. For example, from the above table of values, if the voltages are assumed to be unknown, the circuit voltage can be obtained by multiplying together the known resistance and current values for any of the circuit resistances. Using the values for each resistor in turn, you find that the circuit voltage is 120 volts in each case.

$E_1 = I_1R_1 = 1.5 \times 80 = 120$ volts

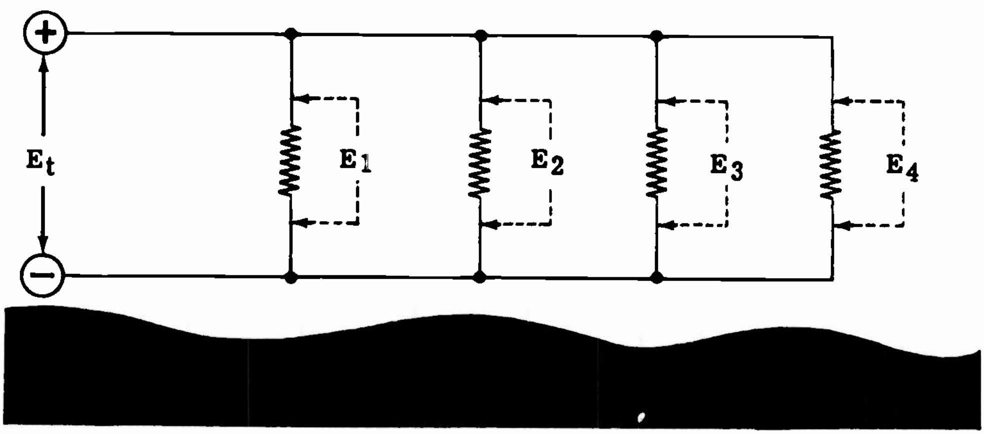
$E_2 = I_2R_2 = 2.5 \times 48 = 120$ volts

$E_3 = I_3R_3 = 4 \times 30 = 120$ volts

$E_4 = I_4R_4 = 2 \times 60 = 120$ volts

$E_t = I_tR_t = 12 \times 10 = 120$ volts

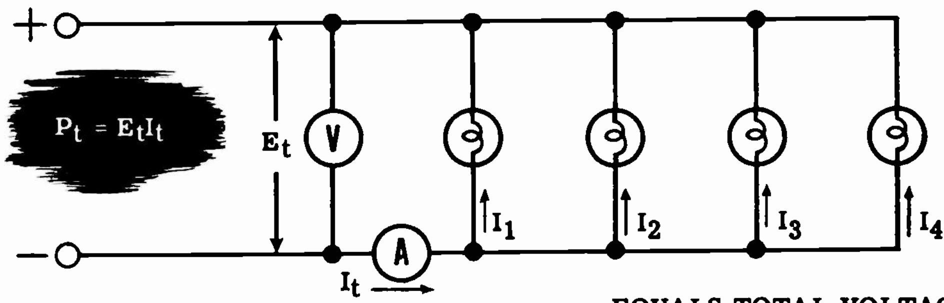
CHECKING PARALLEL CIRCUIT VOLTAGES



Power in Parallel Circuits

You have seen that the power used by a resistor is equal to the current through the resistor multiplied by the voltage across the resistor ($P = EI$), and you have also seen how the total power in a series circuit is equal to the sum of the powers used by each resistance in the circuit. This is also true in parallel circuits; that is, the total power used by a parallel circuit is equal to the sum of the power used by all resistances in the circuit, and can be found by multiplying the total voltage across the circuit by the total circuit current.

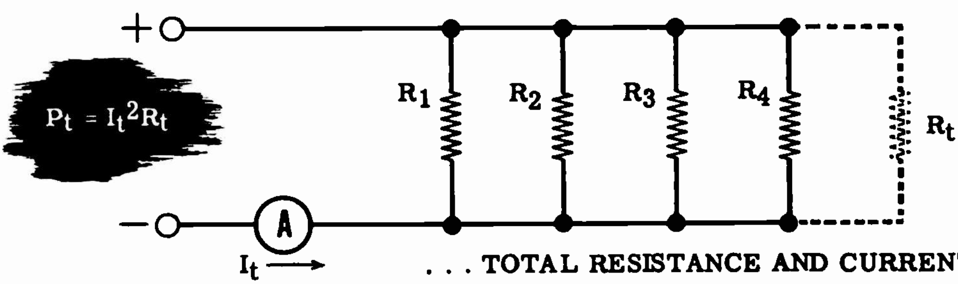
TOTAL POWER IN A PARALLEL CIRCUIT . . .



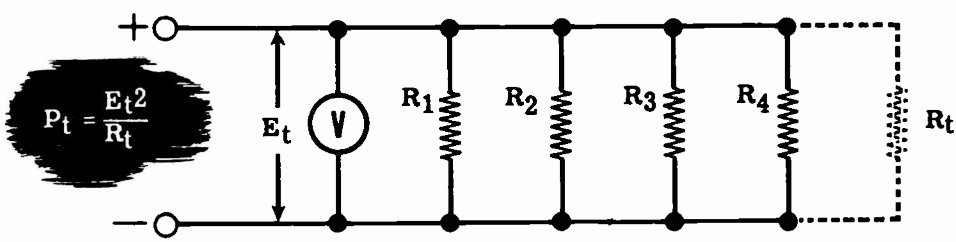
. . . EQUALS TOTAL VOLTAGE TIMES TOTAL CURRENT

The circuit power can also be found by using the rules for parallel circuits to find the total resistance of the circuit if the resistance of all the parts is known. Then total power can be determined by measuring either circuit current or voltage and using the alternate power formulas.

FINDING TOTAL POWER USING . . .



. . . TOTAL RESISTANCE AND CURRENT

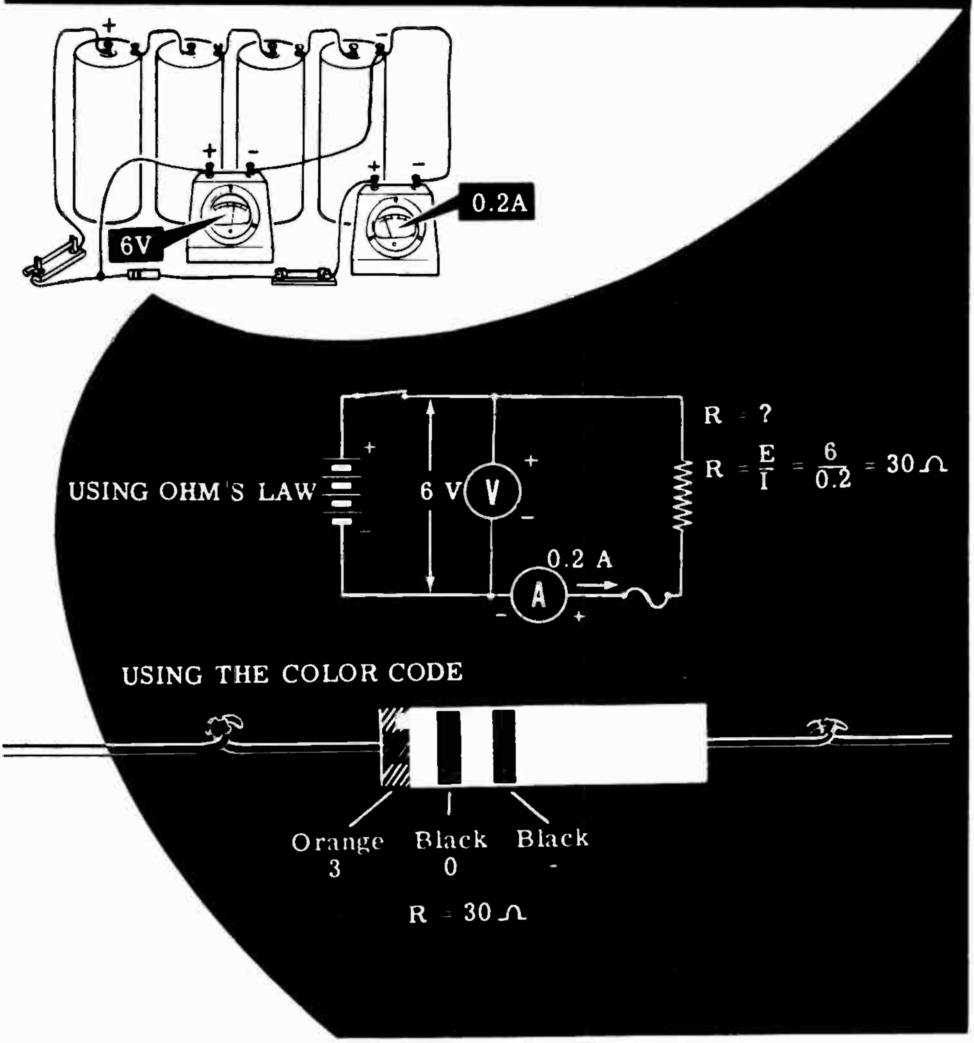


. . . TOTAL RESISTANCE AND VOLTAGE

Demonstration—Ohm's Law and Parallel Resistances

To show how an ammeter and voltmeter may be used as a substitute for an ohmmeter to find the values of the individual and total resistances in a parallel combination, the instructor connects four dry cells in series, to be used as a voltage source. He connects the voltmeter across the dry cell battery to make certain the voltage remains constant at 6 volts. Then the ammeter is connected in series with the (-) terminal of the battery to read the current. He then connects a fuse, a resistor and a switch in series between the (+) terminals of the ammeter and battery. You see that the voltage remains at 6 volts and the current indicated is 0.2 amperes. From Ohm's law the resistance value then is 30 ohms; a check of the color code shows that this is the correct value.

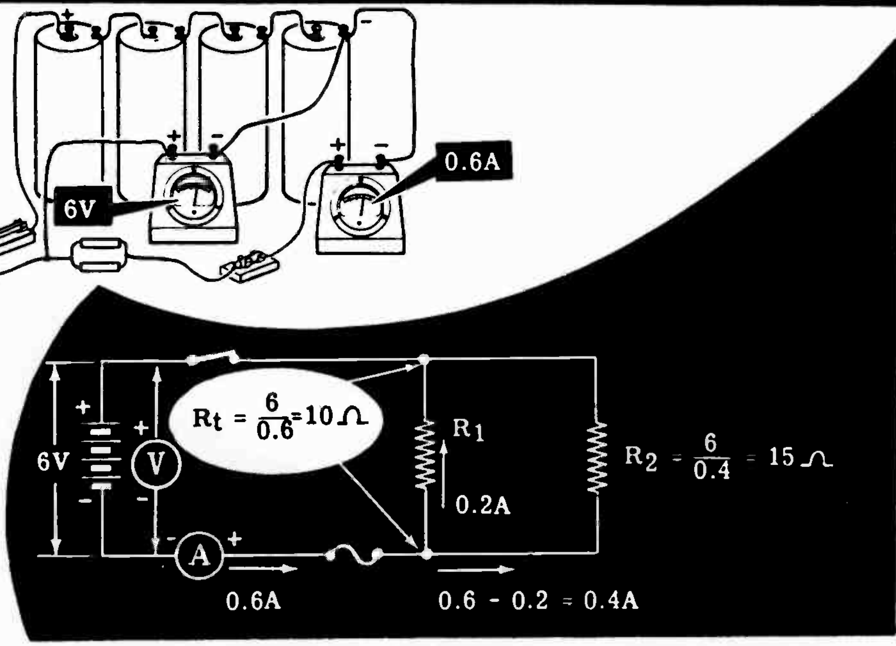
FINDING RESISTANCE WITHOUT AN OHMMETER



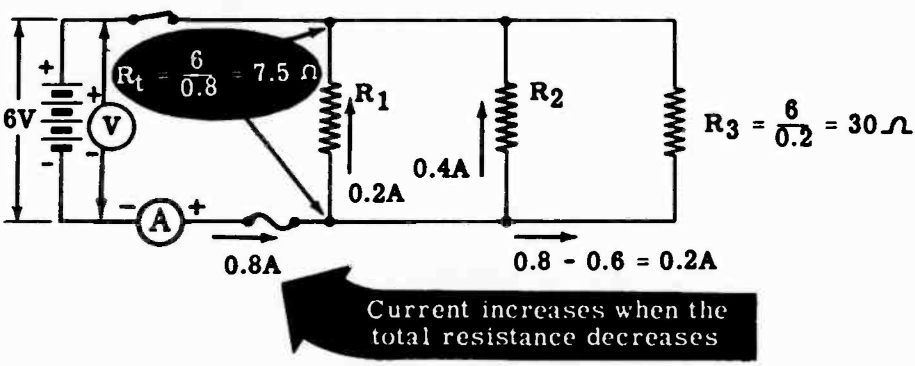
Demonstration—Ohm's Law and Parallel Resistances (continued)

As another resistor is added in parallel, you see that the current reading is 0.6 ampere with no change in voltage. Since the first resistor passes 0.2 ampere, the current through the second resistor is 0.4 ampere. The Ohm's law value of the second resistor then is 6 volts divided by 0.4 ampere or 15 ohms. The total resistance of the parallel combination is equal to 6 volts divided by the total current, 0.6 ampere or 10 ohms.

ADDING A RESISTOR IN PARALLEL REDUCES THE TOTAL RESISTANCE



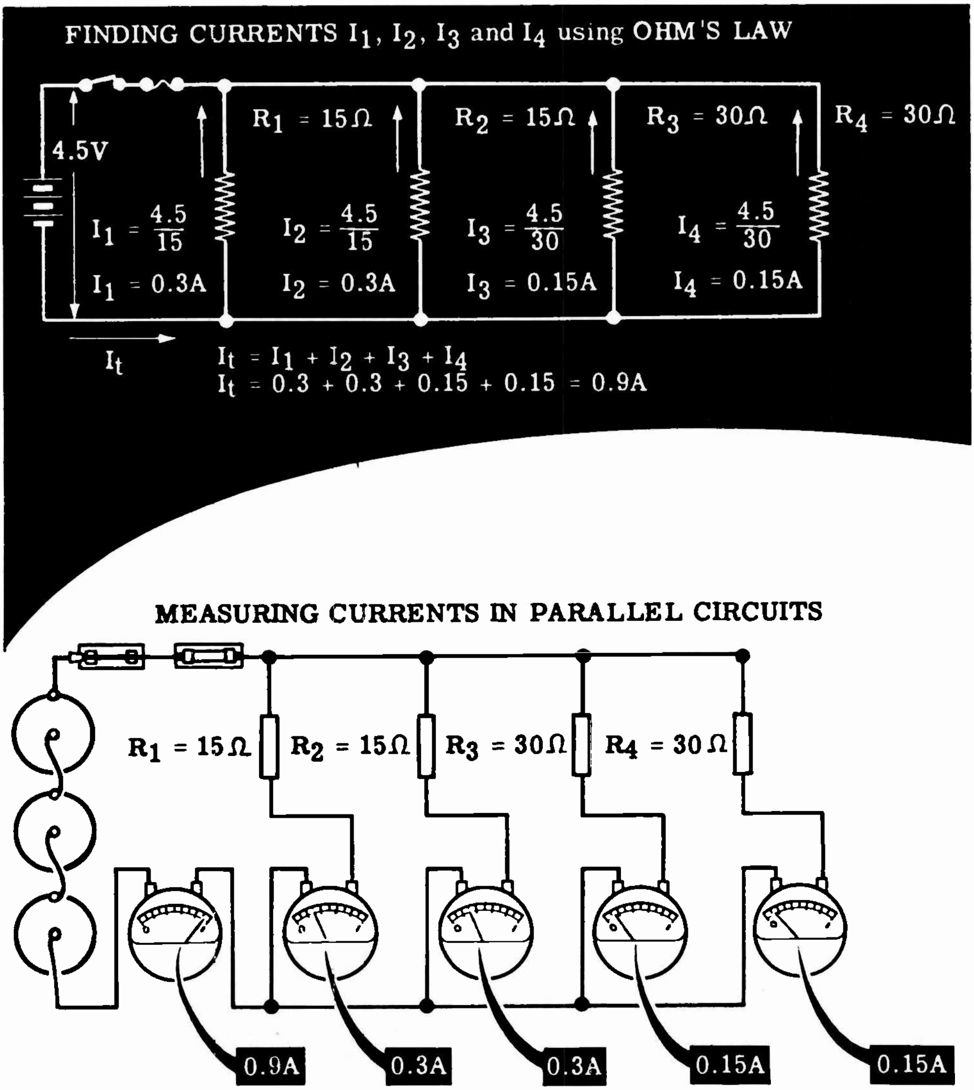
With another resistor added in parallel, you see a further increase in current of 0.2 ampere—showing that the Ohm's law value of the added resistor is 30 ohms. The total current is now 0.8 ampere, resulting in a total resistance value of 7.5 ohms for the parallel combination.



When the instructor disconnects the battery and the various resistors, he checks the total and individual resistances and you see that the Ohm's law and color code values are correct.

Demonstration—Ohm's Law and Parallel Circuit Current

Using only three series-connected cells as a voltage source, the instructor connects the voltmeter across the battery. He then connects four resistors—two 15-ohm and two 30-ohm resistors—across the battery. From Ohm's law the current through the 15-ohm resistors will be 0.3 ampere each and through each 30-ohm resistor 0.15 ampere. The total current will be the sum of the currents through the individual resistances or 0.9 ampere.

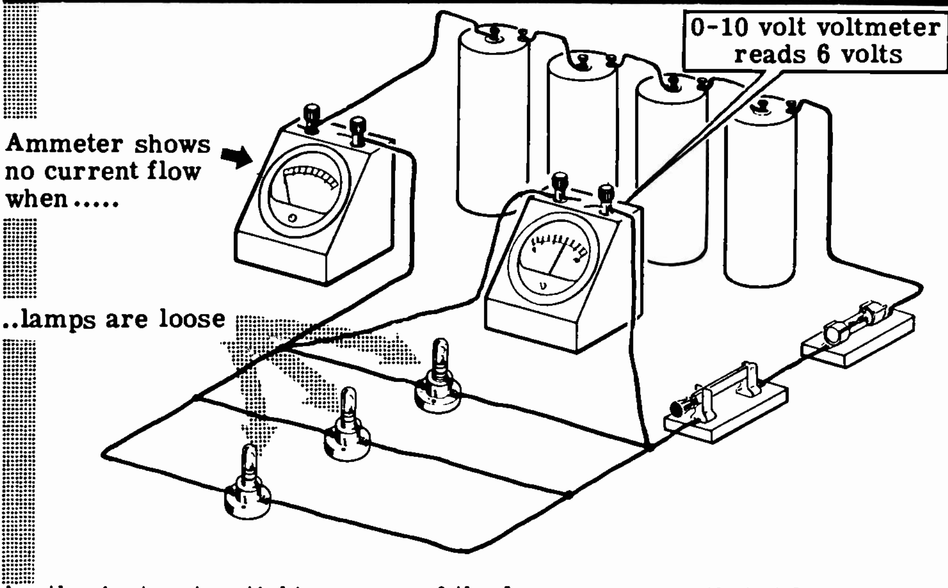


As the instructor inserts an ammeter in the circuit—first to read the total circuit current, then that of the individual resistances—you see that the actual currents are the same as those found by applying Ohm's law.

Demonstration—Power in Parallel Circuits

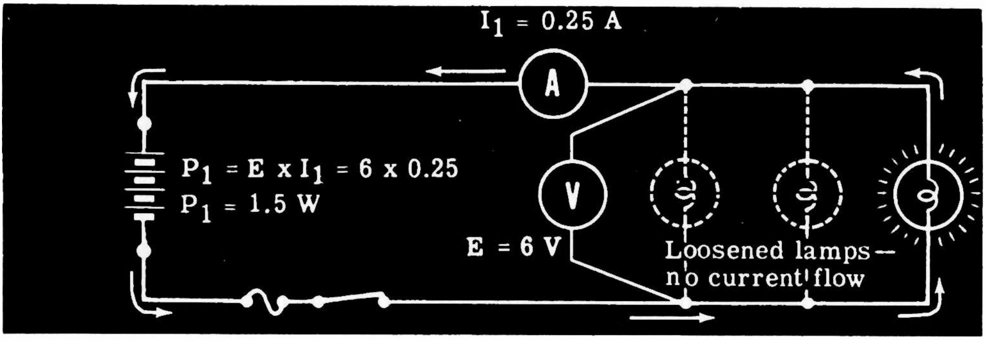
To demonstrate that the power used by a parallel circuit is equal to the power used by all of the parts of the circuit, the instructor connects three lamp sockets in parallel across a six-volt battery, with a 0-1 amp range ammeter in series with the battery lead, and a 0-10 volt voltmeter across the battery terminals. He then inserts 6-volt, 250-ma. lamps in the lamp sockets, but does not tighten them. When he closes the switch you see that the voltmeter indicates battery voltage, but the ammeter shows no current flow, so that no power is being used by the circuit.

MEASURING THE POWER IN A PARALLEL CIRCUIT



As the instructor tightens one of the lamps, you see that it lights and the ammeter shows a current flow of about 0.25 amp. The power used by this one lamp, then, is about 6 volts x 0.25 amp., or 1.5 watts.

POWER USED BY ONE LAMP IN A PARALLEL CIRCUIT

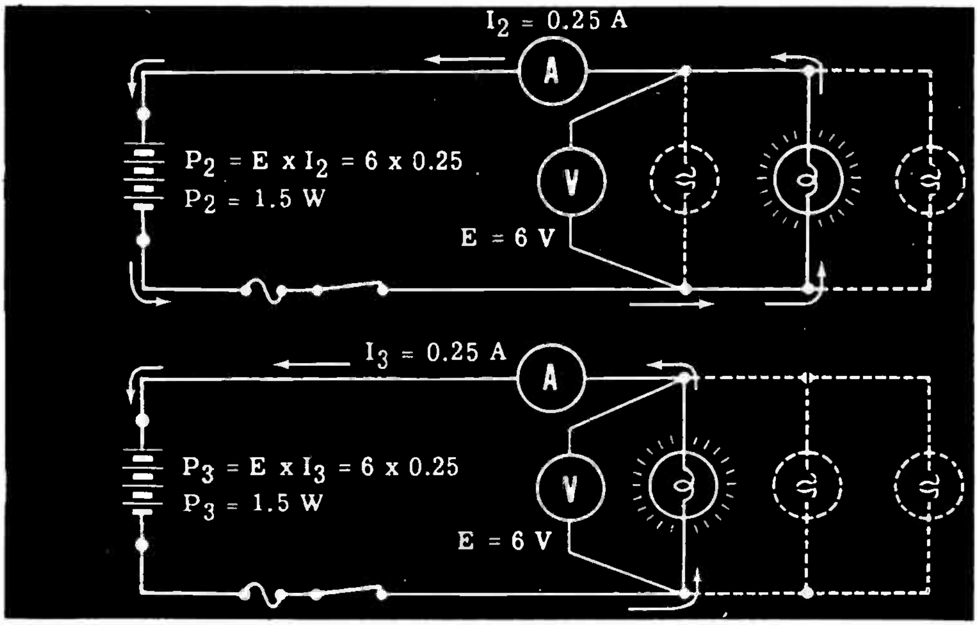


You already know that the voltage across any part of a parallel circuit is equal to the source voltage, so that the voltage across the lamp is equal to the battery voltage.

Demonstration—Power in Parallel Circuits (continued)

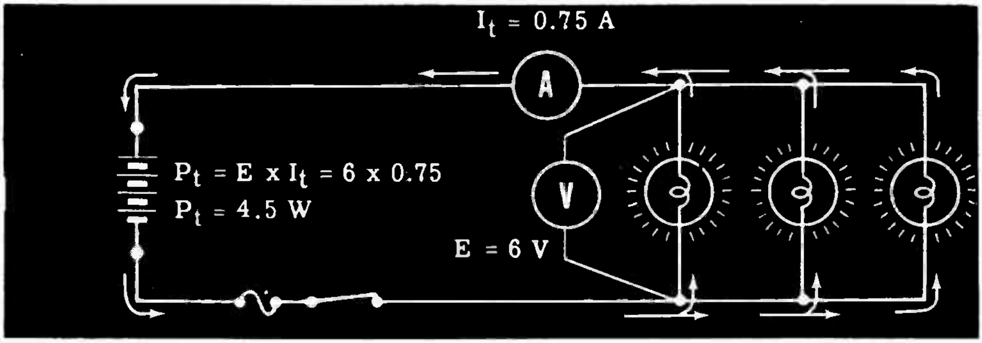
As the instructor loosens the first lamp and tightens each of the other lamps in turn, you see that the current—and hence the power used by each lamp—is about the same. The current measured each time is the current through the one tightened lamp only.

MEASURING POWER IN INDIVIDUAL LAMPS



Next the instructor tightens all three lamps in their sockets. You see that they all light and that the ammeter shows the circuit current to be about 0.75 amp. The voltage is still about 6 volts, so that the circuit power (P_t) equals 0.75 x 6, or about 4.5 watts.

MEASURING TOTAL CIRCUIT POWER

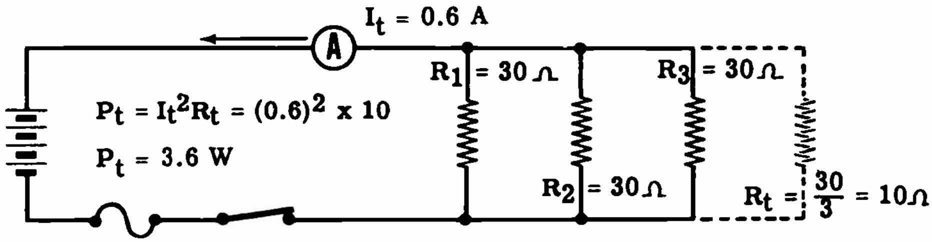


The total circuit power is found to be about 4.5 watts. If you add the power used individually by each of the lamps, the sum is equal to 4.5 watts (1.5 + 1.5 + 1.5 = 4.5). Therefore, you see that the total power used by a parallel circuit is equal to the sum of the power used by each part of the circuit.

Demonstration—Power in Parallel Circuits (continued)

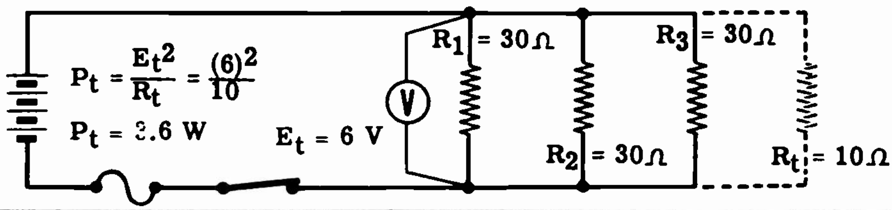
The instructor now replaces the three lamp sockets with 30-ohm resistors. He then removes the voltmeter leads from the battery and closes the switch, and you notice that the ammeter shows a current flow of about 0.6 amp.

The total resistance found by applying the rules for parallel circuits is 10 ohms, so that the circuit power is equal to $(0.6)^2 \times 10 = 3.6$ watts ($P = I^2R$).



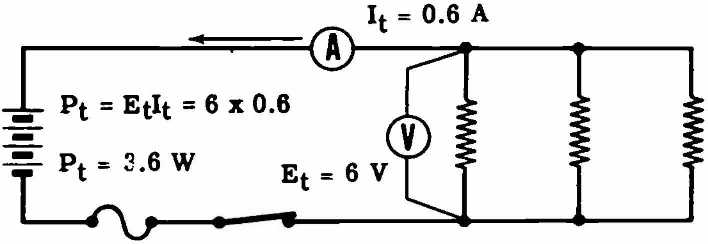
USING TOTAL CURRENT AND RESISTANCE TO MEASURE CIRCUIT POWER

The instructor then removes the ammeter and connects the voltmeter to the battery leads. When the switch is closed the voltage is seen to be about 6 volts, so that the circuit power is equal to $\frac{(6)^2}{10} = 3.6$ watts ($P = \frac{E^2}{R}$).



USING TOTAL VOLTAGE AND RESISTANCE TO MEASURE CIRCUIT POWER

Finally the instructor replaces the ammeter in the circuit and, when power is applied, you see that the current is about 0.6 amp and the voltage is about 6 volts, so that the total circuit power is equal to $6 \times 0.6 = 3.6$ watts ($P = EI$).



USING TOTAL VOLTAGE AND CURRENT TO MEASURE CIRCUIT POWER

Thus you see that the total power in a parallel circuit may be determined, as in a series circuit, whenever any <u>two</u> of the factors—current, voltage and resistance—are known.

Extending the Range of Ammeters

Here is a practical application of Ohm's Law in parallel circuits. You will now learn how the value, or the amount of resistance in a shunt is calculated.

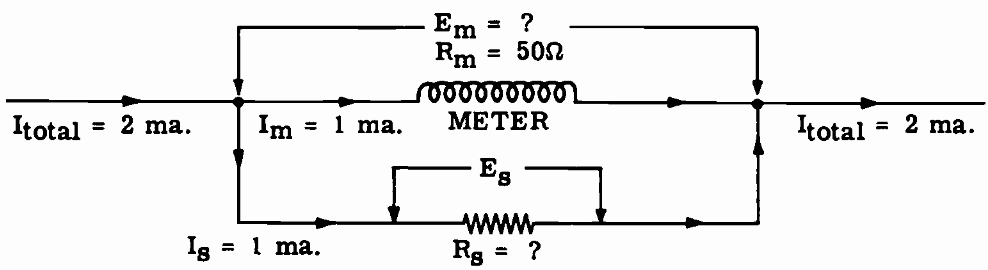
In an earlier topic you learned that the Weston movement for meters, with the 0-1 milliampere range, is practically a basic type and is one with which you will become most familiar. This movement burns out very quickly if more than one milliampere of current is allowed to pass through it. You also learned, however, that this movement can be used without damaging effects, in circuits carrying comparatively high currents, if a shunt resistor of proper value is placed in parallel with the movement. The purpose of the shunt is to bypass a sufficient amount of current around the meter, leaving only enough in the one milliampere movement to give an accurate indication without overheating. Readings are then taken from the appropriate scale on the meter face, or, if the meter scales are not provided, a multiplication factor is applied to the meter reading to determine the exact value.

The resistance value for shunt resistors can be found by using Ohm's Law. In this example, the meter should be deflected full scale by two milliamps. Assume that the resistance of the meter movement is 50 ohms. (Your instructor will provide you with the resistance value of the meter movement with which you are working.) Assume also, that one milliampere of current through the meter causes full-scale deflection. See the diagram below. Using Ohm's Law you find that the voltage drop across the movement is

$$E_m = I_m R_m$$
$$E_m = .001 \times 50$$
$$E_m = .05 \text{ volts}$$

Since the meter movement parallels the shunt resistor R_s, the voltage across the meter and the shunt is the same. The resistance R_s may now be found by using Ohm's Law, because the voltage across the shunt E_s is equal to E_m, and the current through the shunt I_s must be one milliampere since one milliamp is causing full-scale meter deflection.

$$R_s = \frac{E_s}{I_s} = \frac{.05}{.001} = 50 \text{ ohms}$$



Extending the Range of Ammeters (continued)

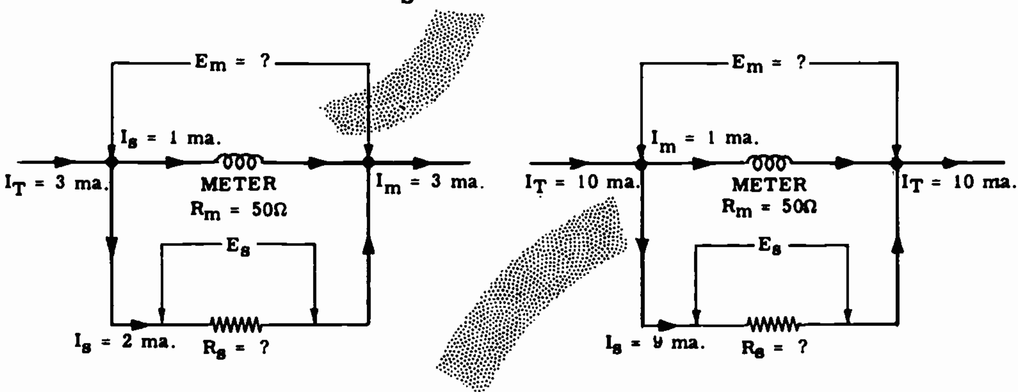
You have learned how to calculate the resistance value of a milliammeter shunt. The value of practically every shunt you will use may be found in the same way. Now you will see some other examples of calculations which you may well have to make in the near future.

Using the same 0-1 ma. milliammeter movement, find the resistance of the shunt which permits safe, full-scale deflection of a three-milliamp current. Note that if the meter movement is in full-scale deflection, one milliamp is flowing in the meter branch of the parallel circuit, and the remaining two milliamps must be flowing through the shunt resistor. The resistance of the meter movement is the same as before; namely, 50 ohms. The voltage drop across the meter is found first.

$$E_m = I_m R_m = .001 \times 50 = .05 \text{ volts}$$

The voltage across the shunt resistor is the same as that across the meter movement. It is a simple matter then, to solve for R_s since both the current and the voltage are known.

$$R_s = \frac{E_s}{I_s} = \frac{.05}{.002} = 25 \text{ ohms}$$



In another example, assume that you wish to extend the range of a 0-1 ma. milliammeter (whose meter movement resistance is 50 ohms) to ten milliamperes. Calculate the resistance value of the appropriate shunt.

Note that if the total current is ten milliamperes, one milliamp will flow through the meter (for full-scale deflection) and nine milliamperes must flow through the shunt resistor. Find the voltage drop across the meter.

$$E_m = I_m R_m = .001 \times 50 = .05 \text{ volts}$$

As you know, E_m is equal to E_s since the meter and R_s are in parallel. Find the resistance of R_s.

$$R_s = \frac{E_s}{I_s} = \frac{.05}{.009} = 5.55 \text{ ohms}$$

Review of Ohm's Law and Parallel Circuits

If a circuit consists of two resistors—R_1 and R_2—in parallel, the following rules for using Ohm's law apply—

R_t, I_t and E_t are used together.

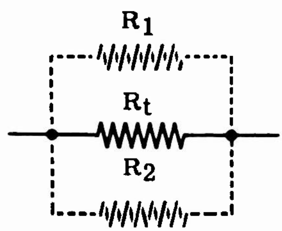
R_1, I_1 and E_1 are used together.

R_2, I_2 and E_2 are used together.

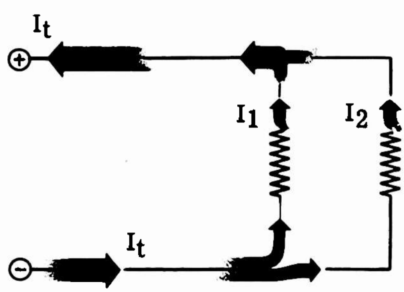
Only quantities having the same subscript can be used together to find an unknown by means of Ohm's law.

Unknown quantities may also be found by applying the following rules for parallel circuits:

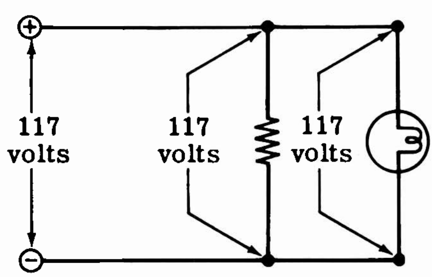
$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$



$$I_t = I_1 + I_2$$



$$E_t = E_1 = E_2$$



Series-Parallel Circuit Connections

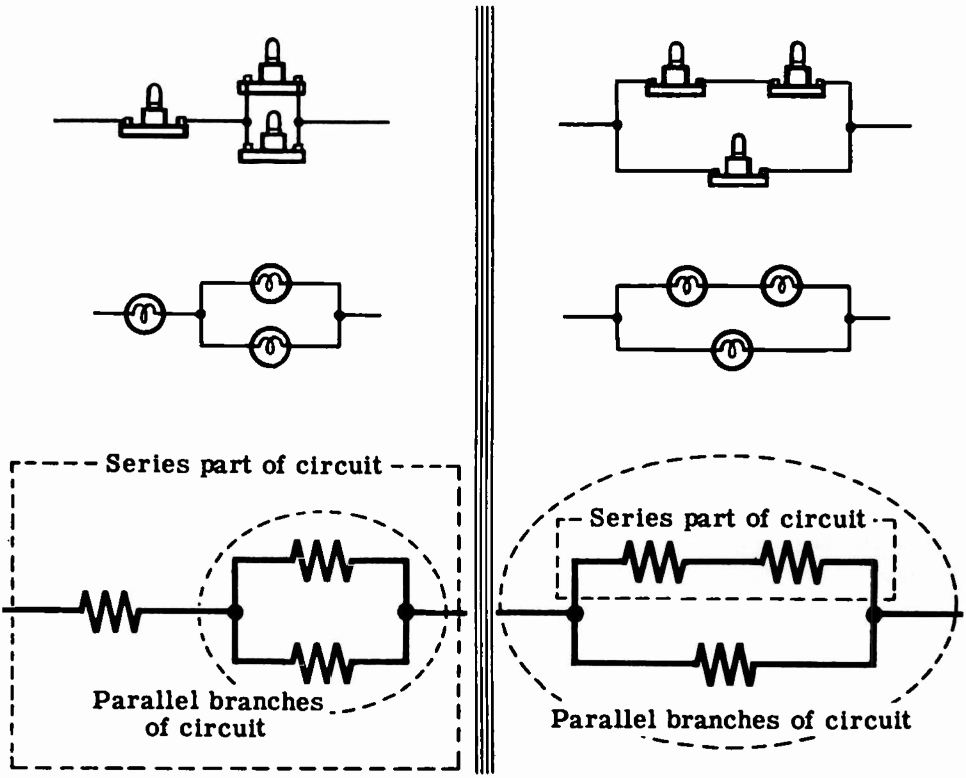
Circuits consisting of three or more resistors may be connected in a complex circuit, partially series and partially parallel. There are two basic types of series-parallel circuits: One in which a resistance is connected in series with a parallel combination, and the other in which one or more branches of a parallel circuit consist of resistances in series.

If you were to connect two lamps in parallel (side-by-side connection) and connect one terminal of a third lamp to one terminal of the parallel combination, the three lamps would be connected in series-parallel. Resistances other than lamps may also be connected in the same manner to form series-parallel circuits.

You can connect the three lamps to form another type of series-parallel circuit by first connecting two lamps in series, then connecting the two terminals of the third lamp across the series lamps. This forms a parallel combination with one branch of the parallel circuit consisting of two lamps in series.

Such combinations of resistance are frequently used in electrical circuits, particularly electric motor circuits and control circuits for electrical equipment.

TWO WAYS OF CONNECTING LAMPS IN SERIES-PARALLEL



Resistances in Series-Parallel

No new formulas are needed to find the total resistance of resistances connected in series-parallel. Instead you break the complete circuit into parts consisting of simple series and parallel circuits, then solve each part separately and combine the parts. Before using the rules for series and parallel resistances, you must decide what steps to use in simplifying the circuit.

For example, suppose you want to find the total resistance of three resistances—R_1, R_2 and R_3—connected in series-parallel, with R_1 and R_2 connected in parallel, and R_3 connected in series with the parallel combination. To simplify the circuit you would use two steps, with the circuit broken down into two parts—the parallel circuit of R_1 and R_2, and the series resistance R_3. First you find the parallel resistance of R_1 and R_2, using the formula for parallel resistances. This value is then added to the series resistance R_3 to find the total resistance of the series-parallel circuit.

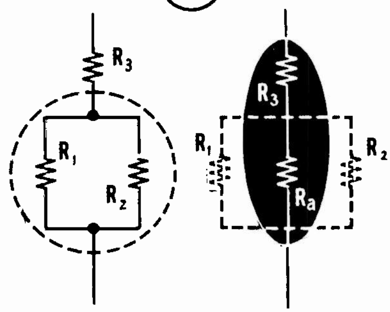
If the series-parallel circuit consists of R_1 and R_2 in series, with R_3 connected across the the steps are reversed. The circuit is broken down into two parts—the series circuit of R_1 and R_2, and the parallel resistance R_3. First you find the series resistance of R_1 and R_2 by adding; then combine this value with R_3, using the formula for parallel resistance.

Combine R_1 and R_2 to find total resistance (R_a) of parallel combination

A

Add R_a and R_3 to find total circuit resistance (R_t)

$$R_a = \frac{R_1 \times R_2}{R_1 + R_2}$$



$$R_t = R_a + R_3$$

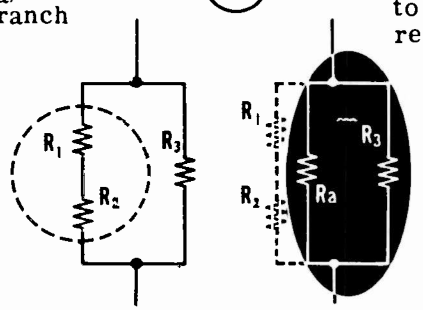
FINDING THE TOTAL RESISTANCE OF SERIES-PARALLEL CIRCUIT

Add R_1 and R_2 to find total resistance (R_a) of series-connected branch

B

Combine the parallel combination of R_a and R_3 to find the total circuit resistance (R_t)

$$R_a = R_1 + R_2$$

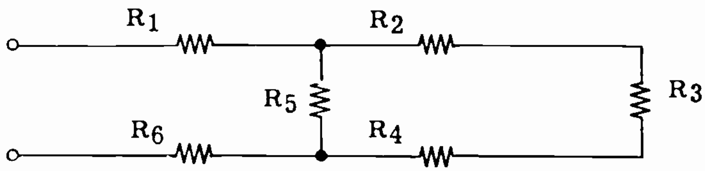


$$R_t = \frac{R_a \times R_3}{R_a + R_3}$$

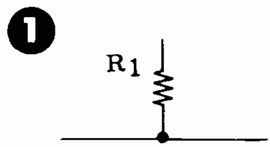
Resistances in Series-Parallel (continued)

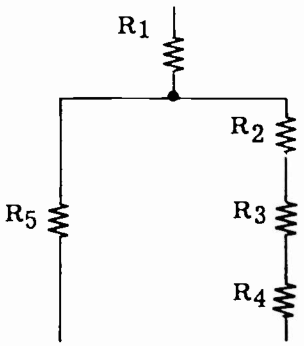
Complex circuits may be simplified and their breakdown made easier by redrawing the circuits before applying the steps to combine resistances.

THE ORIGINAL CIRCUIT



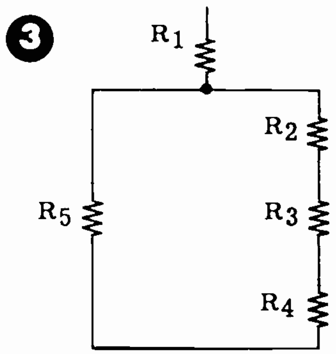
1. Start at one end of the circuit and draw all series resistances in a straight line until you reach a point where the circuit has more than one path to follow. At that point draw a line across the end of the series resistance.



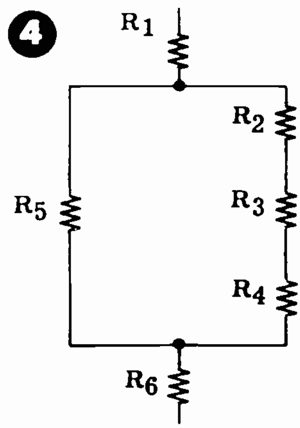


2. Draw the parallel paths from this line in the same direction as the series resistances.

3. Where the parallel paths combine, a line is drawn across the ends to join the paths.



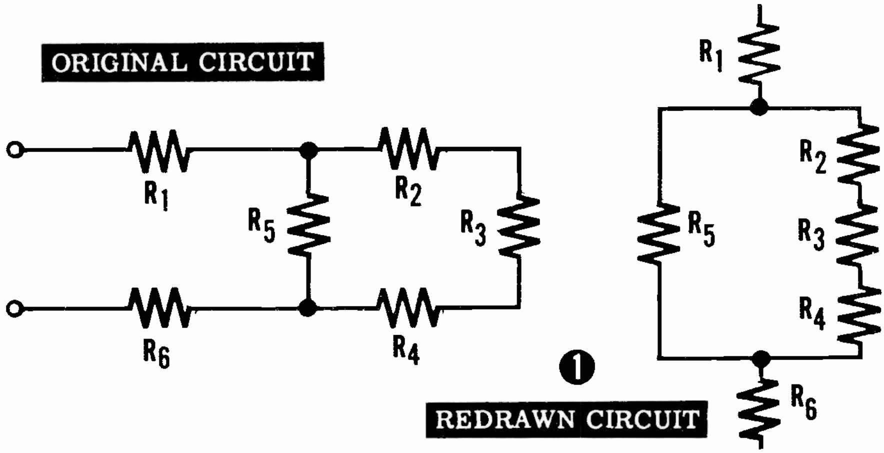
4. The circuit is continued from the center of the parallel connecting line, adding the series resistance to complete the redrawn circuit.



Resistances in Series-Parallel (continued)

The basic steps in finding the total resistance of a complex series-parallel circuit are as follows—

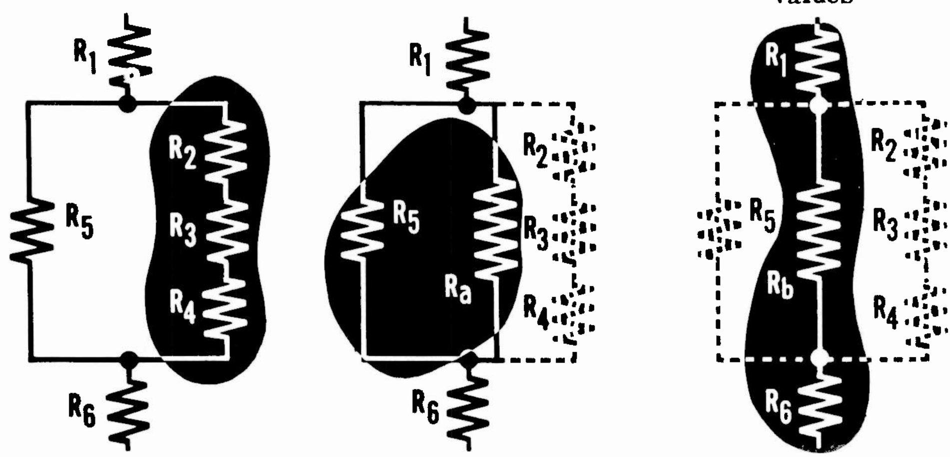
1. Redraw the circuit if necessary.
2. If any of the parallel combinations have branches consisting of two or more resistors in series, find the total value of these resistors by adding them.
3. Using the formula for parallel resistances, find the total resistance of the parallel parts of the circuit.
4. Add the combined parallel resistances to any resistances which are in series with them.



2 Add the series branches

3 Combine parallel part of circuit

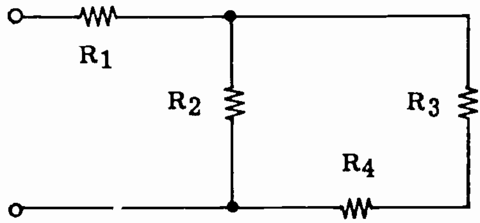
4 Add the series-connected resistance values



Resistances in Series-Parallel (continued)

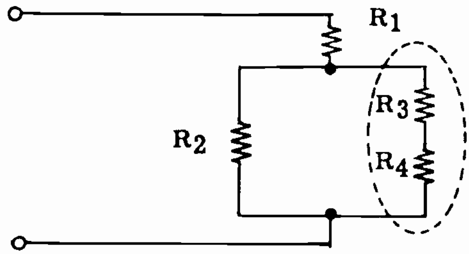
This is how you break down complex circuits to find the total resistances—

Suppose your circuit consists of four resistors—R_1, R_2, R_3 and R_4—connected as shown, and you want to find the total resistance of the circuit.



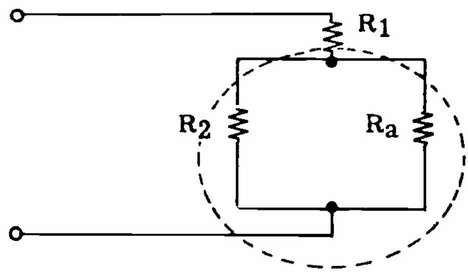
First, the circuit is redrawn and the series branch resistors R_3 and R_4 are combined by addition as an equivalent resistance R_a.

$$R_a = R_3 + R_4$$



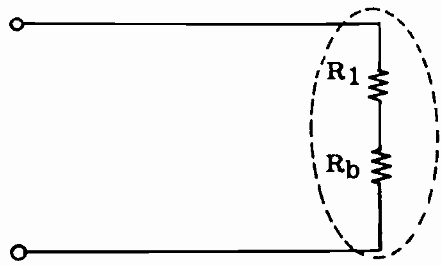
Next, the parallel combination of R_2 and R_a is combined (using the parallel resistance formula) as an equivalent resistance, R_b.

$$R_b = \frac{R_2 \times R_a}{R_2 + R_a}$$



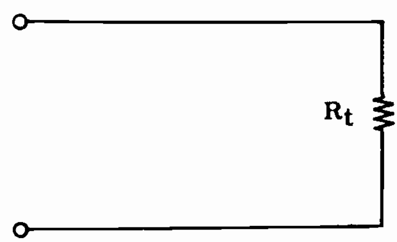
The series resistor R_1 is added to the equivalent resistance—R_b—of the parallel combination to find the total circuit resistance, R_t.

$$R_t = R_1 + R_b$$



R_t = total resistance of series-parallel circuit.

$$R_t = \text{Total Resistance}$$

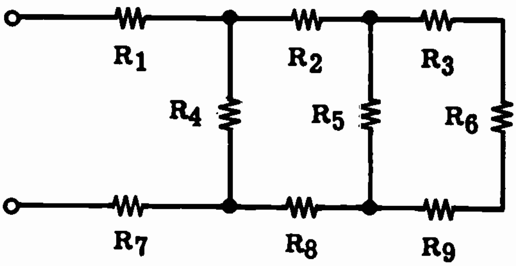


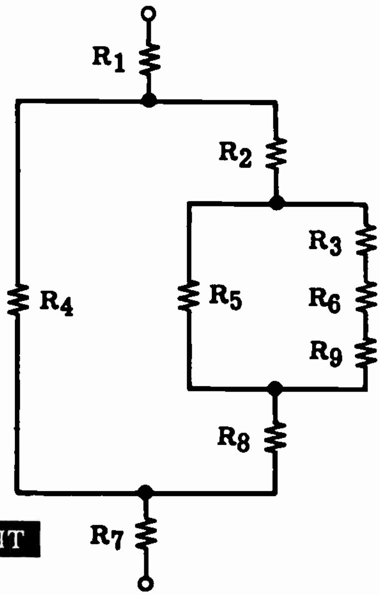
Resistances in Series-Parallel (continued)

More complicated circuits only require more steps, not any additional formulas. For example, the total resistance of a circuit consisting of nine resistors may be found as shown—

1. Redraw the circuit.

ORIGINAL CIRCUIT

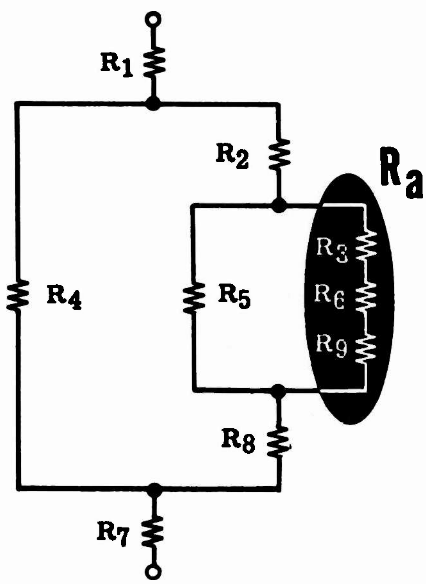




REDRAWN CIRCUIT

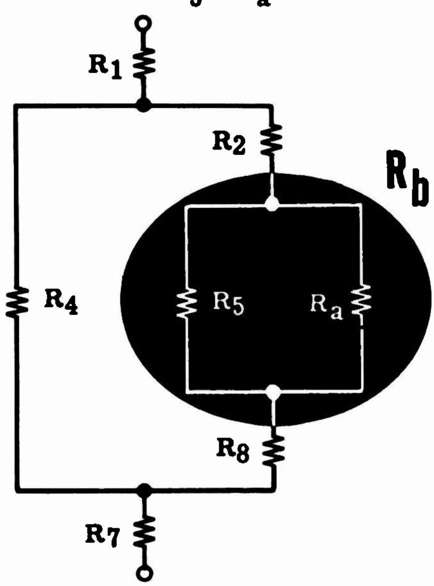
2. Combine the series branch resistors R_3, R_6 and R_9.

$$R_a = R_3 + R_6 + R_9$$



3. Combine the parallel resistances R_5 and R_a.

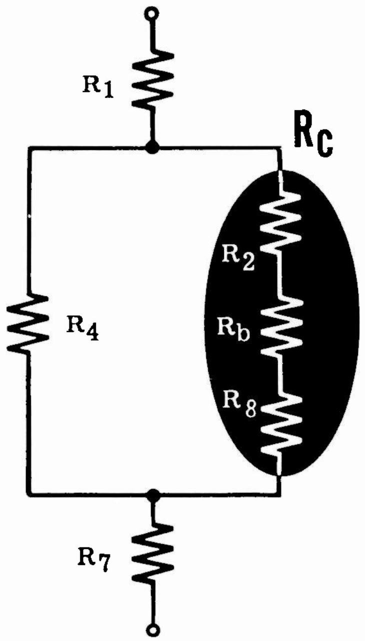
$$R_b = \frac{R_5 \times R_a}{R_5 + R_a}$$



Resistances in Series-Parallel (continued)

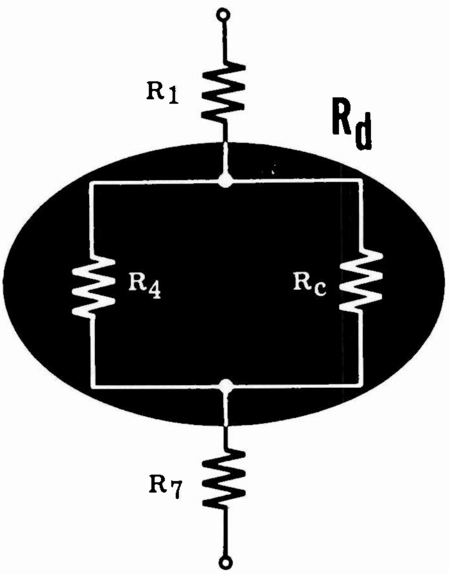
4. Combine the series resistances R_2, R_b and R_8.

$$R_c = R_2 + R_b + R_8$$



5. Combine the parallel resistances R_4 and R_c.

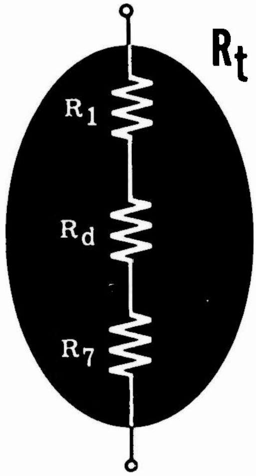
$$R_d = \frac{R_4 \times R_c}{R_4 + R_c}$$



6. Combine the series resistances R_1, R_d and R_7.

$$R_t = R_1 + R_d + R_7$$

7. R_t is the total resistance of the circuit, and the circuit will act as a single resistor of this value when connected across a source of emf.



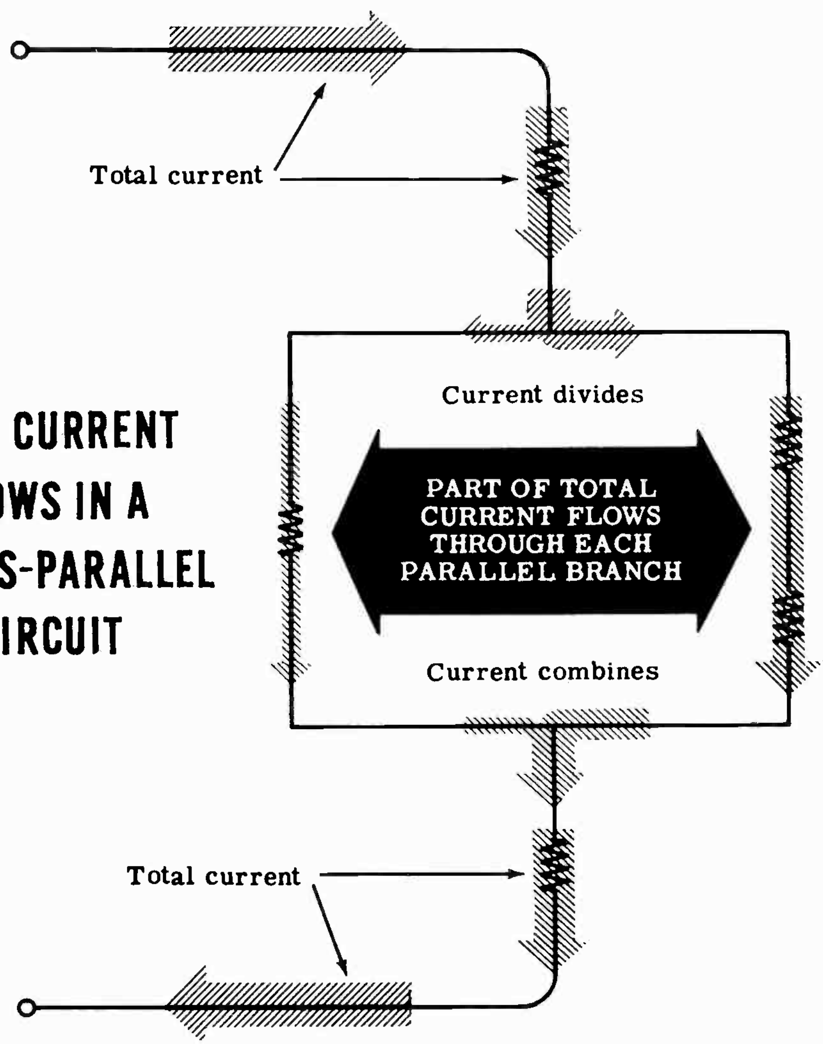
Current in Series-Parallel Circuits

The total circuit current for a series-parallel circuit depends upon the total resistance offered by the circuit when connected across a voltage source. Current flow in the circuit will divide to flow through all parallel paths and come together again to flow through series parts of the circuit. It will divide to flow through a branch circuit and then repeat this division if the branch circuit subdivides into secondary branches.

As in parallel circuits, the current through any branch resistance is inversely proportional to the amounts of resistance—the greater current flows through the least resistance. However, all of the branch currents always add to equal the total circuit current.

The total circuit current is the same at each end of a series-parallel circuit and equals the current flow through the voltage source.

HOW CURRENT FLOWS IN A SERIES-PARALLEL CIRCUIT



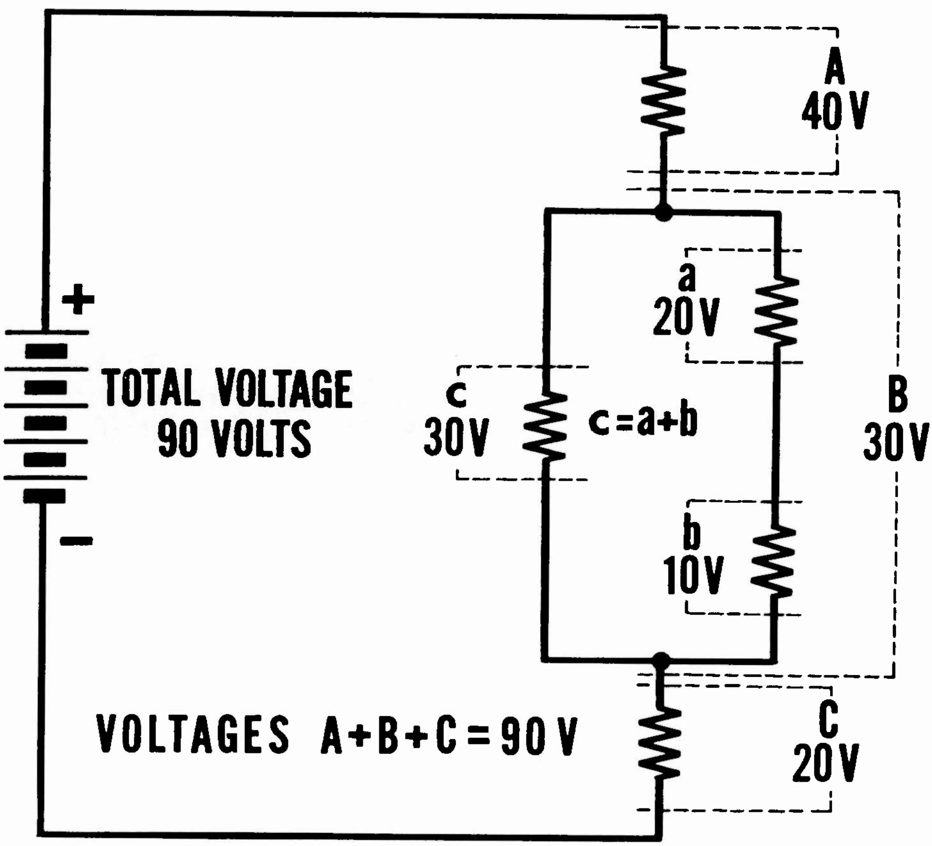
Voltage in Series-Parallel Circuits

Voltage drops across a series-parallel circuit occur in the same way as in series and parallel circuits. Across series parts of the circuit the voltage drops are equal only for equal resistances, while across parallel parts of the circuit the voltage across each branch is the same.

Series resistances forming a branch of a parallel circuit will divide the voltage across the parallel circuit. In a parallel circuit consisting of a branch with a single resistance and a branch with two series resistances, the voltage across the single resistor equals the sum of the voltages across the two series resistances. The voltage across the entire parallel circuit is exactly the same as that across either of the branches.

The voltage drops across the various paths between the two ends of the series-parallel circuit always add up to the total voltage applied to the circuit.

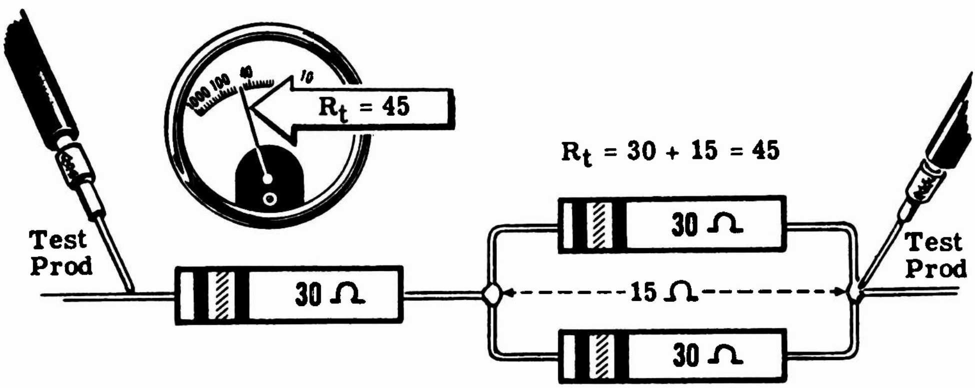
HOW THE VOLTAGE DIVIDES IN A SERIES - PARALLEL CIRCUIT



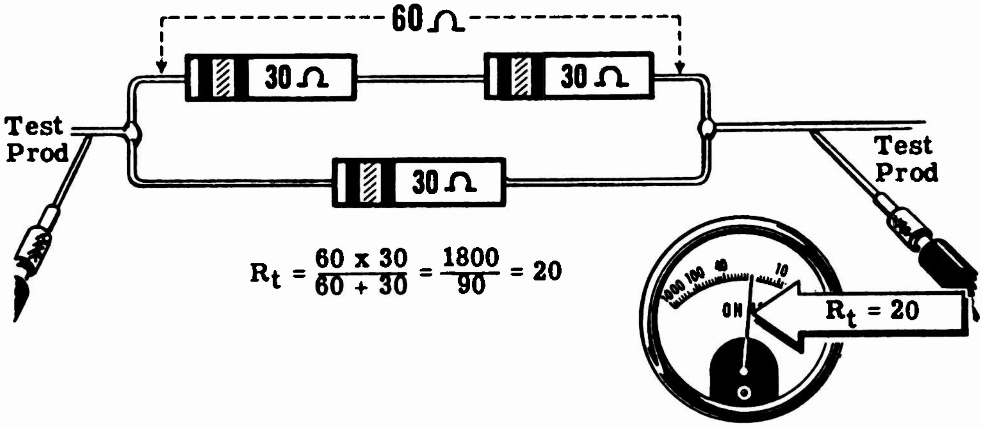
Demonstration—Series-Parallel Connections

Simple series-parallel circuit connections using three resistors are shown first. You see that three resistors having color code values of 30 ohms each are connected together, with one resistor in series with a parallel combination of the other two. This forms a series-parallel circuit and the total resistance is found by combining the parallel 30-ohm resistors to obtain their equivalent resistance, which is 15 ohms, and adding this value to the series 30-ohm resistor—making a total resistance of 45 ohms. You see that, with the resistors so connected, the ohmmeter reads 45 ohms across the entire circuit.

Next, two resistors are connected in series and the third resistor is connected in parallel across the series combination. The total resistance is found by adding the two resistors in the series branch, to obtain the equivalent value of 60 ohms. This value is in parallel with the third 30-ohm resistor, and combining them results in a value of 20 ohms for the total resistance. This value is checked with an ohmmeter and you see that the meter reading is 20 ohms.



HOW DIFFERENT SERIES-PARALLEL CONNECTIONS .... AFFECT RESISTANCE

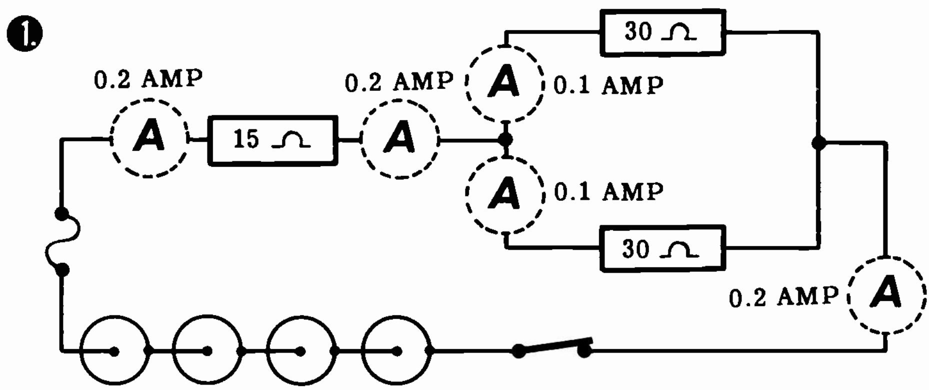


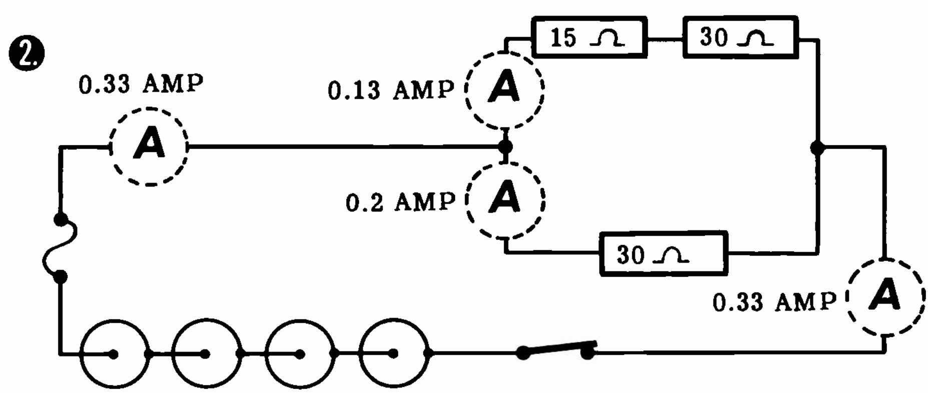
Demonstration—Current in Series-Parallel Circuits

Next the instructor connects a series-parallel circuit—consisting of two 30-ohm resistors connected in parallel and a 15-ohm resistor in series with one end of the parallel resistors—across a six-volt dry cell battery. To show the path of current flow through the circuit, the instructor connects an ammeter in series with each resistor in turn—showing the current flow through each. You see that the current for the 15-ohm series resistor is 0.2 amperes as is the current at each battery terminal, while the current through the 30-ohm resistors is 0.1 amperes each.

The circuit connections are changed with the 15-ohm and one 30-ohm resistor forming a series-connected branch in parallel with the other 30-ohm resistor. As the instructor connects the ammeter to read the various currents, you see that the battery current is 0.33 ampere, the 30-ohm resistor current is 0.2 ampere and the current through the series branch is 0.13 ampere.

SEEING HOW THE CURRENT FLOWS THROUGH SERIES-PARALLEL CIRCUITS

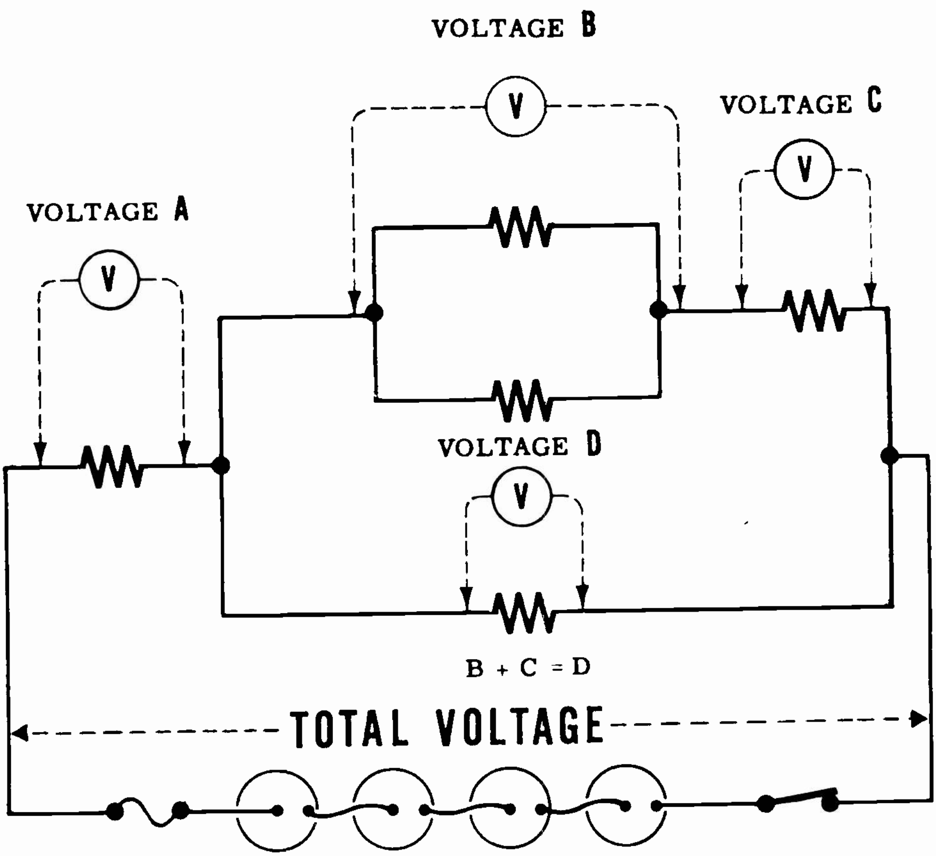




Demonstration—Voltage in Series-Parallel Circuits

To demonstrate the division of voltage across series-parallel circuits, the instructor connects several resistors to form a complex circuit having more than one complete path between the battery terminals. As the instructor traces several possible paths across the circuit and measures the voltage across each resistance, you see that—regardless of the path chosen—the sum of the voltages for any one path always equals the battery voltage. Also, you see that the voltage drop across resistors of equal value differs, depending on whether they are in a series or parallel part of the circuit and on the total resistance of the path in which they are located.

SEEING HOW VOLTAGE DIVIDES IN A SERIES-PARALLEL CIRCUIT



VOLTAGES A+D=TOTAL VOLTAGE
VOLTAGES A+B+C = TOTAL VOLTAGE

Review of Series-Parallel Circuits

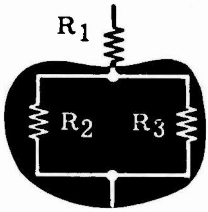
Complex circuits—series-parallel circuits—can be broken down into series and parallel parts so that you may find resistances, currents and voltages. Now you will review the method of breaking down a complex circuit into its basic series and parallel parts.

BREAKING DOWN SIMPLE SERIES-PARALLEL CIRCUITS

1

Combine parallel resistances

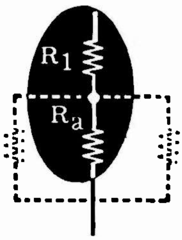
$$R_a = \frac{R_2 \times R_3}{R_2 + R_3}$$



then--

add the series resistances

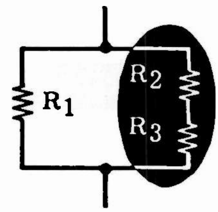
$$R_t = R_1 + R_a$$



2

Add the series resistances

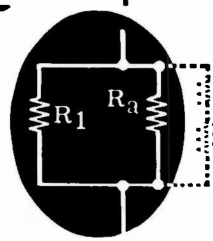
$$R_a = R_2 + R_3$$



then--

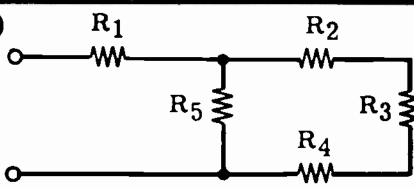
combine parallel resistances

$$R_t = \frac{R_1 \times R_a}{R_1 + R_a}$$

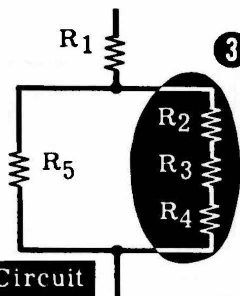


BREAKING DOWN COMPLEX SERIES-PARALLEL CIRCUITS

1



Original Circuit



2 Redraw Circuit

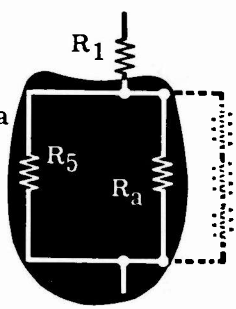
3 Add the series resistances R_2, R_3 and R_4

$$R_a = R_2 + R_3 + R_4$$

4

Combine the parallel resistances R_5 and R_a

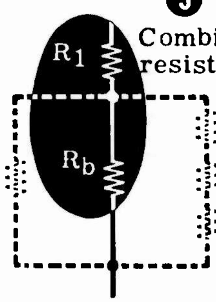
$$R_b = \frac{R_5 \times R_a}{R_5 + R_a}$$



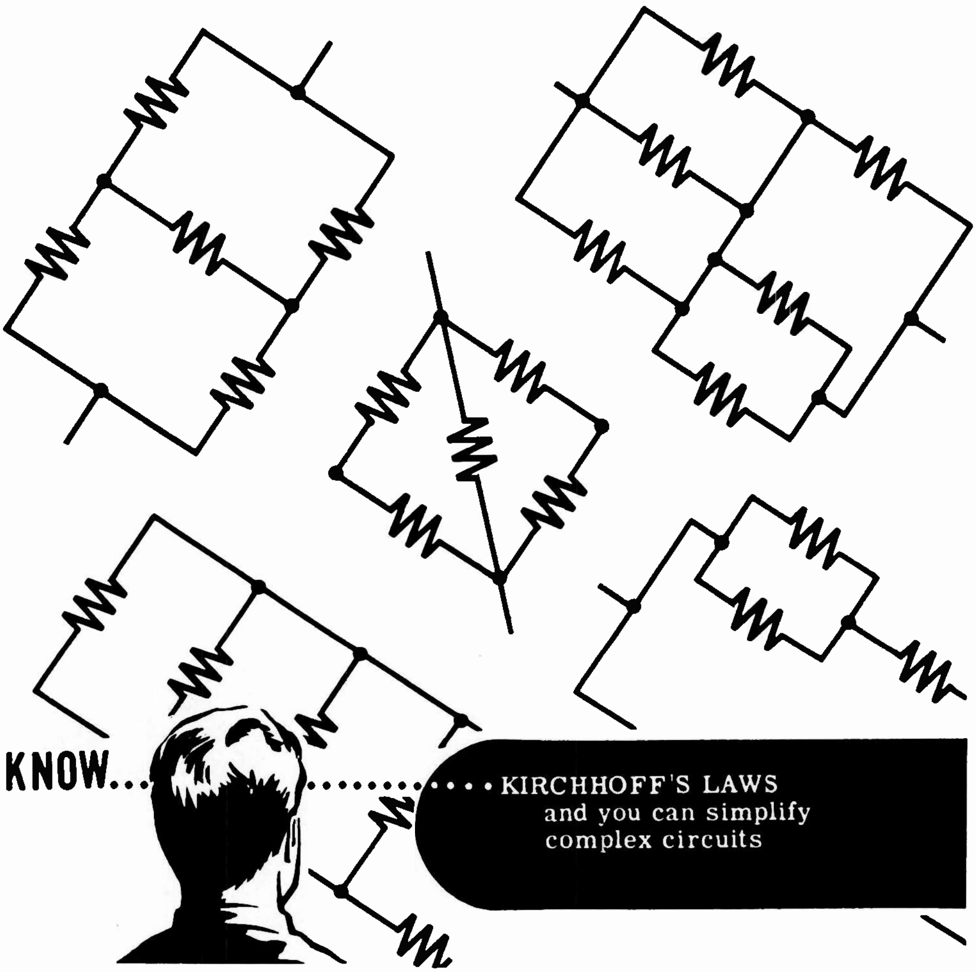
5

Combine the series resistances R_1 and R_b

$$R_t = R_1 + R_b$$



Why Kirchhoff's Laws Are Important



The total circuit resistance, current and voltage of a complex circuit are easily obtained by breaking down the circuit, if all values for each part of the circuit are known. However, you may find that certain resistances are not known, or that you are only concerned with one part of a circuit. To make the solution of any part of a complex circuit easy, two general rules are used—one concerning current and the other concerning voltage. These rules are Kirchhoff's laws—the first law for currents and the second law for voltages. You have been using both of these rules or laws, referring to them as rules for current flow and voltage drops in the various types of circuits. Now you are ready to find out more about Kirchhoff's laws and how they are used to find unknown quantities in any part of a circuit. While the laws relate only to current and voltage, if they are used to find the current and voltage relating to an unknown resistance, the resistance can then be determined by using Ohm's law.

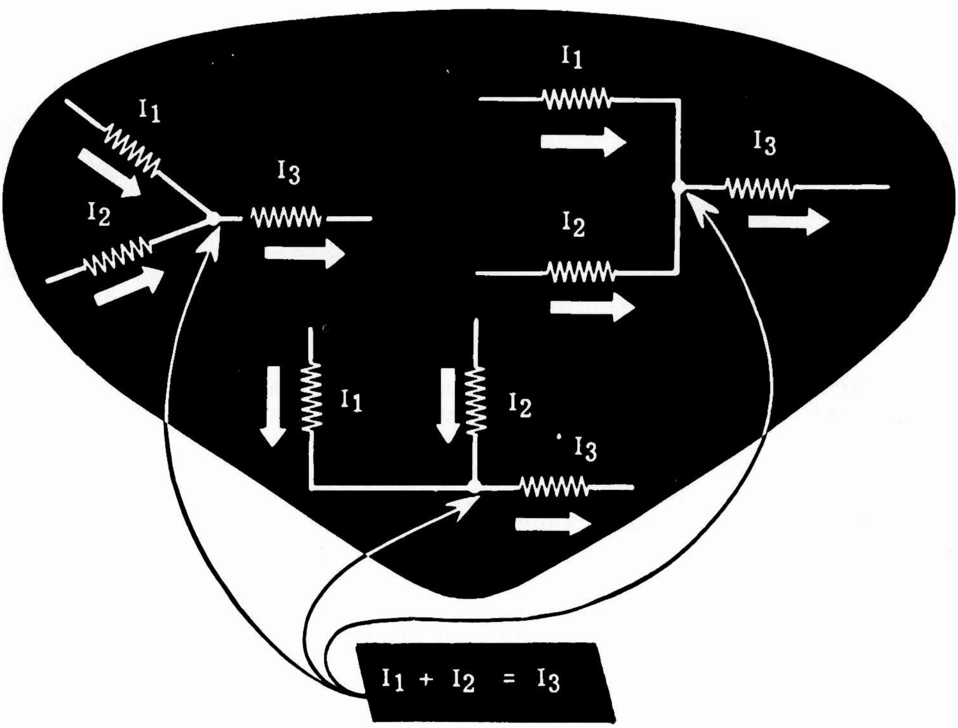
Kirchhoff's First Law

You have found out about current flow in the three types of circuits—series, parallel and series-parallel. You found that the entire circuit current flows through each resistance of a series circuit. In parallel circuits the current divides to flow through more than one path and comes together again after passing through these paths. Series-parallel circuits provide more than one path in some parts of the circuit and only one path in other parts.

Regardless of the circuit connections, you found that the current entering a circuit was exactly the same as that leaving the circuit. This is a direct application of Kirchhoff's First Law, which states that the current entering a junction is equal to the current leaving the junction. The law applies not only to the circuit as a whole but also to every junction within the circuit.

Thus at a junction of three resistances, where two currents—I_1 and I_2—in two of the resistances flow toward the junction and one current—I_3—in the third resistance flows away from the junction, I_3 must equal $I_1 + I_2$.

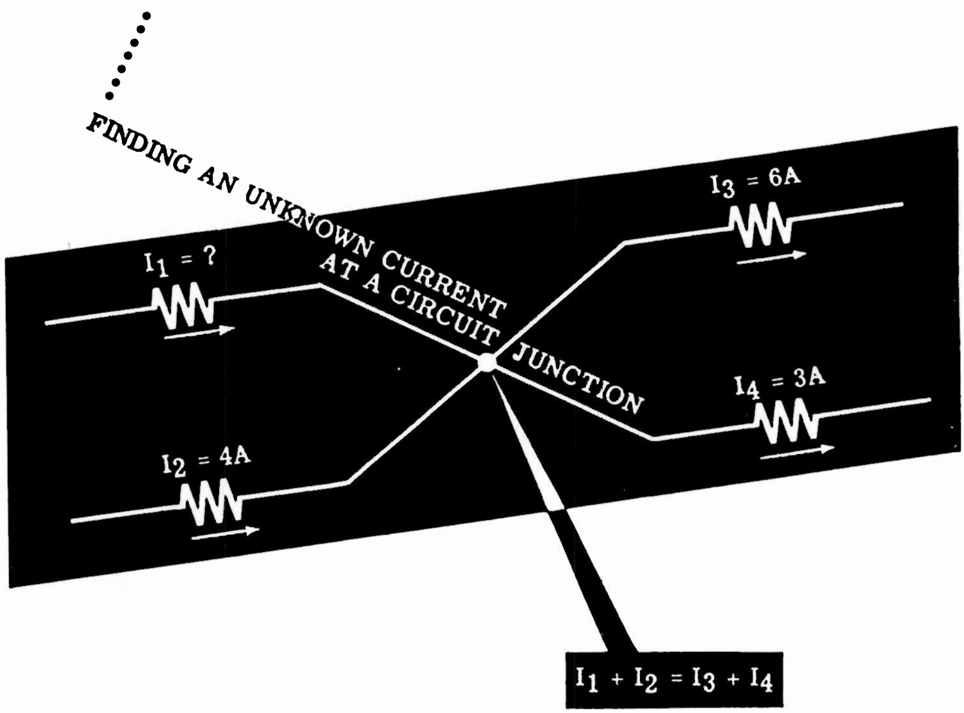
HOW KIRCHHOFF'S FIRST LAW WORKS



Kirchhoff's First Law (continued)

In a complete circuit, the current through each resistance will flow toward a junction at one end of the resistance but away from the junction at the other end of the resistance. To use Kirchhoff's first law you should first indicate the current paths through each resistance of the circuit. Then determine which currents flow toward and which flow away from each junction in the circuit. If certain currents are not known, their value and direction both may be determined by applying Kirchhoff's first law.

The direction of the unknown current is first determined by comparison of the known currents flowing toward and away from the junction. By adding all the known currents flowing toward the junction and those flowing away from the junction, you can determine the direction of the unknown current. At a junction where two currents—I_1 and I_2—enter the junction and two currents—I_3 and I_4—leave the junction, if I_1 is unknown it may be found by subtracting I_2 from the sum of I_3 and I_4. Suppose that I_2 is 4 amperes, I_3 is 6 amperes and I_4 is 3 amperes, then I_1 is equal to 9 amp ($I_3 + I_4$) minus 4 amp (I_2) or 5 amp.



$I_1 + 4A = 6A + 3A$

$I_1 + 4A = 9A$

$I_1 = 9A - 4A$

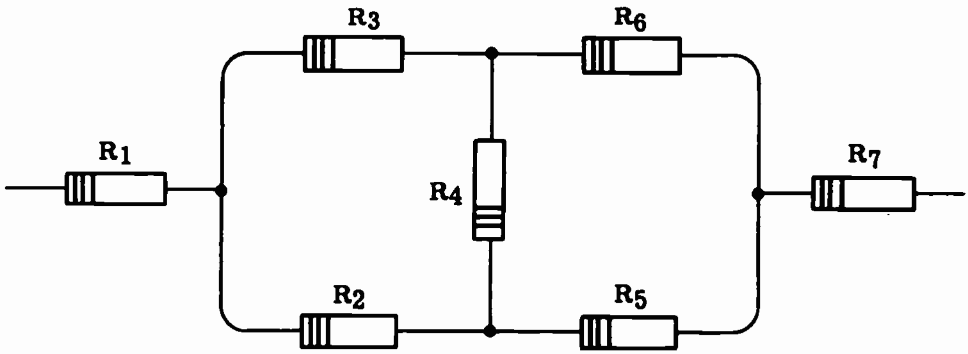
$I_1 = 5$ Amperes

Kirchhoff's First Law (continued)

This is how you use Kirchhoff's first law to find the unknown currents in a circuit—

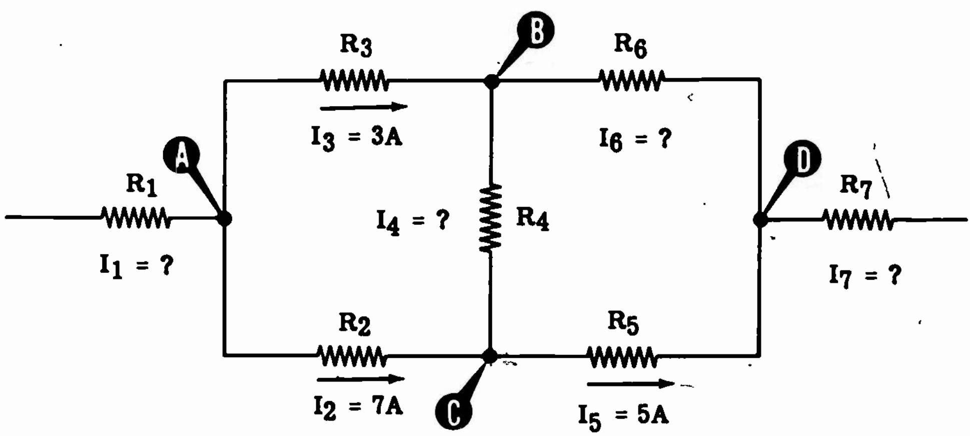
Suppose your circuit consists of seven resistors—R_1, R_2, R_3, R_4, R_5, R_6 and R_7—connected as shown. If the currents through R_1, R_4, R_6 and R_7 are not known, but the currents and their direction through R_2, R_3 and R_5 are known, the unknown currents may be found by applying Kirchhoff's first law to the circuit.

THIS IS HOW YOUR CIRCUIT LOOKS



In this circuit the current I_2 is 7 amperes flowing toward R_5, the current I_3 is 3 amperes flowing toward R_6, and the current I_5 is 5 amperes flowing toward R_7. Draw the circuit in symbol form designating all currents, with values and direction if known. Identify each junction of two or more resistances with a letter.

THE CIRCUIT IN SYMBOL FORM

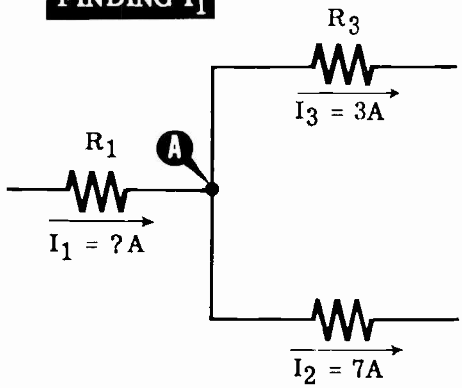


Circuit Junctions—A, B, C and D
Known Currents—I_2, I_3, and I_5
Unknown Currents—I_1, I_4, I_6 and I_7

Kirchhoff's First Law (continued)

Find the unknown currents at all junctions where only one current is unknown, later using these new values to find unknown values at other junctions. From the circuit you can see that junctions A and C have only one unknown. Suppose you start by finding the unknown current at junction A—

FINDING I_1

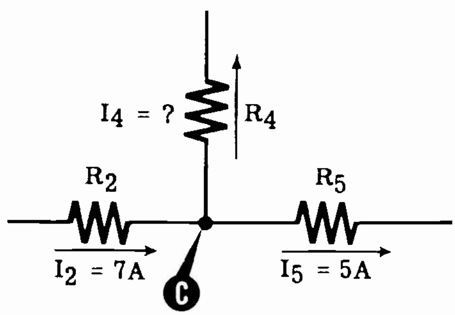


Of the three currents at junction A—I_1, I_2 and I_3—both I_2 and I_3 are known and flow away from the junction. Then I_1 must flow toward the junction, and its value must equal the sum of I_2 and I_3.

$I_1 = I_2 + I_3$
$I_1 = 7$ amp $+ 3$ amp
Then $I_1 = 10$ amp

Next find the unknown current at junction C—

FINDING I_4



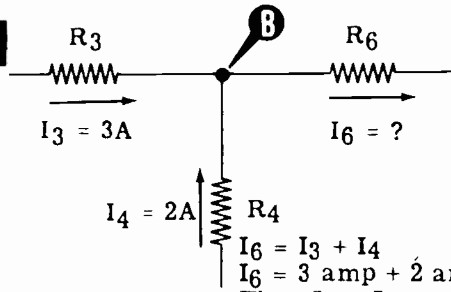
At C two currents—I_2 and I_5—are known and only I_4 is unknown. Since I_2 flowing toward C is greater than I_5 flowing away from C, the third current I_4 must flow away from C. Also, if the current flowing toward C equals that flowing away, I_2 equals I_4 plus I_5.

$I_2 = I_4 + I_5$
7 amp $= I_4 + 5$ amp
Then $I_4 = 2$ amp

Kirchhoff's First Law (continued)

Now that the value and direction of I_4 are known, only I_6 is unknown for junction B. You can find the amount and direction of I_6 by applying the law for current at B.

FINDING I_6

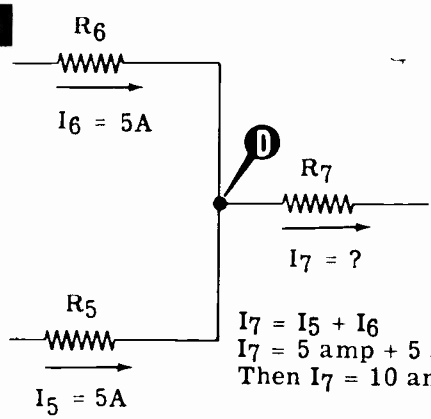


I_3 and I_4 both flow toward B; thus the remaining current I_6 must flow away from B. Also I_6 must equal the sum of I_3 and I_4.

$I_6 = I_3 + I_4$
$I_6 = 3$ amp + 2 amp
Then $I_6 = 5$ amp

With I_6 known, only I_7 remains unknown at junction D.

FINDING I_7

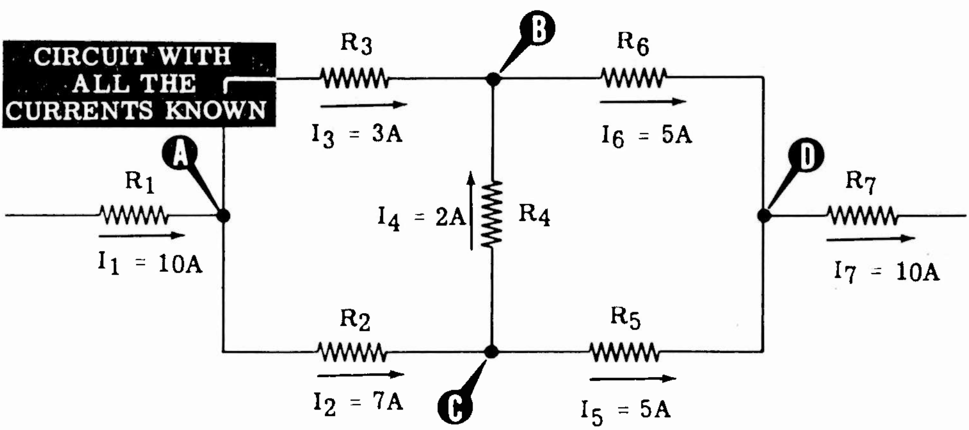


As I_5 and I_6 both flow toward junction D, the current I_7 must flow away from D and is equal to the sum of I_5 and I_6.

$I_7 = I_5 + I_6$
$I_7 = 5$ amp + 5 amp
Then $I_7 = 10$ amp

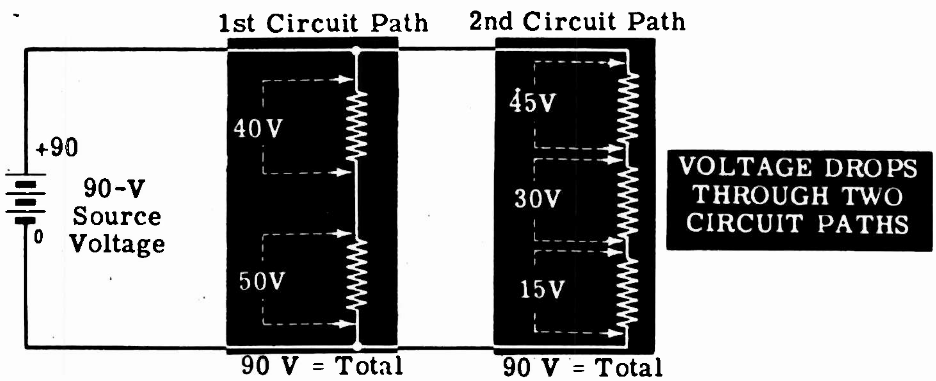
You now know all of the circuit currents and their directions through the various resistances.

CIRCUIT WITH ALL THE CURRENTS KNOWN

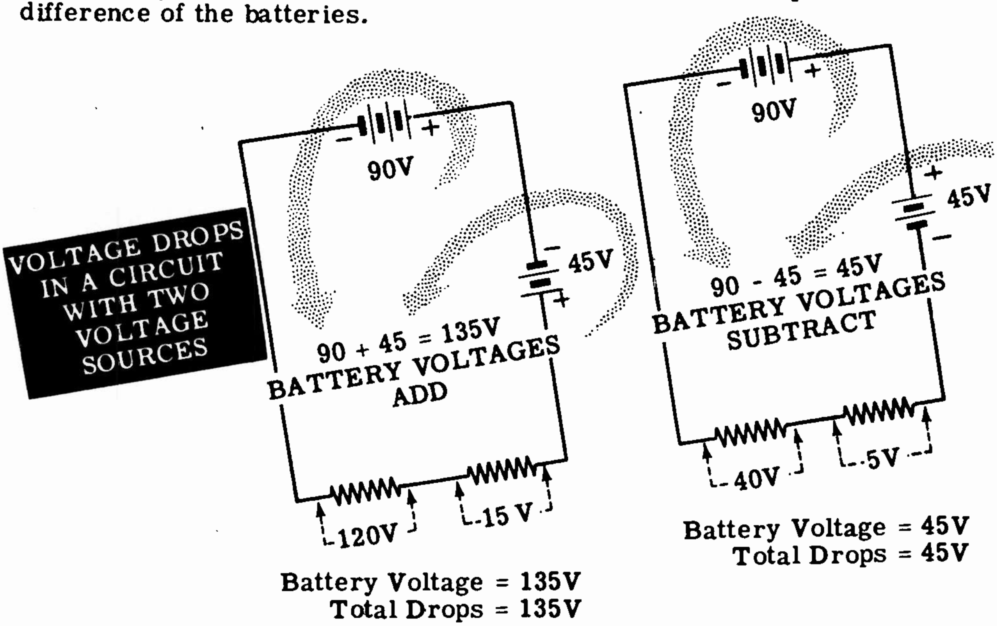


Kirchhoff's Second Law

While working with the various types of circuits, you found that for any path between the terminals of a voltage source, the sum of the voltage drops across the resistances in each path equaled the voltage of the source. This is one way of using Kirchhoff's second law, which states that the sum of the voltage drops around a circuit equals the voltage applied across the circuit. In the circuit shown, the voltage drops across each resistance differ, but the sum of those in any one path across the terminals add to equal the battery voltage.



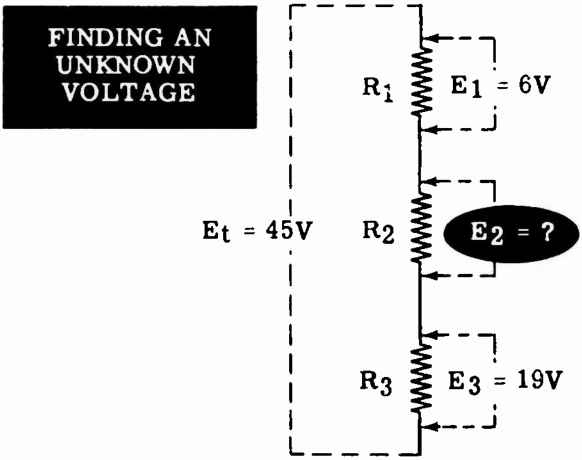
If more than one voltage source is included in the circuit, the actual voltage applied to the circuit is the combined voltage of all voltage sources and the voltage drops will be equal to this combined voltage. The combined voltage will depend on whether the voltages combine to add or subtract. For example, if two batteries are used in the same circuit, they may be connected to either aid or oppose each other. In either case, the total voltage drops across the circuit resistances will equal the sum or difference of the batteries.



Kirchhoff's Second Law (continued)

Whenever all but one of the voltage drops are known in a path between two junctions, the unknown voltage can be determined by applying Kirchhoff's second law if the voltage between the junctions is known. The junctions may be the terminals of a voltage source or they may be two junctions within the circuit itself.

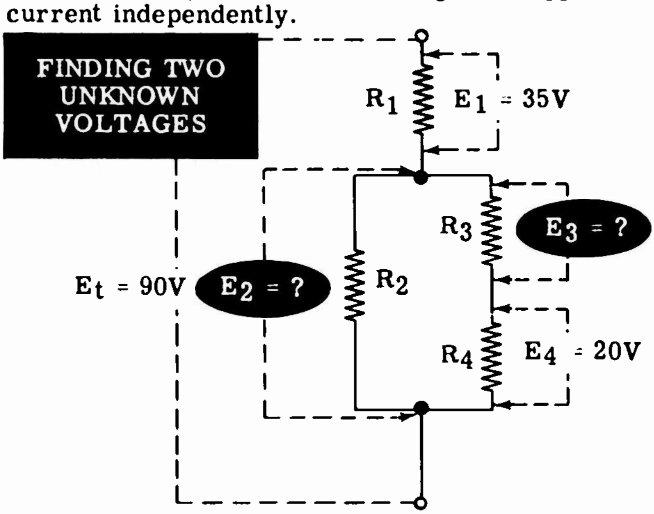
If three resistors—R_1, R_2 and R_3—are connected in series across a known voltage of 45 volts, and the voltage drops of R_1 and R_3 are 6 and 19 volts respectively, the voltage drop across R_2 is found by applying the law for circuit voltages, Kirchhoff's second law.



Finding E_2

$$E_1 + E_2 + E_3 = E_t$$
$$6V + E_2 + 19V = 45V$$
$$E_2 + 25V = 45V$$
$$\text{Then } E_2 = 20V$$

Unknown voltages within a complex circuit are found by first finding the voltage across each branch of the circuit, and then, by applying the law, finding the voltage drops across each resistance in the various branches. For series-parallel circuits the voltage across parallel parts of the circuit is used as the total voltage across the various resistances within that part of the circuit. To find the unknown voltages in the series-parallel circuit shown, the law for voltages is applied to each path across the current independently.



Finding E_2

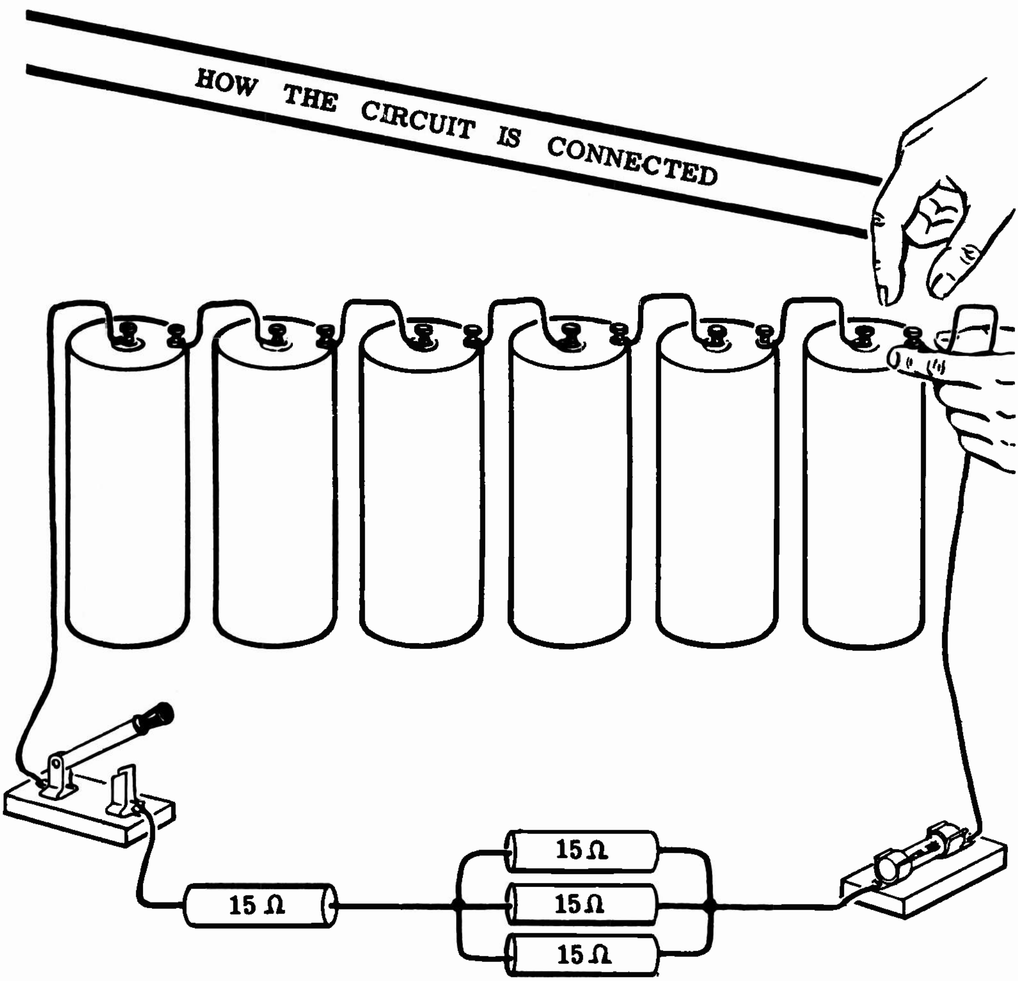
$$E_1 + E_2 = E_t$$
$$35V + E_2 = 90V$$
$$\text{Then } E_2 = 55V$$

Finding E_3

$$E_3 + E_4 = E_2$$
$$E_3 + 20V = 55V$$
$$\text{Then } E_3 = 35V$$

Demonstration—Kirchhoff's First Law

To demonstrate the law of circuit currents, the instructor connects a 15-ohm resistor in series with a parallel combination of three 15-ohm resistors and then connects the entire circuit across a 9-volt dry cell battery with a switch and fuse in series. This circuit is shown in the illustration.

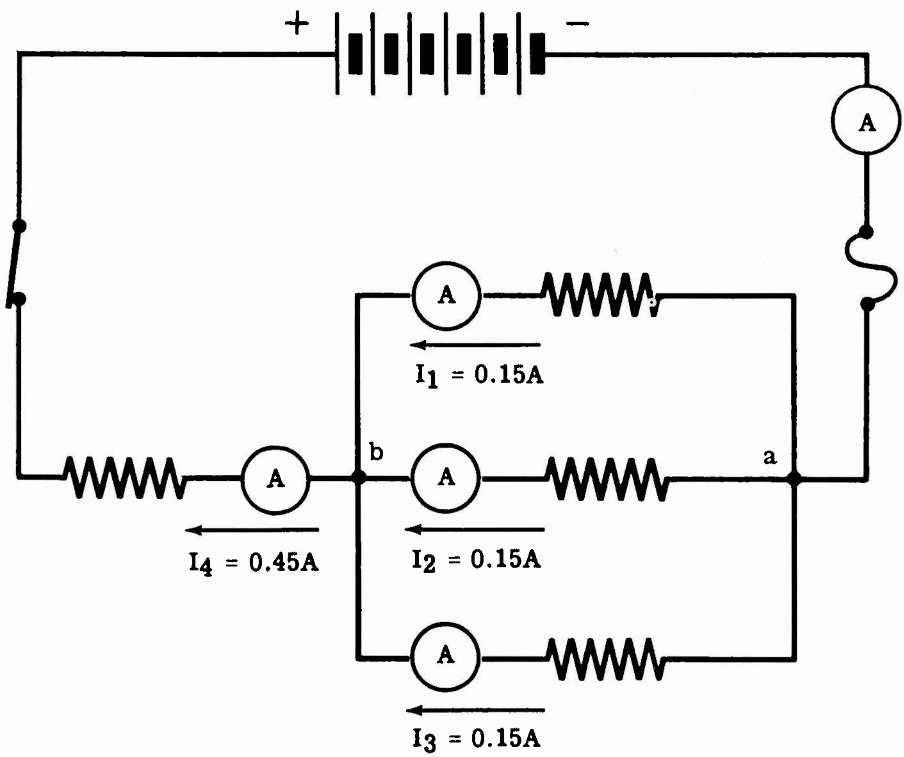


Demonstration—Kirchhoff's First Law (continued)

The total resistance of the circuit is 20 ohms, resulting in a total circuit current of 0.45 ampere by Ohm's law. This total current must flow through the circuit from the (-) to (+) battery terminals. At junction (a), the circuit current—0.45 ampere—divides to flow through the parallel resistors toward junction (b). Since the parallel resistors are equal, the current divides equally, with 0.15 ampere flowing through each resistor. At junction (b), the three parallel currents combine to flow away from the junction through the series resistor.

As the instructor connects the ammeter to read the current in each lead at the junction, you see that the sum of the three currents flowing toward the junction equals the current flowing away from the junction.

CHECK THE CURRENT FLOW AT A CIRCUIT JUNCTION



Current flowing toward the junction = Current flowing away from the junction

$$I_1 + I_2 + I_3 = I_4$$

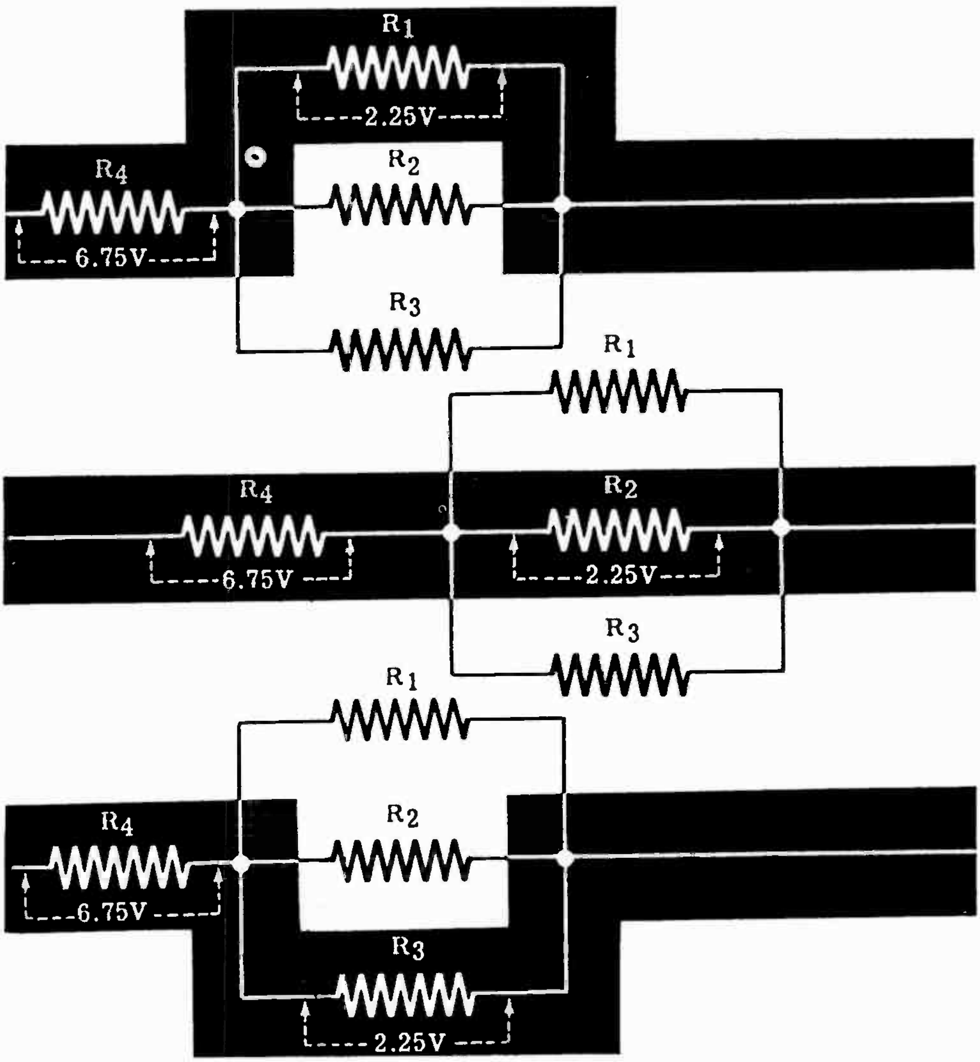
$$0.15 + 0.15 + 0.15 = 0.45\text{A}$$

Demonstration—Kirchhoff's Second Law

Using the same circuit, the instructor measures the voltage across each resistance in the circuit and also the battery voltage. For each path between the terminals of the battery, you see that the sum of the voltage drops equals the battery voltage.

CHECKING THE VOLTAGE DROPS IN EACH PATH THROUGH A CIRCUIT

Circuit Voltage Drops = Source Voltage (Battery)



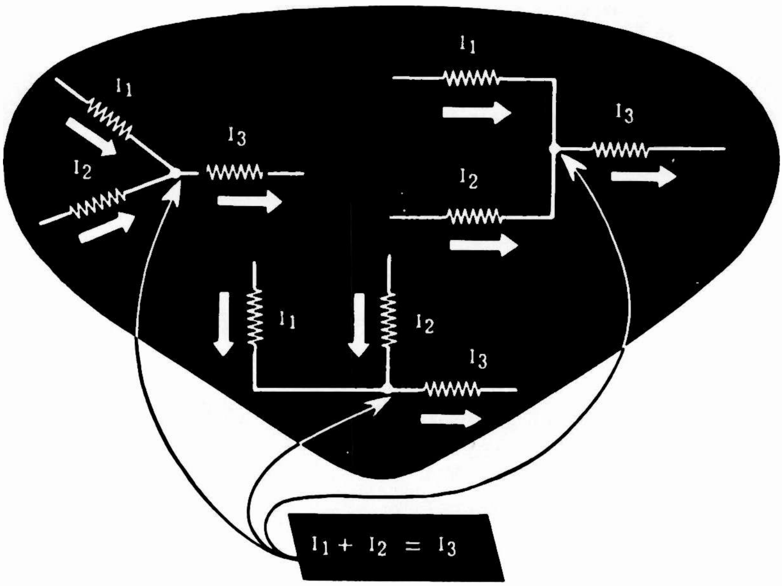
Next, the instructor connects the resistors in a more complex circuit. Again the voltages of the individual resistors are measured, and you see that the sum of the voltages in any complete path across the circuit equals the battery voltage.

Review of Kirchhoff's Laws

When working with complex circuits, you need to be able to simplify them by redrawing the circuit, combining resistances, using Ohm's law and applying Kirchhoff's laws. Most unknown values in a complex circuit can be found by applying Kirchhoff's laws to either part or all of the circuit. Now let's review these basic laws of circuit currents and voltages.

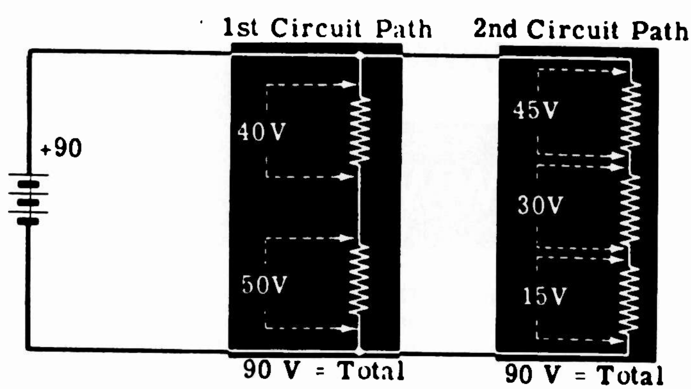
Kirchhoff's First Law

The total current entering (flowing toward) a circuit junction equals the total current leaving (flowing away from) the junction.



Kirchhoff's Second Law

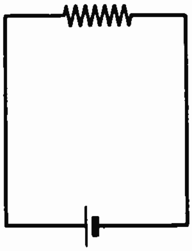
The total voltage drops across the resistances of a closed circuit equal the total voltage applied to the circuit.



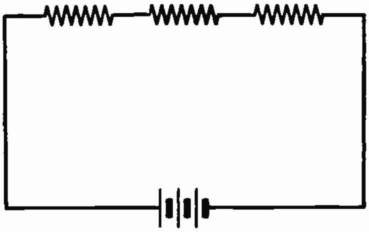
Review of Direct Current Circuits

Now, as a review, suppose you compare the types of circuits you have found out about and seen in operation. Also review the basic formulas which apply to direct current circuits.

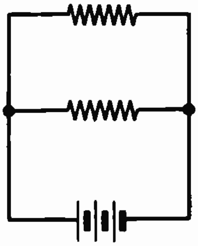
<u>SIMPLE CIRCUIT</u> — A single resistance connected across a voltage source.



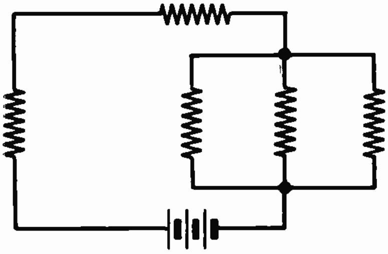
<u>SERIES CIRCUIT</u> — Resistances connected end to end across a voltage source.



<u>PARALLEL CIRCUIT</u> — Resistances connected side by side across a common voltage source.



<u>SERIES-PARALLEL CIRCUIT</u> — Resistances connected partly in series and partly in parallel.



Review of Direct Current Circuits (continued)

OHM'S LAW — The current flowing in a circuit changes in the same direction that voltage changes, and the opposite direction that resistance changes.

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

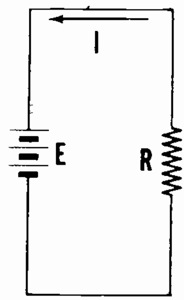
$$I = \frac{E}{R}$$

OHM'S LAW VARIATIONS —

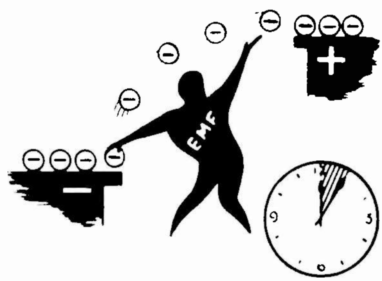
$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \quad I = \frac{E}{R}$$

$$\text{Voltage} = \text{Current} \times \text{Resistance} \quad E = IR$$

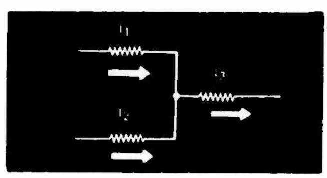
$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}} \quad R = \frac{E}{I}$$



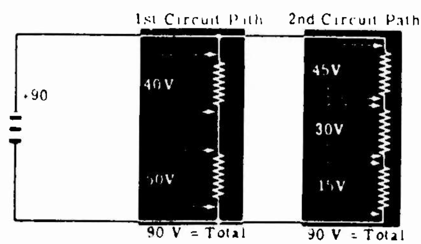
ELECTRIC POWER -- The rate of doing work in moving electrons through a conductor.



KIRCHHOFF'S FIRST LAW -- The total current entering (flowing toward) a circuit junction equals the total current leaving (flowing away from) the junction.



KIRCHHOFF'S SECOND LAW -- The total voltage drops across the resistances of a closed circuit equal the total voltage applied to the circuit.



INDEX

INDEX TO VOL. 2

(Note: A cumulative index covering all five volumes in this series will be found at the end of Volume 5.)

(1) 3,50

$2.50

Basic Electronics is available as a standard course and as an expanded course.

BASIC ELECTRONICS
5 Volume Standard Course by Van Valkenburgh, Nooger & Neville, Inc.

This is the civilian version of Basic Electronics as prepared by the authors for the U. S. Navy Common-Core training program.

Volume 1—Introduction to Electronics . . . What a Power Supply Is . . . Half-Wave Rectifiers—Dry Metal Type . . . Half-Wave Rectifiers—Vacuum Tube Type . . . Half-Wave Rectifiers—Transformer Type . . . The Full-Wave Rectifier Circuit . . . Filter Circuits . . . Voltage Regulator Circuits . . . Other Types of Power Supply Circuits . . . Characteristics of Diode Vacuum Tubes.

Volume 2—Introduction to Amplifiers . . . The Triode . . . The Triode Amplifier . . . The Tetrode and the Pentode . . . The Single-Stage Amplifier . . . The Two-Stage RC Coupled Amplifier . . . The Transformer-Coupled Amplifier . . . The Audio Power Amplifier . . . The Output Transformer . . . The Push-Pull Amplifier . . . Microphones, Earphones and Loudspeakers.

Volume 3—Video Amplifiers . . . Introduction to the RF Amplifier . . . Tuned Circuits . . . A Single-Stage RF Amplifier . . . The Two-Stage RF Amplifier . . . Introduction to Oscillators . . . The Armstrong and Hartley Oscillators . . . The Tuned-Plate Tuned-Grid and Crystal Oscillators . . . Miscellaneous Oscillators.

Volume 4—What a Transmitter Is . . . Class C Amplifiers . . . A Three-Stage Transmitter . . . Frequency Multipliers . . . Transmission Lines . . . Antennas . . . CW Transmission . . . Amplitude Modulation.

Volume 5—Introduction to Receivers . . . Receiver Antennas . . . TRF Receivers — RF Amplifier Stage . . . TRF Receivers — Audio Amplifier Stage . . . TRF Receivers — Regenerative Detector . . . TRF Receivers — Plate Detector . . . The Superheterodyne Receiver . . . Troubleshooting the Superheterodyne Receiver.

BASIC ELECTRONICS
6 Volume Expanded Course by Van Valkenburgh, Nooger & Neville, Inc.

This course consists of the 5-volume standard course plus a sixth volume which expands the instruction into the area of semiconductors, transistors and frequency modulation.

Volume 1—Introduction to Electronics . . . What a Power Supply Is . . . Half-Wave Rectifiers—Dry Metal Type . . . Half-Wave Rectifiers—Vacuum Tube Type . . . Half-Wave Rectifiers—Transformer Type . . . The Full-Wave Rectifier Circuit . . . Filter Circuits . . . Voltage Regulator Circuits . . . Other Types of Power Supply Circuits . . . Characteristics of Diode Vacuum Tubes.

Volume 2—Introduction to Amplifiers . . . The Triode . . . The Triode Amplifier . . . The Tetrode and the Pentode . . . The Single-Stage Amplifier . . . The Two-Stage RC Coupled Amplifier . . . The Transformer-Coupled Amplifier . . . The Audio Power Amplifier . . . The Output Transformer . . . The Push-Pull Amplifier . . . Microphones, Earphones and Loudspeakers.

Volume 3—Video Amplifiers . . . Introduction to the RF Amplifier . . . Tuned Circuits . . . A Single-Stage RF Amplifier . . . The Two-Stage RF Amplifier . . . Introduction to Oscillators . . . The Armstrong and Hartley Oscillators . . . The Tuned-Plate Tuned-Grid and Crystal Oscillators . . . Miscellaneous Oscillators.

Volume 4—What a Transmitter Is . . . Class C Amplifiers . . . A Three-Stage Transmitter . . . Frequency Multipliers . . . Transmission Lines . . . Antennas . . . CW Transmission . . . Amplitude Modulation.

Volume 5—Introduction to Receivers . . . Receiver Antennas . . . TRF Receivers — RF Amplifier Stage . . . TRF Receivers — Audio Amplifier Stage . . . TRF Receivers — Regenerative Detector . . . TRF Receivers — Plate Detector . . . The Superheterodyne Receiver . . . Troubleshooting the Superheterodyne Receiver.

Volume 6—Transistors . . . Semiconductors . . . Frequency Modulation . . . Solid State Electronics . . . Semiconductor Diodes . . . Transistor Construction . . . How A Transistor Operates . . . Commercial Transistors . . . Transistor Circuits . . . Transistorized Superheterodyne Receiver . . . Fundamentals of Frequency Modulation . . . FM Transmitters . . . Antennas and Wave Propagation . . . FM Receivers.

BASIC ELECTRONICS — VOLUME 6 — AVAILABLE SEPARATELY

Volume 6 is a companion volume to the 5-volume standard course on Basic Electronics. It enables individuals, schools, and industrial personnel upgrading programs to expand their instruction into the areas of Semiconductors, Transistors and Frequency Modulation.

Volume 6, Soft Cover   Volume 6, Cloth Bound

For Table of Contents, see Volume 6 of Expanded Course above.

JOHN F. RIDER PUBLISHER, INC., NEW YORK